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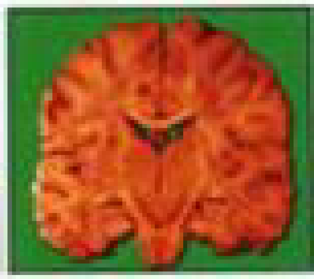
Self Assessment and Review of ANATOMY





Based on facts and concepts of the latest editions of standard books

Highlights

- Comprehensive theory and latest pattern questions in all sub-sections of Anatomy—Embryology, Histology, Neuroanatomy and Gross Anatomy (including Surface and Radiological Anatomy)
- Previous years' questions with explanatory answers from the Entrance Examinations conducted by AIIMS, PGIC, JIPMER, NEET, and DNB
- Reference books include Gray's Anatomy (41st Ed), Keith L Moore (7th Ed), Langman's Embryology (13th Ed), Ross Histology (7th Ed), Barr's Neuroanatomy (10th Ed), Dorland's Medical Dictionary (32nd Ed).

Rajesh K Kaushal

Explained Referenced Answers

All Recent Questions 2016-2001
All India (2012–2001)
AIIMS (Nov 2016–2001)
DNB (2012–2001)
JIPMER (2016–2000)
UPSC (2016–2000)
NEET PG (2016-2012)
Image-based questions

A must-buy book for All India, AIIMS, PGI, JIPMER, DNB, FMGE & State entrance exams

Self Assessment and Review of Anatomy

Rajesh K Kaushal
MD Anatomy (AIIMS, Delhi)
Director, Human Anat Academia
New Delhi

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Jaypee Brothers Medical Publishers (P) Ltd

Headquarters

Jaypee Brothers Medical Publishers (P) Ltd.
4838/24, Ansari Road, Daryaganj
New Delhi 110 002, India
Phone: +91-11-43574357
Fax: +91-11-43574314
Email: jaypee@jaypeebrothers.com

Overseas Offices

J.P. Medical Ltd.
83, Victoria Street, London
SW1H 0HW (UK)
Phone: +44-20 3170 8910
Fax: +44-(0)20 3008 6180
Email: info@jpmedpub.com

Jaypee-Highlights Medical Publishers Inc.
City of Knowledge, Bld. 237, Clayton
Panama City, Panama
Phone: +1 507-301-0496
Fax: +1 507-301-0499
Email: cservice@jphmedical.com

Jaypee Brothers Medical Publishers (P) Ltd.
17/1-B, Babar Road, Block-B, Shaymali
Mohammadpur, Dhaka-1207, Bangladesh
Mobile: +08801912003485
Email: jaypeedhaka@gmail.com

Jaypee Brothers Medical Publishers (P) Ltd.
Bhotahity, Kathmandu, Nepal
Phone: +977-9741283608
Email: kathmandu@jaypeebrothers.com

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Inquiries for bulk sales may be solicited at: jaypee@jaypeebrothers.com

Self Assessment and Review of Anatomy

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It all begins with one word
Passion !

Dedicated to

All those teachers and students,
who illuminate the world around by their honest work, sacrifices, and a purpose of duty !

PREFACE

Long ago I thought of a mission—Human Anatomy Made Simple. Then it was a dream, now realizing that dream into concrete reality is a profound matter of satisfaction and joy.

As Steve Maraboli mentioned: 'The best way to succeed is to have a specific **Intent,** a clear **Vision,** a plan of **Action,** and the ability to maintain **Clarity.'**

Anatomy is an integral component of PG Entrance exams at multiple levels. It is not an important individual subject in itself but, in terms of conceptual and clinical correlates, touches and fetches improved scoring in almost all the major and minor subjects, once mastered well.

The present book is a simplistic quintessential approach to master basic and conceptual Anatomy and its clinical application. Maximum possible content has been covered under various sub-sections of Anatomy, so that the student does not need to look into a plethora of books—in a sense it is 'all in one approach'. It is written in a simple lucid language with neatly labelled line diagrams, along with tables and flowcharts to improve memorization and recall of the vast content.

The latest edition of Gray's Anatomy has abundance of updated information, which is not in accordance with the traditional/conventional teaching. Such information has been included in the present book but its usage in the exams is not yet advisable, and depends upon the discretion of the teacher and the students.

Controversies arise when different authors follow different standard textbooks, for example, a particular question on pemphigus vulgaris may be asked by Anatomy department, but may also interest, Pathology, Dermatology and Medicine departments equally. Such questions have been dealt with profound and relentless research, referring to respective department standard textbooks and Journals to bring you the most appropriate answer possible.

Dear students, I was a medical student, and will remain so throughout my life. We all have been trained to work hard in the best interest of our patients and peers. I respect and honour your tenacity in keeping the fire and zeal alive in your heart and mind, and remain highly motivated despite tough scenarios in life keep presenting in front of you, every possible moment.

Wishing a great success to all the students, in all arenas of life !

Rajesh K Kaushal
MD Anatomy (AIIMS, Delhi)

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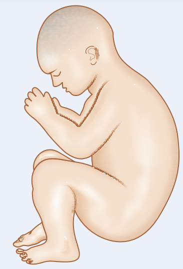
CHAPTER 1

General Anatomy



SKELETON

Parts of Bone

Bone is a calcified connective tissue consisting of **cells** (osteocytes) embedded in a **matrix** of ground substance and collagen fibers.

- It has a superficial thin layer of compact bone around a central mass of spongy bone, and contain internal soft tissue, the marrow, where blood cells are formed.
- It serve as a reservoir for calcium and phosphorus and act as biomechanical levers on which muscles act to produce the movements permitted by joints.

Long bones have a shaft (diaphysis) and two ends (epiphyses). The metaphysis is a part of the diaphysis adjacent to the epiphyses.

- Diaphysis
  - Forms the shaft (central region) and is composed of a thick tube of compact bone that encloses the marrow cavity.
- Metaphysis
  - Is a part of the diaphysis, the growth zone between the diaphysis and epiphysis during bone development.
- Epiphyses
  - Are expanded articular ends, separated from the shaft by the epiphyseal plate during bone growth and composed of a spongy bone surrounded by a thin layer of compact bone.

Bones in the Body

- Bony skeleton consists of 206 bones and is divided into two parts: the axial skeleton and the appendicular skeleton.
- Axial skeleton is the central core unit, consisting of the skull, vertebrae, ribs, and sternum.
- Appendicular skeleton comprises the bones of the extremities.

Table 1: Number of bones present in axial and appendicular skeleton

Number of bones					
Axial skeleton		*Appendicular skeleton*			
1. Skull		**2. Pectoral (shoulder) girdles**		**3. Pelvic (hip) girdle**	
Cranial bones	8	Clavicle	2	Hip bone	2
Facial bones	14	Scapula	2	**Lower limbs**	
Hyoid	1	**Upper limbs**		Femur	2
Ear ossicles (3 in each ear)	6	Humerus	2	Fibula	2
Vertebral bones	26	Ulna	2	Tibia	2
Rib cage		Radius	2	Patella	2
Sternum	1	Carpals	16	Tarsals	14
Ribs	24	Metacarpals	10	Metatarsals	10
		Phalanges	28	Phalanges	28
Total	**80**	**Total**	**60**	**Total**	**66**
Number of bones					
Total bones of axial skeleton		80			
Total bones of appendicular skeleton			60 + 66		
Total bones of the body		**206**			

Sesamoid Bones

Sesamoid bones develop in certain **tendons** and reduce friction on the tendon, thus protecting it from excessive wear.

- They are commonly found where tendons cross the ends of long bones in the limbs.
- Sites of sesamoid bones:
  - In the ear: The lenticular process of incus is a sesamoid bone and therefore is considered the fourth ossicle of middle ear.
  - In the hand: Two sesamoid bones in the distal portions of the first metacarpal bone (within the tendons of adductor pollicis and flexor pollicis brevis).
  - In the wrist: The pisiform of the wrist is a sesamoid bone (within the tendon of flexor carpi ulnaris), develops at age 9–12.
  - In the knee: The patella (within the quadriceps tendon)
  - Fabella in the lateral head of gastrocnemius behind the knee joint.
  - Sesamoid bone in the tendon of peroneus longus where it binds around the cuboid bone.
  - In the foot: Two sesamoid bones in the distal portions of the first metatarsal bone (within the tendons of flexor hallucis brevis.

Pneumatic Bones

Note: Pneumatic bones are the **irregular** bones which contain air-filled cavities within them.

- They are generally produced during development by excavation of bone by pneumatic diverticula (air sacs) from an air-filled space such as the nasal cavity.
- E.g., maxilla, frontal, sphenoid, and ethmoid bones and a part of the mastoid process of the temporal bone.

Note: At birth the mastoid is not pneumatized, but becomes aerated over the first year of life.

Ossification

- Ossification is the process of laying down new bone material by cells called osteoblasts. It is of two types:
  - Membranous ossification is the direct laying down of bone into the mesenchyme (embryonic connective tissue).
  - Endochondral ossification involves osteogenesis in a precursor model of cartilage.
- Membrane (dermal) bones ossify in membrane (intramembranous ossification), and are thus derived from mesenchymal condensations. The flat bones of the skull and face, the mandible, and the clavicle develop by intramembranous ossification.
- Cartilaginous bones ossify in cartilage (endochondral ossification), and are thus derived from preformed cartilaginous models. The bones of the extremities (limbs) and those parts of the axial skeleton that bear weight (vertebral column and thoracic cage) develop by endochondral ossification.
- Membrano-cartilaginous bones are initially formed in membrane but later partly in cartilage. Examples: clavicle, mandible, occipital, temporal, sphenoid.
- Cartilaginous ossification involves primary and secondary centres of ossification:
- Primary center of ossification
  - In long bones, bone tissue first appears in the diaphysis (middle of shaft).
  - Primary centres starts appearing at week 6 of intrauterine life.
  - Chondrocytes multiply and form trabeculae and cartilage is progressively eroded and replaced by bone, extending towards the epiphysis.
  - A perichondrium layer surrounding the cartilage forms the periosteum, which generates osteogenic cells that make a collar to encircles the exterior of the bone and remodels the medullary cavity on the inside.
  - The nutrient artery enters via the nutrient foramen from a small opening in the diaphysis.
    - It invades the primary centre of ossification, bringing osteogenic cells (osteoblasts on the outside, osteoclasts on the inside.)
    - The canal of the nutrient foramen is directed away from more active end of bone when one end grows more than the other.
    - When bone grows at same rate at both ends, the nutrient artery is perpendicular to the bone.
  - Secondary center of ossification
    - The secondary centres generally appear at the ends (epiphysis) of long bones.
    - Secondary ossification mostly occurs after birth except for secondary centers around knee joint (distal femur and proximal tibia), which appear during last weeks of fetal life (or immediately after birth).
    - The epiphyseal arteries and osteogenic cells invade the epiphysis, depositing osteoblasts and osteoclasts which erode the cartilage and build bone. This occurs at both ends of long bones but only one end of digits and ribs.

Ossification centers which appear **prenatally** (ossified at birth) are: diaphysis of long bones, skull bones, vertebral column, ribs and sternum, few foot bones (talus, calcaneum, cuboid).

Primary center of all carpal and tarsal bones (**except** talus, calcaneum and cuboid) appear after birth.

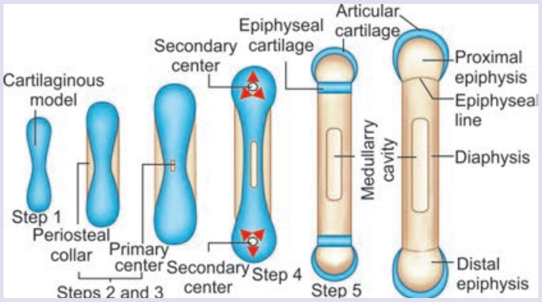
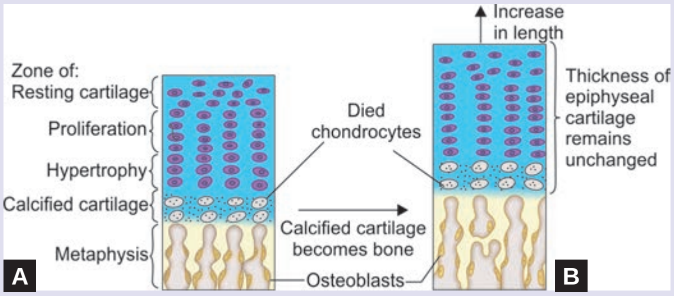


Fig. 1: Ossification of a long bone



Figs. 2A and B: Growth of bone—lengthwise: (A) Four zones of epiphyseal cartilage, (B) Conversion of calcified cartilage into bone

Time period	Bones affected
Second month of fetal development	Ossification in long bones beginning
Fourth month	Most primary ossification centers have appeared in the diaphyses of bone.
Birth to 5 years	Secondary ossification centers appear in the epiphyses
5 years to 12 years in females, 5 to 14 years in males	Ossification is spreading rapidly from the ossification centers and various bones are becoming ossified
17 to 20 years	Bone of upper limbs and scapulae becoming completely ossified
18 to 23 years	Bone of the lower limbs and os coxae become completely ossified
23 to 25 years	Bone of the sternum, clavicles, and vertebrae become completely ossified
By 25 years	Nearly all bones are completely ossified

Growing End

- The growing ends of bones in upper limb are upper end of humerus and lower ends of radius and ulna.
- In lower limb, the lower end of femur and upper end of tibia are the growing ends.
- The nutrient foramen is directed away from the growing end of the bone; their directions are indicated by a memory aid: 'Towards the elbow I go, from the knee I flee'.

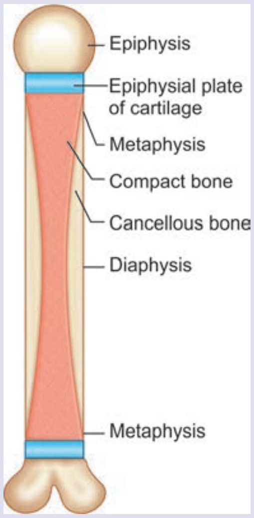


Fig. 3: Parts of a young long bone

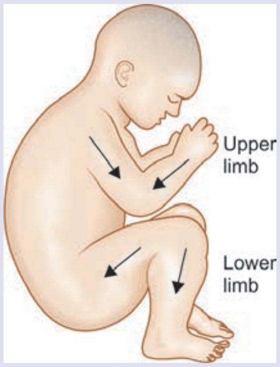


Fig. 4: Direction of nutrient foramina in the limb bones

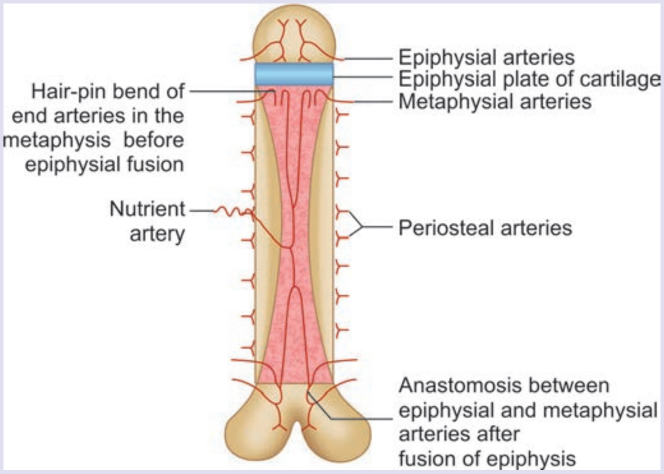


Fig. 5: Arterial supply of a long bone. The upper epiphysis (growing end) has not yet fused with the diaphysis

Blood Supply

Nutrient artery enters the diaphysis (shaft) through the nutrient foramen, runs obliquely through the cortex, and divides into ascending and descending branches in the medullary cavity.

- Each branch divides into a number of small parallel channels which terminate in the adult metaphysis by anastomosing with the epiphysial, metaphysial and periosteal arteries.
- It supplies medullary cavity, inner 2/3 of cortex and metaphysis.
- The nutrient foramen is directed away from the growing end of the bone. Memory aid: Towards the elbow I go, from the knee I flee.

ASSESSMENT QUESTIONS

1. **Bones ossified at birth:** *(PGIC 2015)*
   a. Lower end of femur
   b. Calcaneum
   c. Upper end of tibia
   d. Upper end of humerus
   e. Lower end of humerus

2. **Endochondral ossification is/are seen in:** *(PGIC 2015)*
   a. Long bones
   b. Flat bones of skull
   c. Clavicle
   d. Mandible
   e. Nasal bones

3. **Nutrient artery runs:** *(NEET Pattern 2012)*
   a. Towards metaphysis
   b. Away from metaphysis
   c. Away from epiphysis
   d. None

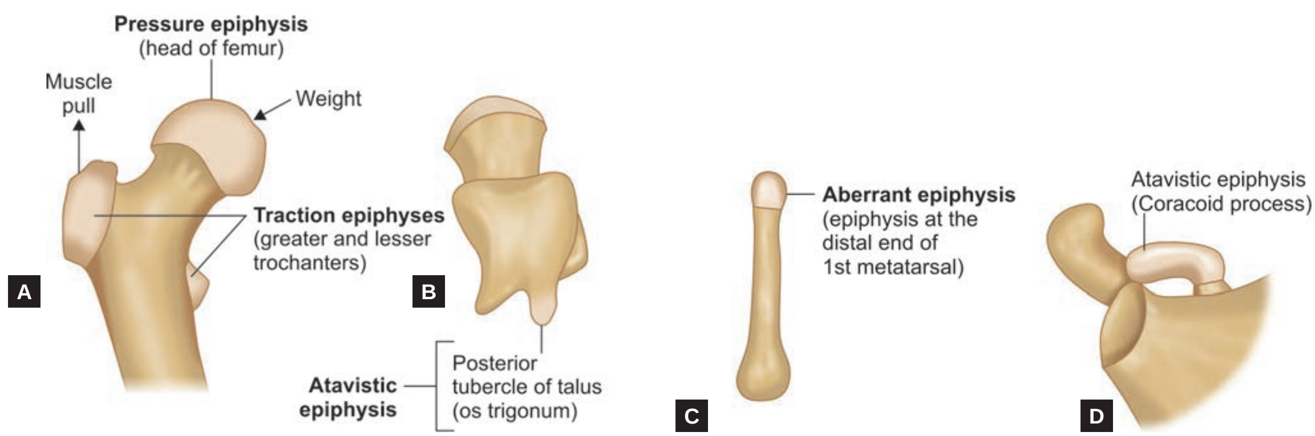
ANSWERS WITH EXPLANATIONS

1. **a. Lower end of femur; b. Calcaneum; c. Upper end of tibia**
   - Secondary centers around knee joint (distal femur and proximal tibia) appear during last weeks of intrauterine life (or immediately after birth).
   - Primary center of all tarsal bones (except talus, calcaneum and cuboid Appear after birth.
2. **a. Long bones**
   - Long bones develop by endochondral ossification, whereas bones of skull; facial skeleton; mandible; clavicle bone develop by membranous ossification.
3. **a. Towards metaphysis**
   - Nutrient artery enters the shaft (diaphysis) of the bone, divides into ascending and descending branches, which run towards and terminate in the adult metaphysis by anastomosing with the epiphyseal, metaphyseal and periosteal arteries.

Epiphysis

There are **four types** of epiphysis**:**

- Pressure epiphysis are the parts of bone involved in weight transmission (and are intracapsular) for e.g. head of humerus and femur and condyles of humerus, femur, tibia etc.



Figs. 6A to D: Types of epiphyses: (A) Pressure and traction epiphyses. (B) and (D) Atavistic epiphyses. (C) Aberrant epiphysis

- Traction epiphysis are present at the ends of bones and develop due to traction by the attached muscles (and are therefore extracapsular), e.g. greater (and lesser) tubercles in humerus and greater (and lesser) trochanter in femur.
  - These epiphyses ossify later than pressure epiphyses.
  - Examples of traction epiphyses are tubercles of the humerus (greater tubercle and lesser tubercle), and trochanters of the femur (greater and lesser). Mastoid process is also a traction epiphysis.
- Atavistic epiphysis: These types of fused bones are called atavistic, e.g. the coracoid process of the scapula, which has been fused in humans with the main bone, but is separate in lower animals.
- Aberrant epiphysis: These epiphyses are deviations from the normal anatomy and are not always present. For example, the epiphysis at the head of the first metacarpal bone, posterior tubercle of talus (as trigonum).

ASSESSMENT QUESTIONS

1. **Which of the following is a traction epiphysis?**
   a. Tibial condyles *(NEET Pattern 2012)*
   b. Trochanter of femur
   c. Coracoid process of scapula
   d. Head of femur

2. **Traction epiphysis is/are:** *(PGIC)*
   a. Head of humerus
   b. Lesser tubercle
   c. Deltoid tuberosity
   d. Coracoid process
   e. Greater trochanter

3. **Which of the following is aberrant epiphysis?** *(NEET Pattern 2015)*
   a. Coracoid process
   b. Greater tubercle of humerus
   c. Base of 1st metacarpal
   d. Base of 2nd metacarpal

4. **Mastoid process is which type of epiphysis?** *(NEET Pattern 2015)*
   a. Pressure
   b. Aberrant
   c. Atavistic
   d. Traction

ANSWERS WITH EXPLANATIONS

1. **b. Trochanter of femur**
   - **Trochanter** of femur is an example of **traction** epiphysis and is extracapsular.
   - **Tibial condyles** and **head of femur** are under the **pressure** epiphysis category and are intracapsular.
   - **Coracoid process** of scapula is an example of **atavistic** epiphysis.

2. **b. Lesser tubercle; e Greater trochanter.**
   - **Traction** epiphysis are present at the ends of bones and develop due to traction by the attached muscles (and are therefore extracapsular), e.g. Greater (and lesser) tubercles in humerus and greater (and lesser) trochanter in femur.
   - **Pressure** epiphysis are involved in weight transmission (and are intracapsular) for e.g. head of humerus and femur and condyles of humerus, femur, tibia etc.
   - Coracoid process in scapula is an example of **atavistic** epiphysis.
   - Deltoid tuberosity is not an epiphysis (it is present on the shaft/diaphysis).

3. **d. Base of 2nd metacarpal**
   - **Aberrant epiphyses** are deviations from the normal anatomy and are not always present. For example, the epiphysis at the head of the first metacarpal bone and at the bases of other metacarpals.

4. **d. Traction**
   - **Traction epiphysis** are present at the ends of bones and develop due to traction by the attached muscles (and are therefore extracapsular).
   - Mastoid process is produced due to the traction by the sternocleidomastoid muscle.

Miscellaneous

ASSESSMENT QUESTIONS

1. **All of the following statements are true for metaphysis of bone EXCEPT:** *(AIPG 2003)*
   a. It is the strongest part of bone
   b. It is the most vascular part of bone
   c. Growth activity is maximized here
   d. It is the region favoring hematogenous spread of infection

2. **All of the following statements are true for metaphysis of bone EXCEPT:** *(AIPG 2003)*
   a. It is the epiphyseal end of diaphysis
   b. Growth activity is negligible here
   c. It is highly vascular
   d. Common site of osteomyelitis in children

3. **TRUE statement is:** *(AIPG 2000)*
   a. Osteoblasts give rise to osteocytes
   b. Growth of bone occurs at diaphysis
   c. Epiphysis is present between metaphysis and diaphysis
   d. Interphalangeal joint is a saddle joint

4. **Pisiform is which type of bone?** *(NEET Pattern 2015)*
   a. Pneumatic bone
   b. Sesamoid bone
   c. Accessory bone
   d. Long bone

5. **All of the following are pneumatic bones EXCEPT:** *(AIPG 2011)*
   a. Frontal
   b. Ethmoid
   c. Mandible
   d. Maxilla

6. **Bone which is pneumatic:** *(PGIC May 2015)*
   a. Maxillary
   b. Parietal
   c. Temporal
   d. Frontal
   e. Ethmoidal

ANSWERS WITH EXPLANATIONS

1. **a. It is the strongest part of bone**
   - The strongest part of bone is diaphysis (not metaphysis).
   - During growth of bone maximum activity occurs at growth plate (physis) and metaphysis.
   - Metaphysis is the most vascular part of bone and most prone for lodging of the infectious agent in hematogenous infection.

2. **b. Growth activity is negligible here**
   - Metaphysis is the epiphyseal end of the diaphysis.
   - Growth activity is maximum at the growth plate (physis) and metaphysis.
   - Metaphysis is richly supplied with arteries forming hairpin bends, hence becomes a common site of osteomyelitis in children, as infectious agent are easily trapped in sluggish blood flow in hairpin bends.

3. **a. Osteoblasts give rise to osteocytes**
   - Osteoblasts that get trapped in Haversian lamellae become osteocyte and assume the function of bone maintenance. They are no longer involved in bone formation.
   - Growth activity is maximum at the growth plate (physis) and metaphysis.
   - Metaphysis is present between diaphysis and epiphysis.
   - Interphalangeal joint is a hinge variety of synovial joint.

4. b. Sesamoid bone
- Sesamoid bones develop in certain tendons and reduce friction on the tendon, thus protecting it from excessive wear.
- They are commonly found where tendons cross the ends of long bones in the limbs.

5. c. Mandible
- Pneumatic bones have air spaces within them.
- It is generally produced during development by excavation of bone by pneumatic diverticula (air sacs) from an air-filled space such as the nasal cavity.

6. a. Maxillary; c. Temporal; d. Frontal; e. Ethmoidal
- Pneumatic bones have air spaces within them and are present around the nasal cavity.
- Parietal bone is not a pneumatic bone.

Joints

Union between bones can be in one of three types: by fibrous tissue; by cartilage; or by synovial joints.

Classification

Synarthrosis (immovable)	Fibrous joints
Amphiarthrosis (slight mobile)	Cartilaginous joint
Diarthrosis (freely mobile)	Synovial joints

Fibrous joints occur where bones are separated only by connective tissue and movement between them is negligible. Examples of fibrous joints are the **sutures** that unite the bones of the vault of the skull and the **syndesmosis** between the lower ends of the tibia and fibula.

Types of fibrous joint	Examples
Suture	Spheno-vomerine joint (schindylesis)
Gomphosis	Tooth and socket joints
Syndesmosis	Middle radioulnar joint Inferior radioulnar joint

Cartilaginous joints are of two varieties, primary and secondary.

- Primary Cartilaginous Joints (synchondroses) are united by hyaline cartilage and permit no movement but growth in the length.
  - A primary cartilaginous joint (synchondrosis) is one where bone and hyaline cartilage meet. Thus all epiphyses are primary cartilaginous joints, as are the junctions of ribs with their own costal cartilages.
  - All primary cartilaginous joints are quite immobile and are very strong. The adjacent bone may fracture, but the bone–cartilage interface will not separate.
  - They Includes epiphyseal cartilage plates (the union between the epiphysis and the diaphysis of a growing bone) and spheno-occipital and manubrio-sternal synchondroses.
- Secondary cartilaginous joints (Symphysis) have bones are united by hyaline plus fibrocartilage.
  - These joints are usually in the midline and are slightly mobile.
  - Include pubis symphysis, midline intervertebral joints.
    - Symphysis is a union between bones whose articular surfaces are covered with a thin lamina of hyaline cartilage. The hyaline laminae are united by fibrocartilage.
    - There may be a cavity in the fibrocartilage, but it is never lined with synovial membrane and it contains only tissue fluid.
    - Examples are the pubic symphysis and the joint of the sternal angle (between the manubrium and the body of the sternum).
    - An intervertebral disc is part of a secondary cartilaginous joint, but here the cavity in the fibrocartilage contains a gel.
    - A limited amount of movement is possible in secondary cartilaginous joints, depending on the amount of fibrous tissue within them. All symphyses occur in the midline of the body.

Types of cartilaginous joint	Examples
Synchondrosis	Spheno-occipital joint Epiphysio-diaphyseal joint (growing bone)
Symphysis	Midline intervertebral joint Sacrococcygeal joint

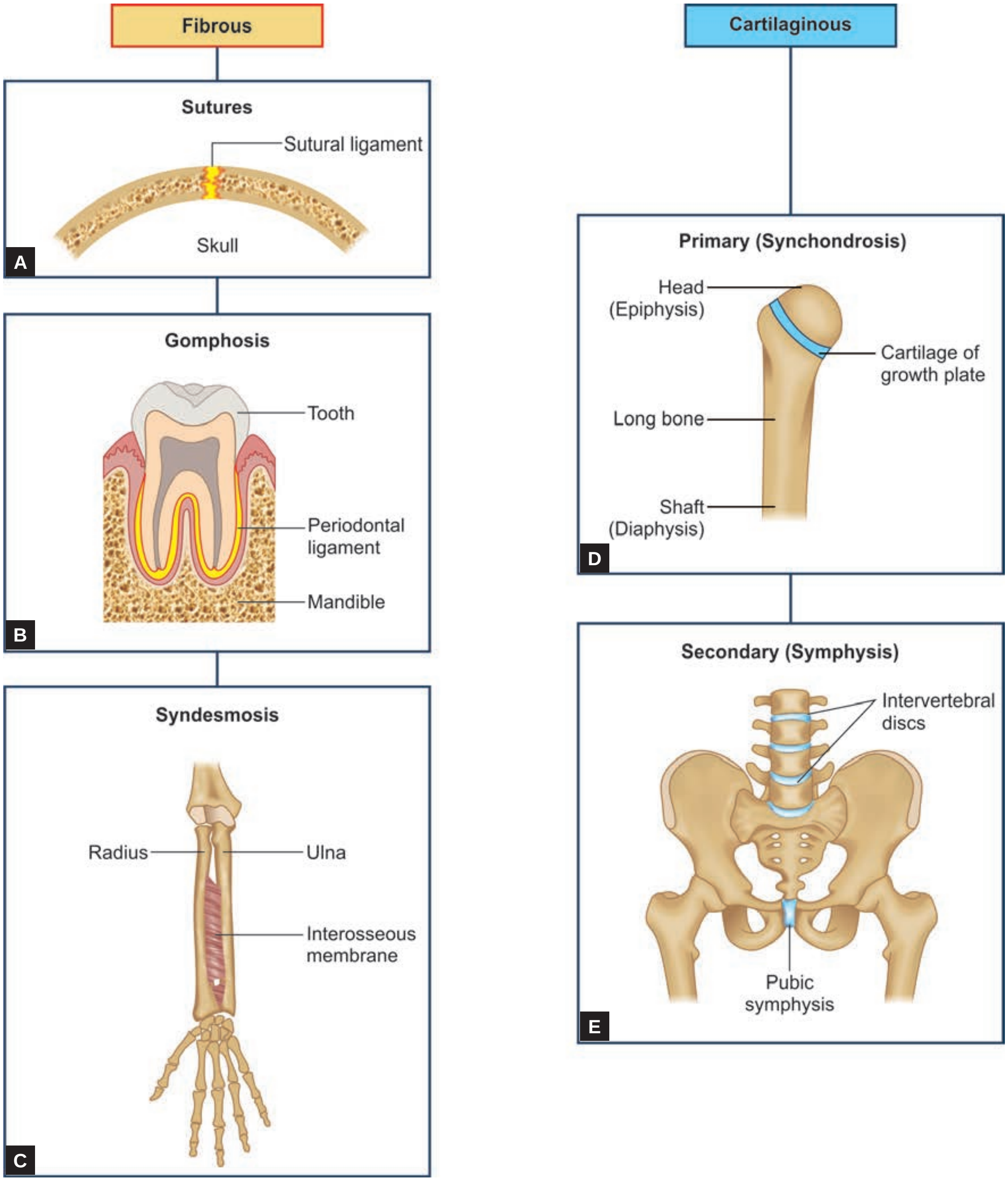
Synovial joints are freely mobile joints.

Synovial joints are uniaxial: Plane, hinge and pivot; Biaxial: Condylar and ellipsoid; Multiaxial: Saddle, ball and socket.

Types of synovial joint	Examples
Plane	• Acromioclavicular • Intercarpal • Intertarsal
Hinge	• Elbow • Interphalangeal
Pivot (Trochoid)	• Atlanto-axial • Superior radio-ulnar • Inferior radio-ulnar
Condylar	• Temporo-mandibular • Knee joint

Types of synovial joint	Examples
Ellipsoid	• Atlanto-occipital • Wrist (radio-carpal) • Metacarpo-phalangeal (knuckle)
Saddle	• Malleus-incus joint • Sternoclavicular • First carpo-metacarpal • Calcaneocuboid
Ball and socket	• Incus-stapes joint • Shoulder • Hip • Talo-calcaneo-navicular

Some authors consider these joints condylar: Atlanto-occipital, wrist (radio-carpal), metacarpo-phalangeal (knuckle).
Some authors consider these joints as modified hinge: Temporo-mandibular, knee joint.

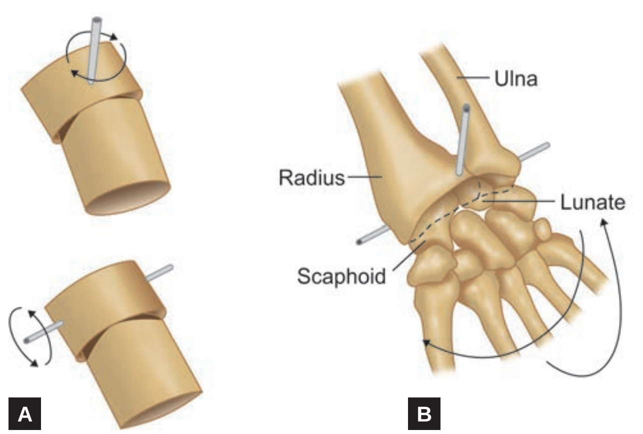


Figs. 7A to E: Fibrous joints (A to C) and Cartilagenous joints (D and E)

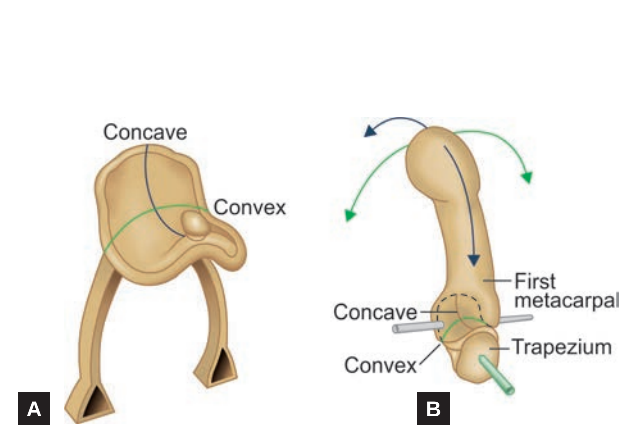
The close and loose-packed positions of joins		
Joint	**Close-packed position**	**Loose-packed position**
Shoulder	Abduction + lateral rotation	Semi-abduction
Ulnohumeral	Extension	Semi-flexion
Radiohumeral	Semi-flexion + semi-pronation	Extension + supination
Wrist	Dorsiflexion	Semi-flexion
2nd–5th metacarpophalangeal	Full flexion	Semi-flexion + ulnar deviation
Interphalangeal (fingers)	Extension	Semi-flexion
Joint	**Close-packed position**	**Loose-packed position**
1st carpometacarpal	Full opposition	Neutral position of thumb
Hip	Extension + medial rotation	Semi-flexion
Knee	Full extension	Semi-flexion
Ankle	Dorsiflexion	Neutral position
Tarsal joints	Full supination	Semi-pronation
Metatarsophalangeal	Dorsiflexion	Neutral position
Interphalangeal (toes)	Dorsiflexion	Semi-flexion
Intervertebral	Extension	Neutral position

	Primary angular motions	Mechanical analogy	Anatomic examples
Hinge joint	Flexion and extension only	Door hinge	Humero-ulnar joint Interphalangeal joint
Pivot joint	Spinning of one member around a single axis of rotation	Doorknob	Humeroredial joint Atlanto-axial joint
Ellipsoid joint	Biplanar motion (flexion-extension and abduction-adduction)	Flattened convex ellipsoid paired with a concave trough	Radiocarpal joint
Ball-and-socket joint	Triplanar motion (flexion-extension, abduction-adduction, and internal-external rotation)	Spheric convex surface paired with a concave cup	Glenohumeral joint Coxofemoral (hip) joint
Plane joint	Typical motions include slide (translation) or combined slide and rotation	Relatively flat surfaces apposing each other, like a book of a table.	Carpometacarpal joints (digits II to IV) Intercarpal joints Intertarsal joints
Saddle joint	Biplanar motion; spin between bones is possible but may be limited by interlocking nature of joint	Each member has a reciprocally curved concave and convex surface oriented at right angles to the other, like a horse rider and a saddle	Carpometacarpal joint of the thumb Sternoclavicular joint
Condyloid joint	Biplanar motion; either flexion-extension and abduction-adduction, or flexion-extension and axial rotation (internal-external rotation)	Mostly spheric convex surface that is enlarged in one dimension like a knuckle; paired with a shallow concave cup	Metacarpophalangeal joint Tibiofemoral (knee) joint
Note: Metacarpophalangeal joint is generally considered as an ellipsoid synovial joint			

Synovial Joints



Figs. 8A and B: An ellipsoid joint (A) is shown as analogous to the radiocarpal joint (wrist) (B) The two axes of rotation are shown by the intersecting pins



Figs. 9A and B: A saddle joint (A) is illustrated as analogous to the carpometacarpal joint of the thumb (B). The saddle in A. Represents the trapezium bone. The rider, if present, would represent the base of the thumb's metacarpal. The two axes of rotation are shown in (B)

- Knee joint is a complex joint (involving more than two bones).
- Femoro-tibial joint structurally resembles a hinge joint, but is considered as a condylar type of synovial joint between two condyles of the femur and tibia. In addition, it includes a saddle joint between the femur and the patella.

ASSESSMENT QUESTIONS

1. Knee is which type of joint?
a. Synarthrosis
b. Symphysis
c. Amphiarthrosis
d. Diarthrosis

2. Joint between epiphysis and diaphysis of a long bone is a type of: *(AIIMS 2004)*
a. Plane Synovial joint
b. Fibrous joint
c. Symphysis
d. Synchondrosis

3. Innervated structures of joints are all EXCEPT: *(NEET Pattern 2013)*
a. Synovium
b. Capsule
c. Articular cartilage
d. Ligaments

4. Ear ossicles articulate with each other through which type of joints? *(NEET Pattern 2012)*
a. Synostosis
b. Synovial
c. Synchondrosis
d. Syndesmosis

5. Median atlantoaxial joint is: *(NEET Pattern 2015)*
a. Condylar
b. Cartilaginous
c. Fibrous
d. Synovial joint

6. Intracapsular articular disc is present in which joint? *(NEET Pattern 2012)*
a. Sternoclavicular joint
b. Elbow
c. Hip joint
d. Knee joint

7. What kind of a joint is syndesmosis? *(NEET Pattern 2012)*
a. Fibrous
b. Plain
c. Pivot
d. Cartilaginous

8. Vomer ala and sphenoidal rostrum junction is: *(NEET Pattern 2013)*
a. Syndesmosis
b. Synostosis
c. Schindylesis
d. Gomphosis

9. Pubic symphysis is which type of joint? *(NEET Pattern 2015)*
a. Synovial
b. Fibrous
c. Cartilaginous
d. None of the above

10. What type of joint is the growth plate *(AIPG 2010)*
a. Fibrous
b. Primary cartilaginous
c. Secondary cartilaginous
d. Plane joint

11. Manubriosternal joint is: *(NEET Pattern 2015)*
a. Primary cartilaginous
b. Secondary cartilaginous
c. Synovial
d. Ellipsoid

12. Inferior tibio-fibular joint is:
a. Synchondrosis
b. Syndesmosis
c. Symphysis
d. Schindylesis

13. The type of joint between the sacrum and the coccyx is a: *(AIPG 2005)*
a. Symphysis
b. Synostosis
c. Synchondrosis
d. Syndesmosis

14. Which of the following is a compound condylar joint? *(NEET Pattern 2012)*
a. Knee
b. TM joint
c. Wrist
d. Elbow

15. Which of the following is a synovial joint of the condylar variety? *(NEET Pattern 2012)*
a. First carpometacarpal joint
b. Metacarpophalangeal joint
c. Interphalangeal joint
d. Radiocarpal joint

16. Which of the following is the type of joints between malleus and incus?
a. Primary cartilaginous
b. Secondary cartilaginous
c. Saddle synovial
d. Ball & socket synovial

17. Atlanto-occipital joint is of synovial variety:
a. Trochoid
b. Ellipsoid
c. Condylar
d. Saddle

ANSWERS WITH EXPLANATIONS

1. d. Diarthrosis
- Synarthrosis are immovable joints and include the fibrous joints.
- Amphiarthrosis are slight mobile and include the cartilaginous joints
- Diarthrosis are freely mobile joints and include the synovial joints.

2. d. Synchondrosis
- Epiphysio-diaphyseal joint is a primary cartilaginous joint – synchondrosis.
- It is found in the growing bone, where the growth plate (hyaline cartilage) connects the epiphysis with the diaphysis, creating a hyaline cartilaginous joint.
- A this site the fate of synchondrosis is synostosis (bony fusion) after the growth plate gets removed and replaced by the bone.

3. c. Articular cartilage
- Articular cartilage is devoid of neurovascular bundle.

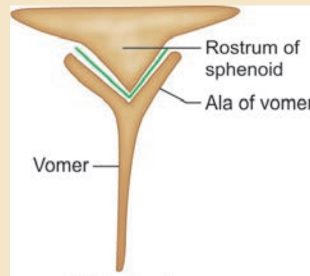
4. b. Synovial
- Malleus-incus joint is a saddle synovial joint and incus -stapes is ball and socket synovial joint.

5. d. Synovial joint
- Median atlanto-axial joint is a pivot synovial joint.

6. a. Sternoclavicular joint
- Few synovial joints have articular disc is present between articulating bones, e.g. sternoclavicular joint, temporomandibular joint.

7. a. Fibrous
- Fibrous joints are three types: sutures, syndesmosis, and gomphoses.

8. c. Schindylesis
- Spheno-vomerine joint is a schindylesis suture at the roof of the nasal cavity.



Schindylesis

9. c. Cartilaginous
- Pubic symphysis is a secondary cartilaginous joint, which is slightly mobile.

10. b. Primary cartilaginous
- Growing bones have epiphyseal (growth) plate between the epiphysis and diaphysis, this epphyseo-diaphyseal joint is primary cartilaginous (synchondrosis).

11. b. Secondary cartilaginous
- Manubriosternal joint is a symphysis (secondary cartilaginous) joint.

12. b. Syndesmosis

13. a. Symphysis
- Sacrococcygeal is a secondary cartilaginous (symphysis) joint.

14. a. Knee
- Knee joint has more than two bones participating (hence compound joint). It is formed by the lateral and medial femorotibial and the femoropatellar joints.
- It is a compound synovial joint incorporating 2 condylar joints between the condyles of the femur and tibia and one saddle joint between the femur and the patella.
- The TM joint is a condylar joint but it involves only 2 bones (not a compound joint).
- The wrist joint is an ellipsoid synovial joint.
- The elbow joint is a hinge synovial joint.

15. b. Metacarpophalangeal joint > d. Radiocarpal joint
- This a wrong question, since Gray's anatomy mentions both the joints under condylar variety.
- Both the joints have condyles with ellipsoid articular surface - are structurally condylar but functionally ellipsoid.
- Some authors mentions metacarpophalangeal as condylar synovial joint only (hence the answer of first preference).

16. c. Saddle synovial
- Malleus and incus have saddle synovial joint.
- Incus and stapes have ball & socket synovial joint.

17. b. Ellipsoid > c. Condylar
- Functionally it is an ellipsoid synovial joint but structurally it is a condylar synovial joint.
- Head flexion and extension occurs at this joint for the nodding (yes) movement.

Muscles

The orientation of individual skeletal muscle fibres is either **parallel or oblique** to the line of pull of the whole muscle.

The range of contraction is long with the former arrangement, while the latter provides increased force of contraction. Sartorius is an example of a muscle with parallel fibres.

Muscles with an oblique disposition of fibres fall into several patterns:

- Muscles with parallel fasciculi: These are muscles in which the fasciculi are parallel to the line of pull and have greater degree of movement. These muscles may be:
  - Quadrilateral e.g. thyrohyoid
  - Strap-like e.g. sternohyoid and sartorius
  - Strap-like with tendinous intersections e.g. rectus abdominis
  - Fusiform e.g. biceps brachii, digastric

- Muscles with oblique fasciculi: When the fasciculi are oblique to the line of pull, the muscle may be triangular, or pennate (feather-like) in the construction. This arrangement makes the muscle more powerful, although the range of movement is reduced. Oblique arrangements are of the following types:
  - Triangular e.g. temporalis, adductor longus.
  - Unipennate e.g. flexor pollicis longus, extensor digitorum longus
  - Bipennate e.g. rectus femoris, flexor hallucis longus
  - Multipennate e.g. tibialis anterior, subscapularis, deltoid (acromial fibers]

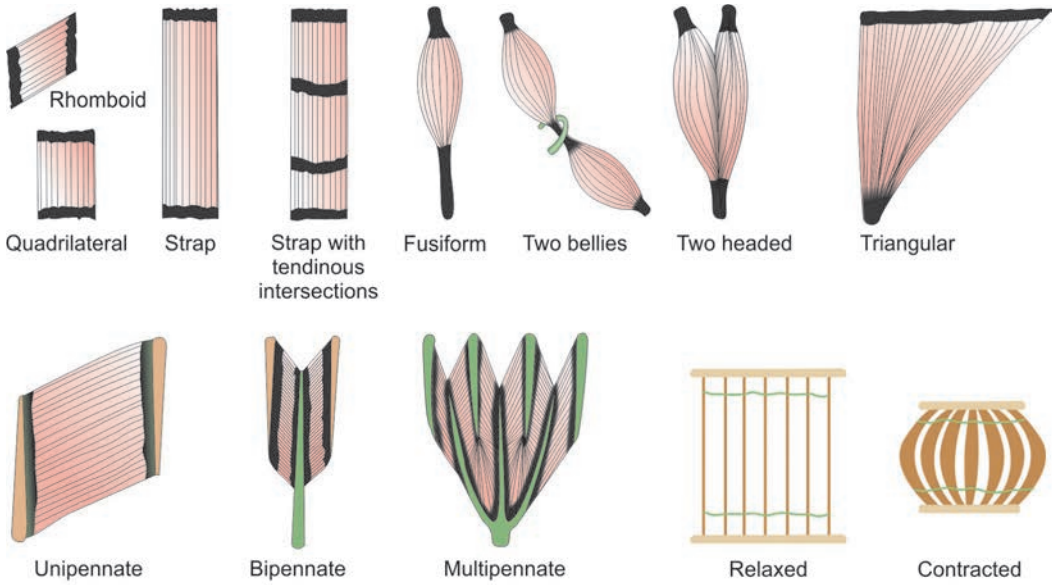


Fig. 10: Muscles with parallel and oblique fasciculi

Common sites of intramuscular injection

Upper arm (Deltoid)	• 5 cm distal to the acromion or • 4 cm proximal to the insertion of deltoid • This is to prevent injury to circumflex humeral nerve.
Gluteal region	• Upper outer (superolateral) quadrant • This is to avoid damage to superior and inferior gluteal vessels and sciatic nerve. • The muscle in which the injection is given is gluteus medius.
Thigh (lateral aspect)(vastus lateralis)	• Infant :- Upper lateral quadrant of thigh below GT • Adult:- Middle third of lateral aspect.

Composite or hybrid muscles:

Definition: (a) A muscle having more than one set of muscle fibres (major criteria); (b) A muscle having more than one nerve supply (minor criteria).

Name of muscle	Nerve supply (part of muscle)
Trapezius	• Spinal accessory nerve (motor) • Ventral rami of C3, 4 (proprioception)
Digastric	• Trigeminal nerve (anterior belly) • Facial nerve (posterior belly)
Brachialis	• Musculocutaneous nerve (motor) • Radial nerve (proprioceptive)
Flexor digitorum profundus	• Median nerve (lateral half) • Ulnar nerve (medial half)
Flexor pollicis brevis	• Median nerve (superficial part) • Ulnar nerve (deep part)
Opponens pollicis	• Median nerve (lateral part) • Ulnar nerve (medial part)
Ilio-psoas	• Direct branches of the anterior rami of L1-L3 (psoas major) • Femoral nerve (iliacus)
Pectineus	• Femoral nerve (anterior fibres) • Obturator nerve (posterior fibres)
Biceps femoris	• Tibial part of sciatic nerve (long head) • Common peroneal nerve (short head)
Adductor magnus	• Tibial part of sciatic nerve (ischial part) • Obturator nerve (adductor part)

Some authors give another definition to **composite** muscle: Composite muscles are those, whose functions are regarded the same in terms of skeletal structure and muscle arrangement condition, as a single muscle model.

- A single muscle itself is considered as a composite muscle, when its different parts work together to perform a particular function and mostly supplied by a single nerve. For example 1)
    - Tongue is a composite muscle made up of various components like longitudinal, transverse, horizontal muscles with different parts innervated by a single nerve supply - hypoglossal nerve. 2)
    - Quadriceps femoris has four parts, involved in one common activity of knee extension and supplied by a single nerve - femoral nerve.
- Unit concept of muscle: In single-unit smooth muscle, either the whole muscle contracts or the whole muscle relaxes.
    - An action potential can be propagated through neighbouring muscle cells due to the presence of many gap junctions between the cells.
    - Due to this property single-unit smooth muscle form a syncytium that contracts in a coordinated fashion uterus, gastro-intestinal tract, and the bladder.

In **multi-unit smooth muscle,** the smooth muscle cells in an organ all behave independently – each cell contract and relaxes on its own.

Single unit type	Multiple unit type
Digestive tract	Iris
Urinary tract (includes ureter, bladder)	Trachea and bronchi
Uterus	Erector pilorum
Blood vessels (except large elastic arteries)	Large elastic artery
	Ducts deferens

ASSESSMENT QUESTIONS

1. Smallest muscle in the body is: *(NEET Pattern 2015)*
a. Interarytenoid
b. Stapedius
c. Corrugator supercilli
d. Superior oblique

2. Composite muscles include the following EXCEPT: *(AIPG 2008)*
a. Pectineus
b. Adductor magnus
c. Rectus femoris
d. Biceps femoris

3. All are composite muscles EXCEPT: *(AIPG 2009)*
a. Pectineus
b. Flexor Carpi ulnaris
c. Biceps femoris
d. Flexor digitorum profundus

4. Muscle having double nerve supply: *(PGIC 2015)*
a. Digastric muscle
b. Omohyoid muscle
c. Trapezius
d. Thyrohyoid muscle
e. Adductor magnus

5. Digastric muscles are the following EXCEPT: *(AIPG 2008)*
a. Occipitofrontalis
b. Sternocleidomastoid
c. Omohyoid
d. Muscular fibres in the ligament of Treitz

6. Most common muscle to be congenitally absent is: *(AIPG 2009)*
a. Pectoralis major
b. Teres minor
c. Semimembranosus
d. Gastrocnemius

7. Which among the following is an intra- articular tendon is? *(JIPMER 2016)*
a. Anconeus
b. Semitendinosus
c. Semimembranosus
d. Popliteus

8. Which of the following is multipennate muscle? *(NEET Pattern 2015)*
a. FPL
b. EPL
c. Deltoid
d. FHL

9. Longest muscle in the body: *(NEET Pattern 2012)*
a. Biceps
b. Triceps
c. Sartorius
d. Quadriceps

10. Multi-unit smooth muscle present at all EXCEPT: *(NEET Pattern 2012)*
a. Blood vessels
b. Iris
c. Gut
d. Ductus deferens

11. Single unit smooth muscles are seen in: *(NEET Pattern 2012)*
a. Iris
b. Ductus deferens
c. Ureter
d. Trachea

12. Muscle with parallel fibres are all EXCEPT: *(AIIMS 2016)*
a. Sartorius
b. Rectus abdominis
c. Sternohyoid
d. Tibialis anterior

ANSWERS WITH EXPLANATIONS

1. b. Stapedius
- The smallest skeletal muscle in the body is stapedius.
- The smallest muscle in the body is arrector pilorum, a smooth muscle in the skin for erection of hair.

2. c. Rectus femoris
- Muscles like adductor magnus, pectineus, biceps femoris are called as composite muscles as they have more than one set of muscles fibres and more than one motor nerve supply.
- Rectus femoris is supplied by only one nerve – the femoral nerve and is not a composite muscle.

3. b. Flexor carpi ulnaris
- Flexor carpi ulnaris is supplied by a single nerve and is not a composite/hybrid muscle.
- Composite/hybrid muscles have more than one set of fibres and are supplied usually by different nerves for different set of fibres.
- Pectineus has anterior set of fibres supplied by the femoral nerve, whereas, posterior set of fibres may be supplied by the obturator nerve.
- Long head of biceps femoris is supplied by the tibial part of sciatic nerve, and the short head is supplied by the common peroneal nerve. This reflects the composite derivation from the flexor and extensor musculature.
- Radial half of flexor digitorum profundus is supplied by the median nerve and the ulnar half is supplied by the ulnar nerve.

4. a. Digastric muscle; c. Trapezius; e. Adductor magnus
- Anterior belly of digastric is supplied by trigeminal nerve and posterior belly by facial nerve.
- Spinal accessory nerve give motor fibres to trapezius muscle, whereas ventral rami of C3,4 are proprioceptive.
- Adductor magnus ischial part is supplied by tibial part of sciatic nerve and adductor part by obturator nerve.
- Inferior belly of the omohyoid is innervated by C1-C3 and the superior belly C1 fibres of ansa cervicalis.
- Thyrohyoid muscle is innervated by C1 fibers travelling with the hypoglossal nerve.

5. b. Sternocleidomastoid
- Sternocleidomastoid is a muscle with two heads and one belly, like the biceps brachii.
- Ligament of Treitz is a digastric muscle with a skeletal muscle belly, which arises from the left crus of diaphragm and a smooth muscle belly which arises from the duodeno-jejunal junction.
- It has an intermediate tendon attaching to the connective tissue around the celiac trunk of aorta.

6. a. Pectoralis major
- Pectoralis major and minor are the most common congenitally absent muscles.
- Agenesis is often partial and may be a part of the syndrome – Poland syndrome.

7. d. Popliteus
- Popliteus has intracapsular origin from the lateral femoral epicondyle. It inserts on the posterior surface of the tibia, just proximal to the soleal line.

8. c. Deltoid
- Multipennate muscle has the fiber bundles converge to several tendons.

9. c. Sartorius
- The longest muscle of body is sartorius muscle.

10. c. Gut
- Gut comes under single-unit smooth muscle, where the whole muscle contracts or the whole muscle relaxes.
- Examples are uterus, gastro-intestinal tract, and the bladder.

11. c. Ureter
- In single-unit smooth muscle, either the whole muscle contracts or the whole muscle relaxes.

12. d. Tibialis anterior
- The individual fibers of a muscle are arranged either parallel or oblique to the long axis of the muscle.
- Tibialis anterior muscle is a multipennate muscle with oblique fibres.
- Muscles with parallel fasciculi: These are muscles in which the fasciculi are parallel to the line of pull and have greater degree of movement. Few examples are:
  - Strap-like e.g. sternohyoid and sartorius
  - Strap-like with tendinous intersections e.g. rectus abdominis

Structures Associated with Muscles

Raphe is the line of union of symmetrical structures by a fibrous or tendinous band such as the pterygomandibular, pharyngeal, and scrotal raphes.

Ligaments

Ligaments are fibrous bands that connect bones to bones or cartilage or are folds of peritoneum serving to support visceral structures.

- They are composed of dense connective tissue, mainly collagen fibres, the direction of the fibres being related to the stresses which they undergo.
- In general ligaments are unstretchable, unless subjected to prolonged strain. A few ligaments, such as the ligamenta flava between vertebral lamina and the ligamentum nuchae at the back of the neck, are made of elastic fibres, which enables them to stretch and regain their original length thereafter.
- Ligaments are usually attached to bone at their two ends.

Tendons

Tendons are fibrous bands of dense connective tissue that connect muscles to bones or cartilage.

- They are supplied by sensory fibers extending from muscle nerves.
- They have a similar structure to collagenous ligaments, and attach muscle to bone.
- They may be cylindrical, or flattened into sheet-like aponeuroses.
- Tendons have a blood supply from vessels which descend from the muscle belly and anastomose with periosteal vessels at the bony attachment.

Synovial sheaths

Where tendons bear heavily on adjacent structures, and especially where they pass around loops or pulleys of fibrous tissue or bone and change the direction of their pull, they are lubricated by being provided with a synovial sheath.

- The parietal layer of the sheath is attached to the surrounding structures, the visceral layer is fixed to the tendon, and the two layers glide on each other, lubricated by a thin film of synovial fluid secreted by the lining cells of the sheath.
- The visceral and parietal layers join each other at the ends of their extent.
- Usually they do not enclose the tendon cylindrically; it is as though the tendon was pushed into the double layers of the closed sheath from one side. In this way blood vessels can enter the tendon to reinforce the longitudinal anastomosis. In other cases blood vessels perforate the sheath and raise up a synovial fold like a little mesentery—a vinculum—as in the flexor tendons of the digits.

Aponeuroses are flat fibrous sheets or expanded broad **tendons** that attach to muscles and serve as the means of origin or insertion of a flat muscle.

Retinaculum

- Is a fibrous band that holds a structure in place in the region of joints.

Bursae

- Are fluid-filled flattened sacs of synovial membrane that facilitate movement by minimizing friction.

Synovial tendon sheaths

- Are synovial fluid-filled tubular sacs around muscle tendons that facilitate movement by reducing friction.

Fascia

- Is a fibrous sheet that envelops the body under the skin and invests the muscles and may limit the spread of pus and extravasated fluids such as urine and blood.

Superficial fascia

Is a loose connective tissue between the dermis and the deep (investing) fascia and has a fatty superficial layer (fat, cutaneous vessels, nerves, lymphatics, and glands) and a membranous deep layer.

- The skin is connected to the underlying bones or deep fascia by a layer of loose areolar connective tissue. This layer, usually referred to as superficial fascia, is of variable thickness and fat content.
- Flat sheets of muscles are also present in some regions. These include both skeletal muscles (platysma, palmaris brevis) and smooth muscles (subareolar muscle of the nipple, dartos, corrugator cutis ani).
- The superficial fascia is most distinct on the lower abdominal wall where it differentiates into two layers. Strong connective tissue bands traverse the superficial fascia binding the skin to the underlying aponeurosis of the scalp, palm and sole.

Deep Fascia

- Is a sheet of fibrous tissue that invests the muscles and helps support them by serving as an elastic sheath or stocking.
- Provides origins or insertions for muscles, forms fibrous sheaths or retinacula for tendons, and forms potential pathways for infection or extravasation of fluids.
- The limbs and body wall are wrapped in deep fascia. It varies widely in thickness.
- In the iliotibial tract of the fascia lata, for example, it is very well developed, while over the rectus sheath and external oblique aponeurosis of the abdominal wall, it is so thin as to be scarcely demonstrable and is usually considered to be absent.
- In other parts, such as the face and the ischioanal fossa, it is entirely absent.
- Where deep fascia passes directly over bone it is always anchored firmly to the periosteum and the underlying bone is described as being subcutaneous.
- In the neck, as well as the investing layer of deep fascia, there are other deeper fascial layers enclosing neurovascular structures, glands and muscles. Intermuscular septa are laminae of deep fascia which extend between muscle groups.
- In the neck, as well as the investing layer of deep fascia, there are other deeper fascial layers enclosing neurovascular structures, glands and muscles. Intermuscular septa are laminae of deep fascia which extend between muscle groups.
- Transverse thickenings of deep fascia over tendons, attached at their margins to bones, form retinaculae at the wrists and ankles and fibrous sheaths on the fingers and toes.

Retinacula at the joints

In the vicinity of the joints, the tendons of the muscles of the leg are bound down by localized, band-shaped thickenings of the deep fascia termed retinacula, which collectively serve to prevent bowstringing of the underlying tendons during muscle contraction.

Portal Venous Circulation

- Portal circulation is a capillary network that lies between two veins. Blood supplying the organ thus passes through two sets of capillaries before it returns to the heart.
- In hepatic portal system blood supplying the abdominal organs passes through two sets of capillaries before it returns to the heart.
- A portal circulation also connects the median eminence and infundibulum of the hypothalamus with the adenohypophysis.
- In the renal glomeruli. The glomerular capillary bed lies between afferent and efferent arterioles and may be considered as a portal circulation, but most of the authors do not mention so (including Gray's anatomy).

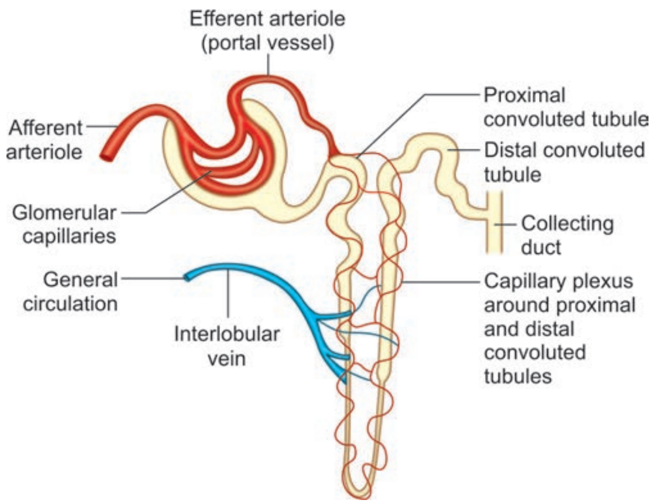
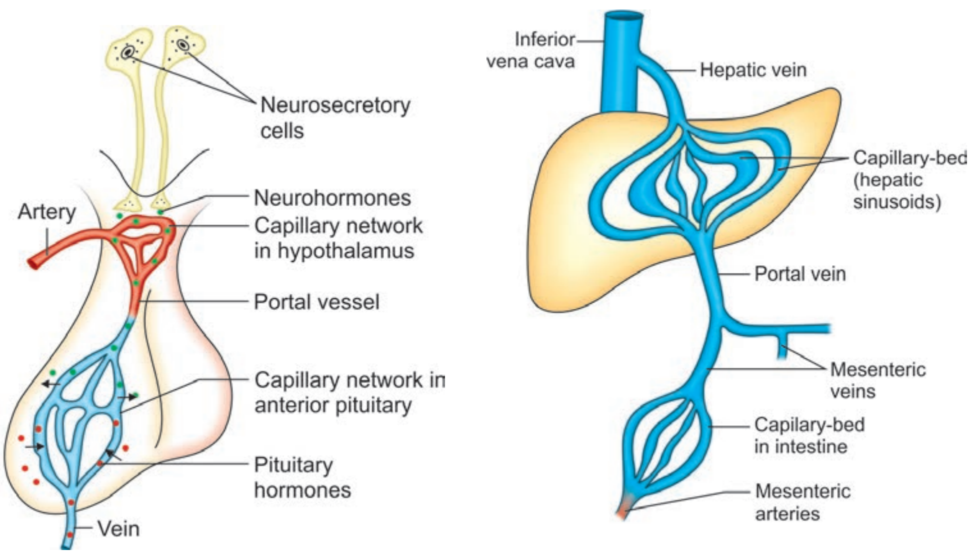


Fig. 11: Renal portal system



Figs. 12A and B: Adenohypophyseal portal system. (B) Hepatic portal system

ASSESSMENT QUESTION

1. **NOT true about shunt vessel is:** *(AIPG 2009)*
   a. It control temperature regulation
   b. It is direct communication between artery and veins
   c. It is under control of local mediators
   d. It is not under autonomic control

ANSWER WITH EXPLANATION

1. **d. It is not under autonomic control**
   - **Shunt vessels** are under the **vasoconstrictive** action of sympathetic nervous system.
   - Under sympathetic control the shunt vessel is able to close completely, **diverting** blood into the normal pathway.
   - Shunt vessels are **direct** arterio-venous communication between smaller arteries and veins.

- Normal flow of blood: Artery→ arterioles→ capillaries→ venules→ veins.
- Shunt vessels basically **bypass** the capillary circulation and connect small arteries to the small veins **in case of resting organ.**
- They serve the **phasic activity** of the organ. When the organ is active these shunts are closed and the blood circulates through the capillaries. According to the **local demands,** the shunt vessels may open/close and can deliver the blood directly to the venules or let it flow normally through the capillaries.
- **Sites of AV shunts:** Skin of the nose, lips, and ears, nasal and alimentary mucosa, erectile tissue, thyroid gland, sympathetic ganglia etc.
- Shunt vessels are important for **temperature regulation** as evidenced in cold environment.
- To conserve central (core) temperature the shunt vessels open up in the peripheries (hand, feet etc.) and the blood bypasses the capillary beds at the tip of the fingers. Hence, we feel our **finger tips getting cold very quickly** as relative to the central body.

Lymphatic System

Lymphatic system is a collection of vessels that function to drain **extracellular fluid** from tissues of the body and return it to the **venous system.**

The lymphatic system consists of lymphatic **organs,** a conducting network of lymphatic **vessels,** and the circulating **lymph.**

Primary or central lymphoid organs **generate** lymphocytes from immature progenitor (stem) cells.

The thymus and the bone **marrow** constitute the **primary lymphoid organs** involved in the production and early clonal selection of lymphocyte tissues.

- Bone marrow is responsible for both the creation of T cells and the production and maturation of B cells. From the bone marrow, B lymphocytes immediately join the circulatory system and travel to secondary lymphoid organs in search of pathogens.
- T lymphocytes on the other hand, travel from the bone marrow to the thymus, where they develop further. Mature T cells join B cells in search of pathogens. The other 95% of T cells begin a process of apoptosis, a form of programmed cell death.

Secondary or peripheral lymphoid organs, which include lymph nodes and the spleen, maintain mature naive lymphocytes and initiate an adaptive immune response.

- The peripheral lymphoid organs are the sites of lymphocyte activation by antigens. Activation leads to clonal expansion and affinity maturation. Mature lymphocytes recirculate between the blood and the peripheral lymphoid organs until they encounter their specific antigen.
- Secondary lymphoid tissue provides the environment for the foreign or altered native molecules (antigens) to interact with the lymphocytes. It is exemplified by the lymph nodes, and the lymphoid follicles in tonsils, Peyer's patches, spleen, adenoids, skin, etc. That are associated with the mucosa-associated lymphoid tissue (MALT).
- In the gastrointestinal wall the vermiform appendix has mucosa resembling that of the colon, but here it is heavily infiltrated with lymphocytes.

Tertiary lymphoid organs (TLOs) are included postnatally in non-lmyphoid tissue such as those affected by chronic infection, autoimmune disease, and chronic allograft rejection, and also in cancer tissue.

- They have a structure similar to that of lymph nodes or Peyer's patches, including T cell zones, B cell follicles, and high endothelial venules (HEV) without encapsulation.

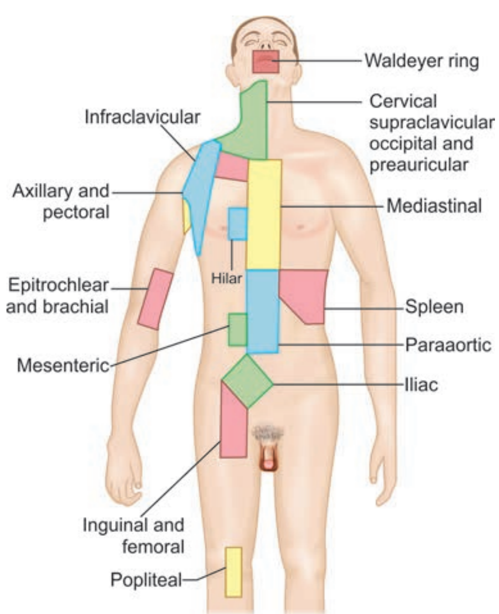


Fig. 13: Location of regional lymph nodes

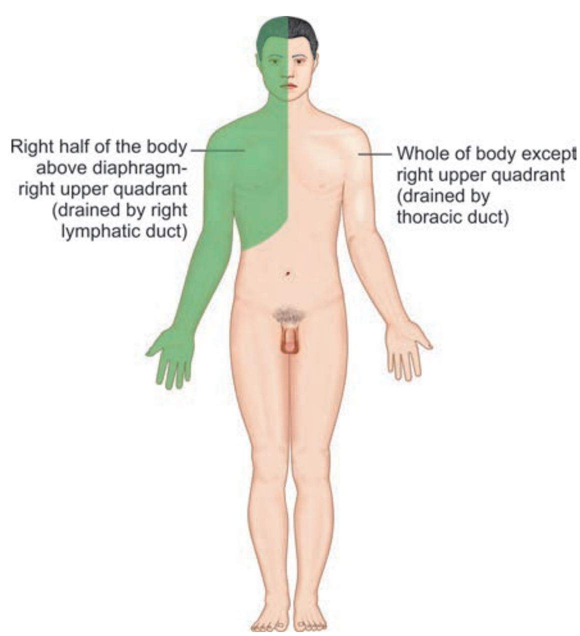


Fig. 14: Lymphatic drainage of body

All regions of the body possess lymphatic drainage except for the brain and spinal cord. Right upper quadrant of the body drains the lymphatics into the right lymphatic duct and rest of the body drains into thoracic duct.

The confluence of lymph trunks receives lymph from **fourma in lymphatic trunks:** The right and left **lumbar lymph trunks** and the right and left **intestinal lymph trunks.**

In a small percentage of population this abdominal confluence of lymph trunks is represented as a dilated sac called the **cisterna chyli**. It is present in the abdomen at **L-1, 2 vertebral levels.**

Thoracic Duct begins in the abdomen at T-12 vertebral level as the continuation of **cisterna chyli.**

- It is usually beaded because of its numerous valves and often forms double or triple ducts.
- It drains the body below diaphragm (lower limbs, pelvis, abdomen) and left half of the body above diaphragm (thorax, upper limb and the head and neck).
- Thoracic duct passes through the aortic hiatus in the diaphragm and ascends through the posterior mediastinum between the aorta and the azygos vein.
- At T-5 vertebral level it deviates to left side of midline and keep ascending up to pass the thoracic inlet. It arches laterally over the apex of the left pleura and between the left carotid sheath in front and the vertebral artery behind, runs behind the left internal jugular vein, and eventually empties into the left venous angle — junction of the left internal jugular and subclavian veins (Beginning right brachiocephalic vein).

Tributaries of thoracic duct:

- Bilateral (right and left) descending thoracic lymph trunks, which convey lymph from the lower intercostal spaces (6 to 11).
- Left upper intercostal lymph trunks, which convey lymph from the left upper intercostal spaces (1 to 5).
- Mediastinal lymph trunks
- Left subclavian lymph trunk
- Left jugular lymph trunk
- Left bronchomediastinal lymph trunk

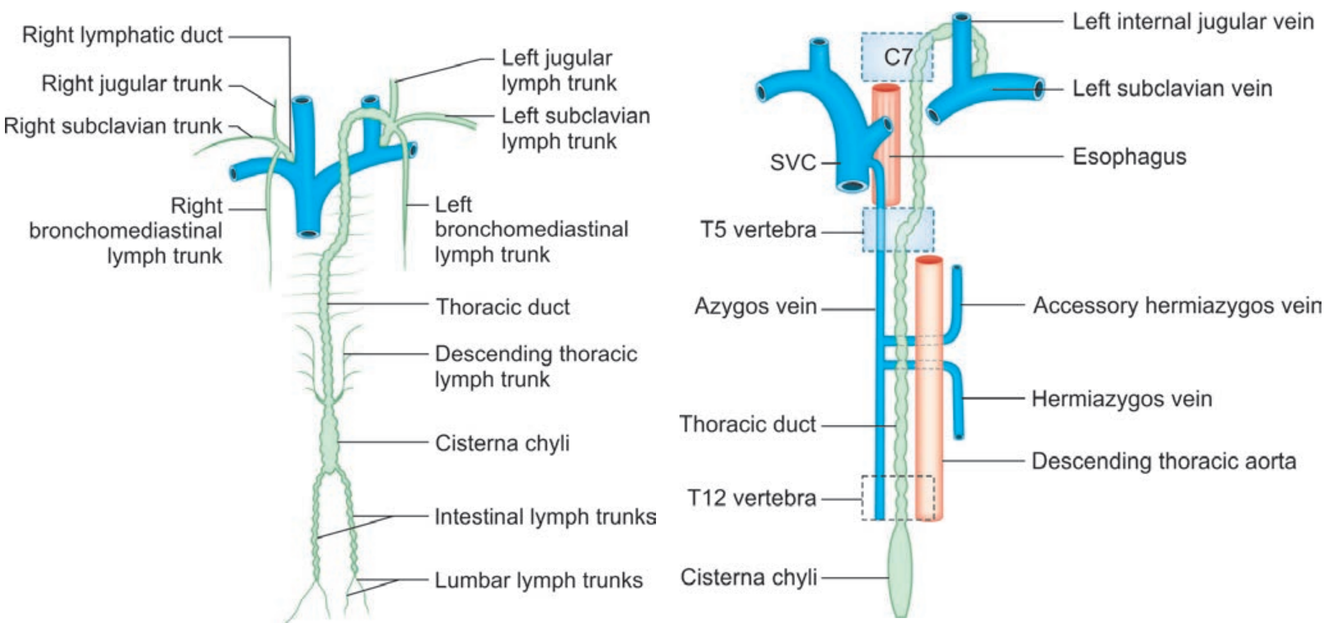


Fig. 15A and B: (A) Thoracic duct and right lymphatic duct. (B) Formation, course and termination of thoracic duct

Right lymphatic duct is a short vessel that drains the right upper half of the body above diaphragm.

- It begins as a convergence of the right sided lymphatic vessels (subclavian lymph trunk, jugular lymph trunk, and bronchomediastinal lymph trunk).
- It drains into the right venous angle - junction of the right internal jugular and subclavian veins (Beginning of left brachiocephalic vein).
- Right lymphatic duct drains right side of the head and neck, upper limb, thorax (including breast and lung) and superficial thoracoabdominal wall (above umbilicus).
- Schematic diagram for lymphatic drainage of the body is given in:

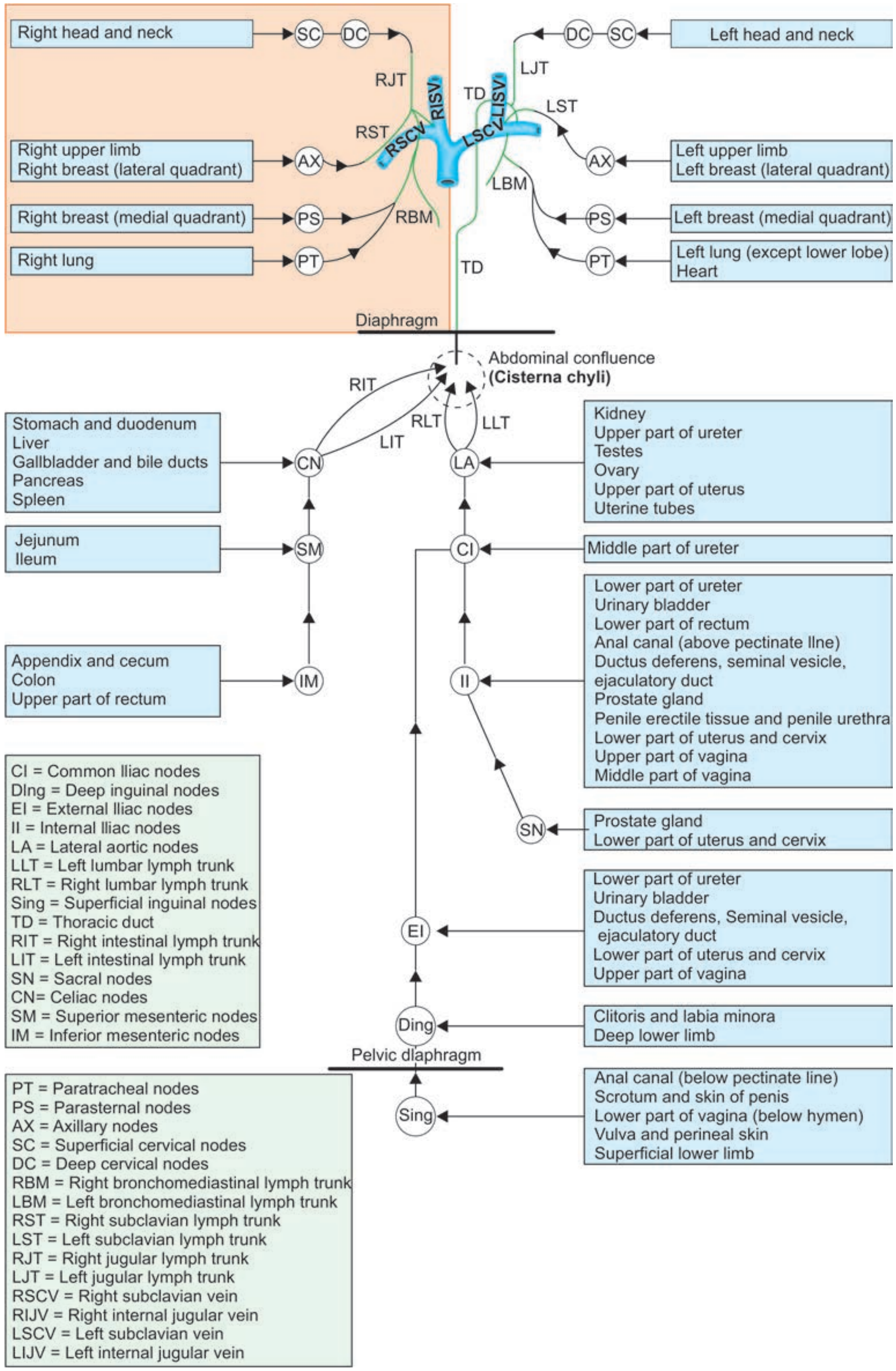


Fig. 16: Summary diagram of specific lymphatic drainage. Arrow indicate direction of lymph flow. Right side of body above diaphragm – Shaded boxed area (light brown), lymph drainage into the right lymphatic duct; Rest of the body lymph drain into the thoracic duct.

ASSESSMENT QUESTIONS

1. **Thoracic duct does NOT drain:** *(NEET Pattern 2013)*
   a. Right upper part of body
   b. Left upper part of body
   c. Right lower part of body
   d. Left lower part of body

2. **All are true about thoracic duct EXCEPT:**
   a. Begins as continuation of cisterna chyli (NEET Pattern 2014)
   b. Largest lymphatic vessel
   c. Passes through the esophageal opening
   d. Ends into junction between left subclavian and internal jugular vein

3. Thoracic duct opens into: *(NEET Pattern 2015)*
   a. Subclavian vein
   b. Internal jugular vein
   c. Right brachiocephalic vein
   d. Left brachiocephalic vein

4. The thoracic duct receives tributaries from all of the following EXCEPT: *(AIIMS 2008)*
   a. Bilateral ascending lumbar trunk
   b. Bilateral descending thoracic trunk
   c. Left upper intercostal duct
   d. Right bronchomediastinal lymphatic trunk

5. All is true about Pecquet duct EXCEPT:
   a. Begins at level of T12
   b. Enters thorax through aortic opening
   c. Crosses from right to left at level of T8
   d. Passes the superior aperture of thorax
   e. Passes in posterior and superior mediastinum

ANSWERS WITH EXPLANATIONS

1. a. Right upper part of body
- Right upper quadrant of the body drains the lymphatics into the **right lymphatic duct** and rest of the body drains into **thoracic duct.**

2. c. Passes through the esophageal opening
- Thoracic duct passes through the **aortic hiatus** in front of the T 12 vertebra, lying on the right side of aorta.

3. d. Left brachiocephalic vein
- Thoracic duct opens into the **left venous** (jugulo-subclavian) **angle,** at the beginning of left brachio-cephalic vein.

4. d. Right bronchomediastinal lymphatic trunk
- Right broncho-mediastinal lymphatic trunk drains into right lymphatic duct **(not thoracic duct).**
- **Theme:** Right half of the body above diaphragm (right superior quadrant) drains into the right lymphatic duct.
- Right lymphatic duct receives the lymphatic drainage from the right half of the head & neck **(Jugular lymphatic trunk);** right upper limb **(right subclavian lymphatic trunk)** and the right thoracic cavity **(right broncho-mediastinal lymphatic trunk** and the **right upper intercostal ducts).**
- Thoracic duct drains the body below the diaphragm and also the remaining left superior quadrant of the body.
  - Hence, it receives the left sided jugular, subclavian and broncho-mediastinal lymphatic trunks.
  - It also receives **left upper intercostal ducts** whereas, right upper intercostal ducts empty into the right lymphatic duct.
- Thoracic duct receives three major lymphatic vessels at its commencement: **Bilateral ascending lumbar ducts; Bilateral descending thoracic ducts** and **Intestinal lymphatic trunks.**
  - Bilateral descending thoracic ducts drain the lower 6 intercostal spaces (embryologically this region comes below diaphragm) and empty into the thoracic duct.
  - As noted above upper 6 intercostal spaces on the right drain into the right lymphatic duct and left upper intercostals into thoracic duct accordingly.
- Important: Right thoracic duct not only receives the lymphatics of right lung (lungs lie above diaphragm) but also lower lobe of left lung ! Upper lobe of left lung drains into the thoracic duct only.
- Externally umbilicus (in place of diaphragm) is taken to be the watershed line i.e., skin above the umbilicus on right side of the body drains into the right lymphatic duct.

5. c. Crosses from right to left at level of T8
- Thoracic (Pecquet) duct crosses from right to left at level of **T5 vertebra.**

Miscellaneous

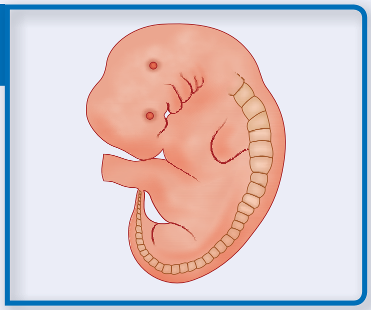
ASSESSMENT QUESTION

1. Embalming solution constituents are all EXCEPT: *(AIIMS 2008)*
   a. Ethanol
   b. Phenol
   c. Glycerine
   d. Formalin

ANSWER WITH EXPLANATIONS

1. a. Ethanol
- **Ethanol** is a preservative and can be used for embalming but is **not** the usual content of embalming fluid/solution. In its place methanol is used, which is cheaper and more toxic to bacteria than ethanol.
  - **Embalming** is the process of treatment of the dead body with antiseptics and preservatives **to prevent putrefaction.**
  - **Preservative** is the substance added to destroy or inhibit the growth of micro-organisms. It alters enzymes and lysins of the body and arrest decomposition — fixing the specimen in such a way that it retains its original structure with minimal alteration.
  - **Formalin** is the most commonly used fixative/ preservative and less commonly used are – Ethanol/ Phenol.
  - **Phenol** is a powerful Fungicide.
  - **Glycerine** is used in the embalming fluid as a hygroscopic/humectant/wetting agent and decreases the loss of water of the preserved structures (maintains hydration). But it is **not** the actual preservative by definition.
  - **Wetting agents** lower the surface tension of water and facilitate penetration and distribution of embalming fluids through the vascular beds into the tissues.

CHAPTER 2

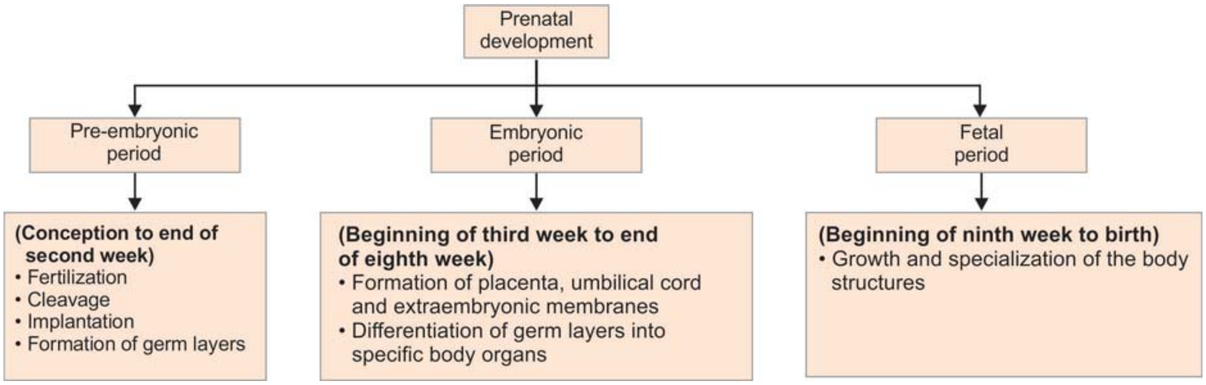


Embryology

Prenatal period is divided into three parts: Pre-embryonic, embryonic and fetal period.

- **Pre-embryonic** period extends from fertilization to the end of second week of intrauterine life.
- **Embryonic period** extends from beginning of the third week to the end of eighth week of intrauterine life.
- **Fetal** stage extends from beginning of the ninth week to birth.

Note: Some authors consider the embryonic period from fertilization to the end of eight week.



Flowchart 1: Subdivision of prenatal period and events occurring in these periods.

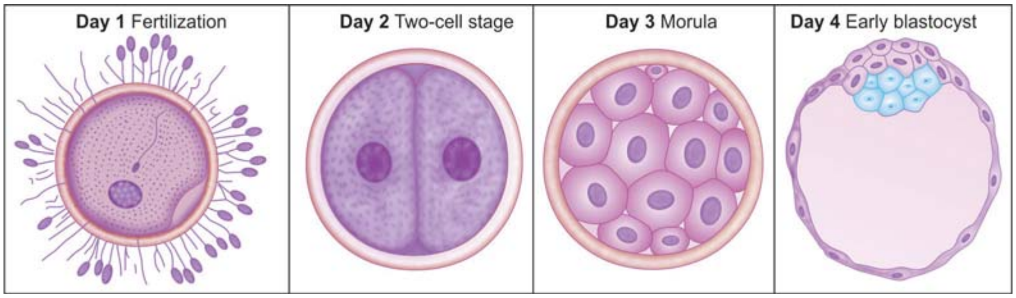


Fig. 1: First week of development

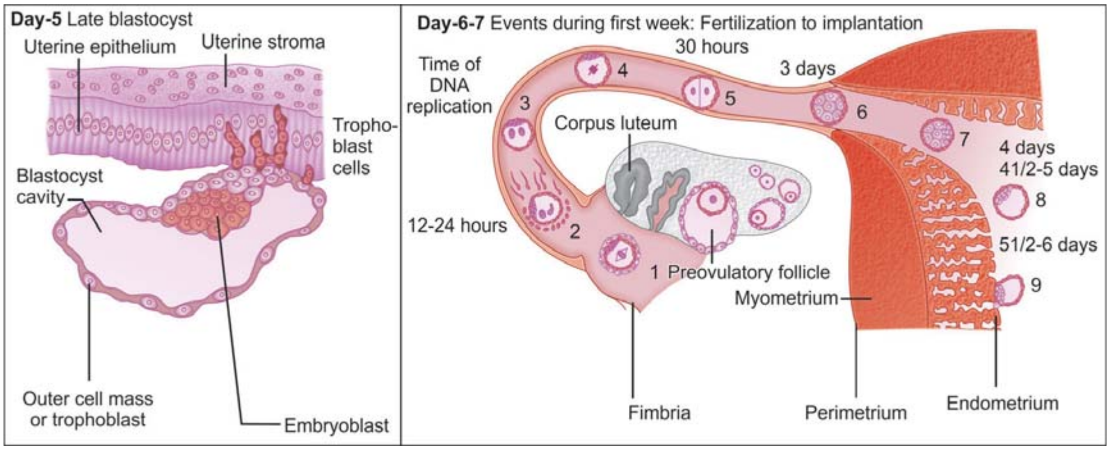


Fig. 2: First week of development (later stage)

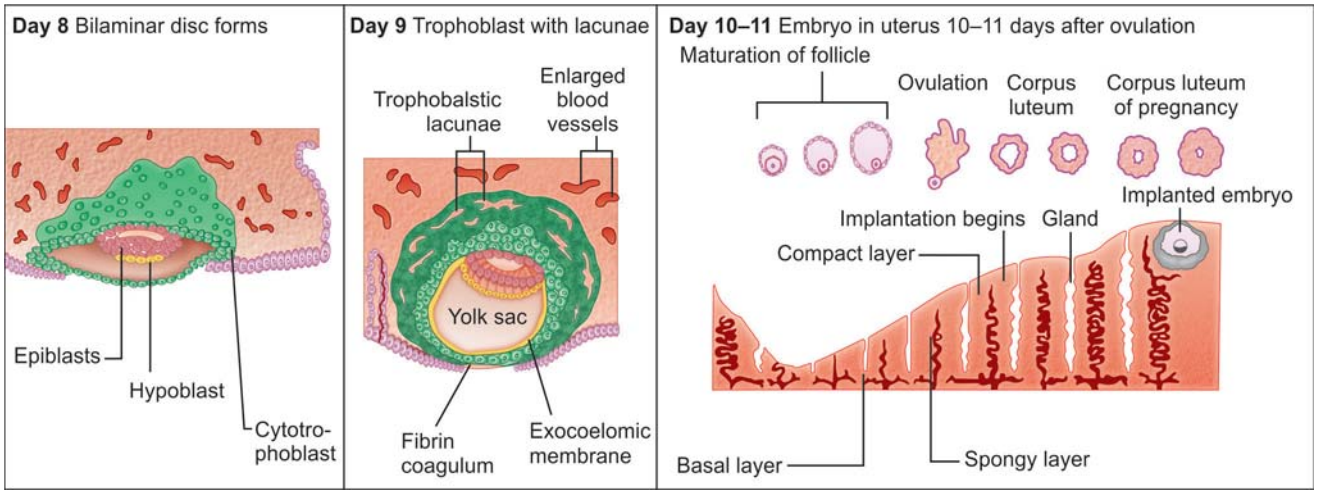


Fig. 3: Second week of development

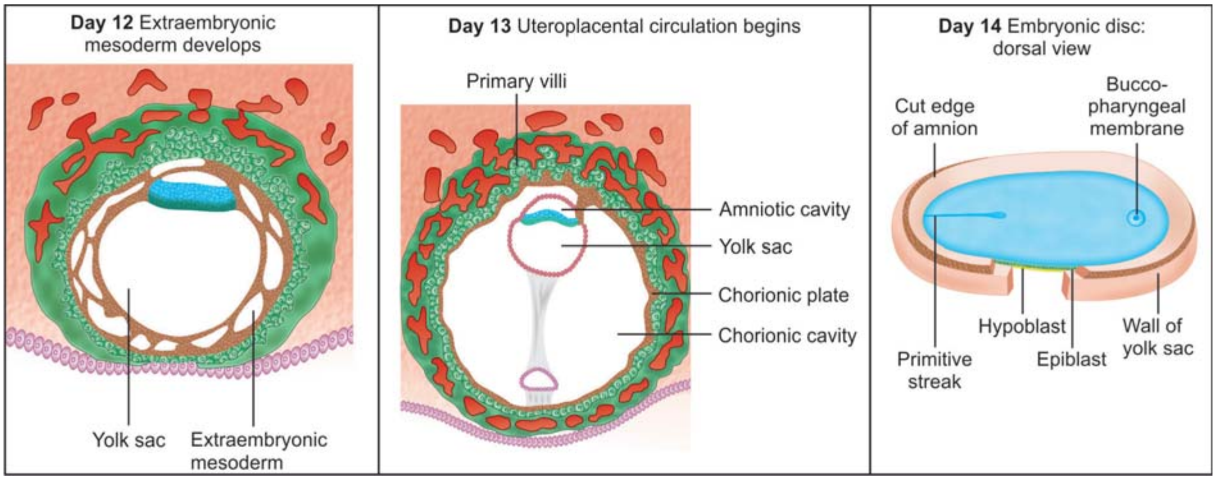


Fig. 4: Second week of development (later stage)

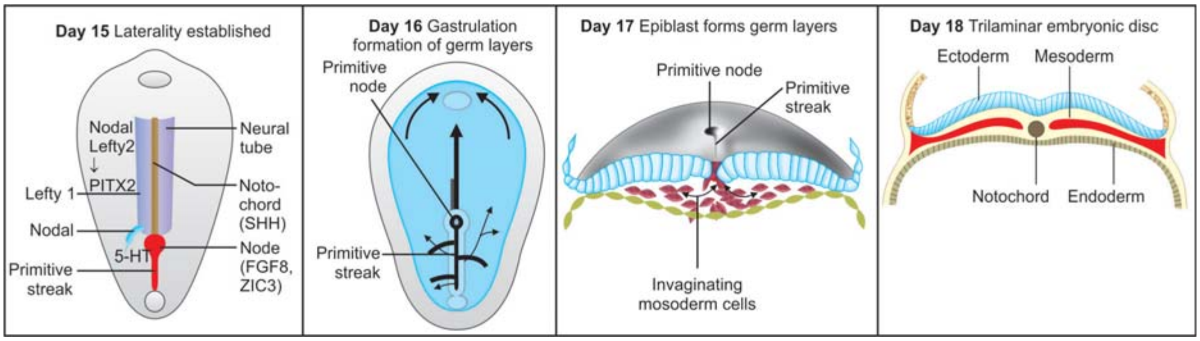


Fig. 5: Third week of development

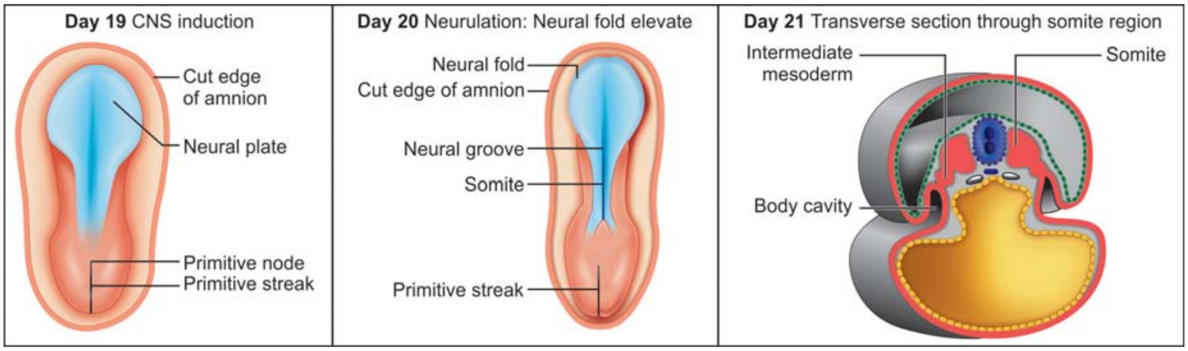


Fig. 6: Third week of development (later stage)

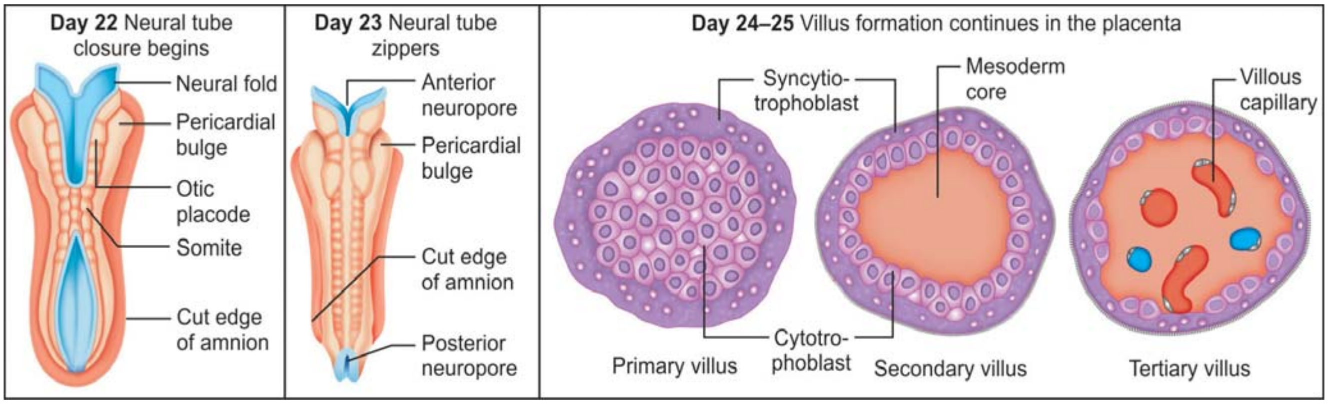
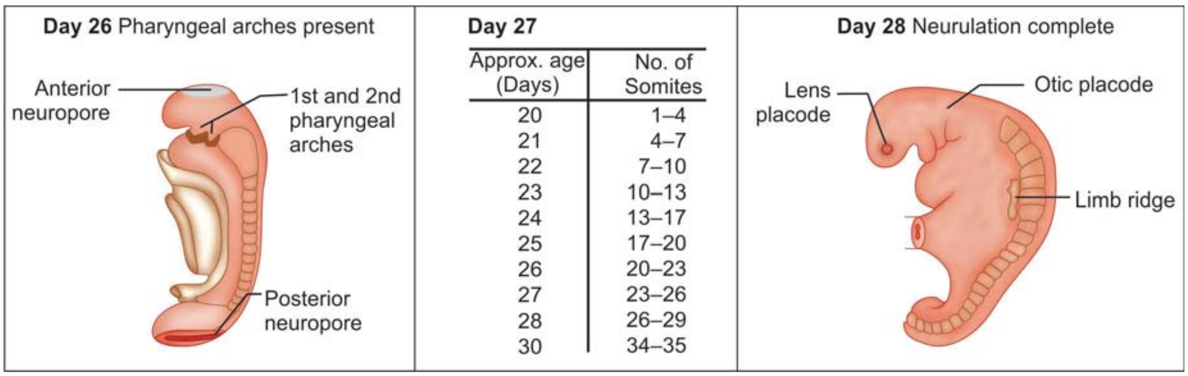


Fig. 7: Fourth week of development



Approx. age (Days)	No. of Somites
20	1–4
21	4–7
22	7–10
23	10–13
24	13–17
25	17–20
26	20–23
27	23–26
28	26–29
30	34–35

Fig. 8: Third week of development (later stage)

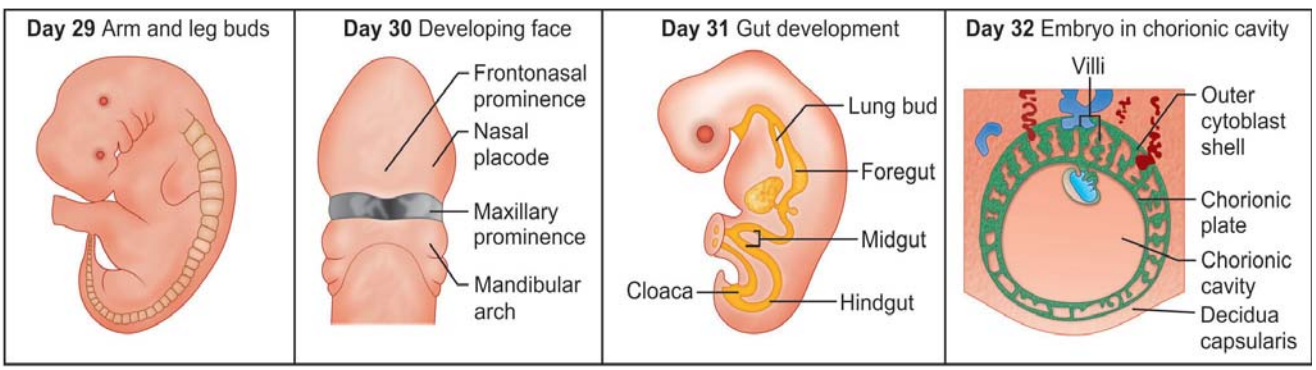


Fig. 9: Fifth week of development

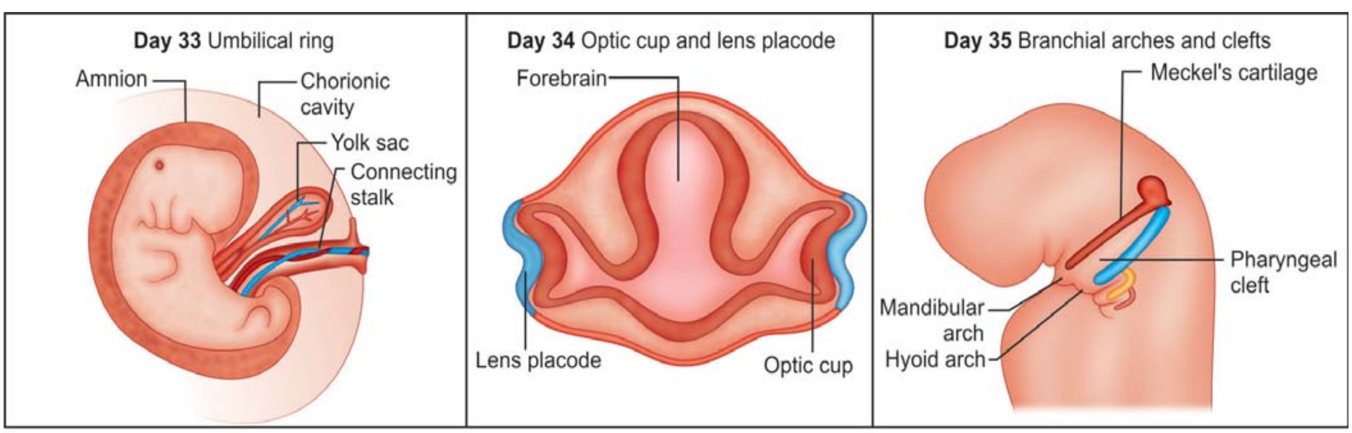


Fig. 10: Fifth week of development (later stage)

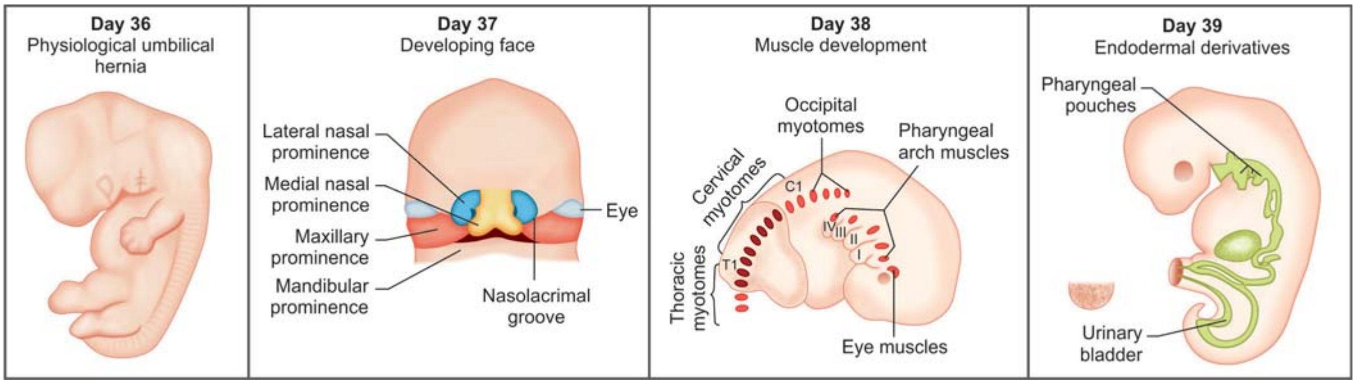


Fig. 11: Sixth week of development

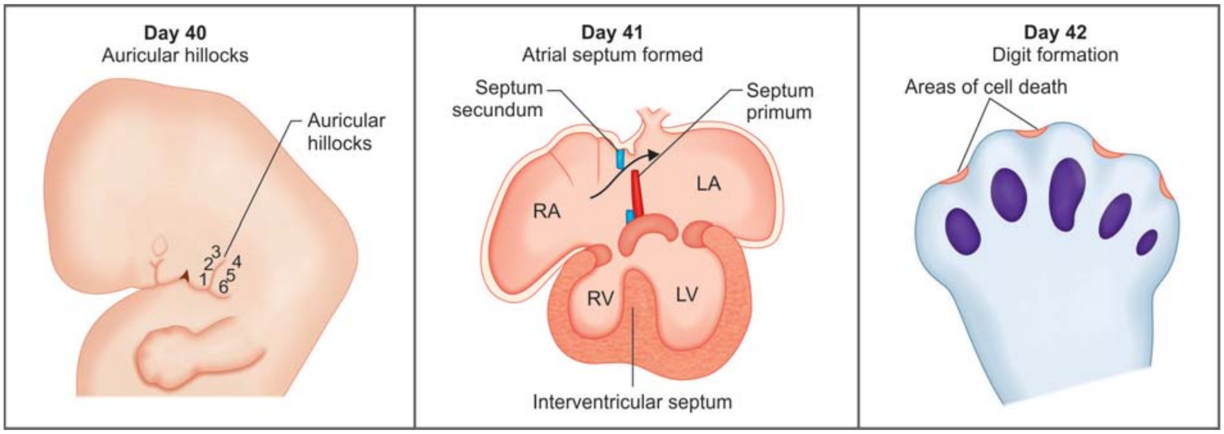


Fig. 12: Sixth week of development (later stage)

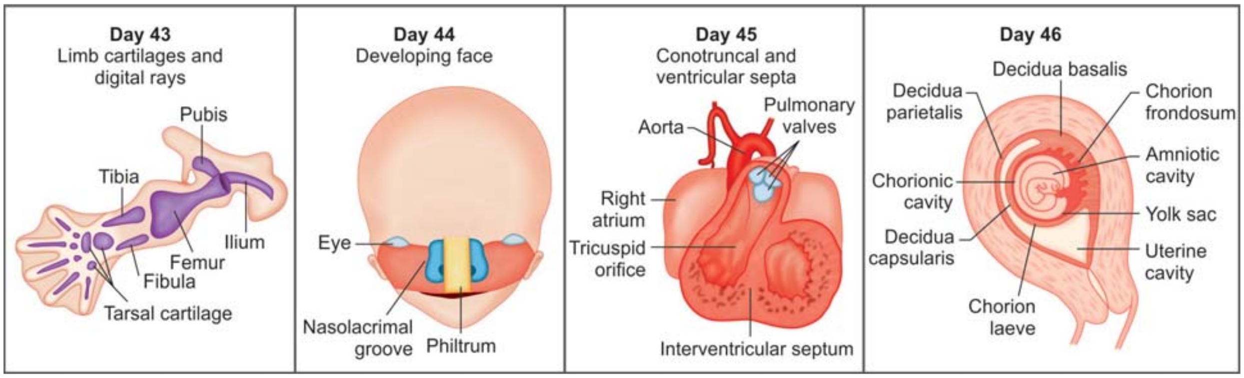


Fig. 13: Seventh week of development

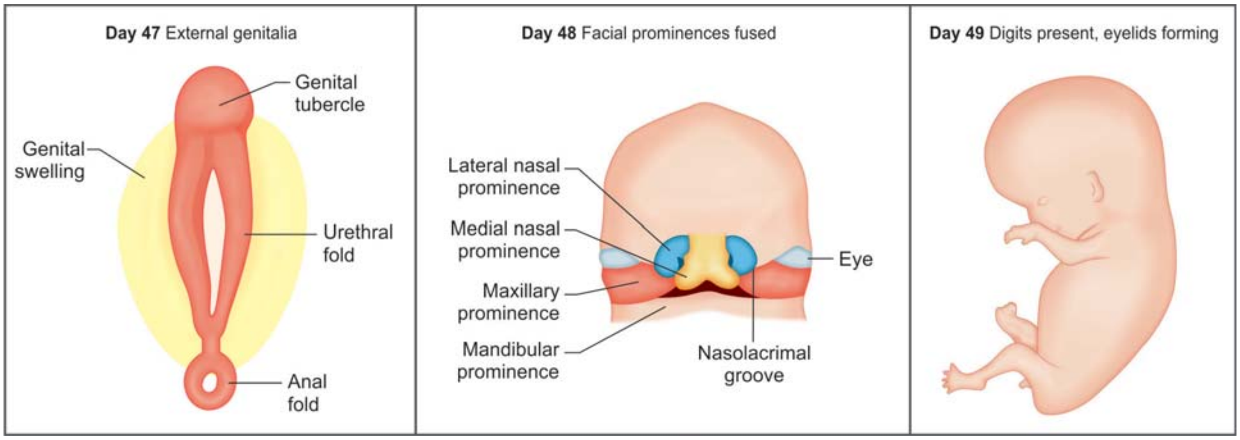


Fig. 14: Seventh week of development (later stages)

Table 1: Embryonic development in days

Week	Days						
Week 1	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
	Fertilization	Embryo with two-cell stage	Formation of morula	Early stage of blasto- cyst	Late stage of blastocyst	Implantation Trophoblast dif- ferentiates into cytotrophoblast and syncyti- otrophoblast	
Week 2	**Day 8**	**Day 9**	**Day 10**	**Day 11**	**Day 12**	**Day 13**	**Day 14**
	• Formation of bilaminar em- bryonic disc	Formation of lacunae in syncytiotrophoblast	Embryo gets completely implanted in endometri- um		Formation of extraem- bryonic mesoderm	Formation of primary villi	Formation of prochordal plate and connecting stalk
Week 3	**Day 15**	**Day 16**	**Day 17**	**Day 18**	**Day 19**	**Day 20**	**Day 21**
	Formation of prim- itive streak	• Migration of mes- enchymal cells from epiblast • Formation of second- ary and tertiary villi	Migration of cells from primitive streak	Formation of trilaminar embryonic disc	• Neurula- tion begins • Formation of neural plate	Formation of neural folds and neural groove	Formation of first pair of so mites

Table 2: Embryonic development In days (Continued)

Week	Days						
Week 4	**Day 22**	**Day 23**	**Day 24**	**Day 25**	**Day 26**	**Day 27**	**Day 28**
	Closure of neural tube begins	• Closure of neural tube with cranial and caudal neuropore • Formation of lens and otic placodes	• Appearance of pericardial heart bulge • Rostral neuropore closes • Two pairs of pharyngeal arches appear	• Formation of optic pit • Three pairs of pharyngeal arches appear	Upper limb bud appears	Formation of otic pit	Neurulation completes
Week 5	**Day 29**	**Day 30**	**Day 31**	**Day 32**	**Day 33**	**Day 34**	**Day 35**
	Upper and lower limb buds become paddle shaped	Development of face begins	Formation of primitive gut tube	Embryo completely surrounded by amnion lies in chorionic cavity	Formation of: • Umbilical ring • Tertiary yolk sac • Umbilical cord	Formation of optic cup and lens placode	Formation of pharyngeal arches and cartilages
Week 6	**Day 36**	**Day 37**	**Day 38**	**Day 39**	**Day 40**	**Day 41**	**Day 42**
	Physiological umbilical hernia occurs	Developing face	Development of muscles	Endodermal derivatives of primitive gut	Formation of auricular hillocks	Atrial septum is formed	Formation of digital rays
Week 7	**Day 43**	**Day 44**	**Day 45**	**Day 46**	**Day 47**	**Day 48**	**Day 49**
	Formation of cartilages in developing limb	Developing face (an advanced stage)	Conotruncal and ventricular septa form	• Subdivision of decidua • Well-formed amniotic cavity and chorion	Indifferent stage of development of external genitalia	Fusion of facial prominences	• Formation of eyelid • Formation of external ear • Presence of digits
Weeks 8	**Day 50**	**Day 51**	**Day 52**	**Day 53**	**Day 54**	**Day 55**	**Day 56**
	Upper limbs are longer and appear bent at elbow Finger distinct but webbed	Eye, external ear, nose, finger, and toes are clearly visible	Large forehead	External genitalia begin to differentiate	Genital tubercle, urethral groove, and anus are clearly visible	Eye, ear, elbow, wrist, knee, and toes are clearly visible	Embryo acquires a miniature human form

Table 3: Key developmental events during the embryonic period	
Developmental events	**Day/days of gestation**
Fertilization	Day 1
Blastocyst	Day 4
Bilaminar embryonic disc	Days 8
Implantation	Day 10
Primary streak appears	Day 15
Primitive heart tube	Day 17
Neurulation, first pair of somite	Day 21
Limb buds	Days 26-28
Primitive gut	Day 31
Physiological herniation	Day 36
Face appears	Day 37
External genitalia	Day 53
Miniature human form	Day 56

Table 4: Developmental of fetus in weeks	
Age (weeks)	**Developmental events**
9	Closed or closing eyes, more rounded head, and herniation of intestines in umbilical cord
10	Intestines in abdomen and early development of fingernails
12	Differentiated external genitalia and well defined neck
14	Erect head, well-developed lower limb, and early finger nail development
16	External ears standing out from the head
18	Vernix caseosa and early toe nail development
20	Lanugo hair
22	Wrinkled and red skin
24	Fingernails and lean body
26	Partially open eyes and eyelashes
28	Open eyes, hair, and slightly wrinkled skin
30	Toe nails and descending testes
32	Fingernails up to finger tips, and pink and smooth skin
36	Plumb body, absence of lanugo hair, toe nails up to toe tips, flexed limbs, and a firm grasp
38	Prominent chest, protruding breasts, testes in the scrotum or inguinal canals, and fingernails beyond finger tips

Table 5: Criteria for estimation of the age of embryo in days		
Age days	**Number of somites**	**Length (mm)**
20-21	1-3	1.5-3
22-23	4-12	2-3.5
24-25	13-20	2.5-4.5
26-27	21-29	3-5
28-30	30-35	4-6

Table 6: Time of appearance of ossification centers	
Bone	**Time of appearance of ossification centers**
• Clavicle	• 8 week of menstrual age
• Mandible and palate	• 9 week
• Vertebral body and neural arch	• 9 week
• Frontal bone	• 1 0-11 weeks

Bone	Time of appearance of ossification centers
• Femur, humerus, scapula, ileum, and phalanges	• 11 week
• Skull base	• 12-14 weeks
• Skull calvaria	• 16 week
• Metatarsals and metacarpals	• Early second trimester
• Calcaneum	• 24-26 weeks

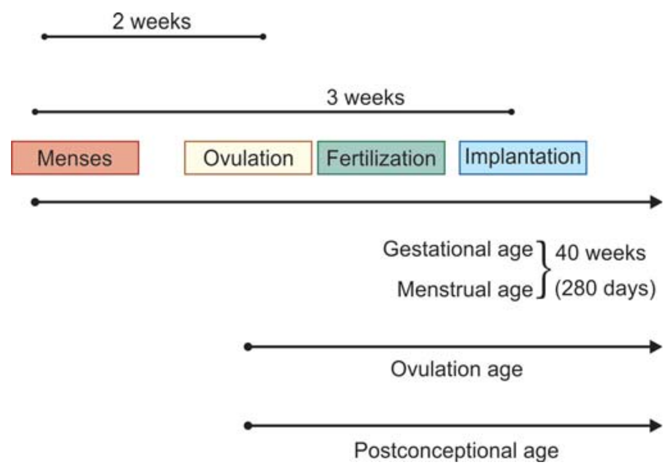


Fig. 15: Terminology used to describe the pregnancy duration

ASSESSMENT QUESTIONS

1. **At the end of 5th week of gestation, how many number of somites can be seen?** *(NEET Pattern)*
   a. 24
   b. 26
   c. 38
   d. 44

2. **Embryonic period of development is:** *(NEET Pattern 2012)*
   a. Up to 16 weeks
   b. Up to 12 weeks
   c. Up to 10 weeks
   d. Up to 8 weeks

3. **Identify the CORRECT pair:** *(NEET Pattern 2013)*
   a. Embryonic period : 9-20 weeks
   b. Fertilization to implantation : 0-4 weeks
   c. Embryonic period : 4-8 weeks
   d. None

ANSWERS AND EXPLANATIONS

1. **d. 44**
   - The first pair of somites arises in the occipital region of the embryo at approximately the 20th day of development.
   - From here, new somites appear in craniocaudal sequence at a rate of approximately three pairs per day until, at the end of the fifth week, 42 to 44 pairs are present.
   - The first occipital and the last five to seven coccygeal somites later disappear (now the total is 37), these remaining somites form the axial skeleton.
   - Because somites appear with a specified periodicity, the age of an embryo can be accurately determined during this early time period by counting somites.

2. **d. Up to 8 weeks**
   - Embryonic period extends from beginning of the third week to the end of eighth week of intrauterine life.
   - Some authors consider the embryonic period from fertilization to the end of eight week.

3. **c. Embryonic period: 4-8 weeks**
   - Embryonic period extends from beginning of the **third week to the end of eighth week** of intrauterine life.

Cell Division

- The cell cycle is an ordered sequence of events, culminating in cell growth and division to produce two daughter cells.
- It generally lasts a minimum of 12 hours, but in most adult tissues can be considerably longer, and is divided into four distinct phases, which are known as G1 (for gap 1), S (for DNA synthesis), G2 (for gap 2) and M (for mitosis).
- The combination of G1, S and G2 phases is known as interphase.
- M is the mitotic phase, which is further divided into four phases.

- DNA synthesis (replication of the genome) occurs during S phase, at the end of which the DNA content of the cell has doubled.
- The times taken for S, G2 and M are similar for most cell types, and occupy 6–8, 2–4 and 1–2 hours respectively. In contrast, the duration of G1 shows considerable variation, sometimes ranging from less than 2 hours in rapidly dividing cells to more than 100 hours, within the same tissue.
- In the ovaries, primary oocytes become diplotene by the fifth month in utero and each remains at this stage until the period before ovulation (up to 50 years).

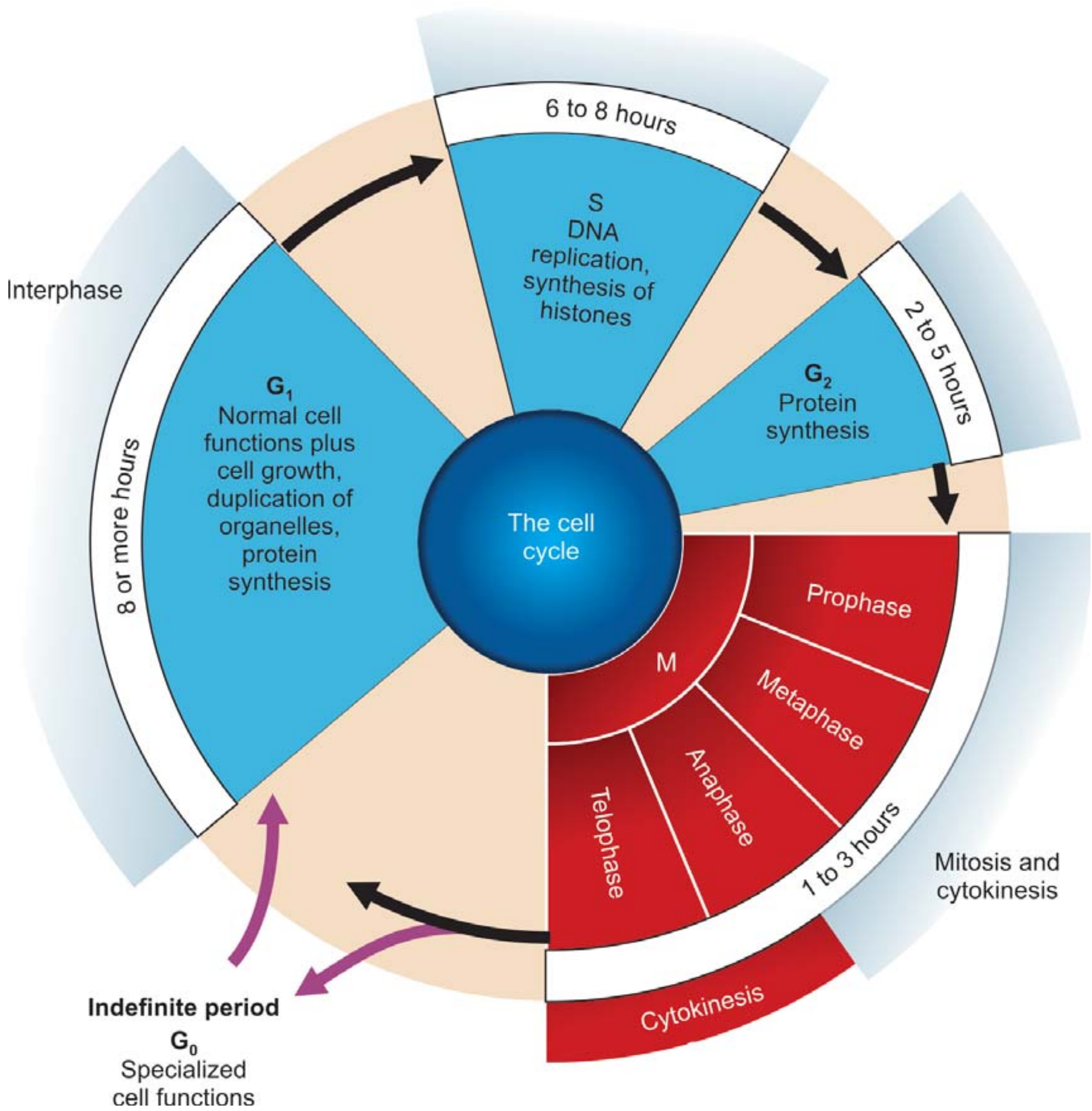


Fig. 16: Stages and duration of cell division (mitosis)

Table 7 Distinguishing features between mitosis and meiosis	
Mitosis	**Meiosis**
• Takes place in somatic cells	• Takes place in germ cells
• Completes in one sequence	• Completes in two sequences, i.e., there are two successive divisions, viz., meiosis I and meiosis II
• Crossing over of chromatids does not take place	• Crossing over of chromatids takes place
• Daughter cells have the same number of chromosomes as parent cells	• Daughter cells have half the number of chromosomes as parent cells
• Daughter cells are identical to each other and to the parent cell	• Daughter cells are not identical to each other and to the parent cell
• Equational division	• Reductional division

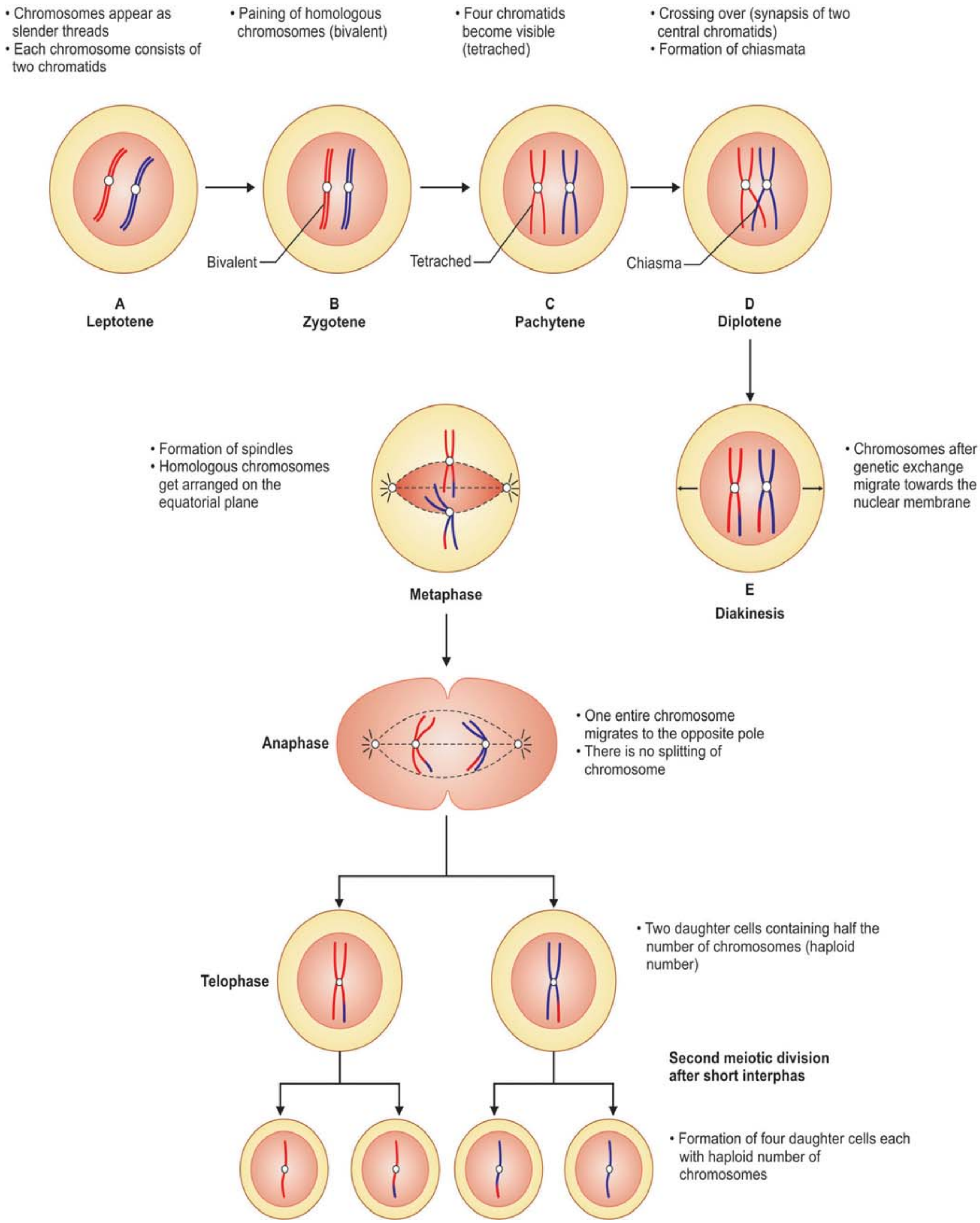
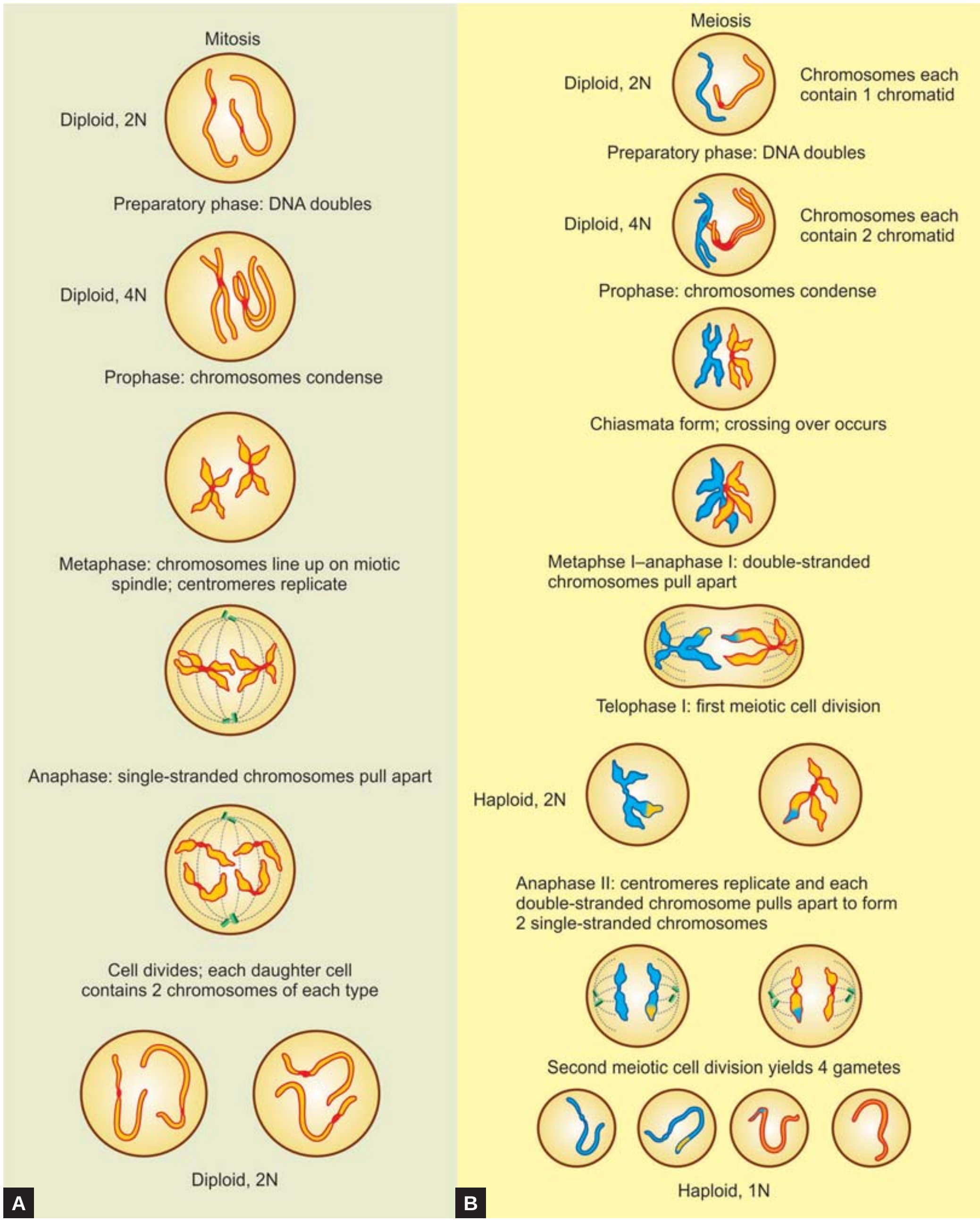


Fig. 17: Meiotic division I and II: A, B, C, D, and E showing five stages of prophase of first meiotic division

Table 8: Events during mitotic and meiotic cell divisions in the germ line			
Stage	**Events**	**Name of cell**	**Condition of Genome**
Resting interval between mitotic cell divisions	Normal cellular metabolism occurs	F Oogonium M Spermatogonium	Diploid, 2N
Mitosis			
Preparatory phase	DNA replication yields double-stranded chromosomes	F Oogonium M Spermatogonium	Diploid, 4N
Prophase	Double stranded chromosomes condense		
Metaphase	Chromosomes align along the equator; centromeres replicate		
Anaphase and telophase	Each double stranded chromosome splits into two single stranded chromosomes, one of which is distributed to each daughter nucleus		
Cytokinesis	Cell divides	F Oogonium M Spermatogonium	Diploid, 2N
Meiosis I			
Preparatory phase	DNA replication yields double-stranded chromosomes	F Primary oocyte M Primary spermatocyte	Diploid, 4N
Prophase	Double stranded chromosomes condense two chromosomes of each homologous pair align at the centromeres to form a four imbed chiasma; recombination by crossing over occurs		
Metaphase	Chromosomes align along the equator; centromeres do not rep/kale		
Anaphase and telophase	One double-stranded chromosome of each homologous pair is distributed to each daughter cell		
Cytokinesis	Cell divides	F One secondary oocyte and the first polar body M Two secondary spermatocytes	Haploid, 2N
Meiosis II			
Prophase	No DNA replication takes place during the second meiotic division; double stranded chromosomes condense		
Metaphase	Chromosomes align along the equator; centromeres replicate		
Anaphase and telophase	Each chromosome splits into two single stranded chromosomes, one of which is distributed to each daughter nucleus		
Cytokinesis	Cell divides	F One definitive oocyte and three polar bodies M Four spermatids	Haploid, 1N



Figs. 18A and B: Types of cell division. A, Mitosis. B, Meiosis.

ASSESSMENT QUESTIONS

1. **Meiosis occurs at which of the following transformation?**
   a. Primary spermatocyte to intermediate spermatocyte
   b. Primary spermatocyte to secondary spermatocyte
   c. Secondary spermatocyte to round spermatid
   d. Round spermatid to elongated spermatid

2. **At birth the ovary contains primary oocyte in which stage of meiosis?** *(AIIMS 2015)*
   a. Prophase I
   b. Metaphase
   c. Anaphase
   d. Telophase I

ANSWERS WITH EXPLANATIONS

1. **b. Primary spermatocyte to secondary spermatocyte**
   - Meiosis - I converts primary spermatocyte into secondary spermatocyte.
   - Later, Meiosis - II changes secondary spermatocyte into the spermatid.

2. **a. Prophase I**
   - In the ovaries, primary oocytes reach diplotene stage of prophase I (meiosis I), by the fifth month in utero and each remains at this stage until the period before ovulation (may be as long as up to 50 years).

Gametogenesis

- Gametogenesis is formation of gamete from primordial germ cells and involves cell division mitosis and meiosis.
- Primordial germ cells (PGCs) are derived from the epiblast, they migrate to the endodermal wall of the yolk sac (fourth week) and then reach the indeterminate gonad by the end of the fifth week, to differentiate into gametes (gametogenesis).
- Aberrant migration may lead to germ cell tumors (for e.g., teratoma).
- Teratomas may arise from PGCs (or from epiblast cells), which are pluripotent cells.
- Therefore, within teratomas are present derivatives of all three germ layers and may include skin, bone, teeth, gut tissue.

Spermatogenesis

- Spermatogenesis is the process in which spermatozoa are produced from spermatogonial stem cells by way of mitosis and meiosis
- The primordial germ cells form spermatogonia, which yield primary spermatocytes by mitosis.
- The primary spermatocyte divides meiotically (Meiosis I) into two secondary spermatocytes; each secondary spermatocyte divides into two spermatids by Meiosis II. These later develop into mature spermatids.
- Thus, the primary spermatocyte gives rise to two cells, the secondary spermatocytes, and the two secondary spermatocytes by their subdivision produce four spermatids.
- Meiosis has two stages, Meiosis I is the actual meiotic reduction division, whereas meiosis II is just like mitosis (equational division).

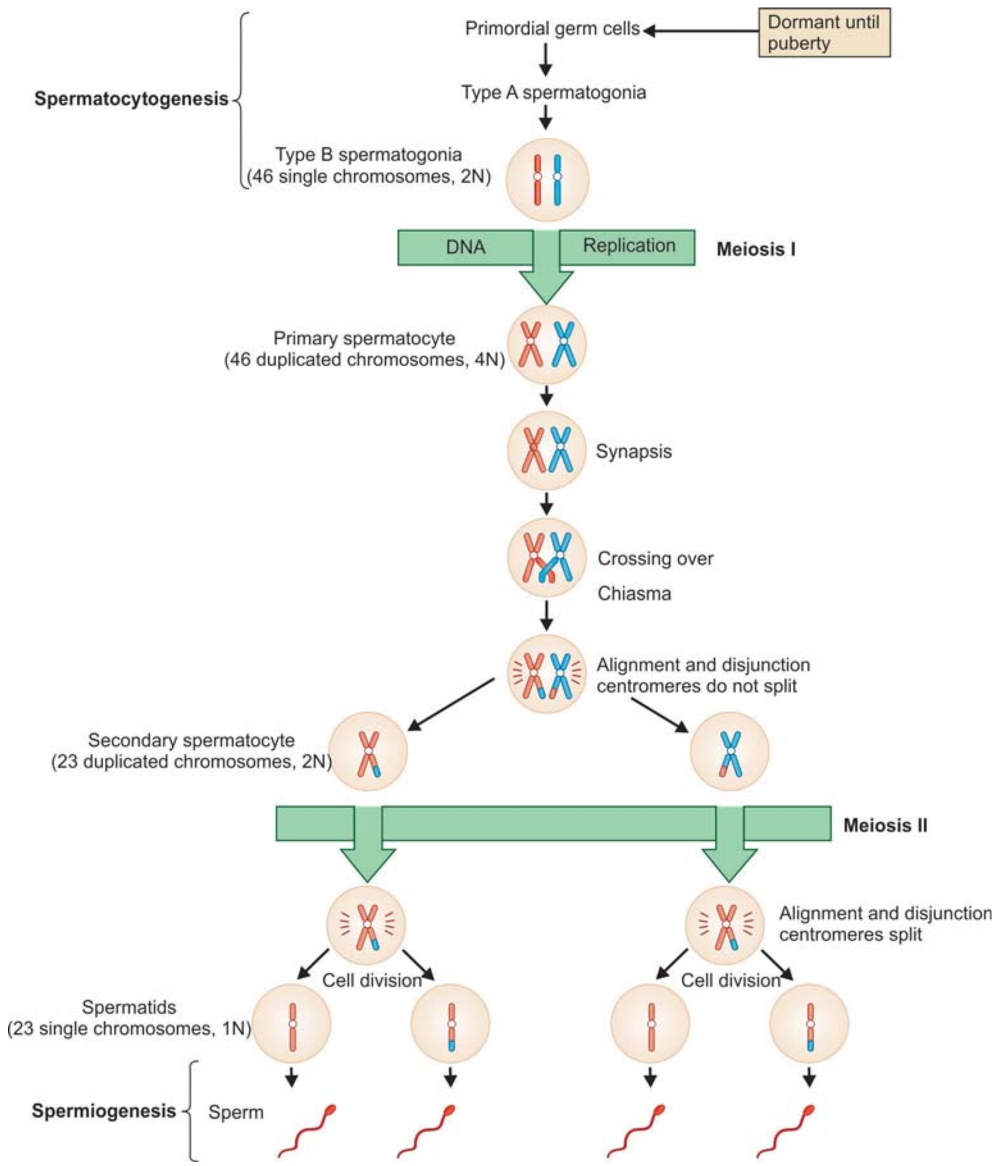


Fig. 19: Spermatogenesis. Only one pair of homologous chromosomes has been shown (red, maternal origin; blue, paternal origin). Synapsis is the process of pairing of homologous chromosomes. The point at which the DNA molecule crosses over is called the chiasma and is where exchange of small segments of maternal and paternal DNA occurs. Note that synapsis and crossing over occur only during meiosis I.

- The spermatid is the haploid male gamete that results from division of secondary spermatocytes. As a result of meiosis, each spermatid contains only half of the genetic material present in the original primary spermatocyte. Early round spermatids undergo further maturational event (spermiogenesis) to develop into spermatozoa.
- Initial stages of spermatogenesis takes place within the testes (seminiferous tubules) and progress to the epididymis where the developing gametes mature, gain progressive motility and are stored until ejaculation.
- Spermatogenesis takes 74 days to complete. If the transport through ductal system is included, it takes 3 months.
- The transit of sperm through the epididymis is thought to take up to 12 days. Though sperms can be stored in the epididymis for several weeks (? 3 month). *(Campbell Walsh Urology - 10th ed)*
- There are three subtypes of spermatogonia in humans:
- Type A (dark) cells, with dark nuclei.
    - These cells are reserve spermatogonial stem cells which do not usually undergo active mitosis.
- Type A (pale) cells, with pale nuclei.
    - These are the spermatogonial stem cells that undergo active mitosis.
    - These cells divide to produce Type B cells.
- Type B cells, which divide (mitosis) to give rise to primary spermatocytes.

Cell type	Chromosomes in human	DNA copy number/chromatids in human	Process entered by cell
Spermatogonium (types Ad, Ap and B)	Diploid (2N)/46	2C/46	Spermatocytogenesis (mitosis)
Primary spermatocyte	Diploid (2N)/46	4C/2 x 46	Spermatogenesis (meiosis I)
Two secondary spermatocytes	Haploid (N)/23	2C/2 x 23	Spermatogenesis (meiosis 11)
Four spermatids	Haploid (N)/23	C I 23	Spermiogenesis
Four functional spermatozoids	Haploid (N)/23	C I 23	Spermiation

ASSESSMENT QUESTIONS

1. Meiosis occurs in: *(AIIMS 2004)*
a. Epididymis
b. Seminiferous tubules
c. Vas deferens
d. Seminal vesicles

2. In early phase division of spermatogonia by: *(NEET Pattern 2014)*
a. Meiosis
b. Mitosis
c. Both Meiosis and Mitosis
d. Maturation

3. TRUE about spermatid: *(NEET Pattern 2015)*
a. Derived from primary spermatocyte
b. Derived from secondary spermatocyte
c. Undergoes mitotic division
d. Undergoes meiotic division

4. Haploid number of chromosomes is seen in: *(NEET Pattern 2012)*
a. Spermatogonia
b. Primary spermatocytes
c. Secondary spermatocyte
d. None

5. In primary spermatocytes the chromosome status is: *(NEET Pattern 2014)*
a. 23-X
b. 23-Y
c. 46-XY
d. None

6. Development of spermatozoa (sperm) from spermatogonium takes how much time: *(NEET Pattern 2014)*
a. 30-35 days
b. 40-45 days
c. 50-55 day
d. 70-75 days

7. Spermatogenesis is completed in:
a. 60 days
b. 64 days
c. 70 days
d. 74 days

8. Meiosis occurs at which of the following transformation? *(AIIMS 2007)*
a. Primary spermatocyte to intermediate spermatocyte
b. Primary spermatocyte to secondary spermatocyte
c. Secondary spermatocyte to round spermatid
d. Round spermatid to elongated spermatid

9. Independent Assortment of chromosome occurs at which level: *(AIIMS 2015)*
a. Primordial germ cells to spermatogonia
b. Spermatogonia to primary spermatocyte
c. Primary spermatocyte to secondary spermatocyte
d. Secondary spermatocyte to spermatids

ANSWERS WITH EXPLANATIONS

1. b. Seminiferous tubules
- Initial stages of spermatogenesis (meiosis) takes place within the seminiferous tubules of testes and progress to the epididymis where the developing gametes mature, gain progressive motility and are stored until ejaculation.

2. b. Mitosis
- There are three subtypes of spermatogonia in humans:
- Type A (dark) cells, which are reserve spermatogonial stem cells which do not usually undergo active mitosis.
  Type A (pale) cells, which are the spermatogonial stem cells that undergo active mitosis to produce Type B cells.
  Type B cells, which divide (mitosis) to give rise to primary spermatocytes.

3. b. Derived from secondary spermatocyte
- Spermatid is the haploid male gamete that results from division of secondary spermatocytes.
- As a result of meiosis, each spermatid contains only half of the genetic material present in the original primary spermatocyte.
- Spermatids undergo spermiogenesis (and not any division) to form the spermatozoa.

4. c. Secondary spermatocyte
- Primary spermatocytes are diploid (2n) cells containing 46 chromosomes. After meiosis I, two secondary spermatocytes are formed.
- Secondary spermatocytes are haploid (n) cells that contain 23 chromosomes.

5. c. 46-XY
- Primary spermatocytes are diploid (2n) cells containing 46 chromosomes (46-XY).

6. d. 70-75 days
- Spermatogenesis is the process in which spermatozoa are produced from spermatogonial stem cells by way of mitosis and meiosis and takes 74 days to complete.

7. d. 74 days >b. 64 days.
- Spermatogenesis takes 74 days to complete. Earlier editions of standard textbooks used to mention it as 64 days (2 months).

8. b. Primary spermatocyte to secondary spermatocyte
- Primary spermatocytes undergo Meiosis I to give two secondary spermatocytes.
- Meiosis has two stages, Meiosis I is the actual meiotic reduction division, whereas meiosis II is just like mitosis (equational division).
- Subsequently, Meiosis - II changes secondary spermatocyte into the spermatid.

9. c. Primary spermatocyte to secondary spermatocyte
- Primary spermatocyte changes to secondary spermatocyte during meiosis I.
- Maternal and paternal chromosomes separate during Meiosis - I by **independent assortment**.
- During meiosis, the pairs of homologous chromosome are divided in half to form haploid cells, and this separation, or **assortment**, of homologous chromosomes is 'random'.
- This means that all of the maternal chromosomes will not be separated into one cell, while the all paternal chromosomes are separated into another.
- Instead, after meiosis occurs, each haploid cell contains a 'mixture' of genes from the organism's mother and father.

Oogenesis

- Primordial germ cells (46, 2N) derived from the epiblast cells, reach the endodermal wall of the yolk sac and differentiate into oogonia (46, 2N), which populate the ovary through mitotic division.
- Oogonium is unique in that it is only female cell in which both 'X' chromosomes are active.
- The majority of oogonia continue to divide by mitosis, but some of them arrest their cell division in prophase of meiosis I and undergo DNA replication to form primary oocytes (46, 4N).
- All primary oocytes are formed by month 5 of fetal life. At birth there are no primordial germ cells or oogonia in the ovary.
- Primary oocytes enter prophase I (of meiosis I), but get arrested there, due to OMI (Oocyte Maturation Inhibitor), which alters the levels of cyclic AMP.
- Primary oocytes remain arrested in prophase (diplotene) of meiosis I from month 5 of fetal life until exposed to LH surge, which starts happening after puberty.
- After puberty, 5 to 15 primary oocytes begin maturation with each ovarian cycle, but only 1 reaches full maturity to undergo ovulation.
- During the ovarian cycle and triggered by the luteinizing hormone (LH) surge, a primary oocyte completes meiosis I to form two daughter cells: the secondary oocyte (23, 2N) and the first polar body, which degenerates.
- LH surge occurs approximately 34-36 hours (wider range: 24-48 hours) before ovulation and LH peak occurs at 10-12 hours before ovulation. First polar body is released at about LH peak (10-20 hours before ovulation).
- The secondary oocyte promptly begins meiosis II but is arrested in metaphase of meiosis II about 3 hours before ovulation. The secondary oocyte remains arrested in metaphase of meiosis II until fertilization occurs.
- Secondary oocyte is degenerated after 24 hours of ovulation, hence fertilization must take place within a few hours, and no more than a day after ovulation. Almost all pregnancies result when intercourse occurs during the 2 days preceding or on the day of ovulation.
- At fertilization, the secondary oocyte completes meiosis II to form a mature oocyte (23, 1N) and a second polar body.
- Approximate number of primary oocytes at 5th month of intrauterine life is 7 million, most of them get degenerated by birth and the count comes down to 600,000 to 2 million. The degeneration continues and at puberty, only 40,000 are present, out of which 400-500 undergo ovulation in the female reproductive life.
- Twelve secondary oocytes are ovulated per year, up to 480 over the entire reproductive life of the woman (40 years × 12 secondary oocytes per year = 480).

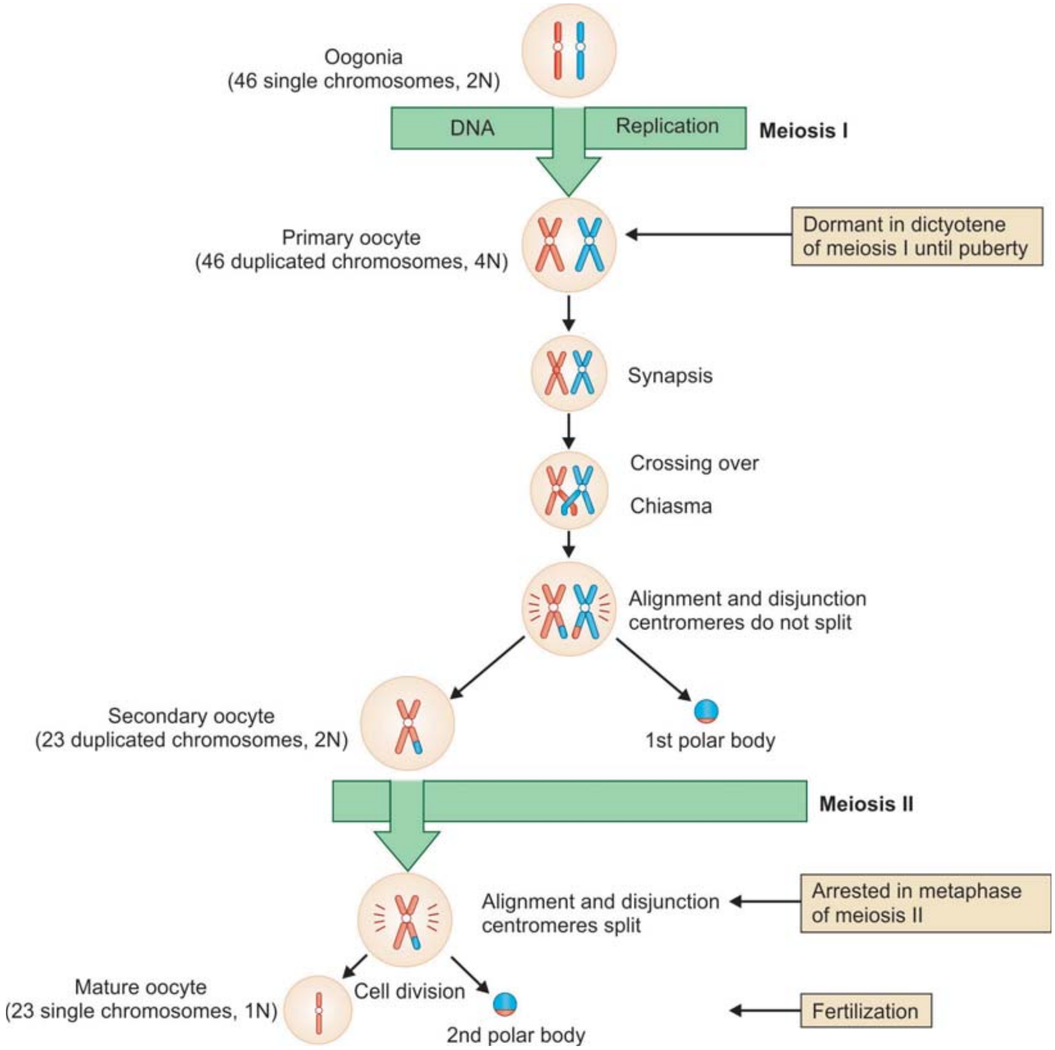


Fig. 20: Oogenesis. Only one pair of homologous chromosomes is shown (red, maternal origin; blue, paternal origin). Synapsis is the process of pairing of homologous chromosomes. The point at which the DNA molecule crosses over is called the chiasma and is where exchange of small segments of maternal and paternal DNA occurs. Note that synapsis and crossing over occur only during meiosis I. The polar bodies are storage bodies for DNA unnecessary for the further function of the cell and probably degenerate. There is no evidence that polar bodies divide or undergo any other activity.

- Meiosis consists of two cell divisions (meiosis I and meiosis II) and results in the formation of gametes containing 23 chromosomes and 1N amount of DNA (1n, 1N), where n is the number of chromosomes and N is the unit (amount) of DNA.
- Meiosis I is a **reduction division** and reduces the chromosome number to half in gamete.
- Meiosis II is an **equational division** (chromosome numbers remain the same).
- During oogenesis, primordial germ cells differentiate into oogonia (46, 2N), which enter meiosis I and undergo DNA replication to form primary oocytes (46, 4N).
- All primary oocytes are formed by the fifth month of fetal life (about 7 million), and remain dormant in prophase (diplotene/dictyotene stage) of meiosis I until the beginning of LH surge (puberty).
- Primary oocyte completes meiosis I to form a secondary oocyte (23,2N) and a first polar body (which later degenerates).
- The secondary oocyte enters meiosis II, remains arrested in metaphase of meiosis II until fertilization occurs.
- At fertilization, the secondary oocyte completes meiosis II to form a mature oocyte (23,1N) and a second polar body.

Cell type	Ploidy/chromosomes	Chromatids	Process	Time of completion
Oogonium	Diploid/46(2N)	2C	Oocytogenesis (mitosis)	Third trimester
Primary Oocyte	Diploid/46(2N)	4C	Ootidogenesis (meiosis I) (Folliculogenesis)	Dictyate in prophase I for up to 50 years
Secondary Oocyte	Haploid/23(1N)	2C	Ootidogenesis (meiosis II)	Halted in metaphase II until fertilization
Ootid	Haploid/23(1N)	1C	Ootidogenesis (meiosis II)	Minutes after fertilization
Ovum	Haploid/23(1N)	1C		

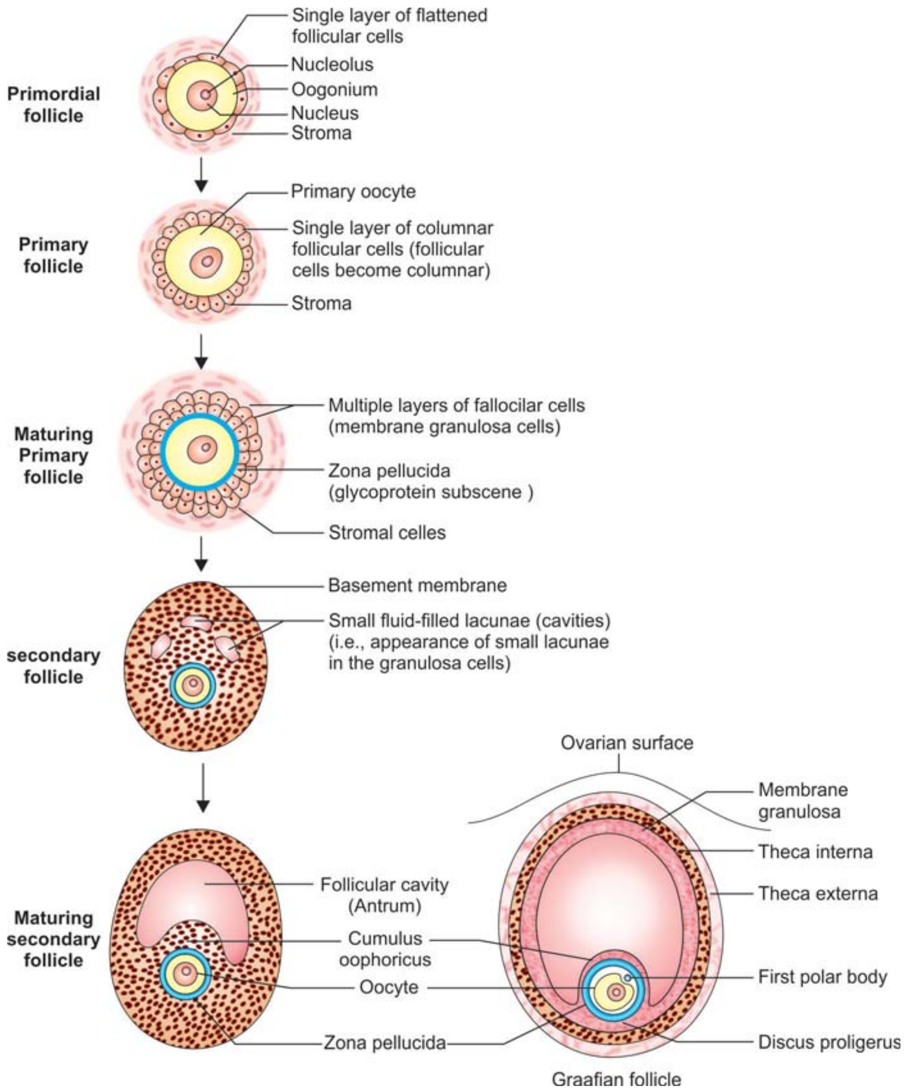


Fig. 21: Development of ovarian follicle

ASSESSMENT QUESTIONS

1. Primary oocyte is formed after: *(NEET Pattern 2013)*
a. First meiotic division
b. Second meiotic division
c. Mitotic division
d. None of the above

2. Polar bodies are formed during: *(AIPG 2006)*
a. Spermatogenesis
b. Organogenesis
c. Oogenesis
d. Morphogenesis

3. In a female child at birth, gonads contain:
a. Primary oocyte arrested at prophase I
b. Secondary oocyte arrested at metaphase II
c. Primordial germ cells
d. Oogonia

4. First polar body is formed after: *(NEET Pattern 2014)*
a. Mitosis
b. First meiosis
c. Second meiosis
d. Fertilization

5. Diplotene and zygotene stages are seen in: *(NEET Pattern 2015)*
a. Prophase
b. Metaphase
c. Anaphase
d. Telophase

6. After first meiotic division, the primary oocyte remains arrested in: *(NEET Pattern 2012)*
a. Diplotene stage
b. Pachytene stage
c. Metaphase
d. Telophase

7. One primary oocyte forms how many ovum/ova: *(NEET Pattern 2013)*
a. 1
b. 2
c. 3
d. 4

8. Cells which surround the oocyte in Graafian follicle are called: *(NEET Pattern 2014)*
a. Discus proligerus
b. Cumulus oophorus
c. Luteal cells
d. Villus cells

9. Fertilization is complete when: *(NEET Pattern 2015)*
a. 1st polar body is formed
b. 2nd polar body is formed
c. Primary oocyte is formed
d. Secondary oocyte is formed

10. Fertilization takes place after how much time of ovulation: *(NEET Pattern 2014)*
a. 1-2 days
b. 5-6 days
c. 8-12 days
d. 12 days

11. Secondary oocyte is: *(NEET Pattern 2013)*
a. Haploid (n) and N
b. Haploid (n) and 2N
c. Diploid (2n) and N
d. Diploid (2n) and 2N

ANSWERS WITH EXPLANATIONS

1. c. Mitotic division
- The majority of oogonia continue to divide by mitosis, but some of them arrest their cell division in prophase of meiosis I and form primary oocytes.
- After first meiosis secondary oocyte is formed and after second meiosis mature oocyte is formed.

2. c. Oogenesis
- Polar bodies are formed as a result of meiosis in ovaries called as oogenesis.
- The first polar body is released before ovulation and the second polar body forms after fertilization.
- Spermatogenesis is not associated with polar body formation.

3. a. Primary oocyte arrested at prophase I
- All primary oocytes are formed by month 5 of fetal life.
- At birth there are no primordial germ cells or oogonia in the ovary.
- Primary oocytes remain arrested in prophase I (of meiosis I) until exposed to LH surge, which starts happening after puberty.

4. b. First meiosis
- Primary oocyte completes meiosis I to form two daughter cells: the secondary oocyte (23, 2N) and the first polar body.

5. a. Prophase
- Prophase I (of meiosis I) is divided into 4 stages: Leptotene, Zygotene, Pachytene and Diplotene.

6. a. Diplotene stage
- Primary oocytes enters prophase I (of meiosis I) and remains arrested in prophase (diplotene) of meiosis I until exposed to LH surge, which starts happening after puberty.

7. a. 1
- One primary oocyte forms one ovum and three polar bodies (which eventually degenerate).
- One primary spermatocytes forms four spermatids.

8. b. Cumulus oophorus
- Oocyte lies eccentrically in the ovarian (Graafian) follicle surrounded by some granulosa cells called cumulus oophorus.
- Discus proligerus is the attachment point of the cumulus oophorus to the most peripheral granulosa cells of an antral follicle.

9. b. 2nd polar body is formed
- At fertilization, the secondary oocyte completes meiosis II to form a mature oocyte (23, 1N) and a second polar body.

10. a. 1-2 days
- After ovulation has occurred, the oocyte (ovum) remains fertilizable for 48 hours, although the chance is mostly lost by 18-24 hours.
- If no fertilization occurs, the oocyte will degenerate between 12 and 24 hours after ovulation.

11. b. Haploid (n) and 2N
- Secondary oocyte is a haploid cell (n) with two units of DNA (2N).

ASSESSMENT QUESTIONS

1. Germ cells are derivative of: *(NEET Pattern 2013)*
a. Epiblast
b. Endodermal sinus
c. Mesoderm
d. Ectoderm

2. Primordial germ cell is derived from: *(AIPG 2007)*
a. Ectoderm
b. Mesoderm
c. Endoderm
d. Mesodermal sinus

3. Abnormal persistence of which of the following cells from primitive streak result in sacrococcygeal teratoma?
a. Primordial germ cells
b. Endodermal cells
c. Mesodermal cells
d. Ectodermal cells

4. All is true regarding events related to oogenesis EXCEPT:
a. Primary oocyte is arrested at prophase – I at birth
b. LH surge occurs 24–48 hrs. prior to ovulation
c. First polar body is released before ovulation
d. Meiosis-II is a reduction division

ANSWERS WITH EXPLANATIONS

1. a. Epiblast > b. Endodermal sinus

- Primordial germ cell is a derivative of epiblast, earlier they were believed to arise from endoderm of yolk sac (endodermal sinus) - Gray's Anatomy (Ed. 41).

2. c. Endoderm

- Primordial germ cell is a derivative of epiblast, earlier they were believed to arise from endoderm of yolk sac (endodermal sinus) - Gray's Anatomy (Ed. 41).
- They become evident at the distal end of primitive streak by the 2nd week of development.
- These cells are migratory cells and reach the endodermal wall of yolk sac (fourth week).
- They reach the indeterminate gonad by the end of the fifth week, to differentiate into gametes (gametogenesis).

Note: Aberrant migration may lead to germ cell tumors (for example, teratoma).

3. a. Primordial germ cells

- Teratomas may arise from PGCs (or from epiblast cells), which are pluripotent cells.
- Therefore, within teratomas are present derivatives of all three germ layers and may include skin, bone, teeth, gut tissue.

4. d. Meiosis II is a reduction division.

- Chromosome number gets reduced to half during meiosis- I (reduction division).
- Maternal and paternal chromosomes separate during meiosis- I.

MENSTRUAL CYCLE

- Luteinizing hormone is produced by gonadotropic cells in the anterior pituitary gland.
- In females, an acute rise of LH triggers ovulation and development of the corpus luteum.
  - LH surge occurs 34-36 hours before ovulation. Some authors mention a wider range: Range: 24-48 hours before ovulation.
- After ovulation has occurred, the oocyte (ovum) remains fertilizable for 48 hours, although the chance is mostly lost by **18-24 hours**. If no fertilization occurs, the oocyte will degenerate between 12 and 24 hours after ovulation.
- After coitus, semen containing mature and immature spermatozoa is discharged into the upper vagina and near the external os.

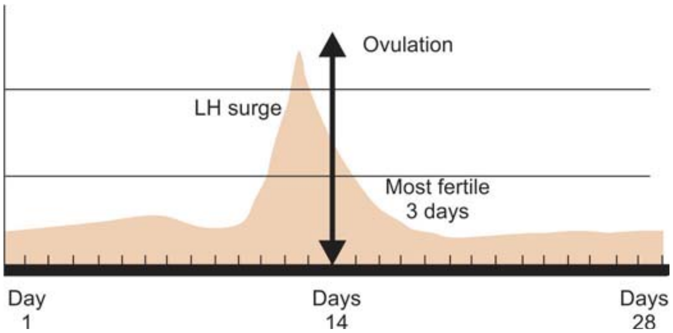


Fig. 22: Menstrual cycle (28 days), showing LH hormonal variation, period of ovulation (mid-cycle, day 14) and most fertile period (two days before ovulation and the day of ovulation)

- Some active sperms enter the cervical canal within a few minutes and invade the mucous alkaline cervical plug which, at the time of ovulation, is softened to allow easier penetration.
- Once they are through the cervix, spermatozoa ascend quickly in 1 to 1 1/2 hours to the tubes and may meet the mature ovum.

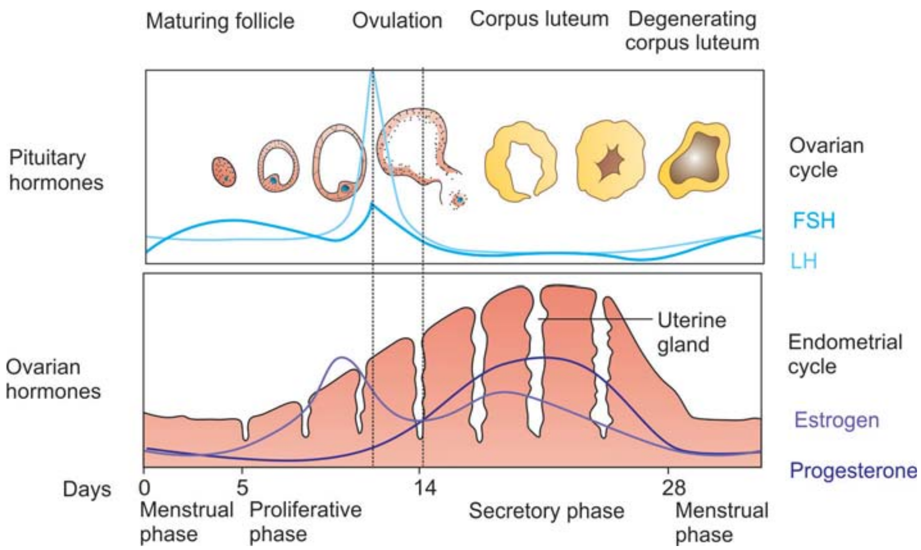


Fig. 23: Ovarian, endometrial, and hormonal events of the menstrual cycle. Pituitary follicle-stimulating hormone (FSH) and luteinizing hormone (LH) directly control the ovarian cycle and also control production of estrogen and progesterone by responding follicles and corpus luteum of the ovary. These ovarian hormones in turn control the cycle of the uterine endometrium.

- All sperms remaining in the vagina for 2 hours or longer are killed by vaginal acidic discharge.
- Although **sperms** remain alive and motile in the cervical canal and uterus for 5-7 days and in the fallopian tubes for 85 hours, they usually do not retain their power of fertilization after **24-48 hours of coitus**.
- Recently, donor **insemination** has indicated that sperms can retain their fertilizing capacity up to 4 days.
- Conception is therefore extremely unlikely unless coitus takes place 1 or 2 days before, or immediately after ovulation (**fertile period - 3 days**); the latter takes place around the 14th day of the 28-day-cycle and is related to the next menstrual period.
- However, pregnancy can occur following coitus on any day of the cycle due to irregularity in the time of ovulation.

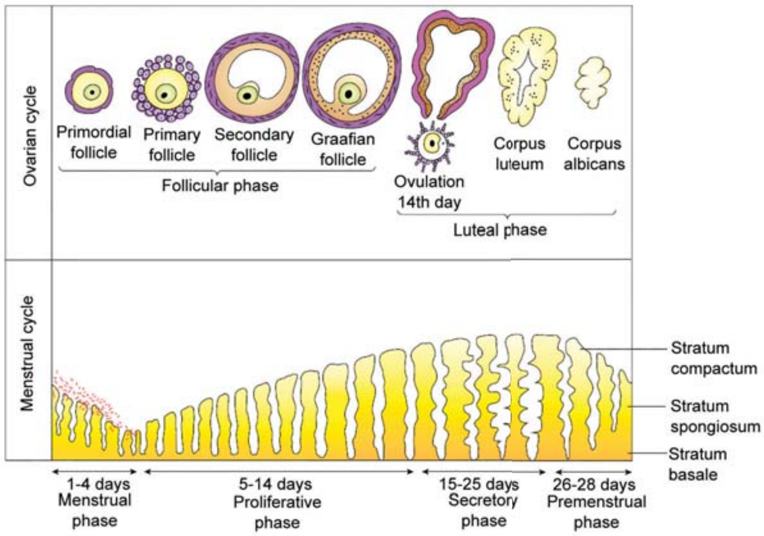


Fig. 24: Correlation between ovarian and menstrual cycles

Table 9: Features of different phases of the menstrual cycle

Phase	Features
Menstrual phase (1-4 days)	Necrosis and shedding of the functional layer of the endometrium associated with bleeding
Proliferative phase (5-14 days)	Regeneration of the functional layer of the endometrium
Secretory phase (15-25 days)	Endometrium becomes thick and soft due to in creased secretory activity of endometrial glands
Premenstrual phase (26-28 days)	Reduced blood supply. Cramping or pain and external spotting of blood

ASSESSMENT QUESTIONS

1. **Sperm remains fertile for how many hours in female genital tract:** *(NEET Pattern 2013)*
   a. 6-8 hrs
   b. 12-24 hrs
   c. 24-48 hrs
   d. 72-96 hrs

2. **Average reproductive life span of ovum is:** *(NEET Pattern 2013)*
   a. 6-12 hrs
   b. 12-24 hrs
   c. 24-26 hrs
   d. 3 days

3. **After how many hours of LH surge does ovulation occur?**
   a. 12-24
   b. 24-48
   c. 24-36
   d. 36-48

ANSWERS WITH EXPLANATIONS

1. c. 24-48 hrs
- Although **sperms** remain alive and motile in the cervical canal and uterus for 5-7 days and in the fallopian tubes for 85 hours, they usually do not retain their power of fertilization after **24-48 hours of coitus**.

2. b. 12-24 hrs
- After ovulation has occurred, the oocyte (ovum) remains fertilizable for 48 hours, although the chance is mostly lost by **18-24 hours**. If no fertilization occurs, the oocyte will degenerate between 12 and 24 hours after ovulation.

3. c. 24-36
- The most appropriate option has been taken as the answer.
- An acute rise of LH triggers ovulation and development of the corpus luteum.
- LH surge occurs 34-36 hours before ovulation. Some authors mention a wider range: Range: 24-48 hours before ovulation.

OVULATION AND FERTILIZATION

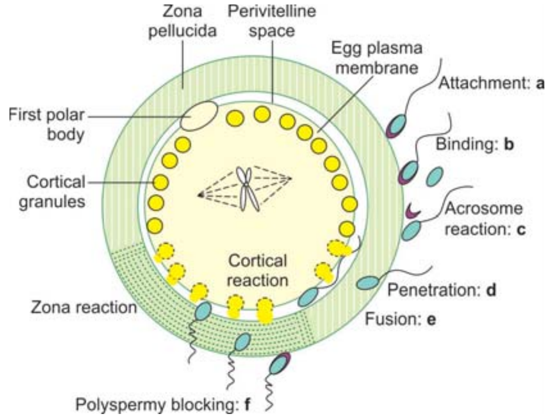


Fig. 25: Stages of sperm attachment (to zona pellucida), acrosome reaction, penetration, fusion, cortical reaction and zona reaction. (a-f)

- Fertilization, which normally occurs in the oviduct, must take place within a few hours, and no more than a day after ovulation. Because of this narrow opportunity window, spermatozoa must be present in the fallopian tube at the time of oocyte arrival.
- Almost all pregnancies result when intercourse occurs during the 2 days preceding or on the day of ovulation.
- *Fertilization occurs in the ampulla of fallopian tube. Zona pellucida is a glycoprotein membrane, which attracts sperms for fertilization.
- Once a single sperm has fertilized the oocyte, the membrane prevents polyspermy. a. Zona pellucida attracts sperm → b. Sperm binds to the membrane → c. **Acrosome reaction** with release of enzymes → d.
- Penetration of sperm into the zona pellucida → e. Fusion of sperm membrane with oocyte membrane → f. **Cortical reaction** (release of cortical granules) → g. **Zona reaction**: Change in the permeability of zona pellucida, preventing polyspermy.
- Acrosome reaction: As the sperm is attracted by zona pellucida (a glycoprotein membrane) it releases enzymes (like acrosin) which allows sperm to penetrate the zona, thereby coming in contact with the plasma membrane of the oocyte.
- Cortical reaction: As the head of the sperm comes in contact with the oocyte surface, it results in release of lysosomal enzymes from cortical granules lining the plasma membrane of the oocyte. The trigger for the cortical granules to exocytose is the release of calcium ions from cortical smooth endoplasmic reticulum in response to sperm binding to the egg.
- Zona reaction: In turn, these enzymes alter properties of the zona pellucida to prevent another sperm penetration (polyspermy) and inactivate species-specific receptor sites for spermatozoa on the zona surface.
- The sequence of reactions is: Acrosome reaction → Cortical reaction → Zona reaction.

Table 10: Chance of pregnancy in days near ovulation

Time	Chance of pregnancy (%)
5 days before ovulation	10
4 days before ovulation	16
3 days before ovulation	14
2 days before ovulation	27
1 day before ovulation	31
Day of ovulation	33
Day after ovulation	0

ASSESSMENT QUESTIONS

1. **Choose the correct sequence of the following embryonic events:** *(NEET Pattern 2013)*
   a. Cortical reaction → Zona reaction → Acrosome reaction
   b. Zona reaction → Acrosome reaction → Cortical reaction
   c. Acrosome reaction → Cortical reaction → Zona reaction
   d. Acrosome reaction → Zona reaction → Cortical reaction

2. **Ion responsible to prevent polyspermy at the time of fertilization in mammals is:** *(NEET Pattern 2015)*
   a. Na
   b. K
   c. Ca
   d. Mg

ANSWERS WITH EXPLANATIONS

1. **c. Acrosome reaction → Cortical reaction → Zona reaction**
   - The sequence of events is: a. Zona pellucida attracts sperm → b. Sperm binds to the membrane → c. **Acrosome reaction** with release of enzymes → d. Penetration of sperm into the zona pellucida → e. Fusion of sperm membrane with oocyte membrane → f. **Cortical reaction** (release of cortical granules) → g. **Zona reaction**: Change in the permeability of zona pellucida, preventing polyspermy.

2. **c. Ca**
   - Cortical reaction: As the head of the sperm comes in contact with the oocyte surface, it results in release of lysosomal enzymes from cortical granules lining the plasma membrane of the oocyte. The trigger for the cortical granules to exocytose is the release of **calcium ions** from cortical smooth endoplasmic reticulum in response to sperm binding to the egg.
   - Zona reaction: In turn, these enzymes alter properties of the zona pellucida to prevent another sperm penetration (**polyspermy**) and inactivate species-specific receptor sites for spermatozoa on the zona surface.

FIRST WEEK OF DEVELOPMENT

With each ovarian cycle, a number of primary follicles begin to grow, but usually only one reaches full maturity, and only one oocyte is discharged at ovulation. At ovulation, the oocyte is in metaphase of the second meiotic division and is surrounded by the zona pellucida and some granulosa cells. Sweeping action of tubal fimbriae carries the oocyte into the uterine tube.

Before spermatozoa can fertilize the oocyte, they must undergo:

1. Capacitation, during which time a glycoprotein coat and seminal plasma proteins are removed from the spermatozoon head
2. The acrosome reaction, during which acrosin- and trypsin-like substances are released to penetrate the zona pellucida

During fertilization, the spermatozoon must penetrate:

1. The corona radiata
2. The zona pellucida
3. The oocyte cell membrane

As soon as the spermatocyte has entered the oocyte:

1. The oocyte finishes its second meiotic division and forms the female pronucleus.
2. The zona pellucida becomes impenetrable to other spermatozoa.
3. The head of the sperm separates from the tail, swells, and forms the male pronucleus

After both pronuclei have replicated their DNA, paternal and maternal chromosomes intermingle, split longitudinally, and go through a mitotic division, giving rise to the two-cell stage. The results of fertilization are the following:

1. Restoration of the diploid number of chromosomes
2. Determination of chromosomal sex
3. Initiation of cleavage

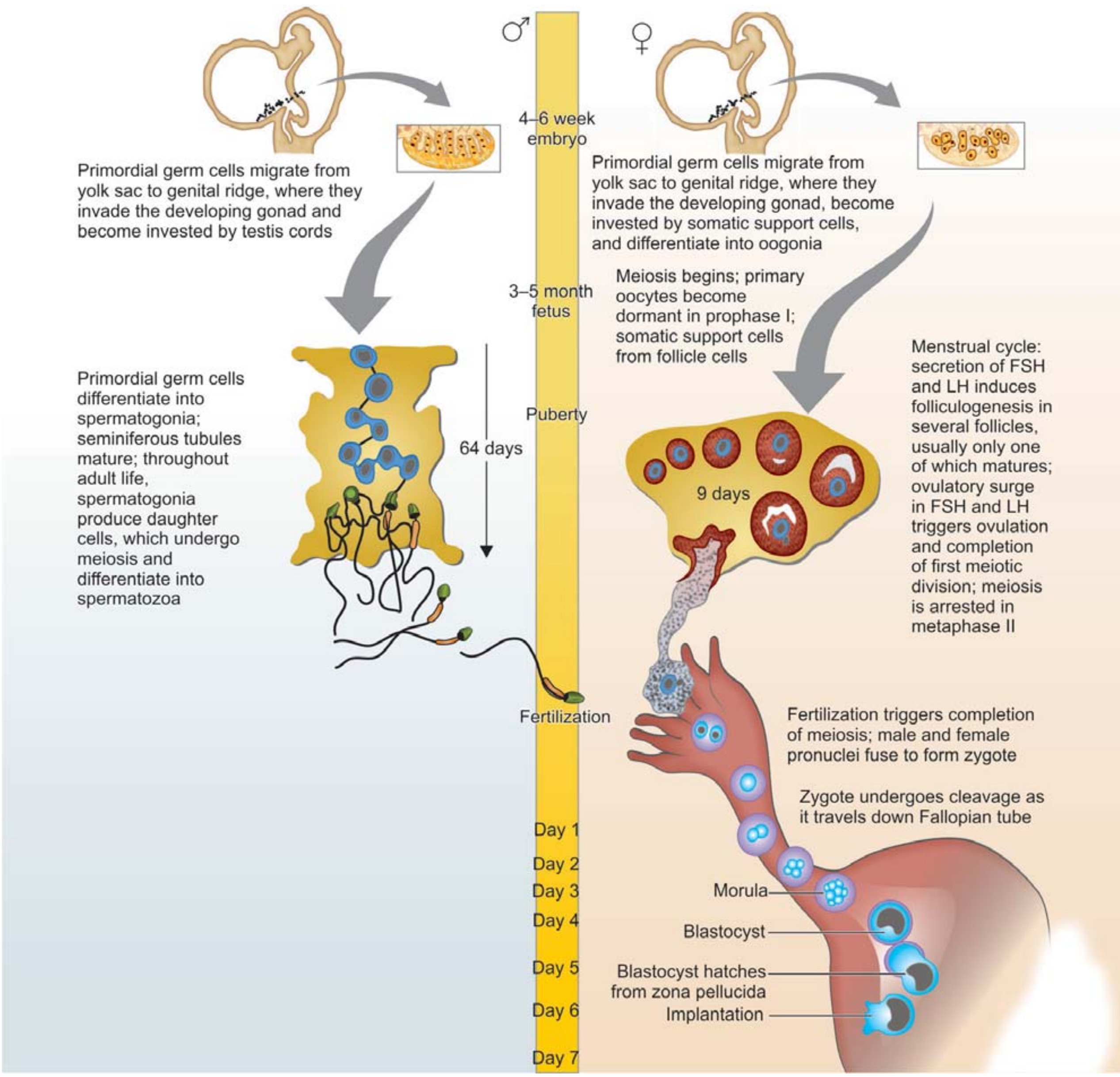


Fig. 26: Gametogenesis and first week of development

- Infertility is a problem for 15% to 30% of couples and can be overcome using assisted reproductive technology (ART). In vitro fertilization (IVF) involves fertilizing eggs in a culture medium and placing them in the uterus at the eight-cell stage. In some cases, eggs are fertilized by intracytoplasmic sperm injection (ICSI), whereby a single sperm is injected into an egg's cytoplasm. These in vitro techniques are associated with an increased risk for birth defects, prematurity, low birth weight, and multiple births. Approximately 1% to 2% of all live births in the United States occur through ART.
- Cleavage is a series of mitotic divisions that results in an increase in cells, blastomeres, which become smaller with each division. After three divisions, blastomeres undergo compaction to become a tighdy grouped ball of cells with inner and outer layers. Compacted blastomeres divide to form a 16-cell morula. As the morula enters the uterus on the third or fourth day after fertilization, a cavity begins to appear, and the blastocyst forms. The inner cell mass, which is formed at the time of compaction and will develop into the embryo proper, is at one pole of the blastocyst. The outer cell mass, which surrounds the inner cells and the blastocyst cavity, will form the trophoblast.
- The uterus at the time of implantation is in the secretory phase, and the blastocyst implants in the endometrium along the anterior or posterior wall. If fertilization does not occur, then the menstrual phase begins, and the spongy and compact endometrial layers are shed. The basal layer remains to regenerate the other layers during the next cycle.
- Advanced morula (**16-64 celled**) enters the uterine cavity at **day 4** to become **blastocyst**. Blastocyst has an inner cell mass (**embryoblast**) and outer cell mass trophoblast. Embryoblast forms the embryo chiefly and **trophoblast** contributes to extraembryonic tissue majorly.

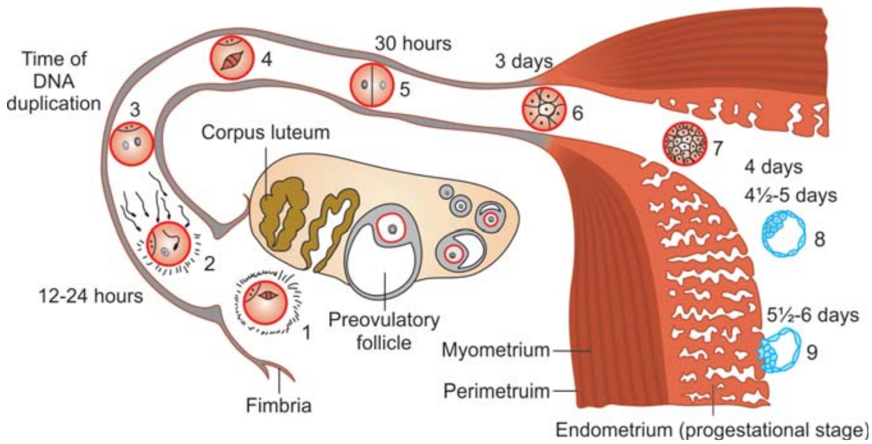
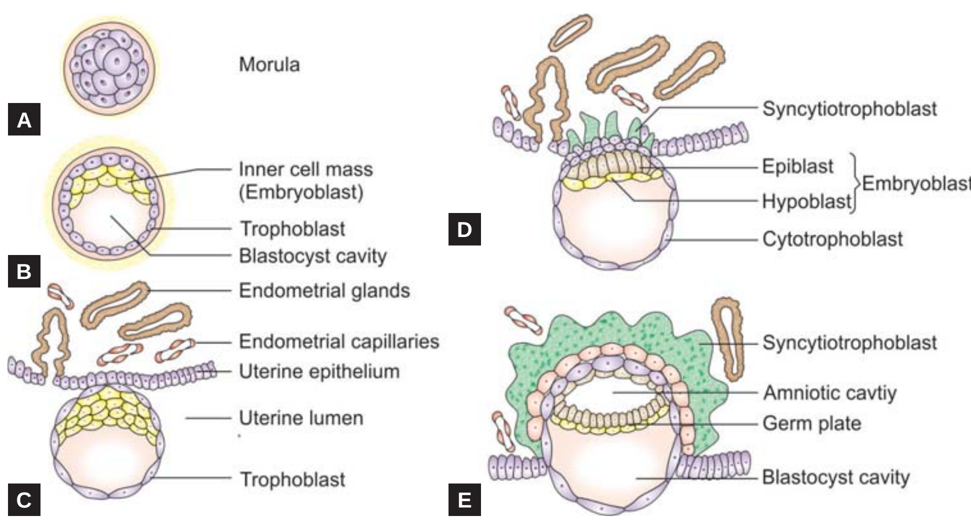


Fig. 27: Events during the first week of human development. 1, oocyte immediately after ovulation; 2, fertilization, approximately 12 to 24 hours after ovulation; 3, stage of the male and female pronuclei; 4, spindle of the first mitotic division; 5, two-cell stage [approximately 30 hours of age); 6, morula containing 12 to 16 blastomeres [approximately 3 days of age); 7, advanced morula stage reaching the uterine lumen [approximately 4 days of age); 8, early blastocyst stage [approximately 4.5 days of age; the zona pellucida has disappeared); 9, early phase of implantation [blastocyst approximately 6 days of age). The ovary shows stages of transformation between a primary follicle and a preovulatory follicle as well as a corpus luteum. The uterine endometrium is shown in the progestational stage.

- At **day 6** trophoblast forms two type of cells: **cytotrophoblast** (inner layer) and **syncytiotrophoblast** (outer layer). Syncytiotrophoblast help in endometrial attachment of blastocyst at **day 6** itself (implantation in progress).
- Inner cell mass (embryoblast) of the blastocyst forms a bilayered embryonic disc having two type of cells: dorsal **epiblast** and ventral **hypoblast**. **Amniotic cavity** develops on the dorsal side and epiblast cell layer lies at the floor of amniotic cavity, whereas hypoblast cell layer is at the roof of **blastocyst cavity** (now called exocoelomic cavity).



Figs. 28A to E: First week of development: Formation of morula and blastocyst and implantation of blastocyst

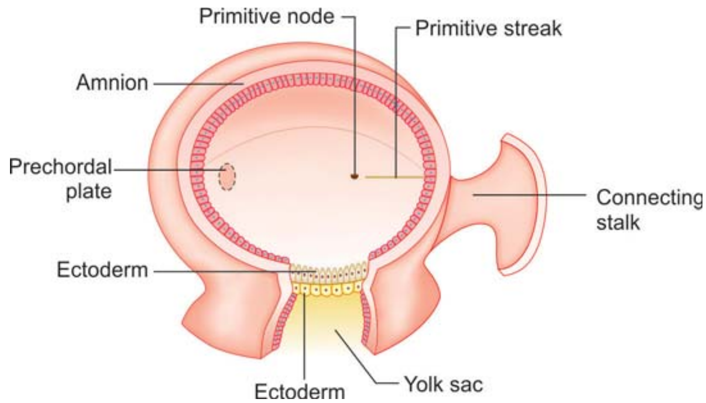


Fig. 29: Dorsal view of the conceptus showing primitive streak.

Amnioblasts cells separate from the epiblast and organize to form a thin membrane, the **amnion**, which encloses the amniotic cavity. Epiblast cells are continuous peripherally with the amnion. Some cells migrate from hypoblast to surround the exocoelomic cavity and form **exocoelomic membrane**, which lines the internal surface of the cytotrophoblast.

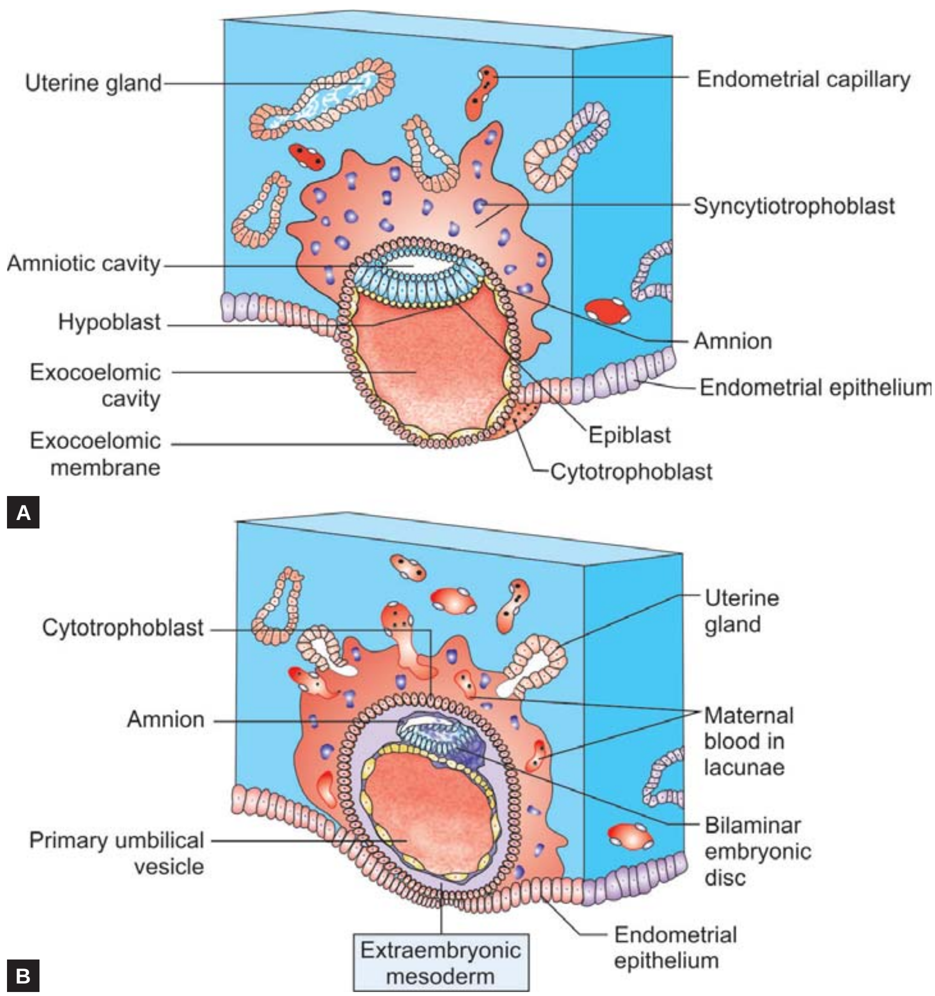


Fig. 30A and B: Implantation of blastocyst. A. Illustration of a section of a partially implanted blastocyst (approximately 8 days after fertilization). B, Illustration of a section through a blastocyst at approximately 9 days.

The exocoelomic membrane and cavity soon become modified to form the **primary umbilical vesicle** (primary yolk sac). The embryonic disc then lies between the amniotic cavity and primary umbilical vesicle. The outer layer of cells from the umbilical vesicle forms a layer of loosely arranged connective tissue, the **extraembryonic mesoderm**.

- At first the walls of the amniotic cavity and yolk sac are in contact with trophoblast. They are soon separated from the latter by extraembryonic mesoderm.

- A cavity, the extraembryonic coelom appears and splits the extraembryonic mesoderm into a somatopleuric layer (in contact with trophoblast) and a splanchnopleuric layer (in contact with yolk sac).
- The trophoblast and underlying somatopleuric mesoderm form a membrane called the chorion.
- The cells forming the wall of the amniotic cavity form the amnion.
- The amniotic cavity is now attached to trophoblast by some mesoderm into which the extraembryonic coelom has not extended. This mesoderm forms the connecting stalk.
- The embryonic disc viewed from the ectodermal side near one edge shows a rounded area called the prochordal plate. Here ectoderm and endoderm are not separated by mesoderm.
- An elevation, the primitive streak, is also seen on the embryonic disc. A line drawn through the prochordal plate and the primitive streak divides the embryonic disc into right and left halves.
- Cells multiplying in the primitive streak move into the interval between epiblast and hypoblast form the mesoderm (Gray's anatomy mentions it as mesoblast) (third germ layer.
- Caudal to the primitive disc a round area called the cloacal membrane is present.
  - Cloacal membrane (plate) is formed at the caudal end of the embryo from adhesion between epiblast and hypoblast cells.
  - Later, it covers the cloaca and eventually breaks down to form openings into the urogenital sinus and anus.

ASSESSMENT QUESTIONS

1. Trophoblast differentiates into cyto and syncytio-trophoblast at post fertilization day:
a. 6-8
b. 8-12
c. 12-14
d. 16-18

2. Fertilized ovum reaches the uterus: *(NEET Pattern 2012)*
a. 3-4 days
b. 6- 8 days
c. 10- 12 days
d. 12-14 days

ANSWERS WITH EXPLANATIONS

1. a. 6-8
Explanation: Trophoblast differentiates into cyto and syncytiontrophoblast at 6th day postovulation/fertilization (Gray's Anatomy; Ed41).

2. a. 3-4 days
- Fertilized ovum forms the morula, which enters uterine cavity on day 4, post ovulation (or postfertilization).

SECOND WEEK OF DEVELOPMENT

- At the beginning of the second week, the blastocyst is partially embedded in the endometrial stroma. The trophoblast differentiates into
  - An inner, actively proliferating layer, the cytotrophoblast; and (2) cuter layer, the syncytiotrophoblast, which erodes maternal tissues. By day 9, lacunae develop in the syncytiotrophoblast. Subsequently, maternal sinusoids are eroded by the syncytiotrophoblast, maternal blood enters the ¡acunar network, and by the end of the second week, a primitive uteroplacental circulation begins. The cytotrophoblast, meanwhile, forms cellular columns penetrating into and surrounded by the syncytium. These columns are primary villi. By the end of the second week, the blastocyst is completely embedded, and the surface defect in the mucosa has healed.
  - The inner cell mass or embryoblast, meanwhile, differentiates into (1) the epiblast and
- The hypoblast, together forming a bilaminar disc. Epiblast cells give rise to amnioblasts that line the amniotic cavity superior to the epiblast layer. Hypoblast cells are continuous with the exocoelomic membrane, and together they surround the primitive yolk sac. By the end of the second week, extraembryonic mesoderm fills the space between the trophoblast and the amnion and exocoelomic membrane internally. When vacuoles develop in this tissue, the extraembryonic coelom or chorionic cavity forms. Extraembryonic mesoderm lining the cytotrophoblast and amnion is extraembryonic somatic mesoderm; the lining surrounding the yolk sac is extraembryonic splanchnic mesoderm.
- The second week of development is known as the week of 2's:
  - The trophoblast differentiates into 2 layers: the cytotrophoblast and syncytiotrophoblast
  - The embryoblast forms 2 layers: the epiblast and hypoblast
  - The extraembryonic mesoderm splits into 2 layers: the somatic and splanchnic layers
  - Two cavities form: the amniotic and yolk sac cavities
- Implantation occurs at the end of the first week. Trophoblast cells invade the epithelium and underlying endometrial stroma with the help of proteolytic enzymes. Implantation may also occur outside the uterus, such as in the rectouterine pouch, on the mesentery, in the uterine tube, or in the ovary (ectopic pregnancies).

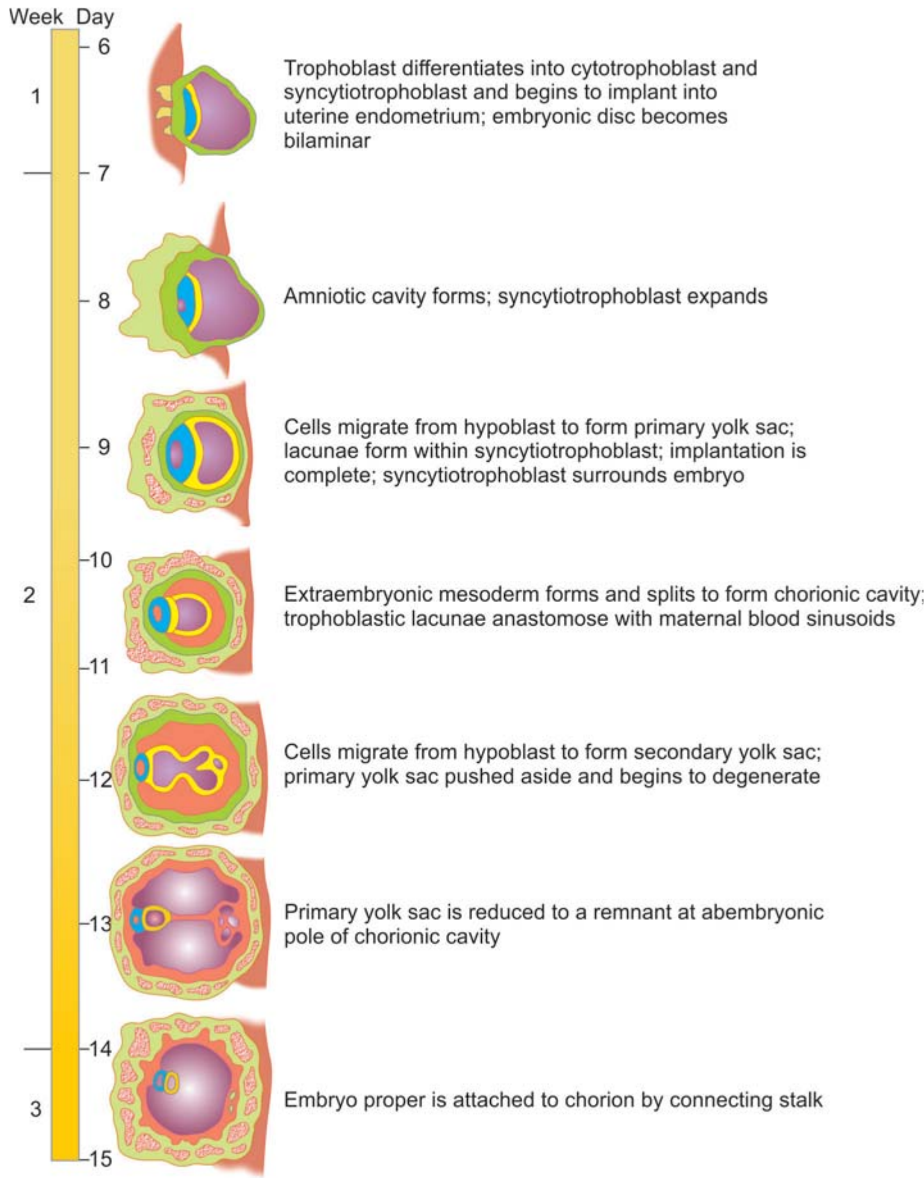
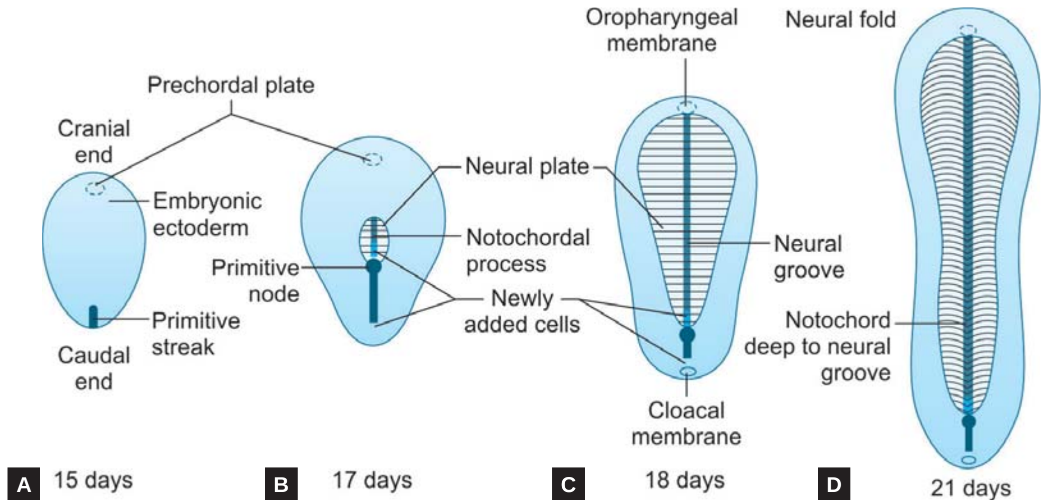


Fig. 31: Second week of development

- Advanced morula (16-64 celled) enters the uterine cavity at day 4 to become blastocyst. Blastocyst has an inner cell mass (embryoblast) and outer cell mass trophoblast. Embryoblast forms the embryo chiefly and trophoblast contributes to extraembryonic tissue majorly.
- Langman's Embryology
- At day 6 trophoblast forms two type of cells: cytotrophoblast (inner layer) and syncytiotrophoblast (outer layer). Syncytiotrophoblast help in endometrial attachment of blastocyst at day 6 itself (implantation in progress).
- Inner cell mass (embryoblast) of the blastocyst forms a bilayered embryonic disc having two type of cells: dorsal epiblast and ventral hypoblast. Amniotic cavity develops on the dorsal side and epiblast cell layer lies at the floor of amniotic cavity, whereas hypoblast cell layer is at the roof of blastocyst cavity (now called exocoelomic cavity).
- **Blastocyst** is the stage at the time of implantation where outer cell mass (trophoblast cells) form a fluid-filled sphere with a small group of inner cell mass (embryoblast cells) at one pole.
- Amnioblasts cells separate from the epiblast and organize to form a thin membrane, the amnion, which encloses the amniotic cavity. Epiblast cells are continuous peripherally with the amnion. Some cells migrate from hypoblast to surround the exocoelomic cavity and form exocoelomic membrane, which lines the internal surface of the cytotrophoblast.
- The exocoelomic membrane and cavity soon become modified to form the primary umbilical vesicle (primary yolk sac). The embryonic disc then lies between the amniotic cavity and primary umbilical vesicle. The outer layer of cells from the umbilical vesicle forms a layer of loosely arranged connective tissue, the extraembryonic mesoderm.



Figs. 32A to D: Dorsal views of the embryonic disc, showing how it lengthens and changes shape during the third week. The primitive streak lengthens by the addition of cells at its caudal end; the notochordal process lengthens by the migration of cells from the primitive node. At the end of the third week, the notochordal process is transformed into the notochord

BLAST CELLS

Embryoblast

- The embryoblast differentiates into two distinct cell layers: the dorsal epiblast and the ventral hypoblast. The epiblast and hypoblast together form a flat, ovoid-shaped disk known as the bilaminar embryonic disk.
- Within the epiblast, clefts develop and eventually coalesce to form the amniotic cavity.
- Hypoblast cells migrate and line the inner surface of the cytotrophoblast and eventually delimit a space called the definitive yolk sac.
- The epiblast and hypoblast fuse to form the prochordal plate, which marks the future site of the mouth.

Trophoblast

- The syncytiotrophoblast continues its growth into the endometrium to make contact with endometrial blood vessels and glands.
- The syncytiotrophoblast does not divide mitotically. The cytotrophoblast does divide mitotically, adding to the growth of the syncytiotrophoblast.
- The syncytiotrophoblast produces human chorionic gonadotropin (hCG).
- Primary chorionic villi formed by the cytotrophoblast protrude into the syncytiotrophoblast.

Extraembryonic Mesoderm

- Is a new layer of cells derived from the epiblast.
- Extraembryonic somatic mesoderm (somatopleuric mesoderm) lines the cytotrophoblast, forms the connecting stalk, and covers the amnion.
- The conceptus is suspended by the connecting stalk within the chorionic cavity.
- The wall of the chorionic cavity is called the chorion and consists of three components: extraembryonic somatic mesoderm, cytotrophoblast, and syncytiotrophoblast.
- Extraembryonic visceral mesoderm (splanchnopleuric mesoderm) covers the yolk sac.

IMPLANTATION

Implantation is the process by which the conceptus (blastocyst) is embedded within the endometrium of the uterus.

- Blastocyst usually implants within the **posterior superior wall** of the uterus in the functional layer of the endometrium during the progestational (**secretory**) **phase** of the menstrual cycle.
- On average, it occurs during the **20th to the 23rd day** after the last menstrual period.
- It is a **week long process**, beginning at day 5 (post-ovulation, or post fertilization) and is completed at day 12.
- It begins at day 5 when blastocyst is hatching out of zona pellucida.
- At day 6 it **attaches to the endometrium**. On the same day 6, the cells of trophoblast divide mitotically into **cytotrophoblast** and **syncytiotrophoblast**.
- The syncytiotrophoblast **invade** the endometrium with the help of proteolytic enzymes secreted by its cells.
- The blastocyst implants deep and completely lies within the endometrium (**interstitial implantation**).

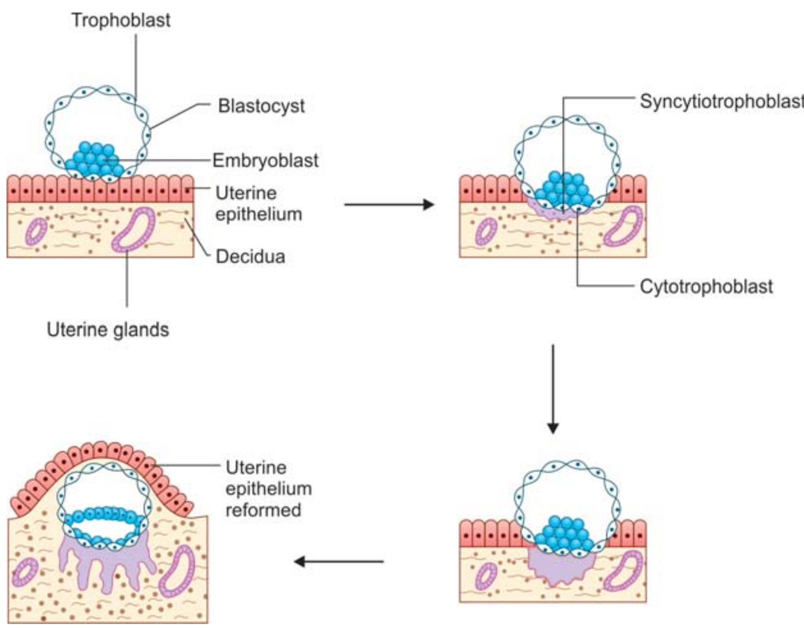


Fig. 33: Steps of implantation

ASSESSMENT QUESTIONS

1. TRUE about morula: *(NEET Pattern 2014)*
a. 4 cells stage
b. 8 cell stage
c. 16 cells stage
d. 24 cells stage

2. Blastocyst comes out of zona pellucida on which day after fertilization? *(NEET Pattern 2014)*
a. 4-7 days
b. 10-12 days
c. 12-15 days
d. 15-20 days

3. Conceptus enters uterine cavity in which cell stage: *(NEET Pattern 2014)*
a. 4 cells
b. 8 cells
c. 16 cells
d. 32 cells

4. The outer layer of the blastocyst forms: *(NEET Pattern 2012)*
a. Primitive streak
b. Yolk sac
c. Embryo proper
d. Trophoblast

5. Implantation occurs at: *(NEET Pattern 2012)*
a. 2-3 days
b. 6-7 days
c. 15-20 days
d. 20-25 days

6. Implantation occurs on which menstrual cycle day: *(NEET Pattern 2014)*
a. 5-7 days
b. 20-22 days
c. 14-18 days
d. 26-28 days

ANSWERS WITH EXPLANATIONS

1. c. 16 cells stage
- **Morula** is generally taken as **16 cell** stage, but the conceptus is called a morula stage when it has more than 12 cells (blastomeres).
- It ends when the blastocyst forms, which occurs when there are 50 to 60 blastomeres present.

2. a. 4-7 days
- Implantation begins at **day 5** when blastocyst is **hatching out of zona pellucida**.

3. d. 32 cells
- Conceptus enters the uterine cavity at **advanced morula** stage (more than 16 cells) at **day 4**.
- It gets converted into blastocyst same day and later attaches to endometrium on day 6 (implantation).

4. d. Trophoblast
- Blastocyst has an inner cell mass (**embryoblast**) which forms the embryo proper and an outer layer of cells (**trophoblast**) which contribute to the formation of placenta.

5. b. 6-7 days
- Implantation is a **week long process**, beginning at day 5 (postovulation, or postfertilization) and is completed at day 12.

6. b. 20-22 days
- Implantation occurs during the **20th to the 23rd day** after the last menstrual period.

IVF

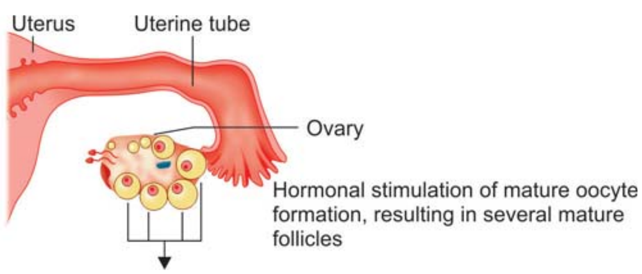


Fig. 34: In vitro fertilization - hyperstimulation of ovary

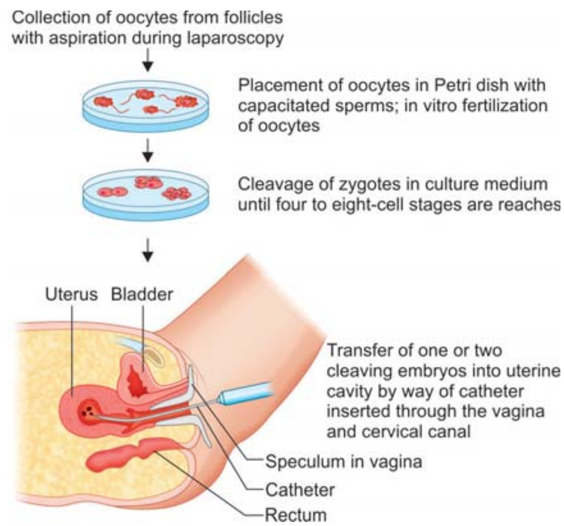
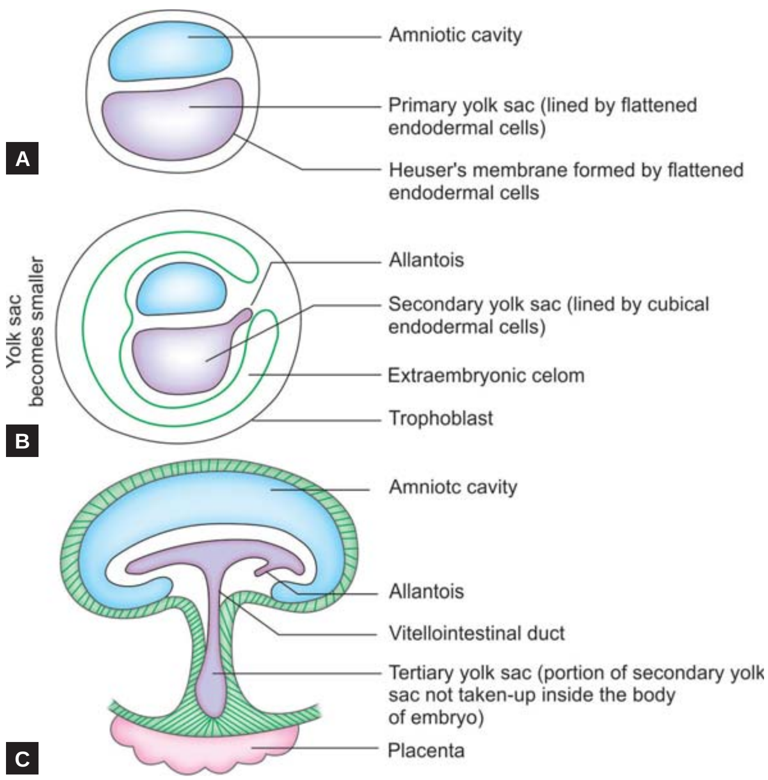


Fig. 35: In vitro fertilization-transvaginal insertion of conceptus into uterus

YOLK SAC (UMBILICAL VESICLE)

- Yolk sac (umbilical vesicle) is a membranous sac attached to an embryo, formed by cells of the hypoblast adjacent to the embryonic disk.
- It is important in early embryonic blood supply, and much of it is incorporated into the primordial gut during the fourth week of development.
- It is the first element seen within the gestational sac during pregnancy, usually at 3 days gestation.
- It is situated on the ventral aspect of the embryo; it is lined by extra-embryonic endoderm, outside of which is a layer of extra-embryonic mesenchyme.
- **Yolk sac** develops from the cavity of blastocyst and passes through **three** stages:



Figs. 36A to C: Yolk sac. A. Primary yolk sac (lined by Heuser's membrane made of flattened cells derived from endoderm B. Secondary yolk sac (becomes smaller due to the formation of extraembryonic celom and cells lining it becomes cuboidal) C. Tertiary yolk sac (part of secondary yolk sac which is not taken up inside the embryonic disc)

- **Primary** yolk sac is the vesicle which develops in the second week.
  - The blastocyst cavity gets converted into primary yolk sac, as it gets lined by flattened cells derived from extraembryonic endoderm (which themselves are derived from hypoblast).
  - This lining formed of flattened cells is called **Heuser's membrane**, which is attached to the undersurface of the hypoblast in the embryonic disc.
  - It is also known as the **exocoelomic cavity**.
- **Secondary** yolk sac is formed when the extraembryonic coelom develops in the extraembryonic mesoderm.
  - It is the remnant of primary yolk sac, has become smaller and lined by cuboidal cells.
- **Definitive** yolk sac is seen during the fourth week of development.
  - Part of the yolk sac gets surrounded by endoderm and incorporated into the embryo as the gut and the remaining part of the yolk sac is called as the final (definitive) yolk sac.
  - It communicates with the midgut via vitellointestinal duct.
- The **vitellointestinal duct** undergoes complete obliteration during the **seventh week**, but in about two percent of cases its proximal part persists as a diverticulum from the small intestine, **Meckel's diverticulum**.
- **Vitelline circulation** functions for absorption of nutritive material from the yolk sac to the embryo. Primitive aorta convey the blood to the wall of the yolk sac, which circulate through a wide-meshed capillary plexus and is carried by the vitelline veins to the tubular heart of the embryo.

ASSESSMENT QUESTION

1. **Umbilical vesicle attains full development at:**
   a. 2 week
   b. 4 week
   c. 6 week
   d. 7 week

ANSWER WITH EXPLANATION

1. **b. 4 week**
   - Umbilical vesicle (yolk sac) is fully developed at week four and is called as definitive (final) yolk sac.

AMNION AND CHORION

- **Amnion** is a thin extraembryonic membrane that is derived from the **epiblast** and surrounds the fluid-filled amniotic cavity around the embryo and fetus.
- It loosely envelops the embryo forming an amniotic sac that is filled with the amniotic fluid.
- It consists of two layers: an outer layer made up of somatopleuric layer of extraembryonic membrane and an inner layer made up of amniogenic cells.

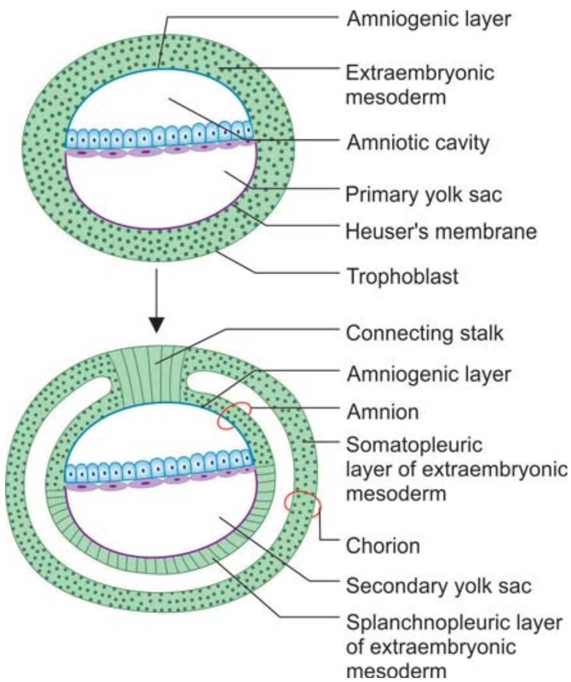
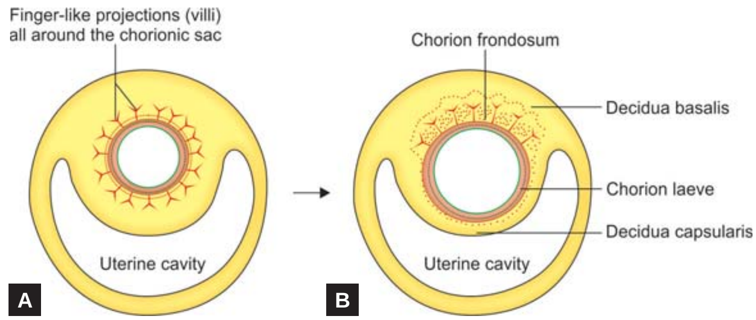


Fig. 37: Formation of amnion

- **Chorion** is the multilayered structure consisting of the somatic layer of **extraembryonic mesoderm**, **cytotrophoblast**, and **syncytiotrophoblast**.
- It contributes the fetal portion of the placenta, including the villi and villus lakes.
- Numerous small fingerlike projections arise from its surface called villi.
- Decidua capsularis: Chorionic villi regress leaving a smooth surface called chorion laeve.
- Decidua basalis: Chorionic villi are well developed (chorion frondosum) and contribute the fetal portion of the placenta.



Figs. 38A and B: Formation of chorion frondosum and chorion laeve. A. Formation of villi all around the chorionic sac. B. Regression of chorionic villi in relation to decidua capsularis.

PRIMITIVE STREAK

- Primitive streak
- It starts developing by the end of the second week (day 14-15) and continues into the third week.
- It appears on the dorsum (back) of the developing embryo, at the caudal (or posterior) end and proceeds towards the cephalic (anterior) end.
- It originates from the anterior epiblast, and appears as an elongating groove (primitive groove) on the dorsal midsagittal surface of the epiblast, along the anterior-posterior axis of the embryo.
- The rostrocaudal and medial-lateral axes of the embryo are defined by the primitive streak.
- The rounded primitive (Hensen's) node is situated at the cranial tip of the primitive streak, and contains a depression called the primitive pit. The primitive pit is continuous with the primitive groove.
- The presence of the primitive streak determine the site of gastrulation and initiate germ layer formation.

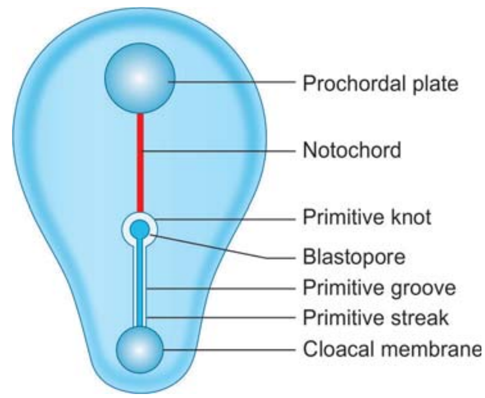


Fig. 39: Dorsal view of embryonic disc showing notochord

Primitive streak is the groove formed in the epiblast at the caudal end of the bilaminar germ disc stage embryo through which epiblast cells migrate to form endoderm and mesoderm during gastrulation.

Primitive node is the elevated region around the **cranial end** of the primitive streak that is known as the '**organizer**' because it regulates important processes such as laterality and formation of the notochord.

Primitive pit is the depression in the primitive node.

ASSESSMENT QUESTIONS

1. Primitive streak initiation and maintenance is due to:

(AIIMS 2007)

a. Brachyury gene
b. BMP-4
c. Nodal gene
d. FGF-β

2. True about primitive streak are all EXCEPT:

(NEET Pattern 2015)

a. 1st sign of gastrulation
b. Derived from epiblast
c. Appear at cranial end
d. All are true

ANSWERS WITH EXPLANATIONS

1. c. Nodal gene

- The primitive streak itself is initiated and maintained by expression of Nodal, a member of the transforming growth factor β (TGF-β) family.
- Once the streak is formed, a number of genes regulate formation of dorsal and ventral mesoderm and head and tail structures.
- Another member of the TGF-β family, bone morphogenetic protein-4 (BMP- 4) is secreted throughout the embryonic disc.

2. c. Appear at cranial end

- Primitive streak appears at the **caudal end** of the embryo.

NOTOCHORD

- Notochord (chordamesoderm) arises from epiblast cells of the medial part of the primitive node.
- It is also called axial mesoderm) is an early forming midline structure in the trilaminar embryo mesoderm layer initially ventral to the ectoderm, then neural plate and finally neural tube.
- It is a transient embryonic anatomy structure, not existing in the adult, defines the axis of embryo and is required for induction and Patterning the surrounding tissues. The Patterning signal secreted by notochord cells is sonic hedgehog (SHH).
- It forms in week 3, is eventually lost from vertebral regions and contributes to the nucleus pulposus of the intervertebral disc during the formation of the vertebral column.
- It forms during gastrulation and soon after induces the formation of the neural plate (neurulation), synchronizing the development of the neural tube.
- Notochord formation:
- Epiblast cells at the floor of the amnion cavity in the blastopore region, form a notochordal process, which later becomes notochordal canal and fuses with the endoderm to form notochordal plate.
- This occurs on the ventral aspect of the neural groove, where an axial thickening of the endoderm takes place next. This thickening appears as a furrow, the margins of which anastomose (come into contact), and so convert it into a solid rod of polygonal-shaped cells (the definitive notochord) which is then separated from the endoderm.
- Notochord extends throughout the entire length of the future vertebral column, and reaches as far as the anterior end of the midbrain, where it ends in a hook-like extremity in the region of the future dorsum sellae of the sphenoid bone.
- Initially it exists between the neural tube and the endoderm of the yolk-sac, but soon becomes separated from them by the mesoderm, which grows medially and surrounds it.
- From the mesoderm surrounding the neural tube and notochord, the skull, vertebral column, and the membranes of the brain and spinal cord are developed.

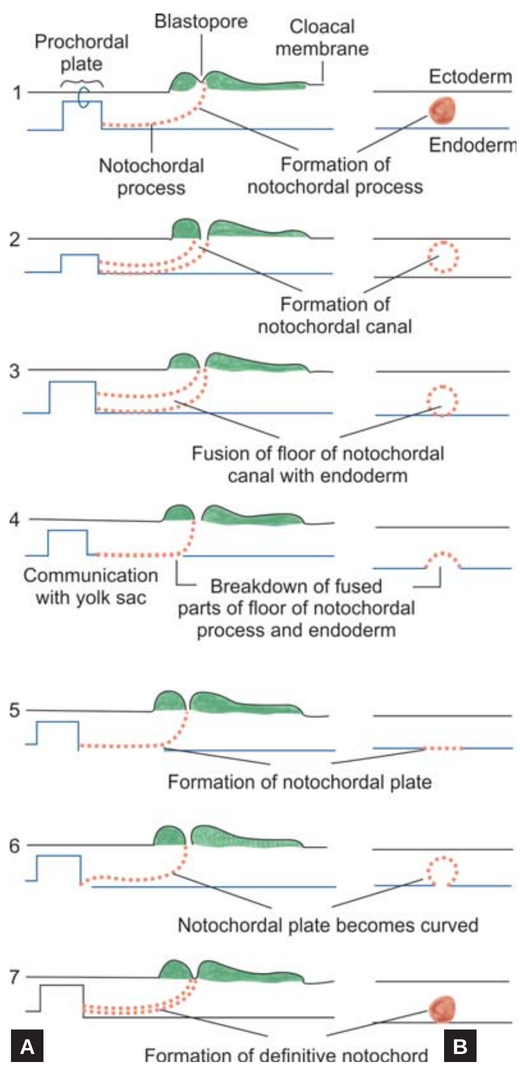


Fig. 40: Stages of formation of notochord. A. As seen in longitudinal section (left side). B. As seen in the horizontal section (right side)

ASSESSMENT QUESTIONS

1. True about notochord are all EXCEPT: *(NEET Pattern 2015)*
a. Defines axis of embryo
b. Serves as primary inductor
c. Derived from hypoblast
d. Remains as nucleus pulposus

2. Remnant of notochord is: *(NEET Pattern 2013)*
a. Annulus fibrosus
b. Nucleus pulposus
c. Ligament flavum
d. Intertransverse ligament

ANSWERS WITH EXPLANATIONS

1. c. Derived from hypoblast

- Epiblast (**not hypoblast**) cells at the floor of the amnion cavity in the blastopore region, form a notochordal process, which later evolve into definitive notochord.
- It is a transient embryonic anatomy structure, not existing in the adult, defines the **axis of embryo** and is required for **induction** and Patterning the surrounding tissues. For example, it induces the formation of the neural plate (neurulation), synchronizing the development of the neural tube.
- It is eventually lost from vertebral regions and contributes to the **nucleus pulposus** of the intervertebral disc during the formation of the vertebral column.

2. b. Nucleus pulposus

- Notochord is a transient embryonic anatomy structure, which defines the **axis of embryo.**
- It is eventually lost from vertebral regions and contributes to the **nucleus pulposus** of the intervertebral disc during the formation of the vertebral column

THIRD WEEK OF DEVELOPMENT

- The most characteristic event occurring during the third week is gastrulation, which begins with the appearance of the primitive streak, which has at its cephalic end the primitive node. In the region of the node and streak, epiblast cells move inward (invaginate) to form new cell layers, endoderm and mesoderm. Cells that do not migrate through the streak but remain in the epiblast form ectoderm. Hence, epiblast gives rise to all three germ layers in the embryo, ectoderm, mesoderm, and endoderm, and these layers form all of the tissues and organs.
- Prenotochordal cells invaginating in the primitive pit move forward until they reach the prechordal plate. They intercálate in the endoderm as the notochordal plate. With further development, the plate detaches from the endoderm, and a solid cord, the notochord, is formed. It forms a midline axis, which will serve as the basis of the axial skeleton. Cephalic and caudal ends of the embryo are established before the primitive streak is formed.
- BMP4 activity and dorsalize mesoderm to form the notochord and somitomeres in the head region. The neurotransmitter serotonin (5-HT) also plays a role in establishing laterality by restricting NODAL expression to the left side. Normal L-R positioning of the organs is called situs solitus, whereas their complete reversal is called situs inversus. When one or more organs are abnormally positioned the condition is called situs ambiguous or heterotaxy. Individuals with situs inversus have a low risk of having other birth defects, but their children have a higher risk, especially for heart defects. In contrast, patients with heterotaxy are at a high risk of having many types of congenital malformations, and almost all will have some type of cardiac abnormality.
- Epiblast cells moving through the node and streak are predetermined by their position to become specific types of mesoderm and endoderm. Thus, it is possible to construct a fate map of the epiblast showing this Pattern.
- By the end of the third week, three basic germ layers, consisting of ectoderm, mesoderm, and endoderm, are established in the head region, and the process continues to produce these germ layers for more caudal areas of the embryo until the end of the fourth week. Tissue and organ differentiation has begun, and it occurs in a cephalocaudal direction as gastrulation continues.
- In the meantime, the trophoblast progresses rapidly. Primary villi obtain a mesenchymal core in which small capillaries arise. When these villous capillaries make contact with capillaries in the chorionic plate and connecting stalk, the villous system is ready to supply the embryo with its nutrients and oxygen.

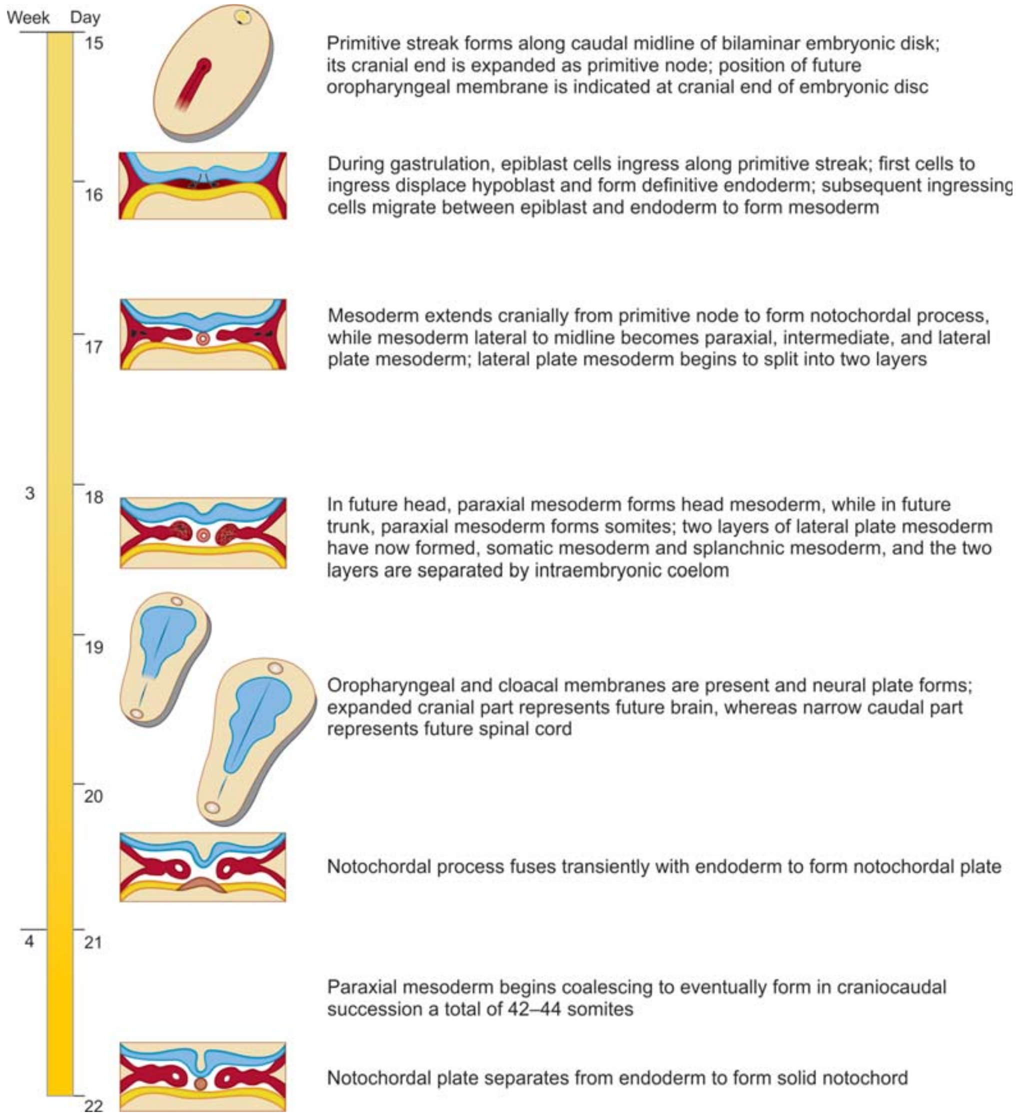


Fig. 41: Third week of development

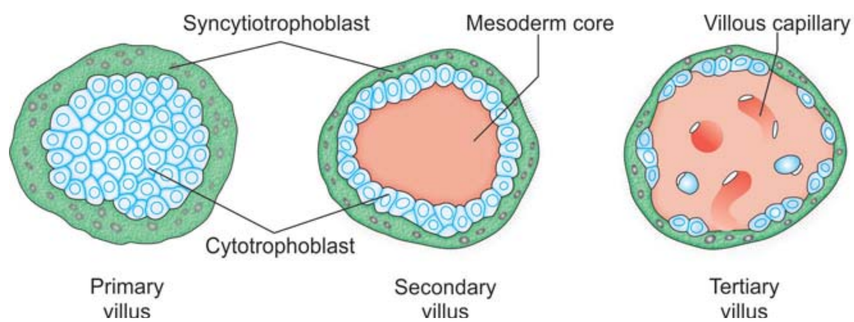


Fig. 42: Developmental stages of villi from primary to secondary (with mesoderm core) and tertiary (with fetal blood vessels)

GASTRULATION

- During gastrulation epiblast cells (in primitive streak) undergo ingression and form three germ layers: endoderm, mesoderm and ectoderm.

Gastrulation

- The first germ layer to form is endoderm.
- Cells settling between the epiblast and endoderm were termed mesoderm and, more recently, it is being called as mesenchyme.
- The remaining epiblast cells then form the ectoderm.
- Later the fourth germ layer develops named as neural crest cells.

- The terms primary and secondary mesenchyme have been used to distinguish between those cells that arise from ingression through the primitive streak and those that arise from neural crest ingression, respectively.
- Head & neck mesenchyme is chiefly derived from neural crest cells.

This process is first indicated by the formation of the primitive streak in the midline of the epiblast. As early as the bilaminar and trilaminar stages of embryogenesis, left side/right side (L/R) axis determination begins with the asymmetric activity sonic hedgehog protein (SHH) only on the future left side since SHH activity is suppressed on the future right side by Activin. In addition, the neurotransmitter serotonin (5HT) plays an important role in L/R axis determination. After L/R axis determination, the L/R asymmetry of a number of organs (e.g., heart, liver, stomach) can be Patterned by the embryo.

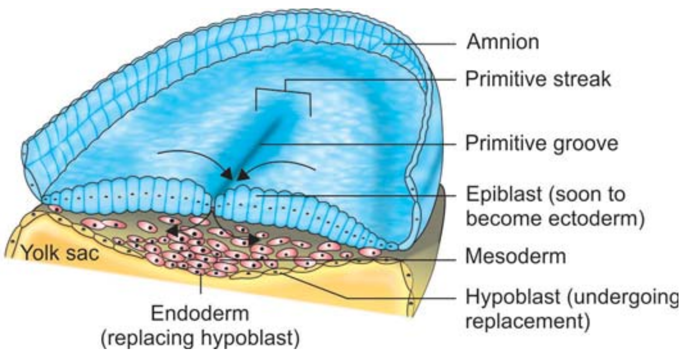


Fig. 43: Gastrulation: Formation of three germ layers from epiblast cells, in the third week of development.

High Yield Points

- **Bone morphogenetic proteins** (BMPs) are members of the **transforming growth factor** β family that serve as signal molecules for a number of morphogenetic events, including **dorsalizing** the central nervous system, participating in **bone formation**, etc.
- **Caudal dysgenesis** (sirenomelia or mermaid syndrome) is caused by insufficient production of mesoderm by the primitive streak.
- Consequently, there are not enough cells to form the lower part of the body so that the legs are fused.
- Renal agenesis is usually the cause of death.
- The defects are most often observed in infants from insulin-dependent diabetics.

ASSESSMENT QUESTIONS

1. First to be developed is: *(NEET Pattern 2013)*
a. Primitive pit
b. Primitive groove
c. Primitive fold
d. Primitive streak

2. Disc with three germ layers are formed at which week of gestation? *(NEET Pattern 2012)*
a. 1 week
b. 3 week
c. 5 week
d. 10 week

3. Indicator of start of gastrulation is the formation of: *(NEET Pattern 2013)*
a. Neural groove
b. Neural pit
c. Primitive streak
d. Formation of notochord

4. Which of the following is TRUE regarding gastrulation?
a. Establishes all the three germ layers *(AIPG 2002)*
b. Occurs at the caudal end of the embryo prior to its cephalic end
c. Involves the hypoblast cells of inner cells mass
d. Usually occurs at 4 weeks

ANSWERS WITH EXPLANATIONS

1. d. Primitive streak
- Primitive streak originates from the anterior epiblast, and appears as an elongating groove (primitive groove) on the dorsal midsagittal surface of the epiblast, along the anterior-posterior axis of the embryo.
- The rounded primitive (Hensen's) node is situated at the cranial tip of the primitive streak, and contains a depression called the primitive pit. The primitive pit is continuous with the primitive groove.

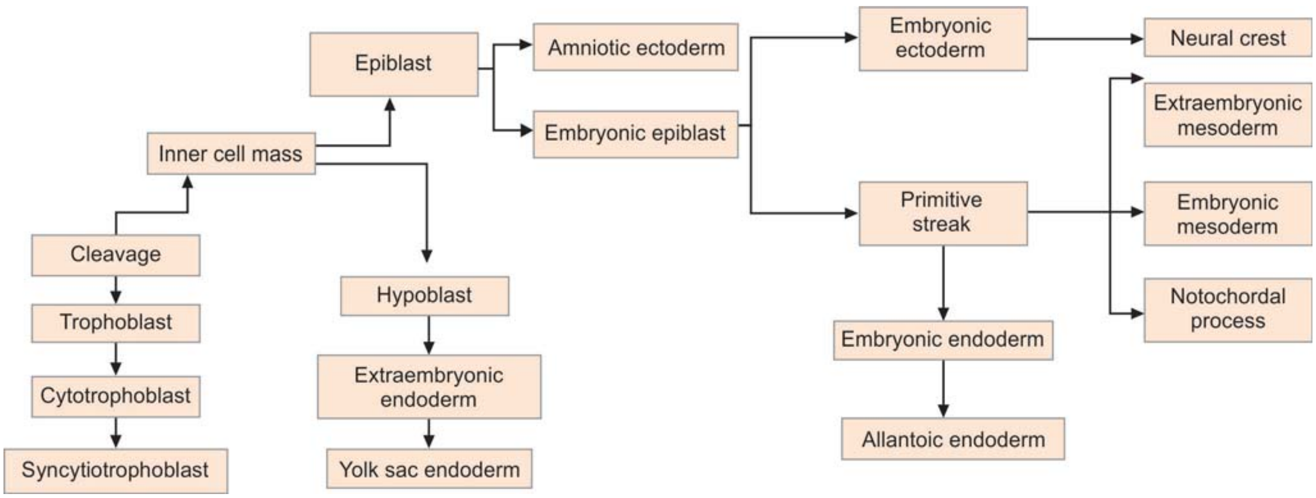
2. b. 3 week
- **Gastrulation** is the process by which **three germ layers** are formed in the **third week** of development.

3. c. Primitive streak
- **Primitive streak** is the groove formed in the **epiblast** at the caudal end of the **bilaminar germ disc** stage embryo through which epiblast cells migrate to form endoderm and mesoderm during **gastrulation**.

4. c. Involves the hypoblast cells of inner cells mass
- **Gastrulation** is the process by which the epiblast cells (**not hypoblast**) undergo ingression and establish **three germ layers**: endoderm, mesoderm and ectoderm.
- It occurs in the **third week** of development.
- Gastrulation has a **cephalocaudal direction**: It begins at the cephalic end and proceeds to wards the caudal end. Hence the three germ layers are first seen near the head region and consequently towards the tail region.

GERM LAYER DERIVATIVES

Flowchart 2: Development of germ layers



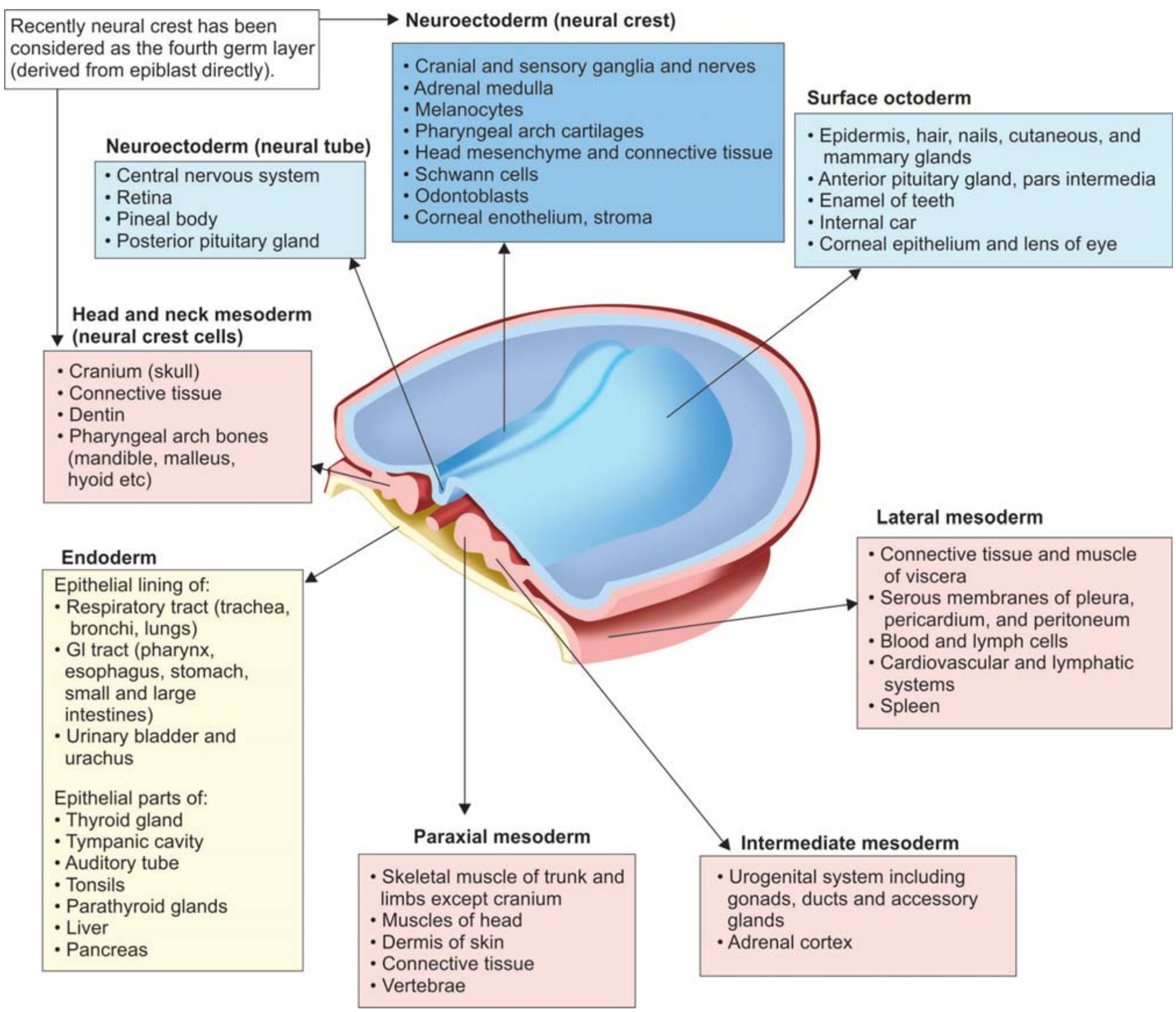


Fig. 44: Germ layer derivatives

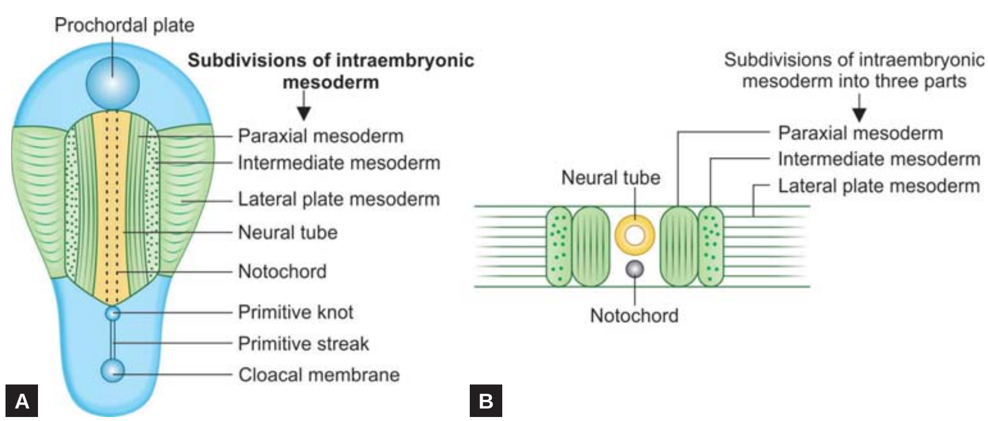
Flg. 11: Structures that will be derived from specific epithelial and mesenchymal populations in the early embryo. Abbreviation: CNS, central nervous system.

Endoderm epithelium	Coelomic wall epithelium	Mesenchyme
• Primitive gut • Foregut - recesses, diverticula and glands of the pharynx • General mucous glandular and duct-lining cells and the main follicular cells of the thyroid • Epithelium of pharyngeal pouches (Tonsil, middle ear cavity, thymus, parathyroids 3 and 4 C cells of thyroid), adenolds, epithelium lining of the auditory tube, tympanic cavity, tympanic antrum, internal lamina of the tympanic membranes. • Respiratory tract - epithelial lining, secretory and duct-lining cells of the trachea, bronchial, bronchloles and aveolar sacs. • Epthelial lining, secretory and duct-lining cells of the oesophagus, stomach and duodenum. • Hepatocytes of liver, biliary tract, exocrine and endocrine cells of the pancreas. • Midgut-epithelial lining, glandular and duct lining cells of the duodenum, jejunum, appendix, caecum, part of transverse colon • Hindgut-epthelial lining, glandular and duct-lining cells of part of the transverse, decending and sigmoid colon, rectum, upper part of anal canal. • Allantosis-urinary bladder, vagina, urethra, secretory cells of the prostate and urethral glands.	• Walls of intra-embryonic coelom • Primitive pericardium - myocardium, parietal pericardium • pericardioperitoneal canals - visceral, parietal and mediastinal pleura, pleuroperitoneal membranes contributing to diaphragm • Splanchnopleuric epithelium - visceral peritoneum of stomach, peritoneum of lesser and greater omental, faicliform ligament, lienorenal and gastrosplenica ligaments • Somatopleuric epithelium - parietal peritoneum • Primitive peritoneal cavity • Splanchnopleuric epithelium - visceral peritoneal covering of mid- and hindgut, the mesentery, transverse and sigmoid mesocolon. • Pronephros, epithelial lining of mesonephric ducts, vas deferens, epididymis, seminal vesicles, ejaculatory duct, ureters, vesical trigone • Mullerian ducts, epithetical lining of uterine tubes, body and cervix of uterus, vagina, broad ligament of uterus. • Germinal epithelium of gonad (note the germ cells are not included on this chart because of their early sequestration into the extraembryonic tissues) • Germinal epithelium forming cortex of suprarenal gland. • Somatopleuric epithelium - parietal peritoneum, tunica vaginalis of testis.	• Paraxial mesenchyme • (somites and somitomeres) • Sclerotome - vertebrae and portions of the neurocranium, axial skeleton • Myotome - all voluntary muscles of the head, trunk and limbs. • Dermatome - demise of skin over dorsal regions. • Intermediate mesenchyme - connective tissue of gonads, mesonephric and metanephric nephrons, samooth muscle and connective tissues of the reproductive tracts • Septum transversum - epicardium, fibrous pericardium, portion of diaphragm, oesophageal mesentery, sinusoids of liver, tissue within lesser omentum and falciform ligament. • Lateral plate mesenchyme • Splanchnopleuric layer - smooth muscle and connective tissues of respiratory tract and associated glands. • Smooth muscle and connective tissues of intestinal tract, associated glands and abdominal mesenteries. • Smooth muscle and connective tissue of blood vessels (also see below) • Somatopleuric layer - appendicular skeleton, connective tissue of limbs and trunk, including cartilage, ligaments and tendons. • Demise of ventral body wall and limbs. • Mesenchyme of external genitalia. • Angiogenic mesenchyme • Endocardium of heart, endothelium of blood and lymphatic vessels, vessels of choroid plexus, sinusoids of liver and spleen, circulating blood cells, microglia, tissue macrophages.
Surface ectoderm epithelium	**Neural plate epithelium**	**Neural crest**
• Entodernal placodes • Adenohypophysis • Sensory neurones of the cranial ganglia V, VII, VIII, IX, X. • Olfactory receptor cells and olfactory epithelium • Epithelial walls of the membranous labyrinth, the cochlear organ of corti. • Lens of the eye • Enamel organs of the teeth • Cranial structures • Secretory and duct-lining cells of the lacrimal, nasal, labial, palaver, oral and salivary glands. • Etchells of the comeas and conjunctive. • Epithelial lining of the external acoustic mealsus and external epithelium of the lymphatic membrane. • Epithelial lining of the lacrimal canaliculi and nasolacrimal duct • Epithelial lining of the paranasal sinuses, lips, cheeks, gums and palate.	• CNS - Brain and spinal cord Neurohypophysis • Prosencephalon (Telencephalon and diencephalon • Mesencephalon - cerebral peduncles, tectum, tegmentum • Rhombencephalon (mecencephalon and myelencephalon) - cerebelium, ports, medulla oblongata. • Spinal cord • All cranial and spinal motor nerves. • All CNS neurones, including preganglionic efferent neurones, with somala within the CNS. • Astrocytes and oligodendrocytes. • Ependyma lining the cerebral verticles, aqueduct and central canal of brain and spinal cord, tarycytes, cells covering the choroid plexuses, circumventricular cells. • Retina and optic nerve (II), epthelium of the iris, ollary body and processes	• Sensory neurones of the cranial ganglia V, VII, VIII, IX, X. • Sensory neurones of the spinal dorsal root ganglia and their peripheral sensory receptors • Satellte cells in all sensory ganglia • Sympathetic ganglia and plexuses: neurones and satellte cells • Parasympathetic ganglia and plexuses: neurones and satellte cells • Enteric plexuses: neurones and gllal cells • Schwann cells of the all the peripheral nerves • Medulla of the suprarenal glands. Chromaffin cells • Carotid body type I cells (and type II, satelite type cells). • Calcilonin-producing cells (C cells) • Melanocytes • Mesenchymal derivatives in the head • Frontal, parietal, squamous temporal, nasal, vomer, palatine bones, maxillae and mandile • Meninges

Surface ectoderm epithelium	Neural plate epithelium	Neural crest
• Epidermal structures • Most of the cutaneous epidermal cells, the secretary, duct-lining and myoepithelial cells of the sweat, sebaceous and mammary glands • Hair and nails. • Proctodeal epithelium and epithelium of the terminal malo urethra		• Choroid and sclera of eye • Connective tissue of lacrimal, nasal, labial, pataline, oral and salivary glands • Dentine of teeth • Connective tissues of thyroid glands and of the pharyngeal pouches, i.e. parathyroid glands, thymus. • Tunica media of the outflow tract of the heart and the great vessels.

MESODERM

- Paraxial mesoderm give rise to somites, which further subdivide into the sclerotomes, myotomes and dermatomes.
- Somites give rise to the vertebrae of the vertebral column, rib cage, and part of the occipital bone; skeletal muscle, cartilage, tendons, and skin dermis (of the back).
- Somites are differentiated into:
  - Dermomyotome: Form skeletal muscles and dermis.
  - Sclerotomes: Surround notochord and project posteriorly to surround neural tube and divide into three parts:
  - Ventral sclerotomes: Forms vertebral body and annulus fibrosus.
  - Lateral sclerotomes : Forms vertebral arch (pedicle and lamina).
  - Dorsal sclerotomes : Forms the spinous process.
- Each lateral plate splits horizontally into the dorsal somatic (parietal) mesoderm, which underlies the ectoderm, and the ventral splanchnic (visceral) mesoderm, which overlies the endoderm.
- The space between these layers becomes the body cavity—the coelom—which stretches from the future neck region to the posterior of the body.
- During later development, the right- and left-side coeloms fuse, and folds of tissue extend from the somatic mesoderm, dividing the coelom into separate cavities.
- The coelom is subdivided into the pleural, pericardial, and peritoneal cavities, enveloping the thorax, heart, and abdomen, respectively.
- Parietal layers of pleura, pericardium and peritoneum develop from the dorsal somatic lateral plate mesoderm, whereas visceral layers of pleura, pericardium and peritoneum develop from the ventral visceral lateral plate mesoderm.



Figs. 45A and B: Subdivisions of intraembryonic mesoderm. A. As seen in embryonic disc. B. As seen in the horizontal section of the embryonic disc

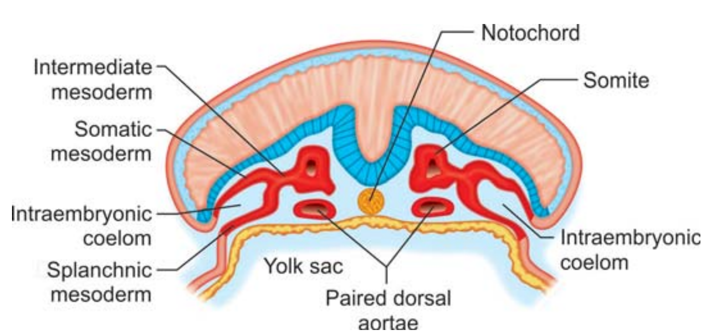
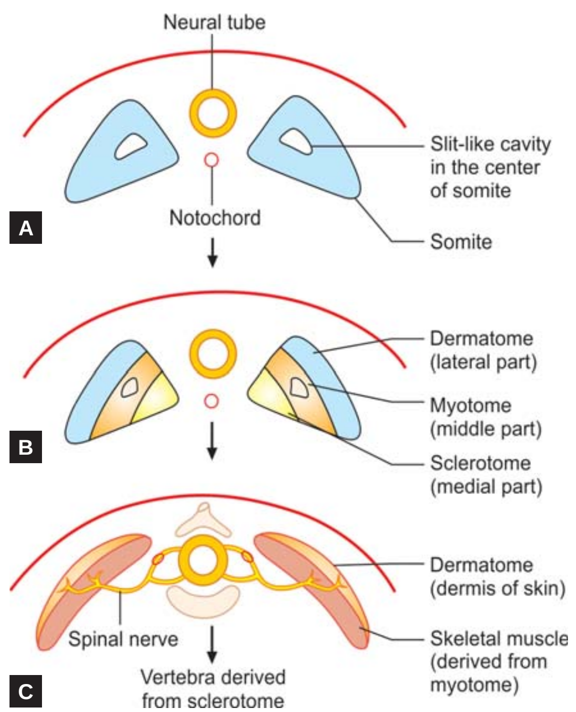


Fig. 46: Development of mesoderm into various sub-divisions.



Figs. 47A to C: Subdivisions of the somites

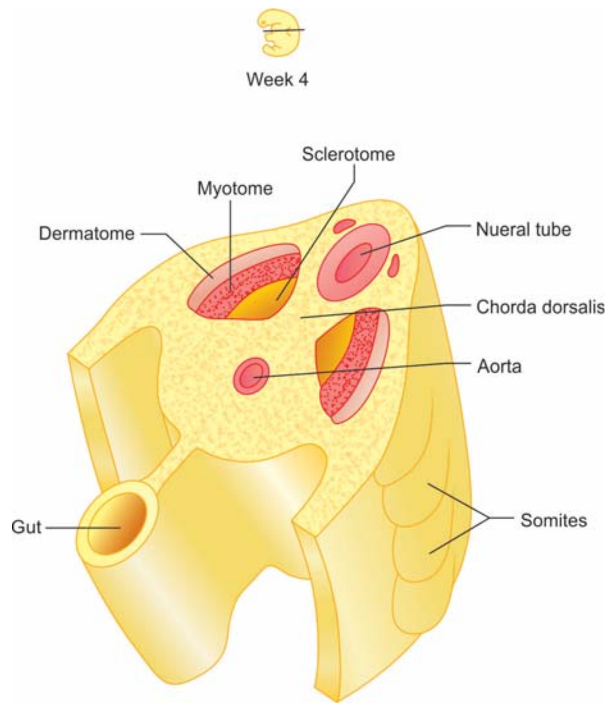
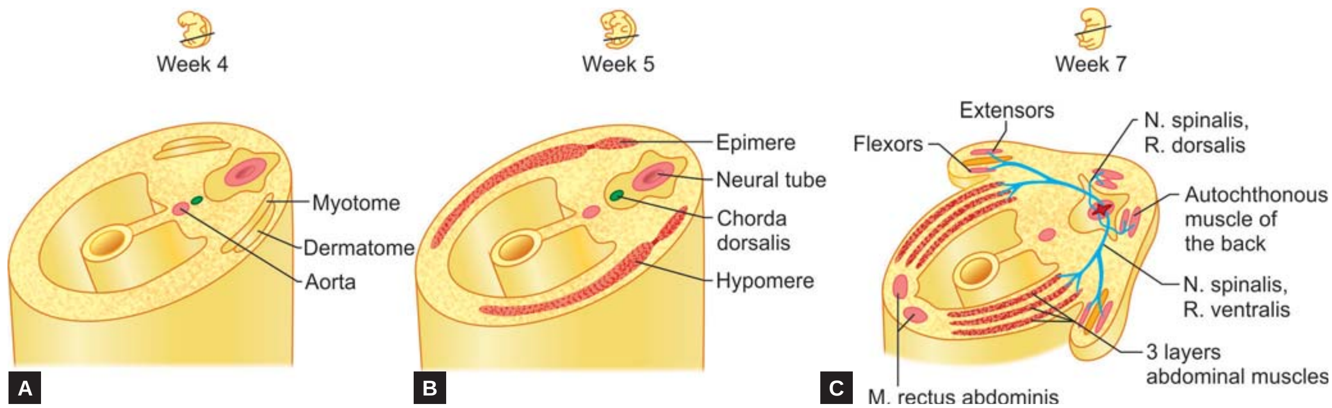


Fig. 48: Development of three parts of somite



Figs. 49A to C: Development of somites and muscle groups

ASSESSMENT QUESTIONS

1. All develop form mesoderm EXCEPT: *(NEET Pattern 2012)*
- a. Skeletal muscle
- b. Testes
- c. Enamel
- d. Ureter

2. Somites develop from: *(NEET Pattern 2014)*
- a. Notochord
- b. Intermediate mesoderm
- c. Paraxial mesoderm
- d. Lateral plate mesoderm

3. All are derived from mesoderm EXCEPT: *(AIIMS 2014)*
- a. Pupillary muscles
- b. Skeletal muscles
- c. Smooth muscle
- d. Extra ocular muscles

4. Development of peritoneal cavity is from: *(NEET Pattern 2012)*
- a. Mesenchyme
- b. Intraembryonic coelom
- c. Ectoderm
- d. Endoderm

5. Which of the following is an intraembryonic coelomic cavity? *(NEET Pattern 2014)*
- a. Amniotic
- b. Chorionic
- c. Pericardial
- d. None of the above

6. At which level the somites initially form? *(NEET Pattern 2014)*
- a. Thoracic level
- b. Cervical level
- c. Lumbar level
- d. Sacral level

ANSWERS WITH EXPLANATIONS

1. c. Enamel
- Enamel of teeth develops from the surface ectoderm.

2. c. Paraxial mesoderm
- **Paraxial mesoderm** give rise to **somites**, which further subdivide into the sclerotomes, myotomes and dermatomes.

3. a. Pupillary muscles
- Iris muscles which control the pupillary aperture (**sphincter** and d**ilator pupillae**) are derived from the neural plate ectoderm.

4. b. Intraembryonic coelom
- Intraembryonic coelom forms the cavities like pericardial, pleural and peritoneal cavities.

5. c. Pericardial
- Intraembryonic coelom forms the cavities like pericardial, pleural and peritoneal cavities.

6. b. Cervical level
- The first pair of somites arises in the **occipital** region of the embryo at approximately the 20th day of development.

NEURAL CREST CELL DERIVATIVES

- Neural crest cells have been considered to arise from the embryonic ectoderm cell layer.
- After gastrulation, neural crest cells are located at the border of the neural plate and the non-neural ectoderm.
- During neurulation, the borders of the neural plate (neural folds) converge to form the neural tube.
- Subsequently, neural crest cells from the roof plate of the neural tube undergo an epithelial to mesenchymal transition, separating from the neuroepithelium and migrating through the periphery where they differentiate into varied cell types.

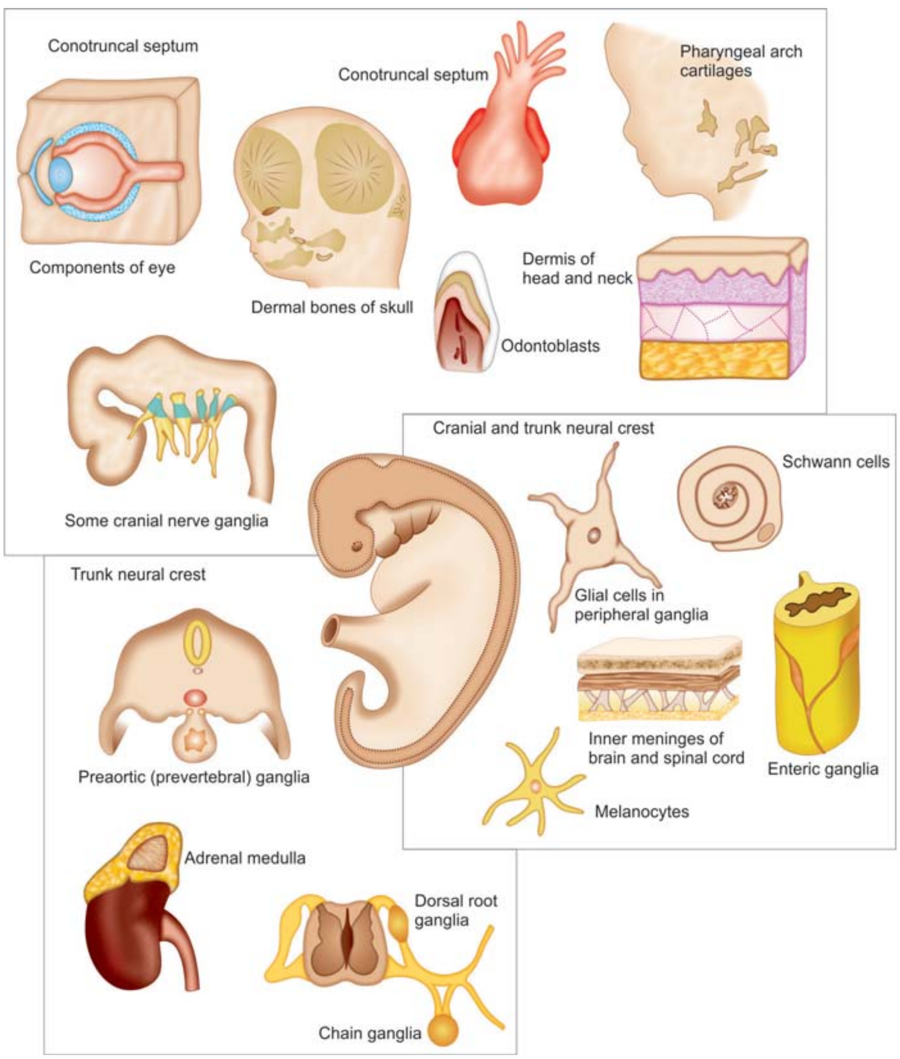


Fig. 50: Derivatives of neural crest cells

- Recently neural crest cells are called as fourth germ layer.
- The neural crest cells (NCCs) have multipotency and long range migration through embryo and its capacity to generate a prodigious number of differentiated cell types.
- For these reasons, although derived from the ectoderm, the neural crest (NC) has been called the fourth germ layer (in addition to the ectoderm, mesoderm and endoderm).
- The neural crest meets all the criteria used to define and identify a germ layer.
- As the fourth germ layer, the neural crest is confined to vertebrates, which are therefore tetrablastic not triploblastic.
- Derivatives
- Neural crest cells originating from different positions along the anterior-posterior axis are divided into four regions: Cranial neural crest, trunk neural crest, vagal and sacral neural crest and cardiac neural crest.
- Neural crest cells give rise to secondary mesenchyme (also called mesoectoderm) and contributes to most of the skeletal and connective tissue components of the head and neck region:
    - Odontoblasts, dental papillae, the chondrocranium (nasal capsule, Meckel's cartilage, scleral ossicles, hyoid), tracheal and laryngeal cartilage, the dermato-cranium (membranous bones), pericytes and smooth muscle of branchial arteries and veins, tendons of ocular and masticatory muscles, connective tissue of head and neck glands (pituitary, salivary, lachrymal, thymus, thyroid) dermis and adipose tissue of calvaria, ventral neck and face.
- Neural crest cells form one of the three pigment cell types - **melanocytes**, which develop from a subpopulation of neural crest cells derived from both the head and the trunk.
- The others pigment cells : retinal pigment epithelium and pigment cells of the pineal organ, both originate from the neuroectoderm (diencephalon).
- Glomus cell type I are very similar structurally to neurons, and they are derived from the **neural crest**, while the glomus cells of type II are similar in function to neuroglia (derived from **neuroectoderm**).
- Glomus cell (type I) is a peripheral chemoreceptor, mainly located in the carotid bodies and aortic bodies, that helps the body regulate breathing. A decrease in the blood's pH, a decrease in oxygen (pO_2), or an increase in carbon dioxide (pCO_2), leads to the carotid bodies and the aortic bodies sending signal to the medulla oblongata (dorsal inspiratory center) to increase the volume and rate of breathing.
- Autonomic ganglia innervate the glomus cells, and some presynaptic sympathetic ganglia synapse with glomus cells.
- Clusters of glomus cells, of which the carotid bodies and aortic bodies are the most important, are called non-chromaffin or parasympathetic paraganglia. They are also present along the vagus nerve, in the inner ears, in the lungs, and at other sites.
- Neoplasms of glomus cells are known as paraganglioma, among other names, they are generally nonmalignant.
- Placodes: Cells within the rostral porencephalic neural fold and smaller populations of cells in bilateral sites lateral to the early brain do not form migratory neural crest cells but remain within the surface epithelium are called as ectodermal placodes.

ASSESSMENT QUESTIONS

1. Derivatives of neural crest is/are: *(PGIC 2003)*
a. Para follicular cells of thyroid
b. Adrenal cortex
c. Adrenal medulla
d. Dorsal root ganglia
e. Autonomic ganglia

2. Sympathetic ganglion develops from: *(NEET Pattern 2015)*
a. Surface ectoderm
b. Mesoderm
c. Neural crest
d. Mesenchymal neuroectoderm

3. Glomus cells are derived from: *(NEET Pattern 2015)*
a. Surface ectoderm
b. Neuroectoderm
c. Mesoderm
d. Endoderm

4. Enumerate the derivatives of neural crest cells: *(PGI Chandigarh Pattern - 2016)*
a. Tunica media of ascending aorta
b. Connective tissue of thymus gland
c. Enamel of teeth
d. Choroid and sclera of eye
e. Mandible bone

5. All are derived from ectoderm EXCEPT: *(NEET Pattern 2012)*
a. Lens
b. Eustachian tube
c. Brain
d. Retina

6. Which of the following is derived from endoderm:
a. Gallbladder
b. Lens
c. Spleen
d. Lymph nodes

7. Auerbanchs plexus and Meissers ganglion cell are derived from: *(AIIMS Nov. 09)*
a. Yolk sac
b. Primordial germ cell
c. Neural crest
d. Fetal GIT

8. Melanoblasts are derived from: *(AP 2K)*
a. Basal epidermal cells
b. Neural crest cells
c. Prickle cells of epidermis
d. Somatopleuric mesoderm

9. Corneal stroma is derived from: *(All India Dec. 13 Pattern)*
a. Paraxial mesoderm
b. Intermediate mesoderm
c. Lateral plate mesoderm
d. Ectoderm

10. All are derived from ectoderm except: *(NEET Dec. 12 Pattern)*
a. Hypophysis
b. Retina
c. Spinal cord
d. Adrenal cortex

11. Ameloblasts in teeth are derived from: *(CET June 14 Pattern)*
a. Mesoderm
b. Endoderm
c. Neural crest cells
d. Ectoderm

12. All are endodermal in origin except: *(MP 2K)*
a. Hepatocyte
b. Odontoblast
c. Alveolar lining cells
d. None

13. Sphineter and dilator pupillae develop from: *(All India Dec. 13 Pattern)*
a. Surface ectoderm
b. Neuroectoderm
c. Mesoderm
d. Endoderm

14. Earliest system to be function in fetus is: *(All India Dec. 13 Pattern)*
a. CNS
b. GIT
c. Circulatory
d. Genitourinary

15. All are derived from ectoderm EXCEPT: *(AIIMS May 14)*
a. Hair follicle
b. Sebaceous gland
c. Arrector pilorum muscle
d. Mammary gland

16. Buccopharyngeal membrane consists of: *(AIIMS May 14)*
a. Mesoderm and endoderm
b. Ectoderm and mesoderm
c. Ectoderm, mesoderm and endoderm
d. Endoderm and ectoderm

ANSWERS WITH EXPLANATIONS

1. a. Para follicular cells of thyroid; c. Adrenal medulla; d) Dorsal root ganglia; e. Autonomic ganglia
- Parafollicular 'C' cells of thyroid are derived from neural crest cells.
- Adrenal medulla is a derivative of neural crest cells, whereas adrenal cortex develops from intermediate mesoderm.
- Most of the ganglia are derived from neural crest cells, including autonomic and dorsal root ganglia.

2. c. Neural crest
- Most of the ganglia are derived from neural crest cells, including sympathetic ganglia.

3. b. Neuroectoderm
- Glomus cell type I are very similar structurally to neurons, and they are derived from the **neural crest**, while the glomus cells of type II are similar in function to neuroglia (derived from **neuroectoderm**).

4. a. Tunica media of ascending aorta; b. Connective tissue of thymus gland; d. Choroid & sclera of eye; e. Mandible bone
- Tunica media
  - Tunica media of proximal vessels of heart develop from neural crest cells.
  - Tunica media of dorsal aorta develops from para-axial mesoderm.
  - Tunica media of most of the blood vessels develop from lateral plate mesoderm (splanchnopleuric layer).
- Few glands like thymus develop from endoderm of pharyngeal pouches, but connective tissue is derived from neural crest cell derived secondary mesenchyme.
- Dentine of teeth develop from odontoblast (neural crest cells), whereas the enamel develop from surface ectoderm.
- Most of the eyeball develop from neural crest cells and the derived mesenchyme, including choroid and sclera of eyeball. Primary mesenchyme has little contribution to eyeball.
- Most of the skull bones are derived from neural crest cell derived (secondary mesenchyme), except lower part of occipital bone (derived from primary mesenchyme).
- Pharyngeal arch bones like mandible develop from neural crest cells.

5. b. Eustachian tube
- Eustachian tube is a derivative of the first pharyngeal pouch (endoderm).

6. a. Gallbladder
- Gall bladder develops from an **endodermal** outpouching of the embryonic gut tube.

7. c. Neural crest
- Neural crest cells form most of the ganglia, including Auerbach and Meissner's ganglia.

8. b. Neural crest cells
- Neural crest cells forms the melanoblasts and melanocytes.

9. d. Ectoderm
- Stroma of cornea develops from neural crest cells derived (secondary) mesenchyme.

Note: Neural crest cells are now considered as fourth germ layer. Earlier neural crest cells were thought to arise from neuroectoderm.

10. d. Adrenal cortex

11. d. Ectoderm
- Ameloblasts develop from the surface ectoderm and form the enamel of teeth.

12. b. Odontoblast
- Odontoblasts develop from the neural crest cells and form the dentine of teeth.
- Hepatocytes (liver) are endodermal derivative of foregut.
- Alveolar cells (lung) are derivative of the endoderm of foregut.

13. b. Neuroectoderm
- Sphincter and dilator pupillae muscles of iris develop from the neural plate ectoderm.

14. c. Circulatory
- Cardiovascular system is the earliest to start developing and become functional.

15. c. Arrector pilorum muscle
- Arrector pilorum muscle is derived from the mesenchyme.

16. d. Endoderm and ectoderm
- Buccopharyngeal membrane has ectoderm fusion with endoderm, with no intervening mesoderm.

High Yield Points

- Leptomeninges (pia-arachnoid) are contributed by neural crest cells.
- Skeletal and connective tissue components of the pharyngeal arches are chiefly derived from secondary mesenchyme (neural crest cells).

MISCELLANEOUS QUESTIONS

ASSESSMENT QUESTIONS

1. All of them are derivatives of ectoderm EXCEPT:
a. Epidermis b. Parotid gland
c. Neurohypophysis d. Arrector pilorum

2. Paraxial mesoderm contribution to development of: *(NEET Pattern 2013)*
a. Parietal peritoneum b. Visceral peritoneum
c. Skeletal muscles d. Peritoneal cavity

3. Extra embryonic mesoderm is derived from: *(AIIMS 2016)*
a. Primary yolk sac
b. Secondary yolk sac
c. Epiblast
d. Hypoblast

4. All the following statements are true concerning the early embryological development EXCEPT:
a. Zona pellucida is a glycoprotein membrane preventing implantation
b. Blastocyst attaches to endometrium on day 6
c. Primordial germ cells are derivative of epiblast
d. The first germ layer to form is ectoderm

5. Trophoblast differentiates into cyto and syncytio-trophoblast at day:
a. 4 b. 6
c. 8 d. 10

6. Trophoblast differentiates into cyto and syncytio-trophoblast at post fertilization day:
a. 6-8 b. 8-12
c. 12-14 d. 16-18

7. Which of the following system becomes functional earliest?
a. Nervous b. Respiratory
c. Cardiovascular d. Gastrointestinal

8. Which of the following is present at the beginning of third week?
a. Notochord b. Primitive streak
c. Mesoderm d. Neural crest cells

9. Dilator pupillae muscle is derived from:
a. Neural crest cells b. Neural plate ectoderm
c. Surface ectoderm d. Mesoderm

10. Endoderm gives all EXCEPT:
a. Urethra b. Endocardium
c. Lungs d. Vagina

11. All is true about notochord EXCEPT:
a. Endodermal
b. Appears at week 3
c. Becomes nucleus pulposus
d. Embryonic notochordal remnant may result in chordoma

12. Structures derived from neural crest cells are all EXCEPT: *(PGIC)*
a. Ganglia
b. Mesenchyme of brain
c. Astrocyte and oligodendrocyte
d. AP septum of heart e) Enamel

13. Which of the following gives rise to the muscular component of dorsal aorta:
a. Intermediate mesoderm b. Lateral plate mesoderm
c. Axial mesoderm d. Para-axial mesoderm

14. Adrenal cortex develops from:
a. Para-axial mesoderm b. Intermediate mesoderm
c. Lateral plate mesoderm d. Neural crest cells

ANSWERS WITH EXPLANATIONS

1. d. Arrector pilorum
- **Arrector pilorum** is a smooth muscle in the skin derived from mesenchyme.
- **Epidermis** and **parotid** salivary gland develop from **surface ectoderm**.
- **Neurohypophysis** is an extension of diencephalon (**neural plate ectoderm**).

2. c. Skeletal muscles
- Paraxial mesoderm give rise to somites, whose myotome component forms the skeletal muscles.
- Each lateral plate splits horizontally into the dorsal somatic (parietal) mesoderm and the ventral splanchnic (visceral) mesoderm by a space.
- The space between these layers becomes the coelomic cavity and is subdivided into the pleural, pericardial, and peritoneal cavities.
- Parietal layers of pleura, pericardium and peritoneum develop from the dorsal somatic lateral plate mesoderm, whereas visceral layers of pleura, pericardium and peritoneum develop from the ventral visceral lateral plate mesoderm.

3. a. Primary yolk sac > d. Hypoblast > c. Epiblast

- The outer layer of cells from the primary umbilical vesicle (yolk sac) forms a layer of loosely arranged connective tissue, the extraembryonic mesoderm.
- The origin of the extraembryonic mesoderm is by no means clear; it may arise from several sources, including the caudal region of the epiblast, the parietal hypoblast; trophoblast or a new germinal population which is yet to be established (Gray's Anatomy Ed 41).

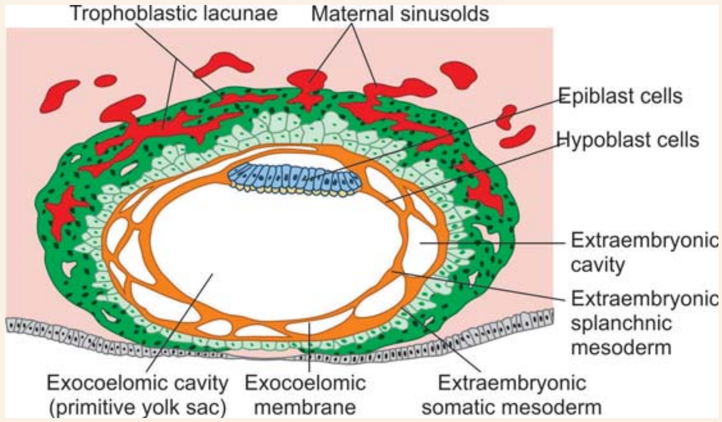


Fig. 51: Formation of extra-embryonic mesoderm

4. d. The first germ layer to form is ectoderm.

- Endoderm is the first germ layer to develop from the epiblast, followed by mesoderm and then ectoderm.

5. b. 6

- Trophoblast in the outer cell mass differentiate into cytotrophoblast and syncytio-trophoblast at the 6th day of development and form placenta.
- Syncytio-trophoblast attaches the conceptus to the endometrium wall and secrete hCG (Human Chorionic Gonadotropin).

6. a. 6-8

- Trophoblast differentiates into cyto and syncytio trophoblast at 6 - 8th day post ovulation/fertilization.

7. c. Cardiovascular

- Uteroplacental circulation is established as early as 12th day of life, embryoplacental circulation at day 17.
- Heart beat begins as early as day 22 of life.

8. b. Primitive streak

- Primitive streak appears at the end of second week and beginning of third week.
- Epiblast cells in the primitive streak forms the notochord, mesoderm and neural crest cells later in the third week.

9. b. Neural plate ectoderm

- Smooth muscles of iris (sphincter and dilator pupillae) develop in the neural plate ectoderm.
- Neural plate ectoderm forms the CNS (Central Nervous System) and some other derivatives as well.

10. b. Endocardium

- Endoderm of the urogenital sinus forms the urethra and vagina epithelium.
- Lung develops from the endoderm of anterior part of foregut.
- Endocardium is present in the heart tube (mesodermal origin).

11. a. Endodermal

- Notochord is the axial mesoderm forming the axis of the embryo.
- It appears at week 3 and later becomes nucleus pulposus of the intervertebral disc.
- Occasionally it may form a tumour- chordoma.

12. c. Astrocytes and oligodendrocyte; e. Enamel

- Astrocyte and oligodendrocyte develop from the neural plate ectoderm.
- Enamel develops from ameloblasts (surface ectoderm).
- Most of the ganglia, head & neck mesenchyme and AP septum of heart develop from neural crest cells.
- Teeth develop from neural crest cells (odontoblast forms dentine) and are covered by surface ectoderm (en-ameloblast forms enamel).

13. d. Para-axial mesoderm

- Muscular component of the dorsal aorta is derived from para-axial mesoderm.
- Lateral plate mesoderm give rise to most of the smooth muscles of the blood vessels with few exceptions:
- Neural crest cells form the smooth muscle cells of the proximal aorta.
- Smooth muscle cells of the dorsal aorta are derived from the para-axial mesoderm.

14. b. Intermediate mesoderm

- Adrenal cortex develops from Intermediate mesoderm along with major portion of genito-urinary system.
- Adrenal medulla develops from neural crest cells.

3–8 WEEKS

- The embryonic period, which extends from the third to the eighth weeks of development, is the period during which each of the three germ layers, ectoderm, mesoderm, and endoderm, gives rise to its own tissues and organ systems. As a result of organ formation, major features of body form are established.
- The ectodermal germ layer gives rise to the organs and structures that maintain contact with the outside world:
  - Central nervous system
  - Peripheral nervous system
  - Sensory epithelium of ear, nose, and eye
  - Skin, including hair and nails
  - Pituitary, mammary, and sweat glands and enamel of the teeth
- Important components of the mesodermal germ layer are paraxial, intermediate, and lateral plate mesoderm. Paraxial mesoderm forms somitomeres, which give rise to mesenchyme of the head and organize into somites in occipital and caudal segments. Somites give rise to the myotome (muscle tissue), sclerotome (cartilage and bone), and dermatome (dermis of the skin), which are all supporting tissues of the body. Signals for somite differentiation are derived from surrounding structures, including the notochord, neural tube, and epidermis. The notochord and floor plate of the neural tube secrete SHH, which induces the sclerotome.
- The dorsal midportion of the somite becomes dermis. Mesoderm also gives rise to the vascular system (i.e. the heart, arteries, veins, lymph vessels, and all blood and lymph cells). Furthermore, it gives rise to the urogenital system: kidneys, gonads, and their ducts (but not the bladder). Finally, the spleen and cortex of the suprarenal glands are mesodermal derivatives.
- The endodermal germ layer provides the epithelial lining of the gastrointestinal tract, respiratory tract, and urinary bladder. It also forms the parenchyma of the thyroid, parathyroids, liver, and pancreas. Finally, the epithelial lining of the tympanic cavity and auditory tube originates in the endodermal germ layer.
- Craniocaudal Patterning of the embryonic axis is controlled by homeobox genes.
- As a result of formation of organ systems and rapid growth of the central nervous system, the initial flat embryonic disc begins to lengthen and to form head and tail regions (folds) that cause the embryo to curve into the fetal position. The embryo also forms two lateral body wall folds that grow ventrally and close the ventral body wall. As a result of this growth and folding, the amnion is pulled ventrally and the embryo lies within the amniotic cavity. Connection with the yolc sac and placenta is maintained through the vitelline duct and umbilical cord, respectively.

TERMINOLOGY

Terminology	
Allantois	The fourth extraembryonic membrane that extends from the yolk sac into the connecting stalk (future umbilical cord), then shifts to the hindgut cloaca. With the yolk sac, it is the first source of embryonic blood cells in mammals. In egg-laying animals, it lines the inner surface of the egg for gas exchange.
Chorion	Extraembryonic membrane derived from the trophoblast of the blastocyst. The smooth chorion and amnion surround the fetus as its protective "bag." The villous chorion is the fetal component of the placenta
Chorionic plate	The chorionic membrane on the fetal surface of the placenta that gives rise to the stem villi. The umbilical vessels extend from the umbilical cord to the villi through the chorionic plate.
Corpus luteum	(L, "yellow body") The endocrine gland in the ovary that is formed from a follicle after release of the ovum at ovulation. It produces progesterone (and estrogen) to prepare the endometrium for pregnancy. If pregnancy does not occur, it degenerates into a corpus albicans ("white body") that eventually disappears
Cotyledons	(G., "a cup-shaped hollow") Irregulany shaped lobes visible on the maternal surface of the placenta circumscribed by deep clefts and decidual septa.
Cytotrophoblastic shell	The cellular plate that attaches the chorionic villi of the placenta to the decidua basalis of the endometrium. It is derived from cytotrophoblast cells that migrate through the external syntrophoblast layer at the maternal ends of anchoring villi.
Decidual reaction	Reaction of maternal connective tissue cells in the decidua basalis to implantation. They swell with glycogen and lipid and produce immunosuppressive molecules to prevent a maternal immune reaction to the conceptus-derived cytotrophoblastic shell of the placenta.
Ectopic	(G., "displaced") A general term for an organ or structure that ends up in an abnormal location. An ectopic pregnancy results from abnormal implantation sites (e.g. uterine rubes, abdominal cavity).
Epiblast	Columnar cells of the inner cell mass of the blastocyst that constitute the primary ectoderm.
Endometrium	(G., "inside of the uterus") The mucosa of the uterus consisting of simple columnar epithelium and very cellular, loose connective tissue with simple tubular glands. Also called decidua (L., "falling off') because much of the mucosa is shed during menstruation.

Terminology	
Exocoelomic cyst	The remnant of the primary yolk are (Heuser's membrane) that is displaced by a second wave of endodermal cell migration from the hypoblast that forms the definitive yolk sac.
Extraembryonic	The tissues and structures that arc outside the embryo. These mostly consist of the extra embryonic membranes: chorion, amnion, yolk sac, and allantois
Extraembryonic mesoderm	The mesoderm that appears between the primary yolk sac and cytotrophoblast then cavitates to line the old blastocyst cavity and complete extraembryonic membrane formation. Its origin is controversial. Various studies have it derived from the cytotrophoblast, yolk sac, or epiblast.
Fimbriae	(L, "fringe") Finger-like projections at the end of the uterine tubes that envelop the ovary at the time of ovulation and sweep the ovum into the ostium of the uterine tube
Follicle (ovarian)	An ovarian follicle is a fluid-filled, cellular envelope surrounding an ovum that enlarges and moves to the surface of the ovary in preparation for ovulation. It is supportive and nutritive for the egg and secretes hormones.
Gastrulation	The production of intraembryonic mesoderm in the third week that makes the bilaminar embryonic disc a trilaminar disc (gastrula)
Heuser's (exocoelomic) membrane	The primary yolk sac formed as endodermal cells migrate to line the inner surface of the cytotrophoblast with a layer of simple squamous epithelium
Hypoblast	Simple cuboidal epithelium of the inner cell mass of the blastocyst that constitutes the primary endoderm. It is displaced by a second wave of migration of hypoblast cells that form the definitive yolk sac coated with extraembryonic mesoderm.
Intermediate mesoderm	Primitive streak mesoderm in the gastrula that gives rise to the gonads, kidneys, and tubules and ducts of the urogenital system. It is "intermediate" between the paraxial columns and lateral plate mesoderm
Lithopedion	(G., "stone 1 child") A dead fetus that has become calcified or hard.
Mesoderm	(G., "middle skin") The inner tissue of the gastrula between the ectoderm and endoderm. It differentiates into two forms: mesenchyme (loose embryonic connective tissue) and the very cellular mesodennal columns (notochord, paraxial columns, intermediate mesoderm, and lateral plate). Extraembryonic mesoderm is the middle layer between the trophoblast and amnion/yolk sac.
Morula	(L., "little mulberry") A product of conception, a morula is the ball of cells 3 to 4 days after fertilization that is ready to enter the uterine cavity
Neurenteric canal	Temporary communication of the amniotic cavity with the yolk sac cavity associated with the development of the notochord.
Notochord	Midline mesoderm originating during gastrulation from the ectodermal primitive knot (node). It induces neurulation, and its only structural derivative is the nucleus pulposus us of an intervertebral disc.
Notochordal canal	The hollow center that develops in the notochordal process. It communicates with the amniotic cavity via the primitive pit in the primitive knot (node).
Notochordal plate	Mesoderm of the notochord that remains after the notochordal canal breaks open into the yolk sac cavity along its entire length to form the neurenteric canal between the amniotic and yolk sac cavities. As a result, the embryonic endoderm flanks the notochordal plate until the latter infolds to form the notochord proper that is again a solid column of mesoderm within the gastrula
Notochordal process	The ininitially solid column of mesoderm originating from the primitive knot (node).
Oropharyngeal membrane	Also called the oral membrane, it is a circular area at the head end of the gastrula where the ectoderm and endoderm remain in tight contact with no intervening mesoderm. It ends up at the junction of the oral cavity and pharynx, where it breaks down. Its equivalent at the tail end of the embryo is the cloacal membrane.
Prechordal plate	Endodermal cells of the future oropharyngeal membrane at the cranial end of the bilaminar disc. It limits the cranial extension of the notochordal process mesoderm during gastrulation.
Villi (placental)	Finger-like projections of the chorion that are the structural and functional units of the placenta. Most are free villi bathed in maternal blood. They originate from large stem villi on the fetal side of the placenta. Anchoring villi extend from the stem villi to the cytotrophoblastic shell that attaches to the decidua basalis.

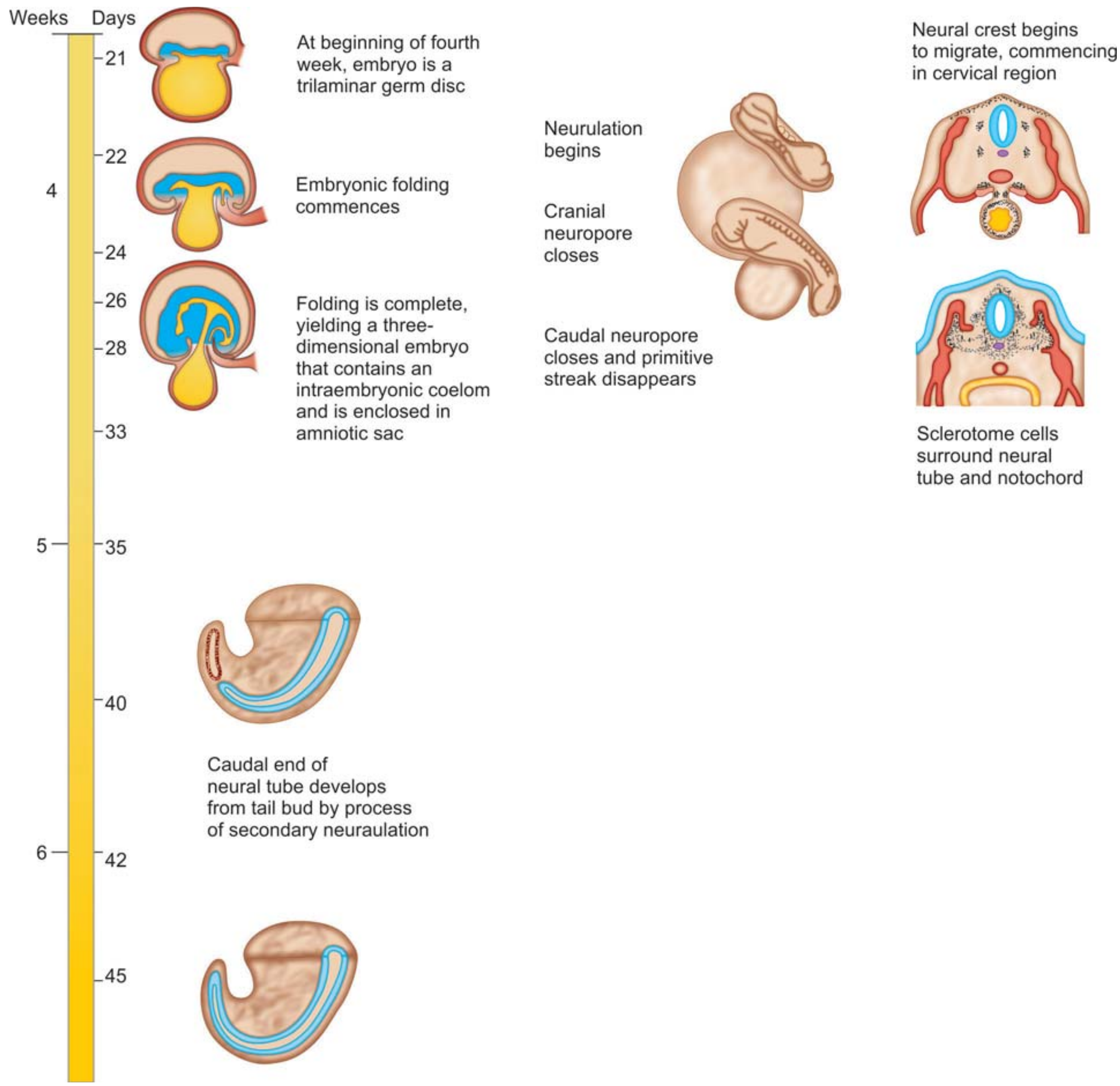


Fig. 52: Fourth week development

PLACENTA, FETAL MEMBRANES AND UMBILICAL CORD

The fetal period extends from the ninth week of gestation until birth and is characterized by rapid growth of the body and maturation of organ systems. Growth in length is particularly striking during the third, fourth, and fifth months (approximately 5 cm per month), whereas increase in weight is most striking during the last 2 months of gestation (approximately 700 g per month). Most babies weigh between 2,700 and 4,000 g (6 to 9 Ib) at birth. Those babies weighing <2,500 g (5 Ib 8 oz) are considered low birth weight; those below 1,500 g (3 Ib 5 oz) are considered very low birth weight. lUGR is a term applied to babies who do not achieve their genetically determined potential size and are pathologically small. This group is distinct from babies that are healthy but are below the 10th percentile in weight for their gestational age and are classified as SGA.

A striking change is the relative slowdown in the growth of the head. In the third month, it is about half the size of the CRL. By the fifth month, the size of the head is about one third of the CHL, and at birth, it is one quarter of the CHL.

During the fifth month, fetal movements are clearly recognized by the mother, and the fetus is covered with fine, small hair.

A fetus born during the sixth or the beginning of the seventh month has difficulty surviving, mainly because the respiratory and central nervous systems have not differentiated sufficiently.

- In general, the length of pregnancy for a full term fetus is considered to be 280 days, or 40 weeks after onset of the last menstruation, or, more accurately, 266 days or 38 weeks after fertilization.

- The placenta consists of two components: (1) a fetal portion, derived from the chorion frondosum or villous chorion, and (2) a maternal portion, derived from the decidua basalis. The space between the chorionic and decidual plates is filled with intervillous lakes of maternal blood. Villous trees (fetal tissue) grow into the maternal blood lakes and are bathed in them. The fetal circulation is at all times separated from the maternal circulation by:
- A syncytial membrane (a chorion derivative) and
- Endothelial cells from fetal capillaries. Hence, the human placenta is of the hemochorial type.
- Intervillous lakes of the full grown placenta contain approximately 150 mL of maternal blood, which is renewed three or four times per minute. The villous area varies from 4 to 14 ml, facilitating exchange between mother and child.
- Main functions of the placenta are (1) exchange of gases; (2) exchange of nutrients and electrolytes; (3) transmission of maternal antibodies, providing the fetus with passive immunity; (4) production of hormones, such as progesterone, estradiol, and estrogen (in addition, it produces hCG and somatomammotropin); and (5) detoxification of some drugs.
- The amnion is a large sac containing amniotic fluid in which the fetus is suspended by its umbilical cord. The fluid (1) absorbs jolts, (2) allows for fetal movements, and (3) prevents adherence of the embryo to surrounding tissues. The fetus swallows amniotic fluid, which is absorbed through its gut and cleared by the placenta. The fetus adds urine to the amniotic fluid, but this is mostly water. An excessive amount of amniotic fluid (hydramnios) is associated with anencephaly and esophageal atresia, whereas an insufficient amount (oligohydramnios) is related to renal agenesis.
- The umbilical cord, surrounded by the amnion, contains (1) two umbilical arteries, (2) one umbilical vein, and (3) Wharton jelly, which serves as a protective cushion for the vessels.
- Fetal membranes in twins vary according to their origin and time of formation. Two thirds of twins are dizygotic, or fraternal; they have two amnions, two chorions, and two placentas, which sometimes are fused. Monozygotic twins usually have two amnions, one chorion, and one placenta. In cases of conjoined twins, in which the fetuses are not entirely split from each other, there is one amnion, one chorion, and one placenta.
- Signals initiating parturition (birth) are not clear, but preparation for labor usually begins between 34 and 38 weeks. Labor itself consists of three stages: (1) effacement and dilatation of the cervix, (2) delivery of the fetus, and (3) delivery of the placenta and fetal membranes.

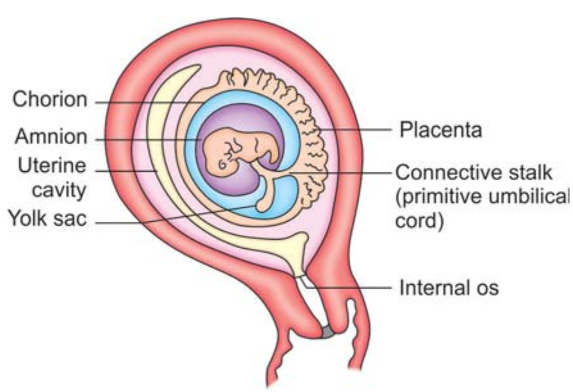


Fig. 53: Fetal membranes

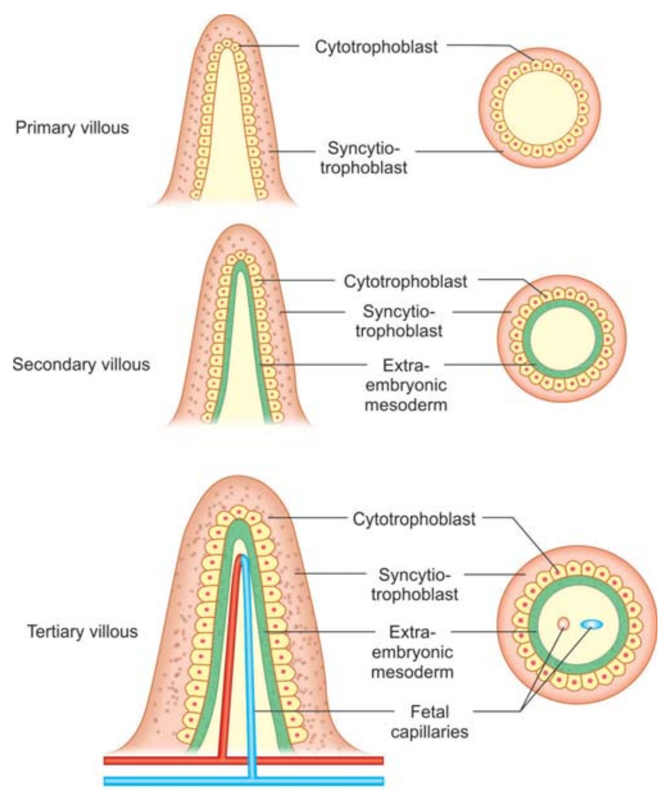
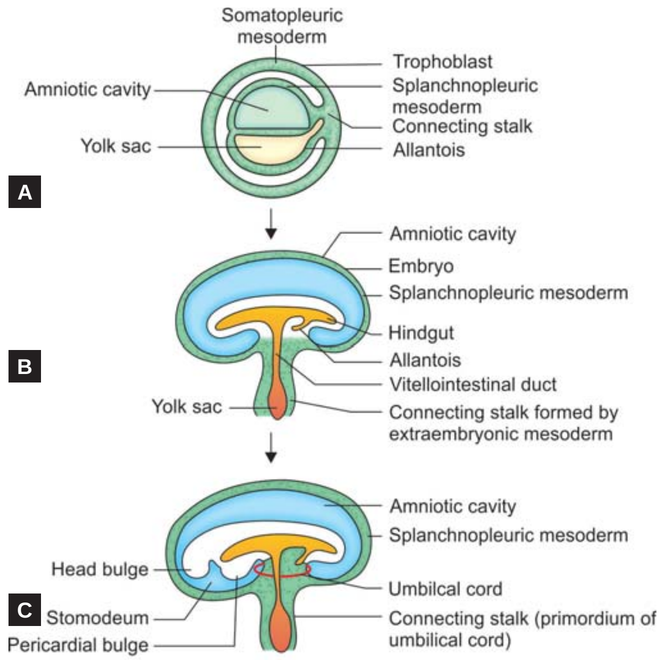
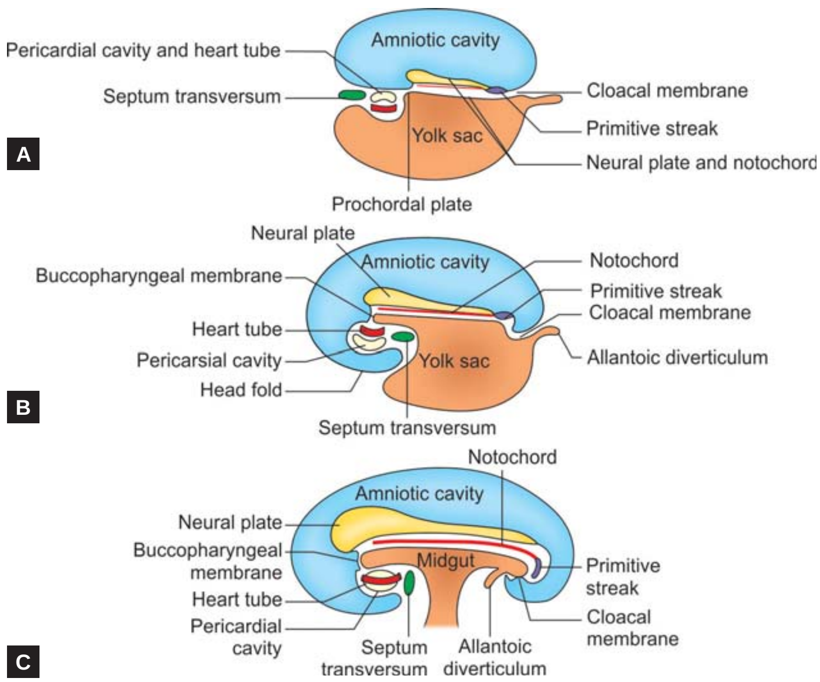


Fig. 54: Three stages of development of villi. Figures on the right side are the sectional views of three types of villi



Figs. 55A to C: Folding of the embryo and formation of the umbilical cord



Figs. 56A and C: Arrangement of structures of embryo before and after the formation of head and tail folds as seen in longitudinal sections. A. Embryonic disc with its important components. B. Embryonic disc after formation of head fold. Note the heart tube comes to lie on the roof of the pericardia! cavity and septum transversum becomes caudal to the pericardial cavity. C. Note the changed relations septum transversum, pericardial cavity, heart tube, and cloacal membrane

Table 12: Arrangement of important structures of embryo before and after the folding in craniocaudal direction

Before folding of embryo	After folding of embryo
• Septum transversum lies cranial to the pericardial cavity and heart tube	• Septum transversum lies caudal to the pericardia[cavity and heart tube
• Heart tube lies below the pericardial cavity	• Heart tube lies above the pericardial cavity (i.e., heart tube jumps from the floor of the pericardial cavity to its roof)
• Prochordal plate	• Prochordal plate forms buccopharyngeal membrane/oral membrane

Before folding of embryo	After folding of embryo
• Cranial part of the neural plate lies above and behind the primitive buccopharyngeal membrane	• Cranial part of the neural plate lies above and in front of buccopharyngeal membrane/oral membrane, and forms the most cranial structure of the embryo
• Yolk sac lies below the embryo	• Most of yolk sac is taken up with the embryo to form primitive gut
• Connecting stalk is attached at the caudal aspect of the embryo	• Connecting stalk is attached on the ventral aspect of the embryo
• Allantois is directed caudally	• Allantois is directed ventrally

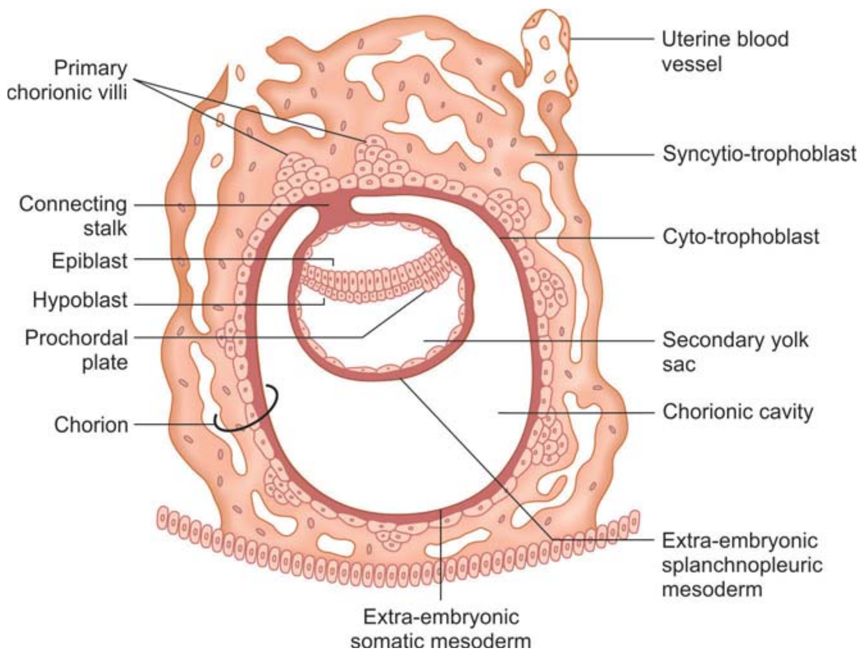


Fig. 57: Development of connecting stalk and primary villi

Connecting stalk is the mesodermal connection that connects the embryo to the placenta.

- It contains the allantois and umbilical vessels and will be incorporated into the umbilical cord with the yolk sac (vitelline) stalk (duct).

Cotyledons are the compartments (15 to 20) in the placenta formed when decidual septa grow into the intervillous spaces.

- These septa never reach the chorionic plate so that there is communication between cotyledons.

High Yield Points

- **Amniochorionic membrane** is formed when expansion of the amniotic cavity obliterates the chorionic cavity causing the amnion to contact the chorion and the two to fuse. It serves as a hydrostatic wedge during the initiation of labor.
- **Chorionic cavity** is the space formed between the extraembryonic mesoderm lining the cytotrophoblast (somatic extraembryonic mesoderm) and that surrounding the yolk sac and embryo (splanchnic extraembryonic mesoderm).
- The chorionic cavity will eventually be obliterated by expansion of the amniotic cavity and fusion of the amnion with the chorion.

PLACENTA

Placenta is formed when the embryo invades the endometrium of the uterus and when the trophoblast forms the villous chorion.

- Villous chorion formation goes through three stages: primary chorionic villi, secondary chorionic villi, and tertiary chorionic villi.

Components

Maternal component of the placenta consists of:

- Decidua basalis, which is derived from the endometrium of the uterus located between the blastocyst and the myometrium.
- Decidua basalis and decidua parietalis (which includes all portions of the endometrium other than the site of implantation) are shed as part of the after birth.
- Decidua capsularis, the portion of endometrium that covers the blastocyst and separates it from the uterine cavity, becomes attenuated and degenerates at week 22 of development because of a reduced blood supply.
- Maternal surface of the placenta is characterized by 8–10 compartments called cotyledons (imparting a cobblestone appearance), which are separated by decidual (placental) septa.

Fetal component of the placenta consists of:

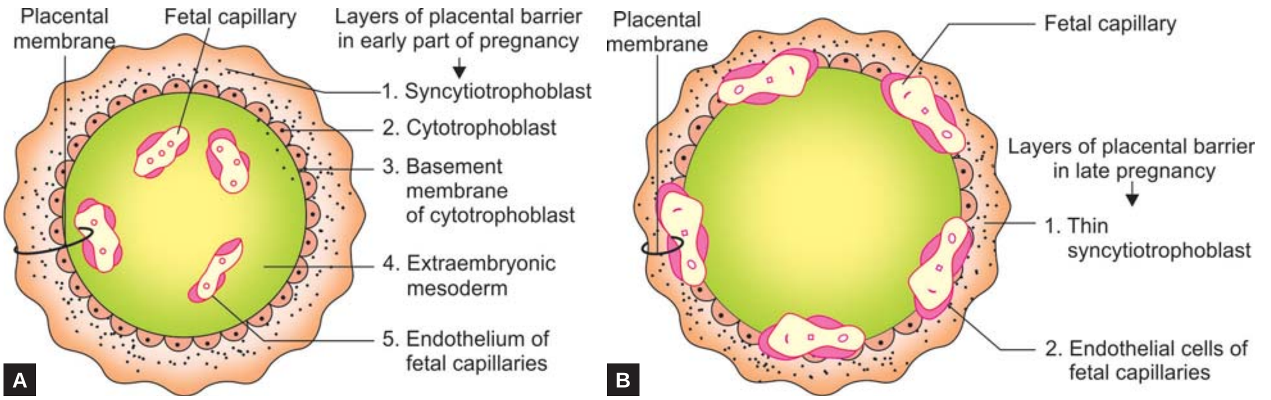
- Tertiary chorionic villi derived from both the trophoblast and extraembryonic mesoderm, which collectively become known as the villous chorion.
- Villous chorion develops most prolifically at the site of the decidua basalis.
- It is in contrast to an area of no villus development known as the smooth chorion (which is related to the decidua capsularis).
- Fetal surface of the placenta is characterized by the well-vascularized chorionic plate containing the chorionic (fetal) blood vessels.
- Fetal surface has a smooth, shiny, light-blue or blue-pink appearance (because the amnion covers the fetal surface), and 5–8 large chorionic (fetal) blood vessels should be apparent.

Placental membrane

In early pregnancy, the placental membrane consists of the syncytiotrophoblast, cytotrophoblast (Langerhans cells), connective tissue, and endothelium of the fetal capillaries.

- Hofbauer cells are found in the connective tissue and are most likely macrophages.

In late pregnancy, the cytotrophoblast degenerates, and the connective tissue is displaced by the growth of fetal capillaries, leaving the syncytiotrophoblast and the fetal capillary endothelium. Placental membrane separates maternal blood from fetal blood.



Figs. 58A and B: Placental membrane (barrier). A. In early pregnancy. B. In late pregnancy

UMBILICAL CORD

- A patent opening called the primitive umbilical ring exists on the ventral surface of the developing embryo through which three structures pass: the yolk sac (vitelline duct), connecting stalk, and allantois. The allantois is not functional in humans and degenerates to form the median umbilical ligament in the adult.
- As the amnion expands, it pushes the vitelline duct, connecting stalk, and allantois together to form the primitive umbilical cord.
- The definitive umbilical cord at term is pearl-white, 1–2 cm in diameter, 50–60 cm long, eccentrically positioned, and contains the right and left umbilical arteries, left umbilical vein, and mucus connective tissue (Wharton's jelly).
- The right and left umbilical arteries carry deoxygenated blood from the fetus to the placenta. The left umbilical vein carries oxygenated blood from the placenta to the fetus.

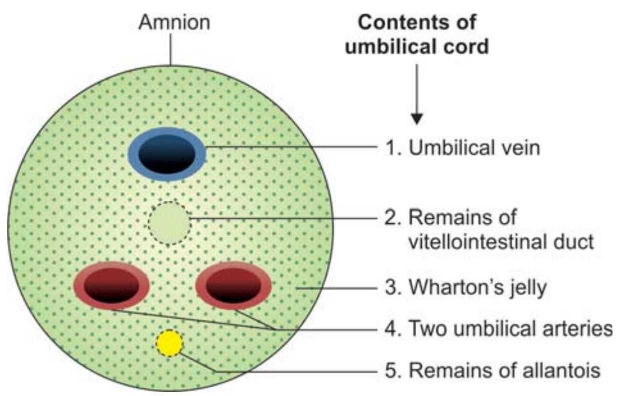


Fig. 59: Cross-section of the umbilical cord

ASSESSMENT QUESTIONS

1. Fetoplacental circulation begins at day:
a. 12 b. 17
c. 22 d. 30

2. Tertiary villi develop by the end of week:
a. 1 b. 2
c. 3 d. 4

3. Placenta develops from: *(CET June 14 Pattern)*
a. Decidua capsularis and Chorion frondosum
b. Decidua capsularis and Decidua basalis
c. Decidua basalis and Chorion frondosum
d. Decidua parietalis and Chorion frondosum

4. Amnion is present on: *(AI 97)*
a. Decidua basalis
b. Fetal surface
c. Maternal surface
d. All of the above

5. Which of the following disappear in umbilical cord? *(AIIMS 92)*
a. Left artery
b. left vein
c. Right artery
d. Right vein

6. Which of the following is true regarding vessels in the umbilical cord? *(NEET Dec. 12 Pattern, AIIMS 2k)*
a. Two arteries and two vein
b. one arteries and one vein
c. Two arteries and the left vein
d. Two vein and the left artery

7. True about umbilical cord? *(CET July 15 Pattern)*
a. Contains two umbilical veins
b. Contains one umbilical artery
c. Right umbilical vein disappears
d. Length is 25-30 cm

8. Cytotrophoblasts invades: *(NEET Dec. 12 Pattern)*
a. Decidua parietalis
b. Decidua basalis
c. Decidua capularis
d. None

9. Transverse anastomosis of two umbilical arteries is known as *(CET Nov. 15 Pattern)*
a. Funis
b. Hoboner
c. Hanis
d. Hyrtl's

ANSWERS WITH EXPLANATIONS

1. b. 17
- Fetoplacental circulation is established at day 17-22 (week 3).
- Uteroplacental circulation is established at day 12 (week 2)
- During week 2 of development, the embryoblast receives its nutrients from endometrial blood vessels, endometrial glands, and decidual cells via diffusion.
- Diffusion of nutrients does not pose a problem, given the small size of the blastocyst during week 2.
- Although the beginnings of a uteroplacental circulation are established during week 2, no blood vessels have yet formed in the extraembryonic mesoderm to carry nutrients directly to the embryoblast (this occurs in week 3).

2. c. 3
- Primary villus: Syncytiotrophoblast with a cytotrophoblast core.
- Secondary villus: Cytotrophoblast core invaded by extraembryonic mesoderm.
- Tertiary villus: Fetal blood vessels invade the mesoderm (week 3).

3. c. Dedicus basalis and Chorion frondosum
- Placenta develops from decidus basalis (maternal component) and chorion frondosum (fetal component).

4. b. Fetal surface
- Amnion is the inner most layer facing fetus

5. c. Right artery
- Right umbilical artery regresses (Right umbilical artery regresses) and left is left.

6. c. Two arteries and the left vein

7. c. Right umbilical vein disappears

8. b Decidua basalis
- Blastocyst in the endometrial stroma has trophoblast, which differentiates into- Cytotrophoblast and Syncytiotrophoblast.
- Synctiotrophoblast invades uterine epithelial cells and cytotrophoblast invades decidua basalis after passing through overlying syncytiocytotrophoblast.

9. d. Hyrtl's
- Two umbilical arteries are connected by a transverse anastomosis called Hyrtl's anastomosis, close to insertion of the cord on the placenta.

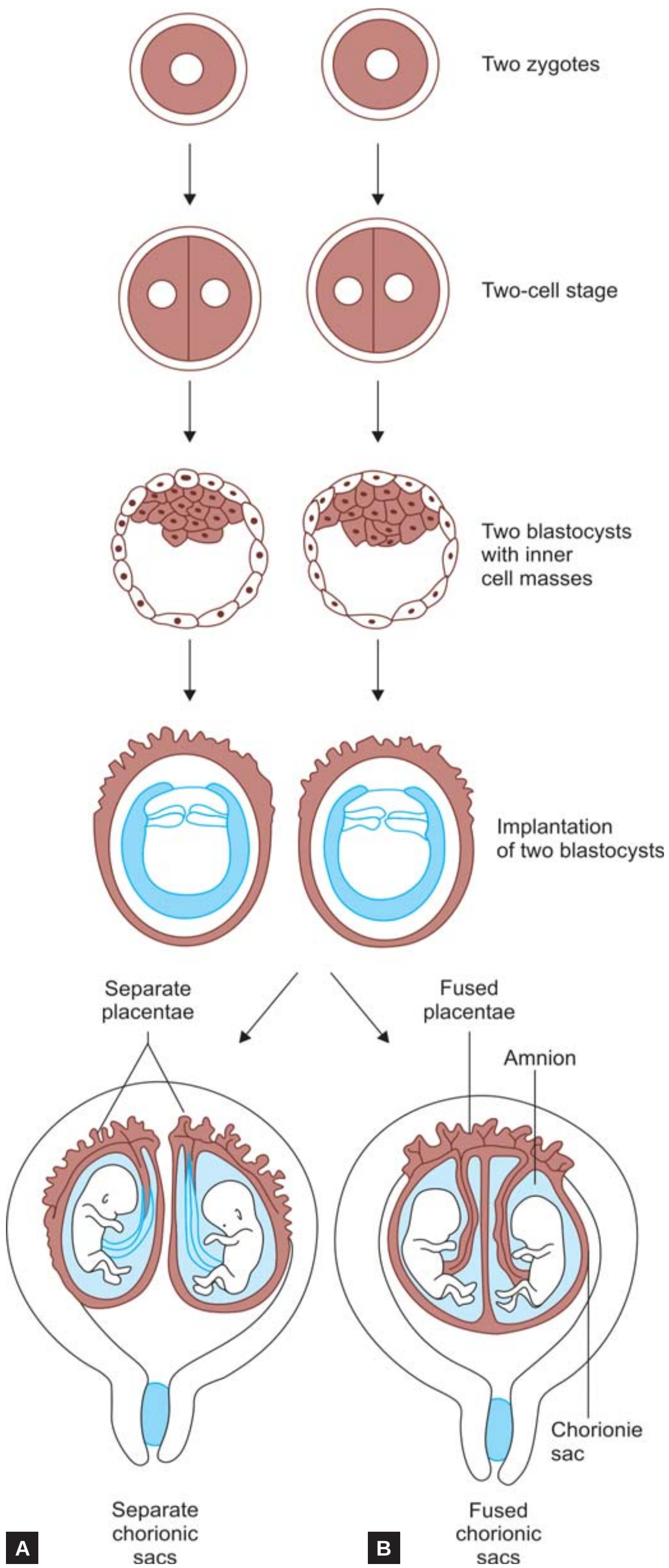
TWINS

- Twins are two offspring produced by the same pregnancy, can be either monozygotic (develop from one zygote, which splits to forms two embryos), or dizygotic (develop from two different eggs).
- Dizygotic (fraternal) twins are more common and result when two eggs are independently fertilized by two different sperms and are implanted in the uterus wall at the same time.
- The two eggs, or ova, form two zygotes, hence the terms dizygotic and biovular.
- Monozygotic (identical twins) occur when a single egg is fertilized to form one zygote (hence, "monozygotic") which then divides into two separate embryos.

Table 13: Differences between monozygotic and dizygotic twins

Monozygotic twins	Dizygotic twins
• Form from single zygote	Form from two zygotes
• Incidence is more common	Incidence is less common
• Genetically identical	Genetically not identical
• Twins are of the same sex	Twins are of the same sex or of different sex

Monozygotic twins	Dizygotic twins
• Resemblance is similar	Resemblance is just like any other two siblings
• Mostly diamniotic, monochorionic, with single placenta	Mostly have two amnions, two chorions, and two placentas
• Are often called conjoined twins	Not seen as conjoined twins



Figs. 60A and B: Dizygotic twins

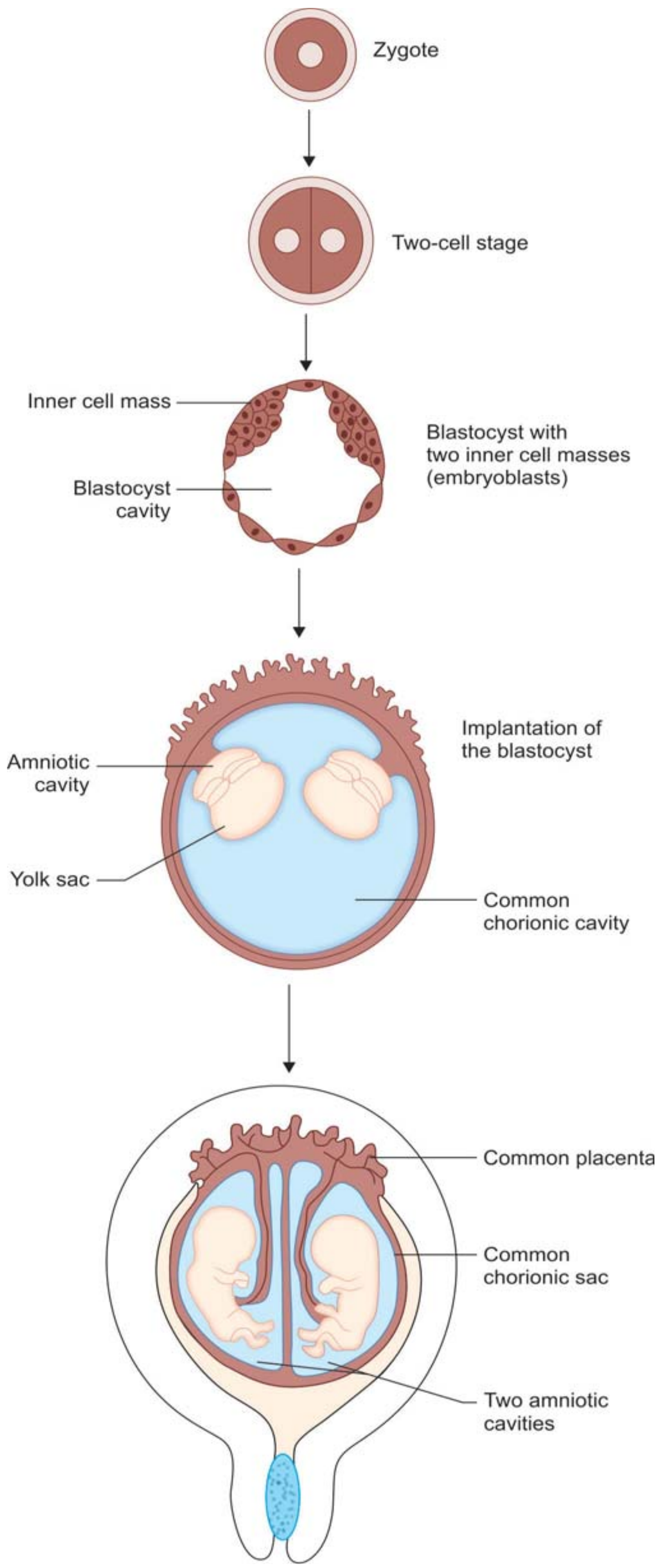


Fig. 61: Monozygotic twins

CARDIOVASCULAR SYSTEM

Refer

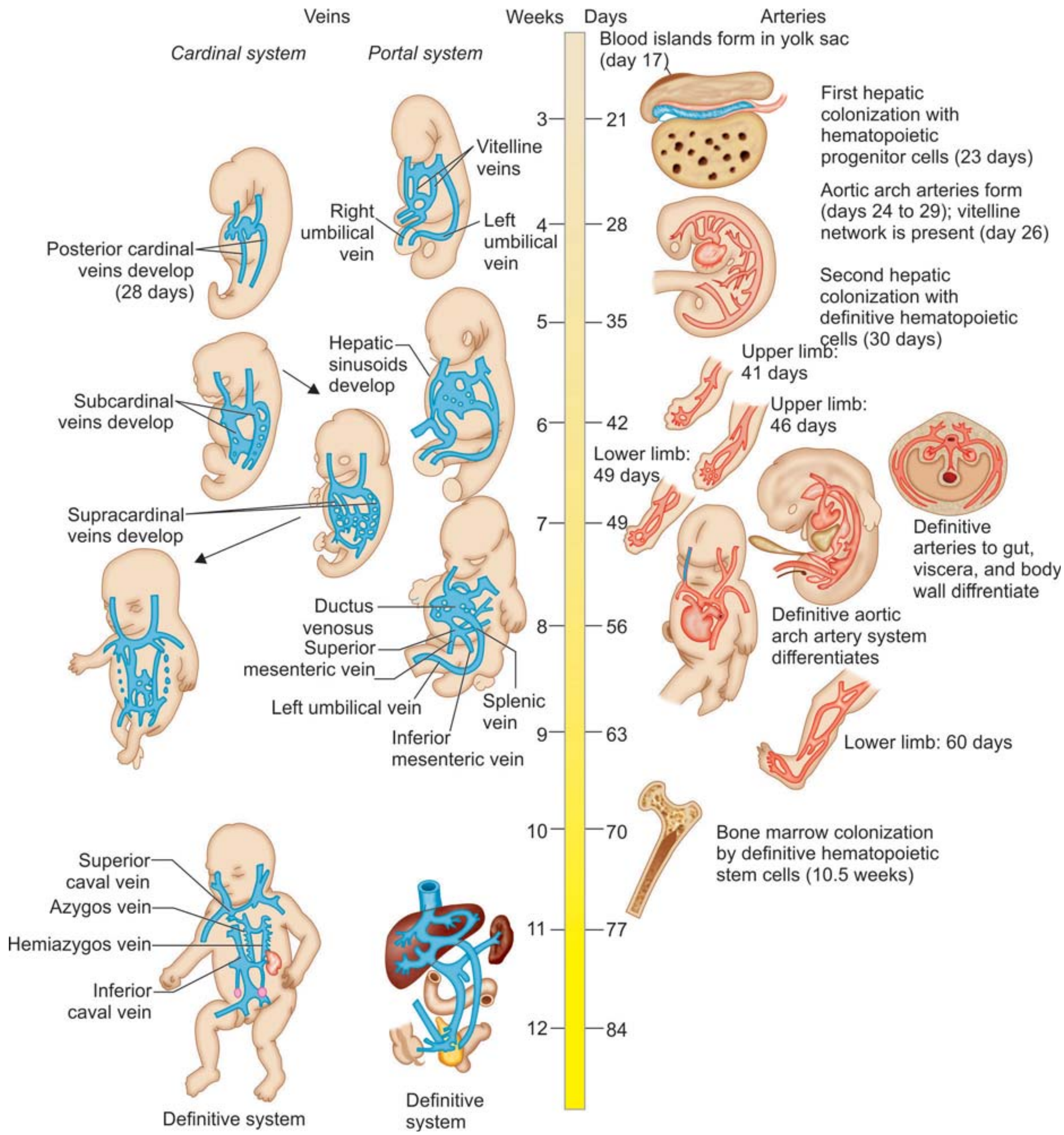


Fig. 62: Development of the arterial and venous systems

ARTERIES

The arterial system develops from the **aortic arches** and branches of the **dorsal aorta**.

Aortic arch branch from the aortic sac to the dorsal aorta traveling in the center of each pharyngeal arch.

- Initially, there are five pairs, but these undergo considerable remodelling to form definitive vascular Patterns for the head and neck, aorta, and pulmonary circulation.
- In the rest of the body, the arterial Patterns develop mainly from the right and left dorsal aortae.
- The right and left dorsal aortae fuse to form the dorsal aorta, which then sprouts posterolateral arteries, lateral arteries, and ventral arteries (vitelline and umbilical).

Aortic arch derivatives

Dorsal aorta

Aortic arch artery	Adult derivative
1.	Maxillary artery (portion of)
2.	Stapedial and hyoid arteries (portion of)
3.	Right and left common carotid artery (portion of) Right and left internal carotid artery (portion of)
4.	Right side: Proximal part of right subclavian artery Left side: Arch of aorta (portion of)
5.	Regresses
6.	Right and left pulmonary arteries (portion of) Ductus arteriosus**

*External carotid artery is a de-novo branch: **Right regresses; left is left.

- Early in development, the recurrent laryngeal nerves hook around aortic arch 6. Later on the right side, the distal part of aortic arch 6 regresses, and the right recurrent laryngeal nerve moves up to hook around the right subclavian artery. On the left side, aortic arch 6 persists as the ductus arteriosus (or ligamentum arteriosus in the adult); the left recurrent laryngeal nerve remains hooked around the ductus arteriosus.

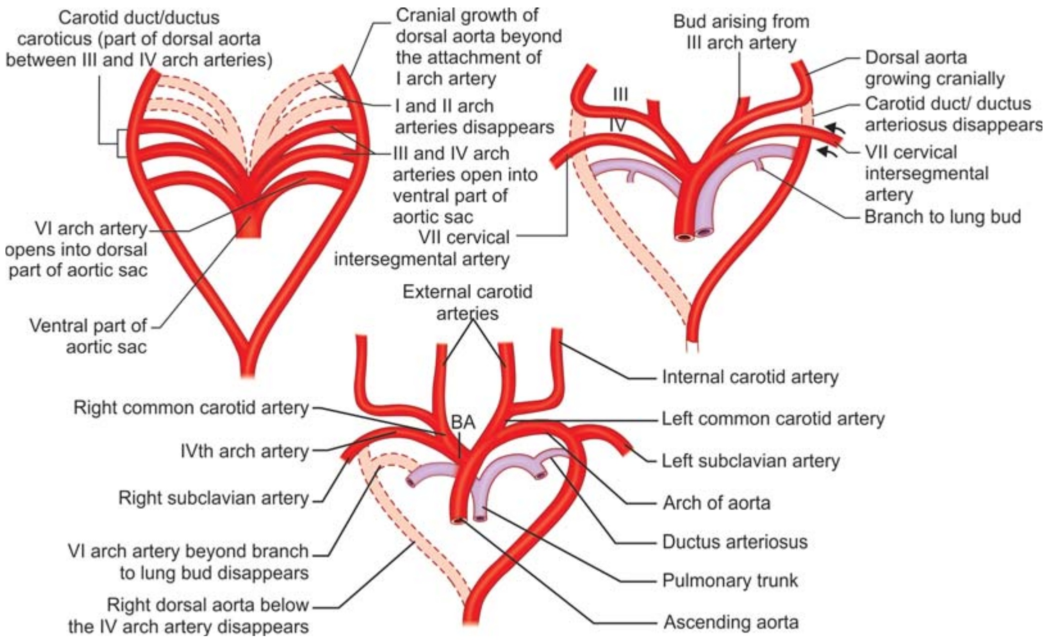


Fig. 63: Development of pharyngeal arch arteries into the adult stage arteries

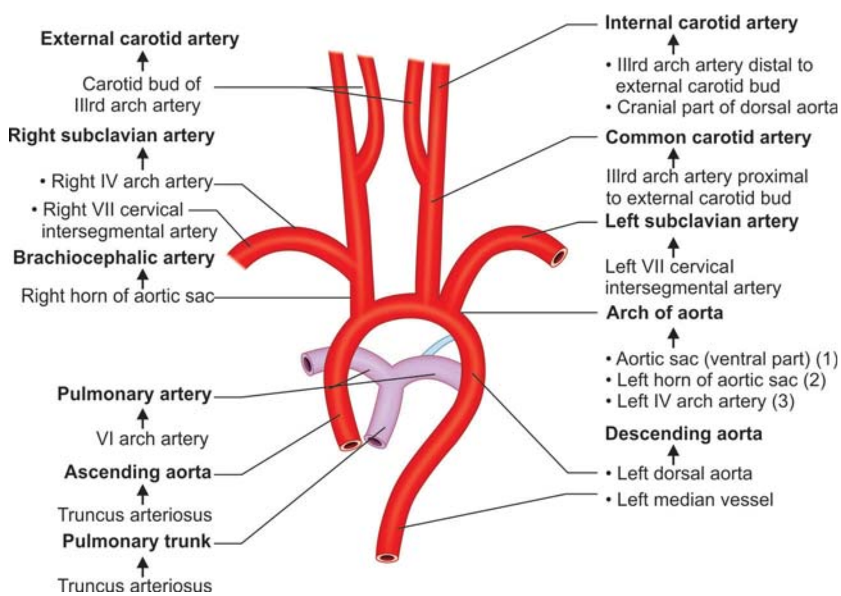
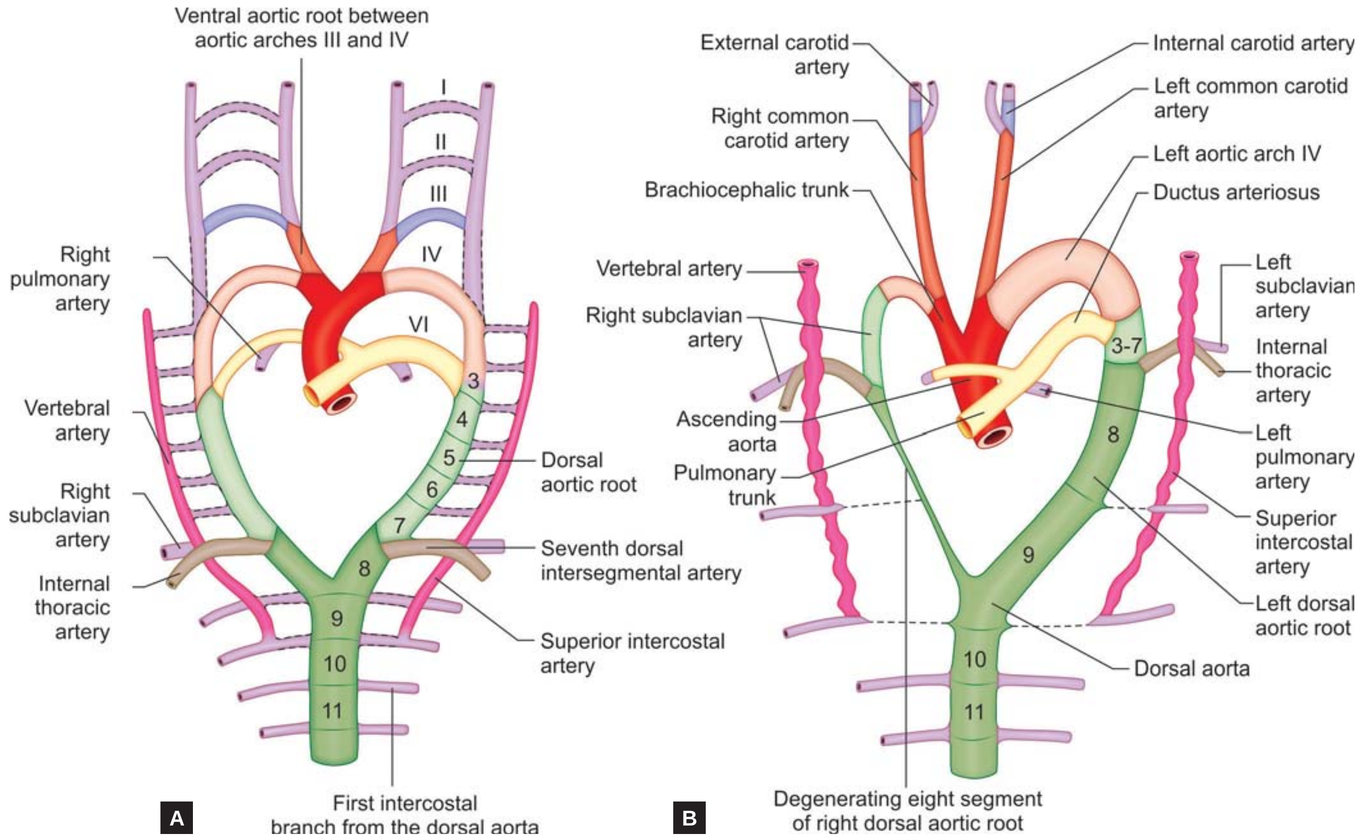


Fig. 64: Development of pharyngeal arch arteries into the adult stage arteries



Figs. 65A and B: Aortic arch arteries and their derivatives

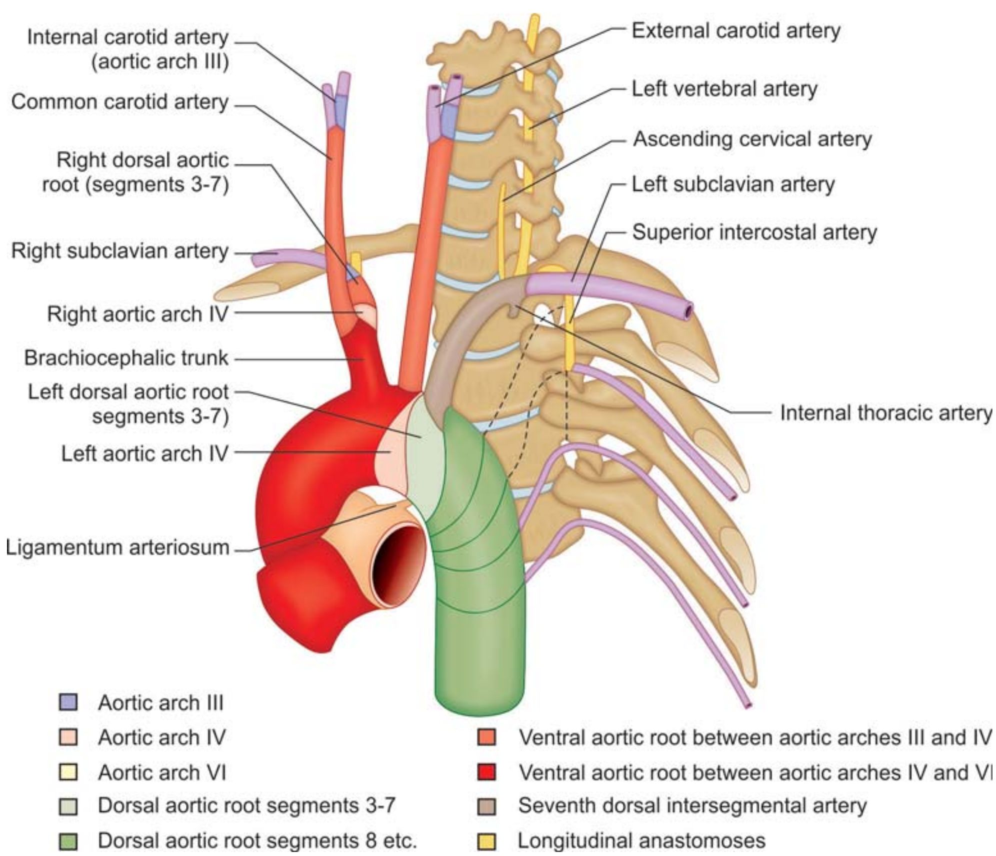


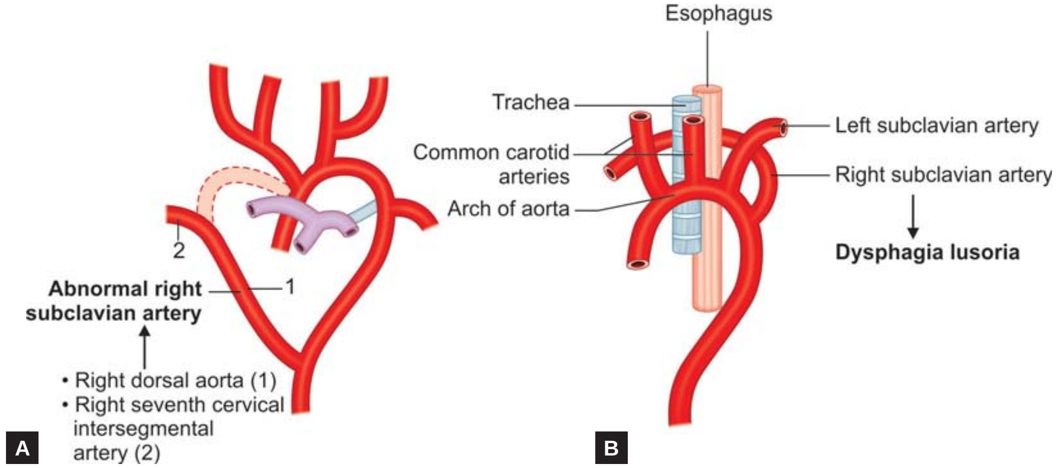
Fig. 66: Aortic arch arteries and their derivatives

Table 14: Source of development of main arteries	
Arteries	**Source of development**
Arch of aorta	(a) Aortic sac (ventral part), (b) left horn of aortic sac, and (c) left fourth arch artery
Brachiocephalic artery	Right horn of aortic sac
Right subclavian artery	(a) Proximal part from right fourth arch artery and (b) distal part from right seventh cervical intersegmental artery
Left subclavian artery	Left seventh cervical intersegmental artery
Common carotid artery	Third arch artery proximal to the external carotid artery bud
Internal carotid artery	Third arch artery distal to the external carotid bud and cranial part of dorsal aorta distal to the attachment of third arch artery
External carotid artery	Bud from third arch artery
Pulmonary arteries	Part of the sixth arch artery between pulmonary trunk and branch to lung bud on each side
Descending aorta	(a) Proximal part from left dorsal aorta distal to attachment of fourth arch artery and (b) distal part from fused dorsal aortae forming single median artery

* Arch of aorta also gets contributions from left dorsal aorta (between the attachment of the fourth aortic arch (artery) and 7th cervical intersegmental artery

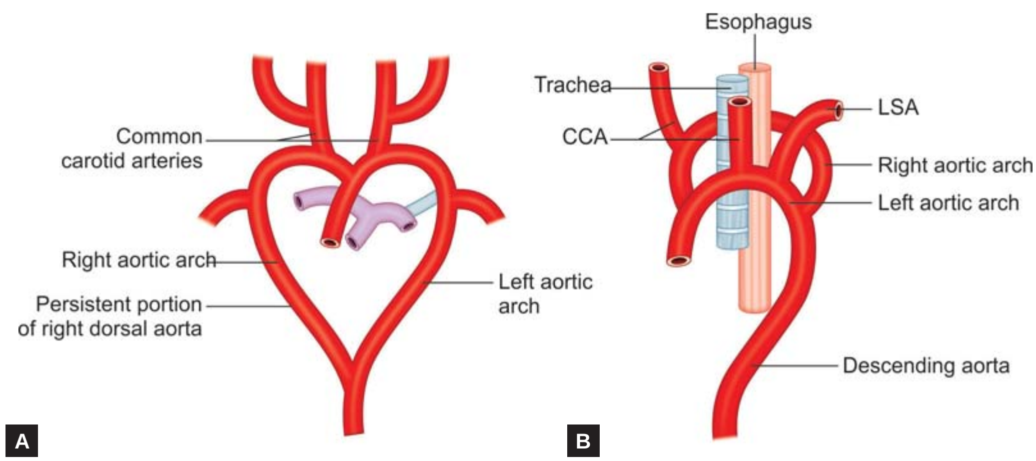
APPLIED ANATOMY

- Abnormal origin of the right subclavian artery. It happens due to disappearance of Right fourth aortic arch and proximal portion of right dorsal aorta. In this case the right subclavian artery is formed by distal portion of right dorsal aorta and right intersegmental subclavian artery (A). Abnormal subclavian artery crosses the midline behind esophagus and trachea creating a vascular ring around them (B).



Figs. 67A and B: Formation of abnormal subclavian artery

- Double aortic arch results due to abnormal persistence of distal portion of right dorsal aorta (A). It leads to formation of double aortic arch, which forms vascular ring around trachea and esophagus and may cause compression.



Figs. 68A and B: Formation of right aortic arch leading to double aortic arch

Derivatives of dorsal aorta

Embryonic artery	Adult derivative
Posterolateral (somatic intersegmental) branches	Arteries of upper and lower limbs Intercostal, lumbar and lateral sacral arteries
Lateral splanchnic arteries	Phrenic arteries Renal and suprarenal arteries Gonadal arteries
Ventral splanchnic arteries (a) Vitelline arteries (b) Umbilical arteries	 (a) Coeliac, superior mesenteric and inferior mesenteric arteries (b) Internal iliac arteries (portion of), superior vesical arteries, medial umbilical ligaments

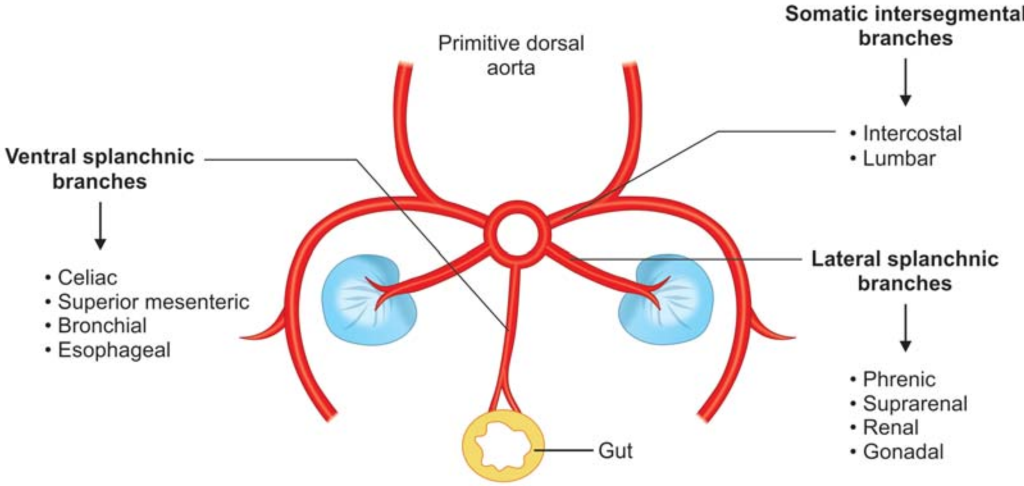


Fig. 69: Main branches of embryonic dorsal aorta

ASSESSMENT QUESTIONS

1. **Which does not take part in formation of right subclavian artery?** *(NEET Pattern 2015)*
   a. 2nd arch artery
   b. 4th arch artery
   c. 7th arch artery
   d. All three

2. **Artery of 2nd pharyngeal arch is:** *(NEET Pattern 2012)*
   a. Maxillary artery
   b. Stapedial artery
   c. Subclavian artery
   d. Common carotid artery

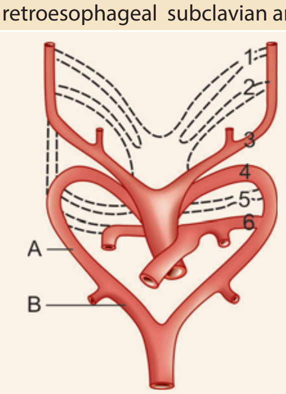
3. **Artery of 3rd arch?** *(NEET Pattern 2015)*
   a. Maxillary
   b. Stapedial
   c. Common carotid
   d. Pulmonary

4. **Right fourth arch artery gives rise to:** *(NEET Pattern 2014)*
   a. Right subclavian artery
   b. Common carotid artery
   c. Internal carotid artery
   d. External carotid artery

5. **Double aortic arch occurs due to:** *(NEET Pattern 2012)*
   a. Nondevelopment of right 4th aortic arch
   b. Nondevelopment of left 4th aortic arch
   c. Nondivision of truncus arteriosus
   d. Persistent distal portion of right dorsal aorta

6. **The commonest variation in the arteries arising from the arch of aorta is:** *(AIPG 2003)*
   a. Absence of brachiocephalic trunk
   b. Left vertebral artery arising from the arch
   c. Left common carotid artery arising from brachiocephalic trunk
   d. Presence of retroesophageal subclavian artery

7. **Aberrant subclavian artery formed due to:** *(AIIMS 2016)*
   a. Persistent A
   b. Persistent B
   c. Persistent A and obliterated B
   d. Obliterated A and persistent B



ANSWERS WITH EXPLANATIONS

1. **b. 4th arch artery**
   - Right subclavian artery is contributed by (proximal to distal): Right fourth arch artery, right dorsal aorta and right seventh cervical intersegmental artery.
2. **b. Stapedial artery**
   - A portion of stapedial artery develops in second pharyngeal arch.
3. **c. Common carotid**
   - Third arch artery forms portions of common carotid artery and internal carotid artery, on each side.
4. **a. Right subclavian artery**
   - Right fourth arch artery contributes to a component of the right subclavian artery.
   - Left fourth arch artery contributes to a component of arch of aorta.
5. **d. Persistent distal portion of right dorsal aorta**
   - Double aortic arch occurs when an abnormal right aortic arch develops in addition to a left aortic arch due to persistence of the distal portion of the right dorsal aorta.
   - This forms a vascular ring around the trachea and esophagus, which may cause difficulties in breathing and swallowing.
6. **c. Left common carotid artery arising from brachiocephalic trunk**
   - Left common carotid artery is a branch of arch of aorta but it may arise from brachiocephalic trunk (30% population).
7. **d. Obliterated A and persistent B**
   - Aberrant subclavian artery: Right fourth aortic arch and proximal portion of right dorsal aorta ('A') disappears and distal portion of right dorsal aorta ('B') persists. In this case, the right subclavian artery is formed by distal portion of right dorsal aorta ('B') and right seventh intersegmental artery.
   - Since this abnormal artery crosses the midline behind esophagus and trachea, a vascular ring is formed by right subclavian artery and aortic arch, which may compress the two visceral tubes.
   - Normally, right subclavian artery is contributed by (proximal to distal): Right fourth arch artery, right dorsal aorta and right seventh cervical intersegmental artery.

VEINS

The venous system develops from the vitelline, umbilical, and cardinal veins, which drain into the sinus venosus.

A. Vitelline Veins

- Return poorly oxygenated blood from the yolk sac.
- Right vein forms the hepatic veins and sinusoids, ductus venosus, hepatic portal, superior mesenteric, inferior mesenteric, and splenic veins and part of the IVC.
- Left vein forms the hepatic veins and sinusoids and ductus venosus.

B. Umbilical Veins

- Carry welloxygenated blood from the placenta.
- Right vein degenerates during early development.
- Left vein forms the ligamentum teres hepatis.

Cardinal Veins

- Return poorly oxygenated blood from the body of the embryo.
- Anterior cardinal vein forms the internal jugular veins and SVC.
- Posterior cardinal vein forms a part of the IVC and common iliac veins.
- Subcardinal vein forms a part of the IVC, renal veins, and gonadal veins.
- Supracardinal vein forms a part of the IVC, intercostal, azygos, and hemiazygos veins.

Venous System. Three systems can be recognized: (1) the vitelline system, which develops into the portal system; (2) the cardinal system, which forms the caval system; and (3) the umbilical system, which degenerates after birth.

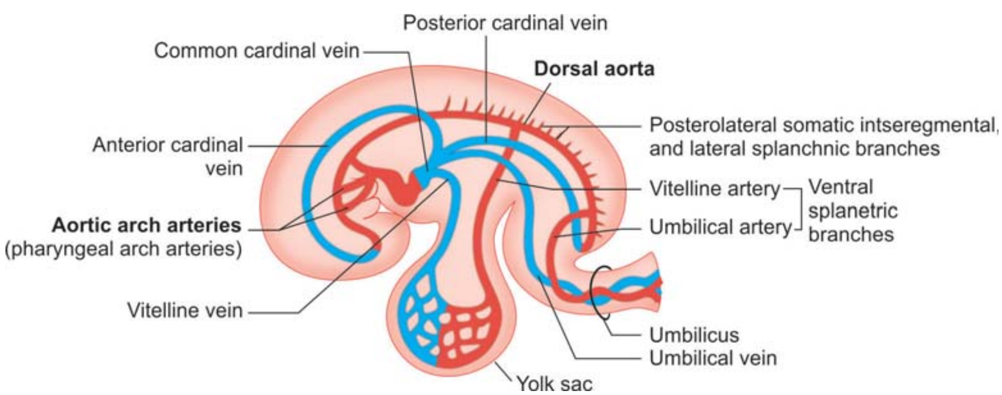


Fig. 70: Embryonic veins (cardinal, vitelline and umbilical).

Table 15: Embryonic veins and their future derivatives	
Embryonic	**Adult**
Vitelline veins	
Right and left	Portion of the IVC/hepatic veins and sinusoids, ductus venosus, portal vein, inferior mesenteric vein, superior mesenteric vein, splenic vein
Umbilical veins	
Right	Degenerates early in fetal life
Left	Ligamentum teres
Cardinal veins	
Anterior	SVC, internal jugular veins
Posterior	Portion of IVC, common iliac veins
Subcardinal	Portion of IVC, renal veins, gonadal veins
Supracardinal	Portion of IVC, intercostal veins, hemiazygos vein, azygos vein

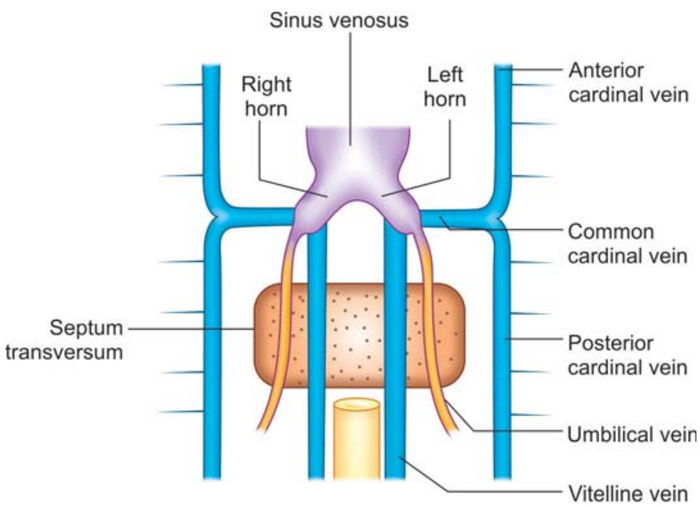


Fig. 71: Three sets of primitive veins

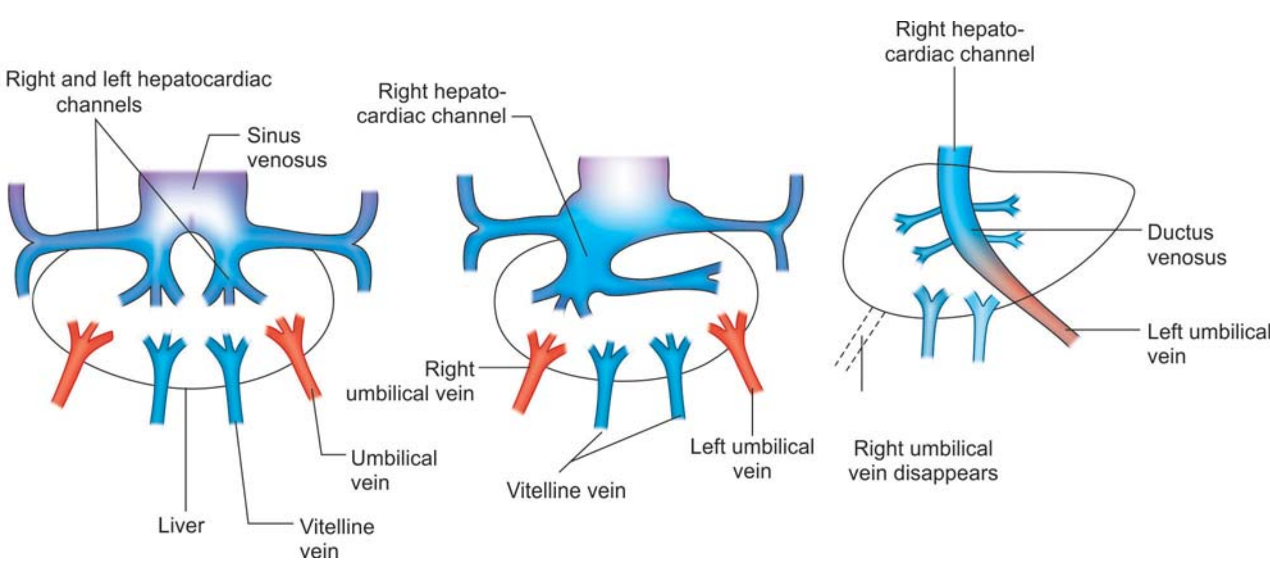


Fig. 72: Fate of umbilical and vitelline veins

In the majority of persistent left superior venae cavae, blood drains into the right atrium via the coronary sinus. When this does not happen, the coronary sinus is absent, and the persistent left superior vena cava drains directly into the atrium. Cyanosis.

VEINS IN THE UPPER BODY

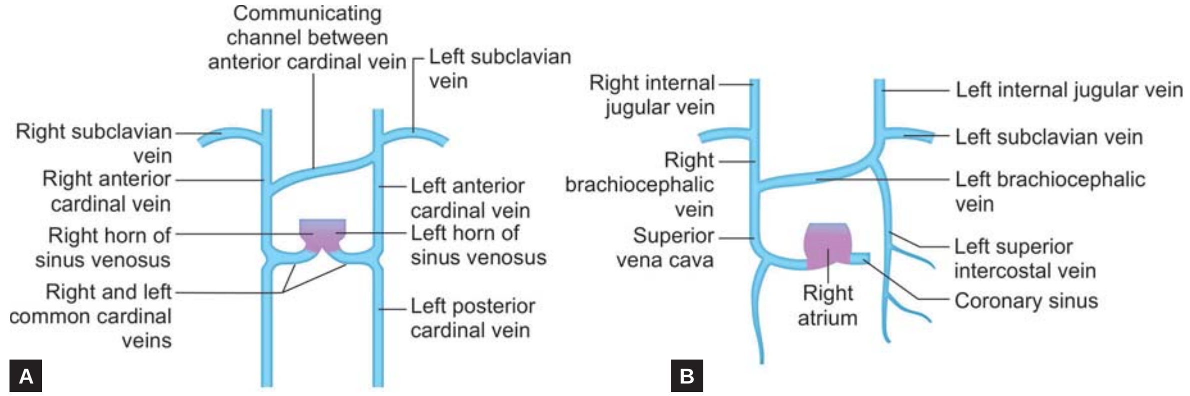
Cardinal veins are system of anterior, posterior, and common cardinal veins that drain the head and body of the embryo in the late third and early fourth weeks.

The major veins of the upper part of the body, viz., internal jugular veins, subclavian veins, right and left brachiocephalic vein, and superior vena cava are derived as follows:

1. Internal jugular vein: It develops from anterior cardinal vein cephalic to the opening of the subclavian vein.
2. Subclavian vein: It develops in the region of the upper limb bud by enlargement of the intersegmental veins in this region.
3. Right brachiocephalic vein: It develops from right anterior cardinal vein above the opening of oblique communicating channel and below the opening of the right subclavian vein.
4. Left brachiocephalic vein: It develops from oblique channel connecting left and right anterior cardinal veins, and left anterior cardinal vein between the opening of communicating channel (vide supra) and left subclavian vein.
5. Superior vena cava: Developmentally it consists of two parts: first and second.

   The first part develops from the right anterior cardinal vein caudal to the oblique transverse anastomosis. The second part develops from the right common cardinal vein. As the right common cardinal vein opens into the right horn of sinus venosus, the superior vena cava at first opens into the right horn of sinus venosus. As and when the right horn of sinus venosus is absorbed into the right atrium, the superior vena cava finally opens into the right atrium.
6. Other veins: As most of the blood is shunted from left to right the following changes occur:
   a. Part of the left anterior cardinal vein below the transverse anastomosis obliterates.
   b. The most of left posterior cardinal vein also regresses. The small cranial part of left posterior cardinal vein along with regressed part of the left anterior cardinal vein caudal to transverse anastomosis forms left superior intercostal vein.
   c. The left horn of sinus venosus regresses and forms coronary sinus. The left common cardinal vein obliterates in its lateral part and forms oblique vein of the left atrium (oblique vein of Marshall) while its medial part contributes to the formation of coronary sinus.

   External jugular veins develop as separate channels.

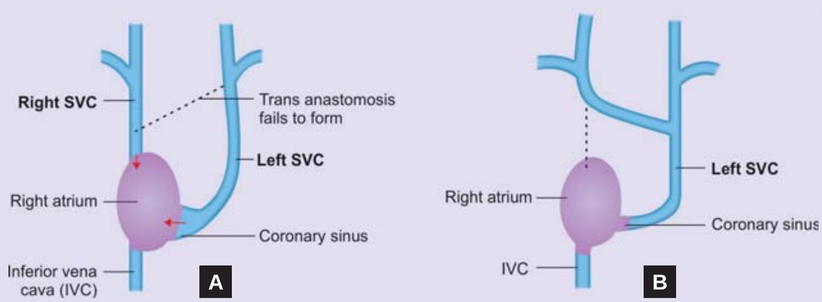


Figs. 73A and B: Development of major vins of the upper parts of the body

Clinical Correlation

Anomalies of superior vena cava

- **Double superior vena cava:** It occurs when the anastomosis between the two anterior cardinal veins fails to form and left anterior cardinal vein persists. Thus, anterior cardinal vein on both sides develops into the superior vena cava. The left superior vena cava opens into the coronary sinus, which in turn opens into the right atrium.
- **Left superior vena cava:** It occurs when the anastomosis does develop between the two anterior cardinal veins, but the blood is shunted from right to left through brachiocephalic vein. As a result, the right anterior cardinal vein below the oblique transverse anastomosis regresses and the left anterior cardinal vein develops into the superior vena cava. The left superior vena cava opens into the coronary sinus.



Figs. 74A and B: Anomalies of the superior vena cava (SVC)

PORTAL VEIN FORMATION

The two vitelline veins lie one on either side of developing duodenum. They soon get interconnected by three anastomotic channels: two ventral and one dorsal.

These anastomotic channels are:

- Proximal ventral anastomosis
- Middle dorsal anastomosis
- Distal ventral anastomosis

The superior mesenteric and splenic veins that develop independently unite with the left vitelline vein just below dorsal anastomosis.

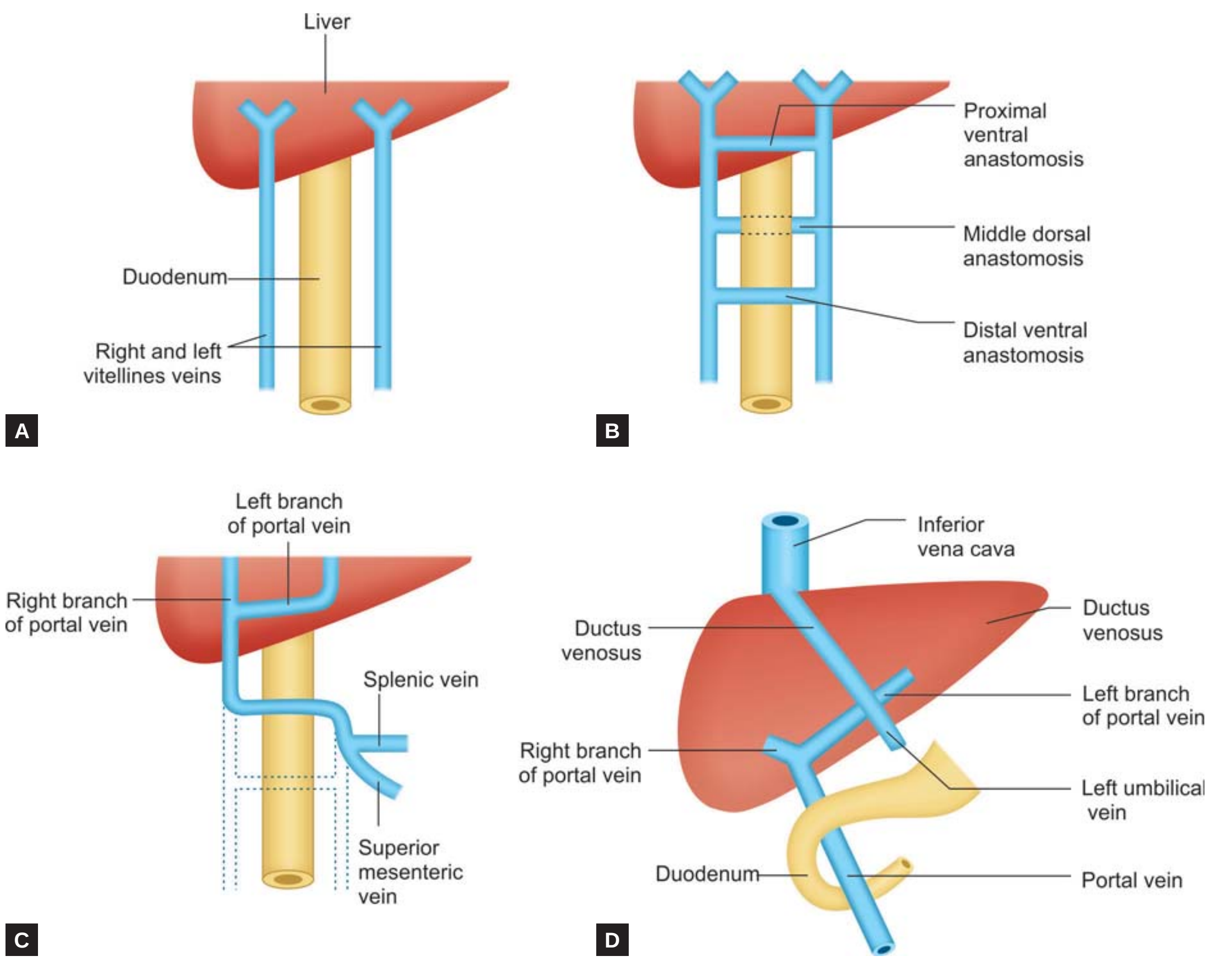
The portal vein develops from three components:

1. Caudal part of left vitelline vein between point at which superior mesenteric and splenic vein open, and the point where dorsal anastomosis joins the left vitelline vein.
2. Middle dorsal anastomosis.
3. Part of right vitelline vein between the dorsal and proximal ventral anastomosis.

The right branch of portal vein develops from the part of right vitelline vein distal to proximal ventral anastomosis.

The left branch of portal vein develops from proximal ventral anastomosis and left vitelline vein distal to proximal ventral anastomosis. Remaining parts of vitelline veins and distal ventral anastomosis disappear along with left hepatocardiac channel.

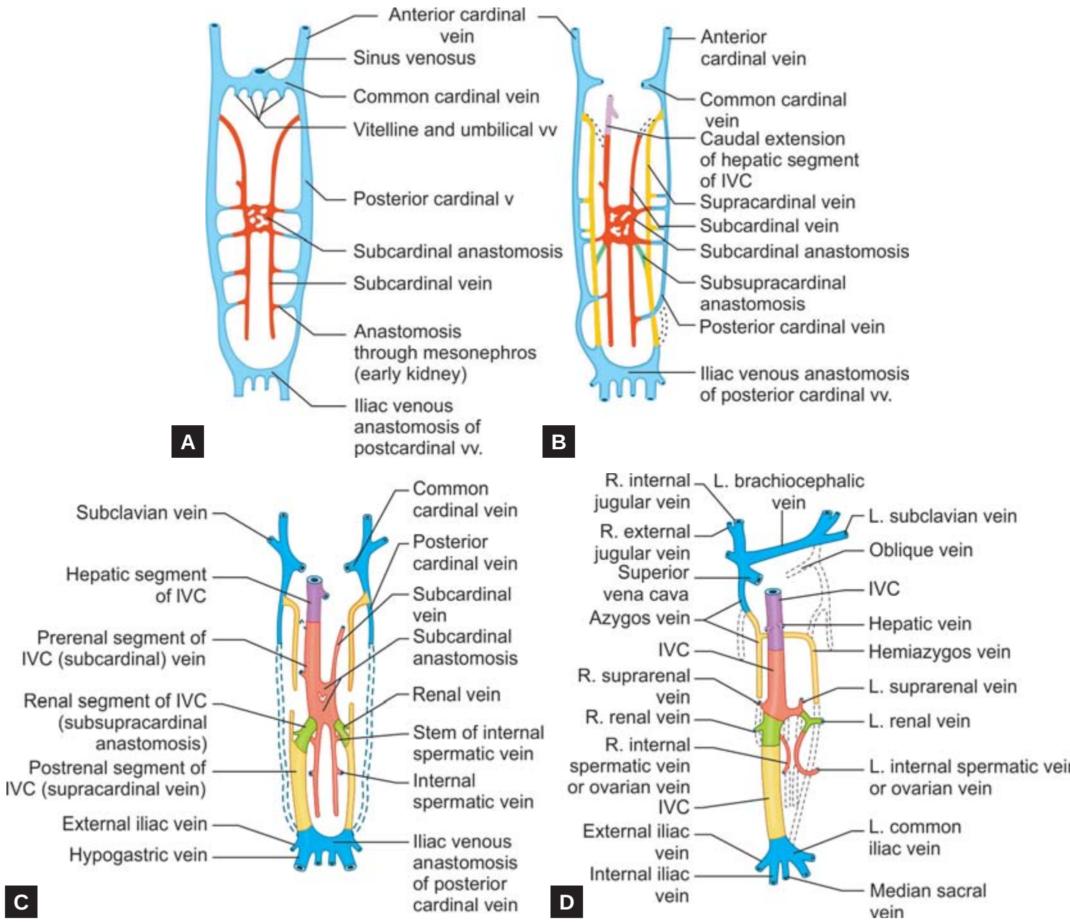
N.B. The development of portal vein explains that it is formed by union of superior mesenteric and splenic veins; it passes dorsally to the duodenum and divides into right and left branches that enter the liver.



Figs. 75A to D: Development of portal vein

IVC FORMATION

Initially, three systems of veins are present: The umbilical veins from the chorion, vitelline veins from the umbilical vesicle, and cardinal veins from the body of the embryos. Next the subcardinal veins appear, and finally the supracardinal veins develop.



Figs. 76A to D: Illustrations of the primordial veins of bodies (trunks) of embryos (ventral views). Initially, three systems of veins are present: the umbilical veins from the chorion, vitelline veins from the umbilical vesicle, and cardinal veins from the body of the embryos. Next the subcardinal veins appear, and finally the supracardinal veins develop. A. At 6 weeks. B. At 7 weeks. C. At 8 weeks. D. Adult. This drawing illustrates the transformations that produce the adult venous Pattern. *IVC*, Inferior vena cava; *L*, left; *R*, Right; *V*, vein; *VV*, veins.

Inferior vena cava develops from six components.

Component	Contributions
Post renal (Sacrocardinal) segment	• Right posterior cardinal vein (1) • Right supracardinal vein (2) • Anastomosis between right supracardinal and subcardinal vein (3)
Renal segment	• Right subcardinal vein (4)
Hepatic segment	• Anastomotic channel between subcardinal vein and right hepatocardiac channel (5) • Right hepatocardiac channel (6)

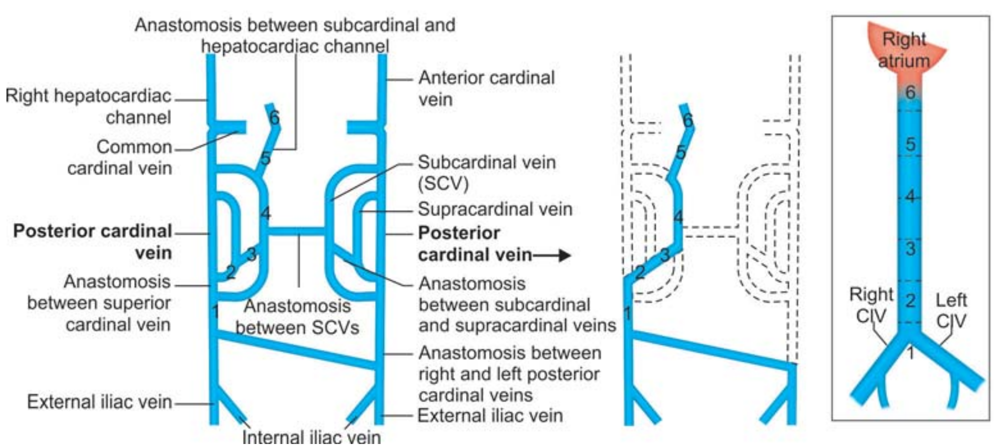


Fig. 77: Development of the inferior vena cava. Figure in the inset on the right shows 1 = Right posterior cardinal vein (sacrocardinal segment). 2 = Supracardinal vein. 3 = Supracardinal-subcardinal anastomosis. 4 = Right subcardinal vein (renal segment). 5 = Anastomotic channel between subcardinal vein and right hepatocardiac channel. 6 = Right hepatocardiac channel (hepatic segment). CIV = Common iliac vein.

Right hepatocardiac channel forms terminal segment (hepatic segment) of the inferior vena cava that first opens into right horn of sinus venosus, and, after the right horn is absorbed in the right atrium, in the right atrium directly.

Clinical Correlations

- Double inferior vena cava may result from due to absence of the anastomosis between two posterior cardinal veins. The left posterior cardinal vein below the level of the renal vein develops into left inferior vena cava while normal inferior vena cava develops on the right side. As a result, inferior vena cava is duplicated below the renal veins. The left inferior vena cava into left renal vein. Double inferior vena cava may result due to persistence of left supracardinal vein is mentioned by most of the authors. Double inferior vena cava may also arise due to persistence of left sacrocardinal vein is mentioned by Langman's embryology. Some authors mention it is due to persistence of both (right and left) subcardinal and supracardinal veins. .

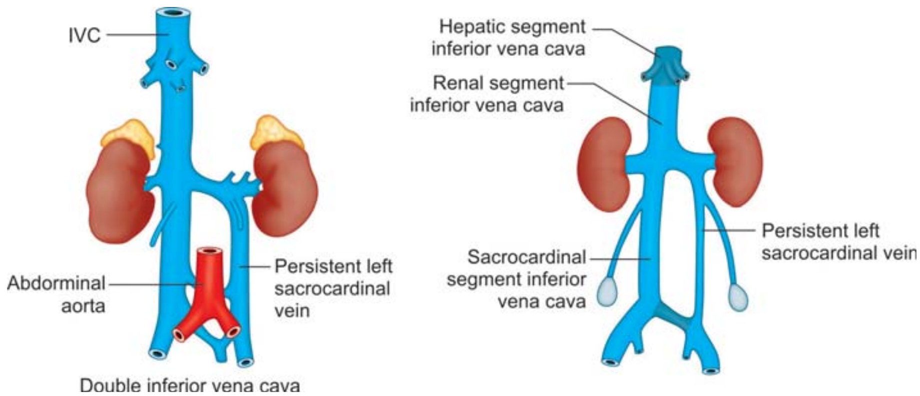
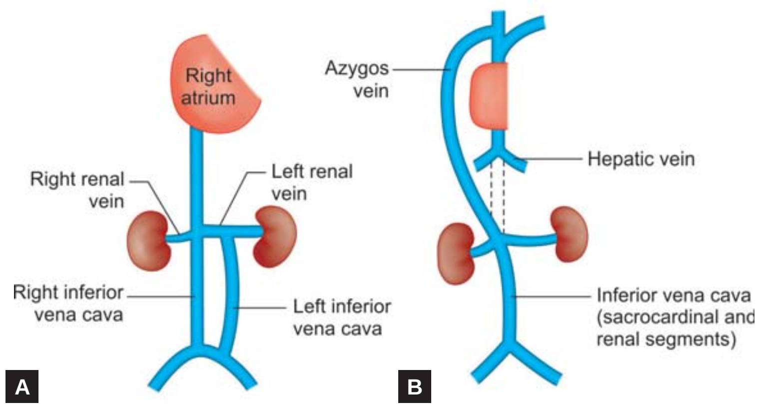


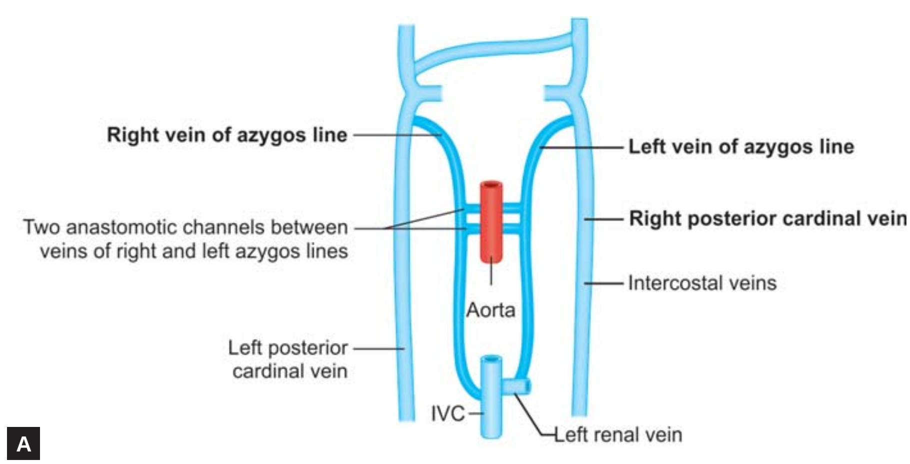
Fig. 78: Formation of double inferior vena cava

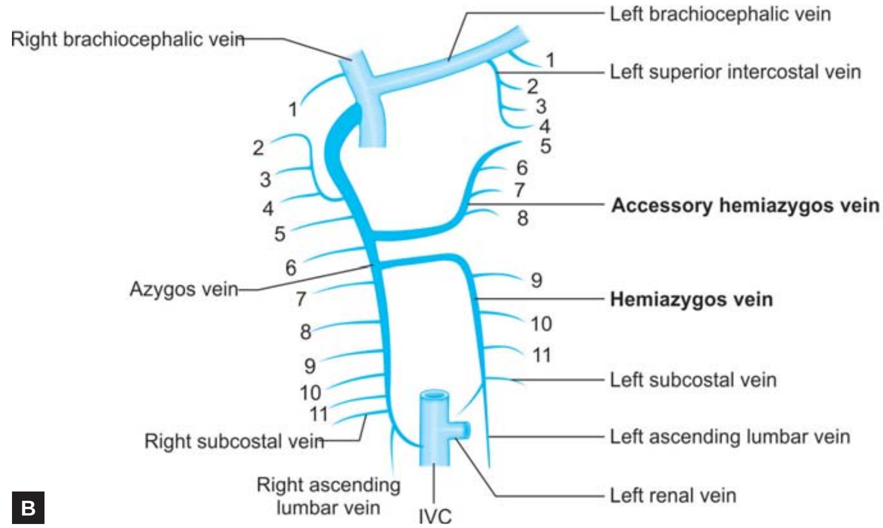
Absence of inferior vena cava may result due to absence of the anastomosing channel between right subcardinal vein and right hepatocardiac channel. The cranial part of right subcardinal vein which normally disappears, persists and carries the blood from the inferior vena cava to the superior vena cava. The hepatic veins directly open into the right atrium at the site of the inferior vena cava.



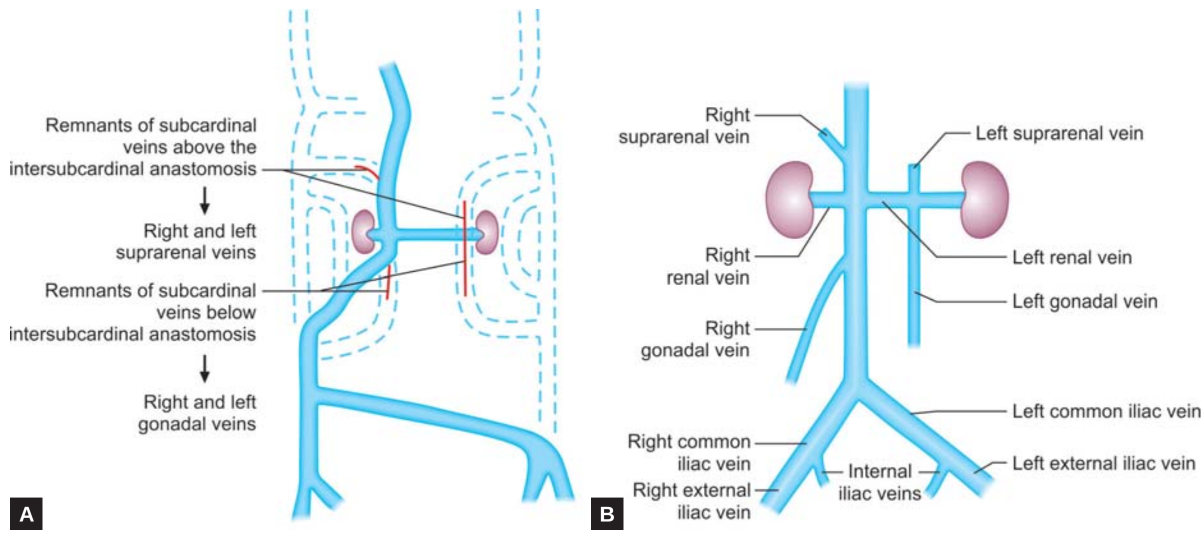
Figs. 79A and B: Anomalies of the inferior vena cava. A. Double inferior vena cava. B. Absence of the inferior vena cava

VEINS IN THE LOWER BODY





Figs. 80A and B: Development of azygos system of veins.



Figs. 81A and B: Development of renal, suprarenal, and gonadal veins. A. Suprarenal and gonadal veins are indicate by red lines. B. Definitive suprarenal and gonadal veins are shown

ASSESSMENT QUESTIONS

1. The most important structure involved in development of inferior vena cava is: *(AIIMS)*
a. Supracardinal vein and subcardinal vein
b. Umbilical vein
c. Anterior cardinal vein
d. Posterior cardinal vein

2. All of the following veins are formed from vitelline vein EXCEPT:
a. Hepatic vein
b. Superior vena cava
c. Inferior vena cava
d. Superior mesenteric vein

3. Derivative of vitelline vein is: *(NEET Pattern 2015)*
a. IVC
b. SVC
c. Ligamentum venosum
d. Ligamentum teres

4. Left sided SVC drains into: *(AIPG 2010)*
a. Right atrium
b. Left atrium
c. Coronary sinus
d. Pericardial space

5. Double inferior vena cava is formed due to persistence of: *(JIPMER)*
a. Sacrocardinal vein
b. Supracardinal vein
c. Subcardinal vein
d. Posterior cardinal vein

6. Double inferior vena cava is formed due to: *(NEET Pattern 2013)*
a. Persistence of sacrocardinal veins
b. Persistence of supracardinal veins
c. Persistence of subcardinal veins
d. Persistence of both supracardinal and subcardinal veins

ANSWERS WITH EXPLANATIONS

1. a. Supracardinal vein and subcardinal vein

- Inferior vena cava develops from several sources, subcardinal vein having significant contribution, especially the renal segment and the postrenal segment (anastomosis between right supracardinal and subcardinal vein).
- Right posterior cardinal vein contributes to the inferiormost component of IVC (sacrocardinal segment).

2. b. Superior vena cava

- Vitelline vein forms portion of the IVC, hepatic veins and sinusoids, ductus venosus, portal vein, inferior mesenteric vein, superior mesenteric vein, splenic vein, etc.
- Superior vena cava is basically contributed by anterior cardinal vein.

3. a. IVC

- Vitelline vein forms portion of the IVC, hepatic veins and sinusoids, ductus venosus, portal vein, inferior mesenteric vein, superior mesenteric vein, splenic vein, etc.

4. c. Coronary sinus

- Left sided superior vena cava drains into the coronary sinus and thence into the right atrium (occasionally directly into the right atrium).
- The etiology is failure of regression of left anterior and common cardinal veins and left sinus horn.
- In this case the right brachiocephalic vein becomes longer, oblique and crosses the midline to reach the superior vena cava.
- Types: 1. Persistent left SVC connecting to right atrium via coronary sinus is only common anomaly of SVC (90% incidence); 2. Persistent SVC connects to left atrium (b) (10% incidence). Most with connection to left atrium have associated ASD.

5. b. > a. > c. > d.

- Double inferior vena cava may result due to persistence of left supracardinal vein is mentioned by most of the authors.
- Double inferior vena cava may also arise due to persistence of left sacrocardinal vein is mentioned by Langman's embryology.
- Some authors mention it is due to persistence of both (right and left) subcardinal and supracardinal veins. It involves the posterior cardinal vein as well.

6. b. > a. > d.

- Double inferior vena cava may result due to persistence of left supracardinal vein is mentioned by most of the authors.

LYMPHATICS

Lymphatic System. The lymphatic system develops later than the cardiovascular system, originating from the endothelium of veins as five sacs: two jugular, two iliac, one retroperitoneal, and one cisterna chyli.

Thoracic duct forms from anastomosis of the right and left thoracic ducts, the distal part of the right thoracic duct, and the cranial part of the left thoracic duct. The right lymphatic duct develops from the cranial part of the right thoracic duct. The lymphatic system is essentially a drainage system that is accessory to the venous system. Hence it is described here.

The lymphatic system develops at the end of the fifth week, about one week later to that of the cardiovascular system. The exact development of lymph vessels is not clear but they may develop in the following two ways: (a) They may form from mesenchyme in situ or (b) they may arise as sac-like outgrowths from the endothelium of veins. In whatever way they develop they connect themselves with the venous system.

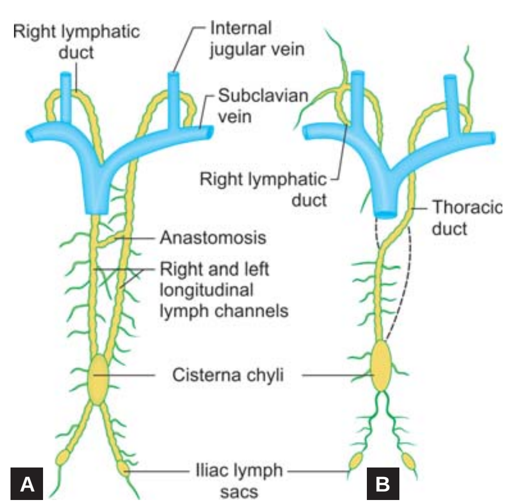
Development of Thoracic Duct

There are three steps in the development of the thoracic duct:

1. Stage I: A network of lymph channels is formed in front of the thoracic part of the vertebral column.
2. Stage II: In this network of lymph channels, two large longitudinal channels appear—one left and another right with a number of cross communications.
3. Stage III: Formation of cross communication between two longitudinal channels opposite to the body of fifth thoracic vertebra. Now the right longitudinal channel below cross communication and the left longitudinal channel above communication persists and gives rise to the thoracic duct. All other channels disappear.

   Thus thoracic duct is derived from the following three sources:

   a. Caudal part of the right longitudinal lymph channel.
   b. Anastomosis between the right and left longitudinal lymph channel.
   c. Cranial portion of the left longitudinal lymph channel.



Figs. 82A and B: Development of thoracic and right lymphatic ducts

Development of Right Lymphatic Duct

It develops from the cranial portion of the right longitudinal lymph channel. Both thoracic and right lymphatic ducts open into the junction of the internal jugular and subclavian vein of the left and right side, respectively.

FETAL CIRCULATION

Highly oxygenated and nutrient-enriched blood returns to the fetus from the placenta via the left umbilical vein. (Note: Highly oxygenated blood is carried by the left umbilical vein, not by an artery as in the adult.) Some blood percolates through the hepatic sinusoids; most of the blood bypasses the sinusoids by passing through the ductus venosus and enters the inferior vena cava (IVC). From the IVC, blood enters the right atrium, where most of the blood bypasses the right ventricle through the foramen ovale to enter the left atrium. From the left atrium, blood enters the left ventricle and is delivered to fetal tissues via the aorta.

- Poorly oxygenated and nutrient-poor fetal blood is sent back to the placenta via right and left umbilical arteries.
- Some blood in the right atrium enters the right ventricle; blood in the right ventricle enters the pulmonary trunk, but most of the blood bypasses the lungs through the ductus arteriosus. Fetal lungs receive only a minimal amount of blood for growth and development; the blood is returned to the left ventricle via pulmonary veins. Fetal lungs are not capable of performing their adult respiratory function because they are functionally immature and the fetus is underwater (ammiotic fluid). The placenta provides respiratory function.
- Circulatory system changes at birth are facilitated by a decrease in right atrial pressure from occlusion of placental circulation and by an increase in left atrial pressure due to increased pulmonary venous return. Changes include closure of the right and left umbilical arteries, left umbilical vein, ductus venosus, ductus arteriosus, and foramen ovale.

Fetal circulation: Oxygenated blood travels from the placenta along the left umbilical vein. Most blood by-passes the liver in the ductus venosus joining the inferior vena cava and then travelling to the right atrium.

- Most of the blood passes through the foramen ovale into the left atrium so that oxygenated blood can enter the aorta and reach the brain at earliest. The remainder goes through the right ventricle with returning systemic venous blood into the pulmonary trunk. The unexpanded lungs present high resistance to flow so that blood in the pulmonary trunk tends to pass down the low-resistance ductus arteriosus into the aorta.
- Blood returns to the placenta via the umbilical arteries (branches of the internal iliac arteries).
- At birth, when the baby breathes, the left atrial pressure rises, pushing the septum primum against the septum secundum and closing the foramen ovale. Blood flow through the pulmonary artery increases and becomes poorly oxygenated as it now receives systemic venous blood. Pulmonary vascular resistance is abruptly lowered as lungs inflate and the ductus arteriosus is obliterated over the next few hours to days.
- At removal of placenta, ligation of the umbilical cord causes thrombosis of the umbilical arteries (becomes medial umbilical ligaments), vein (becomes ligamentum teres) and ductus venosus (becomes ligamentum venosum).

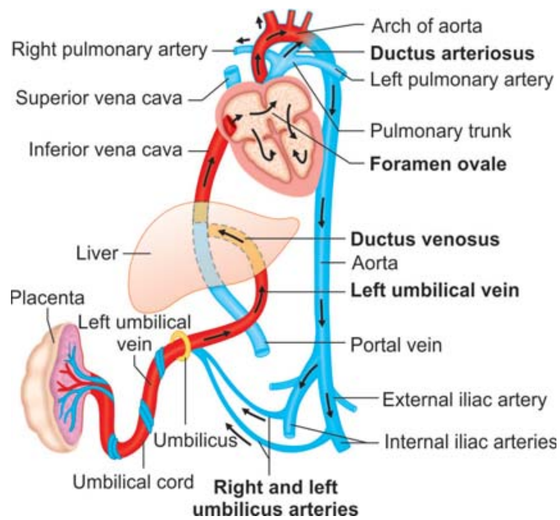


Fig. 83: Fetal circulation

The ductus venosus constricts by 10 to 96 hours after birth and is anatomically closed by 2 to 3 weeks, resulting in formation of the ligamentum venosum

ASSESSMENT QUESTIONS

1. **All of the following pairs for adult derivatives of embryonic structures is correct EXCEPT:**
   a. Umbilical artery: Lateral umbilical ligament
   b. Umbilical vein: Ligamentum teres
   c. Ductus venosus: Ligamentum venosum
   d. Foramen ovale: Fossa ovalis

2. **Anatomical closure of ductus arteriosus occurs at:**
   a. Birth
   b. 3-4 days
   c. 10 days
   d. 30 days

3. **Anatomical closure of ductus arteriosus occurs at:**
   a. 2 weeks
   b. 4 weeks
   c. 12 weeks
   d. 16 weeks

4. **The umbilical vein carries:**
   a. Oxygenated blood towards the placenta
   b. Deoxygenated blood towards the placenta
   c. Oxygenated blood away from the placenta
   d. Deoxygenated blood away from the placenta

ANSWERS WITH EXPLANATIONS

1. **a. Umbilical artery: Lateral umbilical ligament**
   - Umbilical arteries become medial umbilical ligaments.
   - Lateral umbilical ligaments are raised by the inferior epigastric arteries.
   - Median umbilical ligament is raised by urachus attaching to the apex of urinary bladder.

2. d. 30 days
- **Physiological closure** of ductus arteriosus occurs within 1-4 days of birth.
- Often a small shunt of blood stays for 24-48 hours in a normal full term infant.
- At the end of 24 hours (one day), 20 % ducts are functionally close, 82% by 48 hours and 100% at 96 hours (4 days).
- **Anatomical closure** of ductus arteriosus occurs within 2-12 postnatal weeks (1 month to 3 months).
- DA is closed by 8 weeks in 88% of children with a normal cardiovascular system.
- Authorities consider the patent ductus to be abnormal only after 3 months (12 weeks) of age.

3. c. 12 weeks
- Anatomical closure of ductus arteriosus occurs within 2-12 postnatal weeks (1 month to 3 months).

4. c. Oxygenated blood away from the placenta
- Umbilical vein carries oxygenated blood from mother to the baby.

VASCULOGENESIS AND HAEMOPOIESIS

A. **In Extraembryonic Mesoderm:** Vasculogenesis occurs first within extraembryonic visceral mesoderm around the yolk sac on day 17. By day 21, vasculogenesis extends into extraembryonic somatic mesoderm located around the connecting stalk to form the umbilical vessels and in secondary villi to form tertiary chorionic villi. Vasculogenesis occurs by a process in which extraembryonic mesoderm differentiates into angioblasts, which form clusters known as angiogenic cell clusters. The angioblasts located at the periphery of angiogenic cell clusters give rise to endothelial cells, which fuse with each other to form small blood vessels.

B. **In Intraembryonic Mesoderm:** Blood vessels form within the embryo by the same mechanism as in extraembryonic mesoderm. Eventually blood vessels formed in the extraembryonic mesoderm become continuous with blood vessels within the embryo, thereby establishing a blood vascular system between the embryo and the placenta.

Hematopoiesis (blood cell formation) first occurs within the extraembryonic visceral mesoderm around the yolk sac during week 3 of development. During this process, angioblasts within the center of angiogenic cell clusters give rise to primitive blood cells. Beginning at week 5, hematopoiesis is taken over by a sequence of embryonic organs: liver, spleen, thymus, and bone marrow.

TERMINOLOGY

Angiogenesis	Blood vessel development.
Aortic arch arteries	Arteries within the pharyngeal (branchial) arches flanking the foregut that connect the aortic sac with the paired dorsal aortae and give rise to most of the arteries of the neck.
Aortic sac	Arterial chamber at the distal end of the outflow tract of the primitive heart tube ventral to the foregut. It directs blood from the truncus arteriosus into the aortic arch arteries.
Bulbus cordis	A chamber in the primitive heart tube that develops into the upper, smooth, outflow portion of each ventricle.
Cardinal veins	Cardinal, subcardinal, and supracardinal veins are embryonic systems of veins that develop in temporal sequence and form most of the major somatic, renal, and gonadal veins.
Cardiac jelly	A gelatinous connective tissue layer between the endothelial heart tube and the myocardial mantle layer. Its significance is unknown.
Cardiogenic mesoderm	Mesoderm from the primitive streak that migrates around the oropharyngeal (oral) membrane to midline position at the cranial end of the embryo. It is continuous with the lateral plate mesoderm on either side. All structures of the heart and pericardial sac develop from cardiogenic mesoderm.
Coarctation	An abnormal constriction.
Cyanosis	(G., "blue") Bluish coloration of the skin and mucous membranes from lower oxygen levels in the blood.
Ductus arteriosus	A lung shunt connecting the pulmonary trunk to the arch of the aorta. After birth it remains patent for a few weeks before forming the fibrous ligamentum arteriosum.
Ductus venosus	Liver bypass shunting blood from the umbilical vein into the inferior vena cava. It becomes the ligament venosum.
Endocardial cushions	Dorsal and ventral (or superior/inferior) partitions of the heart rube that fuse to first separate blood flow into left and right sides.
Epicardium	Visceral pericardium on the surface of the heart. Cells from the cardiogenic mesoderm on the sinus venosus migrate over the myocardial middle layer to form the epicardium.
Foramen ovale	A lung shunt where blood passes from the right atrium to the left atrium. In common usage it refers to the entire atrial bypass that includes the foramen secundum.
Sinus venosus	The first pan: of the venous end of the heat rube receiving blood from the umbilical vein, common cardinal veins, and vitelline veins.
Stenosis	(G., "narrowing") The narrowing of a vessel, duct, or canal.
Tetralogy of Fallot	"Four" secondary heart defects resulting from a primary spiral septum defect that divides the truncus arteriosus unequally. (1) pulmonary stenosis, (2) ventricular septal defect, (3) aorta overriding and draining both ventricles, and (4) right ventricular hypertrophy.

Transverse sinus	The space between the great arteries and the superior vena cava occupied by the mesentery of the heart. The heart tube sinks into the pericardial coelom and becomes suspended by a mesentery, the dorsal mesocardium. As the arterial and venous ends of the heart: tube approach each other, the mesocardium breaks down to form the transverse sinus.
Vitelline vessels	Circulation to the yolk sac, which is the first source of blood cell production. The proximal, intraembryonic portions persist as the major midgut and hindgut arteries, liver veins, and hepatic portal system.

BODY CAVITIES AND DIAPHRAGM

Formation of the Intraembryonic Coelom

Formation of the intraembryonic coelom begins when spaces coalesce within the lateral mesoderm and form a horseshoe-shaped space that opens into the chorionic cavity (extraembryonic coelom) on the right and left sides.

- Intraembryonic coelom is remodeled due to the craniocaudal folding and lateral folding of the embryo.
- The coelom is like a balloon whose walls closest to the viscera are visceral mesoderm and whose walls closest to the body wall are somatic mesoderm.

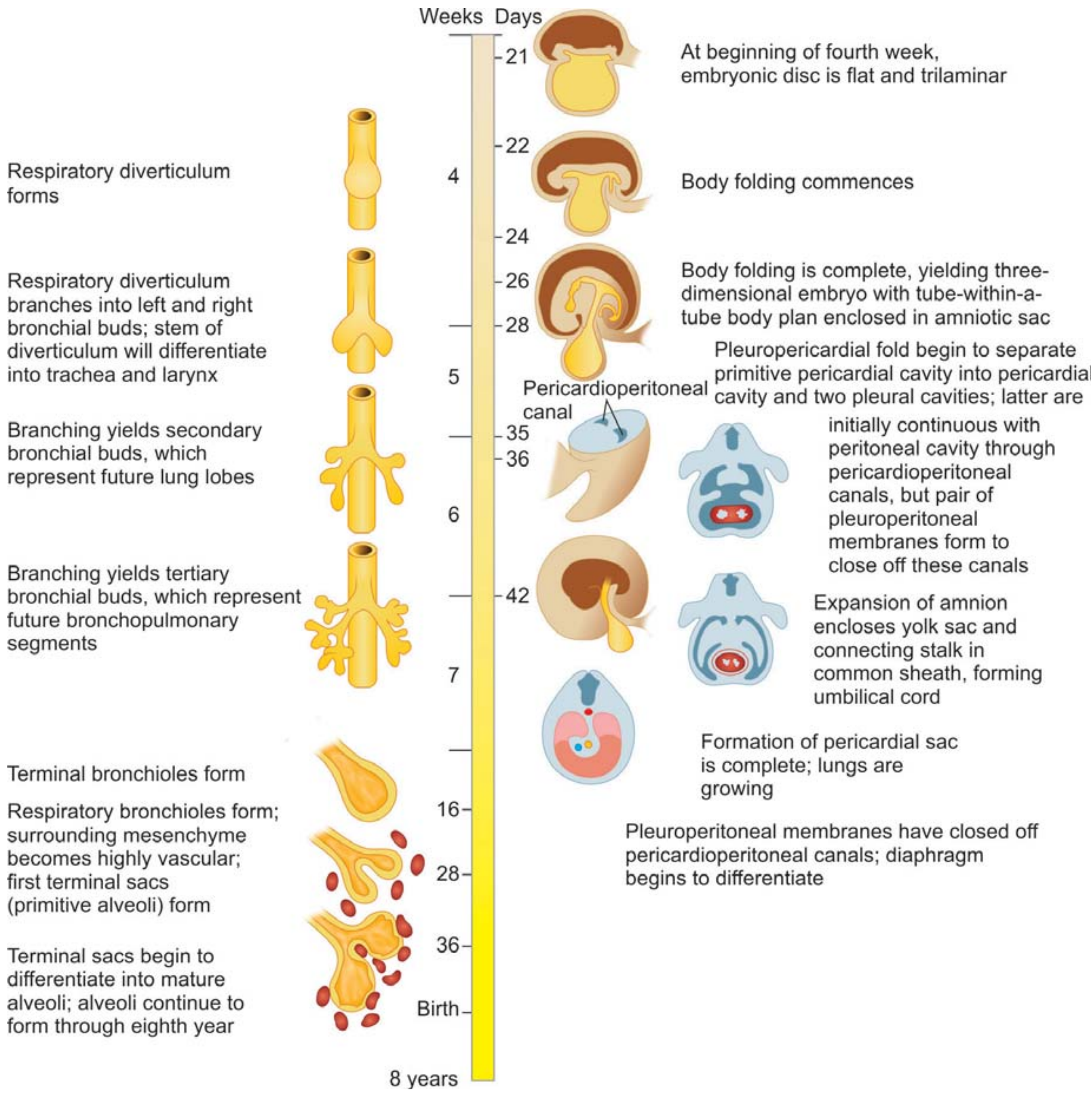
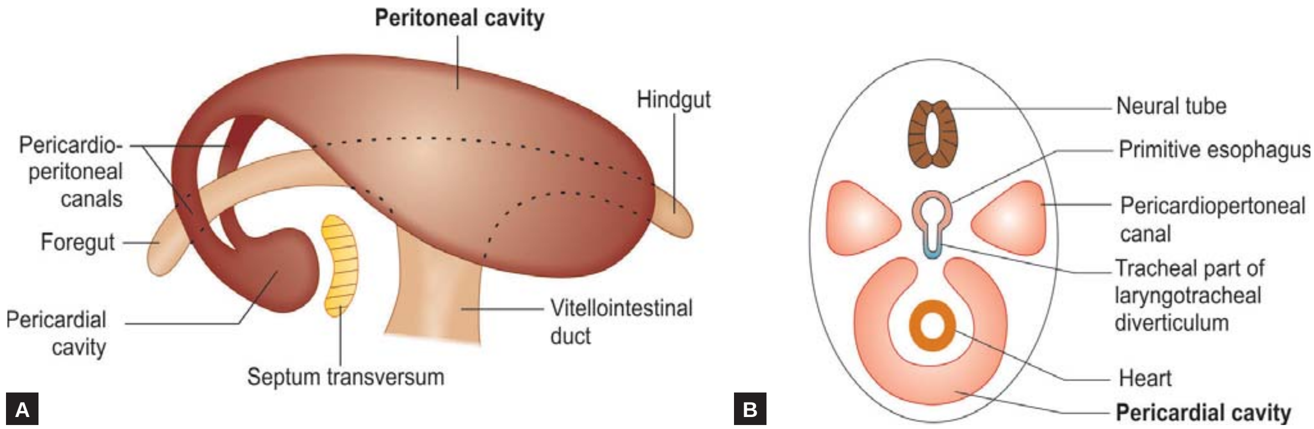


Fig. 84: Development of the lungs, respiratory tree, and body cavities

- It is initially one continuous space but gradually develop partitioning to form the definitive adult pericardial, pleural, and peritoneal cavities.
- The **two partitions** developing are the **paired pleuropericardial membranes** and the **diaphragm**.
- Paired pleuropericardial membranes are sheets of somatic mesoderm that separate the pericardial cavity from the pleural cavities.

- Their formation is aided by lung buds invading the lateral body wall and by tension on the common cardinal veins resulting from rapid longitudinal growth.
- These membranes develop into the definitive fibrous pericardium surrounding the heart.
- **Diaphragm** separates the pleural cavities from the peritoneal cavity and is formed through the fusion of tissue from four different sources: Septum transversum, paired pleuroperitoneal membranes, dorsal mesentery of the esophagus and body wall.



Figs. 85A and B: Parts of intraembryonic celom in relation to the gut. A. Lateral view. B. Transverse section of an embryo to show the relationship of pericardioperitoneal canals in relation to the tracheal part of the laryngotracheal diverticulum

Septum transversum is a thick mass of mesodermal tissue that occupies the space between the thoracic cavity and yolk stalk in the early embryo:

- It is located between the primitive heart tube and the developing liver
- It works like a partition to separate thoracic and abdominal cavities
- It gives rise to central tendon of diaphragm and the ventral mesentery of the foregut.
- Ventral mesentery itself gives derivatives: Falciform ligament, Lesser omentum, Coronary ligament.
- The cephalic portion of the septum transversum takes part in the formation of the diaphragm, while the caudal portion into which the liver grows forms the ventral mesentery (or ventral mesogastrium, when referring to the portion at the stomach).
- The lesser omentum is formed, by a thinning of the mesoderm or ventral mesogastrium, which attaches the stomach and duodenum to the anterior abdominal wall.
- By the subsequent growth of the liver this leaf of mesoderm is divided into two parts, viz., the lesser omentum between the stomach and liver, and the falciform and coronary ligaments between the liver and the abdominal wall and diaphragm.

Diaphragm is contributed by the septum transversum mesenchyme (ventrally); the dorsal mesooesophagus and paired pleuroperitoneal membranes (posteriorly) and excavated body wall (posteriorly and laterally).

- Skeletal muscles of diaphragm develop from cervical somites (myotomes), hence it is supplied by phrenic nerve (C: 3,4,5).
- Septum transversum is the primordium of the central tendon of the diaphragm.
- Paired pleuroperitoneal membranes are sheets of somatic mesoderm that appear to develop from the dorsal and dorsolateral body wall.
- Dorsal mesentery of the esophagus is invaded by myoblasts and forms the crura of the diaphragm in the adult.
- Body wall contributes muscle to the peripheral portions of the definitive diaphragm.

Embryonic structure	Adult derivative
Cervical somites (myotomes)	Skeletal muscle of diaphragm
Septum transversum	Central tendon of diaphragm
Pleuroperitoneal membrane	Posterior and peripheral part of diaphragm
Dorsal mesentery of esophagus (dorsal meso-esophagus)	Crura of diaphragm
Body wall mesoderm	Peripheral posterolateral portion

Positional Changes of the Diaphragm

- During week 4 of development, the developing diaphragm becomes innervated by the phrenic nerves, which originate from C3, C4, and C5 and pass through the pleuropericardial membranes.
- By week 8, there is an apparent descent of the diaphragm to L1 because of the rapid growth of the neural tube.
- The phrenic nerves are carried along with the 'descending diaphragm,' while they remain associated with the fibrous pericardium.

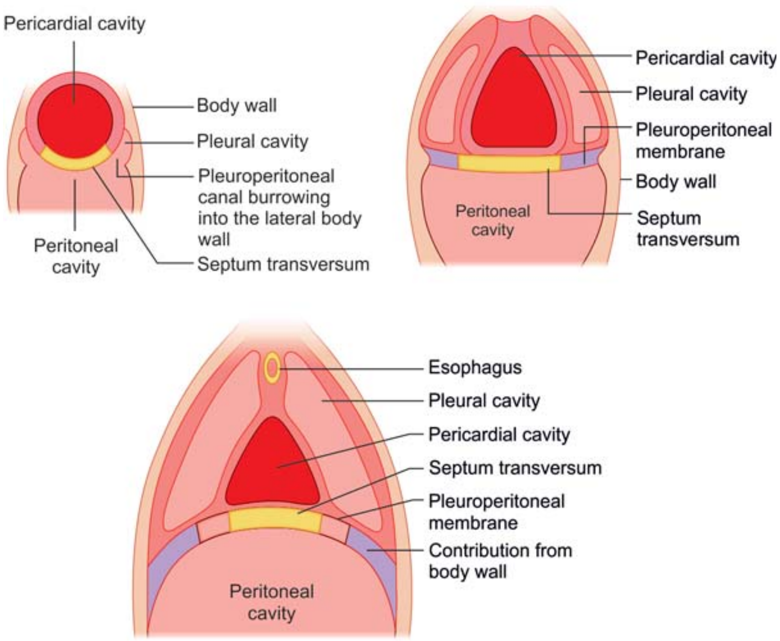
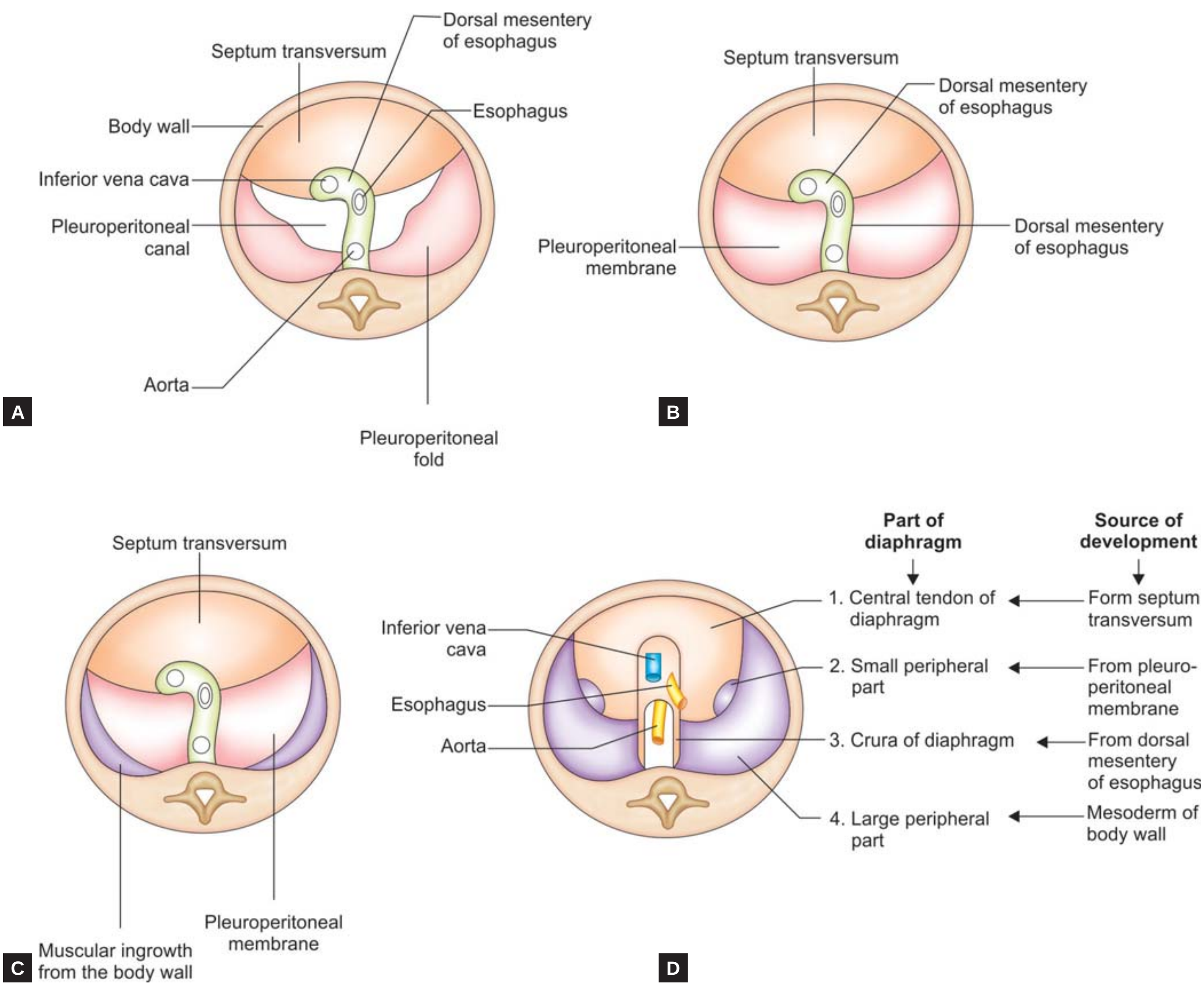


Fig. 86: Splitting of lateral body wall by developing pleural cavities



Figs. 87A to D: Successive stages (A, B, C, and D) of the development of the diaphragm

Bochdalek Hernia

Deficiency in the pleuroperitoneal membrane or its failure to fuse with the other parts of the diaphragm leads to Bochdalek hernia (congenital diaphragmatic hernia), presenting as neonatal emergency.

- Abdominal contents are herniate into the left pleural cavity, usually the stomach and/or the small bowel, colon, liver and spleen.
  There is associated left lung hypoplasia and right mediastinal shift (and resulting cyanosis).
- Mother presents with polyhydramnios and baby has scaphoid (flattened) abdomen, cyanosis, and difficulty in breathing.
- Immediate nasogastric intubation is performed, and the surgery is postponed by few days till the patient is stabilized.
  Bochdalek's hernia is the most common (85–90%) variety and present with a posterolateral defect (usually left-80%).
- Although these hernias have been attributed to failure of the pleuroperitoneal membrane to develop or fuse with the other components of the diaphragm, some authorities believe the primary abnormality is lung hypoplasia, and the herniation of the abdominal contents is secondary.
- Morgagni hernia is a rare variety of congenital diaphragmatic hernia and lies anteromedial (usually right) opening in the diaphragm.

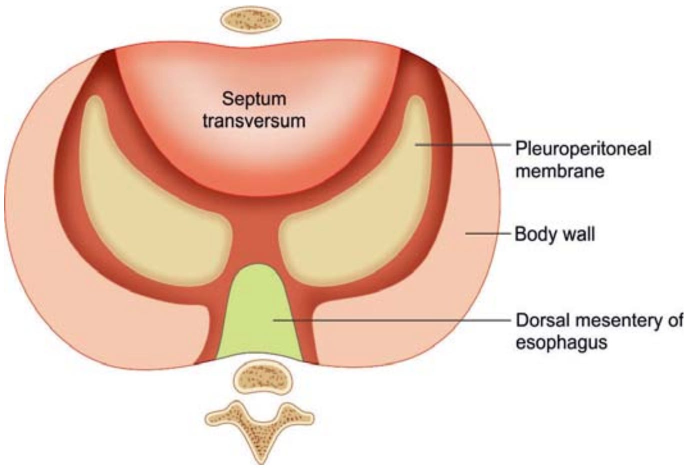


Fig. 88: Developmental components of the diaphragm

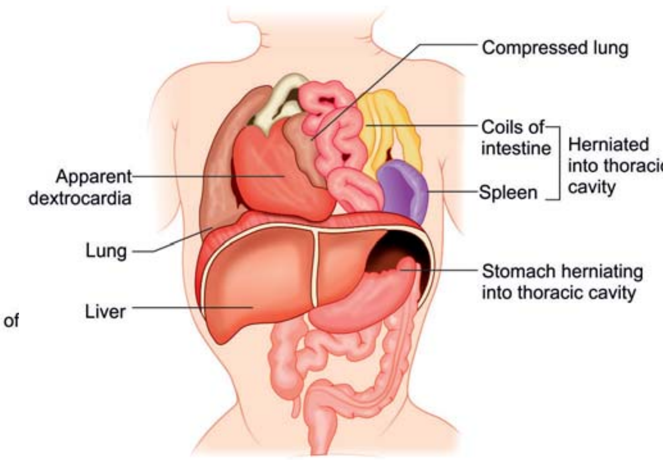
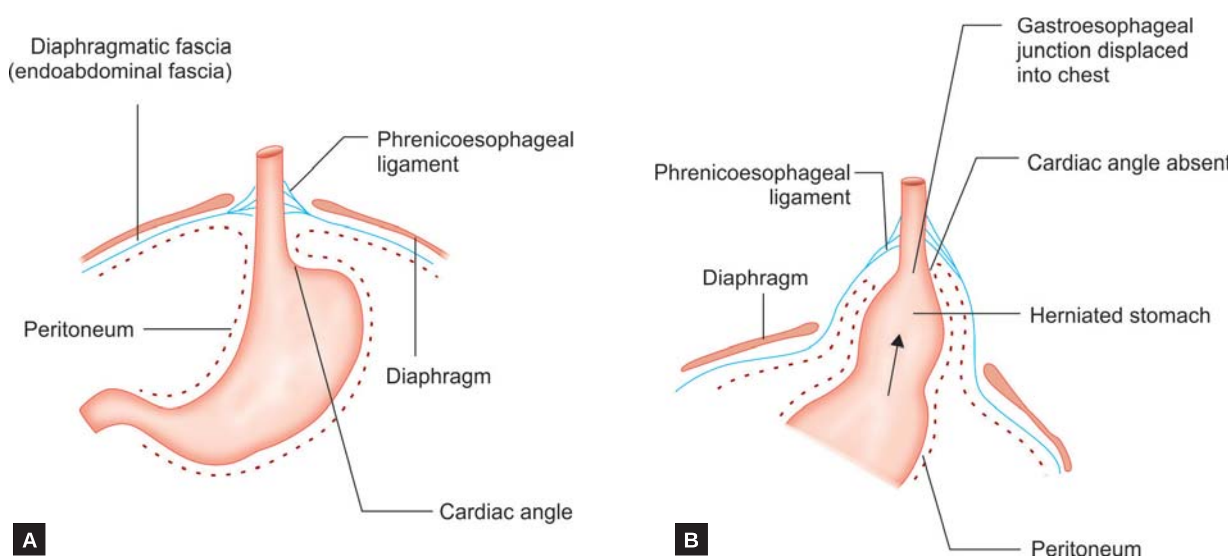


Fig. 89: Posterolateral hernia of diaphragm

Esophageal Hiatal Hernia

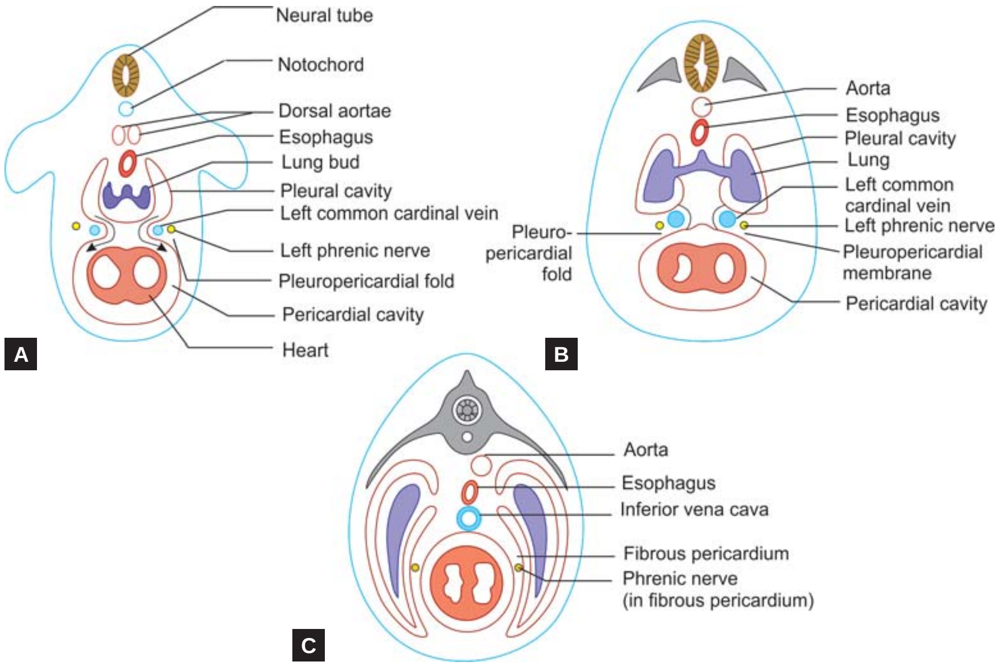
It is a herniation of the stomach through the esophageal hiatus into the pleural cavity caused by an abnormally large esophageal hiatus.

- An esophageal hiatal hernia renders the esophago-gastric sphincter incompetent so that stomach contents reflux into the esophagus.
- Clinical signs in the newborn include vomiting (frequently projectile) when the infant is laid on its back after feeding.

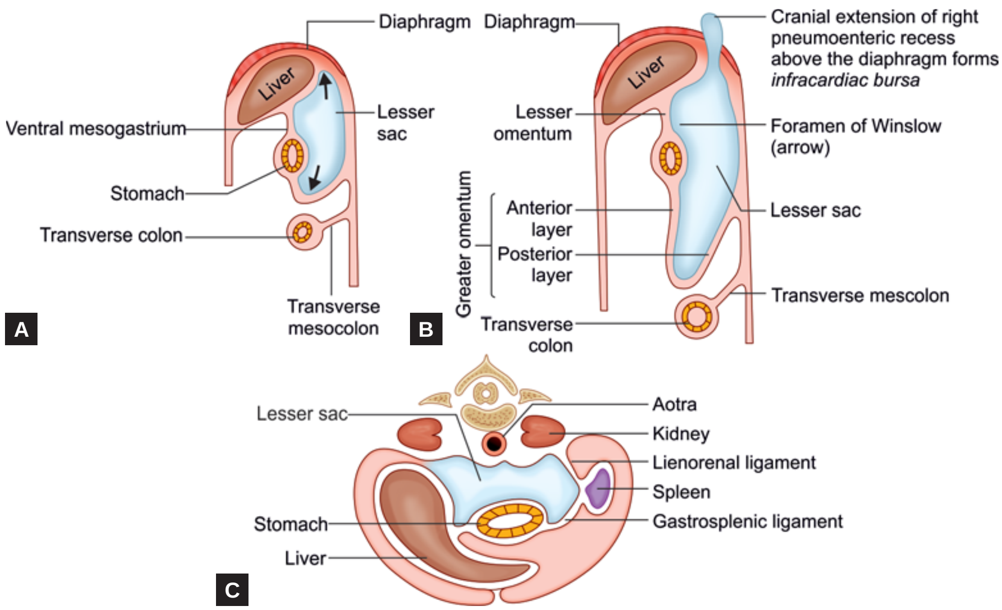


Figs. 90A and B: Acquired hiatal (sliding) hernia: A. Normal position of stomach; B. Herniated stomach

Further development of Body cavities



Figs. 91A to C: Transverse section through embryos cranial to septum transversum. A. Position of pleuropericardial canals and pleuropericardial folds. B. Development of pleural cavities due to growth of lungs and formation of pleuropericardial membrane. C. Fusion of pleuropericardial membranes. Note the position of phrenic nerve in the fibrous pericardium.



Figs. 92A to C: Sagittal section of developing peritoneal cavity showing the development of lesser sac. A. and B. Downward and cranial extensions of lesser sac. C. Formation of splenic recess. Note, derivations of parts of sac are numbered by Arabic numerals: 1. from cranial extension of pneumoenteric recess, 2. from parts of the peritoneal cavity that comes to lie behind ventral mesogastrium, 3. from right pneumoenteric recess, and 4. from cavity provided by elongation and folding of the greater omentum on itself and from cavity between gastrosplenic and lienorenal ligaments

Table 16: Parts of lesser sac derived from various embryonic sources

Part of lesser sac	Source of development
Vestibule	Part of peritoneal cavity that comes to lie behind the ventral mesogastrium (now lesser omentum)
Superior recess	Cranial extension of right pneumoenteric recess below diaphragm
Inferior recess	Cavity formed by elongation and folding of greater omentum on itself
Splenic recess	Part of right pneumoenteric recess extending to the left between gastrosplenic and lienorenal ligaments

ASSESSMENT QUESTIONS

1. **Diaphragm does not develop from:** *(AIIMS 2015)*
   a. Body wall
   b. Pleuroperitoneal membrane
   c. Pleuropericardial membrane
   d. Septum transversum

2. **Diaphragm develops form all EXCEPT:** *(AIPG 2011)*
   a. Septum transversum
   b. Dorsal mesocardium
   c. Pleuroperitoneal membrane
   d. Cervical myotomes

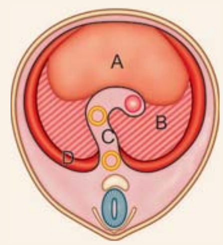
3. **Myoblasts of diaphragm develops from which somites:** *(NEET Pattern 2012)*
   a. Cervical 1-3
   b. Cervical 2-4
   c. Cervical 3-5
   d. Cervical 5-7

4. **All are derivatives of Septum Transversum EXCEPT:** *(AIIMS 2010)*
   a. Falciform ligament
   b. Ligamentum teres
   c. Coronary ligament
   d. Lesser omentum

5. **Bochdalek hernia occurs in:**
   a. Anterolateral part of the diaphragm
   b. Posterolateral part of diaphragm
   c. Retrosternal area
   d. Posterior to diaphragm

6. **Most common site of Morgagni Hernia is:** *(AIPG)*
   a. Left anterior
   b. Right posterior
   c. Right anterior
   d. Left posterior

7. **In the following diagram for diaphragm development, congenital diaphragmatic hernia occurs usually due to defect in:** *(AIIMS 2016)*
   a. A
   b. B
   c. C
   d. D



ANSWERS WITH EXPLANATIONS

1. **c. Pleuropericardial membrane**
   - Diaphragm doesn't have contribution from pleuropericardial membrane, which are sheets of somatic mesoderm that separate the pericardial cavity from the pleural cavities and form fibrous pericardium surrounding the heart.

2. **b. Dorsal mesocardium**
   - Dorsal meso-esophagus (**not mesocardium**) contributes to the crura of the diaphragm.

3. **c. Cervical 3-5**
   - Skeletal muscles of diaphragm develop from cervical somites (myotomes), hence it is supplied by phrenic nerve (C: 3,4,5).

4. **b. Ligamentum teres**
   - **Ligamentum teres** is a remnant of left umbilical vein and is not derived from septum transversum.
   - **Septum transversum** gives rise to central tendon of diaphragm and the ventral mesentery of the foregut.
   - **Ventral mesentery** itself gives derivatives: Falciform ligament, Lesser omentum, Coronary ligament.

5. **b. Posterolateral part of diaphragm**
   - **Bochdalek** hernia is a posterolateral defect, usually on the left side.
   - **Morgagni's** hernia is usually right retrosternal defect in the diaphragm.

6. **c. Right anterior**
   - Morgagni's hernia is a congenital diaphragmatic hernia, which is a rare entity (Bochdalek hernia is more common).
   - Morgagni's hernia is commonly seen on the right anteromedial aspect of diaphragm.
   - Normally the diaphragm has anteromedial costo-xiphoid deficiencies (Larry's space/Morgagni foramen). The normal contents of Larry's space are superior epigastric vessels (which next enter the rectus sheath).
   - In Morgagni's hernia, the transverse colon passes through the foramen to herniate into the anterior mediastinum (thorax).
   - Bochdalek's hernia, which occurs on the posterolateral aspect of diaphragm, is more common on the left side.

7. **b. B**
   - The most common congenital diaphragmatic hernia is Bochdalek hernia. It occurs due to deficiency in the pleuroperitoneal membrane (B), usually on the left side.
   - Bochdalek hernia presents with left postero lateral defect in the diaphragm, leading to intestinal herniation into the thorax.
   - **Key:** A - Septum transversum; B - Pleuroperitoneal membrane; C - Dorsal mesentery of esophagus; D - Body wall mesoderm.

GIT - EMBRYOLOGY

- Primitive gut tube is formed from the incorporation of the dorsal part of the yolk sac into the embryo due to the craniocaudal folding and lateral folding of the embryo.
- The **epithelium** of the digestive system and the parenchyma of its derivatives originate in the **endoderm**; whereas, connective tissue, muscular components, and peritoneal components originate in the **mesoderm**.

- **HOX genes** in the mesoderm are induced by SHH secreted by gut endoderm and regulate the craniocaudal organization of the gut and its derivatives.
- The primitive gut tube extends from the oropharyngeal membrane to the cloacal membrane and is divided into the foregut, midgut, and hindgut.
- Early in development, the epithelial lining of the gut tube proliferates rapidly and obliterates the lumen, which later is reacquired by recanalization.
- The **pharyngeal** gut gives rise to the pharynx and related glands.
- The **foregut** gives rise to the esophagus, the trachea and lung buds, the stomach, and the duodenum proximal to the entrance of the bile duct.
  - In addition, the liver, pancreas, and biliary apparatus develop as outgrowths of the endodermal epithelium of the upper part of the duodenum.

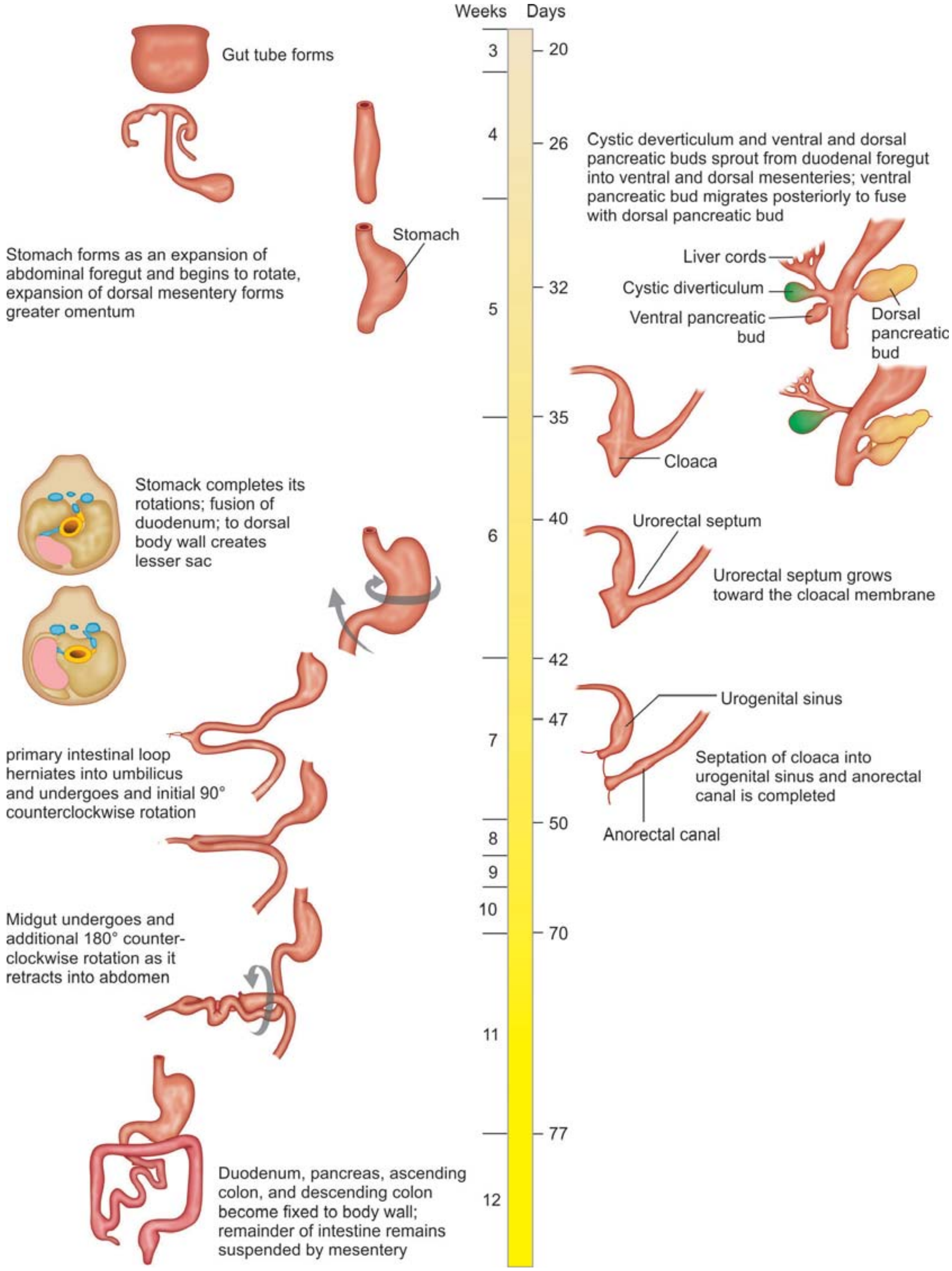


Fig. 93: Development of the gut tube and its derivatives

- The epithelial **liver** cords and biliary system growing out into the septum transversum differentiate into parenchyma.
- Hematopoietic cells (present in the liver in greater numbers before birth than afterward), the Kupffer cells, and connective tissue cells originate in the mesoderm.
- The **pancreas** develops from a ventral bud and a dorsal bud that later fuse to form the definitive pancreas.

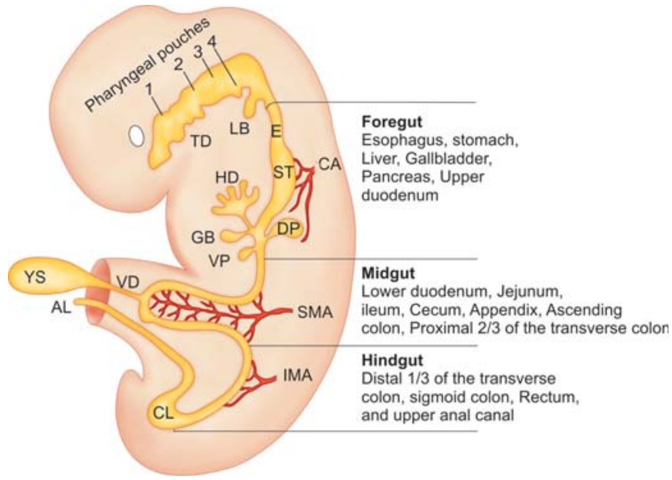


Fig. 94: Derivatives of the three parts of gut tube

- The **midgut** forms the primary intestinal loop, gives rise to the duodenum distal to the entrance of the bile duct, and continues to the junction of the proximal two-thirds of the transverse colon with the distal third.
  - At its apex, the primary loop remains temporarily in open connection with the yolk sac through the vitelline duct.
  - During the sixth week, the loop grows so rapidly that it protrudes into the umbilical cord (physiological herniation).
  - During the 10th week, it returns into the abdominal cavity.
  - While these processes are occurring, the midgut loop rotates 270° counterclockwise.
- **Hindgut** gives rise to the region from the distal third of the transverse colon to the upper part of the anal canal.
  - The distal part of the anal canal originates from ectoderm.
  - The hindgut enters the posterior region of the cloaca (future anorectal canal), and the allantois enters the anterior region (future urogenital sinus).
- The **urorectal septum** will divide the two regions and breakdown of the cloacal membrane covering this area will provide communication to the exterior for the anus and urogenital sinus.
- The **anal canal** itself is derived from endoderm (cranial part) and ectoderm (caudal part).
- The caudal part is formed by invaginating ectoderm around the proctodeum.

Structures	Foregut	Midgut	Hindgut
Organs	Esophagus, stomach, liver, gall bladder, pancreas, 1/2 of duodenum	1/2 of duodenum, jejunum, ileum, cecum, ascending colon, 2/3 of transverse colon	1/3 of transverse colon, descending and sigmoid colon, rectum, and 2/3 of anal canal
Arteries and branches	**Celiac** splenic, left gastric, short gastric, common hepatic, right gastric, gastroduodenal	**Superior Mesenteric** inferior pancreaticoduodenal, intestinal middle colic, right colic, ileocolic	**Inferior Mesenteric** left colic, superior rectal
Veins	Portal vein	Portal vein	Portal vein
Lymph	Celiac nodes (supracolic compartment)	Superior mesenteric nodes (infracolic compartment)	Inferior mesenteric nodes (infracolic compartment)
Nerves: Parasympathetic	Vagus	Vagus	Pelvic splanchnic (S2-S4)
Sympathetic	Greater thoracic splanchnic (T5-T9)	Lesser thoracic splanchnic (T10, T11)	Least thoracic splanchnic (T12), upper lumbar splanchnic (L1, L2)
Pain refers to:	Epigastric region	Umbilical region	Suprapubic region

CLINICAL CORRELATIONS

Tracheoesophageal Fistula

The upper part of the foregut is divided by a septum (the tracheoesophageal septum) into the esophagus posteriorly and the trachea and lung buds anteriorly, deviation of the septum may result in abnormal openings between the trachea and esophagus.

Hirschsprung's Disease

- Hirschsprung disease occurs due to nonmigration of neural crest cells into the distal part of the gut tube colon/rectum.
- It is usually characterized by an **aganglionic** portion of gut that does not display peristalsis, and a dilated segment of structurally normal colon (mega) proximal to this site.
- Histologically, there is either an absence or a reduction in the number of ganglia and postganglionic neurons in the Auerbach's myenteric plexus of the affected segment of gut; postganglionic innervation of the muscle layers is also often defective.

- It is believed that the condition is caused by a failure of neural crest cells to colonize the gut wall appropriately.
- Midrectum are the most common sites but, in severe cases, the rectum, sigmoid, descending and even proximal colon can be aganglionic. Rectal biopsy is a-ganglionic.
- Infants with Hirschsprung's disease show delay in the passage of meconium, constipation, vomiting and abdominal distension.

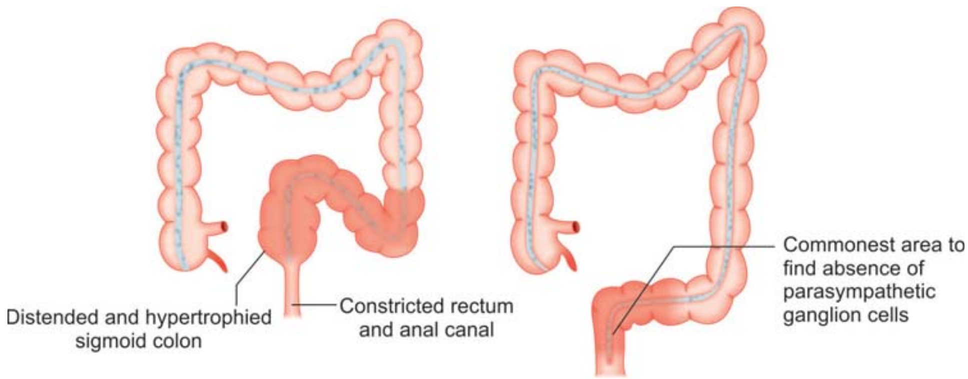
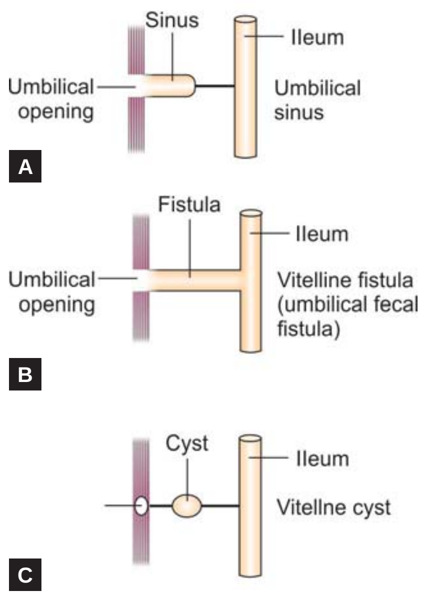


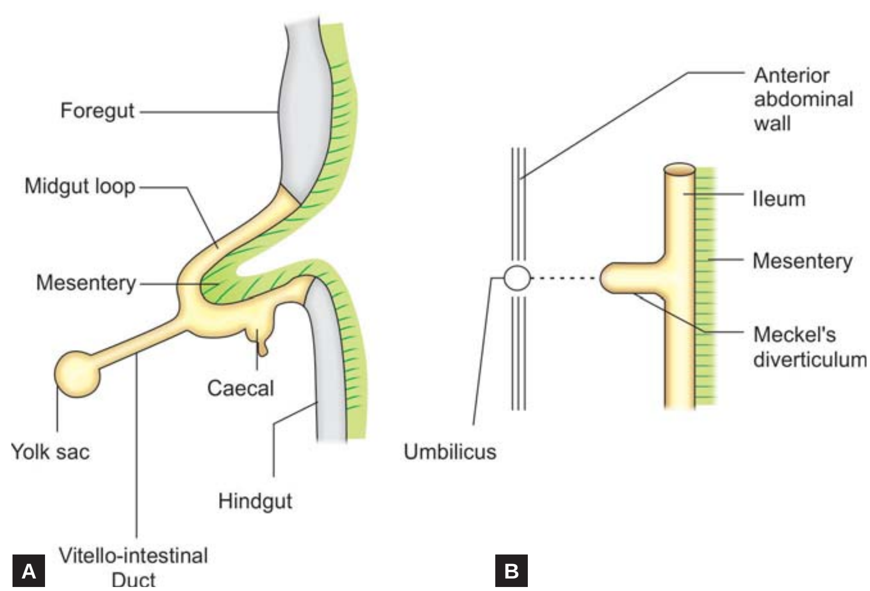
Fig. 95: Main characteristics of primary megacolon (Hirschsprung's disease)

Meckel's Diverticulum

- A congenital ileal diverticulum (of Meckel); found in **2–3% of individuals** and represents the remnant of the proximal part of the **vitellointestinal duct**.
- It projects from the **antimesenteric border** of the terminal ileum and is commonly located between **50 and 100 cm** (2 feet) from the ileocaecal junction.
- It is variable in length (usually **2 inches** in adults) and often possesses a short 'mesentery'.
- The lumen of the diverticulum usually has a calibre similar to that of the ileum.
- Small heterotopic areas of gastric body type epithelium, pancreatic, colonic or other tissues may also occur in the wall of a diverticulum.
- Heterotopic gastric tissue may lead to ulceration and bleeding in the adjacent normal ileal mucosa.
- Diverticular inflammation may mimic acute appendicitis; pain is referred to the periumbilical region.



Figs. 96A to C: A. Umbilical sinus. B. Umbilical fistula. C. Vitelline cyst



Figs. 97A and B: Meckel's anomalies arise from the abnormal persistence of vitellointestinal duct

PERITONEAL FOLD (EMBRYOLOGY) AND MESENTERY

- Peritoneum
- Parietal layer is derived from somatopleuric layer (lateral plate mesoderm)
  - Innervated by somatic nerves (sensitive to prick and cut).
- Visceral layer is derived from splanchnopleuric layer (lateral plate mesoderm)
  - Innervated by ANS (insensitive to prick and cut).

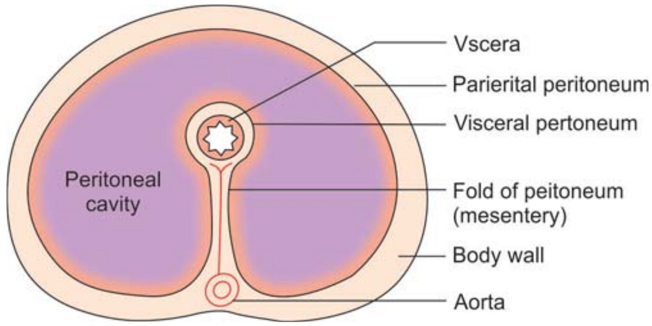


Fig. 98: Schematic transverse section of the abdomen showing arrangement of the peritoneum

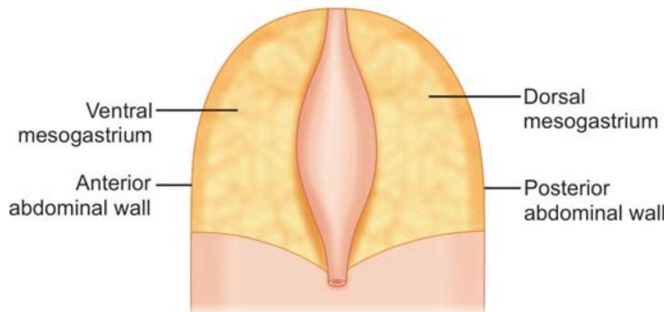


Fig. 99: Side view of stomach showing dorsal and ventral mesogastrium

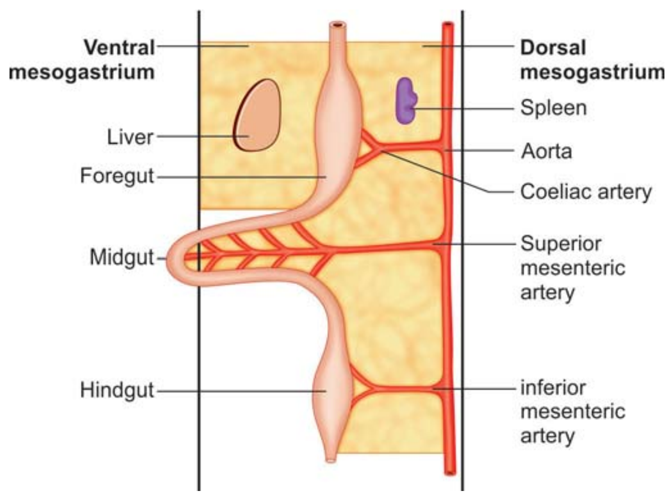


Fig. 100: Schematic diagram showing three parts of the primitive gut with their arteries and mesenteries

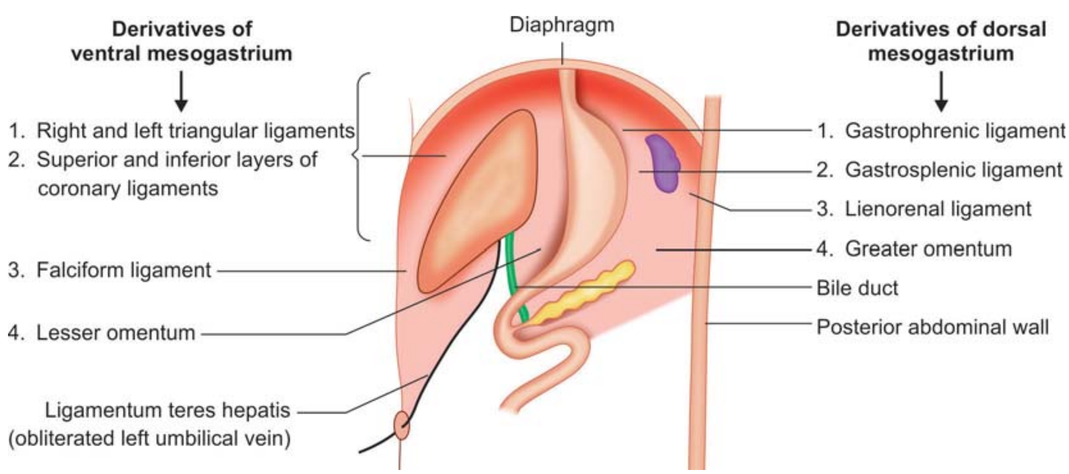
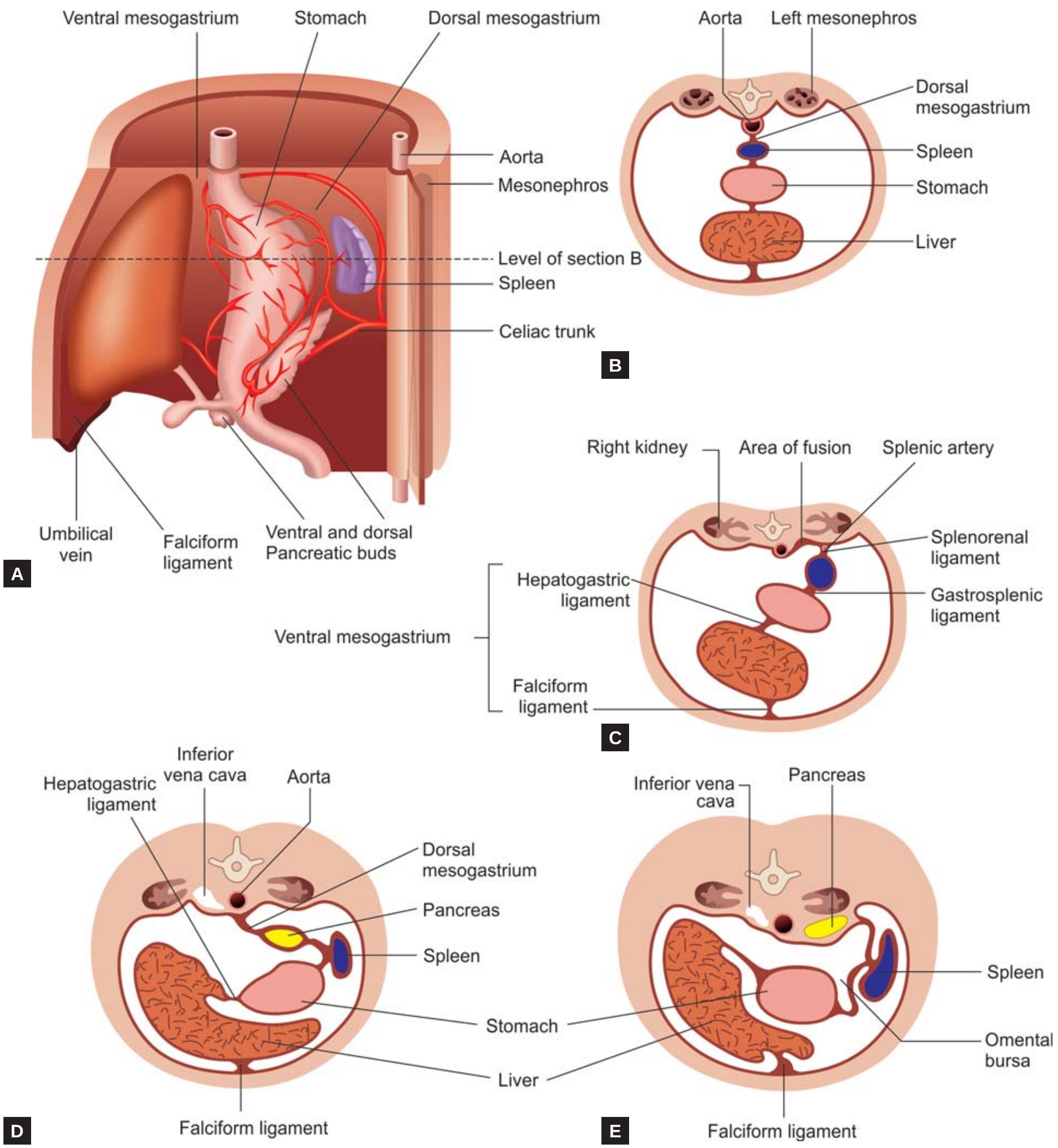


Fig. 101: Derivatives of ventral and dorsal mesogastrium



Figs. 102A to E: A, Left side of the stomach and associated structures at the end of the fifth week. Note that the pancreas, spleen, and celiac trunk are between the layers of the dorsal mesogastrium. B. Transverse section of the liver, stomach, and spleen at the level shown in A. illustrating their relationship to the dorsal and ventral mesenteries. C. Transverse section of a fetus showing fusion of the dorsal mesogastrium with the peritoneum on the posterior abdominal wall. D and E. Similar sections showing movement of the liver to the right and rotation of the stomach. Observe the fusion of the dorsal mesogastrium to the dorsal abdominal wall. As a result, the pancreas becomes retroperitoneal

Mesenteries

The primitive gut tube is suspended within the peritoneal cavity of the embryo by a ventral and dorsal mesentery from which all adult mesenteries are derived.

Table 17: Derivation of adult mesenteries

Embryonic mesentery	Adult mesentery
Ventral	Lesser omentum (hepatoduodenal and hepatogastric ligaments), falciform ligament of liver coronary ligament of liver, triangular ligament of liver
Dorsal	Greater omentum (gastrorenal, gastrosplenic, gastrocolic, and splenorenal ligaments), mesentery of small intestine, mesoappendix, transverse mesocolon, sigmoid mesocolon

- Lesser omentum contains the right and left gastric vessels, and its right free margin contains the proper hepatic artery, bile duct, and portal vein, forming the anterior wall of the epiploic foramen.
- Greater omentum contains the right and left gastroepiploic vessels.
- The mesentery proper contains the superior mesenteric vessels and branches and tributaries.
- The transverse mesocolon contains the middle colic vessels.
- The sigmoid mesocolon contains the sigmoid vessels, and the mesoappendix contains the appendicular vessels.
- Lienogastric (gastrosplenic) ligament contains the short gastric and left gastroepiploic vessels, and the lienorenal (splenorenal) ligament contains the splenic vessels and tail of the pancreas.
- The free margin of the falciform ligament contains the ligamentum teres hepatis, which is the fibrous remnant of the left umbilical vein, and the paraumbilical vein, which connects the left branch of the portal vein with the subcutaneous veins in the region of the umbilicus.

Table 18: Characterization of abdominal structures by location and support

Characterization	Organ
Intraperitoneal (supported by mesentery)	Abdominal esophagus, stomach, first 2 cm of superior part of duodenum (duodenal cap), liver, gall bladder, pancreatic tail, spleen, jejunum, ileum, caecum (variable), appendix, transverse colon, sigmoid colon
Secondarily retroperitoneal (adherent)	Duodenum (except initial 2 cm), pancreas (except tail), caecum, ascending and descending colon, rectum (upper 2/3)
Extra/ retroperitoneal	Thoracic esophagus, rectum, kidneys, ureters, adrenals, abdominal aorta, Inferior vena cava

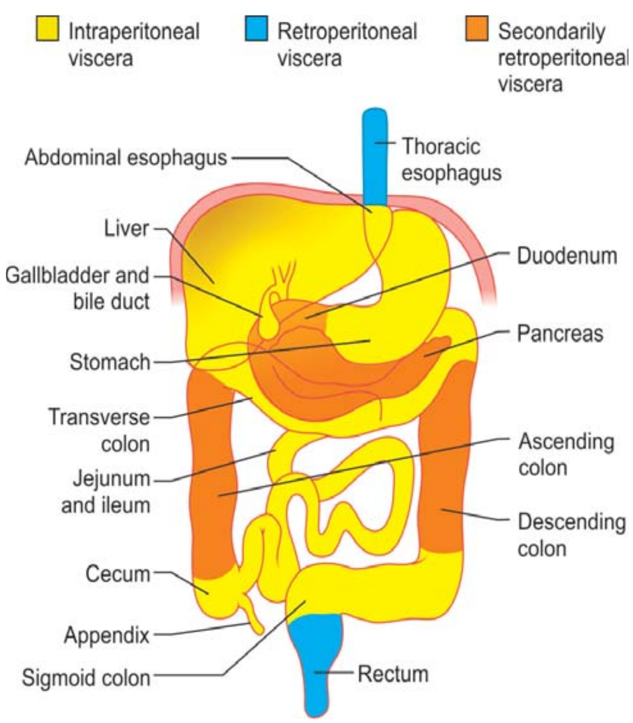


Fig. 103: Development of retroperitoneal structures

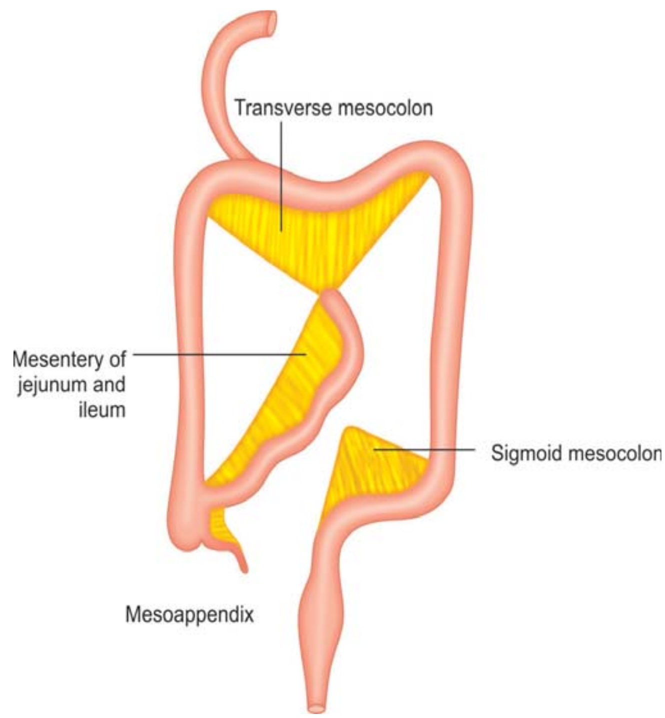


Fig. 104: Fate of dorsal mesentery of midgut and hindgut

The transverse mesocolon attaches to the transverse colon that lies between the colic flexures.

The sigmoid mesocolon is that region of the mesentery to which the sigmoid colon is attached at the gastrointestinal mesenteric margin.

The mesoappendix is the portion of the mesocolon connecting the ileum to the appendix. It may extend to the tip of the appendix. It encloses the appendicular artery and vein, as well as lymphatic vessels, nerves, and often a lymph node.

The mesorectum is that part attached to the upper third of the rectum.

Spleen develops in cephalic part of dorsal mesogastrium from its left layer during 6th week of intrauterine life into a number of nodule which soon fuse to form a lobulated spleen.

- The notches in the superior border of adult spleen are representatives of growth that separated the lobules during fetal period.

Gastrosplenic ligament is part of the greater omentum, derived from the dorsal mesogastrium.

- It connects the greater curvature of stomach with the hilum of the spleen.
- Contents: Short gastric vessels and left gastroepiploic vessels.

ASSESSMENT QUESTIONS

1. **Which of the following structure doesn't develop in mesentery of stomach?** *(AIIMS 2010)*
   a. Liver
   b. Kidney
   c. Spleen
   d. Pancreas

2. **Part of colon with no mesentery:** *(NEET Pattern 2015)*
   a. Transverse colon
   b. Sigmoid colon
   c. Ascending colon
   d. Rectum

3. **Gastrosplenic ligament contains:** *(NEET Pattern 2015)*
   a. Splenic vessels
   b. Tail of pancreas
   c. Short gastric artery
   d. Portal vein

4. **Ventral mesogastrium derivatives include all EXCEPT:** *(JIPMER 2001)*
   a. Falciform ligament
   b. Coronary ligament
   c. Lesser omentum
   d. Gastrosplenic ligament

5. **Which one of the following ligaments contains splenic artery?** *(NEET Pattern 2014)*
   a. Gastrosplenic ligament
   b. Splenocolic ligament
   c. Splenorenal ligament
   d. Splenophrenic ligament

6. **Which of the following structure develop in ventral part of ventral mesentery of stomach?**
   a. Falciform ligament
   b. Hepatogastric ligament
   c. Lesser omentum
   d. Splenogastric ligament

7. **Spleen develops from:** *(NEET Pattern 2015)*
   a. Ventral mesogastrium
   b. Dorsal mesogastrium
   c. Hindgut mesentery
   d. Midgut mesentery

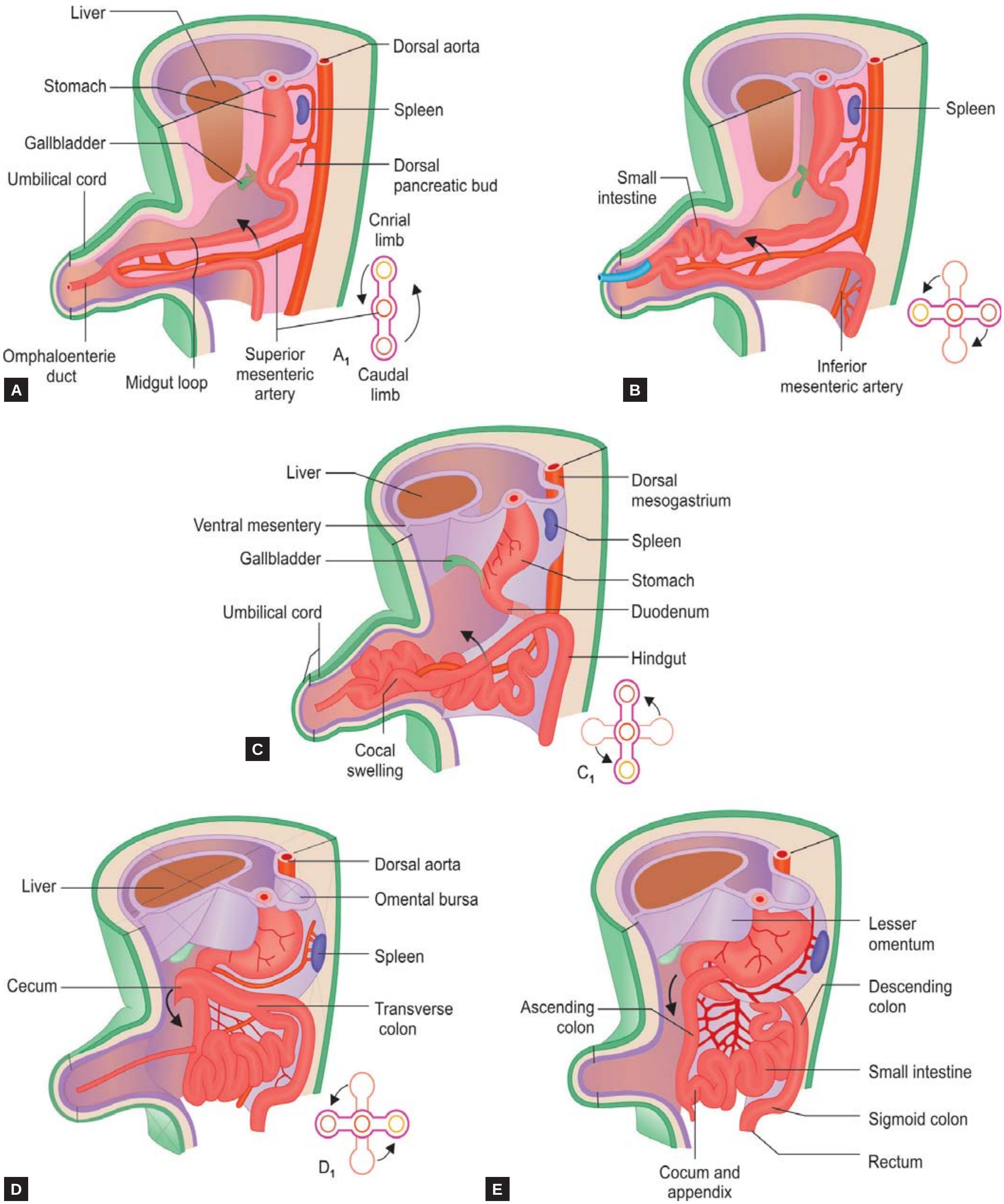
8. **During development spleen lobulation is related to:** *(NEET Pattern 2015)*
   a. Lateral
   b. Superior
   c. Inferior
   d. None

ANSWERS WITH EXPLANATIONS

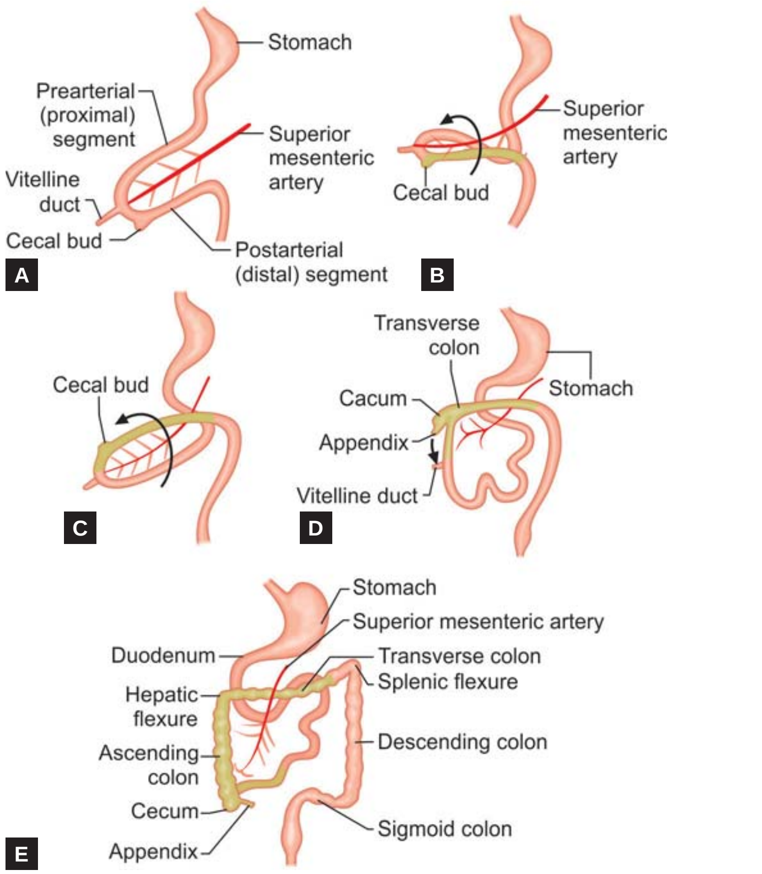
1. **b. Kidney**
   - **Kidney** lies on the posterior abdominal wall and develops behind peritoneum (is retroperitoneal).
   - **Liver** develops in ventral mesentery and **pancreas** and spleen develop in dorsal mesentery.
2. **c. Ascending colon**
   - Ascending and descending colon have no mesentery.
3. **c. Short gastric artery**
   - **Gastrosplenic** ligament contains **short gastric vessels** and **left gastroepiploic vessels**.
4. **d. Gastrosplenic ligament**
   - Gastrosplenic ligament develops in dorsal mesogastrium.
5. **c. Splenorenal ligament**
   - Splenorenal ligament (lienorenal ligament) is a double fold of peritoneum, where the wall of the general peritoneal cavity comes into contact with the lesser sac between the left kidney and the spleen.
   - It carries splenic artery and vein between its two layers.
6. **a. Falciform ligament**
   - Falciform ligament develops in the ventral part of the ventral mesentery and lesser omentum (hepatogastric ligament) in the dorsal part of ventral mesentery.
7. **b. Dorsal mesogastrium**
   - Spleen develops in cephalic part of dorsal mesogastrium from its left layer.
8. **b. Superior**
   - **Spleen** develops in the dorsal mesogastrium as a number of nodule which fuse to form a lobulated spleen.
   - The notches in the superior border of adult spleen are representatives of growth that separated the lobules during fetal period.

GUT ROTATION

- Midgut forms a U-shaped loop (**midgut loop**) that herniates through the **primitive umbilical ring** into the extraembryonic coelom (i.e., physiological umbilical herniation) beginning at **week 6.**
- The midgut loop consists of a cranial limb and a caudal limb.
- The cranial limb forms the jejunum and upper part of the ileum.
- The caudal limb forms the **caecal diverticulum**, from which the cecum and appendix develop; the rest of the caudal limb forms the lower part of the ileum, ascending colon, and proximal 2/3 of the transverse colon.
- The midgut loop rotates a total of **270° anticlockwise** around the superior mesenteric artery as it returns to the abdominal cavity, thus reducing the physiological herniation, around week 10-11.



Figs. 105A to E: Herniation and rotation of the midgut loop. A, At the beg inning of the sixth week. A" Transverse section through the midgut loop, illustrating the initial relationship of the limbs of the midgut loop to the superior mesenteric artery. Note that the midgut loop is in the proximal part of the umbilical cord. B, Later stage showing the beginning of midgut rotation. B1, Illustration of the 90-degree counterclockwise rotation that carries the cranial limb of the midgut to the right. C. At approximately 10 weeks, showing the intestines returning to the abdomen. C_1, Illustration of a further rotation of 90 degrees. D, At approximately 11 weeks, showing the location of the viscera (internal organs) after contraction of intestines. D1, Illustrations of a further rotation of 90-degrees rotation of the viscera, for a total of 270 degrees. E, Later in the fetal period, showing the cecum rotating to its normal position in the lower right quadrant of the abdomen



Figs. 106A to E: Rotation of midsut loop as seen in left side view. A. Primitive loop before rotation. 8. Antidodcwisc 90° rotation of midgut loop while it is in the extraembryonic celom in the umbilical cord. C. Anticlockwise 180° rotation of midgut loop as it is withdrawn into the abdominal cavity. D. Descent of cecum takes place later. E. Intestinal loops in final position

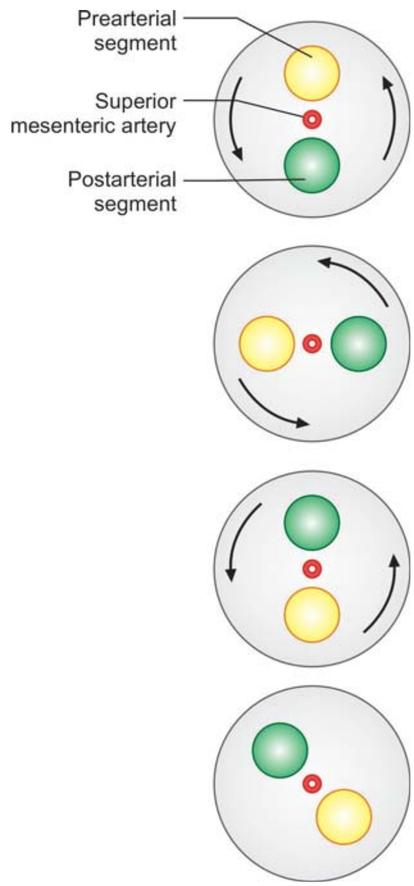


Fig. 107: Schematic diagrams to show the orientation of prearterial and postarterial segments of midgut loop during different phases of its rotation

Clinical Correlations

Omphalocele is a ventral body wall defect caused by failure of physiologically herniated loops of bowel to return to the body cavity in the 10-11th week.

- Omphalocele occurs when abdominal contents herniate through the umbilical ring and persist outside the body covered variably by a translucent peritoneal membrane sac (a light-gray, shiny sac) protruding from the base of the umbilical cord.
- Large omphaloceles may contain stomach, liver, and intestines.
- Omphaloceles are usually associated with multiple congenital anomalies like chromosomal defects, cardiovascular and neural tube defects.

Gastroschisis occurs when there is a defect in the ventral abdominal wall usually to the **right of the umbilical ring** through which there is a massive evisceration of intestines (other organs may also be involved).

- The intestines are **not covered by a peritoneal membrane**, are directly exposed to amniotic fluid, and are thickened and covered with adhesions.
- It is seen on the right side of the umbilicus (unlike omphalocele, which is a midline defect).
- Operative correction is possible, but volvulus remains a problem, due to presence of a long mesentery.

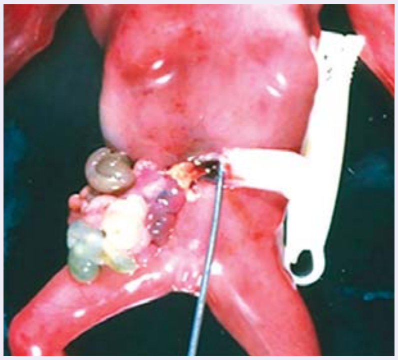


Fig. 108: Gastroschisis

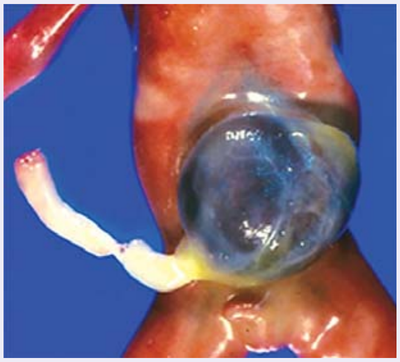


Fig. 109: Omphalocele

Rotation anomalies (**Malrotations**) are defects of gut rotation and commonly classifies as **three** variants:

1. Non-rotation, 2. Mixed rotation, 3. Reverse rotation.

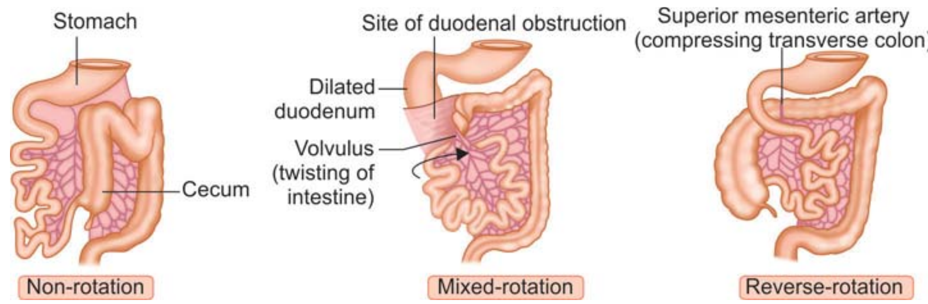


Fig. 110: Rotation anomalies

Malrotations (rotation anomalies)

1. **Non-rotation: The small intestine lies on the right side of the abdomen** and the entire large intestine lies on the left. Although patients are generally **asymptomatic**, if volvulus (twisting) occurs, the superior mesenteric artery may be obstructed, resulting in infarction and gangrene of the associated intestine.

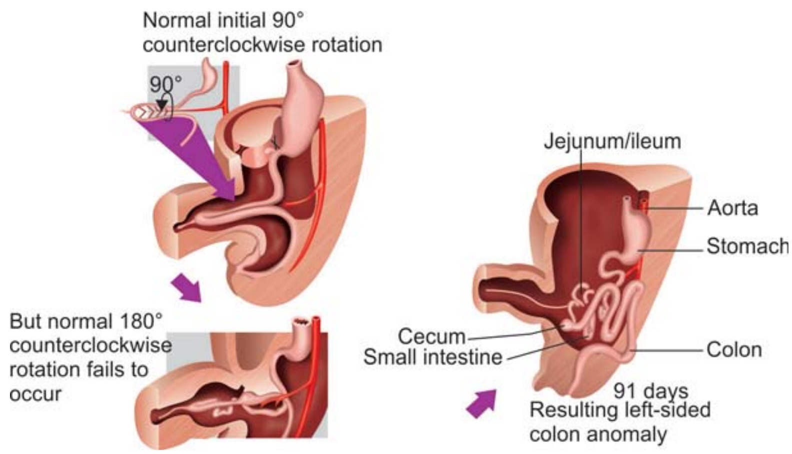


Fig. 111: Non-rotation of the gut leading to left-sided colon

Non-rotation

Pathology: The primary intestinal loop **fails to undergo the normal 180-degree counterclockwise rotation as it is retracted** into the abdominal cavity). The earlier 90-degree rotation may occur normally. The result of this error is that the original cranial limb of the primary intestinal loop (consisting of presumptive jejunum and ileum) ends up on the right side of the(consisting mainly of presumptive colon) ends up on the left side of the body.

2. Incomplete rotation (**Mixed rotation**): The **cecum lies just inferior to the pylorus of the stomach** and is fixed to the posterior abdominal wall by peritoneal bands (**Ladd Band**) that pass over the duodenum. These bands and volvulus usually cause duodenal obstruction.

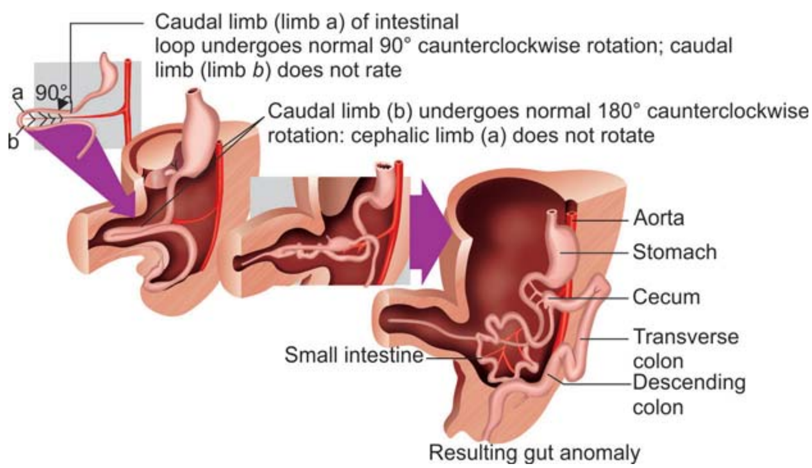


Fig. 112: Mixed rotation of the gut. In this malformation, the cranial and caudal limbs of the primary intestinal loop rotate independently. As a result the cecum becomes fixed near the midline just inferior to the pylorus of the stomach

Pathology: Only the cephalic limb of the primary intestinal loop undergoes the initial 90-degree rotation, whereas only the caudal limb undergoes the later 180-degree rotation. The result of this **mixed or uncoordinated behavior** of the two limbs is that the distal end of the duodenum becomes fixed on the right side of the abdominal cavity, and the **cecum becomes fixed near the midline just inferior to the pylorus of the stomach**. This abnormal position of the cecum may cause the duodenum to be enclosed by a band (**Ladd Band**) of thickened peritoneum, thereby leaving the small intestines tethered on the right by a narrow mesentery, which increases the risk of an intestinal obstruction.

3. **Reverse rotation**: The midgut loop rotates in a **clockwise rather than a counterclockwise** direction. As a result, the duodenum lies anterior to the superior mesenteric artery, rather than posterior to it, and the **transverse colon lies posterior to the superior mesenteric artery** instead of anterior to it. In these infants, the transverse colon may be obstructed by pressure from the superior mesenteric artery.

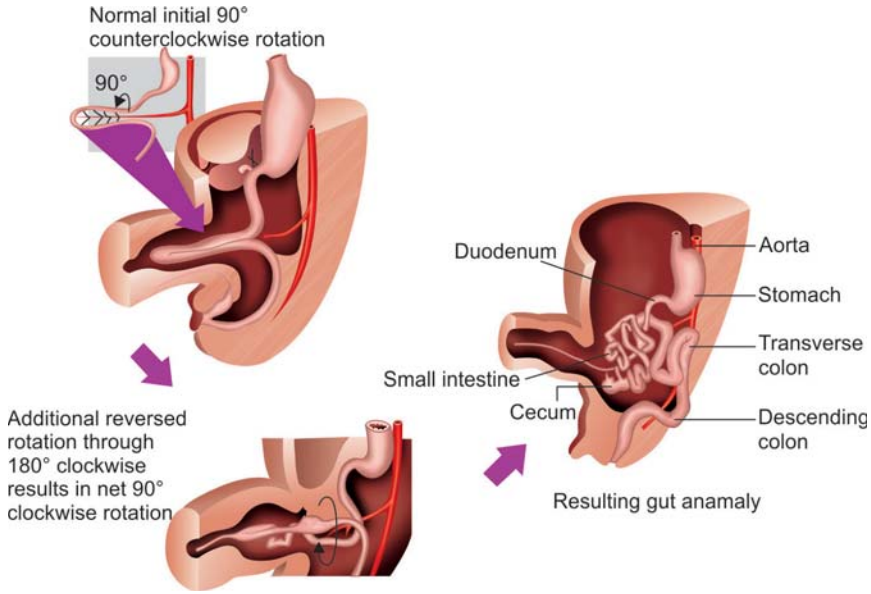


Fig. 113: Mixed rotation of the gut. In this malformation, the cranial and caudal limbs of the primary intestinal loop rotate independently. As a result, the cecum becomes fixed near the midline just inferior to the pylorus of the stomach

Pathology: In reversed rotation of the midgut, the primary intestinal loop undergoes the initial 90-degree counterclockwise rotation normally, **but the second 180-degree rotation occurs clockwise instead of counterclockwise**, so the net rotation of the midgut is 90 degrees clockwise. This rotation brings the regions of the midgut and hindgut into their normal spatial relationships, with one important exception: the duodenum lies ventral to the transverse colon instead of dorsal to it. The duodenum thus does not become secondarily retroperitoneal, whereas the region of the transverse colon underlying it does.

Stomach

In week 4, a fusiform dilatation forms in the foregut, which gives rise to the primitive stomach.

- The primitive stomach rotates 90° clockwise around its longitudinal axis.
- As a result of this clockwise rotation, the dorsal mesentery is carried to the left and eventually forms the greater omentum.
- The left vagus nerve (CN X) innervates the ventral surface of the stomach; and the right vagus nerve (CN X) innervates the dorsal surface of the stomach.

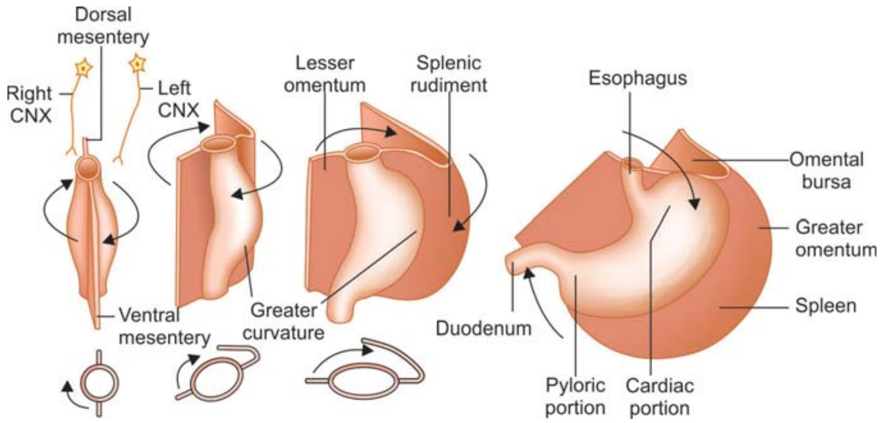


Fig. 114: Rotation of stomach to right side by 90 degrees, taking lesser curvature to right side and greater curvature to left side and formation of lesser sac behind the stomach

RECTUM AND ANAL CANAL

- The terminal end of the hindgut is an endoderm-lined pouch called the **cloaca**, which contacts the surface ectoderm of the proctodeum to form the **cloacal membrane**.
- **Cloaca** is partitioned by the **urorectal septum** into the rectum and upper anal canal and the urogenital sinus.
- The cloacal membrane is partitioned by the urorectal septum into anal membrane and urogenital membrane.
- The urorectal septum fuses with the cloacal membrane at the future site of the **perineal body**.
- The **upper anal canal** develops from the hindgut and the **lower anal canal** develops from the proctodeum, which is an invagination of surface ectoderm caused by a proliferation of mesoderm surrounding the anal membrane.
- The junction between the upper and lower anal canals is indicated by the **pectinate line**, which also marks the site of the former anal membrane.
- Pectinate line lies at the lower border of the anal columns.

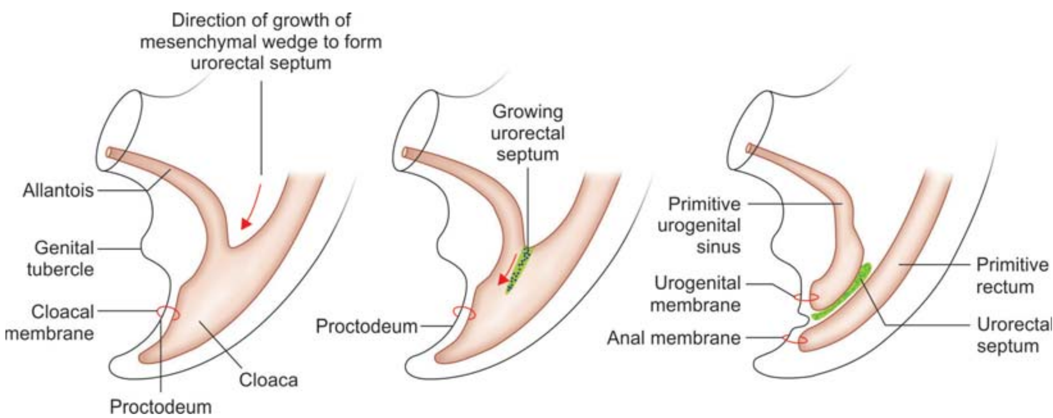


Fig. 115: Successive stages of formation of urorectal septum, which divides the cloaca into anterior part (the primitive urogenital sinus) and posterior part (the primitive rectum)

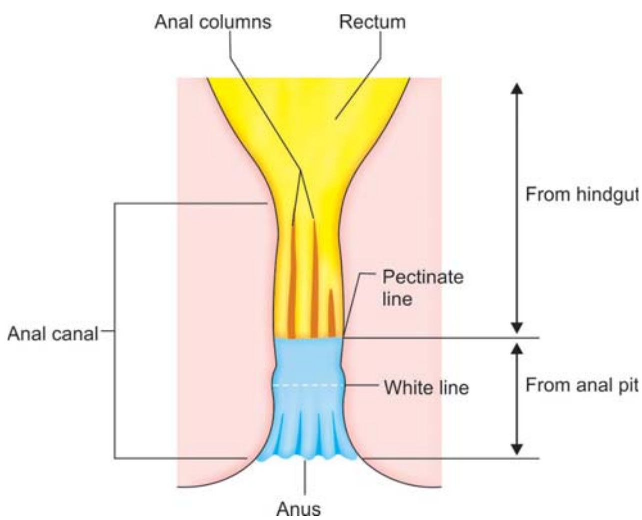


Fig. 116: The rectum and anal canal, showing their developmental origins. Note that the superior two-thirds of the anal canal are derived form the hindgut, whereas the inferior one-third of the anal canal is derived form the anal pit. Because of their different embryologic origins, the superior and inferior parts of the anal canal are supplied by different arteries and nerves and have different venous and lymphatic drainages

ASSESSMENT QUESTIONS

1. Physiological hernia reduces at month?
   a. 1
   b. 2
   c. 3
   d. 4

2. Which is NOT associated with vitello-intestinal duct?
   a. Ileal diverticulum
   b. Umbilical sinus
   c. Enterocystoma
   d. Mesenteric cyst

3. Meckel's diverticulum is a remnant of: *(AIIMS 2005)*
   a. Stenson's duct
   b. Wolffian duct
   c. Mullerian duct
   d. Vitellointestinal duct

4. Regarding Meckel's diverticulum all are true EXCEPT: *(AIIMS-2015)*
   a. At anti-mesenteric border
   b. Vitello-intestinal duct remnant
   c. 3″ long
   d. Pain at umbilicus

5. **Remnant of omphalomesenteric duct is /are:** *(PGIC 2013)*
   a. Umbilical fistula
   b. Umbilical sinus
   c. Meckel's diverticulum
   d. Median umbilical fold
   e. Omphalocele

6. **Hirschsprung's disease is specifically known as:**
   a. Congenital megacolon
   b. Aganglionic megacolon
   c. Congenital aganglionic megacolon
   d. Congenital atretic aganglionic megacolon

7. **From which of the following is the duodenum derived?** *(NEET Pattern 2013)*
   a. Foregut
   b. Midgut
   c. Foregut and midgut
   d. Midgut and hindgut

8. **Descending colon is supplied by:** *(JIPMER 2016)*
   a. Superior mesenteric artery
   b. Inferior mesenteric artery
   c. iliolumbar artery
   d. Lateral sacral artery

9. **TRUE regarding Meckel's diverticulum is:** *(JIPMER 2016)*
   a. Present in mesenteric border
   b. All 3 layers of gut wall are present
   c. Presents commonly with lower abdominal pain
   d. Second commonest congenial anomaly of GI tract

10. **Rectum develops from:** *(NBEP 2013)*
    a. Cloaca
    b. Hind gut
    c. Allantoic remnants
    d. Urogenital sinus

11. **The caecum is found to be placed below the stomach and in midline. Which of the following abnormalities would have taken place in the rotation of gut?** *(AIIMS Pattern 2010)*
    a. Malrotation
    b. Non rotation
    c. Mixed rotation
    d. Reverse rotation

12. **An infant present with an omphalocele at birth. Which of the following applies to this condition?**
    a. It is also seen in patients with congenital aganglionic megacolon
    b. It results from herniation at the site of regression of the right umbilical vein
    c. It is caused by a failure of recanalization of the midgut part of the duodenum
    d. It is caused by failure of the midgut to return to the abdominal cavity after herniation into the umbilical stalk

13. **Regarding Gastroschisis and omphalocele, which one is FALSE?**
    a. Intestinal obstruction is common in gastroschisis
    b. Liver is the content of omphalocele
    c. Gastroschisis is associated with multiple anomalies
    d. Umbilical cord is attached in normal position in gastroschisis

14. **Rectum develops from:** *(NEET Pattern 2012)*
    a. Cloaca
    b. Hind gut
    c. Allantoic remnants
    d. Urogenital sinus

ANSWERS WITH EXPLANATIONS

1. **c. 3**
   - Physiological umbilical hernia: At week 6, the gut tube connected to the yolk sac herniates into the region of umbilical cord.
   - The hernia regresses at week 10-11 and the gut tube returns back to the abdominal cavity.
   - Non-regression of the hernia results in Omphalocele.

2. **d. Mesenteric cyst**
   - Vitello-intestinal duct anomalies may lead to Meckel's ileal diverticulum, Meckel's umbilical sinus, Meckel's enterocystoma.
   - Mesenteric cyst is one of the rarest abdominal tumors present in the mesentery, and is not derived from vitellointestinal duct.

3. **d. Vitellointestinal duct**
   - **Meckel's diverticulum** is the persistent vitellointestinal duct.
   - Vitellointestinal duct is also called as omphalo-enteric duct or yolk stalk, which connects the embryonal gut tube with the yolk sac and normally should disappear.
   - **Stenson's duct** carries secretions of parotid gland, which is very much functional in adult individual.
   - **Wolffian duct** is the other name of mesonephric duct, which forms the male reproductive organs mainly. It forms some vestigial remnants in the females like Gartner's duct.
   - **Mullerian duct** lies around the mesonephric duct and is also called as para-mesonephric duct. Its remnant in males are prostatic utricle and appendix of testis.

4. **c. 3" long**
   - **Meckel's diverticulum** is an outpouching (fingerlike pouch) of the ileum, derived from an unobliterated vitelline duct and located 2 feet proximal to the ileocecal junction on the antimesenteric side.
   - It is a **true diverticulum** having all the layers of gut tube.
   - It is approximately **2 inches** long, occurs in approximately 2% of the population, may contain two types of ectopic tissues (gastric and pancreatic), presents in the first two decades of life and more often in the first 2 years, and is found two times as frequently in boys as in girls.
   - It represents persistent portions of the embryonic yolk stalk (**vitelline** or omphalomesenteric **duct**) and may be free or connected to the umbilicus via a fibrous cord or a fistula.
   - Patient may present with discomfort (and pain) in epigastrium and **umbilical** region (**midgut pain**).

5. a. Umbilical fistula; b. Umbilical sinus; c. Meckel's diverticulum
- Omphalomesenteric (vitello-intestinal) duct is an embryonic structure which connects the yolk sac to the midgut.
- It gets obliterated between the 5th and 9th week of gestation, failure of which result in remnants like Meckel's diverticulum/cyst/fistula.
- Median umbilical fold is a peritoneal fold raised by allantoic remnant called urachus.
- Omphalocele occurs due to non-regression of the physiological umbilical hernia.

6. c. Congenital aganglionic megacolon
- Hirschsprung disease occurs due to non-migration of neural crest cells into the distal part of the gut tube colon/rectum.
- There is absence of myenteric (Auerbach's) ganglia, which is a parasympathetic component for faecal evacuation.
- The diseased segment gets narrowed down and the normal proximal segment is dilated (mega-colon) due to faecal retention.
- Rectal biopsy is a-ganglionic. The presenting complaint is chronic constipation and on per rectal examination, there occurs sudden gush of the retained faeces.

7. c. Foregut and midgut
- Proximal half of duodenum is derived from foregut and distal half from the midgut.

8. b. Inferior mesenteric artery
- Descending colon is a part of hind gut supplied by branches of inferior mesenteric artery.

9. b. All 3 layers of gut wall are present
- **Meckel's diverticulum** is called a true diverticulum, since it has **all the layers** of gut tube.
- It is located at the **antimesenteric** border and is a midgut derivative (pain around the umbilicus).
- It is **the most common** congenital anomaly of gastrointestinal tract.

10. a. Cloaca > b. Hind gut
- Rectum develops in the **cloaca** region of **hind gut.**
- **Cloaca is** the terminal end of the hindgut, which develops urorectal septum.
- Anterior to the septum develops **urogenital sinus,** whereas **rectum** develops posteriorly.

11. c. Mixed rotation
- In mixed rotation the intestine doesn't rotate as it re-enters the abdomen after physiological hernia leading to caecum located just inferior to the pylorus of the stomach in the midline.

12. d. It is caused by failure of the midgut to return to the abdominal cavity after herniation into the umbilical stalk
- **Omphalocele** is a ventral body wall defect caused by failure of physiologically herniated loops of bowel to return to the body cavity in the 10th week.
- Congenital aganglionic megacolon is **Hirschsprung disease**.
- **Gastroschisis** Ventral body wall defect resulting from a lack of closure of the lateral body wall folds in the abdominal region resulting in protrusion of intestines and sometimes other organs through the defect. It results from herniation at the site of regression of the right umbilical vein.
- Failure of recanalization of the midgut part of the duodenum leads to **duodenal atresia.**

13. c. Gastroschisis is associated with multiple anomalies
- It is omphalocele (not gastroschisis) which is associated with multiple anomalies.

14. a. Cloaca > b. Hind gut
- The terminal end of the **hindgut** is an endoderm-lined pouch called the **cloaca,** which is partitioned by the **urorectal septum** into the **rectum** and upper anal canal and the urogenital sinus.

LIVER AND HEPATOBILIARY TREE

- The **endodermal** lining of the foregut forms an outgrowth (called the **hepatic diverticulum**) into the surrounding mesoderm of the septum transversum.
- Cords of **hepatoblasts** (called hepatic cords) from the hepatic diverticulum grow into the **mesoderm of the septum transversum**.
- The hepatic cords arrange themselves around the vitelline veins and umbilical veins, which course through the septum transversum and form the hepatic sinusoids.
- The liver bulges into the abdominal cavity, thereby stretching the septum transversum to form the ventral mesentery, consisting of the falciform ligament and the lesser omentum.
- The falciform ligament contains the left umbilical vein, which regresses after birth to form the ligamentum teres.
- The lesser omentum can be divided into the hepatogastric ligament and hepatoduodenal ligament.

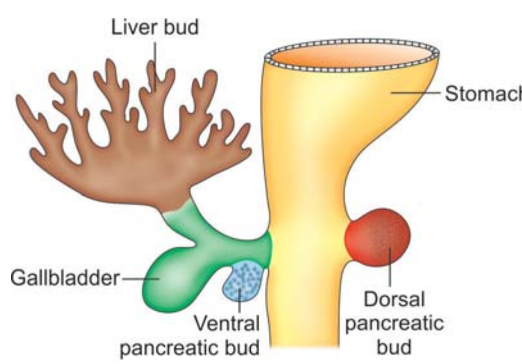
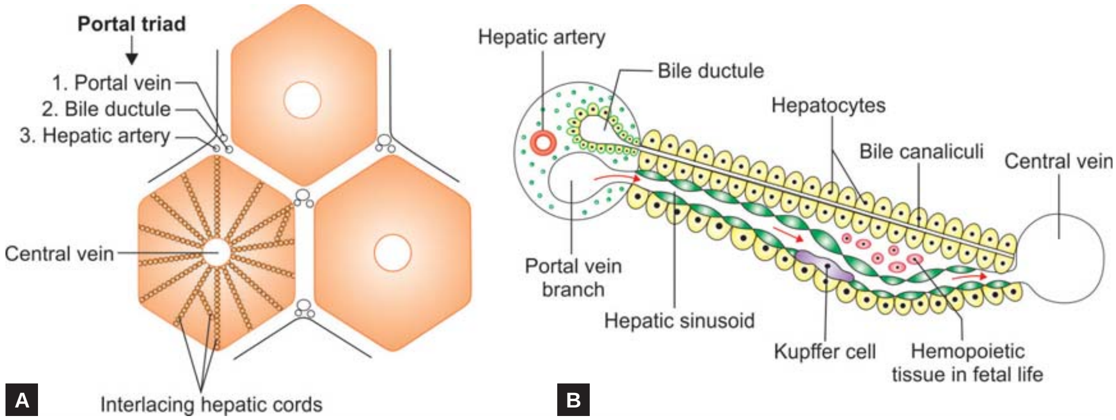


Fig. 117: Development of pancreas

- The hepatoduodenal ligament contains the bile duct, portal vein, and hepatic artery (i.e., portal triad).
- The connection between the hepatic diverticulum and the foregut narrows to form the bile duct.

- An outgrowth from the bile duct gives rise to the **gallbladder** rudiment and **cystic duct**.



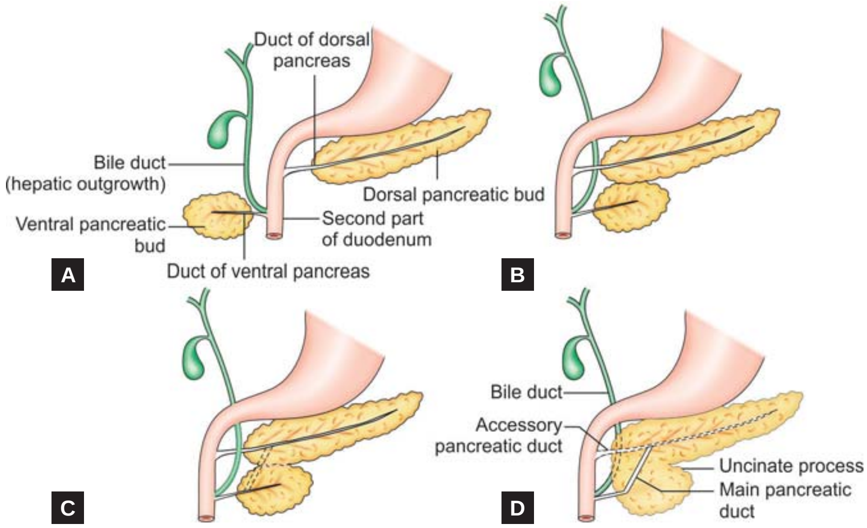
Figs. 118A and B: Histological components of developing liver. A. Arrangement of hepatic cords. Note, they radiate from central vein towards periphery. B. Location of bile canaliculi and bile ductule (derivatives of hepatic bud), liver sinusoids (derivatives of vitelline and umbilical veins), and hemopoietic tissue (derivative of septum transversum)

Table 19: Source of development of various components of the liver

Embryonic structure	Adult derivatives
• Hepatic bud	Liver parenchyma Bile canaliculi and bile ductules
• Vitelline and umbilical veins within septum transversum	Liver sinusoids
• Septum transversum (mesodermal in origin)	• Connective tissue stroma of the liver including Glisson's capsule (fibrous capsule of the liver) • Peritoneal coverings of liver • Kupffer cells • Hemopoietic cells • Blood vessels of liver

PANCREAS

- Pancreas develops from the two pancreatic buds. The ventral pancreatic bud and dorsal pancreatic bud are direct outgrowths of foregut endoderm.
- Within both pancreatic buds, endodermal tubules surrounded by mesoderm branch repeatedly to form acinar cells and ducts (i.e., exocrine pancreas).
- Isolated clumps of endodermal cells bud from the tubules and accumulate within the mesoderm to form islet cells (i.e., endocrine pancreas).
- Due to the 90° clockwise rotation of the duodenum, the ventral bud rotates dorsally and fuses with the dorsal bud to form the definitive adult pancreas.
- The ventral bud forms the **uncinate** process and a portion of the head of the pancreas.



Figs. 119A to D: Schematic diagrams showing stages (A, B, C, and D) of formation of the adult pancreas and its ducts (main and accessory) by the fusion of the dorsal and ventral pancreatic buds

- The dorsal bud forms the remaining portion of the head, body, and tail of the pancreas.
- The **main pancreatic duct** is formed by the anastomosis of the distal two-thirds of the dorsal pancreatic duct (the proximal one-third regresses) and the entire ventral pancreatic duct.
- The proximal portion of the dorsal pancreatic bud gives rise to the **accessory pancreatic duct**

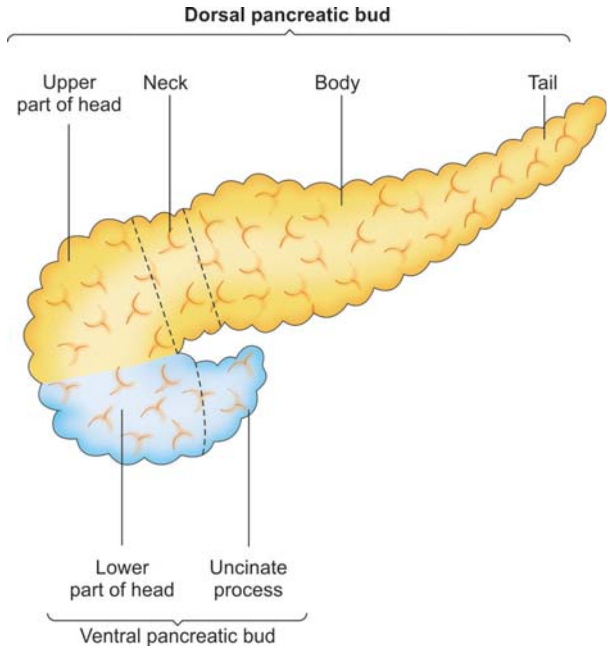


Fig. 120: Derivation of various parts of paracreas from dorsal and ventral pancreatic buds

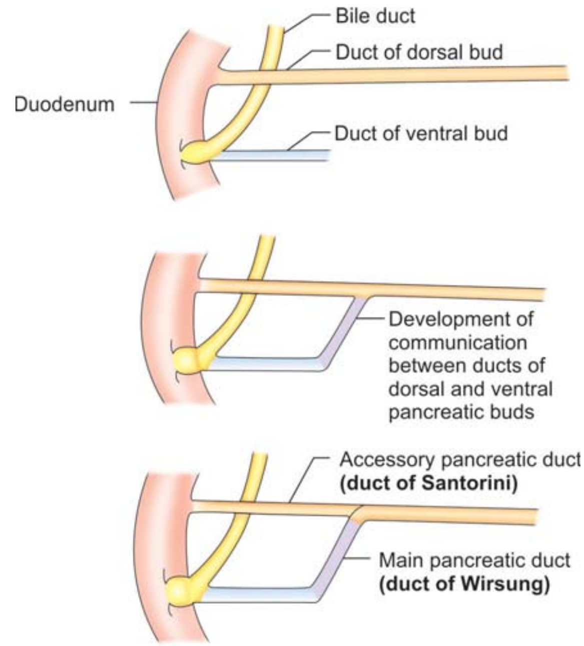


Fig. 121: Schematic diagram to show the development of main and accessory pancreatic ducts

Clinical Correlations

- **Pancreatic divisum** is the most common anomaly of pancreatic develop documented clinically (3-10%).
  - The ducts of the pancreas are not fused to form a full pancreas, but instead it remains as a distinct dorsal and ventral duct.
  - Without the proper fusion of both ducts the majority of the pancreas drainage is mainly through the accessory papilla.
- Pancreas develops from a ventral bud and a dorsal bud that later fuse to form the definitive pancreas. Sometimes, the two parts surround the duodenum **(annular pancreas)**, causing constriction of the gut.

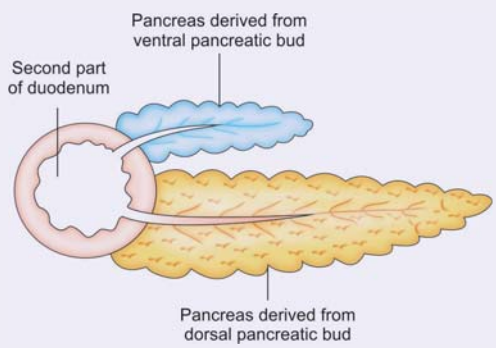


Fig. 122: Divided pancreas

ASSESSMENT QUESTIONS

1. Most common site of ectopic pancreatic tissue is: *(AIIMS 2007)*
   a. Stomach
   b. Jejunum
   c. Appendix
   d. Hilum of spleen

2. Ventral pancreatic duct give rise to: *(NEET Pattern 2015)*
   a. Body
   b. Tail
   c. Neck
   d. Uncinate process

3. Most common congenital anomaly of the pancreas is: *(NEET Pattern 2012)*
   a. Pancreas divisum
   b. Pancreatic cysts
   c. Ectopic pancreas
   d. Inversion of pancreatic ducts

4. Pancreas divisum indicates which of the following? *(NEET Pattern 2012)*
   a. Duplication of the pancreas
   b. Failure of fusion of dorsal and ventral pancreatic buds
   c. Formation of more than two pancreatic buds
   d. Formation of only one pancreatic bud

ANSWERS WITH EXPLANATIONS

1. a. Stomach

- Ectopic pancreatic tissue is most frequently seen in the stomach, duodenum & jejunum.
- Rarely it may be seen in the wall of spleen.

2. d. Uncinate process

- Pancreas develops from the two pancreatic buds:
- The larger one is dorsal pancreatic bud and forms the major portion of pancreas.
- The smaller one is ventral pancreatic bud, which forms the lower part of the head and **uncinate process** of pancreas.

3. a. Pancreas divisum

- **Pancreatic divisum** is the most common anomaly of pancreatic develop documented clinically (3-10%).
- The ducts of the pancreas are not fused to form a full pancreas, but instead it remains as a distinct dorsal and ventral duct.
- Without the proper fusion of both ducts the majority of the pancreas drainage is mainly through the accessory papilla.

4. b. Failure of fusion of dorsal and ventral pancreatic buds

- In **Pancreatic divisum** the ducts of the pancreas are not fused to form a full pancreas, but instead it remains as a distinct dorsal and ventral duct.

MISCELLANEOUS QUESTIONS

ASSESSMENT QUESTIONS

1. Derivatives of midgut: *(NEET Pattern 2015)*
a. Rectum
b. Appendix
c. Liver
d. Stomach

2. Primitive gut is derivatives of: *(CET June 14 Pattern)*
a. Yolk sac
b. Amniotic cavity
c. Allantoic cavity
d. Coelum

3. Ventral mesogastrium derivatives include A/E: *(JIPMER 01)*
a. Falciform ligament
b. Coronary ligament
c. Lesser omentum
d. Gastrosplenic ligament

4. From which of the following is the duodenum derived? *(NEET Dec. 12 Pattern)*
a. Foregut
b. Midgut
c. Foregut and midgut
d. Midgut and hindgut

5. Rectum develops from: *(NEET Dec. 12 Pattern)*
a. Cloaca
b. Hind gut
c. Allantoic remnants
d. urogenital sinus

6. True about anal membrane: *(All India Dec. 13 Pattern)*
a. Perforates at 6 week
b. Develops from anterior part of cloacal membrane
c. Lies at proximal part of proctodaeum
d. Covers urogenital sinus

7. All develop from endodermal cloaca except: *(NEET Dec. 12 Pattern)*
a. Rectum
b. Anal canal
c. Sigmoid
d. Primitive urogenital sinus

8. Endodermal cloaca gives rise to all of the following except: *(NEET Dec. 12 Pattern)*
a. Rectum
b. Lower 1/2 of anal canal
c. Upper 1/2 of anal canal
d. Mucous membrane of bladder

9. Urinary bladder develops from: *(CET July 15 Pattern)*
a. Proallantoic hind gut
b. Proctodeum
c. Cloaca
d. None

10. All of them develop in the mesentery of stomach except: *(AIIMS Nov. 12,10)*
a. Liver
b. Spleen
c. Kidney
d. Pancreas

11. Artery of hindgut is: *(All India Dec. 13 Pattern)*
a. Coeliac trunk
b. Superior mesenteric
c. Inferior mesenteric
d. None

12. Before formation of head and tail folds, the most cranial part of embryo: *(CET June 14 Pattern)*
a. Septum tansversum
b. Neural plate
c. Notochord
d. Primitive streak

13. All are derivatives of septum transversum except: *(AI 11)*
a. Falciform ligament
b. Ligamentum teres
c. Coronary ligament
d. Mesentary of Lesser sac

14. Ligamentum teres of liver is a remnant of: *(PGI May 10)*
a. Ductus venosus
b. Umbilical artery
c. Ductus arteriosus
d. Peritoneum
e. Left umbilical vein

15. Median umbilical ligament is derived from: *(All India Dec. 13 Pattern)*
a. Proximal part of umbilical artery
b. Distal part of umbilical artery
c. Urachus
d. Umbilical vein

16. Most common site of ectopic pancreatic tissue is: *(AIIMS May 07)*
a. Stomach
b. Jejunum
c. Appendix
d. Hilum of spleen

17. Pancreas divisum indicates which of the following? *(NEET Dec. 12 Pattern)*
a. Duplication of the pancreas
b. Failure of fusion of dorsal and ventral pancreatic buds
c. Formation of more than two pancreatic buds
d. Formation of only one pancreatic bud

18. If two buds of pancreas do not fuse, the anomaly is: *(NEET Dec. 12 Pattern)*
a. Ectopic pancreas
b. Pancreatic divisum
c. Annular pancreas
d. Accessory pancreas

19. False about gastroinstestinal development is: *(PGI May 15)*
a. Lower respiratory system develops from foregut
b. Stomach rotates 90° clock wise and its posterior wall grows faster
c. Duodenum rotates to right and is retroperitoneal
d. Dorsal bud form uncinate process
e. Dorsal duct forms santorini duct

20. Meckel's diverticulum is a remnant of: *(All India Dec. 13 Pattern)*
a. Stenson's duct
b. Wolffian duct
c. Mullerian duct
d. Vitellointestinal duct

ANSWERS WITH EXPLANATIONS

1. b. Appendix
- Vermiform appendix is a derivative of midgut.
- Liver & stomach are foregut derivatives and rectum is a hindgut derivative.

2. a. Yolk sac.
- Gut tube develops from the endoderm of yolk sac.

3. d. Gastrosplenic ligament
- Gastrosplenic ligament develops in dorsal mesentery

4. c. Foregut and midgut
- Proximal half of the duodenum develops from foregut and distal half from midgut.

5. a. Cloaca > b. Hindgut.
- Rectum develops from the distal part of the hind gut - the cloaca.

6. c. Lies at proximal part of proctodaeum
- Distal end of cloaca is covered by cloacal membrane which has two parts.
- Urogenital membrane is the ventral (anterior) part of cloacal membrane and covers primitive urogenital sinus.
- Anal membrane is the dorsal (posterior) part of cloacal membrane and covers primitive rectum.
- Anal membrane lies between these two and line of junction of these two parts is represented in later life by anal valves (pectinate line).
- Anal membranes perforates at 9 week to let open the gut tube to the exterior at proctodaeum.

7. c. Sigmoid
- Sigmoid colon develops from the hind gut.

8. b. Lower 1/2 of anal canal
- Lower part of anal canal below the pectinate line develops from ectodermal invagination i.e., proctoderm.

9. c. Cloaca.
- Urinary develops in the ventral part of the cloaca.

10. c. Kidney
- Kidney is a retroperitoneal structure and do not develop in mesentery.

11. c. Inferior mesenteric
- Inferior mesenteric artery supplies the derivatives of the hind gut.

12. a. Septum transversum
- Before formation of head and tail folds, septum transversum is the most cranial structure in embryonic disc.

13. b. Ligamentum teres
- Ligamentum teres is an adult remnant of the left umbilical vein.

14. e. Left umbilical veion
- Ligamentum teres is an adult remnant of the left umbilical vein.

15. c. Urachus
- Median umbilical ligament is the remnant of urachus (obliterated allantois)

16. a. Stomach

- Accessory pancreatic tissue may be found anywhere from the distal end of esophagus to the tip of primary intestinal loop. Most frequently it lies in mucosa of stomach and in Meckel's diverticulum.

17. b. Failure of fusion of dorsal and ventral pancreatic buds

- Pancreatic divisium occurs when ventral and dorsal buds fail to fuse with each other.

18. b. Pancreatic divisum.

- Pancreatic divisium occurs when ventral and dorsal buds fail to fuse with each other.

19. d. Dorsal bud form uncinate process

- Foregut is subdivided into two parts: Pre-laryngeal or cephalic part (pharyngeal gut)- which gives rise to floor of mouth, pharynx and lower respiratory tract.
- *Post-laryngeal (caudal part) gives rise to esophagus, stomach, proximal part of duodenum (up to opening of hepatopancreatic ampulla), liver and extrahepatic biliary system, and pancreas.
- *Stomach rotates by 90 degrees clockwise around its longitudinal axis and original posterior wall grows faster than anterior forming greater and lesser curvatures, respectively.
- Duodenum grows rapidly forming a C- shaped loop that projects ventrally, rotates to the right and becomes retroperitoneal.
- *Uncinate process is formed by ventral pancreatic bud.
- *Proximal part of duct of dorsal bud forms accessory pancreatic duct (Duct of Santorini).

20. d. Vitellointestinal duct

- Abnormal persistence of vitellointestinal duct leads to Meckel's anomalies.

RENAL SYSTEM

Major portion of genitourinary system develops from **intermediate mesoderm**. **Endoderm** of the hind gut contributes to the **terminal portion** of the tubes.

- **Intermediate mesoderm** forms a longitudinal elevation along the dorsal body wall called the **urogenital ridge**.
- A portion of the urogenital ridge forms the **nephrogenic cord**, which gives rise to the urinary system.
- The nephrogenic cord develops into three sets of nephric structures (from cranial to caudal segments): the pronephros, mesonephros, and the metanephros.
- **Pronephros**
  - Develops by the differentiation of mesoderm within the nephrogenic cord to form pronephric tubules and the pronephric duct.
  - It is the cranial-most nephric structure, develops in cervical region and is a transitory structure that regresses completely by week
- **Mesonephros**
  - Develops by the differentiation of mesoderm within the nephrogenic cord to form mesonephric tubules and the mesonephric duct (Wolffian duct).
  - It is the middle nephric structure, develops in thoracic and lumbar region and is a partially transitory structure.
  - Most of the mesonephric tubules regress, but the mesonephric/Wolffian duct persists and opens into the urogenital sinus.
  - Ducts and tubules from the mesonephros form the conduit for sperm from the testes to the urethra. Wolffian duct in females is mostly vestigial.
- **Metanephros**
  - Develops from an outgrowth of the mesonephric duct (called the ureteric bud) and from a condensation of mesoderm within the nephrogenic cord called the metanephric mesoderm.
  - It is the caudal-most nephric structure.
  - It begins to form at week 5 and is functional in the fetus at about week 10.
  - The fetal kidney is divided into lobes, in contrast to the definitive adult kidney, which has a smooth contour.

  The **metanephros** forms the permanent kidney, having two portions: excretory & collecting system.
- Excretory system is constituted by the nephrons, collecting system originates from the ureteric bud, an outgrowth of the mesonephric duct.
- Ureteric bud gives rise to the ureter, renal pelvis, major & minor calyces, and the entire collecting system.
- Connection between the collecting and excretory tubule systems is essential for normal development.

  Early division of the ureteric bud may lead to bifid or supernumerary kidneys with ectopic ureters.

Kidneys develop in the pelvic region and later ascend into the abdomen (lumbar area), abnormal ascent of the kidney, may result in anomalies like horseshoe kidney.

Urinary bladder develops from cloaca, which is a common collecting region for the primitive kidneys and gut system. Urorectal septum in cloaca region subdivides it into the urogenital sinus (anteriorly) and the rectum/anal canal (posteriorly).

Urogenital sinus gives us several derivatives like urinary bladder, **urethra** in the in the female and male (prostatic & membranous portions).

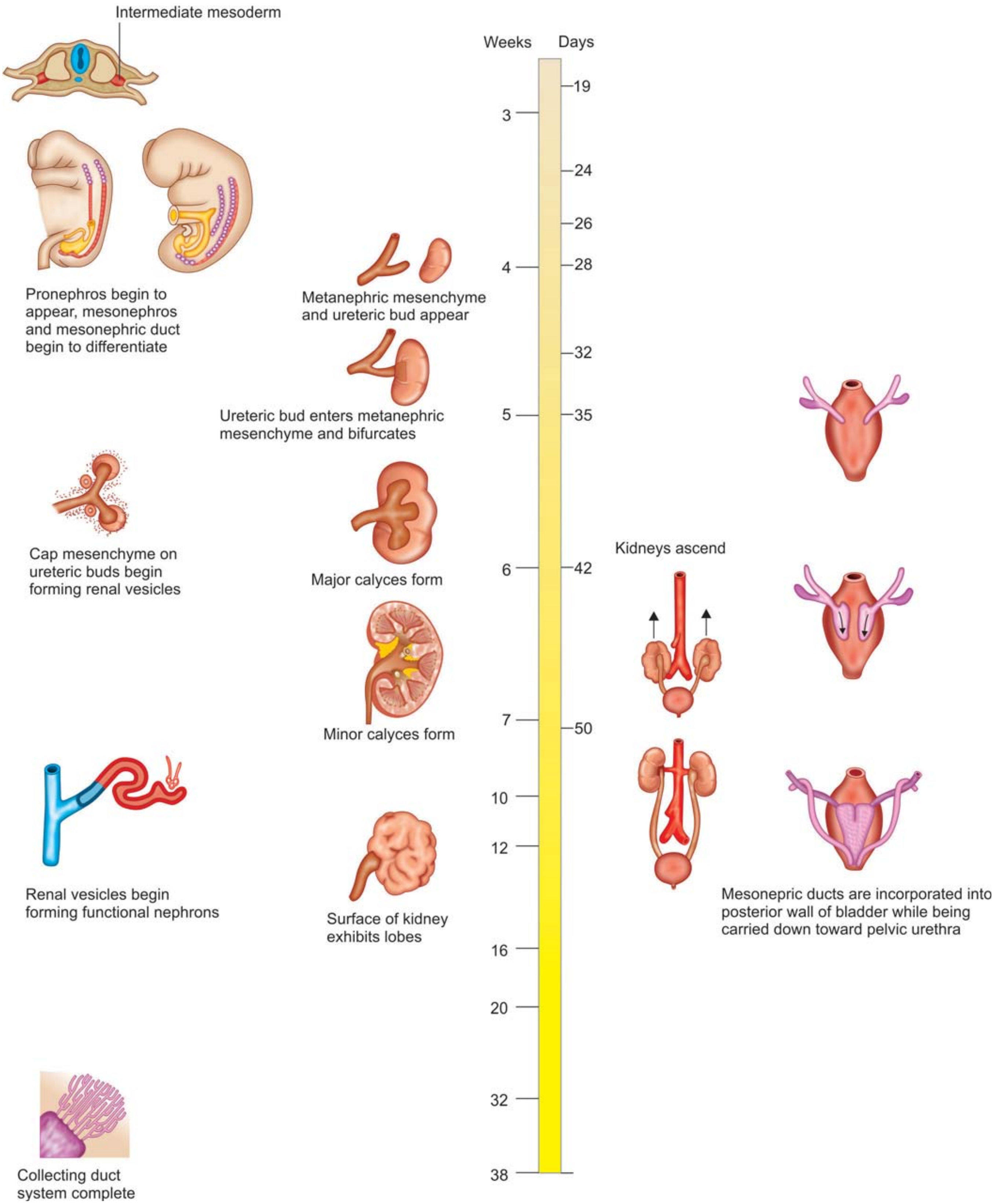
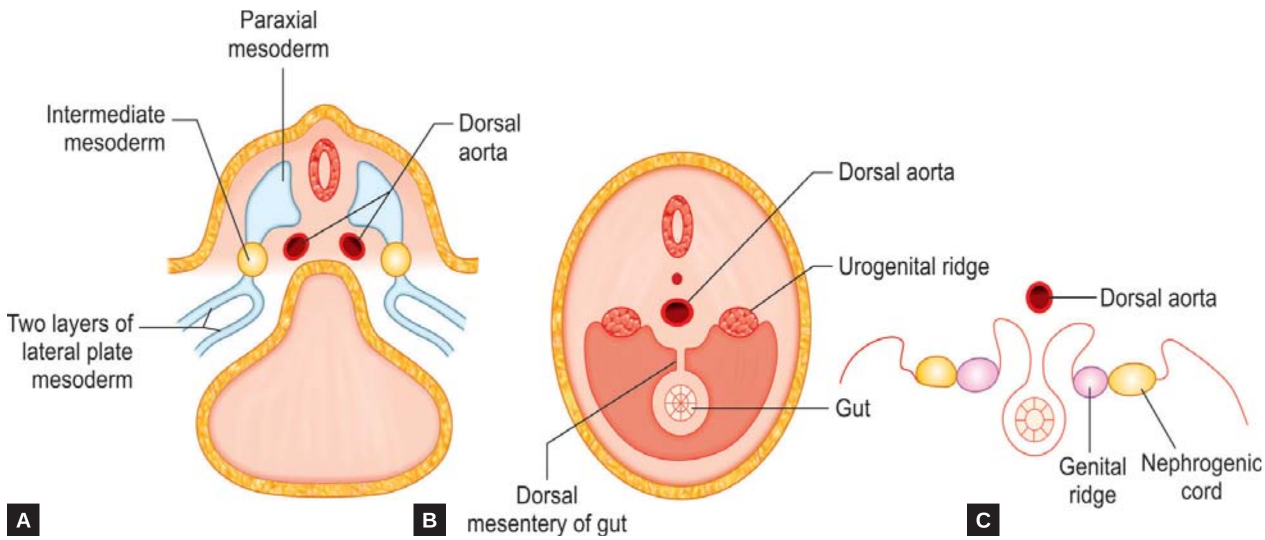


Fig. 123: Development of the urinary system

Development of renal system



Figs. 124A to C: Stage of formation of nephrogenic cord. A. location of intermediate mesoderm. B. Formation of urogenital ridge. C. Differentiation of urogenital ridge into genital ridge and nephrogenic cord.

Table 20: The sequence of events of pronephros, mesonephros, and metanephros

Nephrogenic cord/tissue	Location	Segmentation	Time of appearance	Functional status	Duct
Pronephros	Cervical region	Segmented	Beginning of the fourth week	Nonfunctional/ disappears	Pronephric duct persists
Mesonephros	Thoracolumbar region	Segmented	End of the fourth week	Functional for a short period then disappears, except for its caudal excretory tubules	Mesonephric duct persists
Metanephros	Sacral region	Nonsegmented	Beginning of the third month	Functional	Ureter

Ascent of the Kidneys

Fetal metanephros is located at vertebral levels S1-S2, whereas the definitive adult kidney is located at vertebral level T12-L3.

- The change in location results from a disproportionate growth of the embryo caudal to the metanephros.
- During the relative ascent, the kidneys rotate 90°, causing the hilum, which initially faces ventrally, to finally face medially.
- Vascular buds from the kidneys grow toward and invade the common iliac arteries, while in pelvis.
- Growth of the embryo in length causes the kidneys to 'ascend' to their final position in the lumbar region.
- Rather than 'drag' their blood supply with them as they ascend, the kidneys send out new and slightly more cranial branches and then induce the regression of the more caudal branches.
- Eventually the renal arteries are branches of the abdominal aorta.
- Arteries formed during the ascent may persist and are called supernumerary arteries. Supernumerary arteries are end arteries. Therefore, any damage to them will result in necrosis of kidney parenchyma.

Development of Collecting System

- **Ureteric bud** is an outgrowth of the mesonephric duct.
- It initially penetrates the metanephric mesoderm and then undergoes repeated branching to form the ureters, renal pelvis, major calyces, minor calyces, and collecting ducts.

Development of Nephron

The inductive influence of the collecting ducts causes the metanephric mesoderm to differentiate into metanephric vesicles, which later give rise to primitive S-shaped renal tubules that are critical to nephron formation.

- The renal tubules differentiate into the connecting tubule, the distal convoluted tubule, the loop of Henle, the proximal convoluted tubule, and the Bowman's capsule.
- Tufts of capillaries called glomeruli protrude into Bowman's capsule.

- Nephron formation is complete at birth, but functional maturation of nephrons continues throughout infancy.

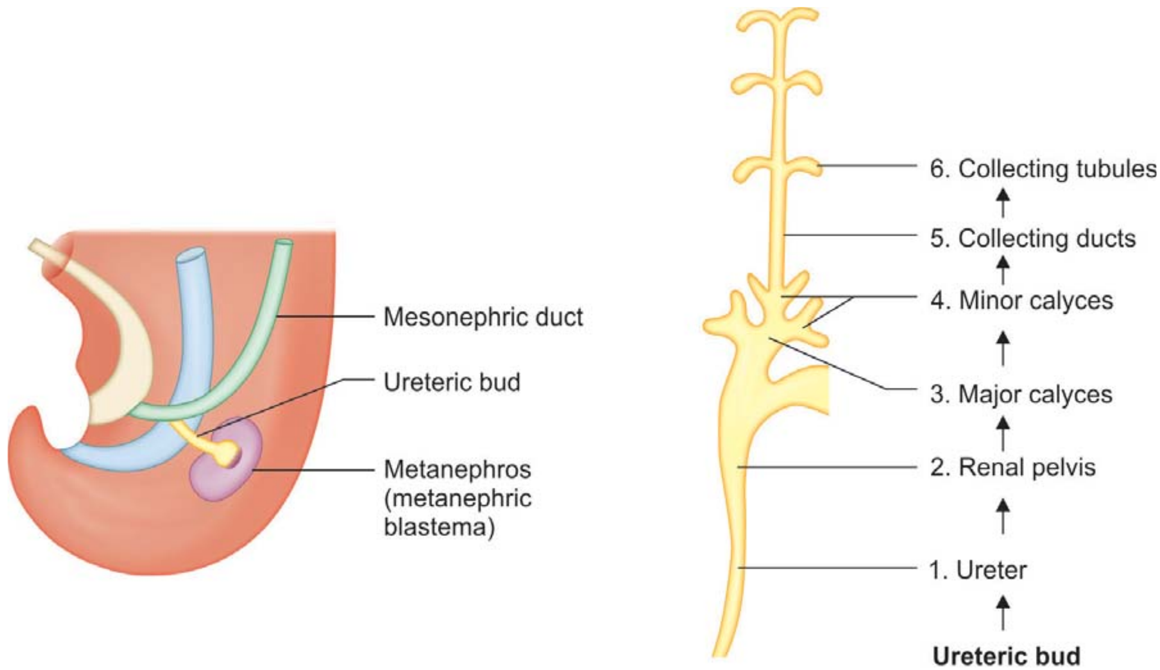


Fig. 125: Development of ureteric bud and metanephric blastema as seen in lateral view of embryo. Figure in the insert shows structures derived from the ureteric bud.

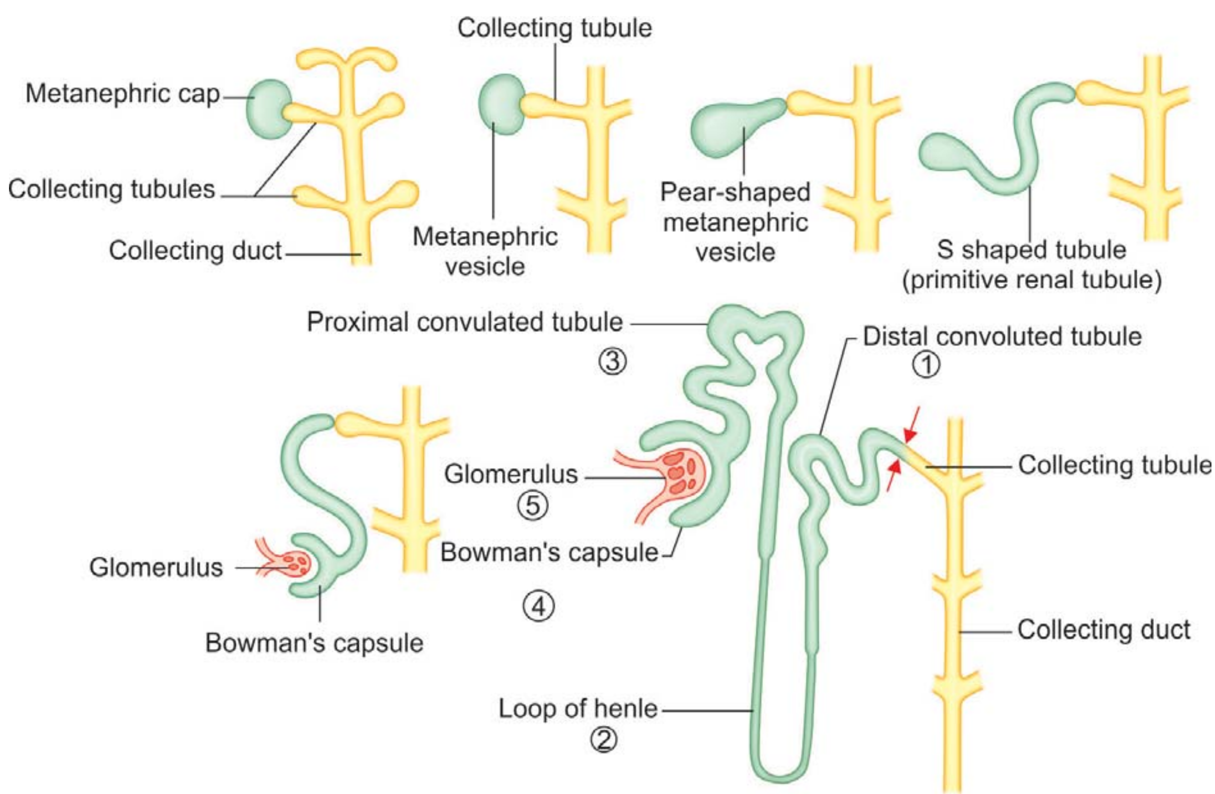
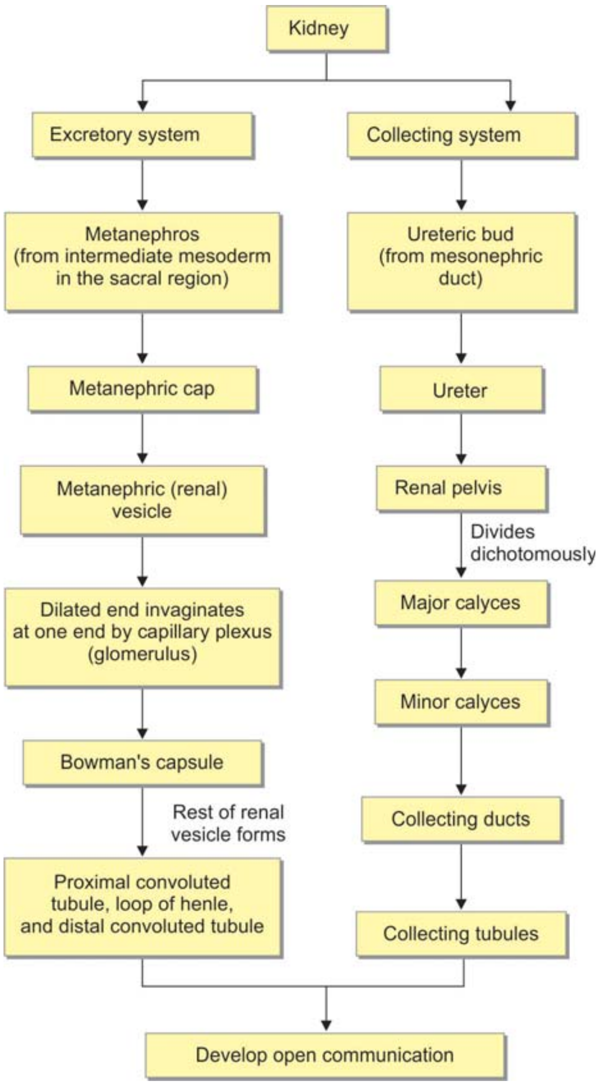
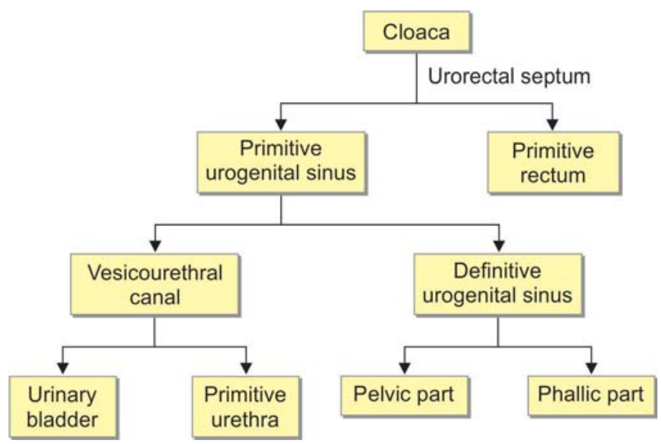


Fig. 126: Stages of development of nephron (excretory system of the kidney consisting of 3 million nephrons). Note each nephron consists of distal convoluted tubule (1), loop of Henle (2), proximal convoluted tubule (3), Bowman's capsule (4), and glomerulus (5). Arrows (red) indicate the place where excretory unit (blue) establishes a communication with the collecting system (yellow).

Flowchart 3: Development of kidney



Flowchart 4: Subdivision of cloaca



Embryo	Adult Derivative
Metanephric mesoderm Metanephric vesicles S-shaped renal tubules	Connecting tubule Distal convoluted tubule Loop of Henle Proximal convoluted tubule Renal (Bowman's) capsule Renal glomerulus
Ureteric bud	Ureter Renal pelvis Major calyx Minor calyx Collecting duct

Development of excretory and collecting parts of kidney

URINARY BLADDER AND URETHRA

Urinary bladder is formed from the upper portion of the urogenital sinus, which is continuous with the allantois.

- The **allantois** becomes a fibrous cord called the urachus (or median umbilical ligament) in the adult.
- The lower ends of the mesonephric ducts become incorporated into the posterior wall of the bladder to form the **trigone** of the bladder.

Allantois is an **endodermal** diverticulum that extends from the ventral region of the urogenital sinus to the umbilicus.

- Later, its distal portion, called the **urachus**, becomes a fibrous cord and forms the **median umbilical ligament**.

- If it remains patent, then it may form a **urachal fistula** or **cyst** in this region.

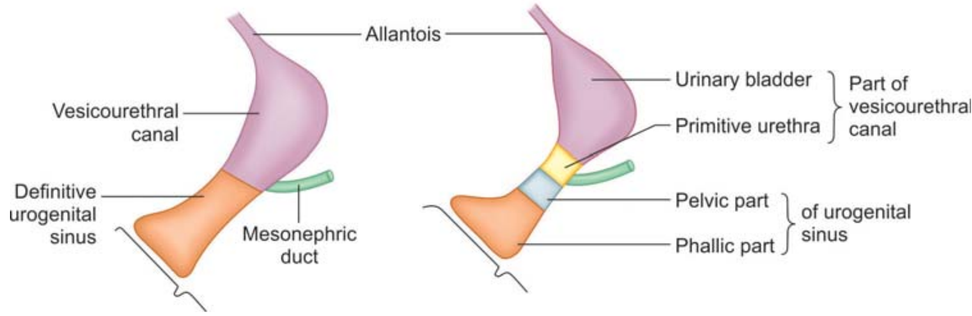


Fig. 127: Subdivisions of primitive urogenital sinus

Table 21: Development of the urinary blader

Embryonic structure	Adult derivatives
Cranial dilated part of vesicourethral canal	Endodermal epithelial lining of the whole urinary bladder except in the region of trigone
Absorption of mesonephric ducts in the dorsal wall of the vesicourethral canal	Mesodermal epithelial lining in the region of trigone of urinary bladder
Splanchnopleuric intraembryonic mesoderm surrounding vesicourethral canal	Muscular and serous coats of the urinary bladder
Allantois	Urachus (median umbilical ligament) and apex of urinary bladder

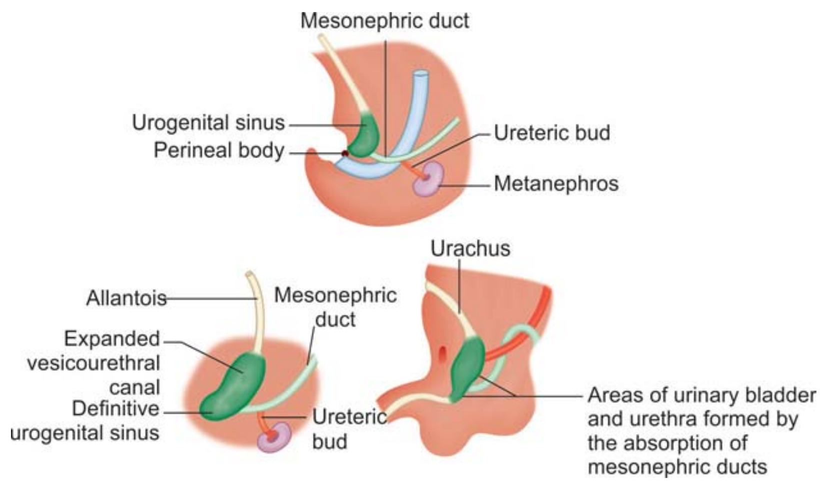
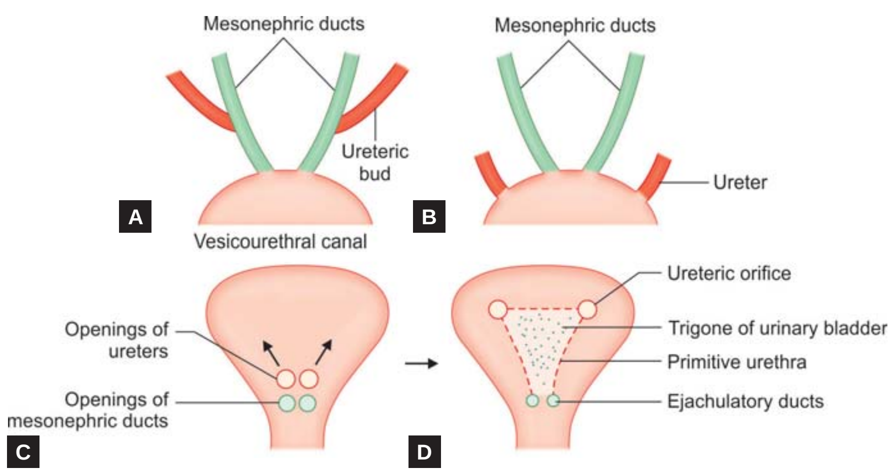


Fig. 128: Absorption of mesonephric ducts into the vesicourethral canal. Note parts of posterior wall of urinary bladder and urethra are formed by the absorption of mesonephric ducts



Figs. 129A to D: Formation of trigone of the urinary bladder. A. Opening of mesonephric ducts into the vesicourethral canal. B. Absorption of mesonephric ducts into the vesicourethral canal. C. At first, openings of ureters and mesonephric ducts are close together. D. Further absorption of ureters causes ureteric openings to shift laterally and upward.

In both sexes, the mesonephric (or Wolffian) duct gives origin on each side to the ureteric bud, which forms the ureter, the pelvis of the ureter, the major and minor calyces and the collecting tubules of the kidney. Its inferior end is absorbed into the developing bladder and forms the trigone and pat of the urethra.

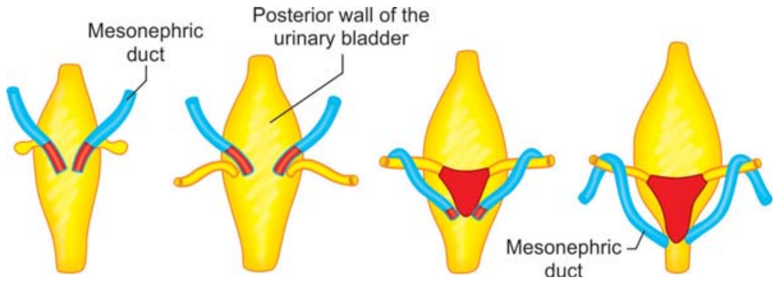


Fig. 130: Development of trigone (urinary bladder). The terminal portion of mesodenphric duct (mesoderm) are absorbed into the posterior wall of urogenital sinus to form trigone

The terminal portion of mesonephric duct gets absorbed into the posterior wall of urinary bladder to form the trigone (mesodermal).

Note: Proximal part of mesonephric duct (**Wolffian duct**) form the conduit for sperm from the testes to the urethra and give rise to **epididymis, ductus deferens, seminal vesicle, common ejaculatory duct**. In the female, these ducts regress.

Table 22: Development of male and female urethra

Urethra	Embryonic source of development
Female urethra	• Caudal part of vesicourethral canal • Pelvic part of definitive urogenital sinus
Male urethra 1. Prostatic part a. Above the level of opening of ejaculatory ducts (colliculus seminalis) b. Below the level of openings of ejaculatory ducts 2. Membranous part 3. Penile part 4. Terminal part (which occupies the glans penis)	• Caudal part of vesicourethral canal • Pelvic part of definitive urogenital sinus • Pelvic part of definitive urogenital sinus • Phallic part of definitive urogenital sinus • Surface ectoderm

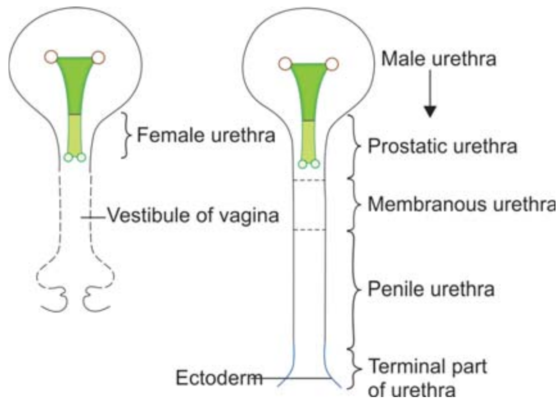
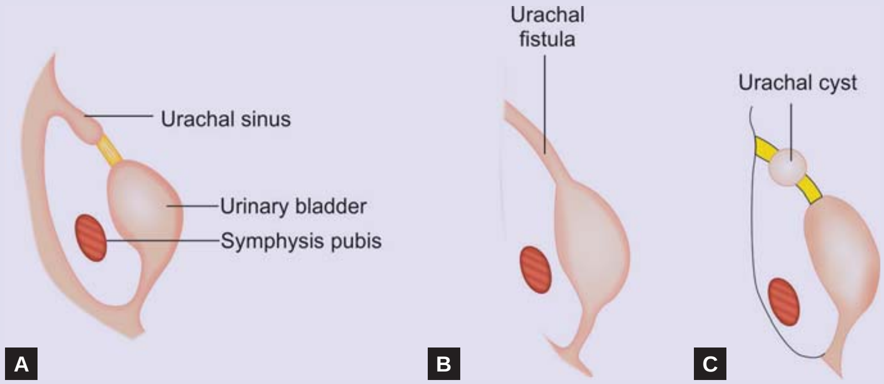


Fig. 131: *Development of urethra. A. Female urethra. B. Male urethra*

Clinical Correlations

- **Renal agenesis** occurs when the ureteric bud fails to develop, thereby eliminating the induction of metanephric vesicles and nephron formation.
- **Congenital polycystic kidney**: Luminal continuity between the nephrons and collecting tubules has failed to establish.
  - The glomeruli continue to excrete urine which accumulates in the tubules due to lack of outlet.
  - As a result tubules undergo cystic enlargements (retention cysts).
- **Pelvic kidney** is an ectopic kidney that occurs when kidneys fail to ascend and thus remain in the pelvis.
  - Two pelvic kidneys may fuse to form a solid lobed organ called a cake (rosette) kidney.
- **Horseshoe kidney** develops as a result of fusion of the lower poles of two kidneys.
  - The ureters pass anterior to the isthmus and may get obstructed due to impingement.
  - The **inferior mesenteric artery** also passes anterior to the isthmus and the horseshoe kidney gets trapped behind the **inferior mesenteric artery** as it attempts to ascend toward the normal adult location
- **Bladder exstrophy** is a ventral body wall defect caused by lack of closure of the lateral body wall folds in the pelvic region resulting in protrusion of the bladder through the defect.
- **Urachal fistula or cyst** occurs when a remnant of the allantois persists, thereby forming fistula or cyst.
- It is found along the midline on a path from the umbilicus to the apex of the urinary bladder.
- A urachal fistula forms a direct connection between the urinary bladder and the outside of the body at the umbilicus, causing urine drainage from the umbilicus.



Figs. 132A to C: Congenital anomalies of urachus. A. Urachal sinus. B. Urachus fistula. C. Urachal cyst

ASSESSMENT QUESTIONS

1. The WRONG statement regarding kidney development is: *(NEET Pattern 2015)*
a. Glomerulus develops from metanephros
b. Ureter develops from metanephric diverticulum
c. Connecting tubule is a derivative of ureteric bud
d. Terminal portion of mesonephric duct forms trigone

2. The ureter develops from: *(AIIMS 2007)*
a. Metanephros
b. Mesonephros
c. Mesonephric duct
d. Paramesonephric duct

3. Most common aberration in renal vessel development: *(AIPG 2010)*
a. Supernumerary arteries
b. Supernumerary renal vein
c. Double renal vein
d. Double renal artery

4. Initially renal arteries are branches of: *(NEET Pattern 2015)*
a. Internal pudendal artery
b. External iliac artery
c. Common iliac artery
d. Aorta

5. Mesonephric derivatives are all EXCEPT: *(AIIMS 2015)*
a. Glomerulus
b. Para-oophoron
c. Vas deferens
d. Epididymis

6. Derivative(s) of mesonephric duct includes: *(PGIC 2014)*
a. Some part of prostatic urethra
b. Seminal vesicle
c. Round ligament of uterus
d. Vas deferens
e. Common ejaculatory duct

7. Urinary bladder develops from: *(NEET Pattern 2012)*
a. Ectoderm
b. Mesoderm
c. Endoderm
d. Neural crest cells

8. The transitional epithelium lining the urethra and the bladder is derived from:
a. Mesoderm
b. Endoderm
c. Wall of the yolk sac
d. Paramesonephric duct

9. A child complains of fluid coming out of umbilicus on straining. The diagnosis is:
a. Patent vitellointestinal duct
b. Gastroschisis
c. Umbilical hernia
d. Urachal fistula

10. Ascent of horseshoe-shaped kidney is prevented by:
a. Superior mesenteric artery
b. Inferior mesenteric artery
c. Superior mesenteric vein
d. Inferior mesenteric vein

11. Collecting tubules of kidney develop from: *(All India Dec. 13 Pattern)*
a. Ureteric duct
b. Mesonephric duct
c. Paramesonephric duct
d. Wolffian duct

12. Kidney develops from: *(All India Dec. 15 Pattern)*
a. Metanephron
b. Mesonephron
c. Blastema
d. All of the above

13. Ureteric bud arises from: *(All India Dec. 13 Pattern)*
a. Paramesonephric duct
b. Mullerian duct
c. Mesonephric duct
d. Mesonephric tubule

14. Epithelium of ureter develops from: *(AIIMS Nov. 07)*
a. Mesonephros
b. Metanephros
c. Pronephros
d. Paramesonephric duct

15. Proximal convoluted tubules develops from: *(JIPMER 98)*
a. Mesonephric duct
b. Metaephric tubules
c. Mesonephric tubules
d. Ureteric buds

16. Uro-rectal septum separates the cloaca into: *(AIIMS 94)*
a. Rectum and bladder
b. Anus and urethra
c. Allantois and bladder
d. Rectum and unogenital sinus

17. Trigone of urinary bladder develops from *(All India Dec. 15 Pattern)*
a. Urogenital sinus
b. Vesicourethral canal
c. Mesonephric duct
d. Endoderm

18. Bladder develops from *(NEET Dec. 12 Pattern)*
a. Ectoderm
b. Mesoderm
c. Endoderm
d. Neural crest cells

19. Urachus fistula is: *(PGI Dec. 04 AMU 06,Up 08)*

a. Patent allantois
b. Ectopic hernia
c. Patent vitellointestinal tract
d. Meckel's diverticulum
e. Umbilical hernia

ANSWERS WITH EXPLANATIONS

1. c. Connecting tubule is a derivative of ureteric bud

- **Connecting tubule** is a part of nephron and develops from metanephric blastema.

Note: Ureter develops from ureteric bud, which is also called as metanephric diverticulum by some authors.

2. c. Mesonephric duct

- **Mesonephric duct** gives the **ureteric bud** which later develops into **ureter**.

3. a. Supernumerary arteries

- The most common aberration in renal vessel development is supernumerary (accessory) renal arteries.
- Approximately 25% of adult kidneys present with 2 - 4 renal arteries (more common on left side).
- Supernumerary arteries arise from the aorta and follow the main renal artery to the hilum of kidney.
- Usually they are given superior to the main renal artery.
- The arteries may also enter the kidney directly to reach the poles (superior/inferior) instead of hilum.
- Supernumerary arteries are twice as common as supernumerary renal veins.

4. c. Common iliac artery

- Kidney's start developing in the pelvic region and are supplied by branches of common iliac arteries.
- Subsequently as kidneys begin to ascend into the abdomen they receive their blood supply from the distal end of the aorta.
- Eventually they receive their most cranial arterial branches, which become the renal arteries, from the abdominal aorta.
- Normally, the caudal primordial branches undergo involution and disappear.

5. a. Glomerulus.

- **Glomerulus** (excretory system) is derived from 'metanehric' blastema (and **not mesonephros**).
- Mesonephric duct gives ureteric bud to form the collecting system of kidney (and not excretory system).
- Wolffian system (developing from Mesonephric duct) gives male reproductive tubes (and becomes vestigial in females).
- Wolffian system in males forms: **Epididymis**, **Vas deferens**, Seminal vesicle, Common ejaculatory ducts, etc.
- Vestigial remnant of Wolffian (mesonephric) system in females are: Epi-oophoron, **Para-oophoron**, Gartener's duct.

6. a. Some part of prostatic Urethra; b. Seminal vesicle; d. Vas deferens; e. Common ejaculatory duct

- In both sexes, the mesonephric duct gives origin to the ureteric bud, which forms the ureter, renal pelvis, major and minor calyces and the collecting tubules of the kidney.
- Its inferior (caudal) end is absorbed into the developing urinary bladder and forms the trigone and posterior wall of the proximal urethra.
- In males mesonephric duct becomes Wolffian duct and its superior (cranial) end is joined to the developing testis by the efferent ductules of the testis.
- Its derivatives are: Epididymis, vas (ductus) deferens, seminal vesicle, common ejaculatory duct.
- Round ligament of the uterus develops from the part of gubernaculum lying between uterus and the labium majus.

7. c. Endoderm

- Urinary bladder develops from the endoderm of vesicourethral canal (cranial part of urogenital sinus).
- The trigone is derived from absorbed distal part of mesonephric duct (mesodermal).

8. b. Endoderm.

- Epithelium of urinary bladder, urethra and vagina develop from endoderm of urogenital sinus.

9. d. Urachal fistula

- Non-obliteration of allantois (hindgut diverticulum) may result in patent allantoic (urachal) fistula, which leads to leakage of urine from the urinary bladder towards the umbilicus, especially on straining.

10. b. Inferior mesenteric artery

- The normal ascent of the kidneys allows the organs to take their place in the abdomen below the adrenal glands.
- However with a horseshoe kidney, ascent into the abdomen is restricted by the inferior mesenteric artery (IMA) which hooks over the isthmus.
- Hence horseshoe kidneys are low lying than normal.

11. a. Ureteric duct.

- Ureteric bud contributes to collecting system and gives derivatives like collecting tubules.

12. d. All of the above.

- Kidney has two parts: The excretory system (true kidney) develops from the metanephric blastema.
- The collecting system develops from Mesonephric duct (ureteric bud).
- Ureteric bud penetrates metanehros to convert it into metanephric blastema, which later develops into true kidney.

13. c. Mesonephric duct

- Ureteric bud arises from the mesonephric duct.

14. a. Mesonephros

- Epithelium of ureter develops from the mesonephric duct, as the ureteric bud.

15. b. Metaephric tubules
- Metanephric tubules form the excretory system of kidney, including nephron parts like PCT (proximal convoluted tubules).

16. d. Rectum and unogenital sinus
- Urorectal septum divides the cloaca region into urogenital sinus (anterior) and rectum (posterior)

17. c. Mesonephric duct
- The terminal portion of mesonephric duct gets absorbed into the posterior wall of urogenital sinus and forms the trigone of urinary bladder.

18. c. Endoderm
- Urinary bladder develops from the ndoderm of urogenital sinus.

19. a. Patent allantois
- Allantois gets obliterated to form urachus, which may remain patent to form urachal fistula.

Urinary System

High Yield Point
- Urinary bladder, liver, pancreas are endodermal derivatives, but kidney is mesodermal *(JIPMER 2006)*

GENITAL SYSTEM

- Genital system consists of (a) gonads or primitive sex glands, (b) genital ducts, and (c) external genitalia.
- The sex of the individual is not established till week 7 (indeterminate embryo).
- Indeterminate embryo
  - The genotype of the embryo (46,XX or 46,XY) is established at fertilization.
  - During week 1–6, the embryo remains in a sexually indifferent or undifferentiated stage. The genetically female and male embryos are phenotypically indistinguishable.
  - During week 7, the indifferent embryo begins phenotypic sexual differentiation.
  - By week 12, female or male characteristics of the external genitalia can be recognized.
  - By week 20, phenotypic differentiation is complete.
  - Phenotypic sexual differentiation is determined by the SRY gene located on the short arm of the Y chromosome and may result in individuals with a female phenotype, an intersex phenotype, or a male phenotype. The SRY gene encodes for a protein called testes-determining factor (TDF).
- The SRY gene on the Y chromosome produces testes determining factor (TDF) and regulates male sexual development.
  - Sertoli and Leydig cells start developing in the testes.
  - Expression of the SRY gene causes (a) development of the medullary (testis) cords, (2) formation of the tunica albuginea, and (c) failure of the cortical (ovarian) cords to develop.
- Ovarian development occurs in the absence of the SRY gene and in the presence of WNT4, the master gene for this differentiation process.
  - It leads to formation of ovaries with (1) typical cortical cords, (2) disappearance of the medullary (testis) cords, and (3) failure of the tunica albuginea to develop.
- Primordial germ cells originate in the epiblast cells (primitive streak), migrate to the endodermal wall of yolk sac and thence to the genital ridge (during the 4th to 6th weeks).
- During the indifferent stage, there are two duct systems: the mesonephric duct and paramesonephric duct.
- Testosterone, produced by Leydig cells in the testes, stimulates development of the mesonephric ducts to form the efferent ducts, epididymis, vas deferens, seminal vesicle and ejaculatory duct.
- Müllerian inhibiting substance (Anti Mullerian hormone), produced by Sertoli cells in the testes, causes regression of the paramesonephric (Mullerian) ducts.
- Dihydrotestosterone stimulates development of the external genitalia, including the penis and scrotum.
- Estrogens (together with the absence of testosterone) regulate development of the paramesonephric ducts, which leads to genesis of the uterus, uterine tube and upper 1/3 of the vagina.
- Estrogens also stimulate differentiation of the external genitalia, including the clitoris, labia, and lower portion of the vagina.
- **External genitalia** also begin in an indifferent stage.
- Initially, a genital tubercle, two genital swellings, and two cloacal folds form on the exterior of the floor of the pelvis.
- When the urorectal septum reaches the interior of this floor to separate the anal canal from the primitive urogenital sinus (soon to form the bladder), the cloacal folds are now called the urethral folds.
- In the male, the genital tubercle grows and is called the phallus.
  - As it grows, it pulls the urethral folds together and these fuse forming the shaft of the penis.
  - Meanwhile, the genital swellings become larger to form the scrotal swellings, and these also come together and fuse in the midline.
- In females, the genital tubercle forms the clitoris, the urethral folds the labia minora, and the genital swellings the labia majora.
  - In female there is a lack of fusion of the primordial structures.
  - The analogous structures in female for penis is clitoris and scrotum is the labia majora.

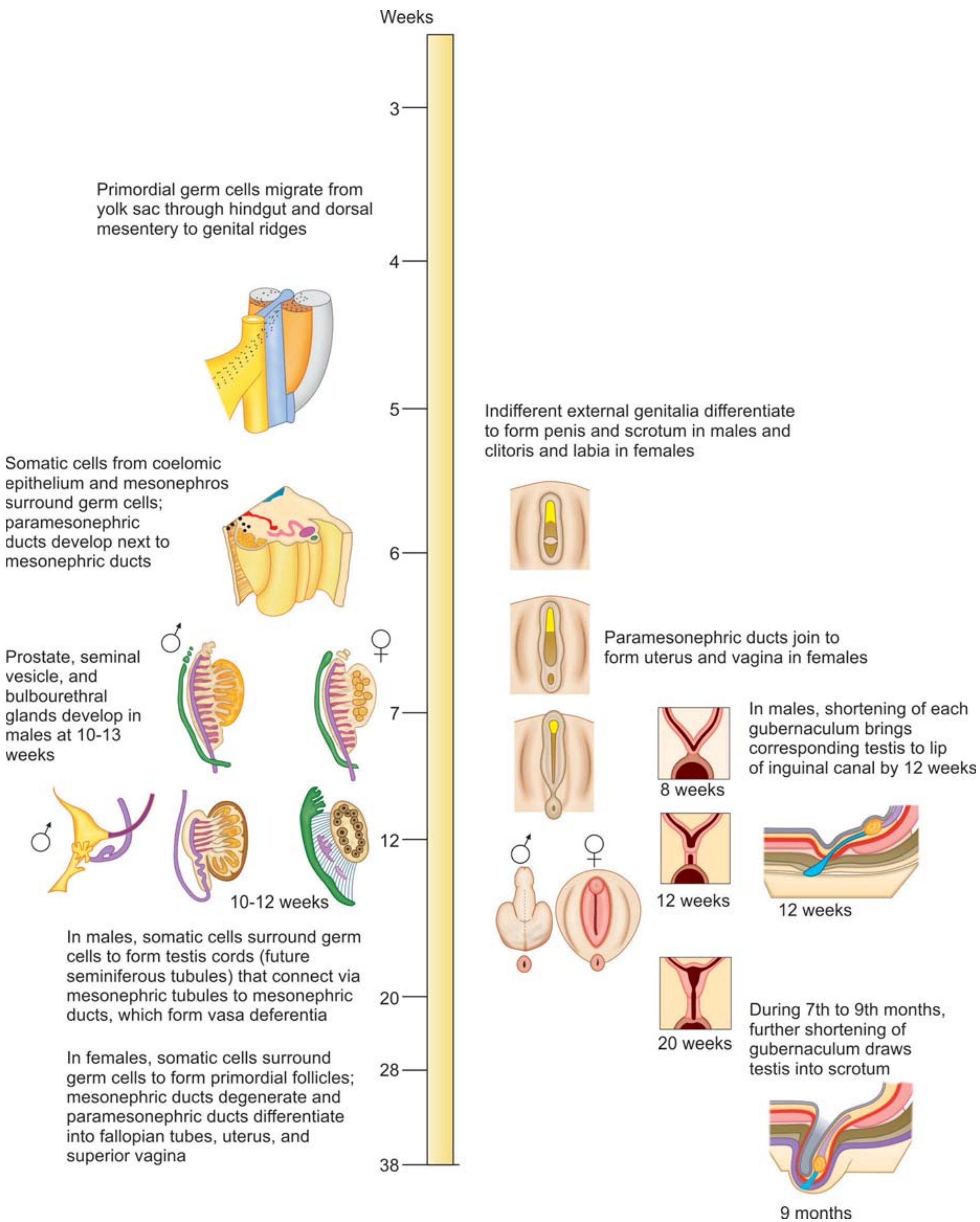


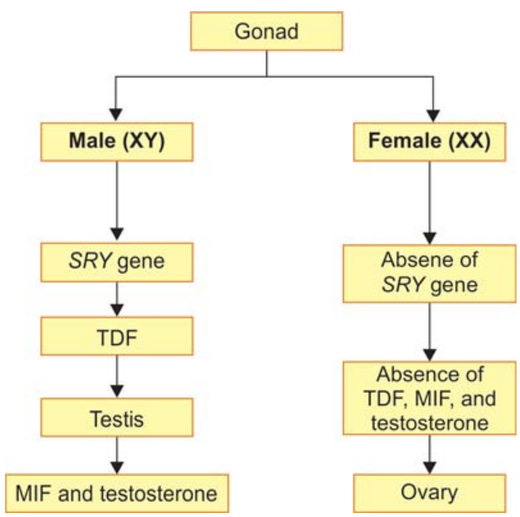
Fig. 133: Development of the reproductive SRY

Table 23: Embryonic structures and their homologous adult derivatives in male and female

	Adult derivatives	
Embryonic structure	**In male**	**In female**
1. Indifferent gonad	Testis	Ovary
a. Primordial germ cells	Spermatogonia	Oogonia
b. Surface epithelium of gonad	Sertoli cells/supporting cells	Follicular cells
c. Mesenchyme	Leydig cells (interstitial cells)	Theca cells (forming theca interna and externa)
2. Gubernaculum	Gubernaculum testis	a. Round ligament of ovary b. Round ligament of uterus

	Adult derivatives	
Embryonic structure	**In male**	**In female**
3. Mesonephric tubules a. Cranial tubules b. Caudal tubules	 Efferent ductules Paradidymis	 Epoophoron Paroophoron
4. Mesonephric duct	Duct of epididymis Vas deferens Seminal vesicle Ejaculatory duct	Gartner's duct
5. Paramesonephric duct	Appendix of testis Prostatic utricle	Uterine tubes Uterus Cervix Upper part of vagina
6. Urogenital sinus	Urinary bladder Urethra (prostatic membranous and penile) Prostate gland Bulbourethral glands	Urinary bladder Urethra (membranous) and vestibule of vagina Paraurethral glands (of Skene) Greater vestibular glands
7. Mullerian tubercle	Seminal colliculus (verumontanum)	Hymen
8. Genital tubercle	Penis	Clitoris
9. Urethral folds	Penile urethra	Labia minora
10. Genital swellings	Scrotum	Labia majora

Flowchart 5: Genetic basis of phenotypical differentiation of testis and ovary



Flowchart 6: Influence of chromosome complement of primordial germ cells on indifferent gonad

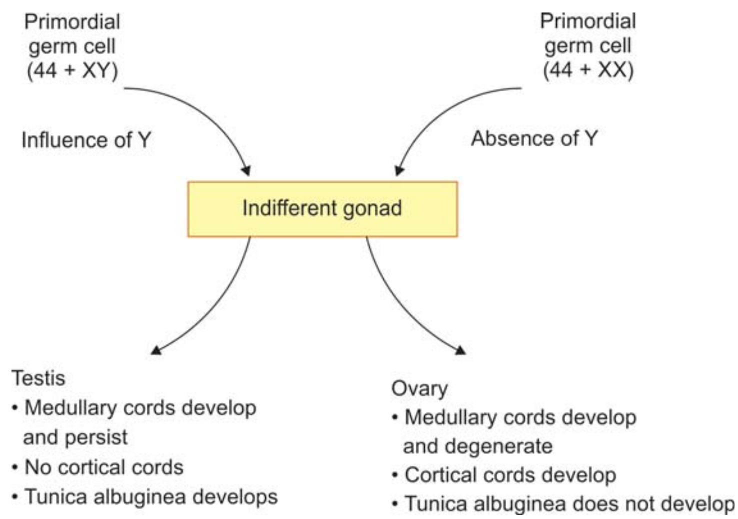
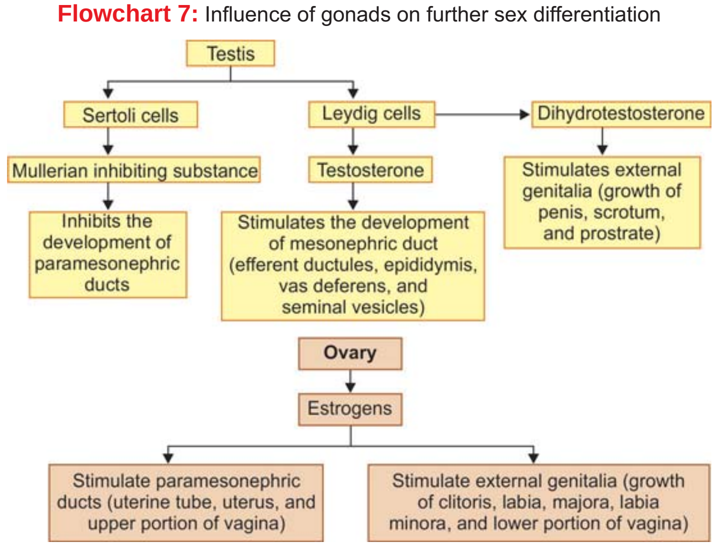


Table 24: Differences in development of testis and ovary

Testis	**Ovary**
• Formation of only one generation of sex cords (medullary cords) that produce seminiferous tubules and rete testis	Formation of two generations of sex cords: a. First generation of sex cords (medullary cords) form stroma of ovarian medulla b. Second generation of sex cords (cortical cords) form primordial follicles (ovarian follicles)
• Formation of tunica albuginea separating seminiferous tubules from surface epithelium	• No formation of tunica albuginea. Hence ovarian follicles are not separated from surface epithelium

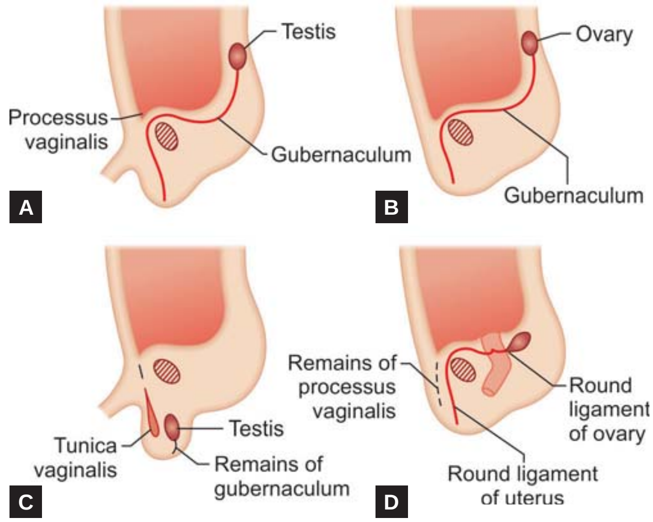
Flowchart 7: Influence of gonads on further sex differentiation



The urogenital sinus is considered in three parts: (1) the cephalad or vesicle portion, which will form the urinary bladder; (2) the middle or pelvic portion, which creates the female urethra; and (3) the caudal or phallic part, which will give rise to the distal vagina and to the greater vestibular (Bartholin) and paraurethral (Skene) glands.

Gubernaculum is the embryonic structures which begin as undifferentiated mesenchyme attaching to the caudal end of the gonads (testes and ovaries).

- As the scrotum and labia majora form in males and females, respectively, the gubernaculum aids in the descent of the gonads (both testes and ovaries).
- The testes descend to a greater degree than the ovaries and ultimately pass through the inguinal canal.
- In males the upper part of the gubernaculum degenerates and lower part persists as the gubernaculum testis (scrotal ligament), which secures the testis to the most inferior portion of the scrotum, tethering it in place and limiting the degree to which the testis can move within the scrotum.
- In females the gubernaculum has two vestigial remnants in females, the ovarian ligament and the round ligament of the uterus (ligamentum teres uteri) which respectively serve to support the ovaries and uterus in the pelvis.



Figs. 134A to D: Descent of gonads from the abdomen region, pulled by gubernaculum

High Yield Points

- Primordial germ cells are derived from the epiblast cells, which later migrate to the endodermal wall of yolk sac and finally reach the genital ridge.
- Between the 3rd and 5th gestational weeks, an elevation of intermediate mesoderm on each side of the fetus - the urogenital ridge begins development into the urogenital tract.
- Genital ridge forms the gonads (testis and ovary).
- There are 7 million oocytes at 5th month of intrauterine life, 2 million at birth and about 400 undergo ovulation.
- It takes 74 days to complete spermatogenesis.
- Upper part of genital tube develops from intermediate mesoderm, whereas lower part from endoderm of urogenital sinus.
- Upper 1/3 vagina develops from Mullerian duct (intermediate mesoderm), whereas lower vagina develops from endoderm of urogenital sinus.
- The Mullerian ducts become the fallopian tubes, uterus, and upper vagina.
- The Wolffian duct give rise to epididymis, ductus deferens, seminal vesicle and common ejaculatory ducts.
- Mesonephric or Wolffian vestiges can persist as Gartner duct cysts (anterolateral wall of vagina).
- Organ of Rosenmüller (Epoophoron) is a remnant of the mesonephric tubules present near the ovary and fallopian tube.
- The appendix testis (hydatid of Morgagni) is a vestigial remnant of the Mullerian duct, attached to the upper pole of the testis.
- Sex determination is not possible before week 7 (indeterminate embryo stage).
- It is impossible to visually differentiate between male and female external genitalia until week 12.
- At 26-28 weeks the testes pass through the deep inguinal ring and inguinal canal. From 28 weeks the testes pass through the superficial inguinal ring and thence to scrotum. It is at the base of scrotum before birth (by the end of nine months).

MALE REPRODUCTIVE SYSTEM

Testis

Intermediate mesoderm forms a longitudinal elevation along the dorsal body wall called the **urogenital ridge**, which later forms the **gonadal ridge**.

- Primary sex cords develop from the gonadal ridge and incorporate primordial germ cells (XY genotype), which migrate into the gonad from the wall of the yolk sac.
- The primary sex cords extend into the medulla of the gonad and lose their connection with the surface epithelium as the thick tunica albuginea forms.
- The primary sex cords form the seminiferous cords, tubuli recti, and rete testes.
- Seminiferous cords consist of primordial germ cells and sustentacular (Sertoli) cells, which secrete MIF.
- Mesoderm between the seminiferous cords gives rise to the interstitial (Leydig) cells, which secrete testosterone.
- Seminiferous cords remain as solid cords until puberty, when they acquire a lumen and are then called seminiferous tubules.

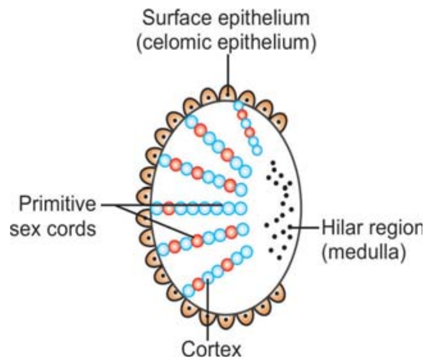


Fig. 135: Indifferent gonad

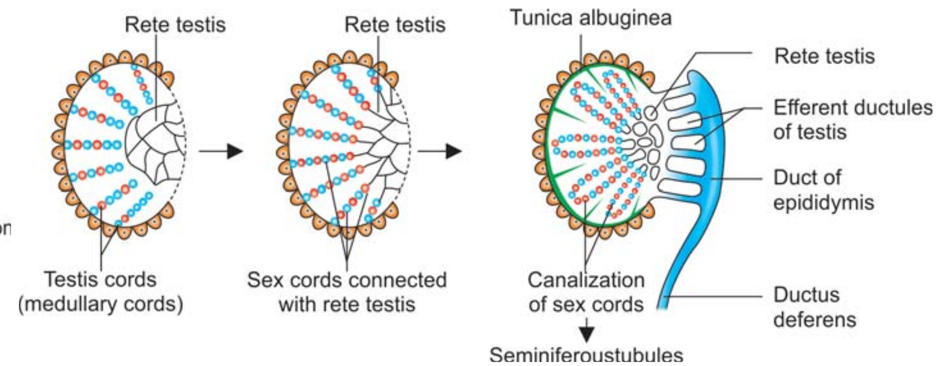


Fig. 136: Development of testis

Descent of Testis

Testis starts developing in the abdomen (lumbar region) and later descends down to the pelvis and reach the scrotum eventually, as a result of disproportionate growth of the upper abdominal region away from the pelvic region.

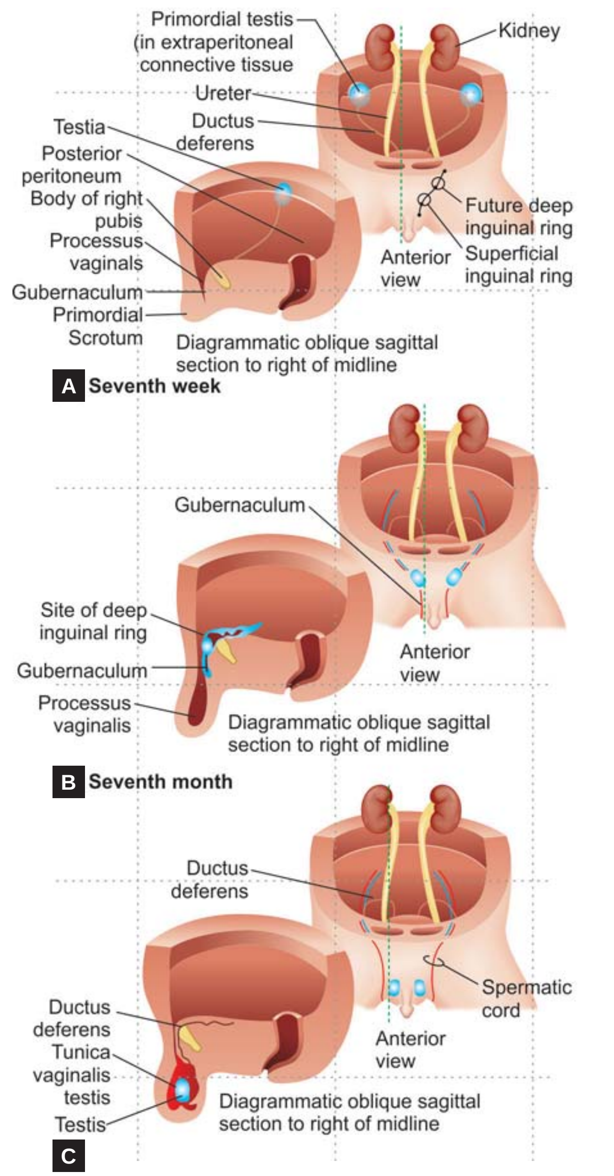
- Gubernaculum pulls the caudal pole of testis to the scrotum and eventually anchor the testes within the scrotum.
- The peritoneum evaginates alongside the gubernaculum to form the processus vaginalis. Later in development, most of the processus vaginalis is obliterated except at its distal end, which remains as a peritoneal sac called the tunica vaginalis of the testes.
- Testis is present in the abdomen at **2nd month** (7th week), descends down to pelvis (iliac fossa) during **third month.**
- It is present at the deep inguinal ring at the **end of 6th month**, and starts passing through inguinal canal at **7th month**.
- It lies at superficial ring at **eighth month** and enters the scrotum at the **beginning of ninth month**.
- It reaches its final position in the scrotum just before birth (**end of ninth month**) and after birth (in few babies).

Position of testis	Month (week) of Intrauterine life
Abdomen	2nd month (7th week)
Pelvis (Iliac fossa)	During 3rd month (12th week)
Deep inguinal ring	At the end of 6th month (24th week)
Pass inguinal canal	During 7th month (25 -28 week)
At superficial inguinal ring	Eight month (29 - 32 week)
Enters scrotum	Beginning of ninth month (33 week)
At the base of scrotum	Before birth (End of 9th month/36th week)

Development of the Genital Ducts

Mesonephric (Wolffian) ducts and tubules

- Mesonephric ducts develop in the male as part of the urinary system because these ducts are critical in the formation of the definitive metanephric kidney.
- Mesonephric ducts then proceed to additionally form the epididymis, ductus deferens, seminal vesicle, and ejaculatory duct.
- A few mesonephric tubules in the region of the testes form the efferent ductules of the testes.
- Vestigial remnants of the mesonephric duct (appendix epididymis) and mesonephric tubules (paradidymis) may be found in the adult male.



Figs. 137A to C: Formation of inguinal canals and relocation of testes. A. In a 7 week embryo, the testis is attached to the posterior abdominal wall. B. A fetus as 28 weeks (seventh month) shows the process vaginalis and testis passing through the inguinal canal. The testis passes posterior to the processus vaginalis, not through it C. In a newborn infant, obliteration of process vaginalis occured. The remains of the processus vaginalis have formed the tunica vaginalis of the testis. The remains of the gubernaculum has disappeared

Paramesonephric (Mullerian ducts)

- Under the influence of MIF, the cranial portions of the paramesonephric ducts and the uterovaginal primordium regress.
- Vestigial remnants of the paramesonephric duct (called the appendix testis) is present in the adult male.

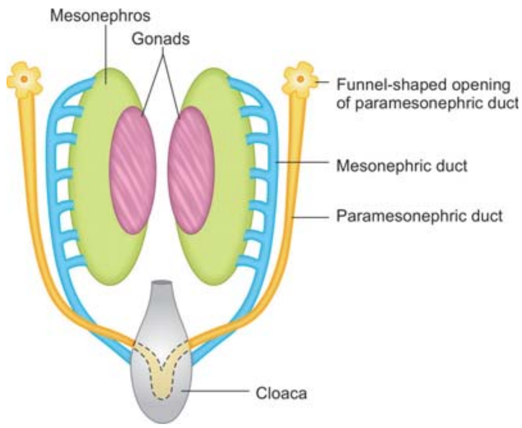


Fig. 138: Two pairs of genital ducts during the indifferent stage of development of gonads.

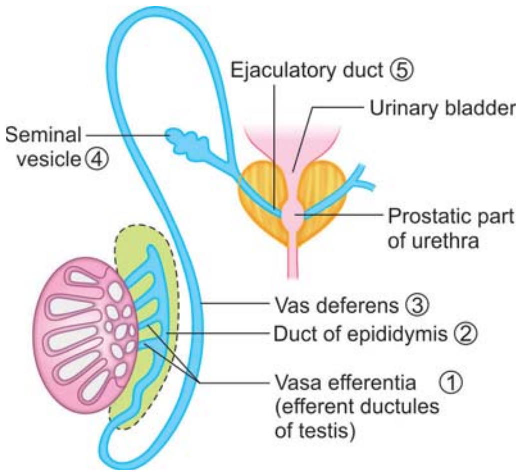


Fig. 139: Derivatives of mesonephric duct

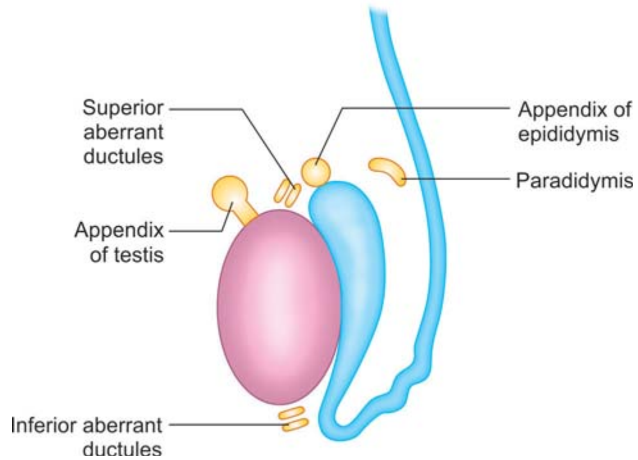


Fig. 140: Vestigeal remnants of mesonephric and paramesonephric ducts in males

Clinical Correlations

Hypospadias occurs when the urethral folds fail to fuse completely, resulting in the external urethral orifice opening onto the ventral surface of the penis.

- It is generally associated with a poorly developed penis that curves ventrally, known as chordee.

Epispadias occurs when the external urethral orifice opens onto the dorsal surface of the penis.

- It is generally associated with exstrophy of the bladder.

Cryptorchidism (undescended testes) occurs when the testes fail to descend into the scrotum.

- Descent of the testes is evident within 3 months after birth.
- Bilateral cryptorchidism results in sterility and an increased risk of testicular cancer.

Hydrocele of the testes may result when a small patency of the processus vaginalis remains so that peritoneal fluid can flow into the processus vaginalis, which results in a fluid-filled cyst near the testes.

Congenital inguinal hernia may result due to persistent process vaginalis.

- Loops of intestine may herniate into the scrotum or labia majora.
- It is most common in males and is generally associated with cryptorchidism.

ASSESSMENT QUESTIONS

1. Testis lies at deep inguinal ring upto: *(NEET Pattern 2013)*

a. 4 months
b. 5 months
c. 7 months
d. 9 months

2. Position of testis at 24-28 weeks of intrauterine life *(NEET Pattern 2015)*

a. Inguinal region
b. Lumbar region
c. Superficial inguinal ring
d. Deep inguinal ring

3. Gubernaculum is attached to
a. Cranial pole of testis
b. Caudal pole of testis
c. Body of testis
d. Epididymis

4. Testes completely descend in the scrotum by the age of
a. End of 7th month of intrauterine life
b. End of 8 month of intrauterine life
c. End of 9 month of intrauterine life
d. After birth

ANSWERS WITH EXPLANATIONS

1. c. 7 months
- The most appropriate option has been chosen as the answer.
- Testis is present at the deep inguinal ring at the **end of 6th month**, and starts passing through inguinal canal at **7th month**.

2. a. Inguinal region
- Testis passes through the inguinal canal during 25 – 28 th week (7th month) of intrauterine life.

3. b. Caudal pole of testis
- **Gubernaculum** is the embryonic structures which begin as undifferentiated mesenchyme attaching to the caudal end of the gonads (testes and ovaries).

4. d. End of 9th month of intrauterine life
- Testis lies at superficial ring at **eighth month** and enters the scrotum at the **beginning of ninth month**.
- It reaches its final position in the scrotum just before birth (**end of ninth month**) and after birth (in few babies).

FEMALE REPRODUCTIVE SYSTEM

Ovary

Intermediate mesoderm forms a longitudinal elevation along the dorsal body wall called the urogenital ridge, which later forms the **gonadal ridge**.

- Primary sex cords develop from the gonadal ridge and incorporate primordial germ cells (XX genotype), which migrate into the gonad from the wall of the yolk sac.
- Primary sex cords extend into the medulla and develop into the rete ovarii, which eventually degenerates.
- Secondary sex cords develop and incorporate primordial germ cells as a thin tunica albuginea forms.
- The secondary sex cords break apart and form isolated cell clusters called primordial follicles, which contain primary oocytes surrounded by a layer of simple squamous cells.

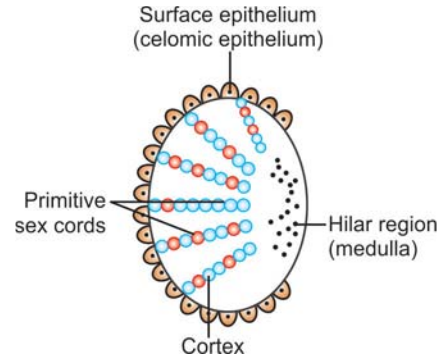


Fig. 141: Indifferent gonad

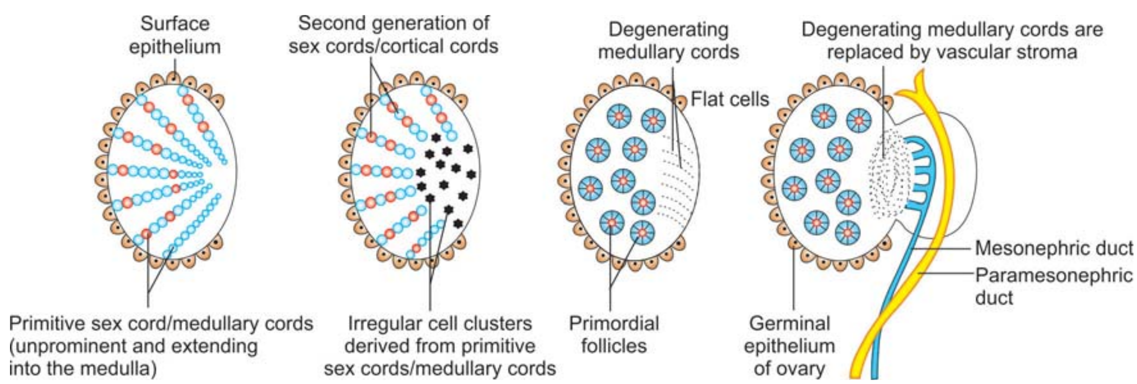


Fig. 142: Development of the ovary

Descent of Ovaries

Ovaries originally develop within the abdomen but later undergo a relative descent into the pelvis as a result of disproportionate growth.

- The gubernaculum is a band of fibrous tissue along the posterior wall that extends from the medial pole of the ovary to the uterus at the junction of the uterine tubes, forming the ovarian ligament.
- The gubernaculum then continues into the labia majora, forming the round ligament of the uterus.

Development of Genital Ducts

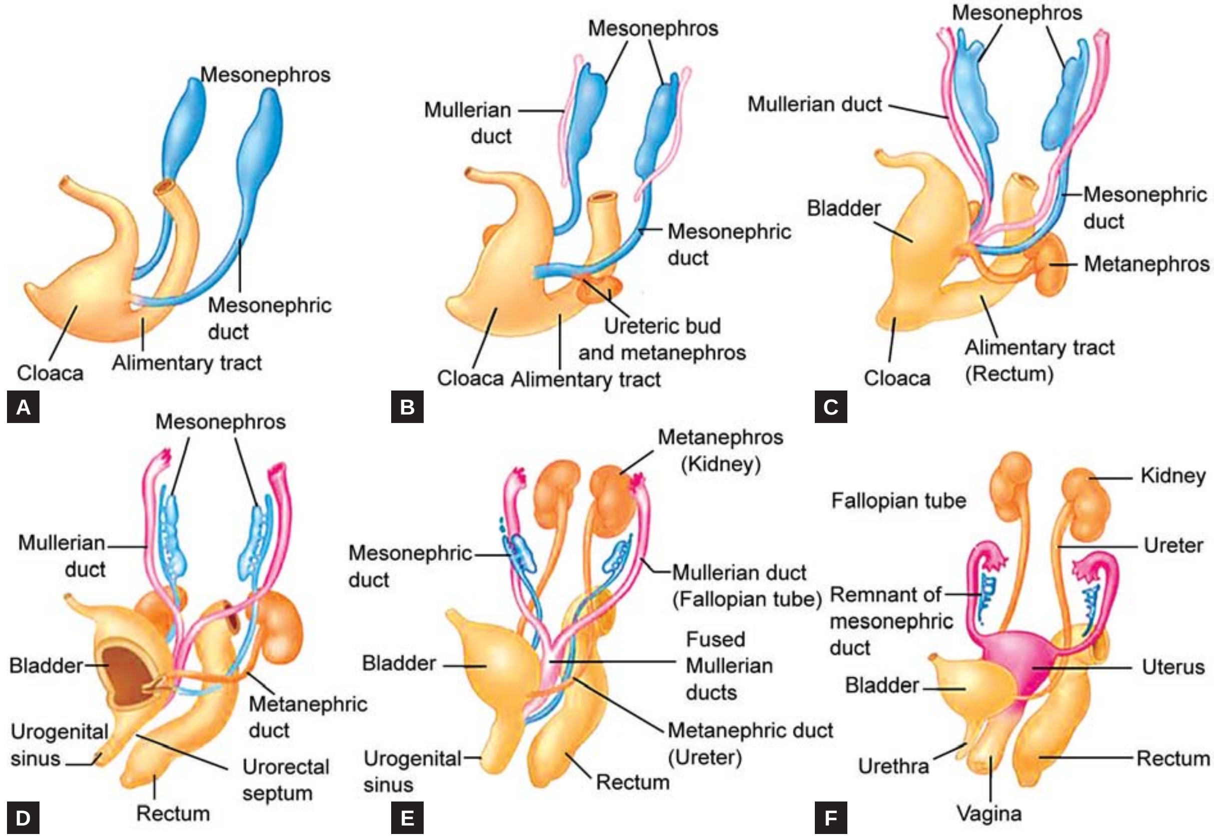
Paramesonephric (Mullerian ducts)

- Cranial (unfused) portions of the paramesonephric ducts develop into the uterine tubes.
- Caudal portions of the paramesonephric ducts fuse in the midline to form the uterovaginal primordium and thereby bring together two peritoneal folds called the broad ligament.

- Uterovaginal primordium develops into the uterus, cervix, and superior 1/3 of the vagina.
- Paramesonephric ducts project into the dorsal wall of the cloaca and induce the formation of the sinovaginal bulbs. The sinovaginal bulbs fuse to form the solid vaginal plate, which canalizes and develops into the inferior two-thirds of the vagina.
- Vestigial remnants of the paramesonephric duct may be found in the adult female and are called the hydatid of Morgagni.

Mesonephric (Wolffian) ducts and tubules

- Mesonephric ducts develop in the female as part of the urinary system because these ducts are critical in the formation of the definitive metanephric kidney. However, they degenerate in the female after formation of the metanephric kidney.
- Vestigial remnants of the mesonephric ducts may be found in the adult female called the appendix vesiculosa and Gartner's duct.
- Vestigial remnants of the mesonephric tubules are called the epoophoron and the paroophoron.



Figs. 143A to F: Development of reproductive system in female. Mullerian (paramesonephric) duct (mesodermal) gives: Uterus, uterine tube and upper third of vagina. Lower third of vagina, urinary bladder and urethra develop from urogenital sinus (endoderm). Kidney develops from metanephric blastema after it is stimulated by the ureteric bud (formed in mesonephric duct)

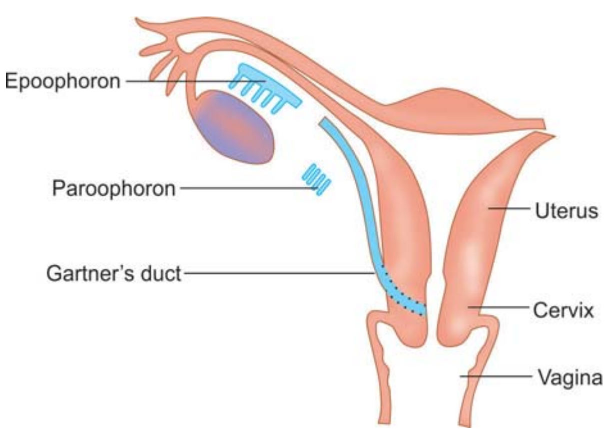


Fig. 144: Vestigeal remnants of mesonephric duct in females

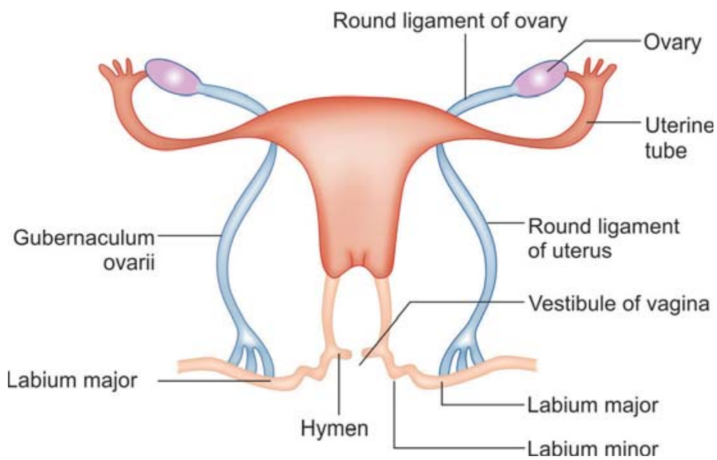


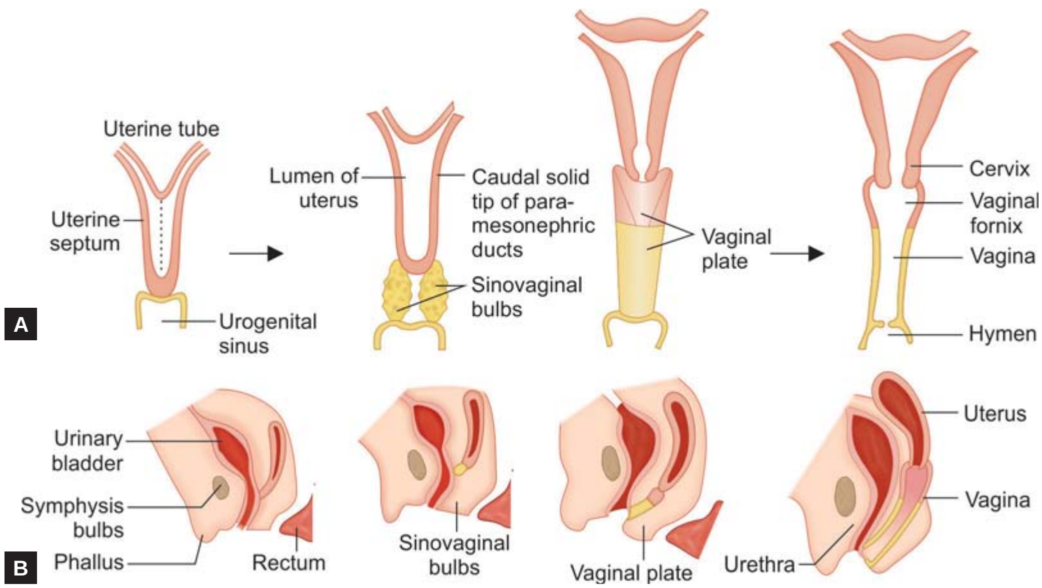
Fig. 145: Descent of ovary

Development of Vagina

- Upper 1/3rd of vagina develops from Mullerian (paramesonephric) duct (mesoderm) and lower 2/3 is derived from the endoderm of urogenital sinus.
- The caudal portions of the Mullerian ducts fuse in the midline to form the uterovaginal primordium, which contributes to upper 1/3 of vagina.
- The paramesonephric ducts project into the dorsal wall of the cloaca (urogenital sinus) and induce the formation of the sinovaginal bulbs.
- The sinovaginal bulbs fuse to form the solid vaginal plate, which canalizes and develops into the lower two-thirds of the vagina.

Table 25: Development of vagina and its associated structures

Embryonic structures	Adult derivatives
• Mesodermal upper part of vaginal plate (derived from uterovaginal canal)	• Upper part of vagina including fornices of vagina
• Endodermal lower part of vaginal plate (derived from sinovaginal bulbs)	• Lower part of vagina
• Thin plate of tissue separating vagina and phallic part of urogenital sinus	• Hymen
• Phallic part of definitive urogenital sinus	• Vestibule of vagina



Figs. 146A and B: Development of the uterus and vagina. A. Frontal view. B. Side view

Structure	Origin
Epithelium	Urogenital sinus (Endoderm)
Smooth muscles	Lateral plate mesoderm (Splanchnic)
Skeletal muscles	Para-axial mesoderm
Hymen	Endoderm

- Human chorionic gonadotrophin (hCG) is a glycoprotein hormone produced by the syncytiotrophoblast; it stimulates the production of progesterone by the corpus luteum (i.e., maintains corpus luteum function).
- hCG can be assayed in maternal blood at day 8 or maternal urine at day 10 using RIA (radioimmunoassay) with antibodies directed against the β-subunit of hCG.

Clinical Correlations

- Hydatid cyst of Morgagni arises from the hydatid of Morgagni, which is a remnant of the paramesonephric duct.
- Kobelt's cyst arises from the appendix vesiculosa, which is a remnant of the mesonephric duct.
- Mullerian agenesis involves the paramesonephric ducts can result in vaginal, cervical, uterine, uterine tube, or combined anomalies. For e.g., Lower vagina agenesis, cervix agenesis, uterus and cervix hypoplasia, and uterine tube agenesis.
- Uterus anomalies may occur when
  - One paramesonephric duct fails to develop or incompletely develops-Unicornuate uterus.
  - There is a complete lack of fusion of the paramesonephric ducts-Didelphys (double uterus.
  - There is partial fusion of the paramesonephric ducts-Bicornuate uterus.
  - The medial walls of the caudal portion of the paramesonephric ducts partially or completely fail to resorb- Septate uterus.

ASSESSMENT QUESTIONS

1. **The upper 3/4th of vagina develops from:** *(NEET Pattern 2012)*
   a. Mulllerian duct
   b. Wolffian duct
   c. Genital ridge
   d. Genital swelling

2. **Vaginal epithelium is derived from:** *(AIIMS 2013)*
   a. Endoderm of genital ridge
   b. Endoderm of urogenital sinus
   c. Mesoderm of genital ridge
   d. Mesoderm of urogenital sinus

3. **Mullerian duct anomaly may include the absence of any of the following EXCEPT:**
   a. Uterus
   b. Vagina
   c. Ovary
   d. Uterine tube

4. **Clitoris in females is embryologically derived from:**
   a. Urogenital sinus
   b. Genital swelling
   c. Genital tubercle
   d. Urogenital membrane

5. **Organ of Rosenmüller (epoophoron) is derivative of:**
   a. Mulllerian duct
   b. Wolffian duct
   c. Urogenital sinus
   d. Paramesonephric duct

6. **Ovarian ligament and Round ligament of uterus are derivatives of:**
   a. Peritoneum
   b. Transversalis fascia
   c. Processus vaginalis
   d. Gubernaculum

ANSWERS WITH EXPLANATIONS

1. **a. Mulllerian duct**
   - The upper portion of vagina develops from mesoderm of Mulllerian duct and lower portion from endoderm of urogenital sinus.
   - Various standard textbooks mention various lengths, the best to be followed is upper 1/3 rd and lower 2/3 rd.

2. **b. Endoderm of urogenital sinus > c. Mesoderm of genital ridge**
   - Vaginal epithelium is derived from **endoderm of the urogenital sinus** as per standard textbooks on embryology, though the topic is controversial.
   - The paramesonephric ducts (Mullerian duct) project into the dorsal wall of the cloaca and induce the formation of the sinovaginal bulbs. The sinovaginal bulbs fuse to form the solid vaginal plate, which canalizes and develops into the inferior two thirds of the vagina.
   - Upper 1/3 of vagina develops from the Mullerian duct. Although the vagina has a dual origin, most authorities agree that the epithelial lining of the entire vagina is of **endodermal** origin.
   - Recently this concept has been challenged and there is a new school of thought expressing that vaginal origin is entirely mesodermal.

3. **c. Ovary.**
   - Ovaries develop from genital ridge (not Mullerian duct).

4. **c. Genital tubercle.**
   - Glans penis and clitoris develop from the genital tubercle (phallus).

5. **b. Wolffian duct.**
   - Epoophoron is a vestigial remnant of Wolffian duct in females.

6. **d. Gubernaculum**
   - In females the **gubernaculum** has two vestigial remnants in females, the ovarian ligament and the round ligament of the uterus (ligamentum teres uteri) which respectively serve to support the ovaries and uterus in the pelvis.

EXTERNAL GENITALIA

Proliferation of mesoderm (dorsal somatic, lateral plate mesoderm) around the cloacal membrane causes the overlying ectoderm to rise up so that three structures are visible externally, which include the phallus, urogenital folds, and labioscrotal swellings.

Male

- Phallus forms the penis (glans penis, corpora cavernosa penis, and corpus spongiosum penis).
- Urogenital folds form the ventral aspect of the penis (i.e., penile raphe).
- Labioscrotal swellings form the scrotum.

Female

- Phallus forms the clitoris (glans clitoris, corpora cavernosa clitoris, and vestibular bulbs).
- Urogenital folds form the labia minora.
- Labioscrotal swellings form the labia majora and mons pubis.

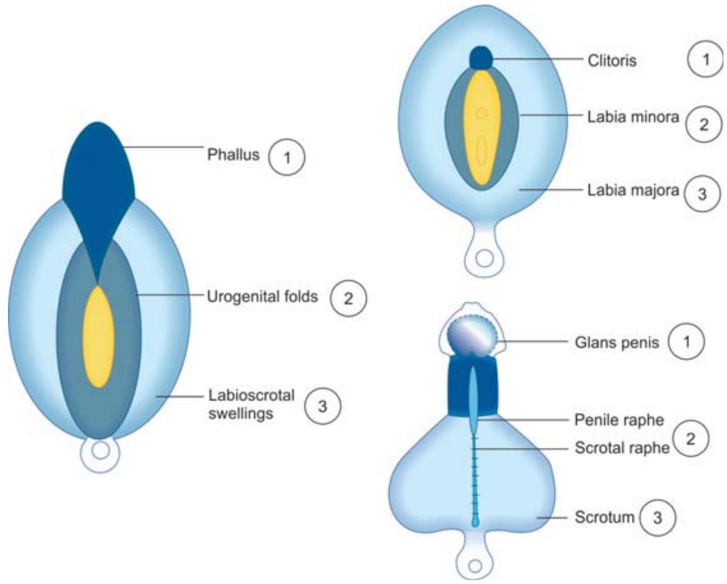


Fig. 147: Development of external genitalia

TERMINOLOGY

Allantois	(G., "sausage-like") A vestigial endodermal extension of the cloaca into the umbilical cord in mammals. In egg-laying animals it lines the inner surface of the egg for gas exchange.
Appendix of the testis	A remnant of the paramesonephric duct in the male. It is attached to the superior pole of the testis.
Appendix vesiculosa	Persistence of the cranial end of the mesonephric (wolffian) duct in females lateral to the ovary/epoophoron.
Bicomuate	(L, "two horns") Double uterus characteristic of most mammals, but an anomaly in primates whose single uterus comes from fused paramesonephric (mullerian) ducts.
Bowman's capsule	The epithelial covering of the glomerular capillaries. It has a visceral layer of podocytes and simple squamous parietal layer. The urinary space between the two continues into the proximal convoluted tubule of the nephron.
Cloaca	(L., "sewer") A dilation at the caudal end of the hindgut that divides to form the rectum, urinary bladder, urethra vestibule prostate and related structures.
Cryptorchidism	(G. "hidden testis") An undescended testis not in the scrotum.
Epoophoron	Remnants of mesonephric tubules and a segment of mesonephric duct between the ovary and uterine tube. These correspond to efferent ductules and duct of the epididymis in males.
Gartner's duct	Remnants of the mesonephric duct in the broad ligament of the uterus. They may form cysts.
Germinal epithelium	A term for the epithelium on the surface of the ovary. It was thought that this epithelium gave rise to primordial germ cells (oogonia). Follicular cells come from ovarian epithelium but the germ cells migrate from the wall of the gut tube into the ovary.
Glomerulus	Tuft of capillaries in the in the renal corpuscle of a nephron where urine is filtered from the blood.
Hydatid (of Morgagni)	A persistent part of the cranial end of the paramesonephric (mullerian) duct that does not contribute to the uterine tube.
Hymen	A membrane that is a remnant from a secondary cavitation of the vagina after endodermal cells from the urogenital sinus fill the lumen of lower part of the uterovaginal primordium (from the fused paramesonephric ducts). It is not a vestige of the cloaca! membrane.
Hypospadias	Failure of the urogenital folds to fuse completely on the ventral surface of the penis in the formation of the penile urethra. Urine escapes from a ventral opening in the newborn penis.
Indifferent stage	The 8-week embryo that has identical primordial in both sexes. As embryos of each sex develop they lose the primordial of the opposite sex.
Intermediate mesoderm	Mesoderm in the gastrula between the paraxial column and lateral plate that gives rise to the kidney's and gonads.
Mesonephros	(G., 'middle kidney') The first functioning kidney in the embryo, it develops from the intermediate mesoderm of the gastrula and is closely applied to the primitive gonad. It disappears as the permanent metanephric kidney forms. In the male, the mesonephric duct and tubules become connected to the testis to form the male genital duct system (e.g., ductus deferens, ejaculatory duct).

Nephron	The structural and functional unit of the kidney where urine is filtered from the blood, concentrated, processed, and transported. In sequence, it consists of a glomerulus, proximal convoluted tubule, Henle's loop, and a distal convoluted tubule that connects with a collecting tubule.
Paramesonephric (mollerian) duct	Primordium of the uterine tubes, uterus, and upper vagina.
Paroöphoron	Remnants of mesonephric tubules medial to the ovary and the location of the vestigial epoophoron.
Pronephros	(G.,'first kidney") The first kidney to develop at the cranial end of the intermediate mesoderm. It has a brief existence and never functions.
Prostaticutride	A midline, blind pouch off the prostatic urethra that is the remnant of the caudal end of the paramesonephric duce. The male equivalent of the vagina.
Renal corpuscle	Glomerular capillaries surrounded by Bowman's capsule, the site of filtration of urine from the bloodstream in the cortex of the kidney.
Sinovaginal bulbs	Pa.ired outgrowths of the sinus tubercle of the urogenital sinus at the base of the uterovaginal primordium that are induced by contact of the fused paramesonephric ducts with the urogenital sinus. They form a solid endodermal vaginal plate at the bottom of the vagina that cavitates and gives rise to all of the vaginal epithelium.
Sinus tubercle	Swelling of the ruogenital sinus in which the left and right paramesonephric ducts contact the sinus.
Urachus	Fibrous remnant of the allantois extending from the top of the bladder to the umbilicus.
Urogenital sinus	The anterior product of the division of the cloaca that consists of the primitive urinary bladder a pelvic portion, and a lower genital portion (urogenital sinus proper) that gives rise to the urethra and all related glands in both sexes and the testibule and lower vagina in the female.
Urogenital folds	Primordia that give rise to the labia minora surrounding the vestibule in the female and the penile urethra and ventral penis in the male.
Urorectal septum	The tissue in the natural cleft between the a Hantois and hindgut tube. It extends inferiorly to divide the cloaca into the rectum and a urogenital sinus that becomes urinary bladder, urethra, vestibule, prostate, and related structures.

ASSESSMENT QUESTIONS

1. **External genitalia develop from:** *(NEET Pattern 2015)*
   a. Intermediate mesoderm
   b. Para-axial mesoderm
   c. Somatopleuric lateral plate mesoderm
   d. Splanchnopleuric lateral plate mesoderm

2. **Which of following is the feature of Y chromosome:** *(NEET Pattern 2012)*
   a. Acrocentric
   b. Telocentric
   c. Submetacentric
   d. Metacentric

3. **Faster sperm is with which sex chromosome:** *(NEET Pattern 2012)*
   a. X chromosome
   b. Y chromosome
   c. Both same
   d. None

4. **Regarding genital development, TRUE is:** *(AIIMS 2007)*
   a. Y chromosome is associated with ovary development
   b. Genital ridge starts developing at 5th week
   c. Male genitals develop earlier than female genitals
   d. External Genital development is complete by 10th week

5. **INCORRECT statement about genital system development is:**
   a. Develop from mesoderm
   b. Genital ridge forms at week 5
   c. Testes develops earlier to ovary
   d. External genitalia are fully differentiated at week 10

6. **Mullerian duct anomaly may include the absence of any of the following EXCEPT:** *(AIPG 2008)*
   a. Uterus
   b. Vagina
   c. Ovary
   d. Uterine tube

7. **Organ of Rosenmullar is remenant of:** *(NEET Dec. 12 Pattern)*
   a. Endodermal sinus
   b. Mullerian duct
   c. Mesonephric tubule
   d. Paramesonephric duct

8. **Round ligament of uterus is derived from:** *(CET June 14 Pattern)*
   a. Gonadal ridge
   b. Mullerian duct
   c. Gubernaculum
   d. Genital tubercle

Genital System

9. **Differentiation of genital ridge takes place at:** *(All India Dec. 13 Pattern)*
   a. 2 months
   b. 3 months
   c. 4 months
   d. 5 months

10. **Primordial germ cells are derived from:** *(NEET Dec. 12 Pattern AI 07)*
    a. Yolk sac endoderm
    b. Yolk sac medoderm
    c. Epiblast
    d. Gonadal ridge

11. **Not true about development of ovary:** *(All India Dec. 15 Pattern)*
    a. Develops in genital ridge
    b. Sex cords are derived from coelomic epithelium
    c. Oocytes are mesodermal in origin
    d. At birth ovary contains 2 million follicles

12. **Number of primodial follicles in ovary at birth are:** *(All India Dec. 13 Pattern)*
    a. 2 million
    b. 6 million
    c. 5 million
    d. 10 million

13. Development of labia majora is from: *(NEET Dec. 12 Pattern)*
a. Urogenital sinus
b. Mullerian duct
c. Genital ridge
d. Genital swelling

14. Clitoris develops from: *(All India Dec. 15 Pattern)*
a. Urogenital sinus
b. Labia scrotal swelling
c. Genital folds
d. Genital tubercle

15. Which is derived from wolfian duct: *(NEET Dec. 12 Pattern)*
a. Appendix of testis
b. Uterus
c. Appendix of epididymis
d. Hydatid of margagni

16. Which of the following is a derivative of paramesonephric duct in males: *(All India Dec. 15 Pattern)*
a. Trigone of bladder
b. Paraphoron
c. Prostatic utricle
d. Gartner's duct

17. Vaginal wall is derived from: *(All India Dec. 13 Pattern)*
a. Endoderm
b. Mesoderm
c. Endoderm and mesoderm
d. Ectoderm and mesoderm

18. Vaginal epithelium develops from: *(AIIMS May 13)*
a. Mesoderm of urogenital sinus
b. Mesoderm of genital ridge
c. Endoderm of urogenital sinus
d. Endoderm of genital ridge

ANSWERS WITH EXPLANATIONS

1. c. Somatopleuric lateral plate mesoderm
- Genital system develops from intermediate mesoderm.

Note: External genitalia develop from somatopleuric lateral plate mesoderm, covering the cloacal region.

2. a. Acrocentric
- Y chromosome is a short acro-centric without the satellite.
- Chromosomes 21 & 22 are also short acrocentric(s) but they with the satellites.

3. b. Y chromosome
- Y chromosome is smaller than X chromosome and Y bearing sperms are lighter, swim faster up the female genital tract, reaching the ovum earlier than the X bearing sperms.

4. b Genital ridge starts developing at 5th week
- The key to sexual dimorphism is the Y chromosome, which contain the TDF (Testes Determining Factor) gene, called as the SRY gene on its short arm.
- Under the influence of TDF, male development occurs; in its absence, female development is established.
- Hence, Y chromosome regulates male sexual development. Genital ridges start developing at the 5th week.
- The gonads do not acquire male or female morphological characteristics until the 7th week of development and sex determination is not possible before week 7.
- External genitalia are not fully differentiated until the 12th week.
- Beyond 12-13 week sex determination is possible by ultrasonographic examination of external genitalia.

5. d. External genitalia are fully differentiated at week 10
- External genitalia become well differentiated, **after 12 weeks** age.
- Not until 3 months, the progressively developing external genitalia attain characteristics that can be recognized as distinctively male or female.
- Genitourinary system develops from **intermediate mesoderm** and the genital ridge is first identified at 32 days (**Week 5**) after ovulation and is indistinguishable between males and females.
- Genetic sex is determined at fertilization by the presence or absence of the Y chromosome.
- The testes, however, do not form until the seventh week of development.
- **Sex determination is not possible before an age of 7 weeks**. During the 7th week, the gonad begins to assume the characteristics of a testis or ovary.
- **Differentiation of the ovary usually occurs somewhat later** than differentiation of the testis.

6. c. Ovary
- Ovary develops from the genital ridge and not the Mullerian duct.
- So, an anomaly of Mullerian duct does not show the absence of ovary.
- Mullerian duct gives rise to the uterus and uterine tubes. It also contributes to the upper third of vagina.

7. c. Mesonephric tubule
- The epoophoron (organ of Rosenmüller or the parovarium) is a remnant of the mesonephric tubules that is found next to the ovary and fallopian tube.

8. c. Gubernaculum
- Gubernaculum is divided into two parts by the developing uterus: Round ligament of ovary and round ligament of uterus.

9. a. 2 months
- Genital ridge appears at week 5 (month 2).

10. c. Epiblast > a. Yolk sac endoderm
- Earlier it was believed that primordial germ cells are derived from the endoderm of yolk sac, but later it was found that they are derivatives of epiblast cells, developing in primitive streak and later migrate to the endodermal yolk sac and fpass through the dorsal mesentery of hindgut to finally reach the geital ridge.

11. c. Oocytes are mesodermal in origin
- Oocytes develop from the primordial germ cells , which themselves are derivatives of epiblast (and not mesoderm).

12. a. 2 million
- Total number of primordial follicles are 1-2 million at birth.

13. d. Genital swelling
- Labia majora develops from the genital (labrioscrotal) swelling.

14. d. Genital tubercle
- Clitoris develops from the genital tubercle (phallus).

15. c. Appendix of epididymis > d. Hydatid of margagni
- The appendix of the epididymis (or pedunculated hydatid) is a small stalked appendage (sometimes duplicated) on the head of the epididymis. It is usually regarded as a detached efferent duct.
- This structure is derived from the Wolffian duct (Mesonephric Duct) as opposed to the appendix testis which is derived from the Müllerian duct (Paramesonephric Duct) remnant.
- The Hydatid of Morgagni can refer to one of two closely related structures:
  - Paratubal cyst (in the female)
  - Appendix testis (in the male)
- Para Tubal Cysts originate from the mesothelium and are presumed to be remnants of the Müllerian duct and Wolffian duct
- The appendix testis (or hydatid of Morgagni) is a vestigial remnant of the Müllerian duct, present on the upper pole of the testis and attached to the tunica vaginalis

16. c. Prostatic utricle
- Prostatic utricle is a vestigeal remnant of mullerian (paramesonephric) duct.
- Trigone of bladder develop from the mesonephric duct terminal portion.
- Para-oophoron, and gartner's duct are vestigeal remnants of Wolffian (mesonephric) duct.

17. c. Endoderm and mesoderm
- Upper 1/3 of vagina develops from mesoderm of Mullerian duct and lower 2/3 from the endoderm of urogenital sinus.

18. c. Endoderm of urogenital sinus
- Vaginal epithelium develops from the endoderm of urogenital sinus. Recently there have been a view that entire vagina develops from the mesoderm (still controversial and not yet updated in Gray's Anatomy 41Ed).

High Yield Points

- **Genotype** of the embryo is established at fertilization, but male and female embryos are **phenotypically** indistinguishable till weeks 6. Testis starts developing at week 7, whereas ovarian development begins at week 10. Male and female characteristics of the **external genitalia** can be recognized by week 12-13. Phenotypic differentiation is **completed** by week 20.
- Before the seventh week of gestation, the fetal gonads are not differentiated into either the male or female genotype. Primordial germ cells migrate into the genital ridge (to form spermatocytes or oocytes). The presence or absence of the Y chromosome (SRY gene - sex-determining region of the Y chromosome) determine gonadal differentiation. All humans are destined to become females (**default mechanism**) until interrupted by Y chromosome.

SKELETAL SYSTEM

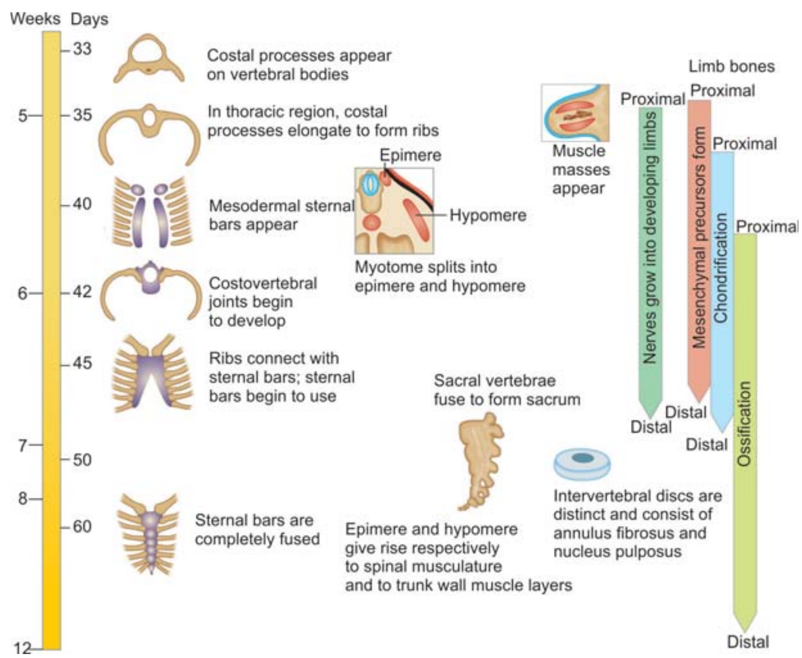
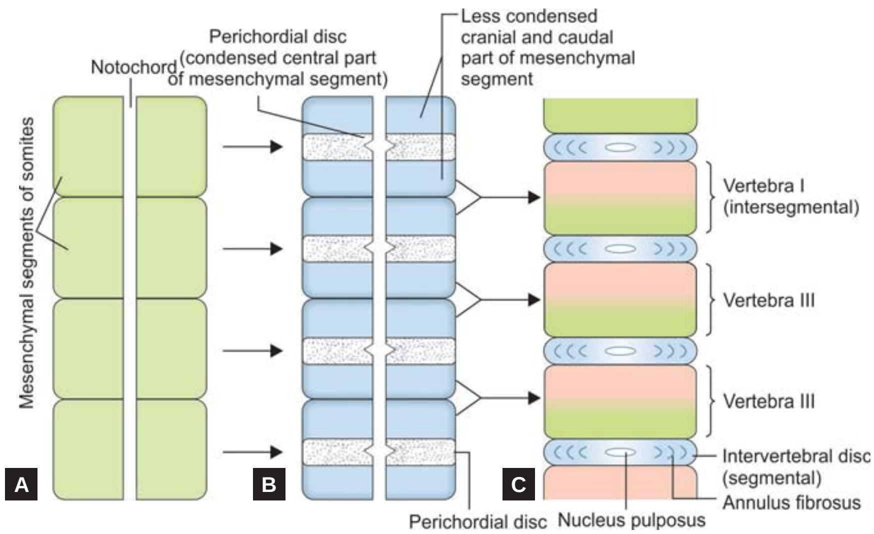


Fig. 148: Formation of the musculoskeletal system

VERTEBRA

- Paraxial mesoderm give rise to somites, which have a component called sclerotome.
- Sclerotomes surround the notochord and project posteriorly to surround neural tube and divide into three parts:
  - Ventral sclerotomes: Forms vertebral body and annulus fibrosus.
  - Lateral sclerotomes : Forms vertebral arch (pedicle and lamina).
  - Dorsal sclerotomes : Forms the spinous process.
- **Ribs** are derived from the **sclerotome** portion of the **somite** (paraxial mesoderm) which form the costal process of the thoracic vertebrae.
- Primary ossification centers appear in the body of the ribs and mostly become cartilaginous during weeks 13-14 of development.
- **Sternum**
- Two mesenchymal **sternal bars**, one on either side of midline, develop in anterior body wall due to condensation of **somatic mesoderm**.
- Later they get converted into cartilaginous sternal bars, which start fusing with each other in a craniocaudal sequence to form the cartilaginous model of the sternum, having manubrium, body (made up of four segments called sternebrae), and xiphoid process.
- Manubrium and body ossify by five double centers from above downward during fifth to sixth months.
- The upper pair of centers form manubrium and the lower four pairs of centers form four sternebrae that fuse with each other from below upward.
- Lower two part of sternum fused by puberty (age of 14 years). The fusion is complete by 25 years of age.
- The xiphoid process ossifies late in life. The center for xiphoid process appears during the third year or later and fuses with the body of sternum at about 40 years.



Figs. 149A to C: Development of vertebral bodies anal interpretable discs. A. Mesenchymal segments around the notochord. B. Differentiation of mesenchymal segment into three parts: condensed central part and less dense cranial and caudal parts. C. Resegmentation due to the formation of vertebra from adjoining two less condensed parts of two adjacent mesenchymal segment (somites)

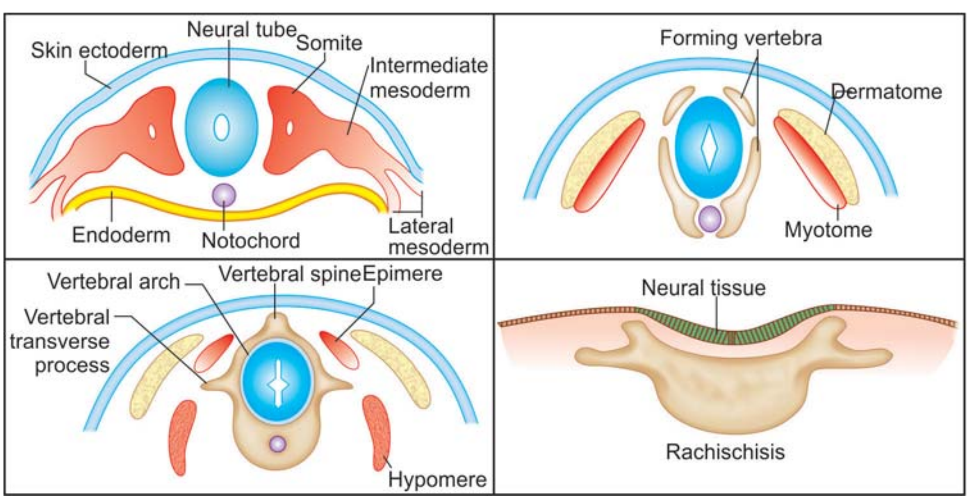
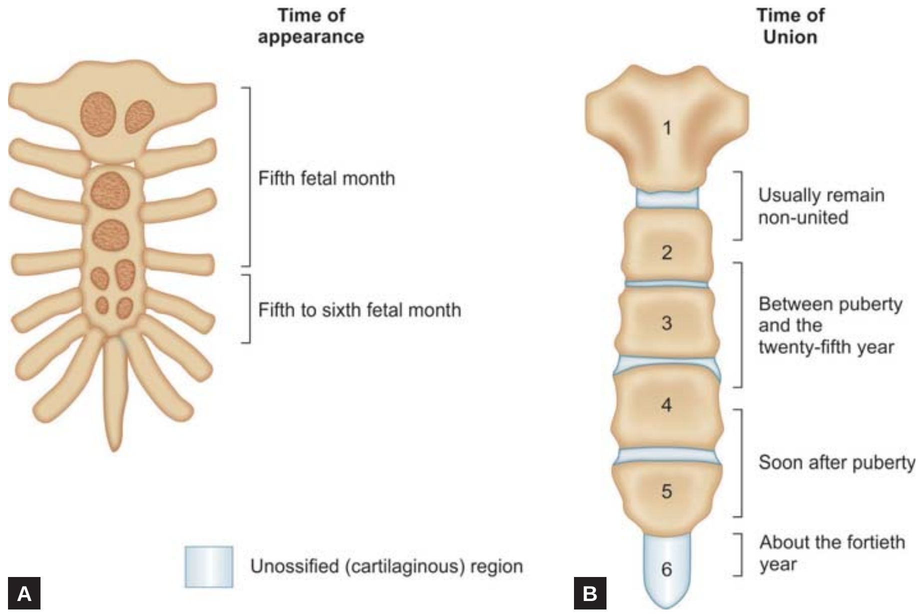


Fig. 150: Formation of vertebra from sclerotomes. Spina bifida occurs in a case of open neural tube defect (rachischisis).



Figs. 151A and B: The ossification of the sternum. A, Before birth. B. After birth

ASSESSMENT QUESTIONS

1. Which of the following is TRUE about vertebral development: *(NEET Pattern 2013)*

a. The notochord forms the annulus fibrosus
b. The sclerotome forms the nucleus pulposus
c. The sclerotome surrounds the notochord only
d. The sclerotome surrounds the notochord and the neural tube

2. Ribs develop from: *(NEET Pattern 2013)*

a. Lateral plate mesoderm
b. Sclerotome
c. Sternal bars
d. Intermediate mesoderm

3. Lumber hemivertebra results due to the abnormal development of: *(AIIMS 2006)*

a. Dorsal sclerotome
b. Intermediate cell mass
c. Notochord
d. Ventral sclerotome

ANSWERS WITH EXPLANATIONS

1. d. The sclerotome surrounds the notochord and the neural tube

- **Sclerotomes** surround the **notochord** and project posteriorly to surround **neural tube** and divide into three parts:
  - Ventral sclerotomes: Forms vertebral body and annulus fibrosus.
  - Lateral sclerotomes : Forms vertebral arch (pedicle and lamina).
  - Dorsal sclerotomes : Forms the spinous process.

2. b. Sclerotome

- **Ribs** are derived from the **sclerotome** portion of the **somite** (paraxial mesoderm) which form the costal process of the thoracic vertebrae.

3. d. Ventral sclerotome

- Absence of one half of the body of the vertebra results in **hemivertebra** and is due to abnormal development of the **ventral sclerotome.**
- **Ventral sclerotome** forms the **body** of the vertebra, and absence of one half of the body (hemivertebra) may result in scoliosis (lateral bending of spine).
- **Dorsal sclerotome** forms the **dorsal part of vertebral arch** including the spine. Defective development of dorsal sclerotome may result in non-union of posterior vertebral arch results in **spina bifida**.
- **Notochord** forms the basis of axial skeleton and causes induction of the development of the vertebra. The adult remnant of notochord forms the **nucleus pulposus**.

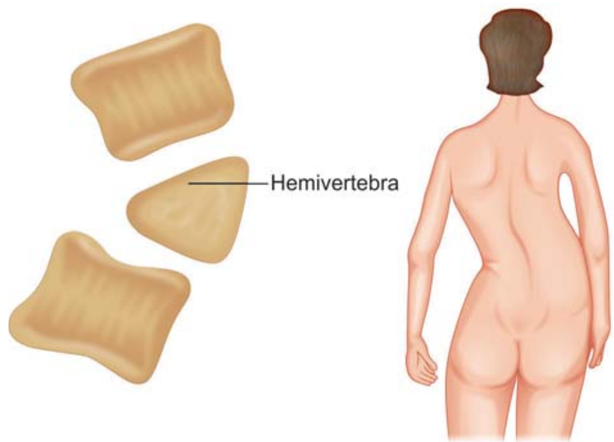


Fig. 152: Hemivertebra (defect of ventral sclerotome) results in scoliosis.

MUSCULAR SYSTEM

- Most muscles arise from the mesoderm. Skeletal muscles are derived from paraxial mesoderm, including (1) somites, which give rise to muscles of the axial skeleton, body wall, and limbs, and (2) somitomeres, which give rise to muscles of the head. Progenitor cells for muscle tissues are derived from the ventrolateral (VLL) and dorsomedial (DML) edges (lips) of the prospective dermomyotome. Cells from both regions contribute to formation of the myotome.
- Some cells from the VLL also migrate across the lateral somitic frontier into the parietal layer of the lateral plate mesoderm. This frontier or border separates two mesodermal domains in the embryo: (1) the primaxial domain that surrounds the neural tube and contains only somite-derived cells (paraxial mesoderm) and (2) the abaxial domain that consists of the parietal layer of lateral plate mesoderm in combination with somite-derived cells that migrate across the frontier into this region.
- Abaxial muscle precursor cells diiferentiate into infrahyoid, abdominal wall (rectus abdominus, extemal and internal obliques, transversus abdominus), and limb muscles. Primaxial muscle precursor cells form muscles of the back, some muscles of the shoulder girdle, and intercostal muscles. Muscles of the back (epaxial muscles) are innervated by dorsal primary rami; muscles of the limbs and body wall (hypaxial muscles) are innervated by ventral primary rami.
- Connective tissue derived from somites, parietal mesoderm, and neural crest provides a template for establishment of muscle Patterns. Most smooth muscles and cardiac muscle fibers are derived from splanchnic mesoderm. Smooth muscles of the pupil, mammary gland, and sweat glands differentiate from ectoderm.

SKELETAL MUSCLES

The muscles and bones of the trunk are derived from the somites. Each somite forms two distinct zones: a sclerotome and a dermomyotome. The former gives rise to the bones of the axial skeleton. The latter gives rise to the dermatome and myotome, in which dermatome forms the dermis of the back skin of the trunk and neck and the myotome forms the muscles of the trunk, limbs and tongue. The dermis and bones of the limbs develop from lateral plate mesoderm. The bones of the head and neck arise from neural crest cells, as does most of the dermis of the head, whereas the pharyngeal arch muscles like masticatory, facial, laryngeal muscles, etc. arise from unsegmented paraxial mesoderm in head.

Table 26: Origins of the Craniofacial Muscles

Mesodermal Origin	Muscles	Innervation
Somitomeres 1 and 2	Superior medial ventral recti	Oculomotor (III)
Somitomere 3	Superior oblique	Trochlear (IV)
Somitomere 4	Jaw closing	Trigeminal (VI)
Somitomere 5	Lateral rectus	Abducens (VI)
Somitomere 6	Jaw opening, other second arch	Facial (VII)
Somitomere 7	Stylopharyngeus	Glossopharyngeal (IX)
Somites 1 ana 2	Intrinsic laryngeals	Vagus (X)
Somites 2-5′	Tongue	Hypoglossal (XII)

“Somites 2 to 5 constitute the occipital group [somite 1 degenerates for the most part].

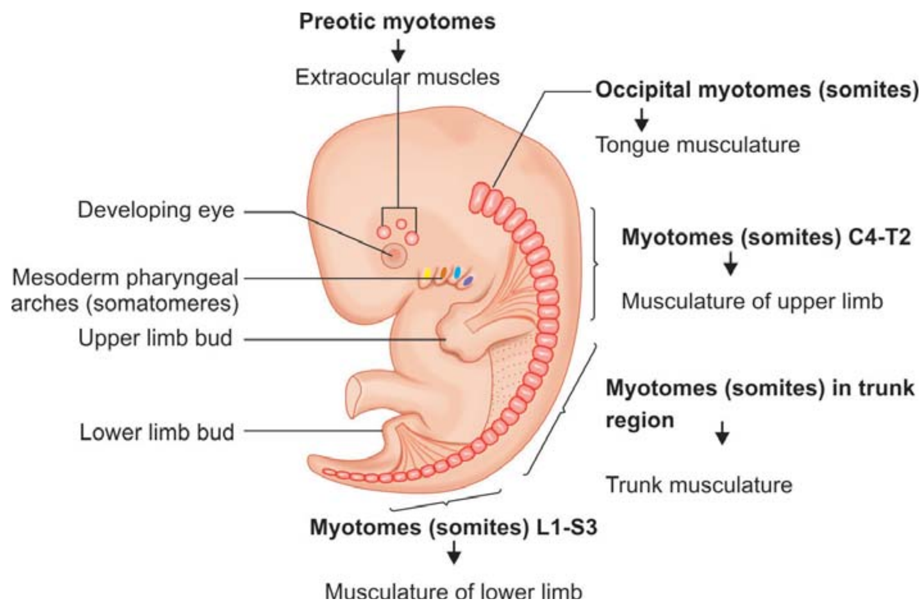


Fig. 153: Myotomes derived from somites and somatomeres in different regions of the body which form skeletal muscles

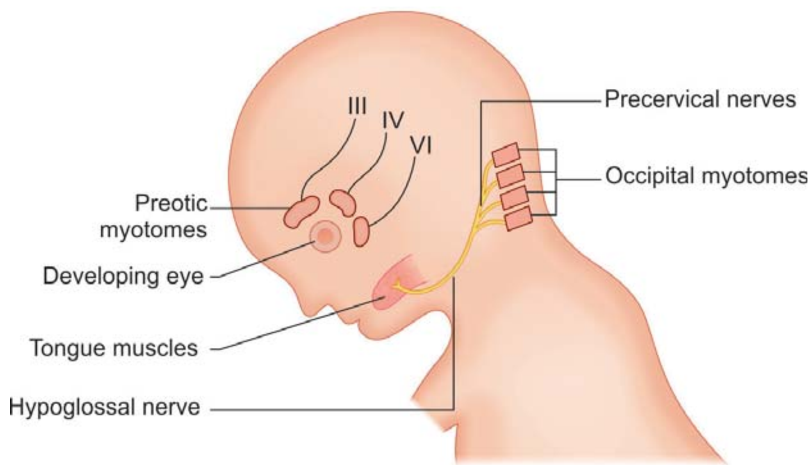


Fig. 154: Development of the muscles of tongue and extrinsic muscles of the eye

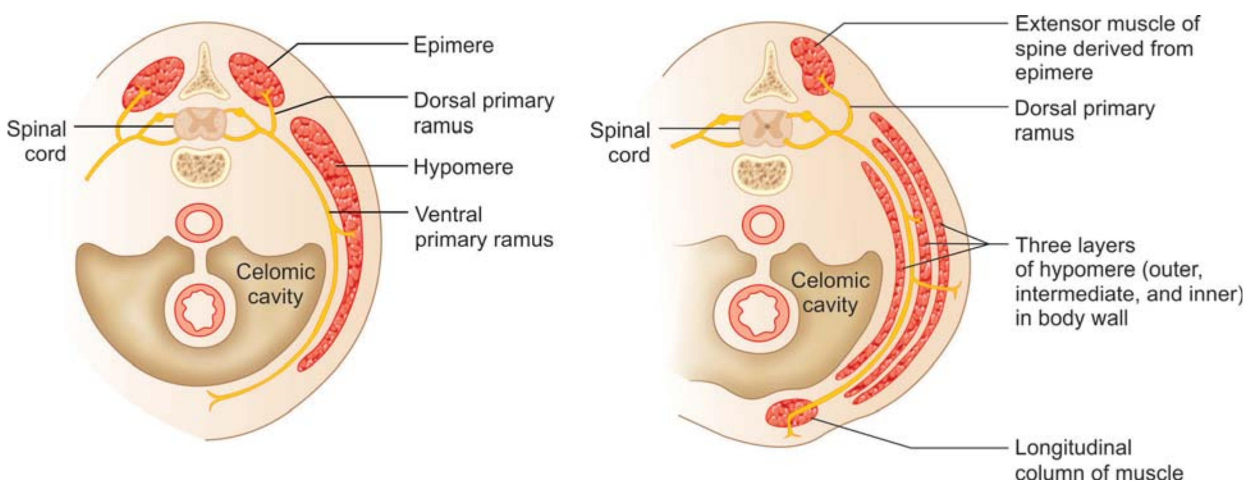


Fig. 155: A Subdivisions of myotome into epimere and hypomere, and their innervation by dorsal primary ramus and ventral primary ramus, respectively. B. Formation of three separate muscles layers from hypomere and ventral longitudinal muscles

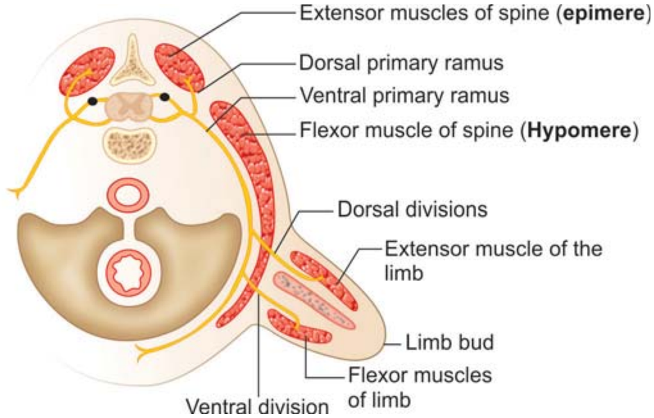


Fig. 156: Development of musculature into the limb bud. Note the extensor (dorsal) and flexor (ventral) components of limb musculature

SMOOTH MUSCLES

ASSESSMENT QUESTIONS

1. **Which of the following gives rise to the muscular component of dorsal aorta:** *(AIPG 2011)*
   a. Intermediate mesoderm
   b. Lateral plate mesoderm
   c. Axial mesoderm
   d. Paraxial mesoderm

ANSWERS WITH EXPLANATIONS

1. **d. Paraxial mesoderm**

Explanation: Muscular comp onent of the dorsal aorta is derived from para-axial mesoderm. Smooth muscles of most of the blood vessels are derived from lateral plate mesoderm (splanchnic layer), with few exceptions:

Region	Source

• Proximal vessels of heart
  ➢ e.g., ascending aorta
• Head and Neck vessels
  ➢ e.g., carotied arery
	Neural crest cells

• Dorsal aorta	Para-axial mesoderm

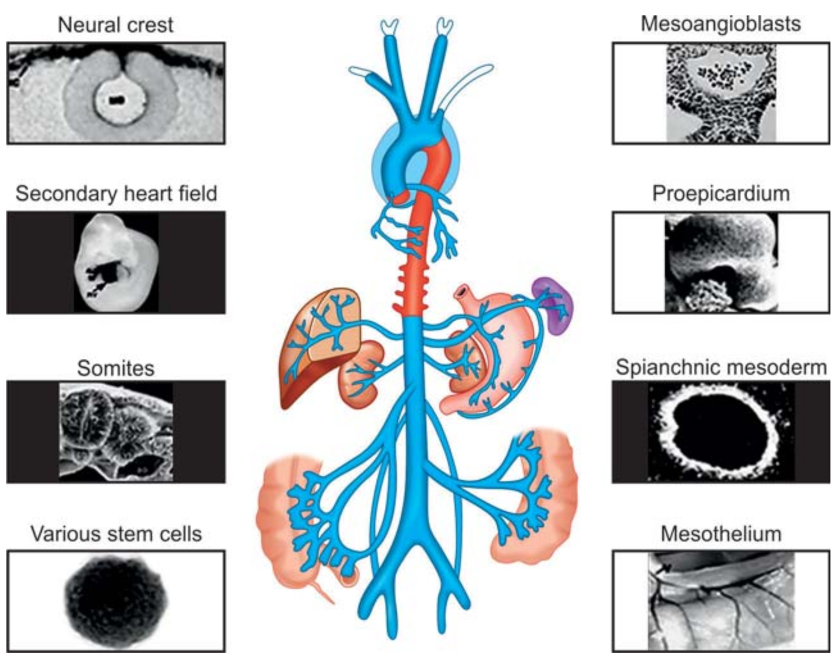


Fig. 157: Smooth muscles of the blood vessels have a variety of origins, as shown in the diagram

ENDOCRINE SYSTEM

Adrenal gland

Embryology

Suprarenal (adrenal) Gland

- Cortex is formed during the second month by a proliferation of the coelomic epithelium in the intermediate mesoderm. Cells pass into the underlying mesenchyme between the root of the dorsal mesogastrium and the mesonephros.
- The cortex is enveloped ventrally, and later dorsally, by a mesenchymal capsule that is derived from the mesonephros.
- **Medulla** forms from **neural crest cells**, which differentiate into chromaffin cells.

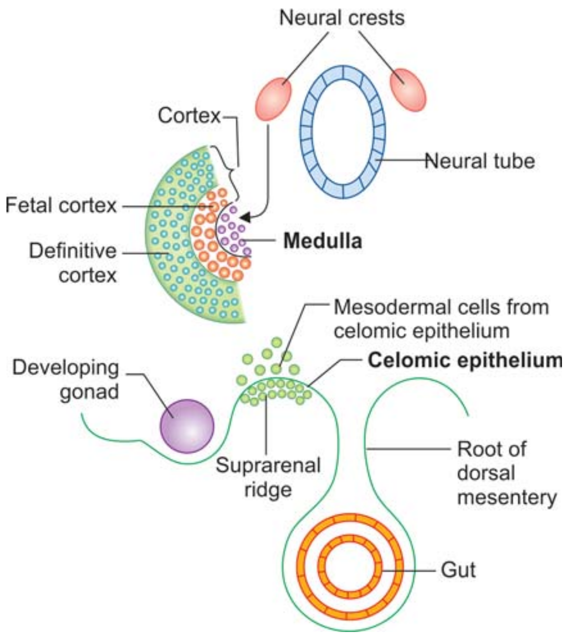


Fig. 158: Development of the adrenal gland

ASSESSMENT QUESTION

1. **Suprarenal gland develops from:** *(NEET Pattern 2015)*
   a. Metanephros
   b. Ureteric bud
   c. Neural crest
   d. Endoderm

ANSWER WITH EXPLANATION

1. **c. Neural crest**
   - **Adrenal medulla** develops from **neural crest cells**, which differentiate into chromaffin cells.
   - **Cortex** is formed by a proliferation of the **coelomic epithelium** (intermediate mesoderm).
   - The cortex is enveloped ventrally, and later dorsally, by a mesenchymal capsule that is derived from the **mesonephros**.
   - **Metanephros** forms the **excretory** portion of **kidney** system and ureteric bud forms the collecting system.
   - Adrenal gland develops in mesoderm (**not endoderm**).

UL & LL

- Limbs develop at the end of the fourth week as buds along the body wall adjacent to specific spinal segments determined by HOX genes (upper limb, C5-T2; lower limb, L2-S2).
- Development of the lower limb is approximately 1 to 2 days behind that of the upper limb.
- During the seventh week of gestation, the limbs rotate in opposite directions.
  - The upper limb rotates 90° laterally, so that the extensor muscles lie on the lateral and posterior surface, and the thumbs come to lie laterally.
  - The lower limb rotates 90° medially, placing the extensor muscles on the anterior surface and the big toe medially.

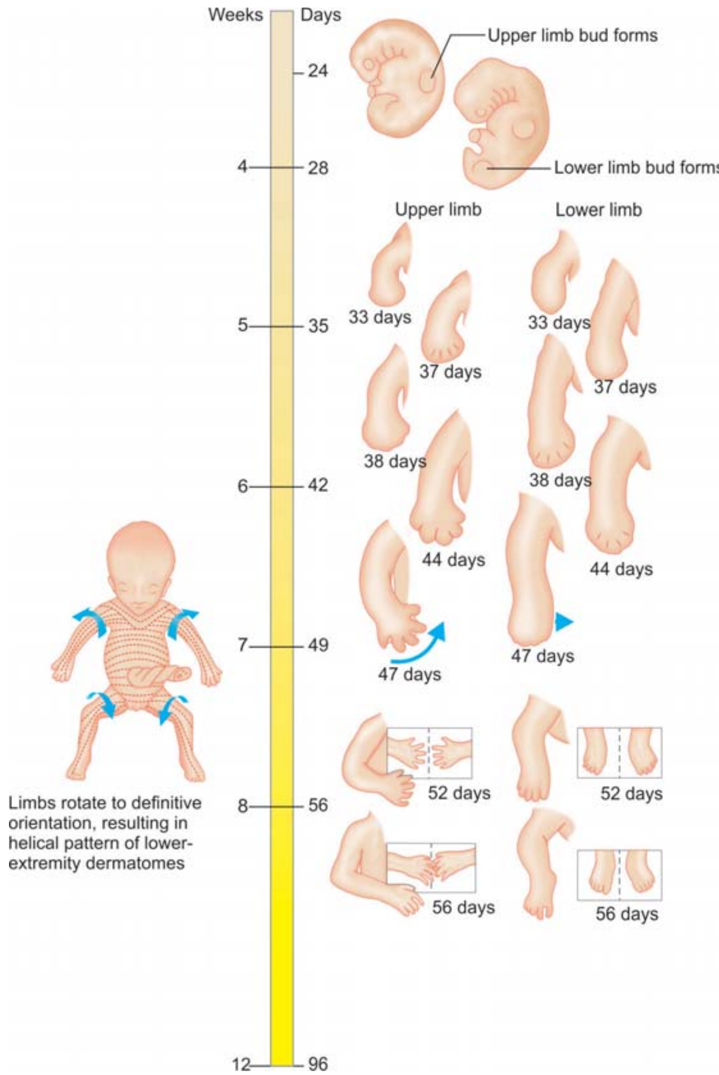


Fig. 159: Development of limb

- Bones of the limb form by endochondral ossification and are derived from the parietal layer of lateral plate mesoderm. Muscle cells migrate from somites in a segmental fashion and segregate into dorsal and ventral muscle groups.
- Later fusion and splitting of these groups into different muscles distorts the original segmental Pattern. Muscles are innervated by ventral primary rami that split into dorsal and ventral branches. The dorsal and ventral branches eventually unite into dorsal and ventral nerves to innervate the dorsal (extensor) and ventral (flexor) compartments, respectively.
- Digits form when apoptosis (programmed cell death) occurs in the AER to separate this structure into five separate ridges. Final separation of the digits is achieved by additional apoptosis in the interdigital spaces. Many digital defects occur that are related to these Patterns of cell death, including polydactyly, syndactyly, and clefts.

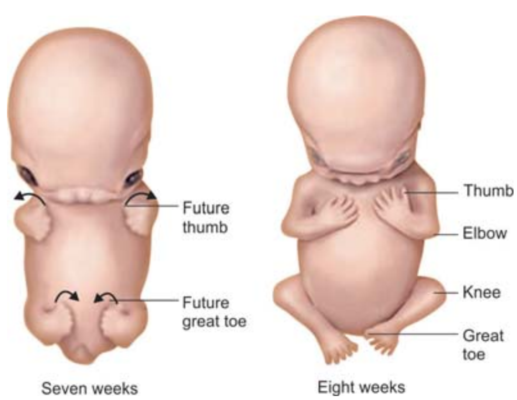


Fig. 160: Rotation of upper limb occurs towards lateral side by 90 degrees (bringing thumb to lateral side). Rotation of lower limb occurs to medial side by 90 degrees (bringing great toe medial).

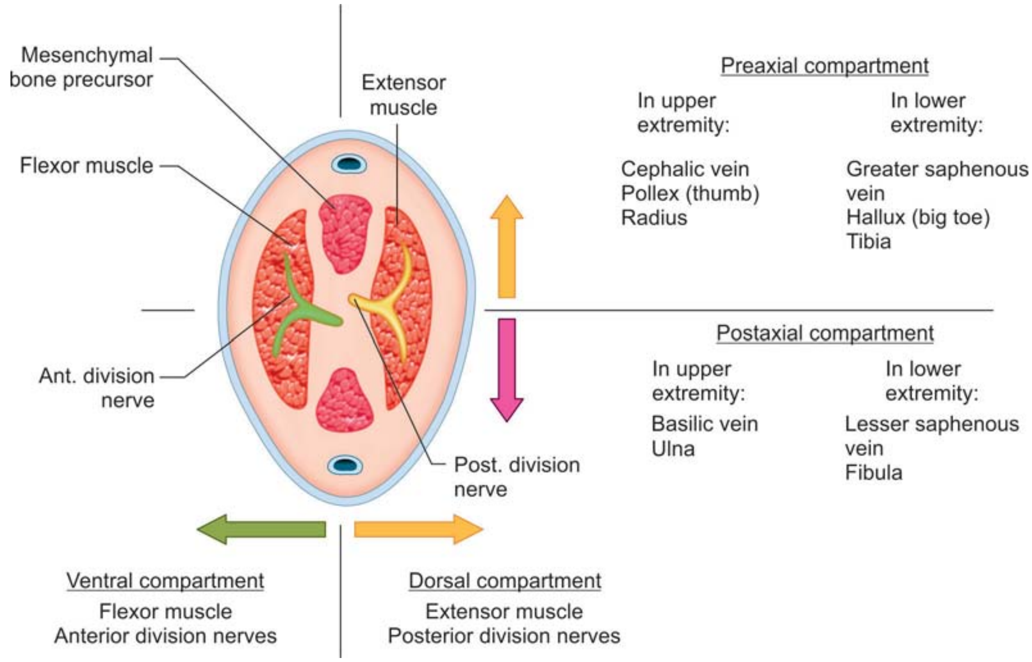
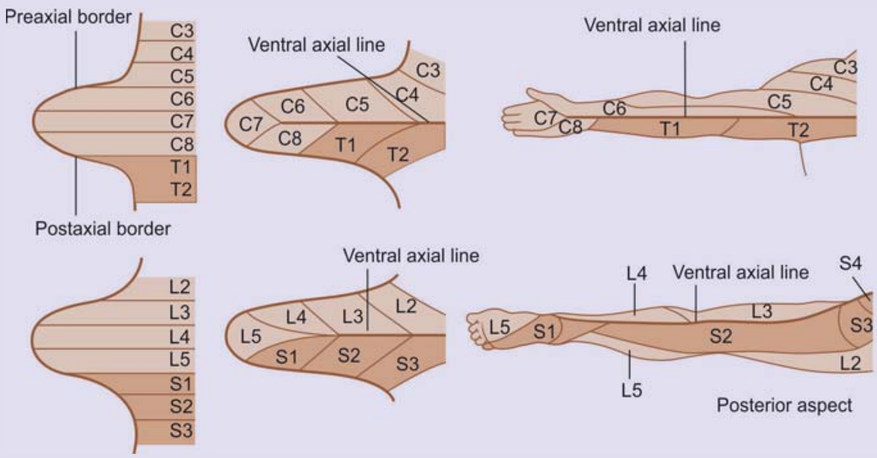


Fig. 161: Development of pre-axial and post-axial structures in upper and lower limbs.

The dorsal and ventral axial lines both reach the **ankle joint** (ventral reaches the medial aspect).

The blood supply to the lower limb is derived from the lateral branch of the fifth lumbar intersegmental artery, which continues into the limb bud as the axial artery.



The preaxial vein becomes the long saphenous vein, which drains into the femoral vein at the saphenous opening.

The postaxial vein becomes the short saphenous vein, which passes deep and joins the popliteal vein.

The lower limb is first recognizable as a laterally projecting thickening in the body wall opposite somites 24–29 at day 28.
The core of mesenchymal cells is derived from both somatopleuric and paraxial mesenchyme.
The lower limb rotates in utero medially 90 degree, while the upper limb rotates laterally 90 degree.
Thus, the limbs are 180 degree out of phase with one another (knee anterior and big toe medial versus elbow posterior and thumb lateral).
The extensor compartment in lower limb comes anterior and the **flexor compartment** becomes **posterior**.

ARTERIES

The axis artery of the upper limb is derived from **seventh cervical intersegmental artery**. The axis artery runs on the **anterior** aspect of the lower limb and terminates in a palmar capillary plexus in hand. Main trunk of axis artery forms **axillary artery**, **brachial artery**, **anterior interosseous artery**, and **deep palmar arch**. The digital arteries of the hand arise from the **palmar capillary plexus**. The median artery develops from the anterior interosseous artery and communicate distally with the palmar capillary plexus. Radial and ulnar arteries develop from the axis artery close to bend of the elbow.

Axis artery	Adult derivatives
Axial artery of upper limb	• Axillary artery • Branchial artery • Anterior interosseous artery • Deep palmar arch

Axis artery	Adult derivatives
Axial artery of lower limb •	• Inferior gluteal artery • Arteria nervi ischiadici • Popliteal artery above popliteus • Lower part of peroneal artery • Some parts of plantar arch

- The aortic arch 4 forms the proximal part of the right subclavian artery.
- The seventh intersegmental artery (ISA-7) contributes to the axial artery of upper limb and forms the distal part of the right subclavian artery and the entire left subclavian artery.
- The subclavian artery (right and left) continues into the limb bud as the axis artery, which ends in a terminal plexus near the tip of the limb bud.
- The axis artery persists in the adult as the **axillary artery, brachial artery, anterior interosseous artery, and deep palmar arch**.
- Developmentally, radial artery is pre-axial and ulnar is a post-axial artery.

Axis Artery of the Lower Limb is derived from fifth lumbar intersegmental artery.

The axis artery runs on the posterior aspect of the lower limb. It forms inferior gluteal artery, a small artery accompanying the sciatic nerve (ischiadic artery), part of popliteal artery (above the popliteus muscle), lower part of peroneal artery and part of plantar arch. The femoral artery is an entirely new (de novo) vessel formed on the ventral aspect of thigh. It develops a connection with the external iliac artery above and popliteal artery below. The external iliac artery is an offshoot of the axial artery.

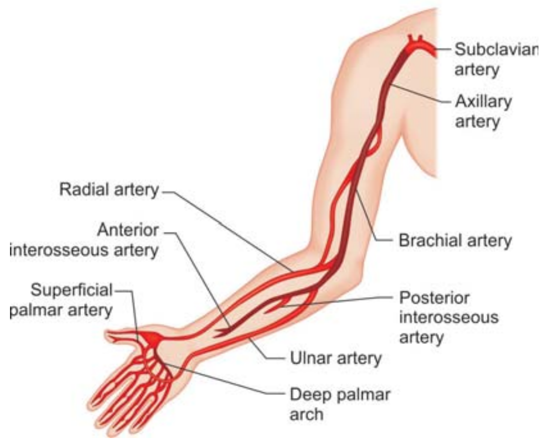


Fig. 162: Development of upper limb arteries.

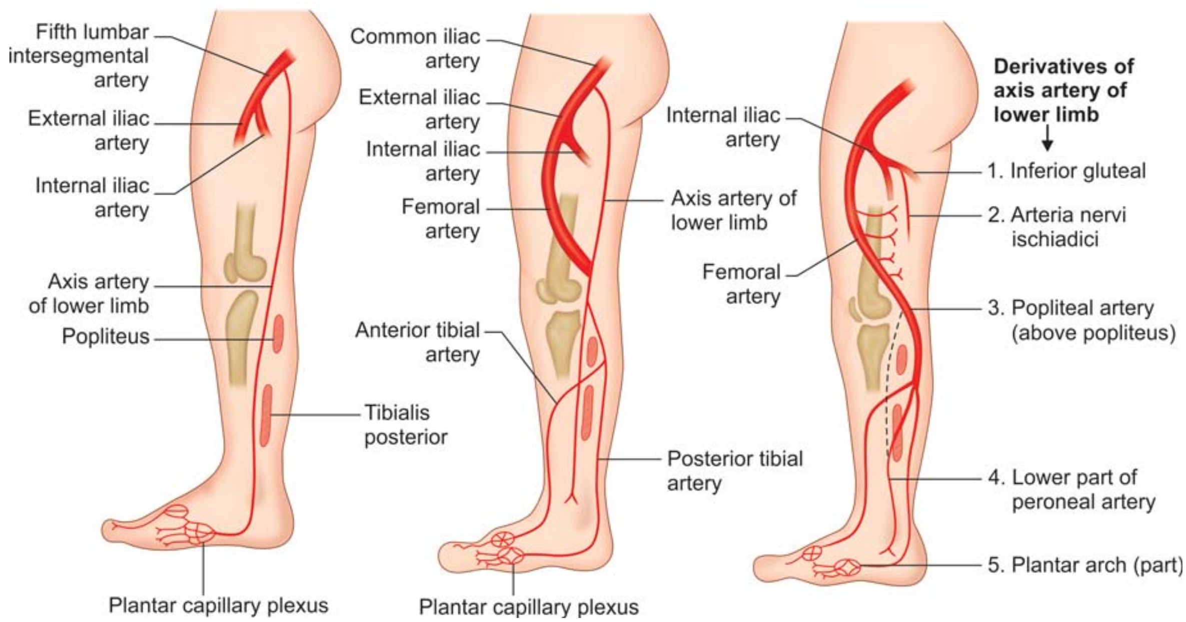


Fig. 163: Stages in the development of arteries of the lower limb

ANOMALIES

Table 27: Some common terms for limb malformations

Term	Definition
Acheiropodia	Absence of the hands and feet
Adactyly	Absence of all digits on a limb
Amelia, ectromelia	Absence of one or more limbs
Arachnodactyly	Elongated digits
Brachydactyly	Shortened digits
Camptodactyly	Flexion contracture of a finger (often fourth or fifth), which cannot be fully extended

Term	Definition
Clinodactyly	Curving of fifth finger toward the fourth
Ectrodactyly	Longitudinal divisions of the autopod into two parts, often with absence of central digits (also called split-hand or split-foot malformation)
Meromelia	Absence of part of a limb
Mesomelia	Shortened zeugopod
Oligodactyly	Absence of any number of fingers or toes
Phocomelia	Absence of proximal limb structures
Polydactyly	Presence of extra digits or parts of digits
Rhizomelia	Shortened stylopod
Syndactyly	Fusion of digits
Synostosis	Fusion of bones or intervening soft tissue
Triphalangeal thumb	A thumb with three rather than two

ASSESSMENT QUESTIONS

1. **Mis-expression of which of the following homeobox genes alters the position of the forelimbs during development:** *(AIIMS)*
   a. HOX A7
   b. HOX B8
   c. HOX C9
   d. HOX D10

2. **Preaxial border of limb is:** *(NEET Pattern 2015)*
   a. Ulnar border of forearm
   b. Fibular border of leg
   c. Radial border of forearm
   d. None of the above

3. **What is the persistent remnant of axial artery of upper limb:** *(NEET Pattern 2015)*
   a. Radial artery
   b. Ulnar artery
   c. Anterior interosseus artery
   d. Posterior interosseous artery

4. **Axis artery of lower limb is derived from:** *(NEET Pattern 2015)*
   a. 1st lumbar intersegmental artery
   b. 3rd lumbar intersegmental artery
   c. 5th lumbar intersegmental artery
   d. Sacral artery

ANSWERS WITH EXPLANATIONS

1 **b. HOX B8**
- The cranial limit of expression of **H0X B8 is** at the cranial border of the forelimb, and mis-expression of this gene alters the position of these limbs.

2. **c. Radial border of forearm**
- **Pre-axial border** of upper limb is the **radial border** and for lower limb it is the tibial border.

3. **c. Anterior interosseus artery**
- Anterior interosseus artery is a remnant of axial artery of upper limb.

4. **c. 5th lumbar intersegmental artery**
- The axis artery of the lower limb is derived from fifth lumbar intersegmental artery.
- The axis artery runs on the posterior aspect of the lower limb.
- It contributes to inferior gluteal artery and parts of popliteal artery, peroneal artery and plantar arch.

CONGENITAL ANOMALIES

Table 28: Summary of common congenital anomalies throughout the body and their embryonic causes

Condition	Embryological Basis
Anencephaly	Absence of pant of the brain from a neurulation defect where the neural tube does not close and the over tying skull is not able to form. It is the head equivalent of spinda bifida with myelocele.
Anular pancreas	A pancreatic head that encircles the duodenum when the ventral pancreatic bud improperly migrates around both sides of the abdominal foregut tube to fuse with the dorsal pancreatic bud and trails pancreatic tissue along its bifid path.
Bladder-rectum fistula	Improper division of the hindgut cloaca into the rectum and urogenital sinus (bladder, urethra, and related glands).
Bicomuate uterus	Bifid uterus ("two horns") that develops from the left and right para mesonephric (mollerian) ducts in addition to the fused uterovaginal primordium. Other abnormalities of the uterus and/or vagina result from improper development of the uterovaginal primordium and/or one or both of the ducts.

Condition	Embryological Basis
Cleft lip/primary palate	Failure of the lower part of the frontonasal process (intennaxillary segment with its median palatine process) to fuse with the maxillary part of the first pharyngeal arch. It can be unilateral or bilateral.
Cleft secondary palate	Failure of the lateral palatine processes of the maxillary part of the first pharyngeal arch to fuse with each other and/or the nasal septum.
Coloboma of the eye	Failure of closure of the ventral cleft: in the optic cup. Can result in anything from a small defect in the iris to large gaps in the iris, ciliary body, and/or retina.
Cryptorchidism	Undescended testes in the abdominal cavity or inguinal canal. Sterility results if both testes are undescended.
Detached retina	The two layers of the optic cup never tightly fuse, and the inner layer (visual retina) can fall away from the outer layer (pigmented retina).
Diaphragmatic harnia	Most often a failure of the pleuroperitoneal membranes to close off the central tendon of the diaphragm to complete the separation of the pleural and peritoneal coelomic cavities.
DiGeorge syndrome	Absence of the thymus and parathyroid gland from defective development of the third and fourth pharyngeal pouches. Results in immune deficiency from defective, T-cell function. Often accompanied by first arch defects of the face and ears.
Double aortic arch	Persistence of the proximal part of the right dorsal aorta to form a vascular sling around the trachea and esophagus. The aorta and the superior and inferior vena cavae are initially paired vessels that may persist.
Ectopia cordis	A gastroschisis-type defect of the thorax where the heart extends outside the thoracic wall.
Ectopic parathyroids	Typically, these are the inferior para thyroid glands from pharyngeal pouch Ill. They descend with the thymus gland, some times all the way into the mediastinum. The superior parathyroid glands are from pouch IV and do not migrate very far to their adult location behind the tllyroid gland.
Ectopic thyroid tissue	Located anywhere along of the patll of the thyroglossal duct: from tile tongue to the trachea anterior to the hyoid bone and larynx. There can also be cysts in a patent duct. The foramen cecum on the tongue is the site of the thyroid diverticulum.
Ectopic ureters	The meranephric ducts (ureters) can open in many locations in the bladder and other organs. They originate from the caudal end of the mesonephric duct and are often "carried" with it to a lower position than nonnal (e.g., urethra), particularly in the male.
Epispadius	A penile urethra that opens on the dorsal surface of the penis due to improper location of the phallic tubercle relative to the urogenital sinus.
Exstrophy of the bladder	A gastroschisis-type defect of the lower abdominal wall where the bladder extends outside the abdominal wall.
External auditory meatus atresia	Failure of the cellular plug in the meatus (developing from the first pharyngeal groove) to canalize. Often related to first pharyngeal arch syndrome, in which neural crest cells fail to migrate into the arch in sufficient numbers.
Gartner's duct cyst	A remnant of the male duct primordium (the mesonephric or wolffian duct) in the broad ligament of the uterus.
Gastroschisis	An abdominal hernia through a body wall defect resulting from incomplete folding of the gastrula or ventral muscle migration. It can look like an omphalocele, but the intestines do not extend into the umbilical cord (they are usually to the right of the umbilical ring), and the viscera are directly bathed in amniotic flu id. The "split stomach" term is a misnomer.
Hepatic segment of inferior vena cava absent	The vitelline veins fail to form the hepatic segment of the inferior vena cava. Blood from the lower inferior vena cava reaches the heart via the azygous vein.
Holoprosencephaly	The most severe consequence of fetal alcohol syndrome, it is the failure of mid line cleavage of the embryonic forebrain. Numerous abnormalities may include a small forebrain, a single ventricle, absence of olfactory bulbs and tracts (arrh in encephaly), and facial deformities (e.g., eyes close together).
Horseshoe kidney	The left and right meranephric kidneys, with their ureteric buds, fuse in the midline of the pelvis and hook around the inferior mesenteric artery as they ascend.
Hydrocephaly	Excess cerebrospinal fluid (CSF) that dilates the ventricles or accumulates around the brain. Results from blockage within the ventricular system (obstructive hydro cephaly, e.g., aqueductal stenosis or atresia of the foramina of Luschka and Magendie) or in the flow of CSF in the subarachnoid space (communicating hydrocephaly).
Hypospadias	A penile urethra that opens on the ventral surface of the penis. The urogenital (UG) folds fail to enclose the distal pan of the UG sinus on the ventral surface of the phallic rubercle (developing penis). The UG endoderm normally connects to an invagination of ectoderm from the tip of the glans penis to complete penile urethra development.
Indirect (congenital) hernia	A patent processus vaginalis (a finger-like extension of parietal peritoneum through the inguinal canal that typically closes) is a ready-made hernial sac. Its partial closure can result in cysts.

Condition	Embryological Basis
Interatrial septa! defect	The embryonic single atrium is divided into left and right chambers by a seprum primum with a foramen secundum and a septum secundum with a foramen ovale. A septal defect usually results when one or both foramina are too large and they overlap too much.
Interventricular septal defect	The embryonic interventricular septum (which becomes the muscular IV seprum) fails to fuse properly with the endocardial cushions and the spiral (aonicopulmonary) septum. This fusion defect is in the upper membranous pan of they septum. Holes can also develop within the muscular IV septum.
MKkel's diverticulum	Remnant of the yolk sac stalk extending from the midgut (ileum). Its inflammation can mimic the pain of appendicitis. The stalk can also be a cyst or fistula.
Megacolon	Lack of peristalsis due to the failure of neural crest cells to migrate into the colon and differentiate into neurons of the enteric nervous system in the smooth muscle wall of the colon.
Multiple renal vessels	A by-product of the unusual mechanism of kidney blood vessel development. Most organs (e.g., gonads, muscles) t rail their blood supply as they migrate. As the kidneys ascend from the pelvis, new vessels develop and connect to them at successively higher levels. The lower on es usually disappear, but may persist as multiple renal vessels from the aorta and/or inferior vena cava.
NasolacrimaJ duct defect	A "tear duct" that opens on the surface at the side of the nose. Results from failure of the middle pan: of the frontonasal process alongside the developing nose to fuse with the maxillary pan of the first pharyngeal (branchial) arch. The ectodermal cleft between these swellings normally invaginates to form the duct.
Oligohydramnios	Low amount of amniotic fluid that results in fetal c.ompression and associated deformities (e.g., Potter's syndrome). May be caused by low fluid production from renal agenes is.
Omphalocele	Congenital umbilical hernia. The rapidly growing intestines of the midgut leave the fetal abdominal cavity and enter the umbilical cord as a normal part of dev elopment. Sometimes, they fail to return to the abdominal cavity.
Pelvic kidney	Failure of the kidneys to ascend from the pelvis, where the metanephric diverticulum originates from the caudal end of the mesonephric duct.
Pharyngeal (branchial) cysts and sinuses	A persistence of the cervical sinus, which is a fusion of pharyngeal grooves II, Ill, and IV below the surface. Cysts and internal sinuses can also be remnants of pharyngeal pouches.
Pharyngeal (branchial) fistulas	Communication between the surface of the neck and the lumen of the pharynx (usually at the palatine tonsil) or larynx when a pharyngeal membrane breaks down between an external pharyngeal groove and internal pharyngeal pouch.
Polyhydramnios	Excess amniotic fluid that may result from anencephaly, esophageal atresia, or other anomalies that impair the drinking, swallowing, and/or absorption of amniotic fluid in the fetus.

SKIN

Skin develops from the **surface ectoderm** and its underlying **mesenchyme**.

- The skin and its associated structures, hair, nails, and glands are derived from **surface ectoderm**.
- Interactions between ectoderm and mesenchyme give rise to the oral and nasal epithelia, as well as teeth.
- **Ectodermal** cells differentiate into the **keratinocytes** and non-keratinocyte epidermal cells include
    - **Melanocytes** - derived from the **neural crest cells**
    - **Langerhans** cells (antigen-presenting cells) - derived from **monocytes** (mesoderm; bone marrow)
    - **Merkel** cells (sensory mechanoreceptors) - derived from surface ectoderm.
- The epidermis regenerates approximately every **30 days**, is carried out by the mitotic activity of stem cells at the basal layer (**stratum germinativum)**. After moving to the surface, cells are sloughed off in the **stratum corneum**.
- The dermis is derived from
    - **Somatopleuric** mesenchyme in lateral plate mesoderm (limbs and body wall)
    - **Dermatomes** that form from somites in paraxial mesoderm (in the back, back covering the epaxial musculature)
    - **Neural crest cells** (in the head and neck)
- **Angiogenic mesenchyme** gives rise to the blood vessels of the dermis.
- Nerves and associated Schwann cells, which are derived from the **neural crest**, enter and traverse the dermis during development.
- By about 20 weeks, the fetus is covered by downy hair, **lanugo** hair, which is shed at the time of birth

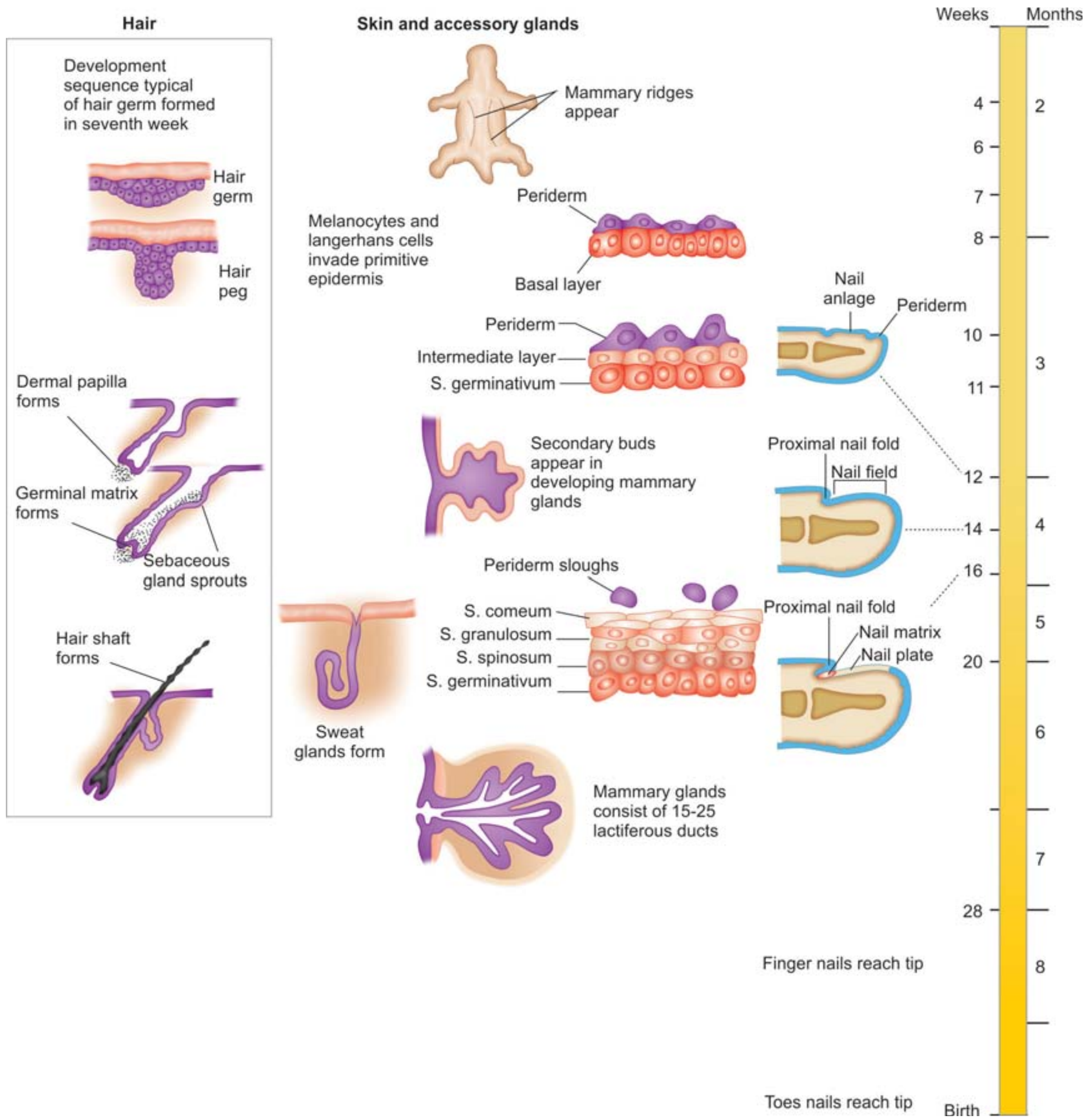


Fig. 164: Development of the skin and its derivatives

High Yield Point

- **Langerhans** cells are derived from monocyte/phagocyte series, they capture antigens from skin and carry to the lymph nodes for further immune activity.

ASSESSMENT QUESTIONS

1. **Melanoblast cells appear in basal layer of epidermis during:**
   a. 3rd month of intrauterine life
   b. 5th month of intrauterine life
   c. 7th month of intrauterine life
   d. 8th month of intrauterine life

2. **Merkel cells are derivatives of:** *(DNB Pattern 2016)*
   a. Surface ectoderm
   b. Neural crest cell origin
   c. Endodermal origin
   d. Monocyte/Phagocyte origin

ANSWERS WITH EXPLANATIONS

1. **a. 3rd month of intrauterine life**
   - During the first 3 months of development, the epidermis is invaded by cells arising from the **neural crest** which synthesize melanin pigment in **melanosomes**.
   - Melanosomes are transported down dendritic processes of **melanocytes** and are transferred intercellularly to **keratinocytes** of the skin and hair bulb to acquire pigmentation of the skin and hair.

2. a. Surface ectoderm > b. Neural crest cell origin

- Earlier **merkel cells** were considered to be derived from **neural crest cells** (Gray's Anatomy - 40th Edition), but more recent studies have indicated that they are in fact epithelial (Gray's Anatomy - 41st Edition) in origin.
- Since skin epithelium is derived from **surface ectoderm**, the merkel cells are derivative of surface ectoderm.

ASSESSMENT QUESTIONS

1. If there is absence of precursor cell of an organ with the subsequent non development of the organ, the condition is called as *(NEET Pattern 2012)*

a. Agenesis
b. Aplasia
c. Atresia
d. Atrophy

2. A person showing two cell lines derived from two different zygotes is known as *(AIIMS 2006)*

a. Chimerism
b. Mosaicism
c. Segregation
d. Pseudo dominance

ANSWERS WITH EXPLANATIONS

1. a. Agenesis

- **Agenesis** is the complete failure of an organ to develop during embryonic growth due to the absence of primordial tissue.
- **Aplasia** is the failure of organ to develop with only rudiment of organ present. It occurs, when precursor cells are present, but they do not differentiate into the organ.
- **Atresia** is the absence or closure of an orifice, tube, duct.
- **Atrophy** is the partial or complete wasting away of a part of the body due to a decrease in cell size and number.

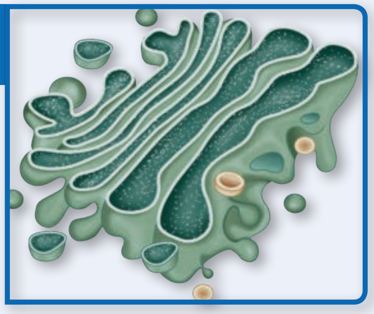
2. a. Chimerism

- A **chimera** is a single organism composed of cells from different zygotes. It may occur by organ transplantation, giving one individual tissues that developed from two genomes. For example, a bone marrow transplant can change someone's blood type.
- **Mosaicism** describes the presence of two or more populations of cells with different genotypes in one individual, who has developed from a single fertilized egg.
- Mosaics and chimera have more than one genetically distinct population of cells. But all genetically different cell lines arise form single zygote in mosaics and form more than one zygote in chimeras.

High Yield Points

- Development of spermatozoa from spermatogonium takes 74 days.
- Storage and Maturation of sperm occurs in Epididymis (and further continue in vas deferens).
- Motility of sperm is gained in Epididymis.
- Capacitation of sperm occurs in female genital tract - isthmus of uterine tube.
- Acrosome cap is derived from golgi body and middle piece contains mitochondria.
- Secondary spermatocyte/Oocyte is a haploid (n) cell with two units of DNA (2N). (n = number of chromosome; N = Amount of DNA)
- Primary oocyte is arrested in Prophase-I (Diplotene) stage till Puberty (PPP).
- First polar body is released 12/24 hours before ovulation.
- Second polar body is released after fertilization.
- **Amniocentesis** is the procedure used to withdraw amniotic fluid for analysis of factors, such as alfa-fetoprotein (AFP) and cells (chromosomes), which provide information about the status of the foetus.

CHAPTER 3



Histology

Cell and Organelles

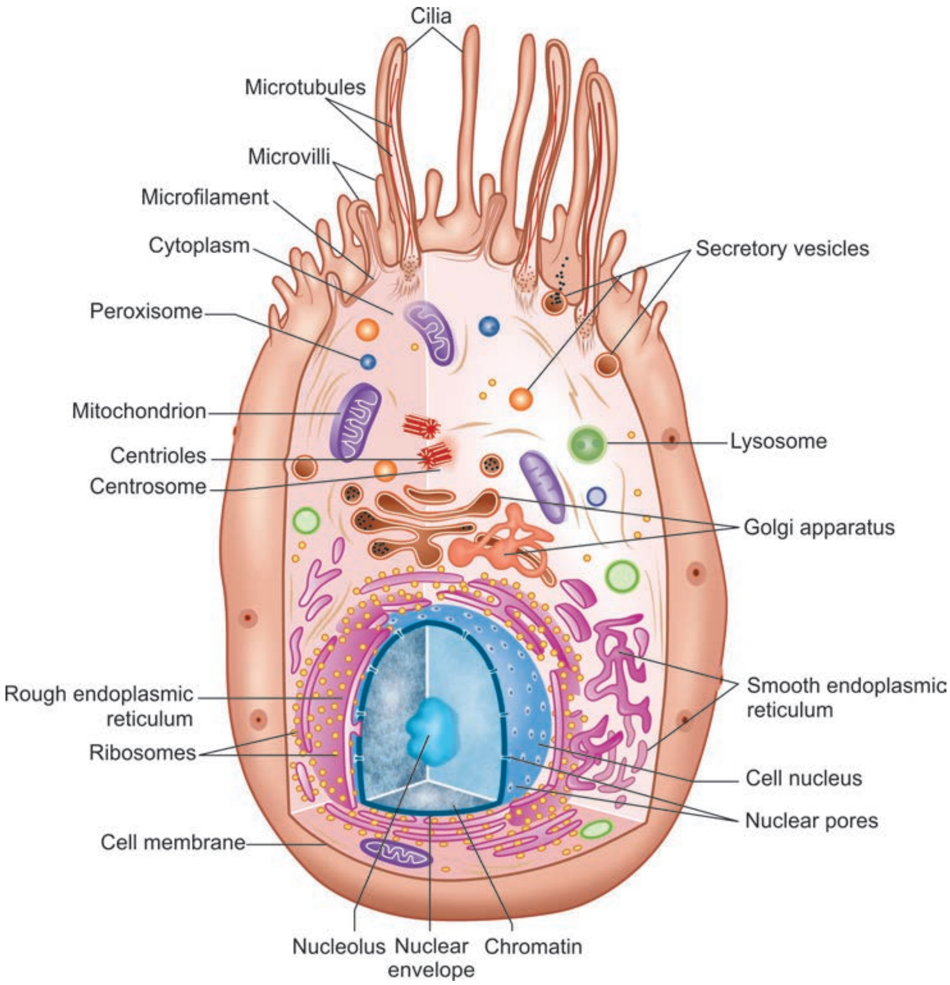


Fig. 1: Cell and its organelles.

Table 1: The characteristic features of pairs of chromosomes in karyotype

Group	Pairs of chromosomes	Features
A	1,2, and 3	Long and metacentric
B	4 and 5	Fairly long and submetacentric
C	6 to 12+ X chromosome	Medium-sized and submetacentric
D	13 to 15	Medium-sized and acrocentric A satellite body is attached to the free end of short arm of each chromosome
E	16 to 18	Fairly short and submetacentric
F	19 and 20	Short and metacentric
G	21 and 22+ Y chromosome	Very short and acrocentric with *satellite* bodies on their short arms

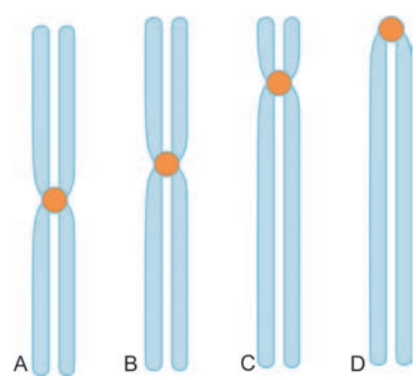
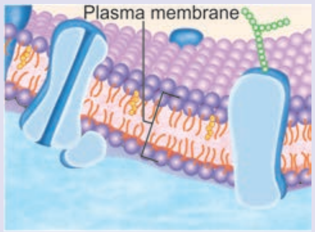
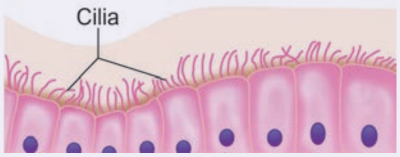
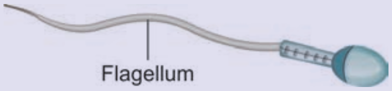
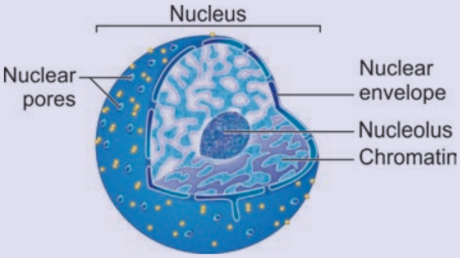
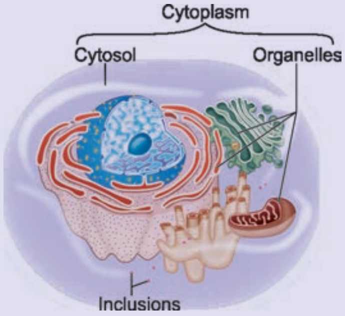
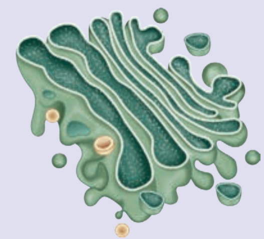
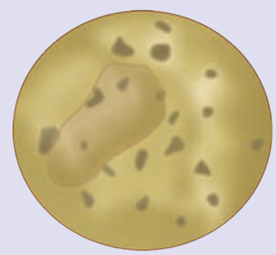
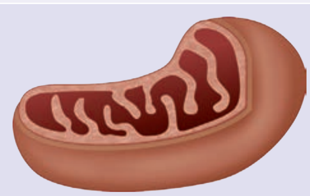
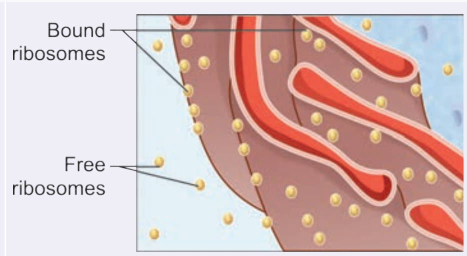
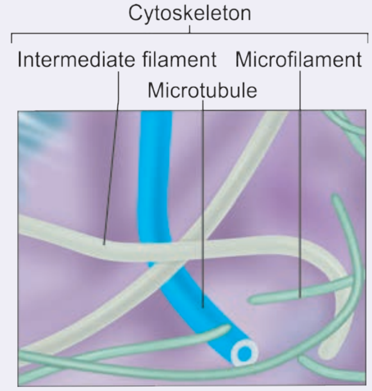
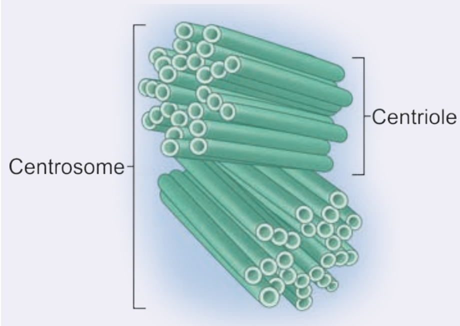
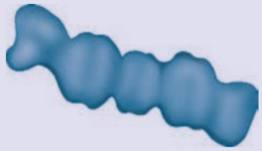


Fig. 2: Morphological types of chromosomes: (A) metacentric, (B) submetacentric, (C) acrocentric, and (D) telocentric.

Table 2: Summary of cellular structural components.

Component	Structure	Major function	Appearance
Plasma membrane	Phospholipid bilayer containing cholesterol and proteins (integral and peripheral) and some carbohydrates (extremally); forms a selectively permeable boundary of the cell	Acts as a physical barrier to enclose cell contents; regulates material movement into and out of the cell; establishes and maintains an electrical charge difference across the plasma membrane; functions in cell communication	
Cilia	Short, numerous membrane extensions supported by microtubules, which occur on exposed membrane surfaces of some cells	Move substances (e.g. mucus, and dissolved materials) over the cell surface	
Flagellum	Long, singular membrane extension supported by microtubules; present on sperm cells	Propels sperm	
Microvilli	Numerous thin membrane folds projecting from the free cell surface; supported by microfilaments	Increae membrane surface area for greater absorption	
Nucleus	Large structure enclosed within a double membrane; contains chromatin, nucleolus and nucleoplasm	Houses the DNA that serves as the genetic material for directing protein synthesis	
Nuclear envelope	Double membrane boundary betweeen cytoplasm and nuclear contents; continuous with rough endoplasmic reticulum	Separates nucleus from cytoplasm	
Nuclear pores	Openings through the nuclear envelope	Allow passage of materials between the cytoplasm and nucleoplasm, including ribonucleic acid (RNA), protein, ions, and small water-soluble molecules	
Nucleolus	Large, prominent structure within the nucleus	Functions in synthesis of ribosomes	
Cytoplasm	Contents of cells between the plasma membrane and nuclear envelope	Responsible for many cellular processes	
Cytosol	Viscous fluid medium with dissolved solutes (e.g. ions, proteins, carbohydrates, lipids)	Provides support for organelles; serves as the viscous fluid medium through which diffusion occurs	
Organelles	Membrane-bound and non-membrane-bound structures	Carry out specific metabolic activities of the cell	
Rough endoplasmic reticulum (rough ER)	Extensive interconnected membrane network that varies in shape (e.g. cistemae, tubules); ribosomes attached on cytoplasmic surface	Modifies, transports, and stores proteins produced by attached ribosomes; these proteins are secreted, become components of the plasma membrane, or serve as enzymes of lysosomes	

Component	Structure	Major function	Appearance
Smooth endoplasmic reticulum (smooth ER)	Extensive interconnected membrane network lacking ribosomes	Synthesizes, transports, and stores lipids (e.g. steroids); metabolizes carbohydrates; detoxifies drugs, alcohol, and poisons; forms vesicles and peroxisomes	
Golgi apparatus	Series of several elongated, flattened sac-like membranous structures	Modifies, packages, and sorts materials that arrive from the ER in transport vesicles; forms secretory vesicles and lysosomes	
Vesicles	Spherical-shaped membrane-bound sacs; contain various types of materials to be transported through the cell	Transport cellular material	
Lysosomes	Spherical-shaped membrane-bound organelles formed from the Golgi apparatus; contain digestive enzymes	Digest microbes or materials (e.g. ingested by the cell, worn-out cellular components, or the entire cell)	
Peroxisomes	Smaller, spherical-shaped membrane-bound organelles formed from the ER or through fission; contain oxidative enzymes	Detoxify specific harmful substances either produced by the cell or taken into the cell; engage in beta oxidation of fatty acids to acetyl CoA	
Mitochondria	Double membrane-bound organelles containing a circular strand of DNA (genes for producing mitochondrial proteins)	Synthesize most ATP during aerobic cellular respiration by digestion of fuel molecules (e.g. glucose) in the presence of oxygen	
Ribosomes	Organelles composed of both protein and ribosomal RNA (rRNA) that are organized into both a large and small subunit; may be bound to a membrane or free in cytosol	Engage in protein synthesis; Bound ribosomes produce proteins that are secreted, incorporated into plasma membrane, and within lysosomes; free ribosomes produce proteins used within the cell	

Component	Structure	Major function	Appearance
Cytoskeleton	Organized network of protein filaments and hollow tubules, including microfilaments, intermediate filaments, and microtubules	Maintains intracellular structural support and organization of cells; participates in cell division; facilitates movement	
Micro-filaments	Actin-protein monomers organized into two thin, intertwined protein filaments (actin filaments)	Maintain cell shape; support microvilli; separate two cells during cytokinesis (a process of cell division); facilitate change in cell shape; participate in muscle contraction	
Intermediate filaments	Various protein components	Provide structural support; stabilize junctions between cells	
Microtubules	Hollow cylinders composed of tubulin protein	Maintain cell shape and rigidity; organize and move organelles; support cillia and flagella; participate in vesicular transport; separate chromosomes during the process of cell division	
Centrosome	Amorphous region adjacent to nucleus; contains a pair of centrioles	Organizes microtubules; participates in mitotic spindle formation during cell division	
Proteasomes	Large, barrel-shaped protein complexes located in both the cytosol and nucleus	Degrade and digest damaged or unneeded proteins; ensure quality of exported proteins	
Inclusions	Aggregates of specific types of molecules (e.g. melanin, protein, glycogen, or lipid)	Serve as temporary storage for these molecules	Variable appearance

Stem Cells

Table 3: Comparison of the different types of stem cell.

	Advantages	Disadvantages
Embryonic stem cells	Pluripotency	Fear of immunological rejection Safety concerns—tumor (teratoma) formation Ethical dilemmas surrounding aborted fetuses Oocytes required
Amniotic fluid stem cells	Pluripotency Non-tumorigenic Can be harvested (through amniocentesis) and manipulated prenatally so that defect can be corrected either in utero or at the time of birth	Low yield – 1% of amniotic fluid cells are c-kit^{+} (CD117^{+}) stem cells Further research concerning origin of cells and characterization required
Umbilical cord stem cells	Ease of procurement with minimal donor morbidity Ease of cryopreservation and banking for future use Minimal ethical concerns	Low yield of stem cells and only finite number of cells available from donor Problems of storage—long-term storage may affect cell quality; cost implications; quality control issues

	Advantages	Disadvantages
Mesenchymal stem cells	Multipotent Large numbers can be harvested Can be enriched from a variety of different tissues including bone marrow, adipose tissue, etc. Easily expanded in tissue culture for tissue engineering purposes Autologous and possess immunomodulatory properties Appear safe in trials Minimal ethical concerns	Differentiation dependent on an appropriate microenvironment Optimal mode of delivery unclear Limited long-term therapeutic potential
Induced pluripotent stem cells	Pluripotent Can be derived from any cell type Probably non-immunogenic	Low efficiency of reprogramming with current techniques (<1%) Safety concerns–viral vector transduction commonly required (risks of viral infection and genetic manipulation) and risk of tumors

Epithelium

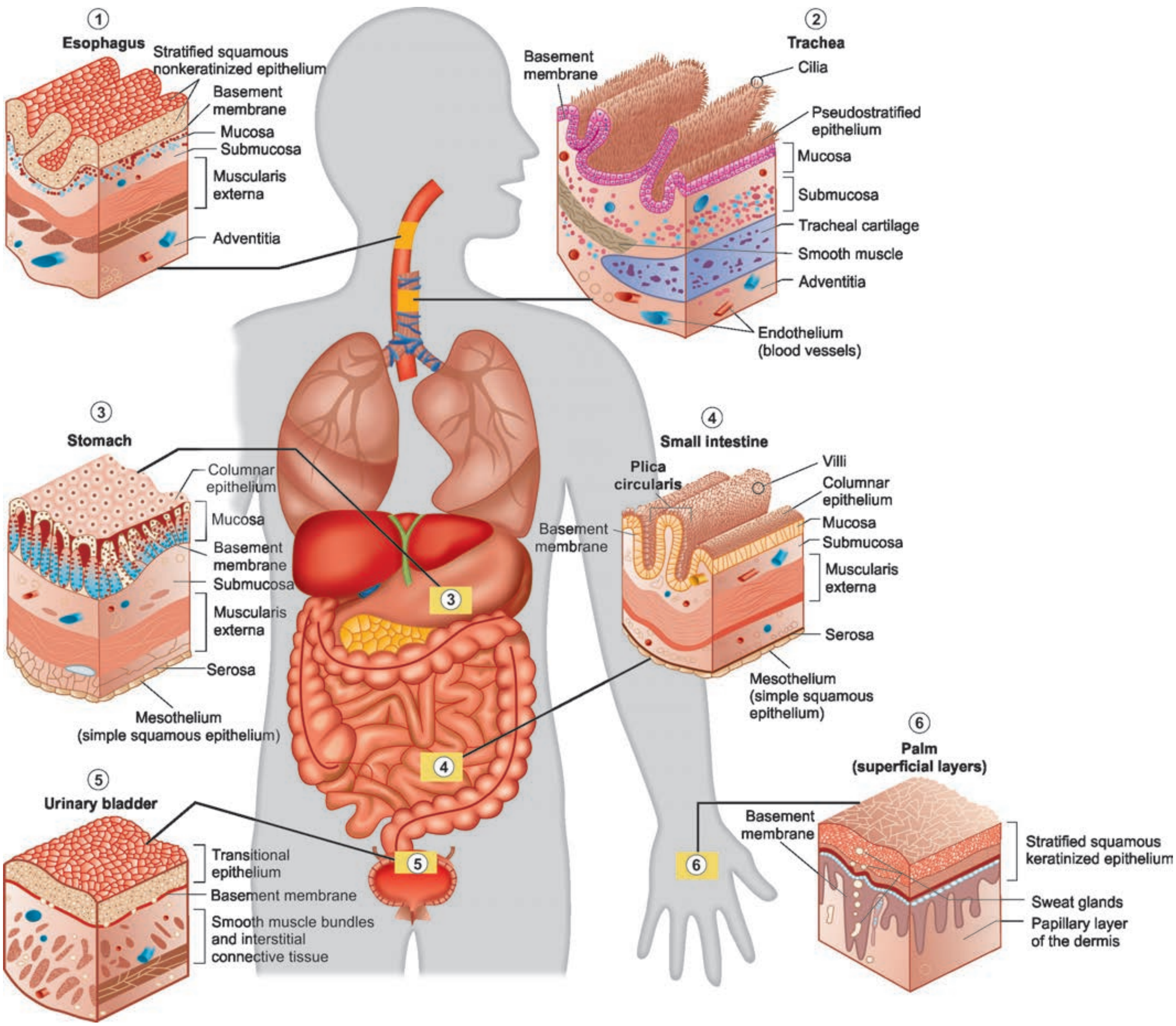


Fig. 3: Different types of epithelia at various sites in the body.

Types of Epithelia

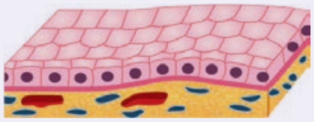
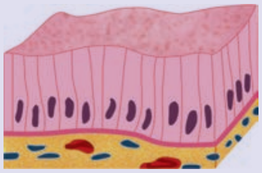
- **Epithelium** is the layer of cells that cover the body surfaces or line the body cavities that open on to it. Epithelial lining at important sites is given in the following table:

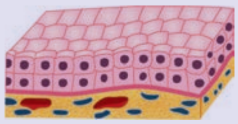
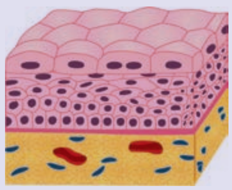
Lining	Site
Simple squamous	• Pericardium, pleura & peritoneum • Type – I pneumocytes (alveoli) • Bowman capsule and Loop of Henle (major part)
Stratified squamous*	• External ear canal (including external surface of tympanic membrane) • Cornea, conjunctiva • Nasal vestibule • Oral cavity: Lips, tongue, palate, tonsils, epiglottis (oral part) • Terminal anal canal (below dentate/pectinate line) • Terminal urethra
Simple cuboidal	• Thyroid follicles • Germinal epithelium of ovary • PCT, DCT and some parts of Henle's loop
Stratified cuboidal	• **Exocrine ducts**, like lacrimal, salivary, sweat
Simple columnar	• Stomach and intestine • Gallbladder • **Collecting tubules** of kidney
Stratified columnar	• Male urethra
Pseudostratified columnar	• Male urethra • Olfactory epithelium • Respiratory tract, e.g. trachea • Eustachean tube • Epididymis, ductus deferens • Urethra
Ciliated columnar	• Respiratory tract • Eustachian tube • Uterine tube & uterus • Central canal of spinal cord and ventricles of brain
Columnar with micro-villi	• Small intestine (striated border) • **Gallbladder (brush border)**
Neuroepithelium	• Ear, Nose, Tongue and Eye (retina)

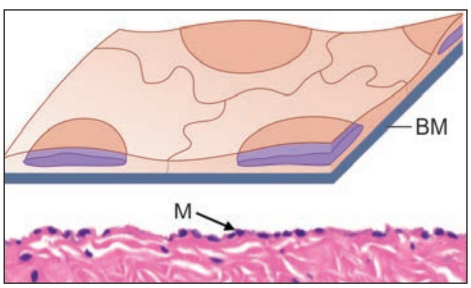
* **Rule**: Epithelium which can be touched by fingers is usually lined by stratified squamous epithelium and is a derivative of ectoderm.

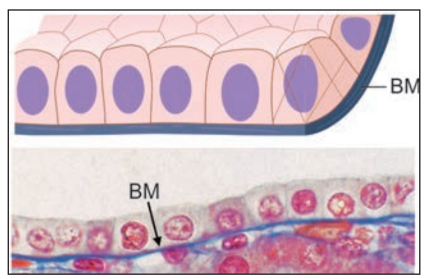
- **Transitional epithelium** is a specialized stratified epithelium with large dome-shaped (umbrella) cells that bulge into the lumen.
  - The dome-shaped cells have a modified apical membrane containing plaques and fusiform vesicles that accommodate the invaginated excess of the plasma membrane, which is needed for the extension of the apical surface when the organ is stretched.

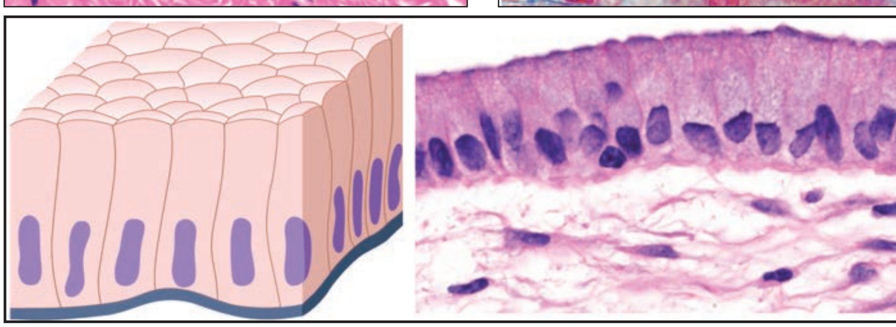
Table 4: Types of epithelium

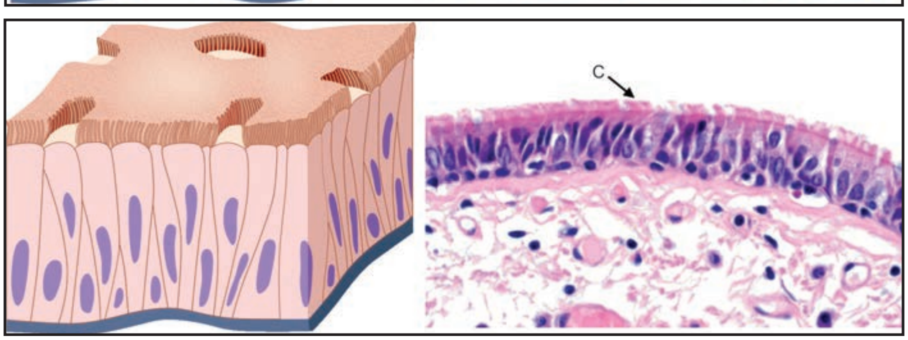
Classification		Some Typical Locations	Major Functions
Simple squamous		Vascular system (endothelium) Body cavities (mesothelium) Bowman's capsule (kidney) Respiratory spaces in lung	Exchange, barrier in central nervous system Exchange and lubrication
Simple cuboidal		Small ducts of exocrine glands Surface of ovary (germinal epithelium) Kidney tubules Thyroid follicles	Absorption and conduit Barrier Absorption and secretion
Simple columnar		Small intestine and colon Stomach lining and gastric glands Gallbladder	Absorption and secretion Secretion Absorption

Classification		Some Typical Locations	Major Functions
Pseudostratified		Trachea and bronchial tree Ductus deferens Efferent ductules of epididymis	Secretion and conduit Absorption and conduit
Stratified squamous		Epidermis Oral cavity and esophagus Vagina	Barrier and protection
Stratified cuboidal		Sweat gland ducts Large ducts of exocrine glands Anorectal junction	Barrier and conduit
Stratified columnar		Largest ducts of exocrine glands Anorectal junction	Barrier and conduit
Transitional (urothelium)		Renal calyces Ureters Bladder Urethra	Barrier, distensible property









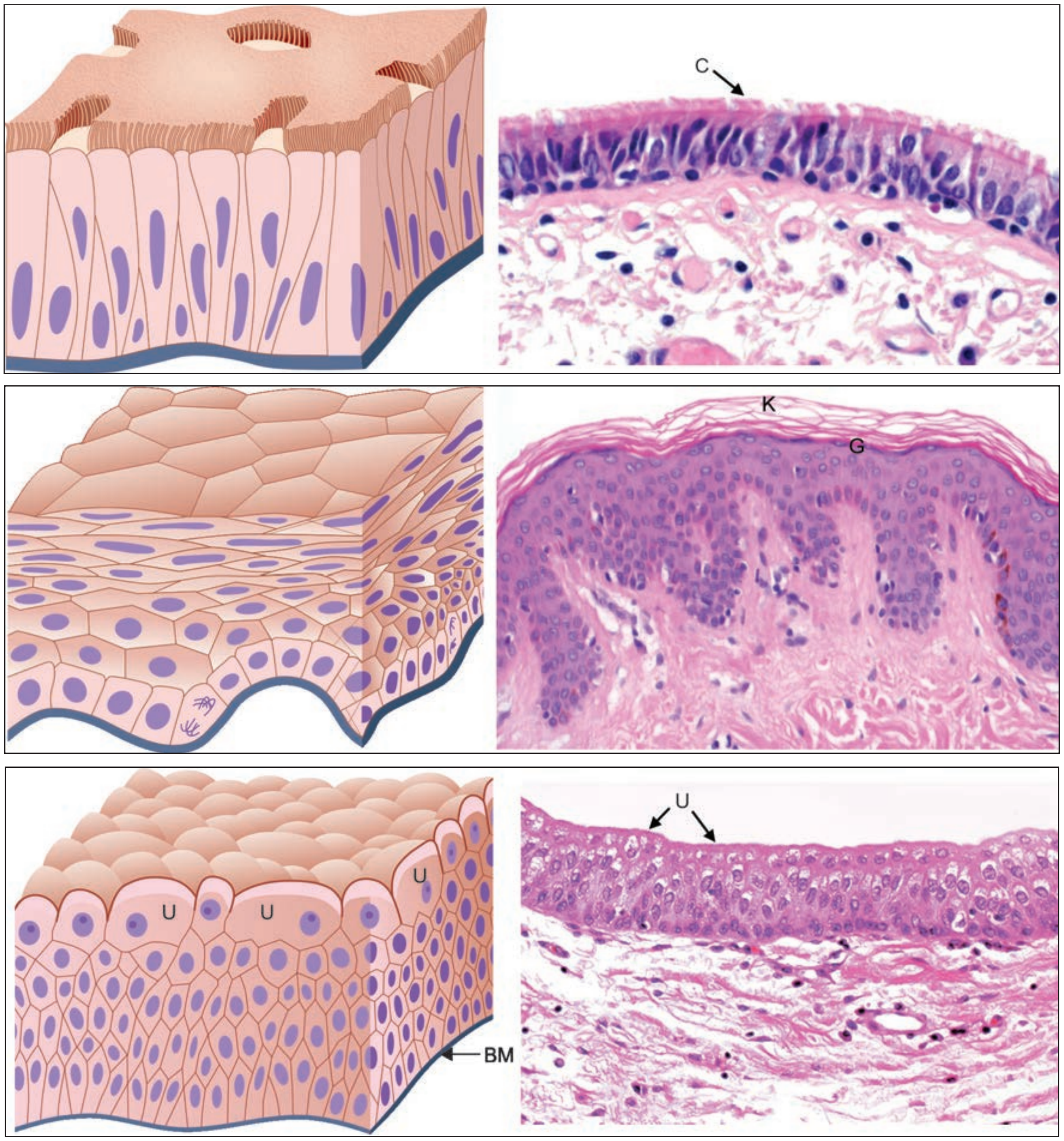


Fig. 4: Types of epithelia (A-G). A - Simple squamous; B - Simple cuboidal; C - Simple columnar; D - Ciliated columnar; E - Pseudostratified ciliated columnar; F - Stratified squamous (keratinized); G - Transitional. (BM - Basement membrane, C - Cilia, K - Keratin, U - Umbrella shaped cell).

- Sensory epithelium **(neuroepithelium)** is present in special sense organs of the **olfactory (nose), gustatory (tongue)** and **vestibulocochlear (ear)** receptor systems. Some authors include **visual(retina)** epthelium under this category.
- **Keratinized epithelium** lines the entire epidermis and the mucocutaneous junctions of the lips, nostrils, distal anal canal, outer surface of the tympanic membrane and parts of the oral lining (gingivae, hard palate and filiform papillae on the anterior part of the dorsal surface of the tongue).
- **Non-keratinized epithelium** is present at surfaces that are subject to abrasion but protected from drying. These include: the buccal cavity (except for the areas noted above); oropharynx and laryngopharynx; oesophagus; part of the anal canal; vagina; distal uterine cervix; distal urethra; cornea; inner surfaces of the eyelids; and the vestibule of the nasal cavities.

Myoepithelial cells (basket cells) are fusiform or stellate in shape, contain actin and myosin filaments, and contract when stimulated by nervous or endocrine signals.

- They **surround** the secretory portions and ducts of some glands, e.g. mammary, lacrimal, salivary and sweat glands, and lie between the basal lamina and the glandular or ductal epithelium.

ASSESSMENT QUESTIONS

1. **Microvilli are absent in:** *(AIIMS 2015)*
   a. Proximal convoluted tube
   b. Collecting duct
   c. Gallbladder/Bile duct
   d. Duodenum
2. **Thyroid follicles are lined by which type of epithelium:** *(NEET Pattern 2013)*
   a. Squamous
   b. Cuboidal
   c. Transitional
   d. None

3. Secreting active thyroid follicles are lined by which type of epithelium: *(NEET Pattern 2013)*
a. Columnar
b. Cuboidal
c. Squamous
d. Pseudostratified squamous

4. The cells belonging to the following type of epithelium are provided with extra reserve of cell membrane: *(AIPG 2003)*
a. Transitional
b. Stratified squamous
c. Stratified cuboidal
d. Stratified columnar

5. Cornea is lined by: *(NEET Pattern 2012)*
a. Ciliated columnar
b. Simple columnar
c. Squamous nonkeratinized
d. Pseudostratified

6. The ducts of all the following glands consist of stratified cuboidal epithelium EXCEPT: *(AIIMS 2005)*
a. Sweat glands
b. Sebaceous glands
c. Salivary glands
d. Pancreas

7. Simple squamous cells line: *(PGIC)*
a. Gallbladder
b. Blood vessels
c. Pleura
d. Ependyma
e. Male urethra

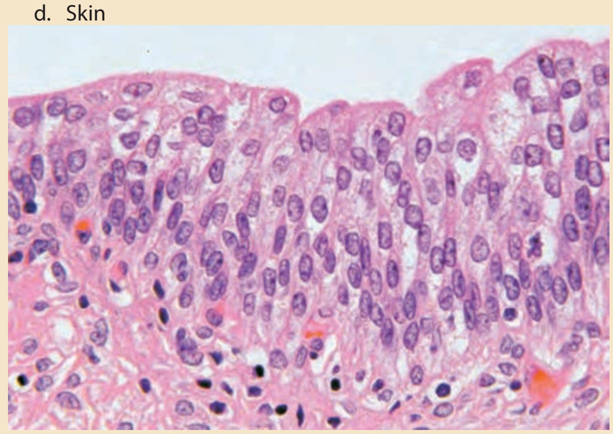
8. A patient presented with acute abdominal pain on clinical suspicion patient underwent cholecystectomy. On histopathological examination the finding is normal. The gallbladder epithelium will be: *(AIIMS 2007)*
a. Squamous
b. Simple columnar
c. Simple columnar with brush border
d. Cuboidal with stereocilia

9. Cell lining of common bile duct is: *(NEET Pattern 2015)*
a. Stratified columnar
b. Stratified squamous
c. Simple cuboidal
d. Simple columnar

10. Basal layer of cell in stratified squamous epithelium is: *(PGIC 2014)*
a. Squamous
b. Transitional
c. Cuboidal-columnar
d. Pseudostratified

11. Lining epithelium of ventricles of brain: *(NEET Pattern 2013)*
a. Squamous
b. Columnar
c. Cuboidal
d. Transitional

12. Identify the organ in the following histology slide: *(AIIMS 2016)*
a. Urinary bladder
b. Gallbladder
c. Bile duct
d. Skin



ANSWERS WITH EXPLANATIONS

1. b. Collecting duct
- All of the given structures are lined by microvilli. We choose **collecting duct** as it could be an answer of first preference.
- **Microvilli** are finger-like projections of epithelia that extend into a lumen and increase the cell's surface area.
- Microvilli constitute the **brush border** of kidney proximal tubule cells and the **striated border** of intestinal absorptive cells.
- The **proximal convoluted tubule** is lined by cuboidal (or low columnar) epithelium with a **brush border** of tall microvilli on its luminal surface. The microvilli facilitate the transport of ions and small molecules against steep concentration gradients.
- **Collecting ducts** are lined by simple cuboidal or columnar epithelium. The pale-staining principal cells have occasional **microvilli**. A second cell type, intercalated or dark cells have longer **microvilli** and more mitochondria and secrete H+ into the filtrate; they function in the maintenance of acid base homeostasis.
- **Gallbladder** epithelium is a single layer of columnar cells with apical microvilli to actively absorb water and solutes from the bile and concentrate it up to ten-fold.
- **Bile ducts** are lined by a single layer of cuboidal-shaped cholangiocytes. The apical surface of each cholangiocyte faces the lumen of the bile duct and displays numerous short **microvilli** as well as a single, long primary cilium that monitors bile flow and bile composition within the bile duct.

- **Duodenum** has enterocytes, which are columnar absorptive cells. Their surfaces bear numerous **microvilli**, which greatly increase the surface area for absorption. Collectively, microvilli are visible by light microscopy as a striated border.

2. **b. Cuboidal**
   - Thyroid follicles are normally lined by **simple cuboidal** epithelium.
   - Actively secreting thyroid follicles are lined by **simple columnar** epithelium.
   - Resting follicles are lined by **simple squamous** epithelium.

3. **a. Columnar**
   - Thyroid follicles are normally lined by simple cuboidal epithelium, but actively secreting thyroid follicles are lined by simple columnar epithelium.

4. **a. Transitional**
   - Transitional epithelium has extra reserve of cell membrane (areas of cytoplasm containing internalized membranes), which gets used up while stretching.
   - This feature of transitional epithelium helps in storage of urine to greater capacity.

5. **c. Squamous nonkeratinized**
   - Cornea is lined by the stratified squamous epithelium, which is nonkeratinized.

6. **b. Sebaceous glands**
   - The ducts of all exocrine glands are generally lined by stratified cuboidal/columnar epithelium, with few exceptions (sebaceous duct) which carries the same lining as that of skin (stratified squamous epithelium).

7. **b. Blood vessels; c. Pleura**
   - Endothelium (blood vessels) and mesothelium (pleura, pericardium, peritoneum) are lined by simple squamous epithelium. Gallbladder is lined by simple columnar epithelium with microvilli (brush border). Ependyma lines the ventricles of brain and has simple cuboidal (to columnar) cells with cilia and microvilli. Male urethra is lined by stratified columnar epithelium in entire length except the beginning (transitional epithelium) and the tip (stratified squamous epithelium).

8. **c. Simple columnar with brush border**
   - Gallbladder is lined by the columnar epithelium with brush border (irregularly placed microvilli).

9. **d. Simple columnar**
   - The intrahepatic ducts, cystic duct, and the common bile duct are lined by a **tall columnar epithelium**.

10. **c. Cuboidal-columnar**
    - The basal layers in stratified squamous epithelium are **columnar**, give rise to layers of cells that change to acquire cuboidal and eventually squamous nature, as they migrate towards the surface.

11. **b. Columnar**
    - Ventricles of brain are lined by simple ciliated columnar epithelium and so is the central canal of spinal cord.

12. **a. Urinary bladder**
    - The slide shows **transitional epithelium**, which is present in urinary tube; hence called urothelium as well.
    - The most superficial cells have a thickened plasma membrane as a result of the presence of intramembranous plaques, which give an eosinophilic appearance to the luminal surface.
    - Large dome-shaped (umbrella) cells that bulge into the lumen may be evident.
    - Identification: At first glance, it looks like a stratified cuboidal epithelium. Several rows of nuclei appear to be topped by a layer of dome-shaped cells which bulge into the lumen of the viscus. Cells of the basal layer are cuboidal or columnar, while the cells of the superficial layer vary in appearance depending on the degree of distension (may be squamous, if stretched).

High Yield Point

- Mesothelium of serous cavities (pleura, pericardium and peritoneum) is lined by simple squamous epithelium.

Cell Junctions

- **Hemidesmosomes** use **integrins** and anchoring filaments (laminin 5) as their adhesion molecules anchored to the basal lamina, whereas **desmosomes** use **cadherins**.
- **Gap junctions** (communicating junctions) resemble tight junctions in transverse section, but the two apposed lipid bilayers are separated by an apparent gap of 3 nm, which is bridged by a cluster of transmembrane channels (**connexons**).
  - Each connexon is formed by a ring of six connexin proteins whose external surfaces meet those of the adjacent cell in the middle. A minute central pore links one cell to the next. Larger assemblies of many thousands of channels are often packed in hexagonal arrays.
  - Gap junctions occur between numerous cells, including hepatocytes and **cardiac myocytes**.

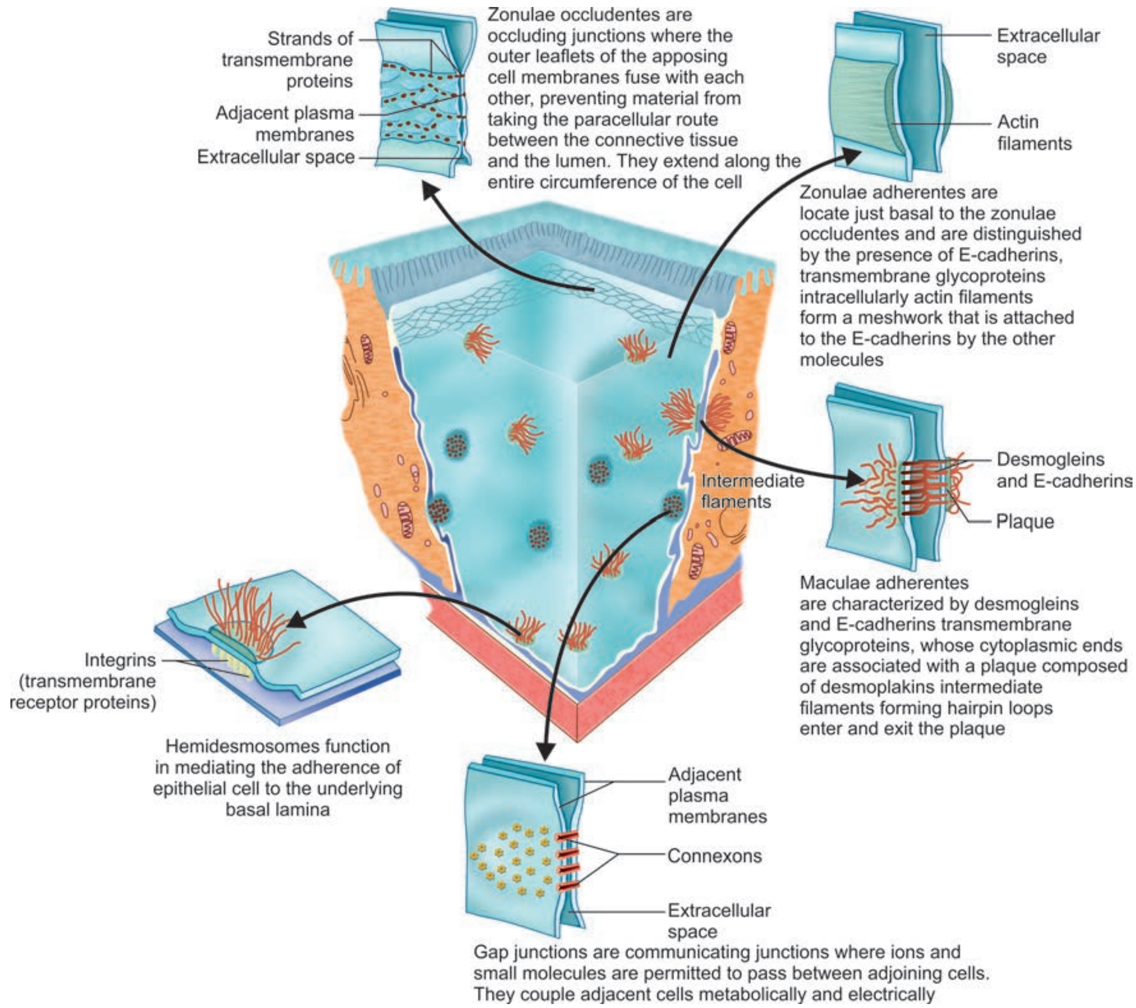


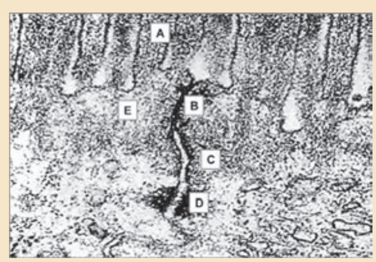
Fig. 5: Cell junctions and their characteristic features.

ASSESSMENT QUESTIONS

1. 20 nm of intercellular gap is found in the following cell junction:

a. Zona occludens
b. Zona adherens
c. Macula adherence
d. Gap junctions

2. In the electron micrograph below, the structure labelled 'D' primarily does which of the following:



a. Forms a spot-weld between cells
b. Facilitates communication between adjacent cells
c. Seals membranes between cells
d. Moves microvilli

3. Which of the following functions in metabolic coupling between adjacent cells:

a. Tight junction
b. Desmosome
c. Gap junction
d. Zonula adherens

4. In pemphigus vulgaris, autoantibodies are formed against which cell adhesion molecule:

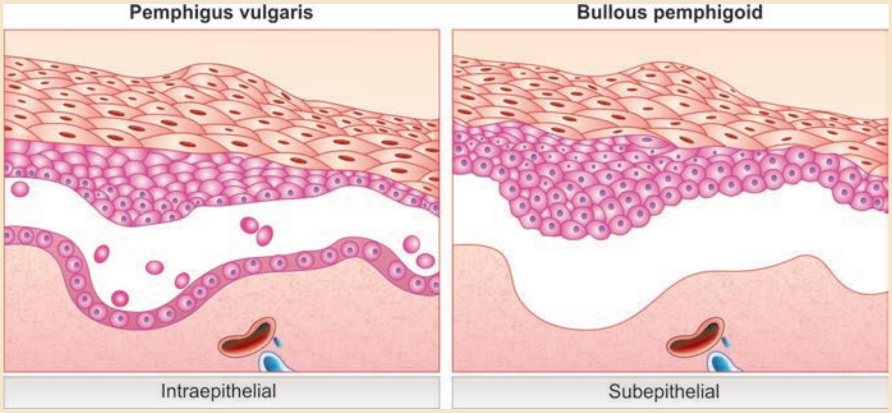
a. Selectin
b. Cadherin
c. Integrin
d. IgSF

5. Intraepidermal blistering of skin is observed in:

a. Erythema
b. Bullous pemphigoid
c. Pemphigus vulgaris
d. SLE

ANSWERS WITH EXPLANATIONS

1. **b. Zona adherens**
   - **Zona adherens** has an intercellular gap of 20 nm and **macula adherens** is 25 nm.
   - Intercellular gap is very narrow at **gap junctions** and almost negligible at **zona occuldens**.
2. **a. Forms a spot-weld between cells**
   The present diagram is an EM (Electron Microscopic) picture showing microvilli, basal body and various cell junctions.
   - Marker A - **Microvilli** (apical surface projections)
   - Marker B - **Zona occludens** (tight junction) - identified by the apical location and narrow intercellulkar gap.
   - Marker C - **Zona adherens** - located below tight junction and has widened intercellular gap (20 nm).
   - Marker D - **Macula adherens** (desmosomes or spot weldings) have still lower location and more widened intercellular gap (25 nm).
   - Marker E - **Basal body**, located at the base and help moving the microvilli.
3. **c. Gap junction**
   - Metabolic coupling (gap junction) allows free exchange of small molecules across the cell membranes. It also works as electrical synapse to conduct impulses across the smooth muscle, cardiac muscle cells.
4. **b. Cadherin**
   - Autoantibodies are directed against the cadherins (of desmosomes) in pemphigus vulgaris, which leads to intercellular separation (Nikolsky sign present).
5. **c. Pemphigus vulgaris**
   - Intraepidermal blistering is a sign of intraepithelial separation as observed in pemphigus vulgaris. Autoantibodies are directed against the hemidesmosomes in bullous pemphigoid, leading to separation of epithelium from the basement membrane (subepidermal lesion).
   - Pemphigus vulgaris is the most common and severe form of pemphigus, seen usually in persons 40 to 60 years old, characterized by chronic, flaccid, easily ruptured blisters on the skin and mucous membranes. It begins focally but then becomes generalized, leaving large, weeping, denuded surfaces that partially crust over but do not heal and enlarge by confluence. Autoantibodies are detected against the cadherins of desmosomes. Nikolsky sign becomes positive.
   - Bullous pemphigoid is a usually mild, self-limited, subepidermal blistering skin disease, sometimes with oral involvement, predominantly affecting the elderly; characteristics include large, tense bullae that rupture to leave denuded areas and have a tendency to heal spontaneously, and cleft formation and deposition of complement, usually with the IgG class of immunoglobulins, at the dermoepidermal junction. Autoantibodies are detected against the hemidesmosomes.



Glands

Table 5: Exocrine gland characteristics

Cellular composition	Example
Unicellular (single cell)	Goblet cell
Multicellular (more than one cell)	Submandibular gland
Duct form	**Example**
Simple (unbranched)	Sweat gland
Compound (branched)	Mammary gland
Type of secretion	**Example**
Serous (watery)	Parotid gland
Mucus (viscous)	Palatal glands
Mixed (serous and mucus)	Sublingual gland
Mode of secretion	**Example**
Merocrine (only secretory product released)	Parotid gland
Apocrine (secretory product along with a portion of cell cytoplasm	Lactating mammary gland (according to some authors)
Holocrine (cell dies and becomes the secretion)	Sebaceous gland

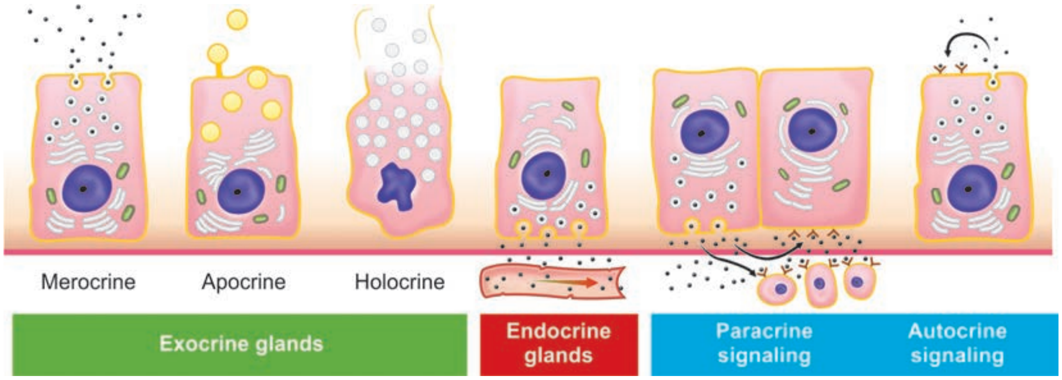


Fig. 6: Types of glands and their mechanism of secretion. Two types of glands (exocrine and endocrine) are shown and two types of signaling mechanisms (paracrine and autocrine) are visualized. Three basic types of secretions are shown in cells of the exocrine glands. Merocrine secretion (most common) involves exocytosis of the vesicle content at the apical cell membrane. Apocrine secretion (like in mammary gland cells) the apical portion of membrane covers the secretion and leaves the cell. Holocrine secretion cause disintegration of secretory cells is seen (as seen in sebaceous glands of hair follicles).

- Based upon the mode of secretion, there are three types of glands: Merocrine (eccrine), apocrine and holocrine.
  - **Merocrine**: The secretions are excreted via exocytosis from secretory cells into an epithelial-walled duct into the lumen or body surface.
    - It is the most common manner of secretion.
    - The gland releases its product and no part of the gland is lost.
    - E.g. most of the sweat glands are of merocrine variety.

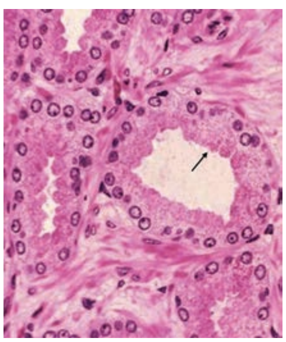


Fig. 7: Merocrine gland—entire cell remains intact.

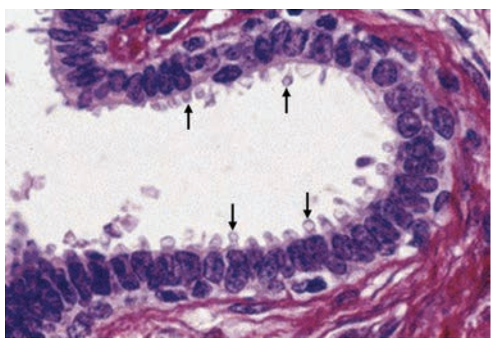


Fig. 8: Apocrine gland—cells are intact except the upper portions being detached as secretions (blebs).

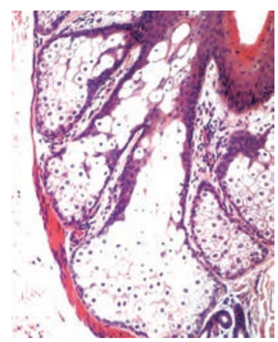


Fig. 9: A sebaceous gland (holocrine) showing a group of secretory acini opening into a hair follicle (top right). The distended sebocytes are filled with their oily secretion (sebum), which is discharged into the hair follicle by the holocrine disintegration of secretory cells.

  - **Apocrine**: The secretions of the cell take off a part of plasma membrane producing membrane-bound vesicles in the lumen.
    - The apical portion of the secretory cell of the gland pinches off and enters the lumen.
    - It loses part of its cytoplasm in their secretions.
    - Few sweat glands belong to apocrine variety. e.g. ceruminous gland and mammary glands are modified sweat glands of apocrine variety.
- **Holocrine**: The secretions are produced in the cytoplasm of the cell and released by the rupture of the plasma membrane, which destroys the cell and results in the secretion of the product into the lumen.
  - Examples: Sebaceous gland (skin), meibomian glands (eyelid).

Table 6: Difference between eccrine and apocrine sweat glands

Eccrine sweat gland	Apocrine sweat gland
Found over most parts of the body	Confined to axilla, pubic and perineal regions, and areolae of the nipples
Develops before birth	Develops after birth at puberty
Develops directly from surface epithelium	Develops from epidermal bud that produces hair follicle
Pours its secretion directly on the skin surface	Pours its secretion in the hair follicles just above the opening of sebaceous gland
Secretes by merocrine mechanism (exocytosis)	Secretes by apocrine mechanism (a portion of secretory cells is shed/pinched off and incorporated into the secretion)
Secretion is watery and involved in temperature control	Secretion is thick and produces an odor that acts as a sexual attractant

- Based upon the type of secretion, there are thrtee types of glands: Serous, mucous and mixed.
  - **Serous glands:** They contain serous acini (cuboidal cells), secreting fluid which is thin, watery in nature and isotonic with blood plasma, e.g. alpha-amylase.
    - E.g. Parotid salivary gland, lacrimal gland.
  - **Mucous glands:** They contain mucous acini (columnar cells), secreting fluid, which is thick and viscous.
    - E.g. Sublingual salivary gland.

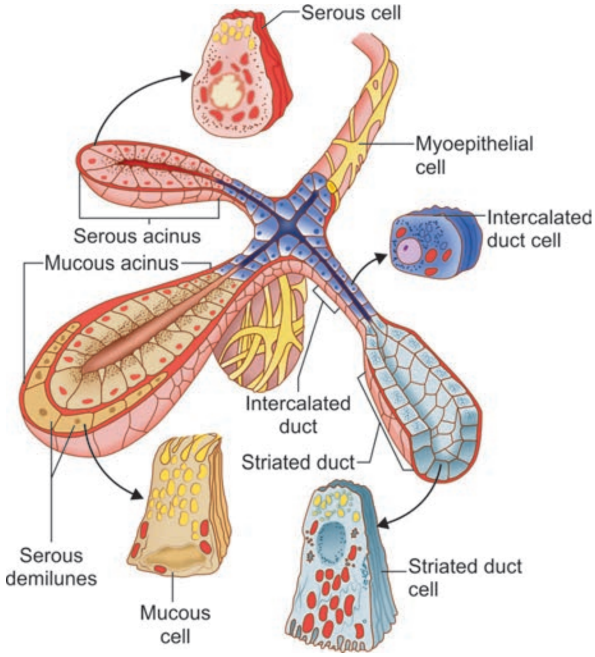
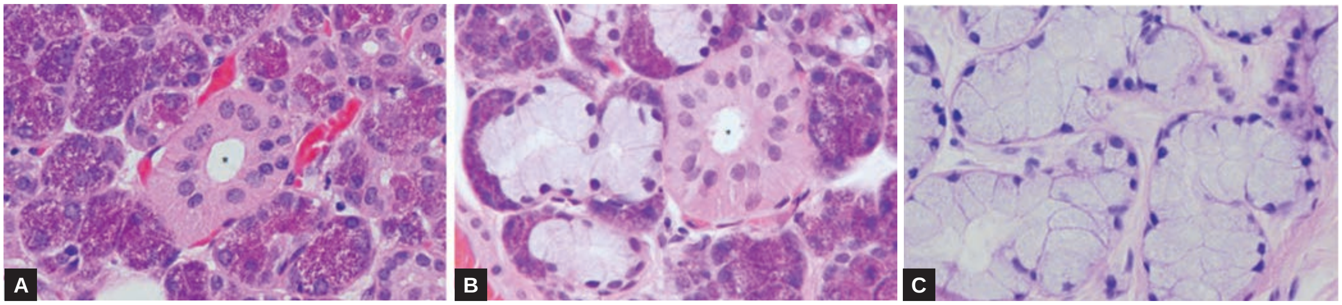


Fig. 10: Types of glands and duct system.



Figs. 11A to C: The microstructure of the salivary glands. (A) The parotid gland. (b) Mixed secretory units of the submandibular gland. (C) Mucous acini in the sublingual gland. Asterisks indicate the lumen of a striated duct.

ASSESSMENT QUESTIONS

1. Which of the following is a holocrine gland: *(NEET Pattern 2013)*
a. Sweat gland
b. Breast
c. Pancreas
d. Sebaceous gland

2. Serous demilunes are present in large number in which gland:
a. Parotid
b. Submandibular
c. Sublingual
d. Pituitary

3. Mammary gland is a type of: *(NEET Pattern 2015)*
a. Modified sweat gland
b. Ceruminous gland
c. Sebaceous gland
d. Holocrine gland

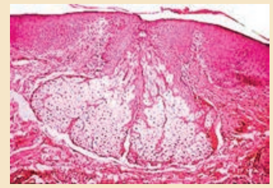
4. Ceruminous glands present in the ear are *(AIIMS 2005)*
a. Modified eccrine glands
b. Modified apocrine glands
c. Mucous gland
d. Modified holocrine glands

5. Which of the following is a holocrine gland: *(NEET Pattern **2012)***
a. Sweat
b. Breast
c. Pancreas
d. Sebaceous

6. Sweat glands are which types of gland *(NEET Pattern 2015)*
a. Simple tubular
b. Simple coiled tubular
c. Compound tubular
d. Compound acinar

7. Mucous glands are absent in: *(NEET Pattern 2012)*
a. Cervix
b. Esophagus
c. Vagina
d. Duodenum

8. Histology slide of a gland is given diagram, identify the type of gland: *(AIIMS 2016)*
a. Apocrine
b. Merocrine
c. Holocrine
d. Endocrine



ANSWERS WITH EXPLANATIONS

1. d. Sebaceous gland
- Sebaceous gland is a holocrine gland since the discharged secretion contains entire secreting cells.
- Sweat glands are of two types: Eccrine (merocrine) is more common in occurrence as compared to apocrine variety.
- Breast (mammary gland) is modified sweat gland of apocrine variety. Another example for similar type is ceruminous (wax) gland in the ear.
- Pancreas is a mixed (exocrine & endocrine) gland. Exocrine secretory units are usually merocrine type.

2. b. Submandibular
- Parotid gland is predominantly a serous gland and sublingual gland is mucous. Submandibular gland is mixed type with a cap of serous gland appearing on mucus gland (serous demilune) in histological preparations.

3. a. Modified sweat gland
- Mammary gland is a modified sweat gland of apocrine variety.

4. b. Modified apocrine glands
- Ceruminous glands are the wax-secreting glands of the external ear and are considered as the modified sweat glands of the apocrine variety.
  - Most of the sweat glands are of eccrine variety, e.g. palm, sole, etc. The secretions of these glands are watery in nature.
  - Apocrine variety of sweat glands are less abundant and restricted to certain regions like peri-genital area, around nipple, external ear (ceruminous glands), etc. Their secretions are viscous.
  - Mucous glands like Goblet cells are holocrine in nature and shed the terminal part of the cells along with their secretions. Sebaceous gland is a holocrine gland.

5. d. Sebaceous
- Holocrine secretions are produced in the cytoplasm of the cell and released by the rupture of the plasma membrane, which destructs the cell and results in the secretion of the product into the lumen, e.g. sebaceous gland.

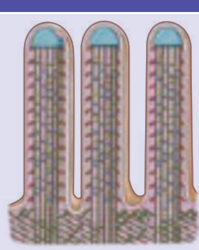
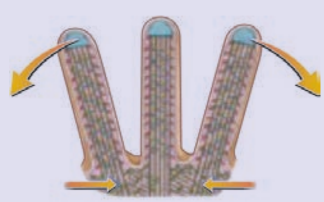
6. b. Simple coiled tubular
- Sweat glands are lined by the simple coiled tubular epithelium.

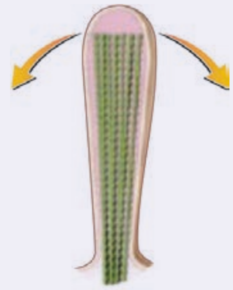
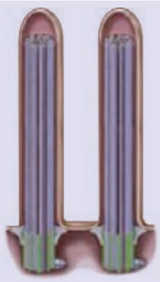
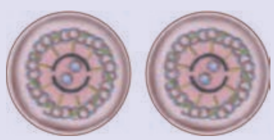
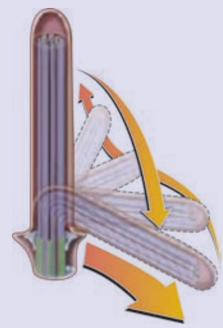
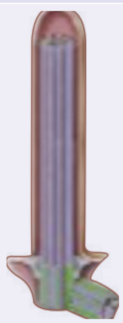
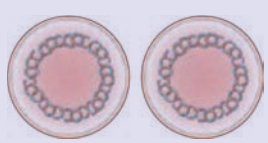
7. c. Vagina
- Vagina has no glands are seen in the mucosa, its surface being kept moist by secretions of glands in the cervix.

8. c. Holocrine
- The given slide in the figure appears to be taken from a section of skin, showing sebaceous glands.
- In holocrine glands, the secretions are produced in the cytoplasm of the cell and released by the rupture of the plasma membrane, which destroys the cell and results in the secretion of the product into the lumen.
- Examples: Sebaceous gland (skin), meibomian glands (eyelid).

Surface Projections

Table 7: Summary of apical domain modification in the epithelial cells

	General structure	Cross-section	Motion trajectory	Localization and function
Microvilli	 Average 1–3 µm in length, bundle of actin filament anchored in the terminal web	 Core of actin filaments cross-linked by actin-bundling proteins; diameter 50–100 nm	 Passive movement due to contraction of terminal web	• Present in many epithelial cells • Increase absorptive surface of the cell • Visible in LM as striated border (intestinal absorptive cells) or brush border (kidney tubule cells)

	Stereocilia	 **Epididymis** **Inner ear** Considerably longer; up to 120 µm, actin filament bundle anchored in the terminal web; capable of regeneration (inner ear)	 Core of actin filaments cross-linked by actin-bundling proteins; diameter 100–150 nm	 Passive movement due to fluid flow (genital system) or vibration of endolymph) inner ear)	• Limited distribution • In male reproductive system (epididymis, proximal part of ductus deferens) have absorptive function • In sensory hair, cells in the inner ear function as mechanoreceptors.
Cilia	Motile	 From 5–10 µm in length (flagella in sperm cells much longer, 50–100 µm), possess axoneme, basal bodies with basal body-associated structures; specific intraflagellar transport system for cilia development and normal function	 Core of microtubules arranged in 9 + 2 pattern with associated motor proteins; diameter about 250 nm	 Active movement; rapid forward movement with slow recovery stroke (half-cone trajectory)	• Most commonly found on epithelia, which function in transporting secretions, proteins, foreign bodies, or cells on their surface (aviduct, trachea and bronchial tree, brain ependyma, and olfactory epithelium) • Present on sperm cells as flagella; provides a forward movement to the sperm cell
	Primary	 Average 2–3 µm in length; possess axoneme, basal bodies; have specialized plasma membrane with calcium entry channels and intraflageller transport system	 Core of microtubules arranged in 9 + 0 pattern; diameter about 250 nm	 No active movement; passively bend due to flow of fluid	• Found in almost all cells in the body • Well-documented in kidney ducts, bile duct epithelium, thyroid gland, thymus, neurons, Schwann cells, chondrocytes, fibroblasts, adrenal cortex, and pituitary cells • Function as a sensory antennae • Generate and transmit signals from extracellular space into the cell
	Nodal	 About 5–6 µm in length; have structure similar to primary cilia except they have an ability for active movement	 Core of microtubules arranged in 9 + 0 pattern with associated motor proteins; diameter about 250 nm	 Active rotational movment (full-cone trajectory)	• Found in the embryo during gastrulation on the bilaminar disc near the area of primitive node • Essentials in developing left-right assymetry of internal organs

(LM: Light microscope).

ASSESSMENT QUESTION

1. **Gallbladder epithelium is:** *(AIIMS 2007)*
   a. Simple squamous
   b. Simple cuboidal with stereocilia
   c. Simple columnar
   d. Simple columnar with brush border

ANSWER WITH EXPLANATION

1. **d. Simple columnar with brush border**
   - **Gallbladder** is lined by columnar cells with irregular microvilli—**brush border**.
   - Small intestine is lined by microvilli arranged in regular fashion—**striated border**.
   - **Brush border** is also present in the proximal convoluted tubule (PCT) of kidney.
   - **Stereocilia** are present in the hair cells of internal ear and epididymis.

Connective Tissue

Table 8: Review of supporting/connective tissue

Category	Component/nature	Details	Function
Matrix fibers	Collagen fibers	Type I collagen, type III collagen, etc.	Strength and structure Stretch and elasticity; elastin is formed on fibrillin microfibers
	Elastin	Elastin and fibrillin	
Ground substances	Glycosaminoglycans (GAGs)	Hyaluronate; proteoglycans	Water-binding gel, provides volume, structure and interacts with supporting cells, epithelial cells, blood vessels and immune cells
	Structural glycoproteins	Fibronectin	Structural glycoprotein; binds and interacts with many connective tissue molecular components
Basement membrane	Interface of cells with connective tissue	Type IV collagen, nidogen, integrins, heparan sulfate, etc.	Specialised structures formed where epithelia and other cells meet connective tissue matrix. Binds the epithelial cells to the connective tissue. Connective tissue and epithelial cells contribute to its formation and maintenance
Cells	Mesenchyme	Mesenchymal cells	Embryological and fetal cells which form connective tissue
	Fibroblasts	Fibroblast	Creates and maintains the connective tissue, fibers and matrix
		Myofibroblast	Activated fibroblast specialised for tissue repair with contractile ability; generates repair/healing with scar
	Adipocytes	White adipose	Specialised tissue for storage of t riglycerides (fat) as an energy reserve but also has metabolic and structural roles
		Brown adipose	Specialised form of adipose tissue most prominent in babies; metabolises triglycerides for heat under the control of the nervous system
	Hematopoietic stem cell-derived	Mast cells	Tissue-resident immune cells involved in immediate hypersensitivity and allergy
		Tissue macrophages	Tissue-resident immune cells with prominent phagocytic abilities and major roles in the immune system
		Lymphocytes, eosinophils, neutrophils, plasma cells	Other immune cells (usually in transit or in response to inflammation)

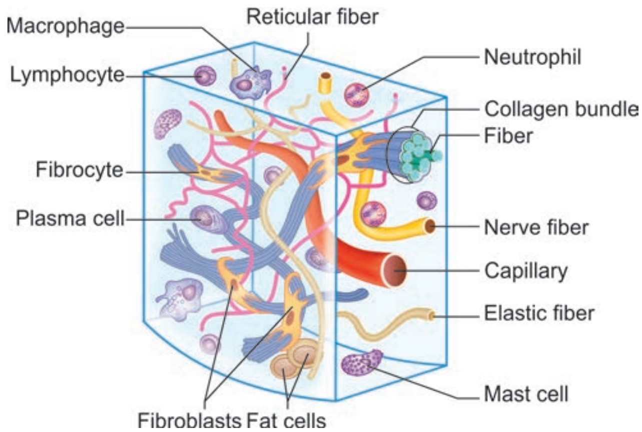


Fig. 12: Loose areolar connective tissue with its predominant cells and fibers.

Table 9: Classification of connective or supporting tissues

	General Organization	Major Functions	Examples
Connective Tissue Proper			
Loose (areolar) connective tissue	Much ground substance; many cells and little collagen, randomly distributed	Supports microvasculature, nerves, and immune defense cells	Lamina propria beneath epithelial lining of digestive tract
Dense irregular connective tissue	Little ground substance; few cells (mostly fibroblasts); much collagen in randomly arranged fibers	Protects and supports organs; resists tearing	Dermis of skin, organ capsules, submucosa layer of digestive tract
Dense regular connective tissue	Almost completely filled with parallel bundles of collagen; few fibroblasts, aligned with collagen	Provides strong connections within musculoskeletal system; strong resistance to force	Ligaments, tendons, aponeuroses, corneal stroma
Embryonic Connective Tissues			
Mesenchyme	Sparse, undifferentiated cells, uniformly distributed in matrix with sparse collagen fibers	Contains stem/progenitor cells for all adult connective tissue cells	Mesodermal layer of early embryo
Mucoid (mucous) connective tissue	Random fibroblasts and collagen fibers in viscous matrix	Supports and cushions large blood vessels	Matrix of the fetal umbilical cord
Specialized Connective Tissues			
Reticular connective tissue	Delicate network of reticulin/collagen III with attached fibroblasts (reticular cells)	Supports blood forming cells, many secretory cells, and lymphocytes in most lymphoid organs	Bone marrow, liver, pancreas, adrenal glands, all lymphoid organs except the thymus

Structure

- Connective tissue is formed primarily of extracellular matrix (ECM), consisting of ground substance and fibers, in which various connective tissue cells are embedded.

Extracellular Matrix

- Ground substance is a colorless, transparent, gel-like material in which the cells and fibers of connective tissue are embedded.
  - It is a complex mixture of glycosaminoglycans, proteoglycans, and glycoproteins.
- Fibers: Collagen, reticular, and elastic
  - Collagen fibers: Although there are at least 25 different types of collagen, the most common collagen types in connective tissue proper are types I and III collagen, both consisting of many closely packed tropocollagen fibrils.
  - Reticular fibers are extremely thin in diameter and are composed primarily of type III collagen
    - Type III collagen fibers constitute the architectural framework of certain organs and glands.
    - Because of their high carbohydrate content, they stain black with silver salts.
- Cells:
  - **Fixed connective tissue cells** include fibroblasts, pericytes, adipose cells, mast cells, and fixed macrophages.
  - **Transient connective tissue cells** include certain macrophages, lymphocytes, plasma cells, neutrophils, eosinophils, and basophils.
    - Fixed cells
- Fibroblasts arise from mesenchymal cells, seldom undergo mitosis except in wound healing.
  - In certain circumstances, they may differentiate into adipocytes, chondrocytes, osteoblasts, etc.

- **Pericytes** (adventitial cells; perivascular cells) are derived from embryonic mesenchymal cells and may retain a pluripotent role.
  - They possess characteristics of endothelial cells as well as smooth muscle cells because they contain actin, myosin, and tropomyosin, suggesting that they may function in contraction where they assist to modify blood flow through capillaries.
    - These are located mostly along capillaries, and during blood vessel formation and repair, they may differentiate into fibroblasts, smooth muscle cells, as well as endothelial cells of blood vessel walls.

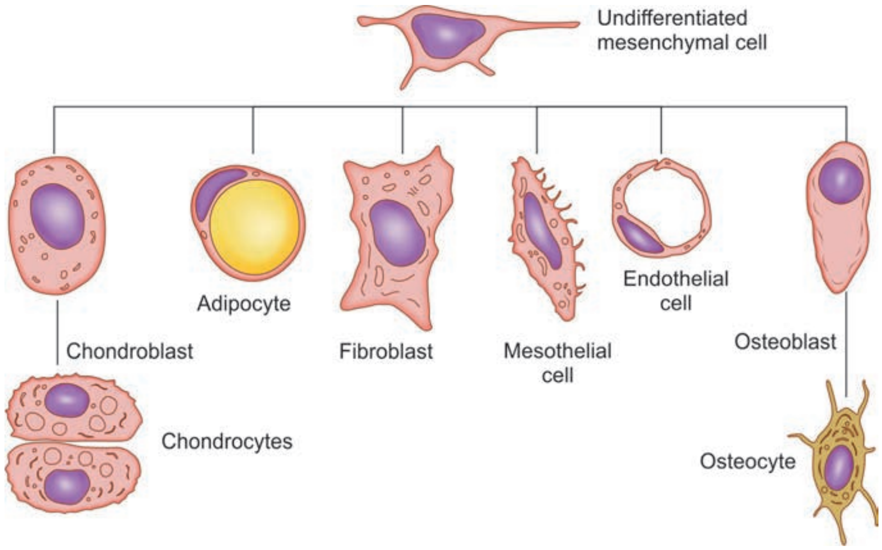
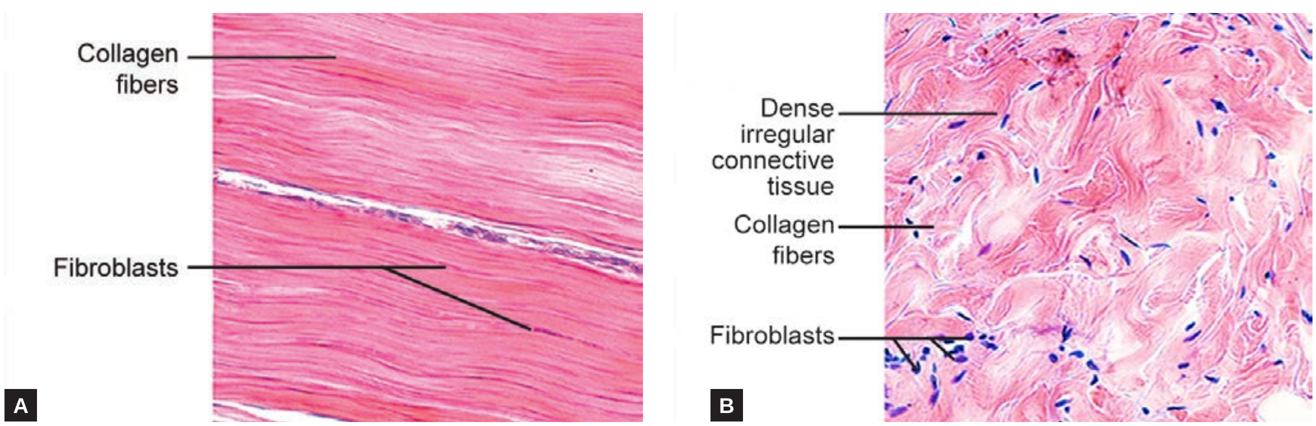


Fig. 13: Connective tissue cells arising from undifferentiated mesenchymal cells

- **Adipose cells** (adipocytes) arise from mesenchymal cells and occasionally from fibroblasts.
  - Are fully differentiated cells but may undergo mitosis if required.
- Unilocular adipocytes contain a single large fat droplet. The cytoplasm and nucleus are squeezed into a thin rim at periphery.
  - These cells have plasmalemma receptors for insulin, growth hormone, norepinephrine, and glucocorticoids to control the uptake and release of free fatty acids and triglycerides.
  - Transient cells
- Dense connective tissue contains more fibers and fewer cells and is classified by the orientation of its fiber bundles into two types:
  - Dense and **irregular** connective tissue (most common), which contains fiber bundles that have no definite orientation. E.g. dermis and organ capsules.
  - Dense, **regular** connective tissue, which contains fiber bundles are arranged in a uniform parallel fashion with few fibroblasts. E.g. tendons, ligaments.



Figs. 14A and B: Arrangement of collagen fibres in A. Dense and regular connective tissue (e.g., tendon); B. Dense and irregular connective tissue (e.g., periosteum).

Collagen Fibers

Table 10: Characteristics of some of the best known collagen types

Molecular type	Cells synthesizing	Major locations in body	Function
I	Fibroblasts	Dermis of skin, tendons, ligaments, fibrocartilage, capsules of some organs	Resists tension
	Osteoblasts	Bone matrix	The arrangement of collagen fibers in compact bone reduces the presence of cleavage planes
	Odontoblasts	Dentin matrix	Structural support and provides a degree of elasticity to dentin
II	Chondroblasts	Hyaline and elastic cartilages	Resists intermittent pressure

Molecular type	Cells synthesizing	Major locations in body	Function
III	Fibroblasts Reticular cells Smooth muscle cells Schwann cells Hepatocyte	Dermis of skin and capsules of some organs Lymph nodes, spleen Smooth muscle Nerve fibers Liver	Forms structural framework Forms external lamina Forms reticular fibers
IV	Endothelial cells Epithelial cells Muscle cells Schwann cells	Blood vessels Epidermis and lining of body cavities Skeletal muscles, smooth muscles, heart Nerve fibers	Forms lamina densa of the basal lamina Forms external lamina
V	Mesenchymal cells	Placenta and dermal-epidermal junction	Unknown
VII	Keratinocytes	Dermal-epidermal junction	Forms anchoring fibrils that secure lamina densa to the underlying connective tissue
IX	Chondrocytes	Hyaline and elastic cartilages (associated with collagen types II and XI)	Binds to type II collagen and affixing it to the proteoglycans of the cartilage matrix
XI	Chondrocytes	Hyaline and elastic cartilages as well as type I collagen	Acts to stabilize the type II and type IX collagen sub-structure of the cartilage matrix; forms the core of type I collagen
XII	Fibroblasts Mesenchymal cells	Dermis of skin Placenta	Binds to surface of type I collagen and assists it in resisting tensile forces
XIII	Various cell types	In various tissues	Assists in the formation of focal adhesions by binding to fibronectin, integrins, and components of the lamina reticularis
XVII	Epidermis of the skin	Hemidesmosomes	It has domains that are embedded in the epidermal cell membrane binding both to keratins as well as to integrins and laminin
XVIII	Epithelial cells	Basal lamina of the retina of the eye	When degraded enzymatically, it inhibits the formation of new blood vessels and induces apoptosis of endothelial cells

ASSESSMENT QUESTIONS

1. **In Hyaline cartilage, type of collagen present is:** *(AIIMS 2007)*
   a. Type 1
   b. Type 2
   c. Type 3
   d. Type 4

2. **Reticular fibers of collagen tissues are present in all EXCEPT:** *(AIIMS 2015)*
   a. Thymus
   b. Bone marrow
   c. Spleen
   d. Lymph node

3. **Following are given the collagen types and the sites of location. Choose the INCORRECT pair:** *(PGIC)*
   a. Skin: type – I
   b. Lens capsule: Type – I
   c. Blood vessel: Type – III
   d. Spleen: Type – III
   e. Hyaline cartilage: Type – I

4. **Which type of collagen is present in basement membrane:** *(AIIMS 2015)*
   a. I
   b. III
   c. IV
   d. V

ANSWERS WITH EXPLANATIONS

1. **b. Type 2**
   - **Hyaline** & elastic cartilages contain **type-II collagen**, whereas fibrocartilage is more like bone & contains type-I cartilage.

2. **a. Thymus**
   - Reticular fibers/collagen type III are absent in thymus.

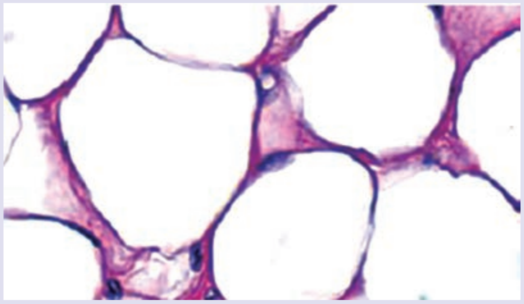
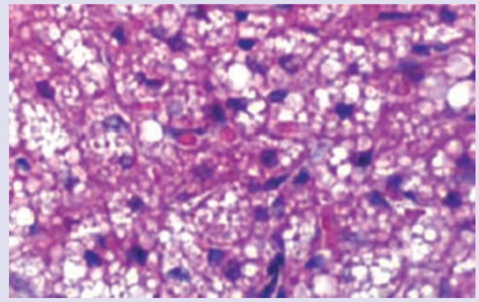
3. **b. Lens capsule: Type I e. Hyaline cartilage: Type II**
   - Generally, capsules have type – I collagen fibers; lens capsule/filtration membrane have type IV collagen fibers. Hyaline cartilage has type II collagen fibers.

4. **c. IV**
   - Basement membrane has type IV collagen fibers.

Adipose Tissue

- The adipose organ is a complex endocrine system, composed of white and brown fat. **White adipose tissue** serves as the primary site of energy storage, storing triglycerides within individual adipocytes, whereas **brown adipose tissue** stores little fat, burning it instead to produce heat and regulate body temperature.

Table 11: Summary of adipose tissue features.

Features	White adipose tissue	Brown adipose tissue
		
Location	Subcutaneous layer, mammary gland, greater omentum, mesenteries, retroperitoneal space, visceral pericardium, orbits (eye sockets), bone marrow cavity	Large amounts in newborns Remnants in adults at the retroperitoneal space, deep cervical and supraclavicular regions of the neck, interscapular, paravertebral regions of the back, mediastinum
Function	Metabolic energy storage, insulation, cushioning, hormone production, source of metabolic water	Heat production (thermogenesis)
Adipocyte morphology	Unilocular, spherical, flattened nucleus, rim of cytoplasm Large diameter (15–150 μm)	Multilocular, spherical, round eccentric nucleus Smaller diameter (10–25 μm)
Precursor cells	Perivascular mesenchymal stem cells	Common skeletal myogenic progenitor cells
Transcription factors "master switch" in differentiation	PPARg/RXR	PRDM16/PGC-1
UCP-1 gene expression	No	Yes (unique to brown fat)
Mitochondria	Few, elongated, filamentous with poorly developed cristae	Many, large, round, with well-developed cristae
Innervation	Few sympathetic nerve fibers	High density of noradrenergic sympathetic nerve fibers
Vascularization	Few blood vessels	Highly vascularized tissue
Response to environmental stress (i.e. cold exposure)	Decreased lipogenesis Increased lipoprotein lipase activity Transdifferentiation to brown adipose tissue	Increased lipogenesis Decreased lipoprotein lipase activity Increased heat production.
Growth and differentiation	Throughout entire life from stromal perivascular cells	During fetal period Decreases in adult life (exceptions: individuals with pheochromocytoma, hibernoma or chronic cold exposure)

ASSESSMENT QUESTION

1. **Brown adipose tissue is present in all of the following sites EXCEPT:** ***(AIIMS 2015)***
   a. Subcutaneous tissue
   b. Around blood vessels
   c. Scapula
   d. Adrenal cortex

ANSWER WITH EXPLANATION

1. **a. Subcutaneous tissue**
   - This is a **controversial** question and the most appropriate choice has been taken as answer. **Brown adipose tissue** is present in large amounts in the newborn, which helps offset the extensive heat loss, later it disappears from most sites except for regions around the kidney, adrenal glands, large vessels (i.e. aorta), and regions of the neck (deep cervical and supraclavicular), regions of the back (interscapular and paravertebral), and thorax (mediastinum).

Hemopoiesis

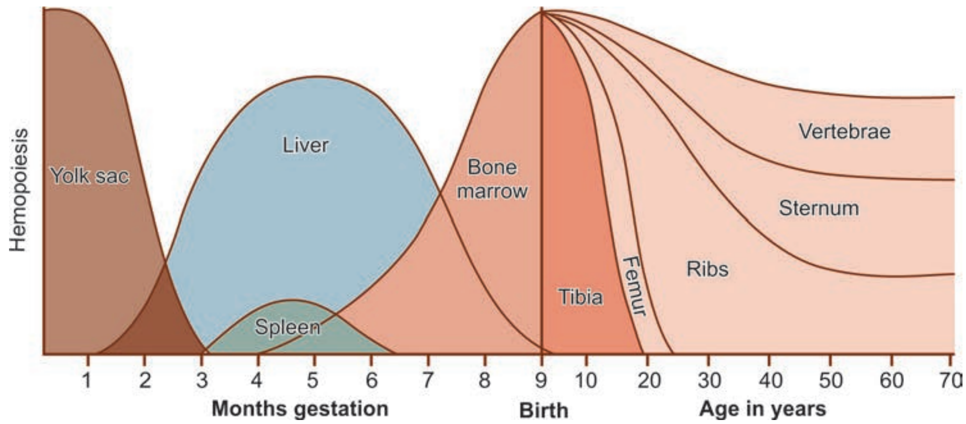


Fig. 15: During embryonic and fetal life, erythrocytes are formed in several organs. Three major organs involved in hemopoiesis can be sequentially identified: the yolk sac in the early developmental stages of the embryo, the liver during the second trimester of pregnancy, and the bone marrow during the third trimester. The spleen participates to a very hemopoiesis occurs in the red bone marrow of all bones, including long bones such as the femur and tibia. In adults, hemopoiesis is maintained primarily in flat bones (e.g., pelvic bones, sacrum ribs sternum, cranium) and vertebrae.

ASSESSMENT QUESTIONS

1. **Dense and regular arrangement of collagen fibers is seen in all EXCEPT:** *(AIIMS 2014)*
   a. Tendon
   b. Ligament
   c. Aponeurosis
   d. Periosteum

2. **Which of the following is NOT a connective tissue:** *(NEET Pattern 2012)*
   a. Blood
   b. Muscle
   c. Bone
   d. Cartilage

3. **What best defines vasa vasorum:** *(NEET Pattern 2012)*
   a. Small blood vessels supplying walls of large blood vessels
   b. Small blood vessels supplying nerves
   c. Vessels accompanying artery
   d. Vessels accompanying nerves

ANSWERS WITH EXPLANATIONS

1. **d. Periosteum**
   - **Periosteum** has dense but no definite orientation (**irregular**) of collagen fibers. Tendon, aponeurosis and ligaments have collagen fiber bundles which are arranged in a uniform parallel (**regular**) fashion.
2. **b. Muscle**
   - Connective tissue connects, supports, binds, or separates other tissues or organs, typically having relatively few cells embedded in an amorphous matrix, often with collagen or other fibers, and including cartilaginous, fatty, and elastic tissues.
   - **Muscle tissue** is identified by its capacity to contract and shorten in length.
3. **a. Small blood vessels supplying walls of large blood vessels**
   - **Vasa vasorum** is a network of small blood vessels that supply the walls of large blood vessels.
   - These are found in large arteries and veins, e.g. aorta and its branches.
   - These vessels supply blood and nutrition for tunica adventitia and outer part of tunica media of large vessels.

Cartilage and Bone

- **Osteoblasts** synthesize type I collagen and bone matrix proteins to form an unmineralized osteoid. Calcium and phosphate are deposited on the cartilaginous matrix to form mineralized bone. Blood supply within the haversian canals supply osteoblasts. Later, osteoblasts become surrounded by bone matrix to become **osteocytes**.
- **Osteocytes** are present in the space called lacuna and communicate with other osteocytes via cytoplasmic extensions called **canaliculi**. They are not directly involved in bone resorption but under the influence of parathyroid hormone (PTH) they stimulate osteoclastic bone resorption, which allows Calcium to be transferred rapidly into the blood.
- **Osteoclasts** are multinucleated cells (formed from monocytes), contain acid phosphatase and under influence of PTH cause bone resorption.
- Bone formation occurs in two ways. During **endochondral** ossification, a cartilage model first forms and is eventually replaced with bone, except at epiphyseal plates and articular cartilages. This type of ossification underlie formation of the axial (vertebral column and ribs) and appendicular (limb) skeletons, with the exception of part of the clavicles.
- During **intramembranous** ossification, bone forms directly from mesenchymal cells without the prior formation of cartilage. This type of ossification underlies formation of the majority of bones of the face and skull.

- **Primary ossification center** appears in the developing bone (at 6 – 12 weeks of intra-uterine life) and forms diaphysis. Secondary ossification centers appear (usually after birth) at the ends of long bones and develop into epiphysis.
- **Nutrient artery** is directed away from the growing ends (towards the elbow I go, from the knee I flee). E.g. Nutrient foramen in tibia is immediately below the popliteal line and directed obliquely downward, away from knee joint. It also suggests that the ends of the bones at knee joint and elbow joints are growing ends.
- **Cancellous** bone is metabolically more active than the cortical bone. **Endosteum** is metabolically more active than periosteum.

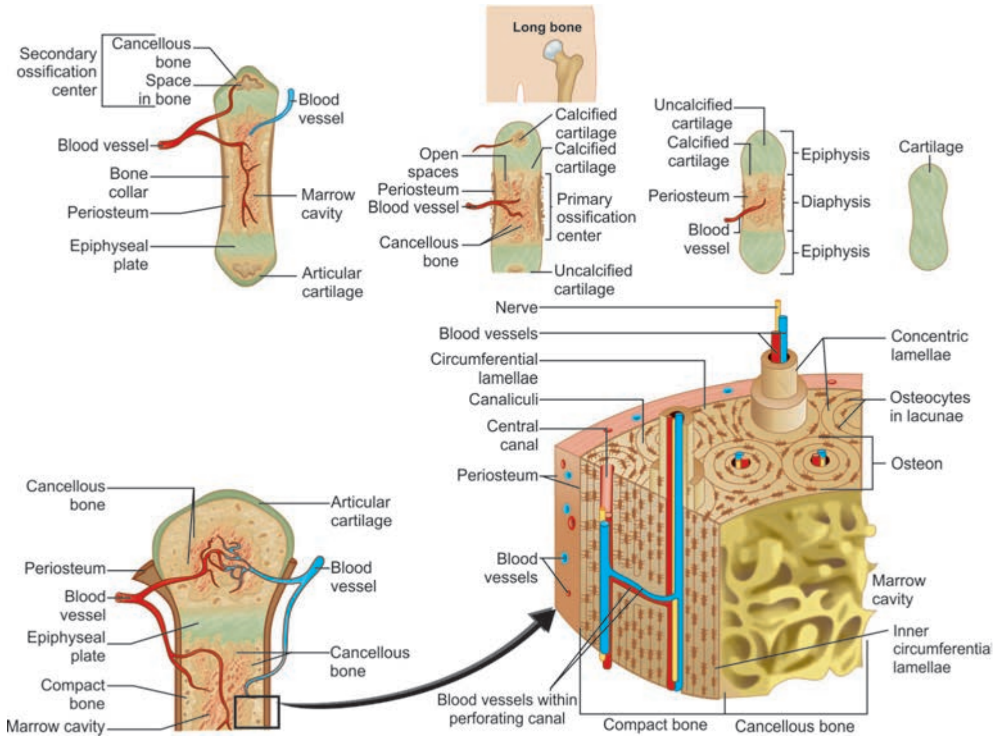


Fig. 16: Endochondral ossification showing the progressive stages of bone formation, from a cartilage model to formed compact bone.

- During endochondral ossification, **five** distinct zones can be seen at the light-microscope level.
  1. Zone of **resting** cartilage. This zone contains normal, resting hyaline cartilage.
  2. Zone of **proliferation**. In this zone, chondrocytes undergo rapid mitosis, forming distinctive looking stacks.
  3. Zone of **maturation/hypertrophy**. It is during this zone that the chondrocytes undergo hypertrophy (become enlarged). Chondrocytes contain large amounts of glycogen and begin to secrete alkaline phosphatase.
  4. Zone of **calcification**. In this zone, chondrocytes are either dying or dead, leaving cavities that will later become invaded by bone-forming cells. Chondrocytes here die when they can no longer receive nutrients or eliminate wastes via diffusion. This is because the calcified matrix is much less hydrated than hyaline cartilage.
  5. Zone of **ossification**. The osteoprogenitor cells (OPCs) are available to continue the process of bone formation.

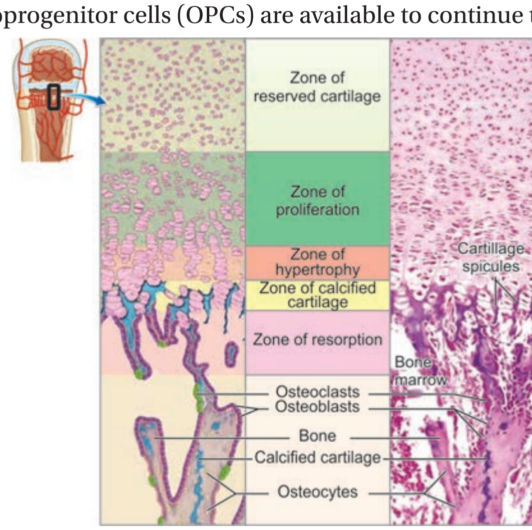


Fig. 17: Active bone formation on the diaphyseal side of the epiphyseal growth plate. Various zones are apparent: chondrocytes undergo divisions, hypertrophy, and eventual apoptosis. Calcified cartilage (blue) is seen in the bone spicules.

- Growth plate is made up of hyaline cartilage and is avascular.
- It starts getting vascularized by formation of new blood vessels—vasculogenesis in zone of calcification, and as it gets vascularized, erosion starts there.
- Then as the chondrocytes are eroded, new cells appear—the bone cells creating zone of ossification.
- It is evident that at epiphyseal growth plate, the cartilage gets destroyed and replaced by bone in a gradual manner.
- **Note:** As the growth plate is ossified, it receives vascular buds & vasculogenesis occurs, the new blood vessels helping the metaphyseal artery to anastomose with the epiphyseal artery.
- Thus, metaphyseal arteries are no more termed as end-artery in an adult.
- Erosion of bone keep happening by the osteoclast cells, which help in enlarging the marrow cavity.

Table 12: Review of skeletal tissues

Structure	Key components and features
Cartilage	Hyaline cartilage: most common type, forms articular surfaces of synovial joints, role in development of bony skeleton. Abundant ground substance.
	Fibrocartilage: found in intervertebral discs and symphyses. Features intermediate between hyaline cartilage and dense regular connective tissue. Abundant collagen.
	Elastic cartilage: forms parts of larynx and external ear. Resembles hyaline cartilage, but abundant elastic fibers.
Bone	Major supporting tissue of the skeleton, composed of cells surrounded by collagenous osteoid matrix which is mineralised by calcium hydroxyapatite deposition.
	Osteoblasts: on surface of bony trabeculae, synthesise new osteoid, becoming entrapped by this and then named osteocytes. In time, osteoid becomes mineralised.
	Osteocytes: inactive osteoblasts trapped within the bone matrix. Fine canaliculi within the bone contain interconnecting cytoplasmic processes from the cells.
	Osteoclasts: large multinucleate cells, lie in small depressions called Howship lacunae, involved resorption and remodelling of bone.
	Woven bone: this is immature bone with randomly orientated collagen fibers, found during development, associated with healing and repair, remodelled into lamellar bone. Lamellar bone: this is mature bone in which the collagen fibers are orientated in parallel arrays, aligned to withstand stresses on the skeleton.
	Cortical bone: parallel columns of bone (osteons) with concentric lamellar around central Haversian canals containing neurovascular bundles
	Cancellous bone: interconnecting network of bony struts with intervening bone marrow.
	Two forms of bone development: intramembranous ossification (mainly skull bones) and endochondral ossification (bone forms on a template of hyaline cartilage).
	Synovial joints (diarthroses): permit extensive movement between articular surfaces. Surfaces lined by hyaline cartilage, fibrous capsule lined by synovium, lubricated by synovial fluid.
	Non-synovial joints: limited movement, bones united by dense collagenous tissues, including dense fibrous tissue (syndesmosis), hyaline cartilage (synchronosis) or fibrocartilage (symphysis).
	Bands of dense regular connective t issue originating from muscle and inserting into bone to transmit the force of muscle contraction so that movement of joints may occur.

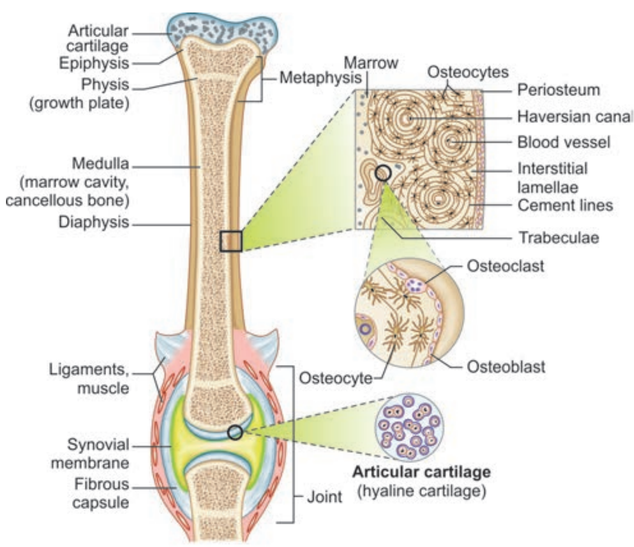


Fig. 18: Parts of bone, Haversian system, types of bone cells and articular cartilage.

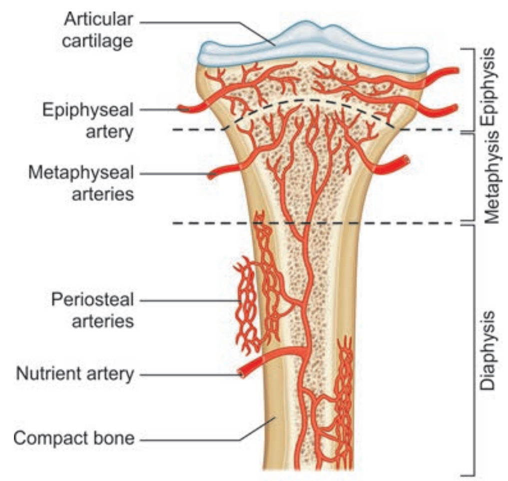


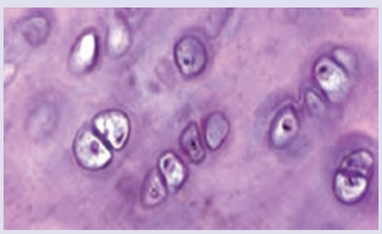
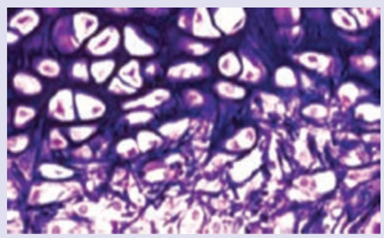
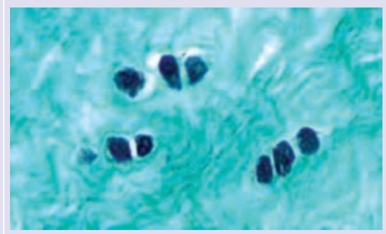
Fig. 19: Arterial supply of an adult long bone. The nutrient artery and the epiphyseal arteries enter the bone through nutrient foramina. These openings in the bone arise developmentally as the pathways of the principal vessels of periosteal buds. Metaphyseal arteries arise from periosteal vessels that become incorporated into the metaphysis as the bone grows in diameter.

Cartilage

Table 13: Cartilage features

Type	Hyaline	Elastic	Fibrocartilage
Identifying characteristics	Type II collagen	Type II collagen	Type I collagen (predominantly)
Perichondrium	Present (except at articular cartilage)	Present	Absent
Location	Most common type • Foetal cartilage • Growth plate • Articular cartilage • Respiratory tube (with few exceptions) • Costal cartilage	Rare ($E^3 T^3 C^2$) • External ear • Eustachian tube • Epiglottis • Tip of nose • Tip of arytenoid • Tritiate cartilage • Corniculate • Cuneiform	Found near the bone/joint • Intervertebral disc • Articular disc • Knee meniscus • Glenoid/acetabular labrum • Insertion of tendons

Table 14: Summary of cartilage features

Features	Hyaline cartilage	Elastic cartilage	Fibrocartilage
			
Location	Fetal skeletal tissue, epiphyseal plates, articular surface of synovial joints, costal cartilages of rib cage, cartilages, of nasal cavity, larynx (thyroid, cricoid, and arytenoids), rings of trachea, and plates in bronchi	Pinna of external ear, external acoustic meatus, auditory (Eustachian) tube, and cartilages of larynx (epiglottis, corniculate, and cuneiform cartilages)	Intervertebral discs, pubic symphysis, articular discs (sternoclavicular and temporomandibular joints). menisci (knee joint), triangular fibrocartilage complex (wrist joint), and insertion of tendons
Function	Resists compression Provides cushioning. smooth. and low-friction surface for joints Provides structural support in respiratory system (larynx, trachea, and bronchi) Forms foundation for development of fetal skeleton and further endochondral bone formation and bone growth	Provides flexible support for soft tissues	Resists deformation under stress
Presence of perichondrium	Yes (except articular cartilage and epiphyseal plates)	Yes	No
Undergoes calcification	Yes (i.e. during endochondral bone formation, during aging process)	No	Yes (i.e. calcification of fibrocartilaginous callus during bone repair
Main cell types present	Chondroblasts and chondrocytes	Chondroblasts and condrocytes	Chondrocytes
Characteristic features of extracellular matrix	Type II collagen fibrils and aggrecan monomers (the most important proteoglycan)	Type II collagen fibrils, elastic fibers, and aggrecan monomers	Types I and II fibers Proteoglycan monomers: aggrecan (secreted by chondrocytes) and sersican (secreted by fibroblasts)
Growth	Interstitially and appositionally, very limited in adults		
Repair	Very limited capability, commonly forms scar, resulting in fibrocartilage formation.		

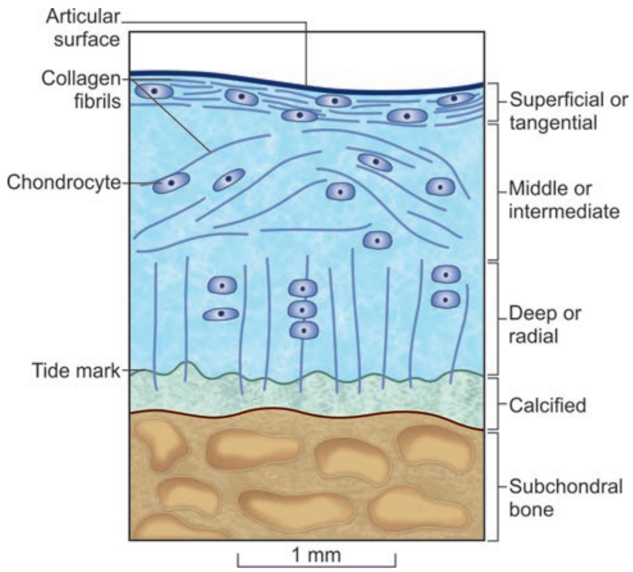


Fig. 20: Articular cartilage has not homogenous structure: Various zones are different in terms of cell size and shape, and the orientation of the collagen fibril network.

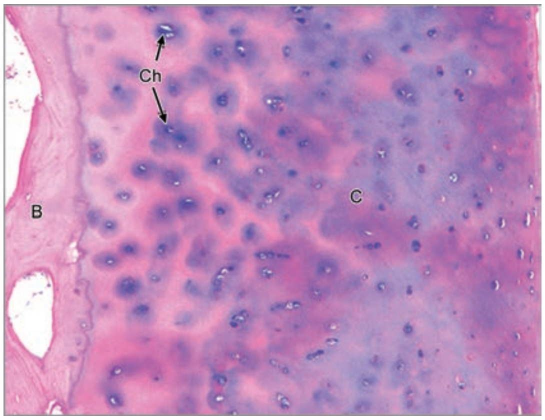


Fig. 21: Articular cartilage on the surface of the head of the femur of a young adult. It is composed of hyaline cartilage C and is attached to the cortical bone B of the head of the femur. The glycosaminoglycans (provide resistance to compression) in the matrix appear bluish in color in the cartilage. Both the glycosaminoglycans and collagen are synthesized and maintained by the chondrocytes.

ASSESSMENT QUESTIONS

1. All cartilage is covered by perichondrium EXCEPT: *(NEET Pattern 2012)*
   a. Articular cartilage
   b. Hyaline
   c. Elastic
   d. Fibrocartilage
   e. None of the above

2. Which of the following is NOT a hyaline cartilage: *(NEET Pattern 2012)*
   a. Articular cartilage
   b. Thyroid cartilage
   c. Meniscus
   d. Nasal septum

3. Collagen found in hyaline cartilage is: *(NEET Pattern 2015)*
   a. Type I
   b. Type II
   c. Type IV
   d. Type V

4. TRUE about hyaline cartilage: *(AIPG 2000)*
   a. Hyaline cartilage covers the articular surface of synovial joints
   b. Hyaline cartilage is present in all synovial joints
   c. Articular cartilage may undergo ossification with aging
   d. Articular cartilage limits the mobility of the joint

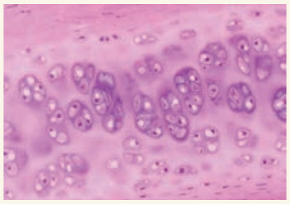
5. Type of cartilage seen at temporomandibular joint is: *(NEET Pattern 2012)*
   a. Hyaline cartilage
   b. Fibrocartilage
   c. Elastic cartilage
   d. All of the above

6. Elastic cartilage is seen in: *(NEET Pattern 2012)*
   a. Articular cartilage
   b. Costal cartilage
   c. Epiglottis
   d. Intervertebral disc

7. The articular cartilage is characterized by all of the following features EXCEPT: *(AIPG 2004)*
   a. It is devoid of perichondrium
   b. It has a rich nerve supply
   c. It is avascular
   d. It lacks the capacity to regenerate

8. Fibrocartilage is found in:
   a. Costal cartilage
   b. Nasal septum
   c. Intervertebral disc
   d. Auditory tube

9. The type of structure shown in the following slide is found in: *(AIIMS 2016)*
   a. Intervertebral discs
   b. Articular discs
   c. Epiphyseal plate
   d. Pinna



ANSWERS WITH EXPLANATIONS

1. d. Fibrocartilage
- Fibrocartilage has no perichondrium and has predominantly type II collagen fibers.

2. c Meniscus
- Meniscus is made up of fibrocartilage.

3. b. Type II
- Hyaline and elastic cartilage have type II collagen fibers.
- Fibrocartilage has predominantly type II collagen fibers.

4. a. Hyaline cartilage covers the articular surface of synovial joints
- Articular cartilage covers the articular surfaces of synovial joints, which is usually of hyaline variety (with few exceptions).
- Articular cartilage in temporomandibular joint, sternoclavicular joint is fibrocartilage (and not of hyaline variety).
- Hyaline cartilages has high tendency to get ossified with few exceptions, e.g. articular cartilage never get ossified.
- Articular cartilage smoothens the articular surfaces and increase the joint mobility.

5. b. Fibrocartilage
- Articular cartilage in temporomandibular joint is fibrocartilage (and not the usual hyaline variety).

6. c. Epiglottis
- Respiratory tube is predominantly lined by hyaline cartilage but in epiglottis it is elastic variety.

7. b. It has a rich nerve supply
- Articular cartilage of typical synovial joints is devoid of nerves and blood vessels.
- It is devoid of perichondrium and has a very low potential for regeneration.

8. c. Intervertebral disc
- Costal cartilage and nasal septum contain hyaline cartilage.Auditory tube has elastic cartilage.

9. c. Epiphyseal plate
- This is a slide of hyaline cartilage, which is found in growth (epiphyseal) plate.
- Identification points:
  - Islands of chondrocytes, scattered in the hyalos matrix.
  - Collagen fibers have the same refractive index as the matrix and are invisible. So, the matrix appears glass-like (hyalos).
  - Intervertebral disc and articular disc has fibrocartilage.
  - Fibrocartilage has relatively few chondrocytes, and they are present among the visible bundles of collagen fibers, running in a wavy fashion.
  - Pinna is made up of elastic cartilage.
  - Elastic cartilage slide shows numerous chondrocytes, scattered among the irregularly arranged elastic fibers.

Bone

Table 15: Summary of bone types and their organization

Types of bone	Histological features	Major locations	Synonyms
Woven bone, newly calcified	Irregular and random arrangement of cells and collagen; lightly calcified	Developing and growing bones; hard callus of bone fractures	Immature bone; primary bone; bone.
Lamellar bone, remodeled from woven bone	Parallel bundles of collagen in thin layers (lamellae), with regularly spaced cells between; heavily calcified.	All normal regions of adult bone	Mature bone; secondary bone
Compact bone, ~80% of all lamellar bone	Parallel lamellae or densely packed osteons, with interstitial lamellae	Thick, outer region (beneath periosteum) of bones	Cortical bone
Cancellous bone, ~20% of all lamellar bone	Interconnected thin spicules or trabeculae covered by endosteum	Inner region of bones, adjacent to marrow cavities	Spongy bone; trabecular bone; medullary bone

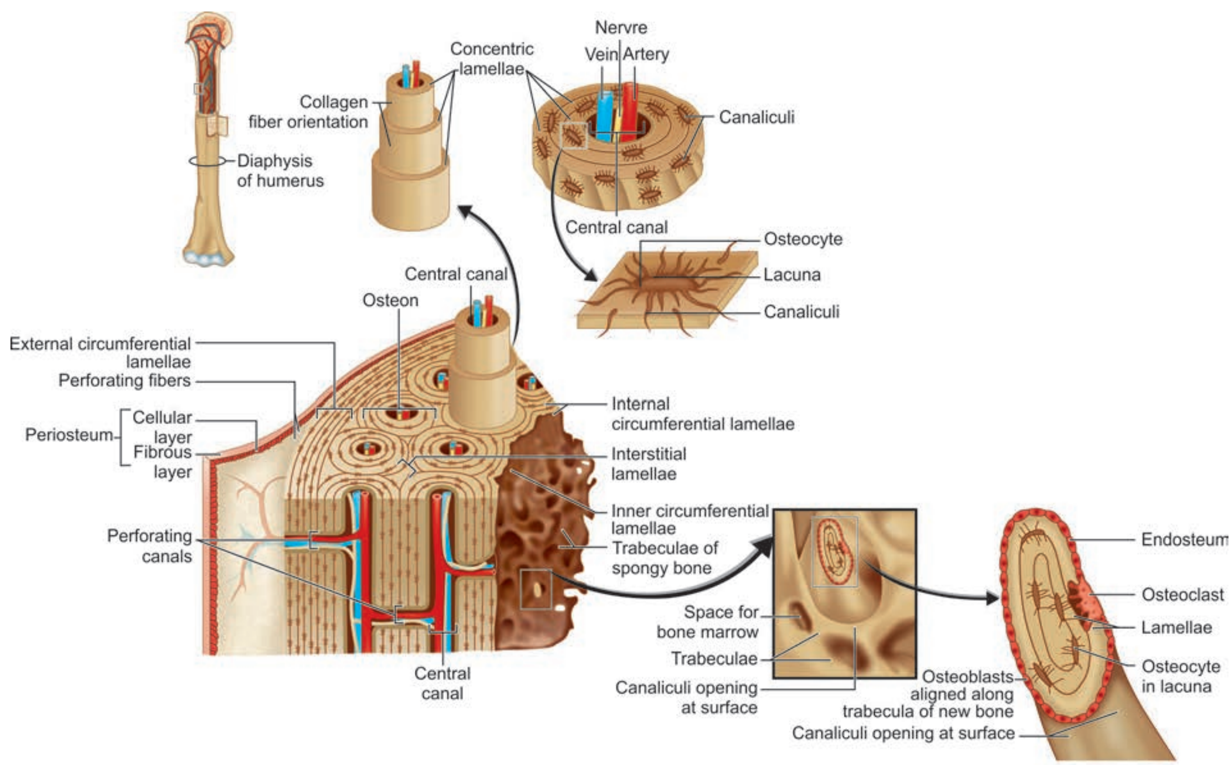


Fig. 22: Structural details of a bone, with osteon arrangement and Haversian system.

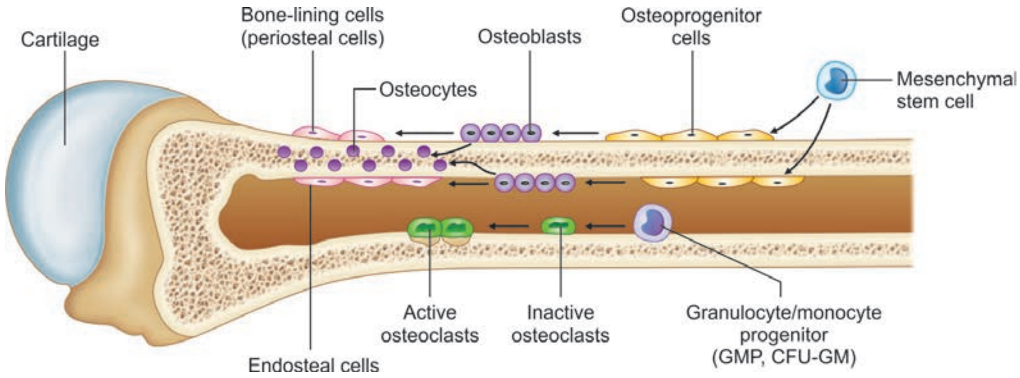
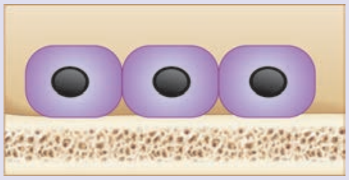
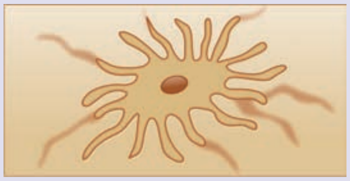


Fig. 23: Cells associated with bone. All cells except osteoclasts originate from the mesenchymal stem cells, which differentiate into osteoprogenitor cells, osteoblasts, and finally osteocytes and bone lining cells. Bone-lining cells on external bone surfaces are part of the periosteum, hence the term periosteal cells. Bone-lining cells on internal bone surfaces are frequently called endosteal cells. Osteoclasts originate from hemopoietic progenitor cells, which differentiate into bone-resorbing cells.

Table 16: Summary of cartilage features in bone

Features	Hyaline cartilage	Elastic cartilage	Fibrocartilage
			
Location	Bone surface, closing cone of resorption canals	Lacunae and canaliculi of bone matrix	Bone surface; cutting cone of resorption canals
Percentage of all cells in the bone	> 5%	~95%	> 1%
Function	Deposits bone matrix; initiates mineralization by releasing matrix vesicles	Maintains bone matrix; senses mechanical stress; regulates calcium and phosphate hemostasis	Resorbs bone by enzymatic hydrolysis of the mineralized bone matrix
Cell morphology	Cuboidal or polygonal, mononuclear cell; basophilic cytoplasm; negative Golgi.	Small, oval, mononuclear cell; pale cytoplasm; long cell processes	Large, multinuclear acidophilic cytoplasm; ruffled border; underlying lacuna
Precursor cells	Osteoprogenitor cell	Osteoblast	Hemopoietic cells (GMP, CFU-GM)
Differentiation process/ transcription factors	CBFA1 (RUNX2); IGF-1	Selection process from osteoblasts	c-fos; NF-kB; RANK-RANKL signaling
Major hormonal/ regulatory receptors	RANKL. PTH receptors	RANKL, PTH receptors	RANK calcitonin receptors; tartrate-resistant and phosphatase (TRAP) receptors
Lifespan	Weeks (~12 days)	Years (~10–20 years)	Days (~3 days)
Biochemical markers	Osteocalcin; bone sialoprotein (BSP-2)	Dentin matrix prtotein-1 (DMP-1); podoplanin (E11 protein); sierostin; fibroblastic growth factor-23 (FGF-23)	Tartrate-resistant acid phosphatase (TRAP); cathepsin K; matrix metallo-proteinase-9 (MMP-9)

CBFA1: Core binding factor alpha-1; GMP/CFU-GM: Granulocyte/macrophage progenitor cells; IGF-1: Insulin-like growth factor 1; PTH: Pan hormone; RANK: Receptor activator of nuclear factor-kB; RANKL, RANK ligand molecule; RUNX2, runt-related transcription factor 2.

Table 17: Difference between compact and spongy bone

	Compact bone	Spongy bone
Density	Dense like ivory	Porous like a sponge
Haversian systems	Present	Absent
Arrangement of bony lamellae	Regular	Irregular
Location in bone	Outer region	Inner region
Bone marrow	Absent	Present
Amount in the body by weight	75%	25%

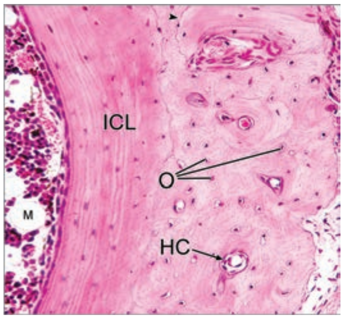


Fig. 24: Microscopic slide of bone and bone marrow from a rib. (M: Bone marrow; ICL: Inner circumferential lamellae; O: Osteocytes; HC; Haversian canal).

- **Periosteum** is a membrane that covers the outer surface of all bones except at the joints of long bones.
- It consists of dense irregular connective tissue, divided into an outer 'fibrous layer' and inner 'osteogenic layer'.
  - The fibrous layer contains fibroblasts, while the osteogenic layer contains progenitor cells that develop into osteoblasts.
  - The osteoblasts are responsible for increasing the width of a long bone and the overall size of the other bone types.
  - After a bone fracture the progenitor cells develop into osteoblasts and chondroblasts, which are essential to the healing process.
- As opposed to osseous tissue, the periosteum has **nociceptive nerve endings**, making it very sensitive to manipulation. It also provides nourishment by providing the blood supply to the body from the marrow.
- Periosteum is attached to the bone by strong collagenous fibers called **Sharpey's fibers,** which extend to the outer circumferential and interstitial lamellae. It also provides an attachment for muscles and tendons.
- **Endosteum** is a thin vascular membrane of connective tissue that lines the surface of the medullary cavity of long bones.
- The osteoblasts and osteoprogenitor cells within the endosteum play an important role in remodeling and repair
- To prevent the bone from becoming unnecessarily thick, osteoclasts resorb the bone from the endosteal side.
- Endosteal surface is resorbed during long periods of malnutrition, resulting in less cortical thickness.
- **Endosteum** is metabolically **more active** than periosteum. The periosteum is highly active during fetal development, when it generates osteoblasts for the appositional growth of bone. The population of osteogenic layer of the periosteum is markedly diminished with age and remodelling of bone is in adult life is a very slow process, but osteoblasts below the endosteum are more active than those below the periosteum.

Red Bone Marrow

- It is vascular and appears red in color due to presence of red blood cells.
- It consists of network of fine **reticular fibers** containing blood forming cells, showing all stages of development.
- At birth it is present in all the bones at all sites, and is an important site of haemopoiesis, but as the age advances the marrow in the medullary cavity of long bones is gradually replaced by yellow marrow.
- In adults the red marrow is found in the cancellous bone. E.g. ends of long bones,
  - Ends of long bones
  - Sternum
  - Ribs
  - Skull bones
  - Iliac crests of hip bones
  - Vertebrae

ASSESSMENT QUESTIONS

1. All physiological processes occur during the growth at the epiphyseal plate EXCEPT: *(AIPG 2005)*
   a. Proliferation & hypertrophy
   b. Calcification & ossification
   c. Vasculogenesis & erosion
   d. Replacement of red bone marrow with yellow marrow

2. Most metabolically active layer in bone is: *(AIIMS 2015)*
   a. Periosteum
   b. Endosteum
   c. Cancellous bone
   d. Cortical bone

3. The Haversian system is found in: *(AIPG 2000)*
   a. Diaphysis of long bones
   b. Cancellous bone
   c. Epiphysis
   d. Spongy bones of children

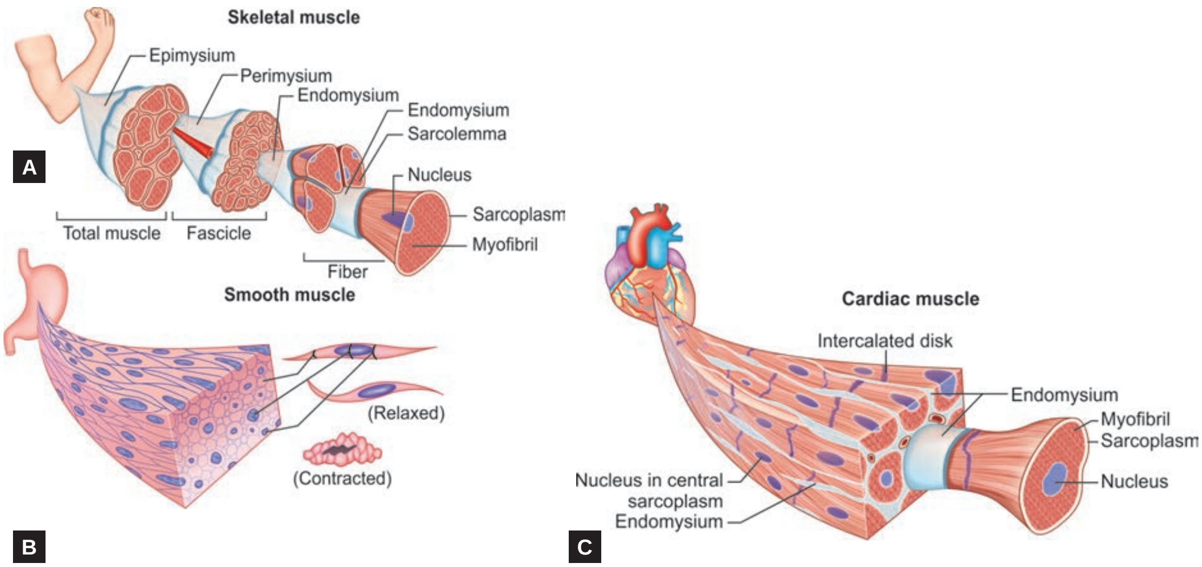
ANSWERS WITH EXPLANATIONS

1. d. Replacement of red bone marrow with yellow marrow
- Replacement of red bone marrow with yellow bone marrow (D) occurs mainly at the diaphysis.
- During endochondral ossification, five distinct zones can be seen at the light-microscope level.

2. b. Endosteum
- This question has confusing options and the most appropriately appearing option has been taken as the answer. **Cancellous** bone is metabolically more active than the cortical bone. **Endosteum** is metabolically more active than periosteum. The periosteum is highly active during fetal development, when it generates osteoblasts for the appositional growth of bone. The population of osteogenic layer of the periosteum is markedly diminished with age and remodelling of bone is in adult life is a very slow process, but osteoblasts below the endosteum are more active than those below the periosteum.

3. a. Diaphysis of long bones
- **Osteon** is the fundamental functional unit of compact bone, which contains haversian system.
- Each osteon consists of concentric layers, or lamellae, of compact bone tissue that surround a central canal, the **haversian canal**.
- Haversian canal carries the **neurovascular bundles** to the bone.
- Osteons are connected to each other and the periosteum by oblique channels called **Volkmann's canals** or perforating canals.

Muscular System



Figs. 25A to C: Structural correlation of three types of muscles.

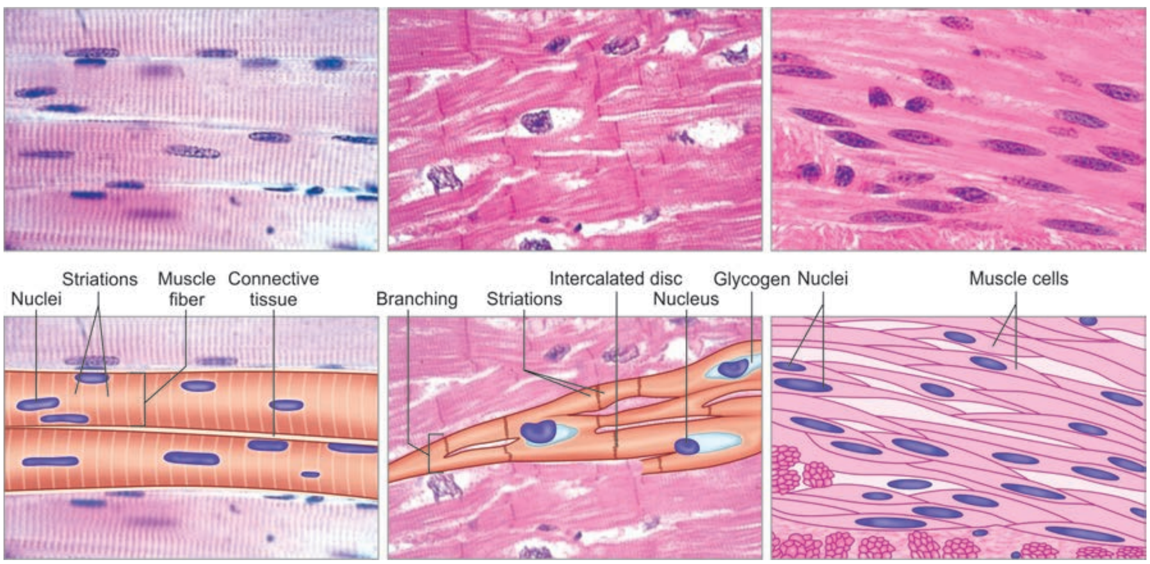


Fig. 26: Microscopic slide and corresponding details shown for three type of muscles.

Table 18: Important comparisons of the three types of muscles

	Skeletal muscle	Cardiac muscle	Smooth muscle
Fibers	Single multinucleated cells	Aligned cells in branching arrangement	Single small, closely packed fusiform cells
Cell/fiber shape and size	Cylindrical 10–100 μm diameter, many cm long	Cylindrical 10-20 μm diameter, 50–100 μm long	Fusiform, diameter 0.2–10 μm, length 50–200 μm
Striations	Present	Present	Absent
Locations of nuclei	Peripheral, adjacent to sarcolemma	Central	Central, at widest part of cell
T tubules	Center of triads at A-I junctions	In diads at Z discs	Absent; caveolae may be functionally similar
Sarcoplasmic reticulum (SR)	Well-developed, with two terminal cisterns per sarcomere in triads with T tubule	Less well-developed, one small terminal cistern per sarcomere in diad with T tuble	Irregular smooth ER without distinctive organization
Special structural features	Very well-organized sarcomeres, SR, and transverse tubule system	Intercalated discs joining cell, with many adherent and gap junctions	Gap junctions, caveolae, dense bodies
Control of contraction	Troponin C binds Ca^{2+}, moving tropomyosin and exposing actin for myosin binding	Similar to that of skeletal muscle	Actin-myosin binding occurs with myosin phosphorylation by MLCL triggered when calmodulin binds Ca^{2+}

Connective tissue organization	Endomysium, perimysium, and epimysium	Endomysium, subendocardial and subpericardial CT layers	Endomysium and less-organized CT sheaths
Major locations	Skeletal muscles, tongue, diaphragm, eyes, and upper esophagus	Heart	Blood vessels, digestive and respiratory tracts, uterus, bladder, and other organs
Key function	Voluntary movements	Automatic (involuntary) pumping of blood	Involuntary movements
Efferent innervation	Motor	Autonomic	Autonomic
Contractions	All-or-none, triggered at motor end plates	All-or-none, intrinsic (beginning at nodes of conducting fibers)	Partial, slow, often spontaneous, wavelike and rhythmic
Cell response to increased load	Hypertrophy (increase in fiber size)	Hypertrophy	Hypertrophy and hyperplasia (increase in cell/fiber number)
Capacity for regeneration	Limited, involving satellite cells mainly	Very poor	Good, involving mitotic activity of muscle cells

Table 19: Major characteristics of skeletal muscle fiber types

	Slow oxidative fibers (Type I)	Fast, oxidative-glycolytic fibers (Type IIa)	Fast, glycolytic fibers (Type IIb)
Mitochondria	Numerous	Numerous	Sparse
Capillaries	Numerous	Numerous	Sparse
Fiber diameter	Small	Intermediate	Large
Size of motor unit	Small	Intermediate	Large
Myoglobin content	High (red fibers)	High (red fibers)	Low (white fibers)
Glycogen content	Low	Intermediate	High
Major source of ATP	Oxidative phosphorylation	Oxidative phosphorylation	Anaerobic glycolysis
Glycolytic enzme activity	Low	Intermediate	High
Rate of fatigue	Slow	Intermediate	Fast
Myosin-ATPase activity	Low	High	High
Speed of contraction	Slow	Fast	Fast
Typical major locations	Postural muscles of back	Major muscles of legs	Extraocular muscles

Skeletal Muscle

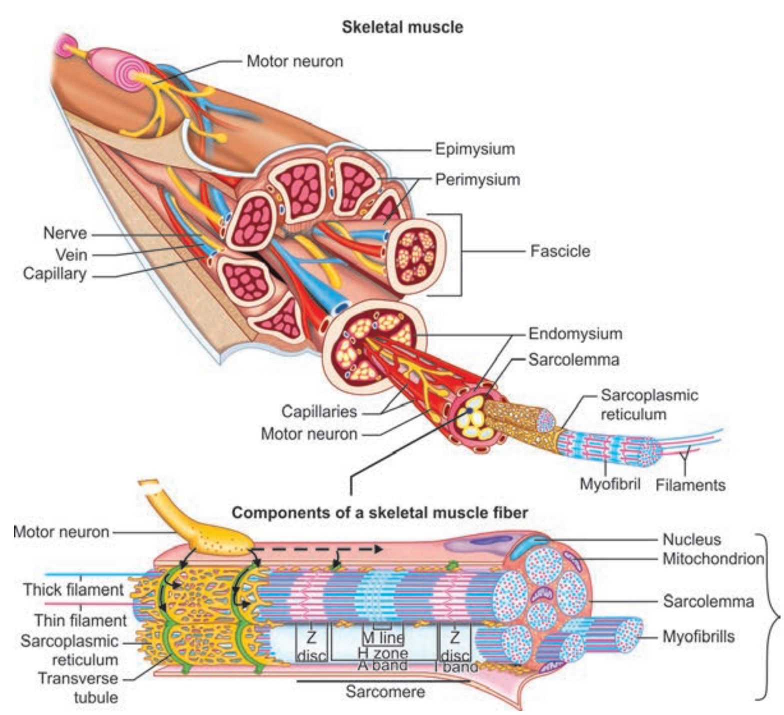


Fig. 27: Microscopic structure of a skeletal muscle, with reference to sarcomere.

- A **sarcomere** is defined as the segment between two neighbouring Z-lines (or Z-discs, or Z bodies). In electron micrographs of cross-striated muscle, the Z-line (from the German "Zwischenscheibe", the disc in between the I-bands) appears as a series of dark lines.
- Surrounding the Z-line is the region of the **I-band** (for **isotropic**). I-band is the zone of thin filaments that is not superimposed by thick filaments.
- Following the I-band is the **A-band** (for **anisotropic**). Named for their properties under a polarizing microscope. An A-band contains the entire length of a single thick filament.
- Within the A-band is a paler region called the **H-zone** (from the German "heller", brighter). Named for their lighter appearance under a polarization microscope. H-band is the zone of the thick filaments that is not superimposed by the thin filaments.
- Within the H-zone is a thin **M-line** (from the German "Mittelscheibe", the disc in the middle of the sarcomere) formed of cross-connecting elements of the cytoskeleton.
- The relationship between the proteins and the regions of the sarcomere are as follows:
- **Actin filaments,** the thin filaments, are the major component of the I-band and extend into the A-band.
- **Myosin filaments,** the thick filaments, are bipolar and extend throughout the A-band. They are cross-linked at the centre by the M-band.
- The giant protein titin (connectin) extends from the Z-line of the sarcomere, where it binds to the thick filament (myosin) system, to the M-band, where it is thought to interact with the thick filaments. Titin (and its splice isoforms) is the biggest single highly elasticated protein found in nature. It provides binding sites for numerous proteins and is thought to play an important role as sarcomeric ruler and as blueprint for the assembly of the sarcomere.
- Another giant protein, nebulin, is hypothesised to extend along the thin filaments and the entire I-Band. Similar to titin, it is thought to act as a molecular ruler along for thin filament assembly.
- Several proteins important for the stability of the sarcomeric structure are found in the Z-line as well as in the M-band of the sarcomere.
- Actin filaments and titin molecules are cross-linked in the Z-disc via the Z-line protein alpha-actinin.
- The M-band proteins myomesin as well as C-protein crosslink the thick filament system (myosins) and the M-band part of titin (the elastic filaments).
- The interaction between actin and myosin filaments in the A-band of the sarcomere is responsible for the muscle contraction (sliding filament model).

Table 20: Effects of contraction on skeletal muscle cross-bands

Bands	Myofilament component	Change in bands during contraction
I	Thin only	Shorten
H	Thick only	Shorten
A	Thick and thin	N change in length
Z disks	Thin only (attached by α-actinin)	Move closer together

Cardiac Muscles

- **Intercalated discs** are microscopic identifying features of cardiac muscle. Cardiac muscle consists of individual heart muscle cells (cardiomyocytes) connected by intercalated discs to work as a single functional organ or syncytium. By contrast, skeletal muscle consists of multinucleated muscle fibers and exhibit no intercalated discs. Intercalated discs support synchronized contraction of cardiac tissue. They occur at the Z line of the sarcomere and can be visualized easily when observing a longitudinal section of the tissue.
- **Three types** of cell junction make up an intercalated disc—fascia adherens, desmosomes and gap junctions.
- **Fascia adherens** are anchoring sites for actin, and connect to the closest sarcomere.
- **Desmosomes** stop separation during contraction by binding intermediate filaments, joining the cells together. Desmosomes are also known as macula adherens.
- **Gap junctions** allow action potentials to spread between cardiac cells by permitting the passage of ions between cells, producing depolarization of the heart muscle.

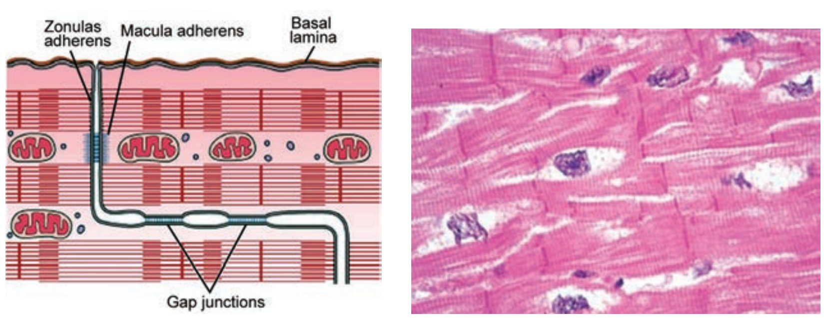
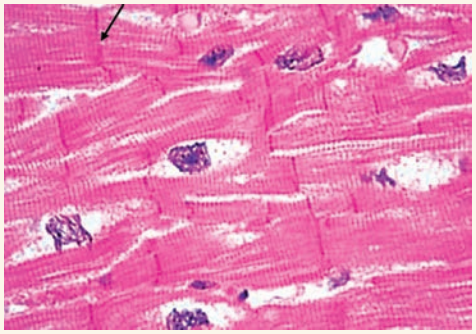


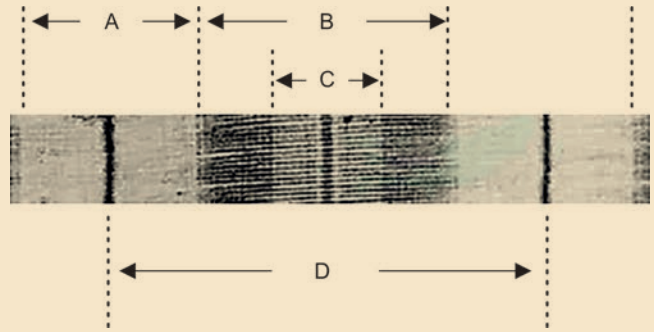
Fig. 28: Cardiac muscles showing various types of cell junctions.

ASSESSMENT QUESTIONS

1. **In the following diagram, the marked structure has all of the following cell junctions EXCEPT:** *(AIIMS 2016)*
   a. Zona occludens
   b. Zona adherens
   c. Macula adherens
   d. Gap junction



2. **In the given EM picture of a sarcomere, identify the structure at marker 'A':** *(AIIMS 2016)*
   a. I band
   b. A band
   c. H band
   d. M band



ANSWERS WITH EXPLANATIONS

1. **a. Zona occludens**
   - This is a diagram of **cardiac muscle** and the marker is pointing towards the **intercalated disc**, which does **not** have zona occludens present in the structure.
   - Three types of cell junction make up an intercalated disc — fascia adherens, desmosomes and gap junctions.

2. **a. I band**
   - This figure is an electron microscopic picture of sarcomere showing various zones, including isotropic I (marker 'A')band.
   - **Key:** A – I (Isotropic) band; B – A (Anisotropic) band; C – H (Heller) band; D – Sarcomere.
   - A sarcomere ('D') is defined as the segment between two neighbouring Z-lines (dark lines).
   - Surrounding the Z-line is the region of the I (Marker 'A') band having thin filaments that are not superimposed by thick filaments.
   - An A band (marker 'B') contains the entire length of a single thick filament.
   - Within the A band is a paler region called the H band (marker 'C'), which is the zone of the thick filaments that are not superimposed by the thin filaments.

Nervous System

Table 21: Review of the central nervous system

Main structures	Sub-structures	Detail and function
Dura mater		Dense fibrous outer layer of central nervous system (CNS); merges with periosteum of skull
Leptomeninges	Pia-arachnoid	Outer brain covering; lined by arachnoidal cells; contains cerebrospinal fluid (CSF)
Choroid plexus		Specialised ventricular structure; produces CSF
Ependyma		Epithelial-like cells with cilia which line ventricles and spinal canal
Spinal cord	White matter columns	Numerous nerve fibers, afferent and efferent
	Anterior horns	Grey matter containing alpha motor neurons
	Spinal canal	Small; lined by ependymal cells; extends from fourth ventricle
	Commissure	Cross-over of nerve fibers in cord near spinal canal
Brainstem	Medulla	Afferent and efferent nerve fibers; relays some signals in nuclei but also processes some (olives) and contains cranial nerve nuclei
	Pons	Afferent and efferent nerve fibers with extensive fibers to cerebellum; pontine nuclei
Cerebellum		Highly branched folia; three cell layers (molecular, purkinje and granular); involved in balance and fine motor skills
Upper brainstem	Substantia nigra	Pigmented neurons; involved in Parkinson's disease
Diencephalon	Thalamus and other basal ganglia	Numerous multifunction relays and processing grey matter nuclei
Cortex	Neocortex	Sensory and motor functions, visual cortex, auditory cortex, language, thought and other higher mental functions
	Ammon's horn	Related to long-term memory

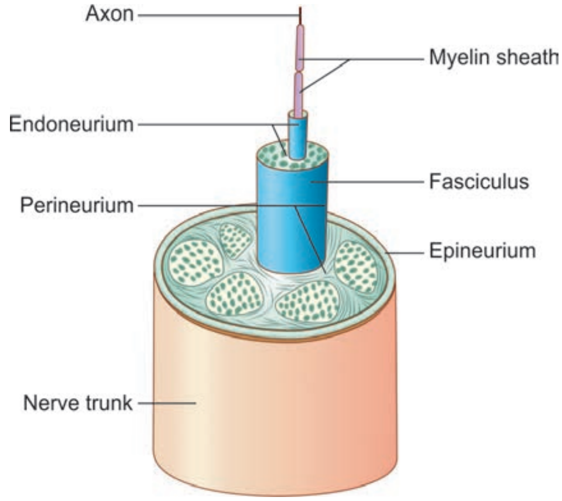


Fig. 29: Microscopic details of a nerve.

Cells of Nervous System

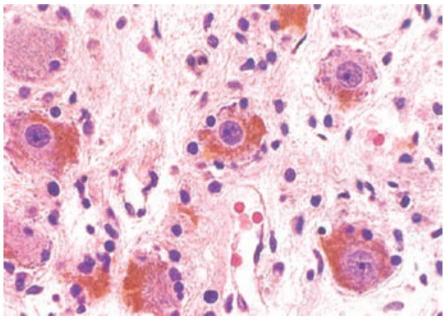


Fig. 30: Sympathetic ganglia- The ganglion cells are multipolar and more widely spaced, being separated by numerous axons and dendrites, many of which pass through the ganglion without being involved in synapses. The nuclei of the ganglion cells tend to be eccentrically located and the peripheral cytoplasm contains brown-stained lipofuscin granules, representing cellular debris sequestered in residual bodies. The satellite cells are smaller in number and irregularly placed due to the numerous dendritic processes of the ganglion cells.

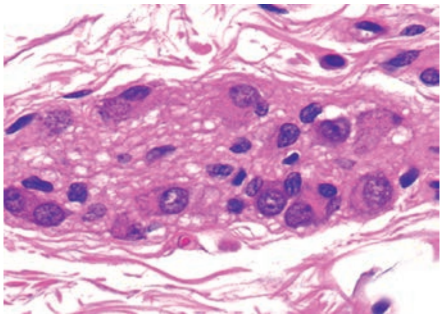


Fig. 31: Parasympathetic ganglion from the wall of the gastrointestinal tract. Like all neurons, the ganglion cells are recognised by their large nuclei, dispersed chromatin, prominent nucleoli, and extensive basophilic cytoplasm. As in other ganglia, the neurons are surrounded by small Schwann cells and afferent and efferent nerve fibers.

Cerebellum

- Identification point: Cerebellar cortex forms a series of deeply convoluted folds or folia supported by a branching central white matter.
- Triple layered cortex
- Cerebellar outer molecular layer ML contains relatively few neurons and large numbers of unmyelinated fibers.
- The inner granular cell layer GL is extremely cellular.
- Between the two is a single layer of huge neurons called Purkinje cells PL

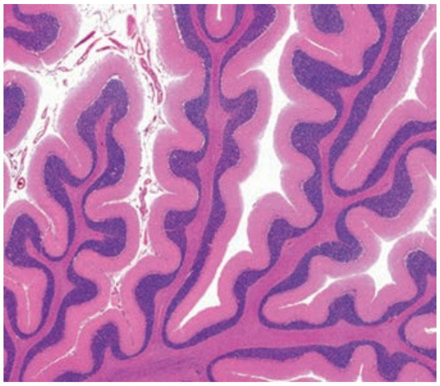


Fig. 32: Cerebellum (low magification).

Fig. 33: Cerebellum (Higher magnification), showing three layers in cerebellar cortex.

Circulatory System

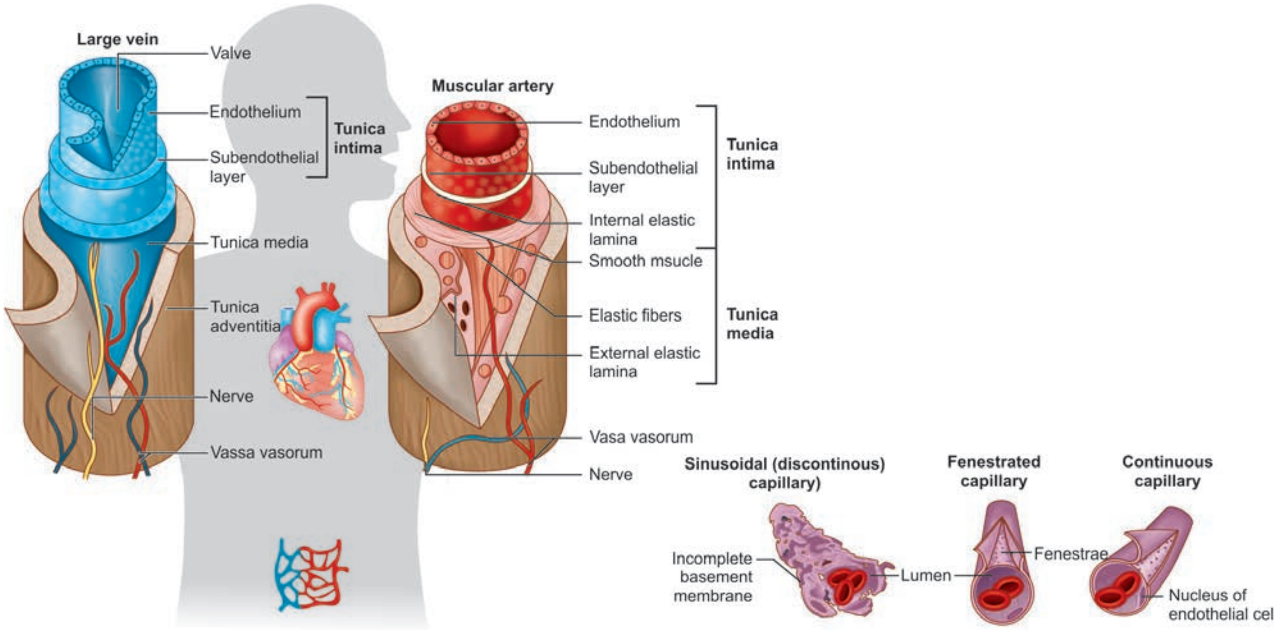


Fig. 34: Muscular artery, large vein, and the three types of capillaries (transverse sections).

Table 22: Size range, major features, and important roles of major blood vessel types

Type of artery	Outer diameter (Approx. Range)	Intima	Media	Adventitia	Roles in circulatory system
Elastic arteries	>10 mm	Endothelium; connective tissue with smooth muscle	Many elastic lamellae alternating with smooth muscle	Connective tissue, thinner than media, with vasa vasorum	Conduct blood from heart and with elastic recoil help move blood forward under steady pressure
Muscular arteries	10–1 mm	Endothelium; connective tissue with smooth muscle, internal elastic lamina prominent	Many smooth muscle layers, with much less elastic material	Connective tissue, thinner than media; vasa vasorum may be present	Distribute blood to all organs and maintain steady blood pressure and flow with vasodilation and construction
Small arteries	1–0.1 mm	Endothelium; connective tissue less smooth muscle	3–10 layers of smooth muscle	Connective tissue, thinner than media; no vasa vasorum	Distribute blood to arterioles, adjusting flow with vasodilation and construction
Arterioles	100-10 µm	Endothelium; no connective tissue or smooth muscle	1–3 layers of smooth muscle	Very thin connective tissue layer	Resist and control blood flow to capillaries; major determinant of systemic blood pressure
Capillaries	10–4 µm	Endothelium only	Pericytes only	None	Exchange metabolites by diffusion to and from cells
Venules (postcapillary, collecting, and muscular)	10–100 µm	Endothelium; no valves	Scattered smooth muscle cells	None	Drain capillary beds; site of leukocyte exit from vasculature
Small veins	0.1–1 mm	Endothelium; connective tissue with scattered smooth muscle fibers	Thin, 2–3 loose layers of smooth muscle cells	Connective tissue, thicker than media	Collect blood from venules
Medium veins	1–10 mm	Endothelium; connective tissue, with valves	3–5 more distinct layers of smooth muscle	Thicker than media; longitudinal smooth muscle may be present	Carry blood to larger veins, with no backflow
Large veins	>10 mm	Endothelium; connective tissue, smooth muscle cells; prominent valves	>5 layers of smooth muscle, with much collagen	Thickest layer, with bundled longitudinal smooth muscle	Return blood to heart

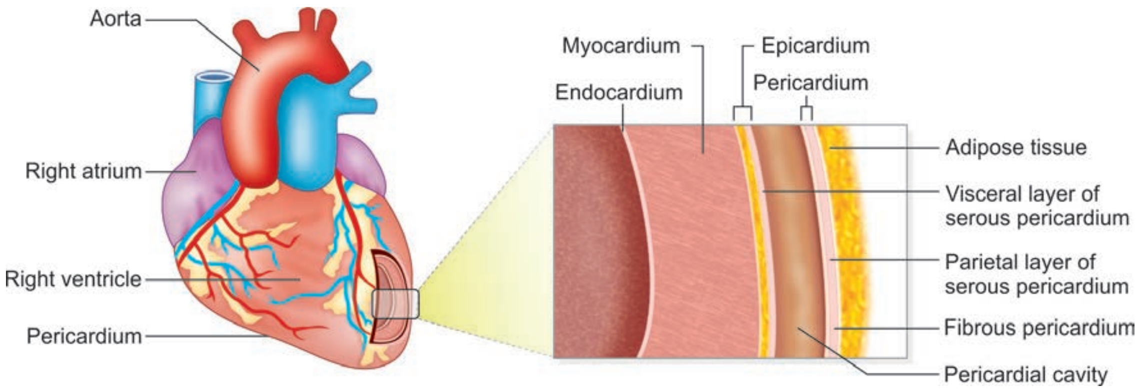


Fig. 35: Layers of the heart and pericardium. The parietal layer of the serous pericardium is reflected back at the great vessels entering and leaving the heart as the visceral layer of the serous pericardium or epicardium. The epicardium lines the outer surface of the heart. The pericardial cavity is a space between the visceral and parietal layers of the serous pericardium, and it is lined by the mesothelial cells. Deep into the epicardium is the myocardium, which consists of cardiac muscle. Adipose tissue of the epicardium contains the coronary arteries and cardiac veins. The inner layer endocardium, is lined by the mesothelium with an underlying thin layer of connective tissue.

Table 23: Review of the circulatory system

Structure	Key components and features
Heart	Epicardium; adventitial fat with vessels and mesothelial surface
	Myocardium; functional syncytium of cardiac myocytes
	Endocardium lining chambers and valves; flattened endothelial cells
	Conducting system; specialised Purkinje fibers and bundle of His
	Valves; core of fibroelastic tissue with surface endothelium
	Spontaneous rhythmic contraction due to cardiac action potential
Vascular system	Aorta; elastic artery with intima, media and adventitia • Many elastic fibers in media • Vasa vasorum to supply adventitia
	Muscular artery; well-defined internal and external elastic lamina
	Arteriole; only 2 or 3 layers of smooth muscle cells
	Capillary; fenestrated or continuous endothelium with pericytes
	Venule; like capillaries, but larger venules may have smooth muscle
	Vein; thin muscular wall, elastic layers less defined than in arteries
Lymphatic system	Vessels responsible for returning tissue fluid to vascular compartment • Tissue fluid formed due to Starling forces • Drainage into great veins via thoracic duct
	Thin-walled channels with valves, lack pericytes
	Larger vessels have smooth muscle in wall, layers poorly defined
	Lymph nodes filter lymph fluid

Arteries

Table 24: Characteristics of the different types of arteries

Artery	Tunica Intima	Tunica media	Tunica adventitia
Elastic arteries (conducting) (e.g. aorta, pulmonary trunk)	Endothelium (containing Weibel-Palade bodies), basal lamina, subendothelial layer, incomplete internal elastic lamina	Layers of smooth muscle cells interspersed with 40-70 fenestrated elastic membranes, thin incomplete external elastic lamina, vasa vasorum	Thin layer of fibroelastic CT, limited vasa vasorum, lymphatic vessels nerve fibers
Muscular arteries (distributing) (e.g., carotid and femoral arteries)	Endothelium (containing Weibel-Palade bodies), basal lamina, subendothelial layer, thick internal elastic lamina	~40 layers of smooth muscle cells, thick external elastic lamina. relatively little additional elastic tissue	Thin layer of fibroelastic CT, limited vasa vasorum, lymphatic vessels, nerve fibers
Arterioles	Endothelium (containing Weibel-Palade bodies), basal lamina, subendothelial layer, internal elastic lamina mostly replaced by elastic fibers	1-2 layers of smooth muscle cells	Ill-defined sheath of loose connective tissue, nerve fibers
Metarterioles	Endothelium and basal lamina	Precapillary sphincter formed by smooth muscle cells	Sparse loose connective tissue

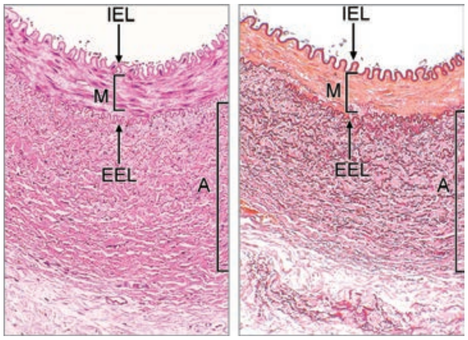


Fig. 36: Muscular artery- The elastic tissue is largely concentrated as two well-defined elastic sheets. One sheet is the ***internal elastic lamina*** **IEL** between the tunica intima and the tunica media. The less prominent and more variable ***external elastic lamina*** **EEL** lies between the tunica media **M** and the adventitia. The tunica intima is usually a very thin layer, not visible at low magnification, and the tunica media **M** is composed of concentrically arranged smooth muscle fibers with scanty elastic fibers between them. The tunica adventitia **A** is of variable thickness and is composed of collagen and a variable amount of elastic tissue. In larger muscular arteries, this layer may contain prominent vasa vasorum.

Table 25: Characteristics of different types of capillaries

Characteristics	Continuous capillaries	Fenestrated capillaries	Sinusoidal capillaries
Location	CT, muscle, nerve tissue; modified in brain tissue	Endocrine glands, pancreas, intestines	Bone marrow, spleen, liver, lymph nodes, certain endocrine glands
Diameter	Smallest diameter	Intermediate diameter	Largest diameter
Endothelium	Forms tight junctions at marginal fold with itself or adjacent cells	Forms tight junction at marginal fold with itself or adjacent cells	Frequently the endothelium and basal lamina are discontinuous
Fenestrae	Not present	Present	Present in addition to gaps

Veins

Table 26: Characteristics of Veins

Type of vein	Tunica intima	Tunica media	Tunica adventitia
Large veins	Endothelium, basal lamina, sub-endothelial CT, some veins possess valves	Connective tissue and a few layers of smooth muscle cells	Bundles of smooth muscle cells are oriented longitudinally. Cardiac muscle cells located where veins enter into the heart; layers of collagen fiber bundles with fibroblasts
Medium and small veins	Endothelium, basal lamina, sub-endothelial CT, some veins possess valves	Reticular and elastic fibers and some smooth muscle cells	Layers of collagen fiber bundles containing fibroblasts
Venules	Endothelium, basal lamina (pericytes are associated with some postcapillary venules)	Some connective tissue, along with a few smooth muscle cells	Some collagen fiber bundles and a few fibroblasts

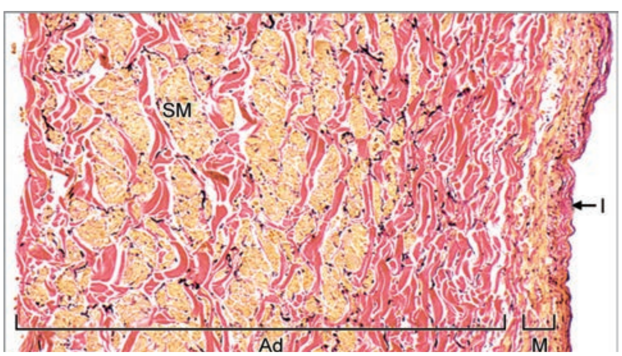


Fig. 37: Inferior vena cava have the thickest walls of all veins, comprising a distinct intima I of fibroelastic tissue, a narrow tunica media **M** composed of mainly circular smooth muscle, beneath which is a thick adventitia **Ad** composed of collagen (red) and thick bundles of longitudinally arranged smooth muscle fibers (yellow) **SM**. There are elastic fibers (black) scattered throughout the wall and, in some areas, there is a variable internal elastic lamina between intima and media.

ASSESSMENT QUESTION

1. **Sinusoids are seen in all of the following EXCEPT:** *(NEET Pattern 2012))*
   a. Liver b. Kidney
   c. Lymph nodes d. Spleen

ANSWER WITH EXPLANATION

1. **b. Kidney**
   - A sinusoid is a small blood vessel that is a type of capillary similar to a fenestrated endothelium.
   - Sinusoids are found in the liver, lymphoid tissue, endocrine organs, and hematopoietic organs such as the bone marrow and the spleen.
   - Non-sinusoidal fenestrated blood capillaries with open fenestrae are only known to be present in the kidney glomerulus.

Lymphoid System

- Lymphoid system consists of capsulated lymphoid tissues (thymus, spleen, tonsils, and lymph
- nodes); diffuse lymphoid tissue; and lymphoid cells, primarily T lymphocytes (T cells), B lymphocytes
- (B cells), and macrophages.
- Capsulated lymphoid organs are of two types, primary lymphoid organs that "educate" lymphocytes so that they become immunocompetent cells; it includes bone marrow and the thymus.
- Secondary lymphoid organs sequester immunogens and allow immunocompetent cells and antigen presenting cells (APCs) to interact with the immunogens and with each other to initiate an immune reaction and eliminate the antigenic attack

Table 27: Review of the immune system

Organ/tissue	Basic structural components	Component functions
Bone marrow	Red marrow	Production of all circulating and tissue resident blood cells including immature T and B lymphocytes Site of B lymphocytes maturation
	Yellow marrow	Resting bone marrow with little haematopoietic activity
Thymus	Cortex	Maturation of immature T lymphocytes
	Medulla	Development of self-tolerance by deletion of self-reactive clones of T cells
Lymph node	Cortex	B cell activation and clonal expansion to produce large numbers of B lymphocytes reactive to specific antigens. Production of memory T lymphocytes
	Paracortex	T cell activation and clonal expansion to produce large numbers of T lymphocytes reactive to specific antigens. Production of memory T lymphocytes.
	Medulla	Plasma cell maturation and secretion of antibody
Mucosal associated lymphoid tissue (MALT)	Tonsils Bronchial-associated lymphoid tissue (BALT) Gut-associated lymphoid tissue (GALT)	All components of MALT function in the same fashion as lymph nodes to protect the body from infective organisms presenting at mucosal surfaces.
Spleen	White pulp	Mounts an adaptive immune response against blood borne infective agents
	Red pulp	Filtering the blood to remove particulate matter Removing damaged and aged erythrocytes Recycling of iron to the bone marrow.

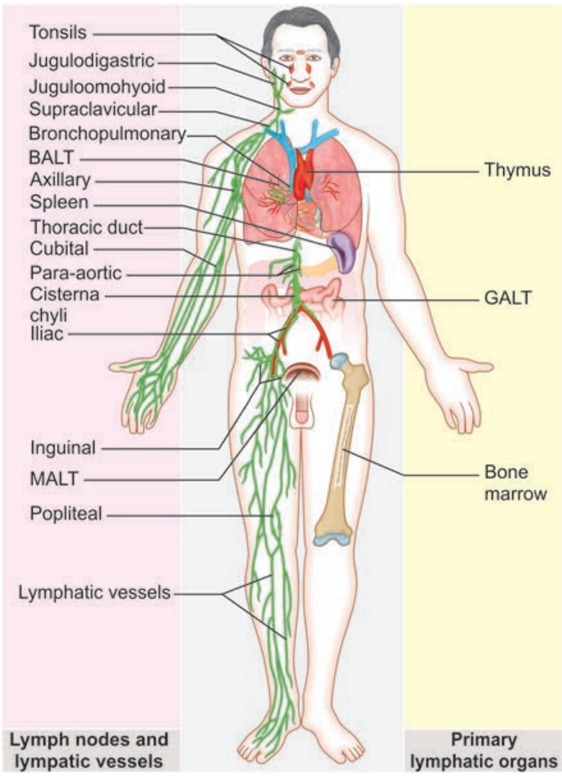
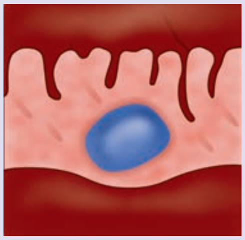
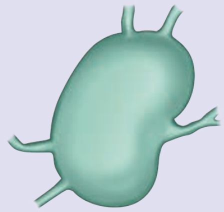


Fig. 38: Lymphatic system consist of a group of cells, tissues, and organs that are responsible for monitoring body surfaces and internal compartments in order to combat foreign microorganisms, transformed cells, and other harmful substances. Lymphocytes are the most important cells of the lymphatic system. They differentiate and acquire immunocompentency in the primary (central) lymphatic organs, which for B lymphocytes is the bone marrow and gut-associated lymphatic tissue (GALT), and for T lymphocytes is the thymus. Lymphocytes then enter into the blood or lymphatic vessels to colonize secondary (peripheral) lymphatic tissues, where they undergo the final stages of antigen-dependent activation. Secondary lymphatic tissues consist of various groups of lymph nodes and aggregations of lmphatic nodules, such as tonsils, bronchus-associated lymphatic tissue (BALT) in lungs, and mycosa-associated lymphatic tissue (MALT) throughtout the genitourinary system (i.e. shown here is the mucosa of the bladder). Lymph is the fluid that is removed from the extracellular spaces of the connective tissues. If flows in lymphatic vessles into the lymph nodes, which are interspersed along the superficial lymphatic vessels (associated with the skin and superficial fascia) and deep lymphatic vessels (associated with main arteries). Ultimately, the lymphatic vessels empty into the bloodstream by joining the large veins at the base of the neck. The thoracic duct is the largest lymphatic vessel.

Table 28: Comparison of the major lymphatic organs

Features	Lymphatic nodules (BALT, GALT, MALT)	Lymph nodes	Thymus	Spleen
				
Major function	Immune surveillance of mucosal membranes	Filter lymph Generate immune response to antigens in the lymph	Develops immunocompetent T lymphocytes	Filters blood Eliminates senescent erythrocytes Generates immune responses to circulating antigens
Connective tissue capsule	No	Yes	Yes	Yes; contains myofibroblasts
Cortex	No	Yes	Yes	No
Medulla	No	Yes	Yes	No
Lymph nodules	Yes	Yes; in the superficial cortex only	No	Yes; in white pulp only
Afferent lymphatic vessels	No	Yes; passing through the capsule	No	No
Efferent lymphatic vessels	Yes	Yes; leaving the node at the hilum	Yes (few); originate in connective tissue septa and capsule	Yes; inconspicuous, originate in white pulp near trabeculae
High endothelial venules (HEVs)	Yes; in well-established lymph nodules (i.e., tonsils, appendix, Peyer's patches)	Yes; associated with deep cortex	No	No
Characteristic features	Diffuse lymphatic tissue with randomly distributed lymphatic nodules underlying epithelial surface	Presence of lymphatic sinuses (subcapsular, trabecular and medullary) Reticular meshwork	Thymic lobules Meshwork of epithelioreticular cells Hassall's corpuscles in medulla only	White pulp with PALS splenic noduling central artery

BALT: Bronchus-associated lymphatic tisse; GALT: Gut-associated lymphatic tissue; MALT: Mucosa-associated lymphatic tissue; PALS: Periarterial.

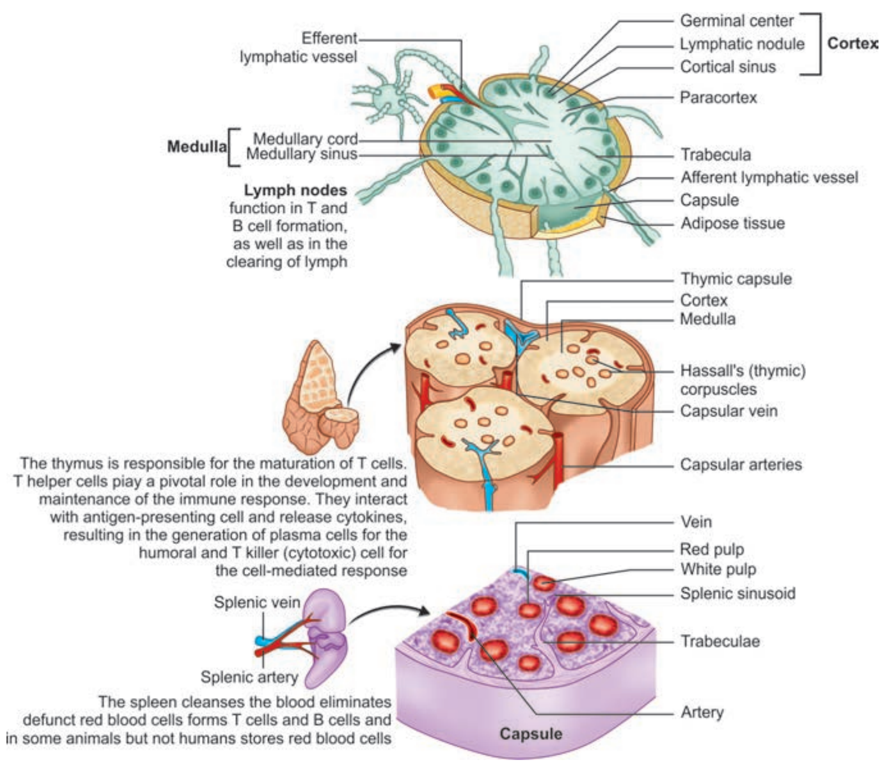


Fig. 39: Comparison of the internal structures of lymph node, thymus and spleen.

Table 29: Approximate percentages of B and T cells in lymphoid organs		
Lymphoid organ	**T lymphocytes (%)**	**B lymphocytes (%)**
Thymus	100	0
Bone marrow	10	90
Spleen	45	55
Lymph nodes	60	40
Blood	70	30

Table 30: Lymphoid organs	
Primary (central) (with stem cells)	Bone marrow (B Lymphocytes → Plasma cell → Antibodies → Humoral Immunity)
	Thymus (T Lymphocytes → Cell mediated Immunity) *DiGeorge syndrome – Bacterial infections
Secondary (peripheral)	Lymph nodes Tonsils Spleen (Type III collagen) MALT (e.g. Peyer patches)

Primary Lymphoid Organs

1. Bone marrow – Has the stem cells that develop into B lymphocytes, which form plasma cells to secrete antibodies (humoral immunity). Most other leukocytes migrate to peripheral sites to fully mature.
2. Thymus – Receive stem cells from bone marrow and train them as T-lymphocyte (cell mediated immunity).
   - Secondary lymphoid organs: Tonsils, lymph nodes, spleen, MALT, etc.
   - Lymphoid organs have type III collagen fibers.
   - Mucosa-associated lymphoid tissue (MALT) is un-encapsulated lymphoid tissue that lines the digestive tract (GALT), respiratory tract (BALT), and genitourinary tract.
   - Peyer patches are found in the lamina propria of the ileum and are separated from the intestinal lumen by a layer of flattened epithelial cells known as microfold cells (M cells).
   - M cells transcytose antigens and present to the underlying Peyer patches, where APCs phagocytose the antigens and present them to resident T cells and B cells.

Lymph Node

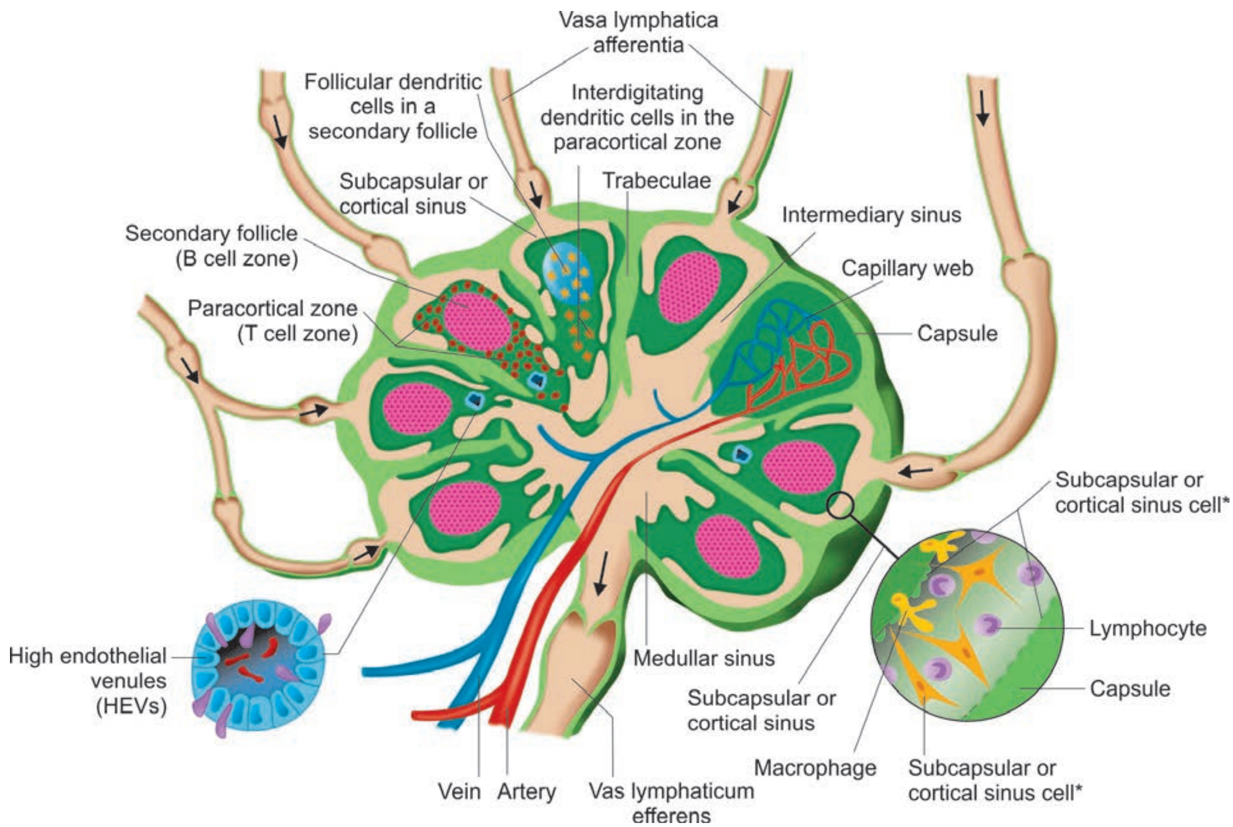


Fig. 40: Detailed internal structure of a lymph node.

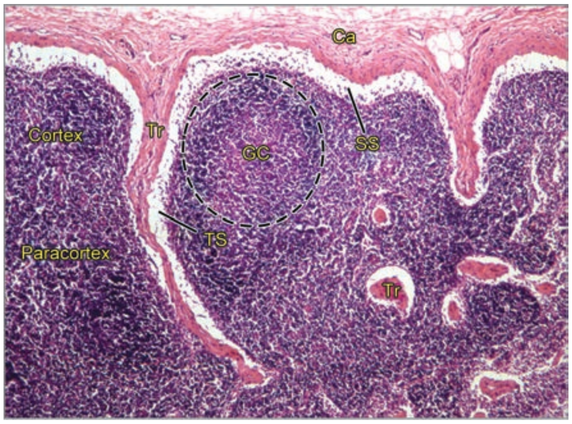


Fig. 41: Microscopic structure of a lymph node. A fibrous connective tissue capsule (Ca) sends in trabeculae (Tr) that extend deeply into the node. A prominent subcapsular sinus (SS) is continuous with trabecular sinuses (TS). The outer cortex consists mostly of B lymphocytes. Deeper parts of the cortex—the paracortex—contain mostly T lymphocytes. A lymphoid nodule (broken line) in the cortex contains a germinal center (GC).

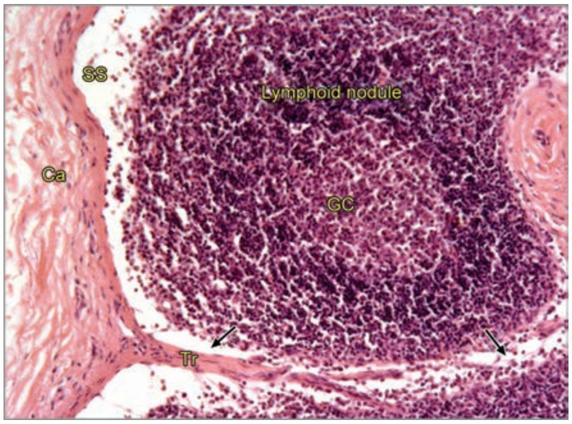


Fig. 42: Microscopic structure of a lymph node (Higher magnification). Collagen fibers of the capsule (Ca) and trabecula (Tr) are seen clearly. A broad subcapsular sinus (SS) drains lymph into smaller trabecular sinuses (arrows). Aside from lymph and lymphocytes, sinuses contain reticular fibers and macrophages, which cannot be seen at this magnification. The lymphoid nodule has a peripheral rim of closely packed lymphocytes around a pale central zone—a germinal center (GC) —that contains mainly activated B lymphocytes.

Thymus

- Precursors of both B cells and T cells are produced in the bone marrow. T-lymphocyte precursors migrate to the thymus, where they develop into T lymphocytes. After the thymus undergoes involution, T lymphocytes (thymocytes) migrate out of the thymus to the peripheral lymphoid organs such as spleen, tonsils, and lymph nodes, where they further differentiate into mature immunologically competent cells, which are responsible for cell-mediated immunity. (However, B-lymphocyte precursors remain in the bone marrow to develop into B lymphocytes, which migrate to the peripheral lymphoid organs, where they become mature immunocompetent B cells, which are responsible for the humoral immunity. Also, B cells differentiate into plasma cells that synthesize antibodies [immunoglobulins].)

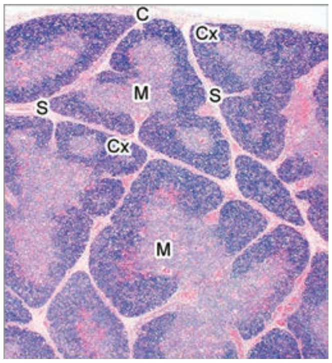


Fig. 43: Thymus is a lobulated organ invested by a loose collagenous ***capsule C*** from which interlobular ***septa S*** containing blood vessels radiate into the substance of the organ. The thymic tissue is divided into two distinct zones, a deeply basophilic outer cortex Cx and an inner eosinophilic medulla **M**.

Spleen

- Spleen is composed of **red pulp** (75%) having large number of red blood cells (and comparatively very few white blood cells) . It consists of **venous sinusoids** and **splenic cords (of Billroth)**.
- **White pulp** (25%) of spleen has large number of white blood cells arranged in diffuse and nodular lymphoid tissue for immune function.
- White pulp has lymphoid follicles with B lymphocytes at the germinal centres, whereas T cell lie in the periphery. The eccentric arterioles in lymphoid follicles are surrounded by peripheral T lymphocytes forming PALS – Peri Arteriolar Lymphatic Sheath.
- Splenic cords of Billroth are present in the red pulp of the spleen between the sinusoids, consisting of fibrils and connective tissue cells with a large population of monocytes and macrophages.
- These contain half of the human body's monocytes as a reserve so that after tissue injury these monocytes can move in and aid locally sourced monocytes in wound healing.
- Erythrocytes pass through the cords of Billroth before entering the sinusoids. The passage into the sinusoids is as a bottleneck, where erythrocytes need to be flexible in order to pass through. In disorders of erythrocyte shape and/or flexibility, such as hereditary spherocytosis, erythrocytes fail to pass through and get phagocytosed, causing extravascular hemolysis.

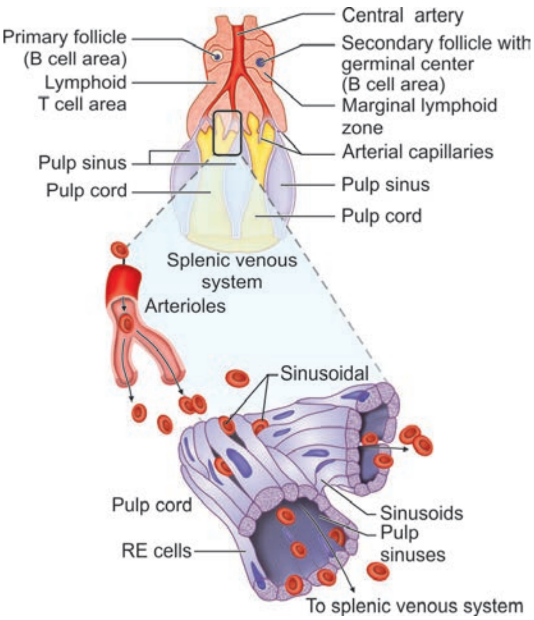
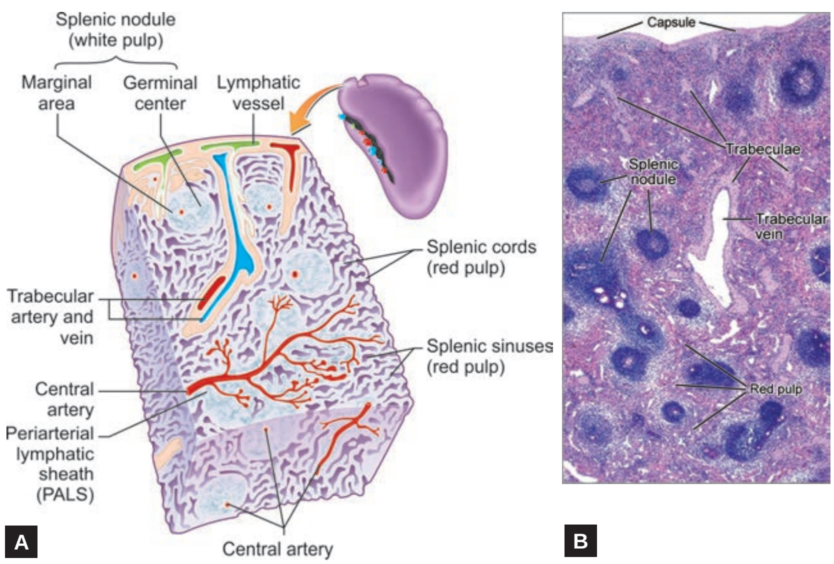


Fig. 44: Spleen comprises many units of red and white pulp centered around small branches of the splenic artery, called central arteris. White pulp is lymphoid in nature and contains B cell follicles, a marginal zone around the follicles, and T cell-rich areas sheathing arterioles. The red pulp areas include pulp sinuses and pulp cords. The cords are dead ends. In order to regain access to the circulation red blood cells must traverse tiny openings in the sinusoidal lining. Stiff, damaged, or old red cells cannot enter the sinuses. (RE: Reticuloendothelial).



Figs. 45A and B: Spleen is divided into white pulp and red pulp. White pulp consists of a cylindrical mass of lymphocytes arranged around a central artery that constitutes the periarterial lymphatic sheath (PALS). Splenic nodules occur along the length of the PALS. When observed in cross-section through part of the sheath that contains a nodule, the central artery appears eccentrically located with respect to the lymphatic mass. The red pulp consists of splenic sinuses surrounded by splenic cords (cords of Billroth). (A) Capsule surrounds the spleen; trabeculae project from it into the substance of the spleen. Both capsule and trabeculae give the appearance of dense connective tissue infiltrated by numerous myofibroblasts. Blood vessels traverse the capsule and trabeculae before and after passage within the substance of the spleen. Lymphatic vessels originate in the white pulp near the trabeculae. (B) Capsule with several trabeculae project into the substance of the spleen. In the center, there is a trabecula containing a trabecular vein through which blood leaves the organ. The red pulp constitutes the greater bulk of the splenic tissue. The white pulp contains lymphatic tissue that follows and ensheathes the central artery. Expansion of the white pulp creates the splenic nodules.

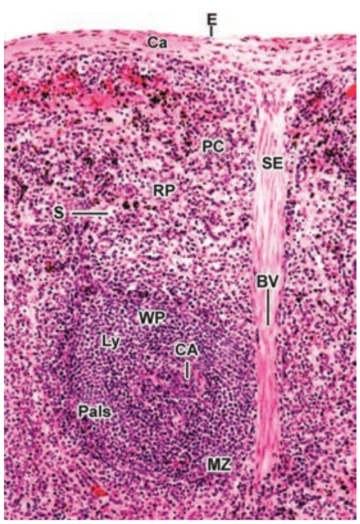


Fig. 46: Spleen possesses a thick collagenous connective tissue capsule (Ca). Since it lies within the abdominal cavity, it is surrounded by a simple squamous epithelium (E). Connective tissue septa (SE), derived from the capsule, penetrate the substance of the spleen, conveying blood vessels (IV) into the interior of the organ. Histologically, the spleen is composed of white pulp (WP) and red pulp (RP). White pulp is arranged as a cylindrical, multilayered sheath of lymphocytes (Ly) surrounding a blood vessel known as the central artery (CA). The red pulp consists sinusoids (S) meandering through a cellular tissue known as pulp cordis (PC). The white pulp of the spleen is found in two different arrangements The one represented in this photomicrograph is known as a periarterial lymphatic sheath (PALS), composed mostly of T lymphocytes. The zone of lymphocytes at the junction of the PALS and the red pulp is known as the marginal zone (MZ).

- **Stave cells** are present in spleen
- Stave (also called Littoral) cells are flattened cells which line the walls of lymph or blood sinuses. They contain myofibrils that allow them to contract thereby opening up channels by which blood is discharged into the splenic substance.

Tonsil

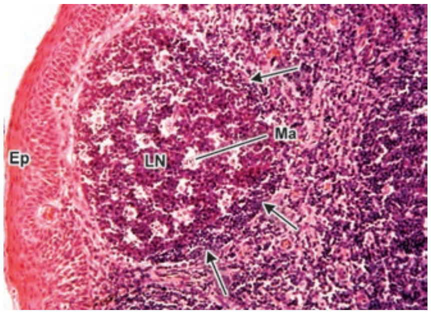


Fig. 47: Lymphoid nodule in the palatine tonsil. Under the stratified squamous epithelium (Ep) that covers the tonsil surface is a profusion of dark-staining, closely packed lymphocytes. A spherical lymphoid nodule (LN) in the lamina propria is capped externally by a mantle zone of similar lymphocytes (arrows). The germinal center of this nodule is not seen. Tonsillar nodules also contain many macrophages (Ma), known as tingible (or stainable) macrophages. Their presence among the smaller, darker lymphocytes produces a unique "starry night" pattern in the nodule, which is a useful distinguishing feature of this tonsil. These macrophages phagocytose developing B lymphocytes in the nodule that are either apoptotic or undergoing degeneration.

ASSESSMENT QUESTIONS

1. **All of the following are categorized as secondary lymphoid organs EXCEPT:** *(PGIC)*
   a. Lymph nodes
   b. Spleen
   c. Thymus
   d. Subepithelial collections of lymphocytes
   e. Bone marrow

2. **Which of the following is the most common site of mucosa-associated lymphoid tissue?** *(AIIMS 2014)*
   a. Stomach
   b. Duodenum
   c. Jejunum
   d. Ileum

3. **Intestinal epithelial cells contain:** *(AIIMS 2012)*
   a. T cells
   b. B cells
   c. Plasma cells
   d. Macrophages

4. **Absence of lymphatics is characteristic of:** *(NEET Pattern 2012)*
   a. Brain
   b. Liver
   c. Lung
   d. Placenta

5. **Subcapsular sinuses are seen in:** *(NEET Pattern 2012)*
   a. Spleen
   b. Thymus
   c. Thyroid
   d. Lymph node

6. **Follicles are present in which part of lymph nodes:** *(NEET Pattern 2013)*
   a. Red pulp
   b. White pulp
   c. Cortex
   d. Medulla

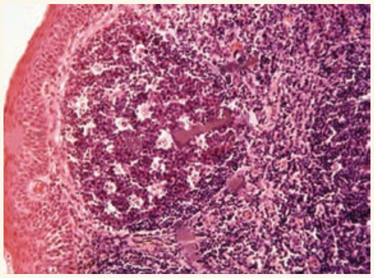
7. **GALT (Gut Associated Lymphoid tissue) is present in:** *(AIPG 2009)*
   a. Submucosa
   b. Lamina propria
   c. Muscularis mucosa
   d. Adventitia/Serosa

8. **All of the following are the components of the white pulp of spleen EXCEPT:** *(AIPG 2006)*
   a. Periarteriolar lymphoid sheath
   b. B cells
   c. Antigen presenting cells
   d. Vascular sinus

9. **Cords of Billroth are present in which part of spleen?** *(NEET Pattern 2013)*
   a. White pulp
   b. Red pulp
   c. Both
   d. Capsule

10. **Stave cells are seen in:** *(NEET Pattern 2012)*
    a. Liver
    b. Spleen
    c. Pancreas
    d. Gallbladder

11. **Identify the lymphatic structure shown in the diagram:** *(AIIMS 2016)*
    a. Tonsil
    b. Spleen
    c. Thymus
    d. Lymph node



ANSWERS WITH EXPLANATIONS

1. **c. Thymus; e. Bone marrow**
   - Primary (central) lymphoid organs have stem cells for lymphopoiesis (bone marrow and thymus). They are involved in providing immunocompetence to the lymphocytes.
   - Secondary (peripheral) lymphoid organs are in the periphery where the lymphocytes execute their immunocompetence, e.g. lymph node, tonsil, spleen, MALT (sub-epithelial collection of lymphocytes) etc.

2. d. Ileum
- The mucosaassociated lymphoid tissue (MALT) is a diffuse system of small concentrations of lymphoid tissue in the lamina propria of mucosa layer in gastrointestinal tract.
- Terminal ileum has large concentrations of MALT arranged in the form of Peyer patches.
- MALT is populated by lymphocytes such as T cells and B cells, as well as plasma cells and macrophages to encounter antigens passing through the mucosal epithelium.

3. a. T cells
- This question has multiple answers, the most appropriate option has been taken as the answer.
- Intestinal epithelium has numerous immunity mediating cells like T lymphocytes, neutrophils, macrophages etc.

4. a. Brain
- Lymphatic capillaries are absent from avascular structures (e.g. epidermis, cornea, cartilage); from the CNS & meninges; choroid, internal ear; Eyeball (except conjunctiva); bone marrow; striated muscle & tendons.

5. d. Lymph node
- Lymph node is identified by presence of subcapsular sinus, containing lymph.

6. c. Cortex
- Lymphoid follicles are present in the cortex region of lymph node.

7.b. Lamina propria
- GALT is present in the lamina propria (mucosa) of the body tubes, though it may also be found in the submucosa occasionally (e.g. vermiform appendix).
- In vermiform appendix the smooth muscle layer of muscularis mucosa is interrupted at places and MALT is present both in mucosa & submucosa.
- Peyer's patches of ileum are under GALT and are mainly present in the lamina propria but may also extend into the Submucosa.
- GALT & BALT (Bronchus Associated Lymphoid Tissue) come under a common term – MALT (Mucosa Associated Lymphoid Tissue).
- Lymphocytes are educated to recognize & destroy specific antigens in the MALT.
- MALT components are observed at other sites also like Mucosa of reproductive tract.

8. d. Vascular sinus
- Vascular sinus comes under the category of red pulp in spleen.
- Spleen is composed of red pulp (75%) having large number of red blood cells (and comparatively very few white blood cells). It consists of venous sinusoids and splenic cords (of Billroth).
- White pulp (25%) of spleen has large number of white blood cells arranged in diffuse and nodular lymphoid tissue for immune function.
- White pulp has lymphoid follicles with B lymphocytes at the germinal centres, whereas T cell lie in the periphery. The eccentric arterioles in lymphoid follicles are surrounded by peripheral T lymphocytes forming PALS – Peri Arteriolar Lymphatic Sheath.

9. b. Red pulp
- Splenic cords of Billroth are present in the red pulp of the spleen between the sinusoids, containing half of the human body's monocytes as a reserve so that after tissue injury these monocytes can move in and aid locally sourced monocytes in wound healing.

10. b. Spleen
- The venous sinuses of spleen have thus been likened to tall wooden barrels with both ends open, with the endothelial cells represented by the wooden staves and hence described as stave cells.

11. a. Tonsil
- This is a slide of lymphatic tissue, showing abundance of lymphocytes (blue dots), one lymphoid follicle is also evident and so is the lining stratified squamous epithelium (characteristic finding in tonsil). None of the other lymphoid organ show any such epithelium except tonsil, though the other findings may be evident.
- Lymphoid tissue can be easily recognised by presence of aggregation of dark staining nuclei (lymphocytes). E.g. tonsil, lymph node, spleen, thymus etc.
- Identification point for spleen is the lymphoid nodule (with pale germinal centre and eccentrically placed arteriole).
- Thymus is identified by multiple Hassall's corpuscles in the central light staining area, surrounded by dense/dark lymphatic tissue in periphery.
- Lymph node has an outer capsule, with a prominent broad subcapsular sinus. Lymphatic nodules are present with pale staining germinal centre and dark staining periphery.

Skin

- **Skin** consists of two components: epidermis and dermis.
- The surface epithelium (epidermis) is of the keratinized stratified squamous variety.
- The deeper dermis consists mainly of bundles of collagen fibers together with some elastic tissue, blood vessels, lymphatics and nerve fibers.
- Colour of skin is determined by the degree of pigmentation produced by melanocytes in the basal layer of the epidermis.
- Hair and nails are a hard type of keratin; the keratin of the skin surface is soft keratin. Each hair is formed from the hair matrix, a region of epidermal cells at the base of the hair follicle, which extends
- **Sweat glands** are exocrine glands with a small tubular structures of the skin that secrete sweat onto an epithelial surface by way of a duct.

- They are distributed all over the skin **except** on the tympanic membranes, lip margins, nipples, inner surface of prepuce, glans penis and labia minora.
- The greatest concentration is in the thick skin of the **palms** and **soles**, and on the face.
- They are two types: Eccrine and apocrine
- **Eccrine** sweat glands are distributed almost all over the human body and has water-based secretion meant primary form of cooling the body.
  - Eccrine glands are innervated by the **sympathetic cholinergic** fibers.
- **Apocrine** sweat glands are rare to find and are mostly limited to axillae, areolae, periumbilical, genital and perianal regions
  - **Ceruminous** glands (ear wax), **mammary** glands (milk), and **ciliary** glands in the eyelids are modified apocrine sweat glands.
  - Their ducts open into hair follicles or directly on to the skin surface.
  - Apocrine glands are innervated by the **sympathetic adrenergic** fibers.

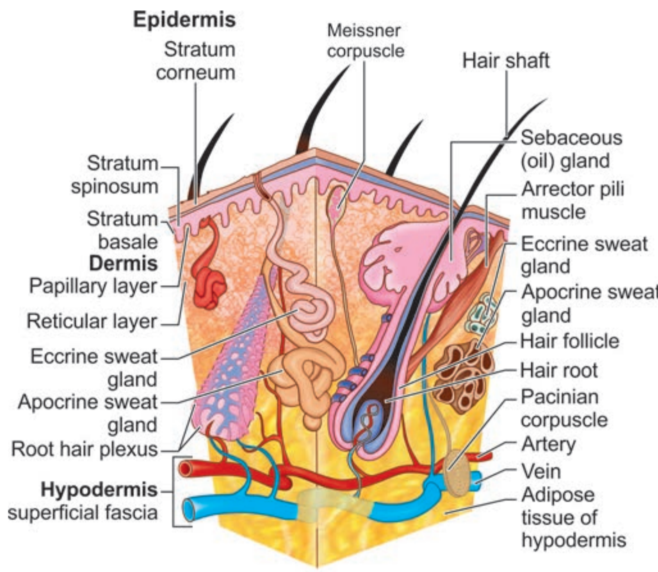


Fig. 48: Skin and its derivatives.

- **Sebaceous glands** are holocrine glands, small saccular structures in the dermis and open into the side of hair follicles.
- They also open directly on to the surface of the hairless skin of the lips, nipples, areolae, inner surface of prepuce, glans penis and labia minora.
- They are in large concentration on the face but none on the palms or soles.
- Androgens act on these glands which have no motor innervation.
- The epidermis of thick skin consists of five layers of cells (keratinocytes): stratum corneum (characterized by dead and dying cells with compacted keratin), stratum lucidum (a translucent layer not obvious in thin skin), stratum granulosum (characterized by keratohyalin granules), stratum spinosum (characterized by tonofibrils and associated desmosomes) and stratum basale (proliferative layer).
- **Langerhans cells** are dendritic cells derived from monocyte-phagocyte series in the bone marrow; lack tonofilaments, desmosomes, and melanosomes. These cells are identified by the presence of tennis racket–shaped organelles known as Birbeck granules. They are found principally in the stratum spinosum of the epidermis, but also in lymph nodes, spleen, and thymus. Their surface markers are characteristic of macrophages, and are antigen-presenting cells involved in contact allergic responses and other cell-mediated immune reactions in the skin (delayed hypersensitivity).
- Langerhans cell histiocytosis is a disease characterized by the excessive proliferation of Langerhans cells, which can manifest as skin or bone lesions.

Table 31: Characteristics of thick and thin skin

Cellular strata (Superficial to deepest)	Thick skin	Thin skin
Epidermis	Is a stratified squamous keratinized epithelium derived from ectoderm. Cells of the epidermis consist of four cell types: keratinocytes, melanocytes, Langerhans cells and Merkel cells.	
Stratum conium (Cornified cell layer)	Composed of several layers of dead, anucleated, flattened keratinocytes (squames) that are being sloughed from the surface. As many as 50 layers of keratinocytes are located in the thickest skin (e.g. sole of the foot).	Only about five or so layers of keratinocytes (squames) comprise this layer in the thinnest skin (e.g. eyelids).
Stratum Lucidum (Clear cell layer)	Poorly stained keratinocytes filled with keratin compose this thin, well-defined layer. Organelles and nuclei are absent.	Layer is absent but individual cells of the layer are probably present.
Stratum granulosum (Granular cell layer)	Only three to five layers thick with polygonal-shaped nucleated keratinocytes with a normal complement of organelles as well as keratohyalin and membrane-coating granules.	Layer is absent but individual cells of the layer are probably present.
Stratum spinosum (prickle cell layer)	This thickest layer is composed of mitotically active and maturing polygonal keratinocytes (prickle cells) that interdigitate with one another via projections (intercellular bridges) that are attached to each other by desmosomes. The cytoplasm is rich in tonofilaments, organelles, and membrane-coating granules, Langerhans cells are present in this layer.	The stratum is the same as in thick skin but the number of layers is reduced.

Cellular strata (Superficial to deepest)	Thick skin	Thin skin
Stratum basale (stratum germinativum)	This deepest stratum is composed of a single layer of mitotically active tall cuboidal keratinocytes that are in contact with the basal lamina. Keratinocytes of the more superficial strata originate from this layer and eventually migrate to the surface where they are sloughed. Melanocytes and Merkel cells are also present in this layer.	This layer is the same in thin skin as in thick skin.
Dermis	Located deep to the epidermis and separated from it by a basement membrane, the dermis is derived from mesoderm and is composed mostly of dense irregular collagenous connective tissue. It contains capillaries, nerves, sensory organs, hair follicles, seat and sebaceous glands, as well as arrector pilli muscles. It is divided into two layers: a superficial papillary layer and a deeper reticular layer.	
Papillary layer	Is composed of loose connective tissue containing capillary loops and terminals of mechanoreceptors. These dermal papillae interdigitate with the epidermal ridges of the epidermis. These interdiginations are very prominent in thick skin.	The papillary layer is comprised of the same loose connective tissue as in thick skin. However, its volume is much reduced. The depth of the dermal/epidermal interdiginations is also greatly reduced.
Reticular layer	Is composed of dense irregular collagenous connective tissue containing the usual array of connective tissue elements, including cells, blood and lymphatic vessels. Sweat glands and cutaneous nerves are also present and their branches extend into the papillary layer and into the epidermis.	Same as in thick skin. Sebaceous glands and hair follicles along with their arrector pilli muscles are observed.

Table 32: Nonkeratinocytes of the epidermis

Nonepithelial cells	Origin	Location	Features	Function
Melanocytes	Derived from neural crest	Migrate into stratum basale during embryonic development. Some remain undifferentiated even in adulthood (reserved to maintain melanocyte population). Do not form desmosomal contact with keratinocytes but some may form hemidesmosomes with basal lamina.	Form long processes (dendrites) that pass into the stratum spinosum. Melanocytes possess melanosomes within their cytoplasm where melanin is manufactured. Melanocytes form associations with several keratinocytes (epidermal-melanin unit). Population = to about 3% of epidermal population.	Manufacture melanin pigment. Melanosomes located in the cytoplasm are activated to produce melanin (eumelanin in dark hair and pheomelanin in red and blond hair). Once melanosomes are filled with melanin, they travel up the dendrites and are released into the extracellular space. Keratinocytes of the stratum spinosum phagocytose these melanin-laden melanosomes. The melanosomes migrate to the nuclear region of the keratinocyte and form a protective umbrella, shielding the nucleus (and its chromosomes) from the ultraviolet rays of the sun. Soon, the melanosomes are destroyed by keratinocyte lysosomes.
				UV rays increase melanin production, its dark-skinned individuals. They are larger and dispersed throughout the cytoplasm. Melanosome destructions at a slower pace in darker skin.
Langerhans cells	Derived from bone marrow	Mostly located in the stratum spinosum	Possess long processes; thus they are known as dendritic cells. Nucleus possesses many indentations. Cytoplasm contains Birbeck granules, elongated vesicles exhibiting a ballooned-out terminus. Do not form desmosomal contact with keratinocytes.	Are antigen-presenting cells. These cells possess surface markers and receptors as well as langerin a transmembrane protein associated with Birbeck granules. Some of these elements facilitate an immune response against the organism responsible for leprosy. Additionally, Langerhans cells phagocytose antigens that enter the epidermis and migrate to lymph vessels located in the dermis and form there into the paracortex of a lymph node to present these antigens to T cells, thereby activating a delayed-type hypersensitivity response.
Merkel cells	Believed to be a modified keratinocyte, although origin is uncertain	Interspersed with keratinocytes of the stratum basale. They are most abundant in the fingertips	Merkel cells form complexes, known as Merkel discs with terminals of afferent nerves.	Merkel cells function as mechanoreceptors (touch receptor). There is some evidence that Merkel cells may also function as neurosecretory cells.

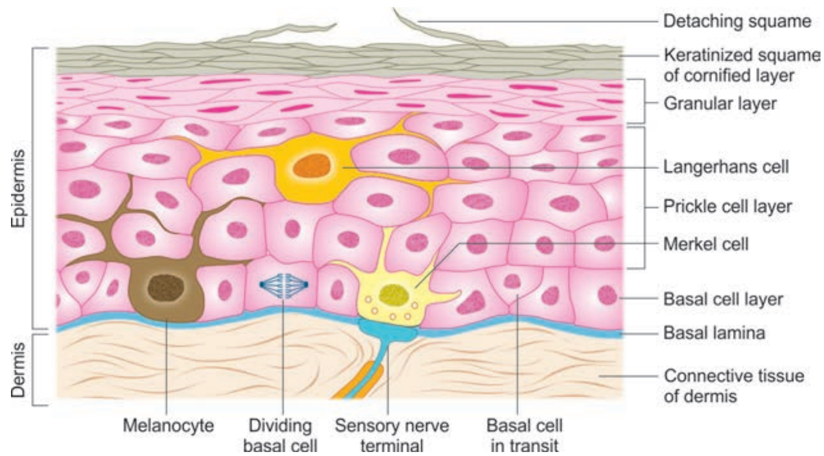


Fig. 49: Layers of skin and the various cells associated with its different layers.

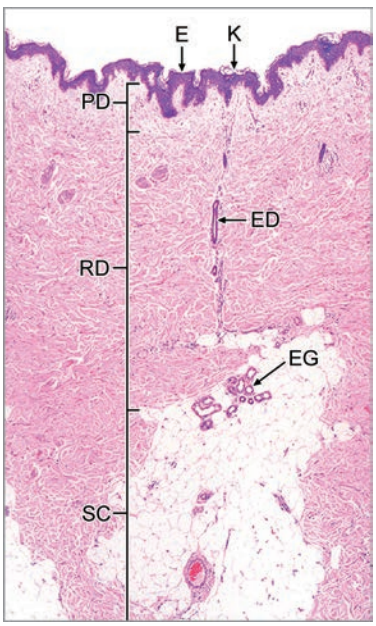


Fig. 50: Basic structure of the skin, with the three component layers: *epidermis, dermis* and *subcutis*. The surface layer in contact with the exterior is the epidermis E, a highly specialised self-regenerating stratified squamous epithelium which produces a non-living surface rich in a protein, keratin K, that is tough and protective and is also partially water resistant. The epidermis also contains non-epithelial cells: melanocytes produce melanin pigment to protect against UV light, Langerhans cells act as antigen-presenting cells act as tough receptors. The epidermis is tightly bound to the underlying dermis by a specialised basement membrane. Additional resistance to frictional shearing force is provided by a series of epidermal downgrowths (rete ridges) which extend into the superficial dermis, with their papillary dermal mirror images projecting upwards (dermal papillae) to provide stronger tethering. These are most developed where exposure to shearing forces is almost constant (e.g. sole, palm). The dermis immediately adjacent to the epidermis is called the papillary dermis PD; it has relatively fine collagen fibers and contains numerous small blood vessels, sensory nerve endings and sensory structures. The reticular dermis, RD is the deeper tough layer of horizontally arranged collagen and elastin fibers with fibroblast The dermis and subcutis contain an assortment of skin adnexa (appendages) such as hair follicles, sebaceous glands, eccrine (sweat) glands EG and ducts ED and, in some areas, apocrine glands.

Table 33: Review of skin

Major structures	Main structures or cells	Brief description/function
Epidermis • Keratin layer • Granular cell layer • Prickle cell layer • Basal cell layer	Keratinocytes	Proliferate from base, move upward and keratinise to form a non-living protective, abrasion resistant waterproofing keratin layer, the stratum corneum
	Melanocytes	Basally located; produce melanin pigment and pass to keratinocytes; provide UV light protection
	Langerhans cells	Antigen-presenting cells throughout epidermis (and superficial dermis)
	Merkel cells	Basally located sensory neuroendocrine cells
	Basement membrane, the dermoepidermal junction	Specialised structure produced by epidermis and dermis in combination; ties the epidermis to dermis
Dermis	Collagen and elastin	Provide strength and elasticity
	Vessels • Papillary/superficial plexus • Cutaneous plexus • Glomus bodies	Supplies dermal papillae and thus epidermis together with superficial dermis Supplies deep dermis and subcutis AV shunts; divert blood from skin to conserve heat; found mainly in hands, feet, ears
Adnexae	Nails	Keratin plates; strengthen tips of fingers and toes
	Pilosebaceous units • Hair follicles • Sebaceous glands • Arrector pili muscles	Produces hair Sebum (oil)-producing holocrine glands Follicle-associated smooth muscle bundles
	Eccrine glands	Produce sweat, a critical means of body cooling
	Apocrine glands	Glands of groin and axilla; produce odour

Major structures	Main structures or cells	Brief description/function
Subcutis	Adipose tissue	Triglyceride (fat) store; provides insulation and structural padding
	Fibrous tissue septae	Strengthens the adipose tissue and ties subcutis to both dermis and underling structues such as fascias
Nerves	Meissner corpuscles	Papillary dermal touch receptors concentrated in hands and foot
	Merkel cell neurites	Papillary dermal touch receptors concentrated in hands and foot
	Free nerve endings	Pain and temperature receptors

- Hair and nails are a hard type of keratin; the keratin of the skin surface is soft keratin.
- Each hair is formed from the hair matrix, a region of epidermal cells at the base of the hair follicle, which extends deeply into the dermis and subcutaneous tissue.
- As the cells move up inside the tubular epidermal sheath of the follicle, they lose their nuclei and become converted into the hard keratin hair shaft.
- **Melanocytes** in the hair matrix impart pigment to the hair cells. The change with age is due to decreasing melanocyte activity. An arrector pili muscle attached to the connective tissue of the base of the follicle passes obliquely to the upper part of the dermis. Contraction of this smooth muscle, with a sympathetic innervation, makes the hair 'stand on end,' and squeezes the sebaceous gland that lies between the muscle and the hair follicle. Hair follicles are richly supplied by sensory nerves.
- Nails consist of nail plates lying on nail beds on the dorsum of the terminal segment of fingers and toes. Compacted keratin-filled squames form the nail plate, which develops from epidermal cells deep to its proximal part. Here the nail plate is overlapped by the skin of the proximal nail fold.
- Blood vessels and sensory nerve endings are plentiful in the nail bed.
- The arteries of the skin are derived from a tangential plexus in the subcutaneous connective tissue.
- Branches from this plexus form a subpapillary network in the dermis. The veins have a similar arrangement to the arteries and arteriovenous anastomoses are abundant. From a meshwork of lymphatic capillaries in the papillary layer of the dermis, lymphatics pass inwards and then run centrally with the blood vessels. Cutaneous nerves carry afferent somatic fibers, mediating general sensation, and efferent autonomic (sympathetic) fibers, supplying smooth muscle of blood vessels, arrector pili muscles and sweat glands. Both free sensory nerve endings and several types of sensory receptors are present in the skin.
- The proportionate surface area of the skin over different regions of the body can be estimated by the 'rule of nines' and this is useful in assessing the need for fluid replacement after burns. This rule is a guide to the size of body parts in relation to the whole: head 9%; upper limb 9%; lower limb 18%; front of thorax and abdomen 18%; back of thorax and abdomen 18%.
- Tension lines of the skin, due to the patterns of arrangement of collagen fibers in the dermis, run as shown in. They are often termed relaxed skin tension lines because they coincide with fine furrows present when the skin is relaxed. Wrinkle lines are caused by the contraction of underlying muscles; they do not always correspond to tension lines. Flexure lines over joints run parallel to tension lines. The cleavage lines originally described by Langer in 1861 on cadavers do not entirely coincide with the lines of greatest tension in the living. Incisions made along skin tension lines heal with a minimum of scarring.

Hypodermis

- **Hypodermis** the layer of loose connective tissue immediately deep to the dermis of the skin. It contains: loosely arranged elastic fibers fibrous bands anchoring skin to deep fascia; fat (**panniculus adiposus**); blood vessels and lymphatics on route to dermis, hair follicle roots; the glandular part of some sweat glands; nerves: free endings; Pacinian corpuscles; bursae: only in the space overlying joints in order to facilitate smooth passage of overlying skin; sheets of muscle: **panniculus carnosus**.
- **Panniculus** (a thin layer) **adiposus** is a layer of adipose connective tissue subjacent to the reticular layer of the dermis. It's distribution defines secondary sexual characteristic: it forms the breasts of females and accentuates the contour of female hips. It functions as an insulating compartment and as a storage site for energy. It is absent in eyelid, external ear, scrotum, penis, nipple and areola. E.g. superficial cervical fascia, Camper fascia (superficial fatty layer of the subcutaneous tissue of the abdomen, external to the membranous layer).
- The **panniculus carnosus** is a thin layer of skeletal muscle within the superficial fascia, deep to the panniculus adiposus. One end of each muscle fiber is attached to the skin, the other end being usually attached to deep fascia or bone.
- E.g. some of the muscles of facial expression, platysma muscle of the neck, palmaris brevis in the hand, subareolar muscle of the nipple, dartos muscle in the scrotum, corrugator cutis ani, etc.

ASSESSMENT QUESTION

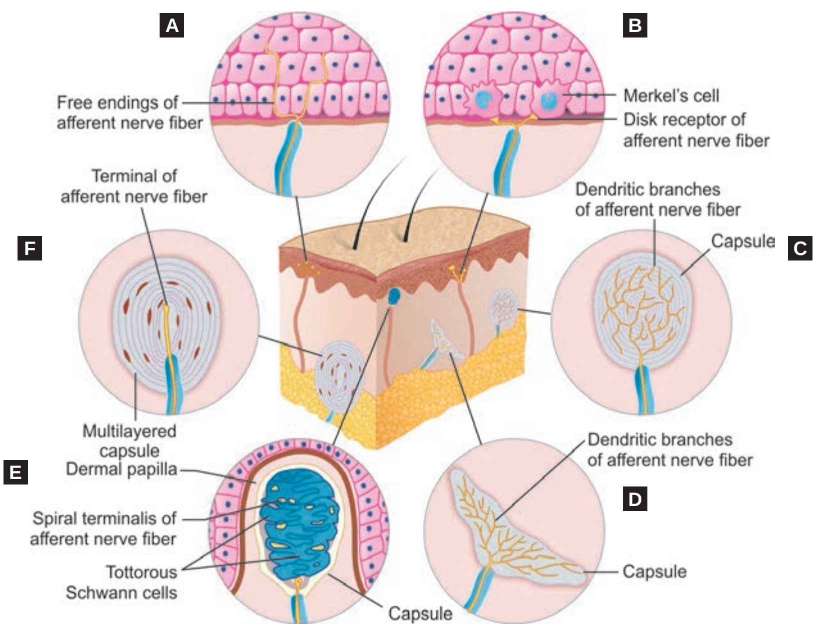
1. **Panniculus adiposus is seen in:** *(AIIMS 2014)*
    a. Scrotum
    b. Orbit
    c. Eyelid
    d. Penis

ANSWER WITH EXPLANATION

1. **b. Orbit**
   - **Panniculus adiposus** is the subcutaneous fat, a layer of adipose tissue underlying the dermis. It is **absent** in eyelid, external ear, scrotum, penis, nipple and areola.

Receptors

- Sensory receptors are of three types :
  1. Exteroceptors—receive information from the outside environment.
  2. Proprioceptors—receive information from muscles, tendons, and joint structures.
  3. Interoceptors—receive information from within the internal environment.
- **Merkel cells** are surface ectoderm derivatives located at the basal layers of epidermis. They are slowly adapting receptors to detect light touch. They are the most capable cells detecting the braille characters (as compared with Meissner corpuscles).
- **Meissner corpuscles** are rapidly adapting, encapsulated receptors in the dermal papillae (dermoepidermo junction). They are distributed in eyelids, lips, nipples, fingertips. They carry fine touch perception, which is essential for tactile discrimination, and reading Braille.
- **Pacinian corpuscles** are rapidly adapting encapsulated receptors in the deep dermis and in the connective tissue of the mesenteries and joints. They carry the information of pressure, touch, and vibration.
- **Ruffini receptors** are slowly adapting encapsulated structure in the dermis and joints. They perceive dermal stretch and pressure.
- **Free nerve endings** are un-encapsulated, nonmyelinated terminations in the skin to carry pain, temperature, etc.
- **Golgi tendon organs** are encapsulated mechanoreceptors sensitive to stretch and tension in tendons and carry proprioceptive information.
- **Muscle spindle** receptors are also encapsulated and carry proprioception. They have intrafusal muscle fibers called flower spray endings and annulospiral endings that sense differences in muscle length and tension.



Figs. 51A to F: Various type of sensory receptors in skin. (A) Epidermal free endings. (B) Merkel's corpuscles containing merkel's cells and disc receptors of afferent myelinated nerve fibe . (C) Krause's end bulb serves as cold receptor. (D) Ruffini s corpuscle in deep layers of the dermis. (E) Meissner's corpuscle in dermal papilla. (F) Pacinian corpuscle located in the deep layer of deep dermis and hypodermis. Sensory nerve fibers in receptors c-f are encapsulated.

- Merkel cells are neural crest cell derivatives located at the basal layers of epidermis. They are slowly adapting receptors to detect light touch. They appear to be the best at reading Braille characters.
- Meissner corpuscles are rapidly adapting, encapsulated receptors in the dermal papillae (dermoepidermal junction). They are distributed in eyelids, lips, nipples, finger tips. They carry fine touch perception, which is essential for tactile discrimination, and reading Braille.
- Pacinian corpuscles are rapidly adapting encapsulated receptors in the deep dermis and in the connective tissue of the mesenteries and joints. They carry the information of pressure, touch, and vibration.
- Ruffini receptors are slowly adapting encapsulated structure in the dermis and joints. They perceive dermal stretch and pressure. Some authors mention them as thermoreceptors.
- Free nerve endings are unencapsulated, nonmyelinated terminations in the skin to carry pain, temperature, etc.

Table 34: Specialized receptors, their functions and locations		
Receptor	**Type**	**Function and location**
Peritrichial nerve endings	Nonencapsulated	Are non myelinated and have no assoc iated Schwann's cells. Most are coupled with ha ir follicles and react to the ha ir's motion. The sensation is interpreted as touch or being tickled.
Merkel's discs	Nonencapsulated	Mechanoreceptors located in the stratum basale ofthe epidermis.
Meissner's corpuscles	Encapsulated	Located in the dermal papillae of the dermis and respond to touch sensations
Pacinian corpuscles	Encapsulated	Resemble an onion since epithelioid cel ls form concentric layers around a naked nerve ending. These corpuscles, located in the hypodermis, mesocolon, and mesentery, respond to vibration, pressure, and deep touch.
Ruffini's endings	Encapsulated	Are composed of highly branched nerve termini surrounded by fibroblast-like cells. They respond to pressure and stretch and are located in nailbeds, periodontal ligament, dermis of the skin, and capsules of joints.
Krause's end bulbs	Encapsulated	These spherical capsules containing a naked nerve ending are located in the connective tissues just deep to the epithelium, capsules of joints, peritoneum, and in the dermis of skin. Their function is not known.
Muscle spindles	Encapsulated	Described in the chapter on Muscle. They function in proprioception. They respond to alteration in the length and rate of change in muscle and thus function in proprioception.
Goigi tend on organs	Encapsulated	Described in the chapter on Muscle. Respond to changes in the tension and the rate of tension change around a joint, th us function in proprioception.
Thermoreceptors	Nonencapsulated	They are assumed to be naked nerve endings located in the epidermis that respond to temperature. Their morphology is not known.
Nociceptors	Nonencapsulated	Branched naked nerve endings located in the epidermis. They are stimulated by extremes in temperature, by damage to the epidermis and underlying structures, as well as by certain chemicals as pain sensation.

Table 35: Specialized receptors, their functions and locations				
Sensory system	**Modality**	**Stimulus**	**Receptor class**	**Receptor cell types**
Somatosensory	Touch	Tap, flutter 5–40 Hz	Cutaneous mechanoreceptor	Meissner corpuscles
Somatosensory	Touch	Motion	Cutaneous mechanoreceptor	Hair-follicle receptors
Somatosensory	Touch	Deep pressure, vibration 60–300 Hz	Cutaneous mechanoreceptor	Pacinian corpuscles
Somatosensory	Touch	Touch, pressure	Cutaneous mechanoreceptor	Merkel cells
Somatosensory	Touch	Sustained pressure	Cutaneous mechanoreceptor	Ruffini corpuscles
Somatosensory	Proprioception	Stretch	Mechanoreceptor	Muscle spindles
Somatosensory	Proprioception	Tension	Mechanoreceptor	Golgi tendon organ

ASSESSMENT QUESTIONS

1. **Which of the following faithfully represents the Braille characters?** *(NEET Pattern 2015)*
   a. Meissner's corpuscle
   b. Merkel cell
   c. Paccinian corpuscle
   d. Ruffini receptor

2. **TRUE about Merkel cell:** *(PGIC)*
   a. Neural crest cell derivative
   b. Rapidly adapting receptor
   c. Dermal stretch receptor
   d. Neural basis for reading Braille text
   e. Detect pain and temperature

ANSWERS WITH EXPLANATIONS

1.b. Merkel cell > a. Meissner's corpuscle

- Merkel fibers faithfully represent the pattern of Braille dots. Meissner's fibers produced a blurry image, while the deep sensors (the Pacinian and Ruffini) encode the Braille dots poorly.

2.d. Neural basis for reading Braille text

- Neural basis for reading Braille is Merkel cell > Meissner's corpuscle (detection capability).
- Merkel cell is a slowly adapting receptor at the basal layer of epidermis for detection of light touch sensations. It is derived from surface ectoderm (some authorities believe it is a neural crest cell derivative).
- Free nerve endings detect pain and temperature form the skin.
- Ruffini receptor perceives dermal stretch.

Respiratory System

Table 36: Histologic features of the upper respiratory tract, larynx, and trachea.

Region	Epithelium	Glands	Musculoskeletal support	Other features and major functions
Vestibules of nasal cavities	Stratified squamous, keratinized to nonkeratinized	Sebaceous and sweat glands	Hyaline cartilage	Vibrissae (stiff hairs) and moisture both filter and humidify air
Most areas of nasal cavities	Respiratory	Seromucous glands	Bone and hyaline cartilage	Rich vasculature and glands warm. humidify, and clean air
Superior areas of nasal cavities	Olfactory, with bipolar neurons	Serous (Bowman) glands	Bone (ethmoid)	Soluble and detect odorant molecules in air
Nasopharynx and posterior oropharynx	Respiratory and stratified squamous	Seromucous glands	Bone and skeletal muscle	Conduct air to larynx; pharyngeal and palatine tonsils
Larynx	Respiratory and stratified squamous	Mucous glands, smaller seromucous glands	Elastic and hyaline cartilage, ligaments, skeletal muscle	Site for phonation; epiglottis closes while swallowing
Trachea	Respiratory	Mainly mucous glands, some serous or mixed glands	C-shaped rings of hyaline cartilage, with smooth (trachealis) muscle in posterior opening of each	Conduct air to primary bronchi entering lungs; some MALT

Table 37: Features of airways within the lungs.

Region of airway	Epithelium	Muscle and skeletal support	Other features and major functions
Bronchi	Respiratory	Prominent spiral bands of smooth muscle: irregular hyaline cartilage plates	Repeated branching; conduct air deeper into lungs
Bronchioles	Simple ciliated cuboidal to columnar with Clara cells	Prominent circular layer of smooth muscle: no cartilage	Conduct air; important in bronchoconstriction and bronchodilation
Terminal bronchioles	Simple cuboidal, ciliated and Clara cells	Thin. incomplete circular layer of smooth muscle; no cartilage	Conduct air to respiratory portions of lungs; Clara cells with several protective functions
Respiratory bronchioles	Simple cuboidal, ciliated and Clara cells, with scattered alveoli	Fewer smooth muscle fibers, mostly around alveolar openings	Conduct air deeper with some gas exchange and protective Clara cells
Alveolar ducts and sacs	Simple cuboidal between many alveoli	Bands of smooth muscle around alveolar openings	Conduct air, with much gas exchange
Alveoli	Types I and II alveolar cells (pneumocytes)	None (but with network of elastic and reticular fibers)	Sites of all gas exchange; surfactant from type II pneumocytes; dust cells

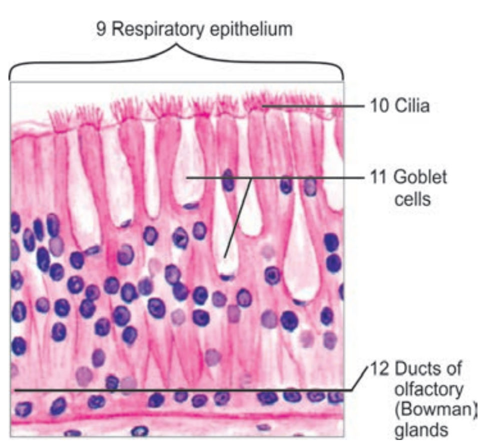


Fig. 52: Respiratory epithelium - Pseudostratified ciliated columnar epithelium with goblet cells.

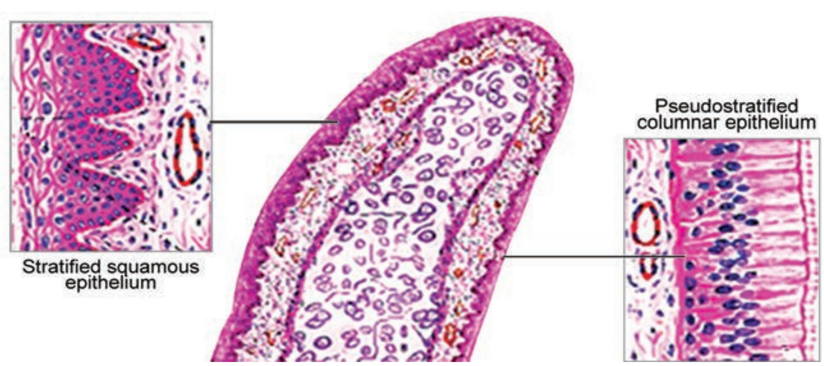


Fig. 53: Epiglottis - Lingual surface is lined by the stratified squamous epithelium; Laryngeal surface is lined by respiratory epithelium and the core has elastic cartilage.

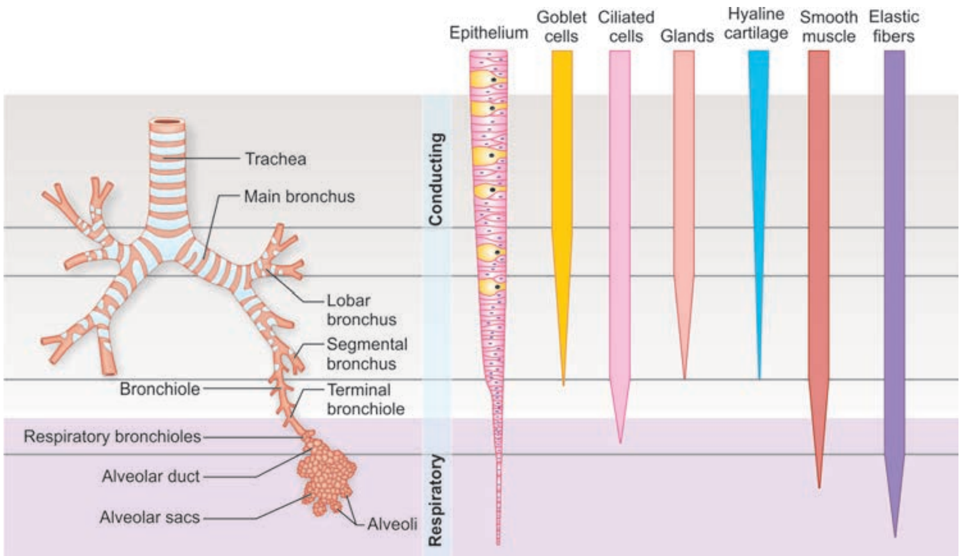


Fig. 54: Tracheobronchial tree and its characteristic microscopic features. Respiratory epithelium changes from columnar to cuboidal to squamous proximo-distally. The number of goblet cells, and hylaine cartilage are almost non-existent beyond the level of bronchus.

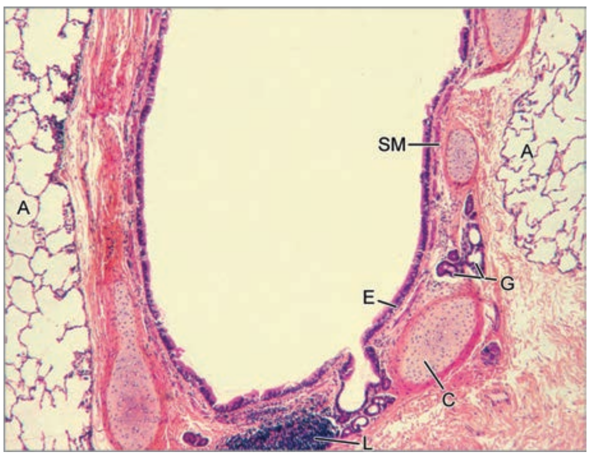


Fig. 55: Intrapulmonary bronchus (cross section) - Lumen is lined by pseudostratified ciliated columnar epithelium with goblet cells (E). Beneath the epithelium in the lamina propria of loose, fibroelastic connective tissue are bundle of smooth muscle cells (SM) wrapped in a spiraling arrangement around the lumen. In the submucosal connective tissue outside of the smooth muscle are irregular plates of cartilage (C), seromucous glands (G), and lymphoid tissue (L). Alveoli (A) are evident in the nearby respiratory tissue.

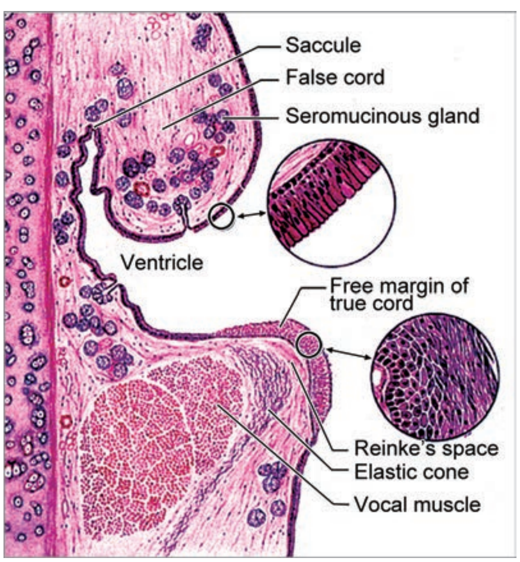


Fig. 56: Larynx is lined by respiratory epithelium except at the vocal cords (which are lined by stratified squamous epithelium). The core cartilage is hyaline in nature.

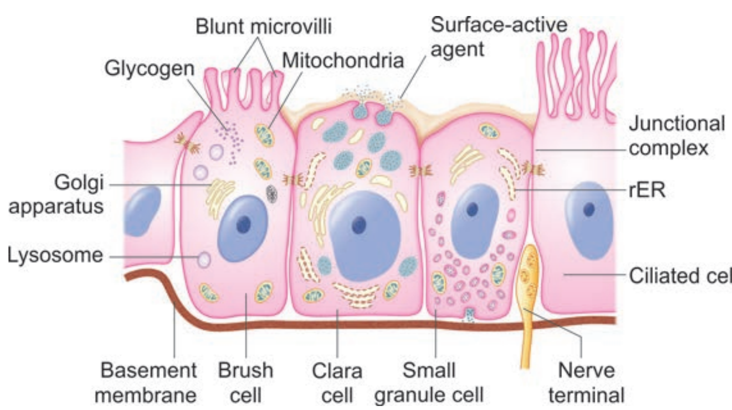


Fig. 57: Terminal bronchiolar epithelium showing several cells - The Clara cell in interposted between the brush cell and the small granule cell. The Clara cell is a nonciliated cell that has rounded apical surface, well-developed basal eER and Golgi apparatus and contains secretory vesicles filled with a surface-active agent containing blunt microvilli, which are distinctive features of this cell. Cytoplasm of the brush cell shows a Golgi apparatus and glycogen inclusions. A small granule cell is shown located between the Clara cell and ciliated cell. This cell contains small secretory vesicles, most of which are in the basal portion of the cell. In addition to the vesicles, the most conspicuous organelles of this cell are rER, a Golgi apparatus, and mitochondria. A nerve terminal is shown within the epithelium.

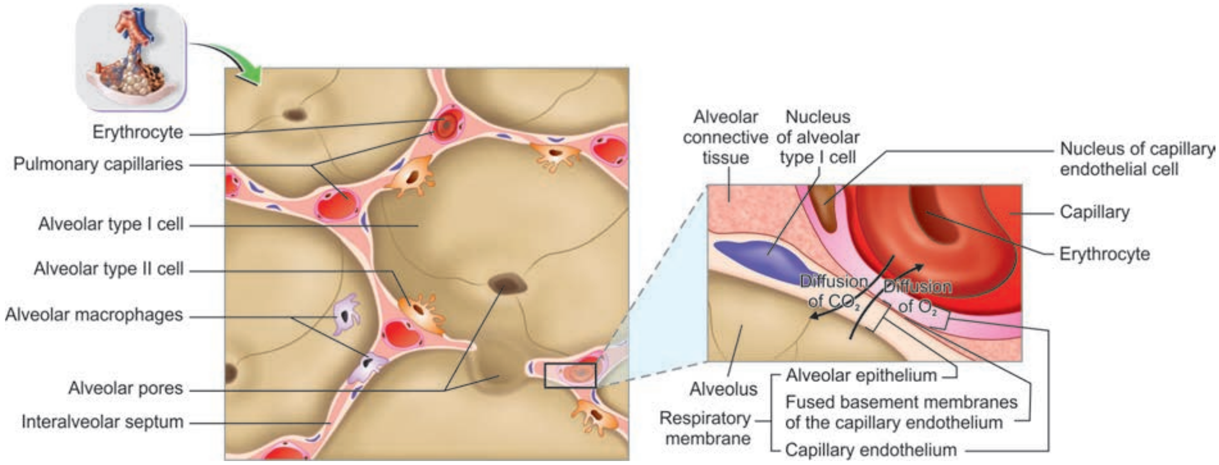


Fig. 58: Microscopic picture of an alveolus, showing respiratory membrane and the respiratory gas exchange.

Table 38: Components of the blood-air barrier

Endothelial Component	Epithelial and Pneumocyte Component	Pneumocyte Component
Attenuated endothelial cell	Combined basal laminae	Attenuated penumocyte I
		Surfactant and fluid coating of the alveolous

- The air–blood barrier consists of alveolar **type I cells,** basal lamina, and capillary endothelial cells. The alveolar **type II** cells secrete surfactant. Gas exchange occurs between the walls of alveoli and pulmonary capillaries, and the newly oxygenated blood enters venules and then pulmonary veins.

ASSESSMENT QUESTIONS

1. Epithelium lining of lingual surface of epiglottis is:
   a. Simple columnar
   b. Pseudostratified ciliated columnar
   c. Simple cuboidal
   d. Stratified squamous epithelium

2. Hyaline cartilage of respiratory tree extends up to: *(NEET Pattern 2012)*
   a. Tertiary bronchiole
   b. Secondary bronchiole
   c. Terminal bronchiole
   d. Bronchi

3. Respiratory bronchiole proceed into: *(NEET Pattern 2015)*
   a. Terminal bronchiole
   b. Bronchi
   c. Tertiary bronchiole
   d. Alveolar duct

4. All of the following cells are found in lung EXCEPT: *(AIPG 2008)*
   a. Kulchitsky cells
   b. Clara cells
   c. Brush cells
   d. Langerhans cells

ANSWERS WITH EXPLANATIONS

1.d. Stratified squamous epithelium
- Epiglottis has two surfaces, the lingual surface is lined by oral epithelium, which is stratified squamous epithelium. The laryngeal surface has respiratory epithelium—pseudostratified ciliated columnar epithelium with goblet cells.
- Larynx is lined by respiratory epithelium (pseudostratified ciliated columnar epithelium with goblet cells) except at the vocal cords, which are lined by stratified squamous epithelium.

2.d. Bronchi
- Hyaline cartilage extends till the **bronchi** and are absent (or scatteredly present) distally in the bronchioles.
- Goblet cells also extend till bronchus level; beyond that they are present scatteredly.

3.d. Alveolar duct
- Bronchioles have a diameter smaller than 1 mm and lack cartilage and glands within their walls. Goblet cells (and cilia) decrease in number and almost negligible at the levels of bronchioles (small lumen). Hyaline cartilage also is almost non-existent at the levels of bronchioles. Epithelium gradually changes from pseudostratified columnar to simple columnar to cuboidal to squamous.
- Alveolus is lined by type-I pneumocyte (simple squamous epithelium) for respiratory gas exchange. Type- II pneumocyte is a cuboidal cell for surfactant secretion.
- Bronchial arteries (branches of descending thoracic aorta) supply till the level of respiratory bronchiole. They perfuse the proximal air conducting pathways including tertiary and terminal bronchioles and reach till the beginning of respiratory unit. Pulmonary arteries alone vascularize the further distal pathways, including alveolar ducts and the alveoli.

4.d. Langerhans cells
- Langerhans cells are antigen presenting cells located in the skin and migrate towards lymphoid tissue. In abnormal conditions like histiocytosis, there they invade the lung in large numbers. Kulchitsky cells are the neuro-endocrine cells found in the lining epithelium of lung and belong to the APUD system. Clara cells are the non-ciliated cuboidal/columnar cells in the wall of terminal / respiratory bronchioles. They function as stem cells for repair of epithelium and also secrete the surfactant lipoproteins like the type-II pneumocytes. Brush cells have microvilli at their surface and are innervated by nerve fibers, and function as receptor cells.

Miscellaneous Questions

ASSESSMENT QUESTIONS

1. **Trachea is lined by:** *(NBEP 2013)*
   a. Stratified squamous epithelium
   b. Ciliated columnar epithelium
   c. Simple columnar epithelium
   d. Pseudostratified columnar epithelium

2. **Which of the following is lined by an epithelium containing ciliated cells and Clara cells?**
   a. Nasopharynx
   b. Trachea
   c. Respiratory bronchiole
   d. Intrapulmonary bronchi

ANSWERS WITH EXPLANATIONS

1. **d. Pseudostratified columnar epithelium.**
   - Trachea is lined by respiratory epithelium - Pseudostratified ciliated columnar epithelium with goblet cells.
2. **c. Respiratory bronchiole.**
   - Clara (club) cells are predominantly present in the terminal bronchiole and also in respiratory bronchiole. They function as stem cells for the repair of respiratory epithelium. They are also involved in de-toxification of the inhaled air. They also secrete surfactant lipoproteins.

High Yield Point

- The tube is lined by respiratory epithelium (pseudostratified ciliated columnar epithelium with goblet cells).

ASSESSMENT QUESTIONS

1. **Trachea is lined by:** *(NEET Pattern 2012)*
   a. Stratified squamous epithelium
   b. Ciliated columnar epithelium
   c. Simple columnar epithelium
   d. Pseudostratified columnar epithelium

2. **Clara cells are present in:** *(NEET Pattern 2012)*
   a. Trachea
   b. Terminal bronchiole
   c. Respiratory bronchiole
   d. Alveoli

ANSWERS WITH EXPLANATIONS

1.d. Pseudostratified columnar epithelium
- Trachea is lined by the respiratory epithelium - pseudostratified ciliated columnar epithelium with goblet cells.

2.b. Terminal bronchiole > c. Respiratory bronchiole
- Clara cells are dome-shaped cells with short microvilli, found in the terminal bronchioles and extend into respiratory bronchioles as well.
- They secrete components of surfactant, are protective in function; are involved in detoxifying harmful substances inhaled and also act as a stem cell, multiplying and differentiating into ciliated cells to regenerate the bronchiolar epithelium.

Digestive System

Table 39: Summary of distinguishing digesting tract features, by region and layers

Region and subdivisions	Mucosa (Epithelium, Lamina Propria, Muscularis Mucosae)	Submucosa (with Submucosal Plexuses)	Muscularis (Inner Circular and Outer Longitudinal Layers, with Myenteric Plexuses between Them)	Adventitia/Serosa
Esophagus (upper, middle, lower)	Nonkeratinized stratified squamous epithelium; cardiac glands at lower end	Small esophageal glands (mainly mucous)	Both layers striated muscle in upper region; both layers smooth muscle in lower region; smooth and striated muscle fascicles mingled in middle region	Adventitia, except at lower end with serosa
Stomach (cardia, fundus, body, pylorus)	Surface mucous cells and gastric pits leading to gastric glands with parietal and chief cells, (in the fundus and body) or to mucous cardiac glands and pyloric glands	No distinguishing features	Three indistint layers of smooth muscle (inner oblique, middle circular, and outer longitudinal	Serosa
Small intestine (duodenum, jejunum, ileum)	Plicae circulares; villi, with enterocytes and goblet cells, and crypts/glands with Paneth cells and stem cells; Peyer patches in ileum	Duodenal (Brunner) glands (entirely mucous); possible extensions of Peyer patches in ileum	No distinguishing features	Mainly serosa

Region and subdivisions	Mucosa (Epithelium, Lamina Propria, Muscularis Mucosae)	Submucosa (with Submucosal Plexuses)	Muscularis (Inner Circular and Outer Longitudinal Layers, with Myenteric Plexuses between Them)	Adventitia/Serosa
Large intestine (cecum, colon, rectum)	Intestinal glands with goblet cells and absorptive cells	No distinguishing features	Outer longitudinal layer separated into three bands, the teniae coli	Mainly serosa, with adventitia at rectum
Anal canal	Stratified squamous epithelium; longitudinal anal columns	Venous sinuses	Inner circular layer thickened as internal sphincter	Adventitia

- **Gut tube has 4 layers:** Mucosa, Submucosa, Muscularis externa and Adventitia/Serosa.
- Lamina propria is a part of Mucosa and contains glands, blood vessels and components of immune system-GALT.
- **Muscularis mucosa** is also a part of Mucosa and mainly composed of smooth muscles. Its contraction moves the mucosa to facilitate secretion and absorption.
- **Submucosa** consists of mainly dense irregular connective tissue. It has neurovascular branches and some lymphatics also. The Meissner's plexus is mainly a collection of parasympathetic neurons observed in submucosa only.
- **Adventitia/Serosa** are the outermost covering of GI tube. Adventitia is chiefly made up of connective tissue, whereas, serosa has the serous membrane made up of squamous epithelium.

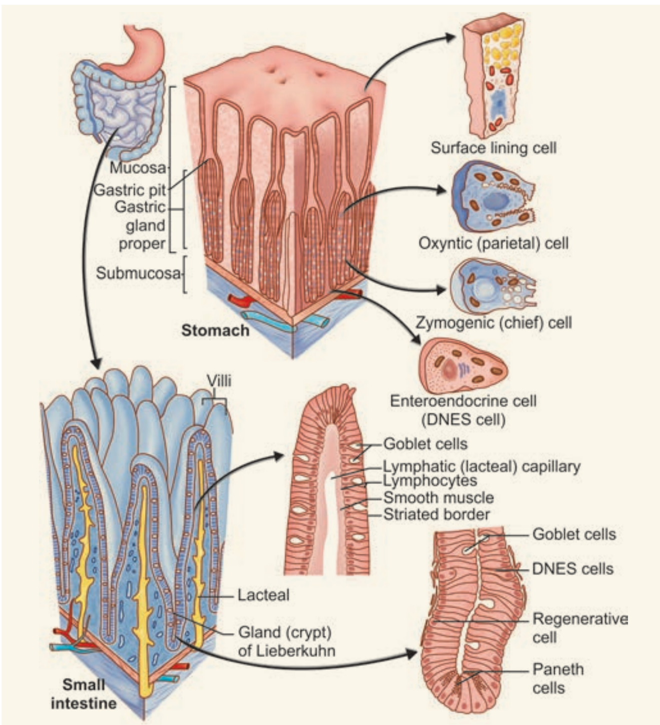


Fig. 59: Mucosa of stomach and intestine showing various type of cells.

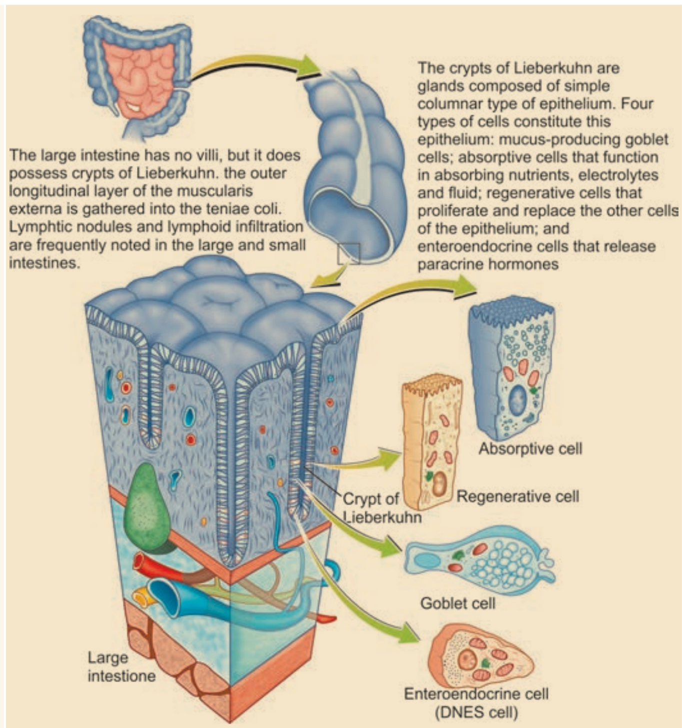


Fig. 60: Large intestine - microscopic features.

Oral Cavity

Table 40: Review of oral tissues

Structure	Details
Oral mucosa	Stratifies squamous epithelium with variable site-dependent keratinization
Teeth	Enamel: surface layer of closely packed calcium hydroxyapatite crystals formed by an extemal ameloblast layer; destroyed with tooth eruption
	Dentine: deeper zone of calcified tissue containing numerous fine parallel tubules radiating from odontoblasts which line the pulp cavity and form dentine
	Pulp: central core of loose tissue with nerves and vessels supplying odontoblasts
Tongue	Muscular organ with layers of skeletal muscle fibers oriented perpendicular to each other; numerous minor salivary glands and surface stratified squamous eprthelium with filiform, fungiform and circumvallate papillae
Taste buds	Sensory organs of taste situated in tongue mucosa
Salivary glands	Serous and/or mucinous glands; found as large glands (parotid, submandibular and sublingual) and innumerable small (minor) glands
Tonsils and lingual tonsils	Lymphoid organs near posterior tongue and extension of similar structures onto posterior tongue

- Oral cavity has non-keratinized stratified squamous epithelium. **Para-keratinization:** persistence of the nuclei of the keratinocytes into the stratum corneum; this is normal only in the epithelium of true mucous membranes of the mouth and vagina.

Esophagus

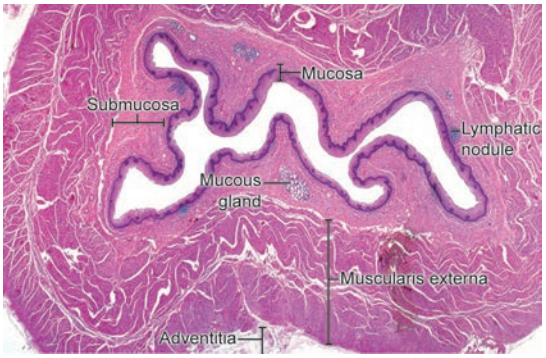


Fig. 61: Osophagus with its characteristically folded wall, giving the lumen an irregular appearance. The mucosa consists of a relatively thick stratified squamous epithelium, a thin layer of lamina propria containing occasional lymphatic nodules, and muscularis mucosae. Mucous glands are present in the submucosa, their ducts, which empty into the lumen of the esophagus, are not evident in this section. External to the submucosa in this part of the esophagus is a thick muscularis externa made up of an inner layer of circularly arranged smooth muscle and an outer layer of longitudinally arranged smooth muscle. The adventitia is seen just external to the muscularis externa.

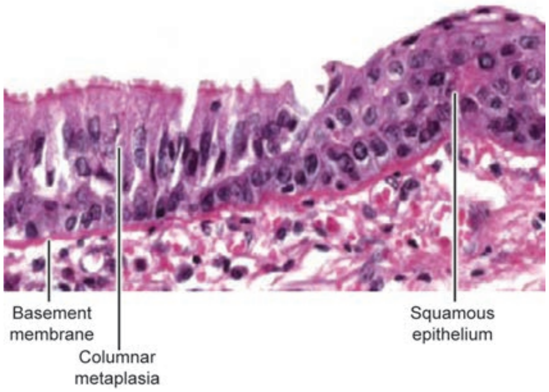


Fig. 62: Intestinal metaplasia in Barret's oesophagus (Replacement of the normal stratified squamous epithelium by the columnar epithelium with goblet cells).

Stomach

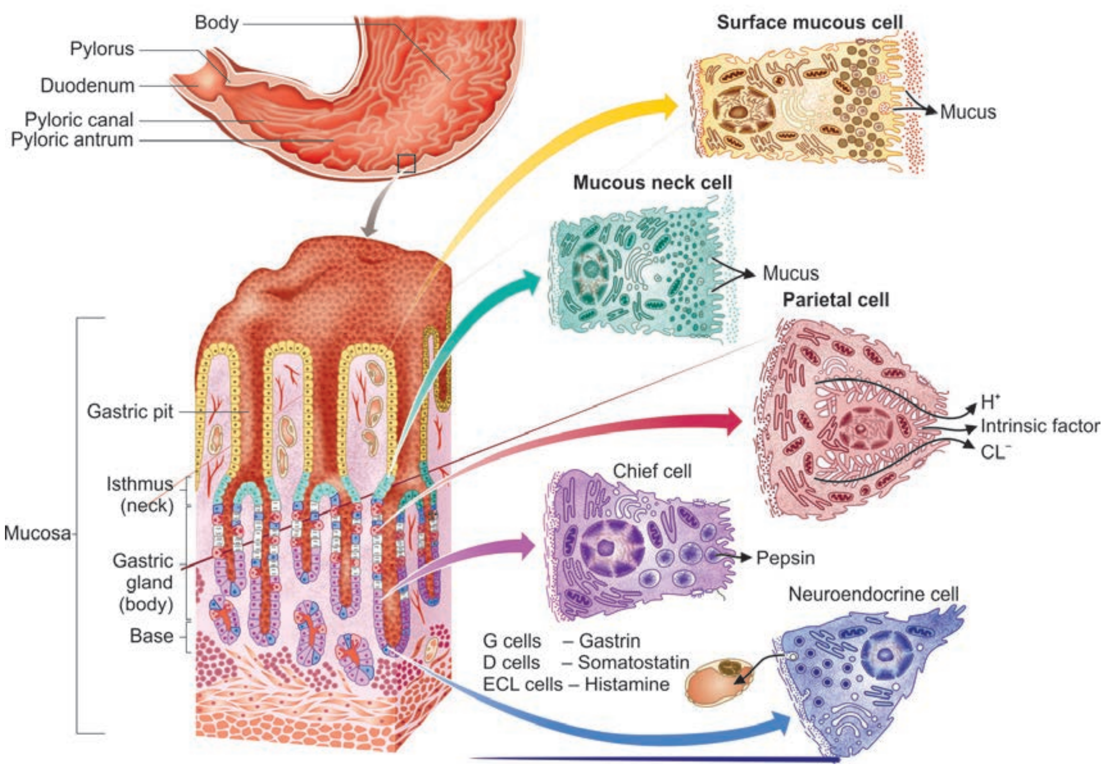


Fig. 63: Gastric pit and gastric glands showing various type of cells present in the mucosal epithelium. (ECL: Enterochromattin-like).

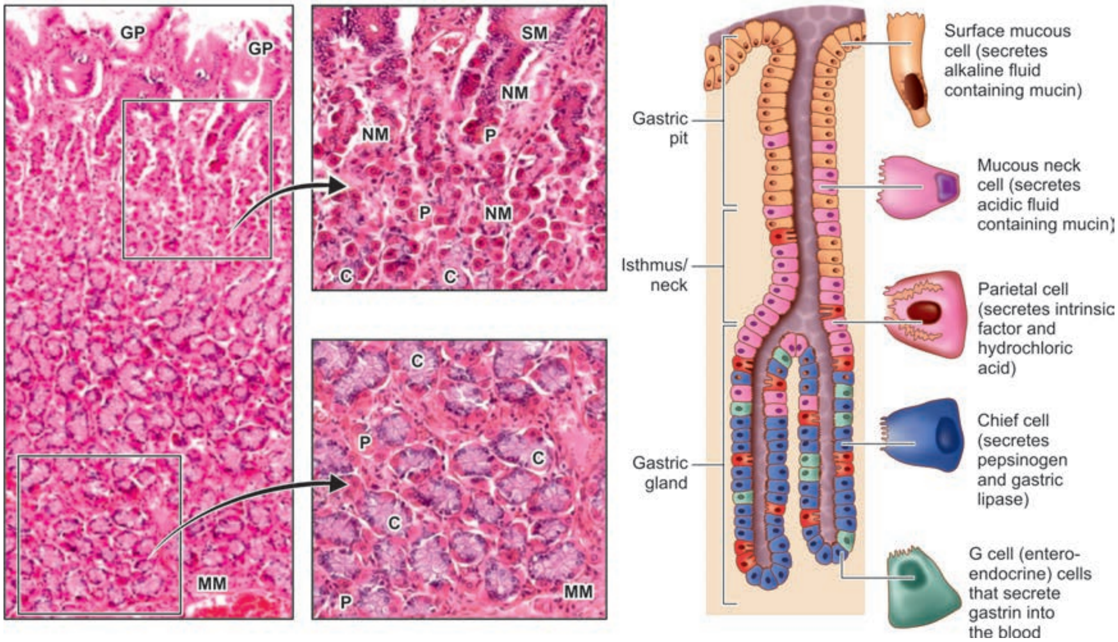


Fig. 64: Microscopic features of the various types of cells present in different regions of the gastric glands.

Table 41: Principal secretions of the epithelial cells of the stomach

Gastric Glands of the Stomach	Approximate Life Span of the Cells	Secretions
Surface lining cells	3-5 days	Visible mucus
Mucous neck cells	6 days	Soluble mucus
Parietal cells	200 days	Hydrochloric acid, gastric intrinsic factor
Chief cells	60-90 days	Pepsin, rennin, lipase precursors
Diffuse neuroendocrine system cells	60-90 days	Gastrin, somatostatin, secretin, cholecystokinin
Regenerative cells	Function to replace epithelial lining of stomach and cells of glands	

Table 42: Various type of cells present in the gastric mucosa

Cell type	Predominant location in Stomach (Gross anatomy)	Predominant location in Gastric gland (Histology)
Mucus	Cardia and Pylorus	Neck
Parietal	Body	Body
Chief	Fundus	Fundus
NEC	Pylorus	Fundus
Stem	Omnipresent	Isthmus

- **Mucus** cells are small, dark stained, columnar cell
- Located close to gastric pit (neck region of gastric gland)
- **Parietal** (Oxyntic) cells are lightly eosinophilic (clear cytoplasm) large cuboidal cell, with central spherical nucleus (fried egg appearance).
- Predominantly present in the upper half of the gland, more so in the body region of the gastric gland.
- They secrete hydrochloric acid and intrinsic factor.
- Gastric intrinsic factor is essential for absorption of vitamin B12 (and erythropoiesis).
  - In pernicious anemia, autoantibodies destroy the parietal cells leading to deficiency of intrinsic factor and resultant Vit. B12 absorption, which further leads to megaloblastic anemia.
- **Chief cells** are small, basophilic columnar cells, more numerous in the lower half of the gland—more so at the base (fundus) of the gastric gland.
- Contain zymogen granules/pepsinogen.
- **Neuroendocrine cells** are small cells, found at the deeper areas—base (fundus) of the gastric gland, along with chief cells.
- **Stem cells** are pluripotent cell, located at the isthmus region of gastric gland.
- They help in repair of gastric epithelium.
- The secretory activities of the chief and parietal cells are controlled by the autonomic nervous system and the hormone gastrin, secreted by the enteroendocrine cells of the pyloric region of the stomach.
- The enteroendocrine cells are also called APUD (amine precursor uptake and decarboxylation) cells.

ASSESSMENT QUESTIONS

1. **Strongest layer of esophagus is:** *(AIPG)*
   a. Mucosa
   b. Submucosa
   c. Muscular externa
   d. Serosa

2. **Barrett's esophagus is diagnosed by which of the following?**
   a. Columnar metaplasia
   b. Columnar dysplasia
   c. Gastric metaplasia
   d. Intestinal metaplasia

ANSWERS WITH EXPLANATIONS

1. **b. Submucosa**
   - The submucosa consists of a layer of fibroelastic connective tissue containing blood vessels and nerves. It is the strongest component of the esophagus and intestinal wall and therefore should be included in anastomotic sutures.

2. **d. Intestinal metaplasia > c. Gastric metaplasia**
   - Biopsy at the site of Barrett's esophagus shows replacement (metaplasia) of normal stratified squamous epithelium by columnar (non-absorptive) epithelium with goblet cells (intestinal metaplasia). **- Harrison Medicine, Bailey and Love Surgery, Robbins Pathology**.
   - Sometimes functional mucous cells, parietal cells, or chief cells may also be present. Barrett's esophagus is lined by gastric metaplasia. **- Gray's anatomy**
   - Barrett's esophagus presents with peptic ulcer of the lower esophagus (often with stricture) and is a pre-malignant condition leading to esophageal adenocarcinoma occasionally.

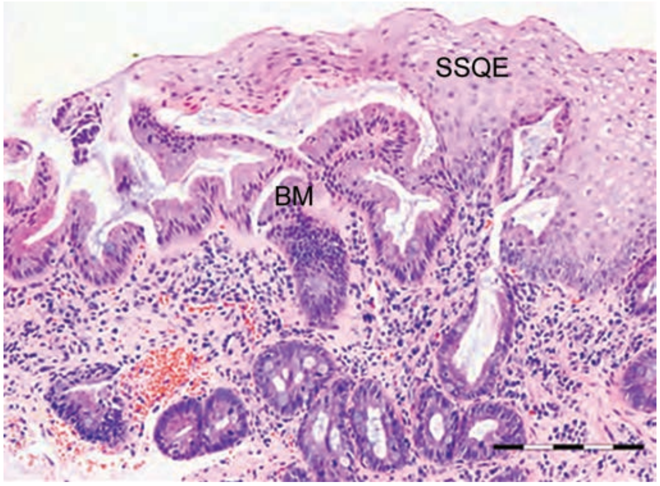


Fig. 65: Intestinal metaplasia in Barret's oesophagus (Replacement of the normal stratified squamous epithelium by the columnar epithelium with goblet cells).

Barrett's Esophagus

a. The squamous epithelium lining the lower esophagus is pathologically replaced by a metaplastic 'intestinalized' columnar epithelium.
b. It may results from chronic episodic reflux of gastric acid and bile into the lower esophagus (GERD).
c. Metaplasia may lead to dysplasia to adenocarcinoma lower end of esophagus.

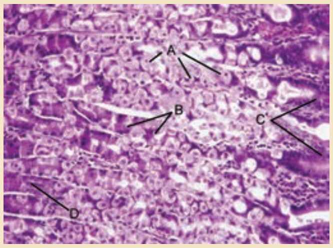
ASSESSMENT QUESTIONS

1. **All are true about esophagus EXCEPT:** *(NEET Pattern 2013)*
   a. Lined by stratified squamous epithelium
   b. Mucosa is thick
   c. Middle third contains both skeletal and smooth muscles
   d. Lower third contains only skeletal muscle

2. **Chief Cells are found in:** *(AIPG 2009)*
   a. Fundus
   b. Pit
   c. Neck
   d. Body

3. **All are correct about stomach EXCEPT:**
   a. Pylorus has more acid secreting cells
   b. Lots of mucous secreting cells in pylorus
   c. Chief cells secrete pepsinogen
   d. Parietal cells secrete intrinsic factor

4. **Which of the following marked cells in the slide secrete hydrochloric acid?** *(AIIMS 2016)*
   a. A
   b. B
   c. C
   d. D



ANSWERS WITH EXPLANATIONS

1. d. Lower third contains only skeletal muscle

a. In the upper third of the oesophagus, the muscularis externa is formed by skeletal muscle; in the middle third, smooth muscle fascicles intermingle with striated muscle; and this increases distally such that the lower third contains only smooth muscle.
b. Oesophagus is lined by a thick mucosa with the stratified squamous epithelium.

2. a. Fundus

a. Chief cells are usually basal (fundal) in location. They are the source of digestive enzymes like pepsin and lipase. These cells are cuboidal with round nucleus and contain lots of zymogen granules.
b. Parietal/Oxyntic cells produce hydrochloric acid and the intrinsic factor. These cells are oval with centrally placed nucleus. They are mainly located in the apical half of the body of gland, reaching as far as the neck.
c. Surface mucus cells are distributed in the gastric pit region of the gastric mucosa. Mucus neck cells are abundant in the neck region (as the name suggests).
d. Neuroendocrine cells are situated mainly in the deeper/basal parts of the glands, along with the chief cells.

3. a. Pylorus has more acid secreting cells.

- Cardia and pylorus of stomach has more mucus producing cells, which help to neutralize the acid in the stomach and prevent ulcer in distal oesophagus and proximal duodenum.

4. a. A.

- HCl is secreted by parietal cells, shown at marker 'A'.
  - They are identified by a large size, lightly eosinophilic (clear cytoplasm) and fried egg appearance.
  - They are located in the upper half of the gastric gland, more so in the body region of the gland.
- A: Parietal cell, B: Mucus neck cell, C: Surface mucus cell, D: Chief cell
- Mucus cells are darker staining, columnar cells located close to gastric pit (neck region of gastric gland).
- Chief cells are small, basophilic columnar cells, more numerous in the lower half of the gland - more so at the base (fundus) of the gastric gland.

Intestine

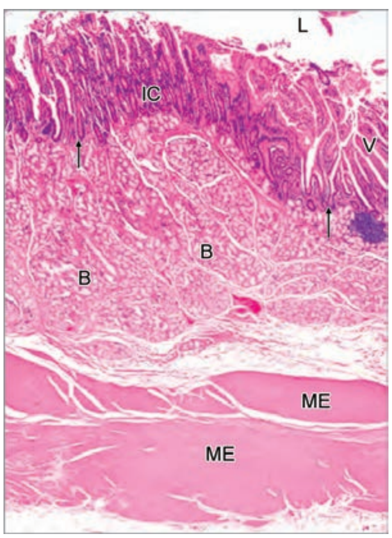


Fig. 66: Duodenum, with villi (V) projecting into the lumen (L); intestinal crypts (IC) of Lieberkuhn in the mucosa, seen mainly in transverse section; muscularis mucosae (arrows); submucosal seromucous (Brunner's) glands (B); and muscularis externa (ME).

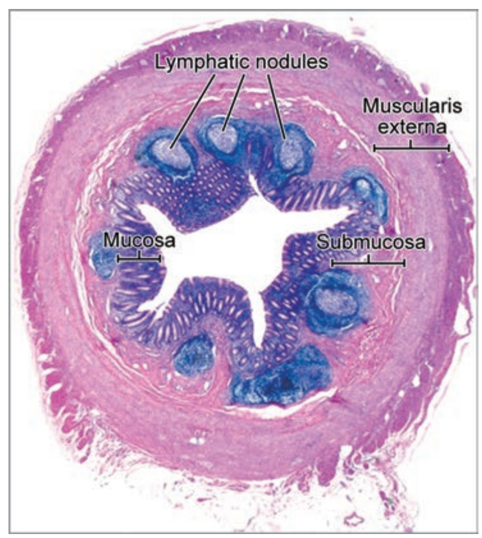


Fig. 67: Microscopic picture of vermiform appendix, showing presence of MALT in mucosa as well as submucosa, alogwith disruption of the muscularis mucosa.

Intestinal Epithelium	
1.	Enterocyte (Absorption)
2.	Goblet cell (Mucus)
3.	Paneth cell (Maintain intestinal flora/Cytokines)
4.	Enteroendocrine cell (Hormones)
5.	M (micro-fold) cell (Immunity)
6.	Stem cell

Anal Canal

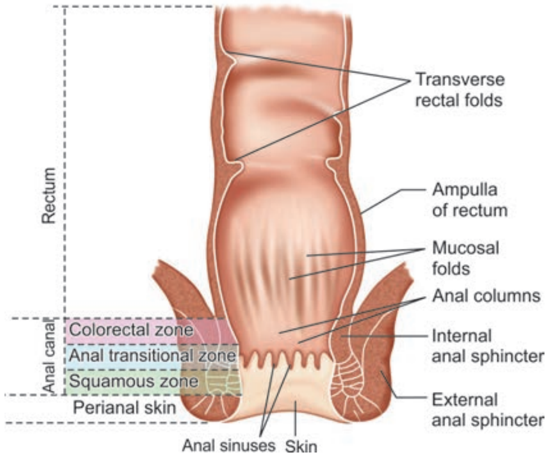


Fig. 68: Rectum and anal canal are the terminal portions of the large intestine, lined by the colorectal mucosa that possesses a simple columnar epithelium containing mostly goblet cells and numerous anal glands. In the anal canal, the simple columnar epithelium undergoes transition into a stratified columnar (or cuboidal) epithelium and then to a stratified squamous epithelium. This transition occurs in the area referred to as the anal transitional zone, which occupies the middle third of the anal canal between the colorectal zone and the squamous zone of the perianal skin.

ASSESSMENT QUESTIONS

1. **Lining epithelium of anal canal below pectinate line is:**
   a. Columnar epithelium
   b. Transitional epithelium
   c. Non-keratinized stratified squamous epithelium
   d. Keratinized stratified squamous epithelium
2. **Cell which does not migrate from the base of the crypt to ends of villi is:** *(AIIMS 2007)*
   a. Enterocyte
   b. Endocrine cell
   c. Paneth cell
   d. Goblet cell
3. **Paneth cells are most distinguished by:**
   a. High zinc content
   b. Numerous lysozyme granules
   c. Rich rough endoplasmic reticulum
   d. Foamy appearance
4. **All of these cells are found in small intestine EXCEPT:** *(NEET Pattern 2014)*
   a. Stem cells
   b. Goblet cells
   c. Neck cells
   d. Paneth cells
5. **Stem cells are seen in:** *(NEET Pattern 2015)*
   a. Retina
   b. Endometrium
   c. Base of intestinal crypts
   d. None of the above
6. **Intestinal epithelium has which cell type?** *(AIIMS)*
   a. T lymphocytes
   b. B lymphocytes
   c. Macrophages
   d. Neutrophils

ANSWERS WITH EXPLANATIONS

1. **c. Non-keratinized stratified squamous epithelium.**
   - Uppermost (colorectal zone) anal canal is lined by the columnar epithelium.
   - Anal transition zone (above dentate line) is lined by the transitional epithelium (columnar changing to cuboidal to squamous epithelia).
   - Squamous zone (below dentate line) is lined by non - keratinized stratified squamous epithelium
   - The terminal most anal canal is lined by keratinized stratified squamous epithelium, where it merges with the anal skin.
2. **c. Paneth cell**
   - Most of the cells in the mucosa of small intestine are derived from the stem cells located in the basal region of the crypts and this progeny migrate out along the wall of the crypts towards the villi (Paneth cell being an exception migrate towards the base).
   - Paneth cells are present in the deeper parts of the intestinal crypts and not at the ends of villi. The villus has mainly the enterocytes and the goblet cells.
   - Endocrine cells are numerous in the intestinal crypts but few of them lie over the villi as well.
3. **b. Numerous lysozyme granules.**
   - Paneth cells is distinguished by the apical eosinophilia in H&E staining. The apical region has large number of lysozymes, which takes eosin, making the paneth cell appear dark pink at the apex.
   - Paneth cells are rich in zinc and have large amount of endoplasmic reticulum as well, but are not the answers of first preference.
   - Mucus in the cells like goblet cells give the foamy appearance and is not a feature of Paneth cells.
   - Paneth cells migrate towards the base of the intestinal glands, occurring in the fundus of the crypts of Lieberkuhn (never found at the luminal surface/villi).
   - They secrete lysozyme (antibacterial enzyme) and other defensive proteins (defensins) and tumour necrosis factor alpha (TNF- α), which help to kill the pathogens and maintain the intestinal flora.

4.c. Neck cells
- At least six types of cells are found in intestinal mucosal epithelium: 1. Columnar cell (Enterocytes): For absorption 2. Goblet cell: Mucus production, 3. Paneth cell: Maintain intestinal flora by secreting antimicrobial substances. 4. Enteroendocrine cell: Secrete paracrine and endocrine hormones 5. M cells (microfold cells), modified enterocytes that cover enlarged lymphatic nodules in the lamina propria. 6. Stem cell: for repair of epithelium.

5. c. Base of intestinal crypts

- Stem cells are located near the base (lower half) of crypts of Lieberkuhn, in the intestine.
- Stem cells form the multiple layers of new epithelial cells, which migrate upwards and reach the tips of the villi.

6. a. T lymphocytes.*Intestinal epithelium has many scattered migratory immune cells, predominantly T lymphocytes for tackling with the antigens in the food (bacteria, protozoa).

Liver and Pancreas

Table 43: Review of liver and pancreas

Structure	Key components and features
Liver	Solid organ composed of plates of hepatocytes with network of portal tracts
	Hepatocytes • Large eosinophilic cells with central nuclei and prominent nucleoli • Cells arranged in plates one cell thick with intervening sinusoids • Diverse metabolic functions • Secretion of bile into canaliculi
	Portal tracts • Branches of: – Bile duct – Portal Vein – Hepatic artery • Surrounded by limiting plate of hepatocytes
	Blood supply • Dual vascular supply – Portal vein (products of digestion but deoxygenated blood) – Hepatic artery (Oxygenated blood from systemic circulation) • Drainage via hepatic vein back to systemic circulation
	Architecture • Classical liver lobule is hexagonal with central venule and peripheral portal tracts. • Liver acinus more frequently relevant, centred around portal area with zonation of hepatocytes
Gallbladder and bile ducts	Bile produced by liver drains via right and left hepatic ducts into common hepatic duct • Bile is stored and concentrated in gallbladder, entering via cystic duct • Gallbladder consists of simple columnar mucosa with loose submucosa and a rather thin muscular wall • Common bile duct is formed by union of cystic duct and common hepatic duct • Common bile duct enters second part of duodenum via ampulla of vater after uniting with pancreatic duct
Pancreas	Exocrine and endocrine components • Exocrine secretory acini draining into ducts • Endocrine islets of Langerhans produce hormones including insulin Exocrine pancreas produces alkaline fluid and digestive enzymes including- • Trypsin • Chymotrypsin Pancreatic lipase

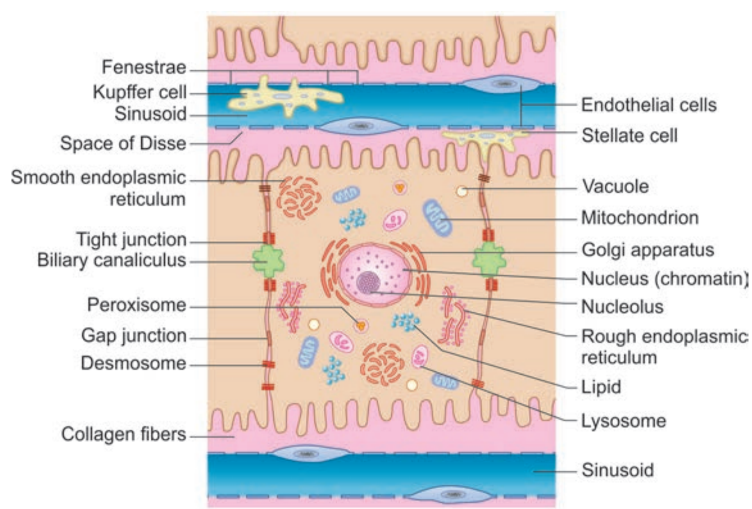


Fig. 69: Hepatocyte, adjacent sinusoids and the various related cells.

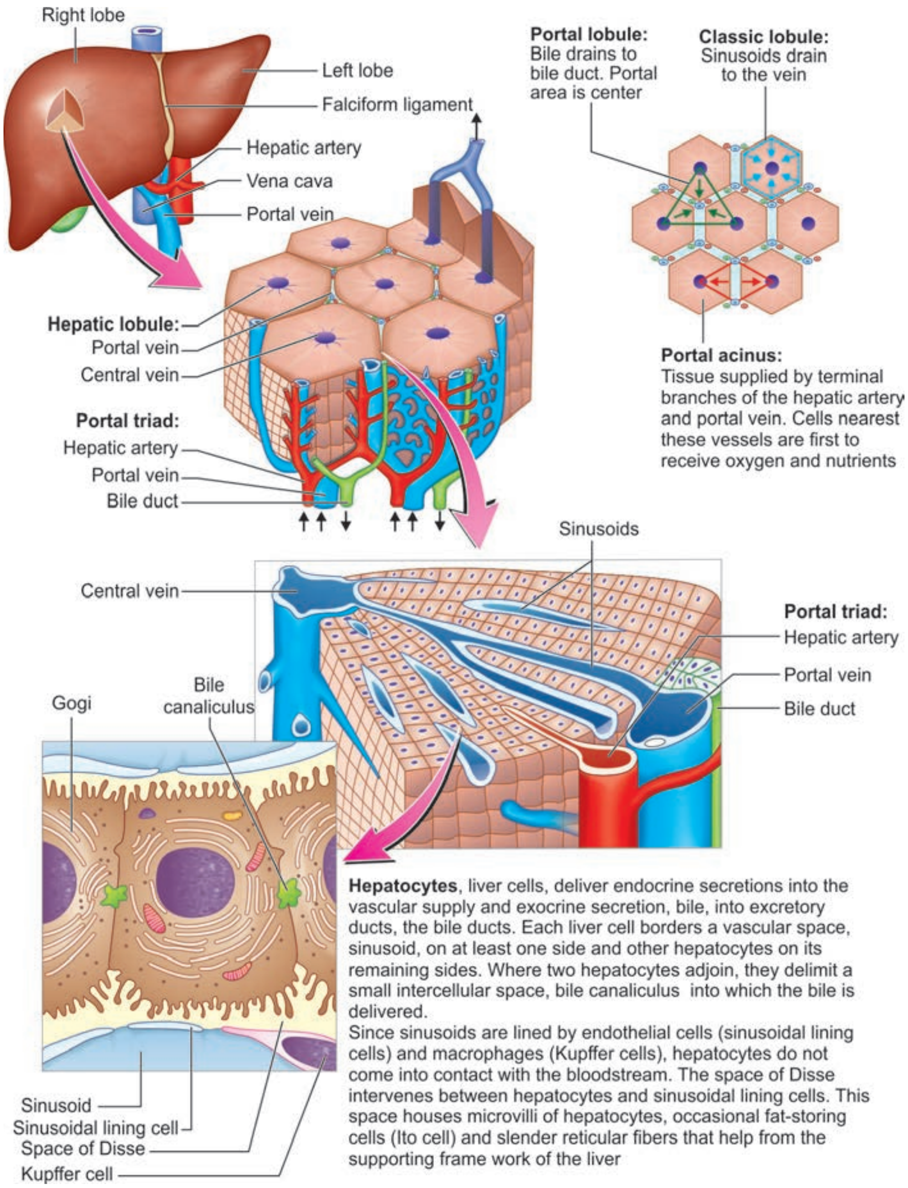
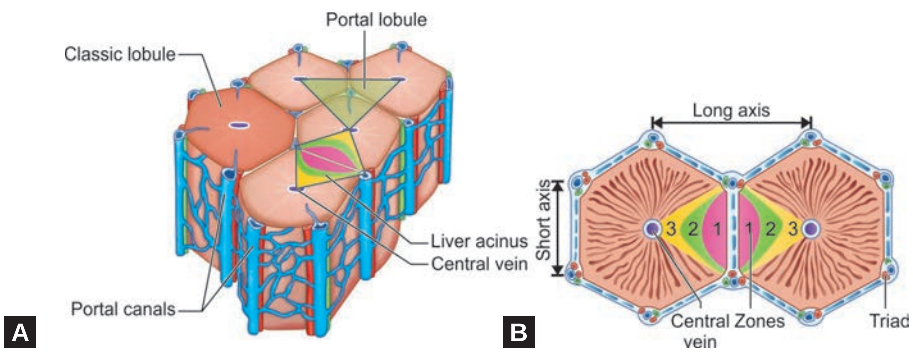


Fig. 70: Histological details of liver, showing portal triads and relation of hepatocytes with sinusoids.



Figs. 71A and B: Comparison of three models of liver organization and function. (A) The outlines of a classic hepatic lobule, portal lobule, and liver acinus are visible on this section of the liver tissue. Note that the hexagonal-shaped classic lobule (red) has the terminal hepatic venule (central vein) at the center of the lobule and the portal canals containing portal triads at the peripheral angles of the lobule. The triangular portal lobule (green) has a portal canal at the center of the lobule and terminal hepatic venules (central veins) at the peripheral angles of the lobule. A diamond-shaped liver acinus (multicolor) has distributing vessels at the equator and terminal hepatic venules (central veins) at each pole. (B) The liver acinus is a functional interpretation of liver organization. It consists of adjacent sectors of neighbouring hexagonal fields of classic lobules partially separated by distributing blood vessels. The zones, marked 1, 2, and 3, are supplied with blood that is richest and most nutrient-oxygenated in zone 1 and least so in zone 3. The terminal hepatic venules (central veins) in this interpretation are at the pointed edges of the acinus instead of in the center, as in the classic lobule. The portal triads (terminal branches of the portal vein and hepatic artery) and the smallest bile ducts are shown at the corners of the hexagon that outlines the cross-sectioned profile of the classic lobule.

- The portal lobule is a triangular unit/area of liver parenchyma bounded by three adjacent central veins. It includes the portions of three classical lobules with portal triad in the centre.
- The liver acinus/hepatic acinus is a diamond-shaped unit/area of liver parenchyma. It includes portions of two classical liver lobules with portal triad at each side of elliptical area and central vein on each end.

Kupffer Cells

- Kupffer cells are hepatic macrophages derived from circulating blood monocytes and originate in the bone marrow. They are long-term hepatic residents and lie within the sinusoidal lumen attached to the endothelial surface.

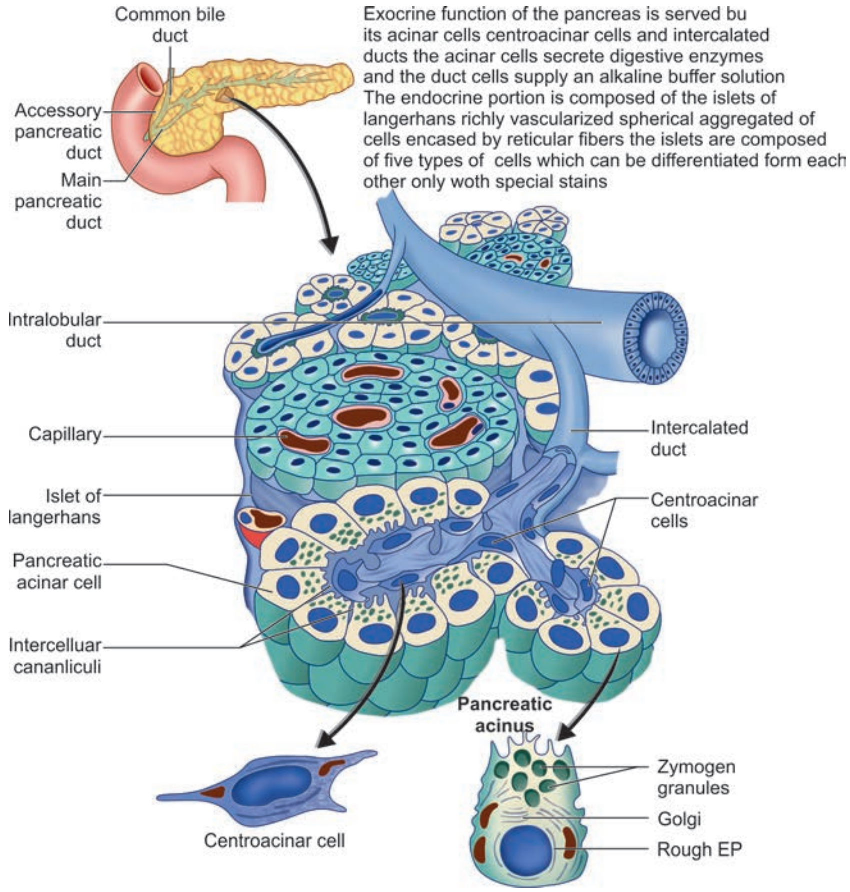


Fig. 72: Histological details of the cell and ducts in pancreas.

ASSESSMENT QUESTIONS

1. Gallbladder epithelium is: *(AIIMS 2007)*
a. Simple squamous
b. Simple cuboidal with stereocilia
c. Simple columnar
d. Simple columnar with brush border

2. Which of the following does not form portal triad in liver? *(NEET Pattern 2015)*
a. Hepatic artery
b. Hepatic vein
c. Bile duct
d. Portal vein

3. Stellate cells of von Kupffer are seen in the sinusoids of which of the following organs:
a. Spleen
b. Bone marrow
c. Liver
d. Adrenal

4. Space of Disse is in: *(NEET Pattern 2014)*
a. Spleen
b. Liver
c. Lymph node
d. Bone

5. Centroacinar cells are present in: *(NEET Pattern 2013)*
a. Pancreas
b. Parotid gland
c. Prostate
d. None

6. All is true about Brunner's gland EXCEPT:
a. Sub-mucosal glands
b. Secrete urogastrone, which inhibit gastric HCl production
c. Secrete human epidermal growth factor
d. Present in the lower duodenum

7. Goblet cells are present in all EXCEPT:
a. Small intestine
b. Large intestine
c. Esophagus
d. Stomach

ANSWERS WITH EXPLANATIONS

1. d. Simple columnar with brush border

- Gallbladder is lined by columnar cells with irregular microvilli-brush border. Small intestine is lined by microvilli arranged in regular fashion -striated border. Brush border is also present in the proximal convoluted tubule (PCT) of kidney. Stereo-cilia are present in the hair cells of internal ear and epididymis.

2. b. Hepatic vein

- Portal triad is a component of the hepatic lobule. It consists of the following five structures: Proper hepatic artery, hepatic portal vein, common bile duct, lymphatic vessels and branch of the vagus nerve. Generally the first three are mentioned in textbooks.

3. c. Liver

- Stellate cells of von Kupffer are specialized macrophages located in the liver, lining the walls of the sinusoids that form part of the mononuclear phagocyte system.

4. b. Liver

a. Perisinusoidal space of Disse is present between a hepatocyte and a sinusoid, containing the blood plasma.
b. Microvilli of hepatocytes extend into this space, allowing proteins and other plasma components from the sinusoids to be absorbed by the hepatocytes.
c. It may be obliterated in liver disease, leading to decreased uptake by hepatocytes of nutrients and wastes such as bilirubin.
d. It contains hepatic stellate cells of Ito, which store fat or fat soluble vitamins including vitamin A. These cells can transform into myofibroblasts, resulting in collagen production, fibrosis, and cirrhosis.

5. a. Pancreas

- Centroacinar cells are an extension of the intercalated duct cells into each pancreatic acinus. The intercalated ducts continue as intralobular ducts which eventually become lobular ducts. These lobular ducts finally converge to form the main pancreatic duct.

6. d. Present in the lower duodenum.

- Brunner's gland are present in the sub-mucosa of the the proximal (upper duodenum).
- They secrete urogastrone, which inhibit parietal cell and acid secretion to reduce the incidence of duodenal ulcer.
- Urogastrone is also known as HEGF, and increases the mitotic activity of the region and helps healing the duodenal ulcer faster, if any.

7. d. Stomach > c. Esophagus

- Goblet cells are absent in the stomach and esophagus, though esophagus may have goblet cells in Barrett's metaplasia (pathology).

Urinary System

- The **nephron** is the structural and functional unit of the kidney.
- The nephron consists of the **renal corpuscle** and a long tubular part that includes a proximal thick segment (proximal convoluted tubule and proximal straight tubule), thin segment (thin part of the loop of Henle), and distal thick segment (distal straight tubule and distal convoluted tubule). The distal convoluted tubule connects to the collecting tubule that opens at the renal papilla.
- The renal corpuscle contains the **glomerulus** surrounded by a double layer of **Bowman's capsule**.
- The filtration apparatus of the kidney consists of the glomerular endothelium, glomerular basement membrane (GBM), and the Bowman's capsule podocytes.
- **Podocytes** extend their processes around the capillaries and develop numerous secondary processes called pedicels (foot processes), which interdigitate with other foot processes of the neighboring podocytes. The spaces between the interdigitating foot processes form filtration slits that are covered by the filtration slit diaphragm.
- **Mesangial cells** are involved in phagocytosis and endocytosis of residues trapped in the filtration slits, secretion of paracrine substances, structural support for podocytes, and modulation of glomerular distention.

Table 44: Important structural and functional characteristics of the uriniferous tubule

Region	Epithelium	Major functions	Summary
Renal Corpuscle	Simple squamous epithelium lining Bowman capsule: podocytes (visceral layer), outer (parietal layer)	Filters blood	Filteration barrier of fenestrated endothelial cells, fused basal laminate, filtration slits between podocyte secondary processes (pedicels)
Proximal Convoluted tubule	Simple cuboidal epithelium with brush border, many compartmentalised mitochondria	Resorbs all glucose, amino acids, filtered proteins; at least 80% Na, Cl, H_2O	The activity of Na pumps in basolateral membranes, transporting Na out of tubule, reduces volume of ultrafiltrate, maintains its isotonicity with blood
Loop of Henle, descending thick limb	Lined by simple cuboidal epithelium with brush border	Same as for proximal convoluted tubule	Same as for proximal convoluted tubule
Loop of Henle, descending thin limb	Simple squamous epithelium	Somewhat permeable to H_2O which enters ultrafiltrate; Na, exist ultrafiltrate	Ultrafiltrate becomes hypotonic with respect to blood: Cl pump in basolateral membranes is primarily responsible for establishing osmo-tic gradients in interstitium of outer medulla

Region	Epithelium	Major functions	Summary
Loop of Henle, ascending thick limb	Simple cuboidal epithelium; compartmentalized mitochondria	Impermeable to H_2O; Cl actively transported out of trouble into interstitium; Na follows	Ultrafiltrate becomes hypotonic with respevt to blood; Cl pump in basolateral membranes is primarily responsible for establishing osmotic gradients in interstitium of outer medulla
JG apparatus macula densa	Simple cuboidal epithelium	Monitors level of Na (or decrease of fluid volume) in ultrafiltrate of distal tubule	Macula densa cells communicate with JG cells in afferent arteriole via gap junctions
JG cells in afferent arteriole	Modified smooth muscle cells containing renin granules	Cells synthesis renin, release it into bloodstream	Renin acts on plasma protein, to trigger events leading to formation of angiotensin II, release of aldosterone from adrenal gland
Distal convoluted tubule	Simple cuboidal cells; compartmentalised mitochondria	Cells respond to aldosterone by removing Na from ultrafilterate	Ultrafilterate more hypotonic in presence of adolosterone; K^+, NH^+, H^+ enter ultrafiltrate
Collecting tubules	Simple cuboidal epithelium; simple columnar epithelium	In absence of ADH, tubule impermeable to H_2O; hypotonic urine excreted	In presence of ADH, tubule permeable to H_2O, which is removed from filtrate, producing hypertonic urine

Table 45: Features of excretory passages

Region	Epithelium	Lamina propria	Muscularis	Comments
Calyces, minor, major	Transitional epithelim	Reticular, elastic fibers	A few inner longitudinal and outer circular smooth muscle fibers	Urine from collecting tubules (ducts of Bellini) empty into minor calyces.
Renal pelvis	Transitional epithelim	Reticular, elastic fibers	Inner longitudinal, outer circular layer of smooth muscle	Expanded upper portion of ureter receives urine from the major calyces.
Ureters	Transitional epithelium lines steliate lumen	Collagen, elastic fibers	Inner longitudinal, outer circular layer of smooth muscle; lower third has additional outermost longitudinal layer	Peristaltic waves propel urine, so it enters bladder in sports.
Urinary bladder	Transitional epithelium: 5 or 6 cell layers in empty bladder; 3 or 4 cell layers in distended bladder Trigone; triangular region; apices are openings of ureters and urethra	Fibroelastic connective tissue rich in blood vessels	Three poorly defined layers of smooth muscle; inner longitudinal, middle circular, outer longitudinal	Plasmalema of deme-shaped cells in epithelium has unique plaques, elliptical vesicles underlying remarkable (empty vs. full) transition. Trigone, unlike most of bladder mucosa, always presents smooth surface.
Urethra female	Transitional epithelim near bladder; remainder stratified squamous	Fibroelastic vascular connective tissue; mucus-secreting glands of Littre	Inner longitudinal, outer circular layer of smooth muscle; skeletal muscle sphincter surrounds urethra at urogenital diaphragm	Female urethra is conduit for urine. External sphincter of skeletal muscle permits voluntary control of micturition.
Urethra male prostatic	Transitional epithelium near bladder; pseudostratified or stratified columnar	Fibromuscular stroma of prostate gland; a few glands of Littre	Inner longitudinal, outer circular layer of smooth muscle	Conduit for urine and semen. Receives secretions from prostate glands, paired ejaculatory ducts.
Urethra male membranous	Pseudostratified or stratified columnar	Fibroelastic stroma; a few glands of Littre	Straiated muscle fibers of urogenital diaphragm form external sphincter	Conduit for urine and semen. external shpincter of skeletal muscle permits voluntary control of micturition.
Urethra male cavernous	Pseudostratified or stratified columnar; at fossa navicularis stratified squamous	Replaced by erectile tissue of corpus spongiosum; many glands of Littre	Replaced by sparse smooth muscle, many elastic fibers in septa lining vascular spaces in erectile tissue	Conduit for urine and semen. Receives secretions of bulbourethral glands present in urogenital diaphragm.

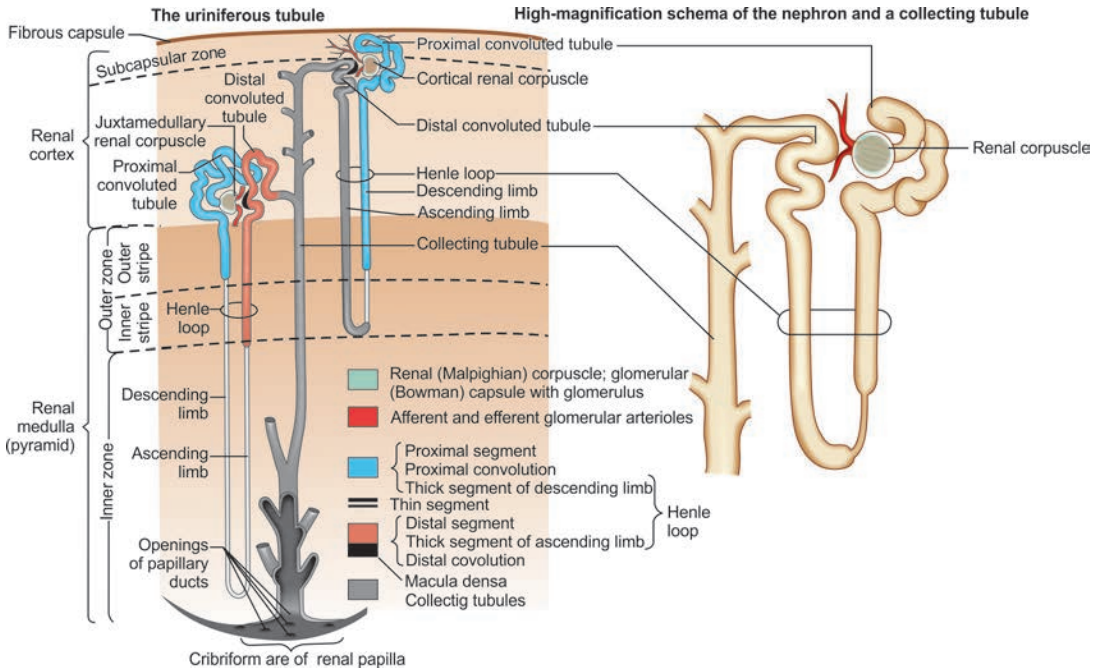


Fig. 73: Histological features of the nephron system in kidney.

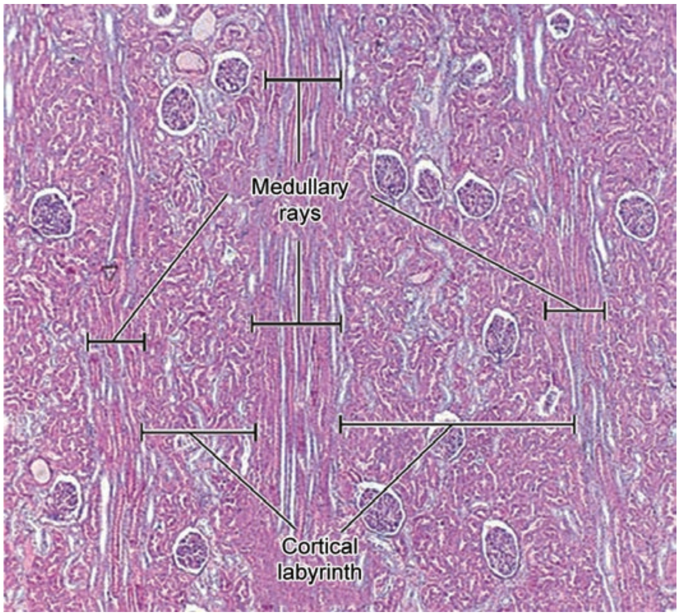


Fig. 74: Histological features of kidney showing glomerulus and the various parts of nephron.

Table 46: Location of the various regions of the uriniferous tubule

Location	Region of the uriniferous tubule
Cortical labyrinth	Renal corpuscle Proximal convoluted tubule Distal convoluted tubule Connecting tubule/arched collecting tubule
Medullary ray	Pars recta of proximal tubule Pars recta of distal tubule Collecting tubules (cortical collecting tubules)
Medulla	Pars recta of proximal tubules Pars recta of distal tubules Descending and ascending thin limbs of Henle's loop Henle's loop Medullary collecting tubules Papillary ducts

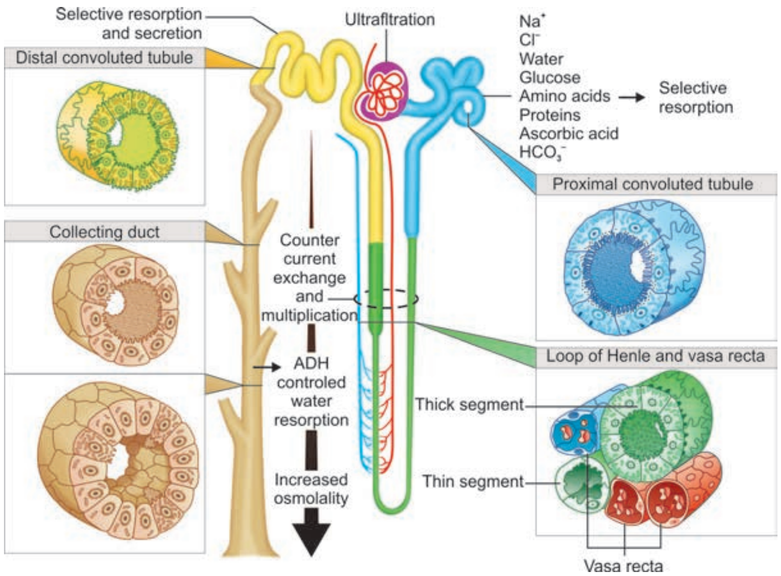


Fig. 75: Microscopic features and principal activities of a nephron and collecting duct. (ADH: Antiduretic hormone).

- PCT (Proximal convoluted tubules) lined with cuboidal brush border
- DCT: Shorter than proximal convoluted tubules, less frequent in cortex, and lack brush border

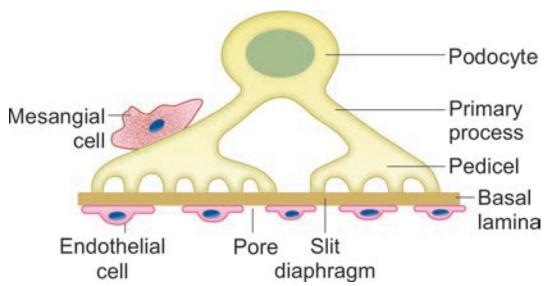
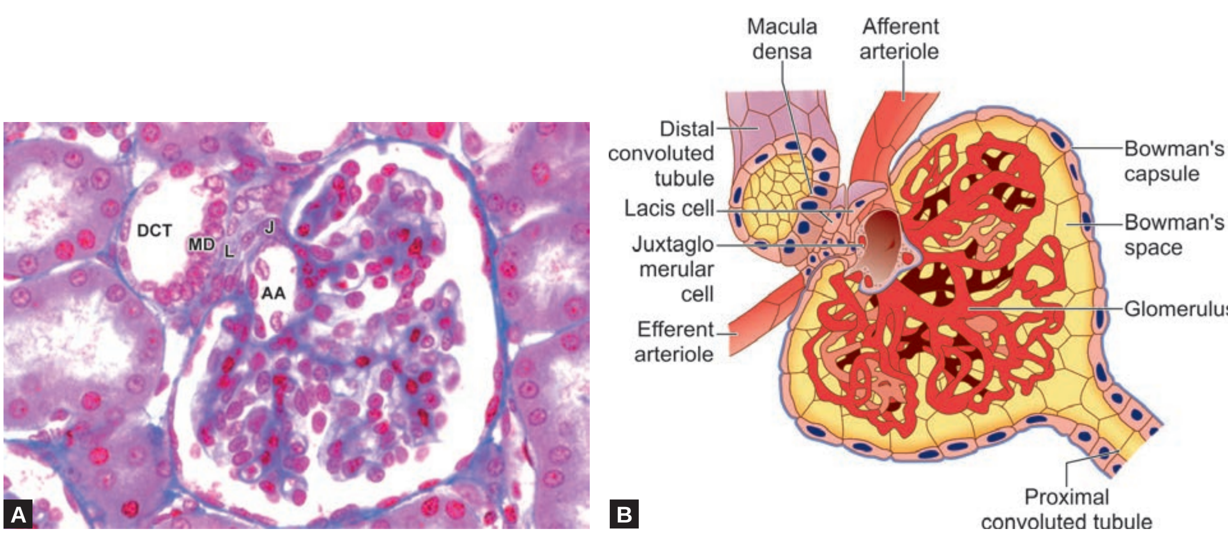


Fig. 76: Components of filtration slits (kidney).

Juxtaglomerular Apparatus (JGA)

- It provides a tubuloglomerular feedback system that maintains systemic arterial blood pressure during a reduction in vascular volume and decrease in filtration rate.
- It includes the **macula densa** (monitors Na^+ concentration in tubular fluid), juxtaglomerular cells (secrete renin), and extraglomerular mesangial cells. It regulates blood pressure by activating the renin angiotensin–aldosterone system (RAAS).
- **Juxtaglomerular cells** are modified smooth muscle cells in afferent arteriole before entering glomerular capsule.
- **Macula densa** is a group of modified distal convoluted tubule cells



Figs. 77A and B: Juxtaglomerular apparatus

Epithelium

- Urothelium (transitional epithelium) begin to appear at the tip of collecting ducts and continues into the minor calyx region and lines major calyx, pelvis, ureter, urinary bladder and the proximal 2 cm of prostatic urethra.
- Male urethra: Proximal half of prostatic urethra (till the opening of common ejaculatory ducts) is lined by the continuation of bladder epithelium – Urothelium. Distally, major length of the male urethra is lined by pseudo-stratified or stratified columnar epithelium. Terminal urethra is lined by stratified squamous epithelium. The terminal most urethra becomes keratinized.

Site	Lining
Proximal*	Transitional (Urothelium)
Major lining	Pseudo-stratified or stratified columnar epithelium
Terminal	Stratified squamous (non- keratinized) epithelium

Female Urethra

Site	Lining
Proximal*	Transitional (Urothelium)
Main lining	Stratified squamous (non- keratinized) epithelium

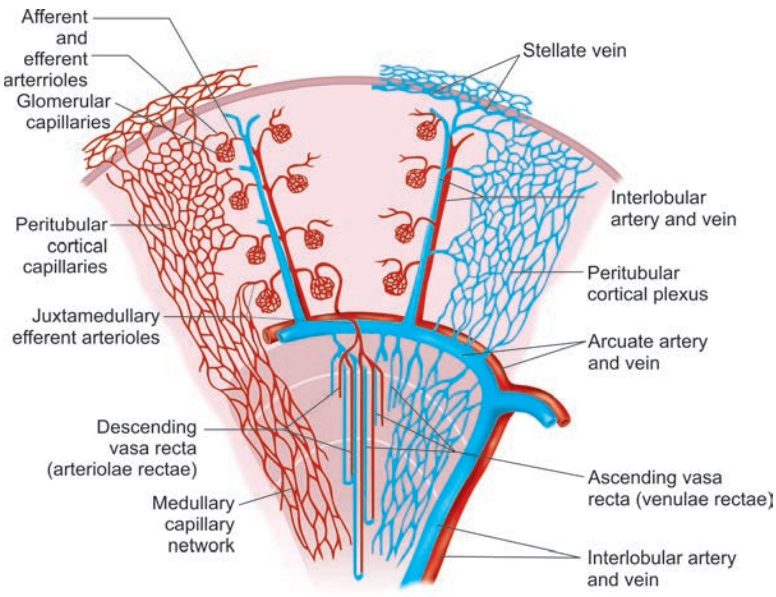


Fig. 78: Renal blood supply. The renal artery gives rise to irterlobar arteries that branch into arcuate arteries at the border between the medulla and cortex. Interlobular arteries branch from the arcuate arteries and travel toward the renal capsule, giving off afferent arterioles that contribute to the glomerular capillaries. Glomeruli in the outer part of the cortex send efferent arterioles to the peritubular cortical capillaries that surround the tubules in the cortex. Glomeruli near the medulla, the juxtamedullary glomeruli, send efferent arterioles almost entirely into the medullary network of capillaries that contains the descending vasa recta. Blood returns from the medulla by the ascending vasa recta and the capillary network via veins that enter the arcuate veins. Stellate veins near the capsule drain the capsular network, and the peritubular cortical plexus drains to both the interlobular and arcuate veins.

ASSESSMENT QUESTIONS

1. **Urothelium lines all EXCEPT:** *(AIIMS 2009)*
   a. Minor calyx
   b. Ureter
   c. Urinary bladder
   d. Membranous urethra

2. **Transitional epithelium is present in:** *(NEET Pattern 2012)*
   a. Renal pelvis
   b. Loop of Henle
   c. Terminal part of urethra
   d. PCT

3. **Urothelium does not line:** *(AIIMS 2007)*
   a. Collecting ducts
   b. Minor calyx
   c. Ureter
   d. Urinary bladder

4. **Which cells line the collecting ducts?** *(NEET Pattern 2013)*
   a. Simple cuboidal
   b. Simple squamous
   c. Simple columnar
   d. Transitional

5. **Ansa nephroni is lined by:** *(JIPMER)*
   a. Columnar
   b. Squamous epithelium
   c. Cuboidal squamous epithelium
   d. Cuboidal and squamous

6. **Duct of Bellini are present in:** *(NEET Pattern 2015)*
   a. Liver
   b. Spleen
   c. Kidney
   d. Lung

ANSWERS WITH EXPLANATIONS

1. **d. Membranous urethra**
   - Membranous urethra is lined by stratified (or pseudostratified) columnar epithelium. Urothelium (transitional epithelium) is present at Terminal lining of collecting tubules, Minor and major calyces, Renal pelvis, Ureter, Urinary bladder and Proximal urethra.
2. **a. Renal pelvis**
   a. Transitional epithelium begins to appear at the terminal portion of collecting ducts and further continue to line minor calyx, major calyx, **renal pelvis**, ureter, urinary bladder and proximal half of prostatic urethra.
   b. Loop of Henle is lined by simple cuboidal epithelium/ simple squamous epithelium (thin segment).
   c. Terminal part of urethra is lined by stratified squamous epithelium.
   d. PCT is lined by simple cuboidal epithelium with microvilli (brush border).
3. **a. Collecting ducts**
   - Urothelium (or transitional) epithelium begin to appear at the tip of collecting ducts and continues into the minor calyx region and lines major calyx, pelvis, ureter, urinary bladder and the proximal 2 cm of prostatic urethra. Collecting ducts are majorly lined by columnar epithelium.
4. **c. Simple columnar**
   - Collecting tubules are lined by simple cuboidal epithelium which gradually change to simple columnar in collecting ducts as the duct system passes from the cortex to the renal papilla.
5. **d. Cuboidal and squamous**
   a. Ansa nephroni is lined by simple squamous epithelium.
   b. The thick descending and ascending limbs are lined by simple cuboidal epithelia.
6. **c. Kidney**
   a. Collecting duct of kidney is also called as papillary duct or duct of Bellini.
   b. They are the largest straight excretory ducts in the kidney medulla and the papillae of which openings form the area cribrosa that open into a minor calyx; they are a continuation of the collecting tubules.

Genital System

- Squamo-columnar junction is present at the endocervix and ectocervix junction. Uterus is lined by ciliated columnar epithelium and vagina has stratified squamous epithelium.

Male

Table 47: Review of male genital tract

Organ	Main components	Cell types	Functions
Testis	Seminiferous tubules	Spermatogenic series cells Sertoli cells	Production of male gametes, spermatozoa Support cells for spermatogenesis
	Interstitium	Leydig cells	Synthesis of androgenic hormones, principally testosterone
	Rete testis	Cuboidal epithelium with cilia and smooth muscle coat	Convey spermatozoa to ductules efferentes and thence to epididymis
Epididymis		Columnar epithelium with stereocilia and smooth muscle coat	Store and mature spermatozoa
Vas deferens		Columnar epithelium and smooth muscle coat, three layers	Carry sperm to urethra during ejaculation
Prostate	Central, transition and peripheral zones and anterior fibromuscular stroma	Epithelium with two cell layers, luminal tall columnar layer and basal cell layer	Produces secretions that mix with seminal fluid
Seminal vesicle		Cuboidal to columnar epithelium with muscular wall	Produce seminal fluid
Penis	Corpus spongiosum and corpora cavernosa	Spongy fibrous tissue containing anastomosing vascular sinuses	Erectile tissue
	Urethra	Lined by urothelium proximally Pseudostratified columnar epithelium distally	Duct for ejaculation (and micturition)

Table 48: Summery of histology and functions of male genital ducts

Duct	Location	Epithelium	Support tissues	Function(s)
Seminiferous tubules	Testicular lobules	Spermatogenic, with sertoli cells and germ cells	Myoid cells and loose connective tissue	Produce sperm
Straight tubules (tubuli recti)	Periphery of the mediastinum testis	Sertoli cells in proximal portions, simple cuboidal in distal portions	Connective tissue	Convey sperm into the rete testis

Duct	Location	Epithelium	Support tissues	Function(s)
Rete testis	In mediastinum testis	Simple cuboidal	Dense irregular connective tissue	Channels with sperm from all seminiferous tubules
Efferent ductules	From rete testis to head of epididymis	Alternating patches of simple cuboidal nonciliated and simple columnar ciliated	Thin circular layer of smooth muscle and vascular loose connective tissue	Absorb most fluid from seminiferous tubules; convey sperm into the epididymis
Epididymal duct	Head, body, and tail of the epididymis	Pseudostratified columnar, with small basal cells and tall principal cells bearing long stereocilia	Circular smooth muscle initially, with inner and outer longitudinal layers in the tail	Site for sperm maturation and short-term storage; expels sperm at ejaculation
Ductus (vas) deferens	Extends from epididymis to ejaculatory ducts in prostate gland	Pseudostratified columnar, with fewer stereocilia	Fibroelastic lamina propria and three very thick layers of smooth muscle	Carries sperm by rapid peristalsis from the epididymis to the ejaculatory ducts
Ejaculatory ducts	In prostate, formed by union of ductus deferens and ducts of the seminal vesicles	Pseudostratified and simple columnar	Fibroelastic tissue and smooth muscle of the prostate stroma	Mix sperm and seminal fluid; deliver semen to urethra, where prostatic secretion is added

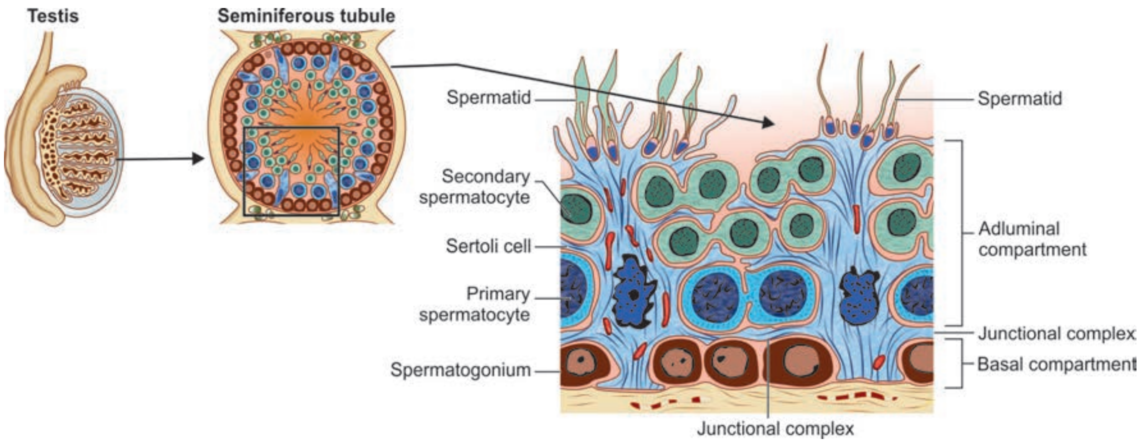


Fig. 79: Seminiferous tubules epithelium. Intercellular bridges are present between spermatocytes and the junctional complexes near the bases of adjacent Sertoli cells. These junctional complexes of the Sertoli cells divide the epithelium into an adluminal and a basal compartment.

Table 49: Functions of sertoli cells

During gestation	After puberty
Synthesize and release antimullerian hormone to suppress the formation of the female genital system and support the development of the male genital system	Physical and nutritional support of developing germ cells Synthesize and release testicular transferrin to transfer iron from seum transferrin to developing germ cells Synthesize and release ABP Establish blood-testis barrier Phagocytose cytoplasm shed during spermiogenesis Synthesize and release inhibin Secrete fructose-rich medium to provide nutrients for spermatozoa released into the male genital ducts
*ABP: Androgen binding protein	

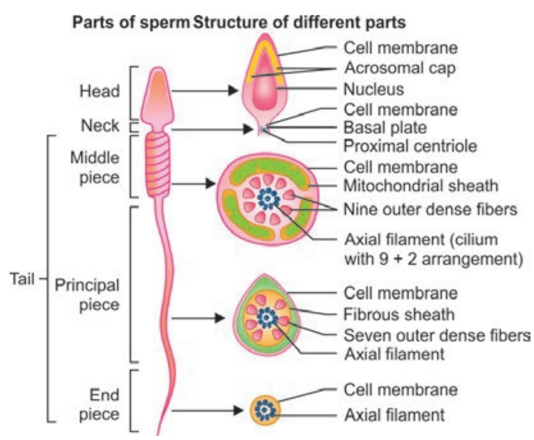


Fig. 80: Parts of the mature sperm are shown on the left side and the sections through the head, neck, middle piece, principal piece, and end piece along with their composition are shown onto the right side.

Table 50: Comparison of structural components of the spermatid and the spermatozoon	
Spermatid (round cell)	**Spermatozoon (elongated cell)**
• Nucleus	• Head
• Golgi apparatus	• Acrosomal cap
• One centrosome	• Two centrioles – One lies in the neck and forms axial filament – Other forms annulus at the distal end of middle piece
• Mitochondria	• Spirally surround the axial filament between the neck and annulus to form the middle piece; the remaining axial filament forms the tail
• Cell membrane	• Cell membrane

- **Blood testis barrier:** The adjacent cytoplasm of **Sertoli** cells are joined by occluding tight junctions, producing a blood–testis barrier that subdivides each seminiferous tubule into a basal compartment and an adluminal compartment. This important barrier segregates the spermatogonia from all successive stages of spermatogenesis in the adluminal compartment and excludes plasma proteins and bloodborne antibodies from the lumen of seminiferous tubules. The more advanced spermatogenic cells can be recognized by the body as foreign and cause an immune response.
- The blood–testis barrier protects developing cells from the immune system by restricting the passage of membrane antigens from developing sperm into the bloodstream. Thus, the blood–testis barrier prevents an autoimmune response to the individual's own sperm, antibody formation, and eventual destruction of spermatogenesis and induction of sterility. The blood–testis barrier also keeps harmful substances in the blood from entering the developing germinal epithelium.

ASSESSMENT QUESTIONS

1. **Sertoli cells in the testis have receptors for:** *(AIIMS 2007)*
   a. FSH
   b. LH
   c. Inhibin
   d. GnRH

2. **Blood testis barrier lies between:**
   a. Leydig - Sertoli
   b. Sertoli - spermatid
   c. Sertoli - myoid
   d. Sertoli - Sertoli

3. **Acrosome cap of sperm is derived from:** *(NEET Pattern 2014)*
   a. Golgi body
   b. Mitochondria
   c. Nucleus
   d. Centromere

4. **Middle piece of sperm contains:** *(NEET Pattern 2015)*
   a. Golgi apparatus
   b. Mitochondria
   c. Lysosome
   d. Ribosome

5. **Corpora amylacea is seen in:** *(NEET Pattern 2012)*
   a. Prostate
   b. Seminal vesicle
   c. Thymus
   d. Testis

ANSWERS WITH EXPLANATIONS

1. a. FSH
- Sertoli cell (a kind of sustentacular cell) is a 'nurse' cell of the testes which is part of a seminiferous tubule.
- It is activated by follicle-stimulating hormone, and has FSH-receptor on its membranes. FSH binds to sertoli cells stimulate testicular fluid production and synthesis of intracellular androgen receptor proteins. Sertoli cells secrete anti-Mullerian hormone and activins also. LH binds to receptors on interstitial cells of Leydig and stimulate testosterone production, which in turn binds to Sertoli cells to promote spermatogenesis. Inhibin is a hormone that inhibits FSH production. It is secreted from the Sertoli cells, located in the seminiferous tubule inside the testes.

2. d. Sertoli - Sertoli
- Blood testis barrier: The adjacent cytoplasm of **Sertoli** cells are joined by occluding tight junctions, producing a blood–testis barrier that subdivides each seminiferous tubule into a basal compartment and an adluminal compartment.

3. a. Golgi body

a. Acrosome is a cap like structure derived from the Golgi apparatus that develops over the anterior half of the head in the spermatozoa.
b. It contains enzymes (including hyaluronidase and acrosin) which help to penetrate zona pellucida- acrosome reaction.

4. b. Mitochondria

a. Midpiece has a central filamentous core with numerous mitochondria spiralled around it, used for ATP production for the journey through the female genital tract.
b. Most of the energy for sperm motility is derived from the metabolism of fructose carried in the seminal fluid.

5. a. Prostate

a. Corpora amylacea are small hyaline masses present in the prostate gland, neuroglia, and pulmonary alveoli.
b. They are accumulations from degenerate cells and secretions with advancing age.
c. In the brain, corpora amylacea are contained in foot processes of astrocytes and are usually present in sub-pial location and around blood vessels.
   – Corpora arenacea ⟶ Pineal gland.

Female

Table 51: Review of the female reproductive system

Part of the female genital tract	Key features
Ovary	Primordial and developing follicles embedded in ovarian stroma Surface covering of epithelium (mesothelium) Corpora lutea and corpora albicantes
Fallopian tube	Muscular wall Folded mucosa Ciliated columnar epithelium
Uterus	Muscular wall—the myometrium Lining endometrium consisting of glands and stroma, varies with the menstrual cycle
Endocervix	Bulk consists of a dense fibromuscular stroma Surface has deep cletts lined by simple columnar mucus-secreting epithelium
Ectocervix	Stroma same as for endocervix Stratified squamous non-keratinising surface epithelium
Vagina	Fibromuscular wall Stratified squamous non-keratinising surface epithelium
Vulva	Stratified squamous epithelium/modified skin
Placenta	Chorionic villi with core of mesenchyme and double surface layer of trophoblast
Breast	Stroma consists of adipose tissue with fibrous septa Branching tubulo-acinar glands Glandular epithelium consists of luminal epithelial cells and underlying myoepithelial cells

Uterine tube

- The mucosa is lined by a single-layered, tall, columnar epithelium, which contains mainly ciliated cells and secretory (peg) cells (so called because they project into the lumen further than their ciliated neighbours), and occasional intraepithelial lymphocytes. In the tube, ciliated cells predominate distally and secretory cells proximally
  - Uterus: Single-layered columnar epithelium.
  - (Before puberty, the epithelium is ciliated and cuboidal).

Ovary

- An **ovarian follicle** is a rounded structure that contains a developing **ovum** surrounded by **follicular cells** and a fluid filled **antral cavity**.
- Ovarian follicles have a cellular covering called the **theca interna** whose cells produce oestrogen.

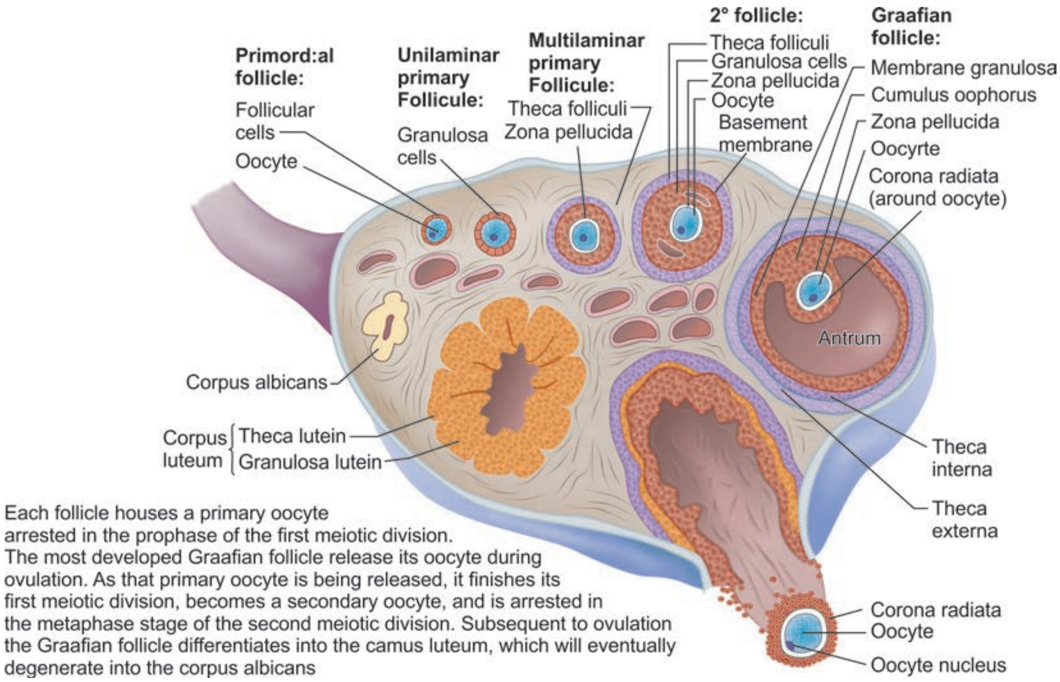


Fig. 81: Microscopic structure of an ovary and ovarian follicles.

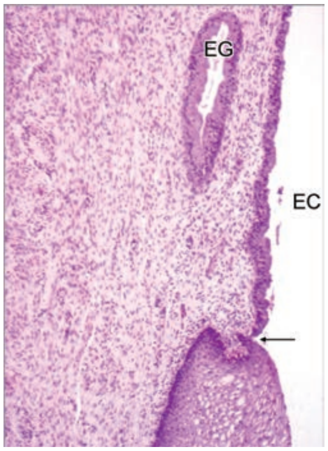


Fig. 82: Uterine cervix showing the transformation zone. The single-layered columnar epithelium lining the endocervical canal (EC) and its endocervical glands (EG) changes abruptly (arrow) to the stratified squamous non-keratinizing epithelium of the external os and ectocervix (below arrow).

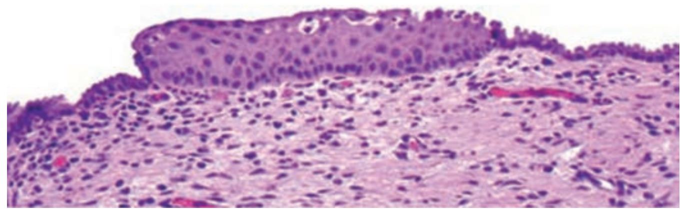


Fig. 83: Squamous metaplasia of the uterine cervix. The center of the image is occupied by an island containing squamous stratified epithelium. This metaplastic epithelium is surrounded on both sides by simple columnar epithelium. Since metaplasia is triggered by reprogramming of stem cells, metaplastic squamous cells have the same characteristics as normal stratified suqamous epithelium.

Table 52: Phases of the menstrual cycle

Phases of the cycle	Lenght (d)	Hormone involved	Endometrial characteristics
Menstrual	3–4	Reduced levels of estrogens and progesterone	Helical arteries are shut down, resulting in necrosis and sloughing of functionalis layer of the endomentrium; epithelial cells in the base of the uterine glands (located in the basal layer of the endometrium) start to reepithelialize the uterine endometrium.
Proliferative (follicular)	10	Increased blood levels of follicle-stimulating hormone (FSH) and estrogens; at the end of the proliferative phase, estrogen, FSH, and luteinizing hormone (LH) blood levels peak.	The denuded surface of the endometrium becomes reepithelialized, the functionalis layer becomes thickened (~3 mm thick), and its helical arteries are reestablished and begin to become coiled; uterine glands are not as yet coiled but begin secretion.
Secretory (luteal)	14	Estrogen levels rise in the blood and progesterone blood levels peak; FSH and LH blood levels are decreased.	Helical arteries and uterine glands of the functionalis become highly coiled; the functionalis reaches its full thickness (~5 mm thick); the uterine glands are filled with their secretory products; cells of the stroma undergo decidual reaction and accumulate glycogen and lipids that provide nutrients for the blastocyst embedding itself in the endometrium.

Table 53: Components of the placental barrier
Endothelial cells of the fetal capillary
Basal lamina of the fetal endothelium
Connective tissue of the secondary villus
Basal lamina of the cytotrophoblasts
Cytotrophoblasts
Syncytiotrophoblasts

ASSESSMENT QUESTIONS

1. **Lining epithelium of fallopian tube is:** *(NEET Pattern 2012)*
   a. Simple columnar
   b. Pseudostratified columnar
   c. Ciliated columnar
   d. Simple cuboidal

2. **Lining epithelium of vagina is:** *(NEET Pattern 2012)*
   a. Pseudostratified columnar epithelium
   b. Keratinized stratified squamous epithelium
   c. Non-keratinized stratified squamous epithelium
   d. Ciliated columnar epithelium

3. **Mucous glands are absent in:** *(NEET Dec 12 Pattern)*
   a. Cervix
   b. Esophagus
   c. Vagina
   d. Duodenum

4. **Gartner's duct is present in:** *(UP 03)*
   a. Vaginal wall
   b. Broad ligament of uterus
   c. Transcervical ligament
   d. Perineal body

5. **Ratio of connective tissue: smooth muscle in cervix:** *(All India Dec 13 Pattern)*
   a. 2:1 b. 5:1
   c. 8:1 d. None

ANSWERS WITH EXPLANATIONS

1. c. Ciliated columnar
- The mucosa of fallopian tube is lined by a single-layered, tall, columnar epithelium, which contains mainly ciliated cells and secretory (peg) cells.
- Uterine cavity is also lined by the ciliated columnar epithelium.

2. c. Non-keratinized stratified squamous epithelium
- Vagina and ectocervix is lined by non-keratinized stratified squamous epithelium.
- Vagina has no glands though cervix has glandular epithelium.
- Squamo-columnar junction is present at the endocervix and ectocervix junction.
- Uterus is lined by ciliated columnar epithelium and vagina has stratified squamous epithelium.

3. c. Vagina.
- Vaginal mucosa has **no glands**.
- Vaginal secretions are **primarily** from the uterus, cervix, and vaginal epithelium in addition to minuscule vaginal lubrication from the Bartholin's glands upon sexual arousal.
- The significant majority of vaginal lubrication is provided by plasma seepage from the vaginal walls (vaginal **transudation**).

4. a. Vaginal wall > b. Broad ligament of uterus
- **Gartner's duct** is present in the **anterolateral wall of the vagina**. It may persist between the layer of the **broad ligament** of the uterus as well.

5. c. 8:1
- **Cervix** consists of fibroelastic connective tissue and contains **relatively little** (10%) smooth muscle.
- The elastin component of the cervical stroma is essential to the **stretching capacity** of the cervix during childbirth.
- The amount of smooth muscle **varies** between the upper (25%), middle (16%) and lower (6%) portions of the cervix.

Endocrine System

Table 54: Review of endocrine system

Organ	Component	Major cell type	Major products
Pituitary	Anterior pituitary	Somatotrophs	Growth hormone (GH)
		Thyrotrophs	Thyroid stimulating hormone (TSH)
		Gonadotrophs	Luteinising hormone (LH) Follicle stimulating hormone (FSH)
		Lactotrophs	Prolactin
		Corticotrophs	Adrenocorticotrophic hormone (ACTH)
	Pars intermedia	Corticotroph-like cells	Melanocyte stimulating hormone (α-MSH)
	Posterior pituitary	Neurones with Herring bodies Pituicytes (gilal cells)	Oxytocin Vasopressin (ADH)
Thyroid		Follicular epithelial cells	Thyroxine (T_4) Tri-iodothyronine (T_3)
		C- cells	Calcitonin
Parathyroid		Principal (chief) cells Oxyphil cells	Parathyroid hormone (PTH)
Adrenal cortex	Zona glomerulosa	Secretory cells in clusters	Mineralocorticoids (mainly aldosterone)
	Zona fasciculata	Secretory cells in parallel cords	Glucocorticoids (mainly cortisol) Small amounts of androgenic sex hormones
	Zona recticularis	Secretory cells in irregular cords	Androgens Glucocorticoids
Adrenal medulla		Chromaffin cells	Adrenaline (epinephrine) Noradrenaline (norepinephrine)
Pancreas	Islets of Langerhans	Alpha cells	Glucagon
		Beta cells	Insulin
		Gamma cells	Somatostain
		PP cells	Pancreatic polypeptide
Pineal		Pinealocytes	Melatonin
Diffuse neuroendocrine system	Widespread in gastrointestinal and respiratory tracts	Neuroendocrine cells	Many different products, including gastrin, secretin, CCK, 5-HT (serotonin), entroglucagon, somatostatin, substance P, vasoactive intestinal peptide (VIP), bombesin, gastric inhibitory polypeptide (GIP), motilin and pancreatic polypeptide (PP), leu-enkephalin, calcitonin

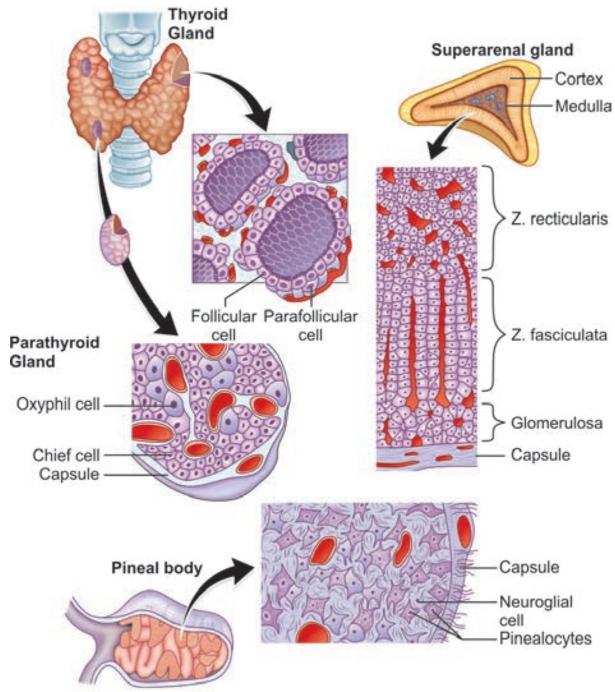


Fig. 84: Microscopic features of the endocrine glands - Thyroid, paratyhroid, adrenal and pineal.

ASSESSMENT QUESTIONS

1. **Secreting active thyroid follicles are lined by which type of epithelium?** *(NBEP 2014)*
   a. Simple squamous
   b. Simple cuboidal
   c. Simple columnar
   d. Stratified cuboidal

2. **Corpora arenacea is seen in:** *(NEET Pattern 2012)*
   a. Prostate
   b. Pineal
   c. Seminal vesicle
   d. Breast

ANSWERS WITH EXPLANATIONS

1. **c. Simple columnar**
   - Thyroid follicles are lined by simple cuboidal epithelium. The epithelium changes to simple columnar in actively secreting state (increased amount of endoplasmic reticulum), and to simple squamous epithelium in hypo-secretion (resting follicle).

   Pineal gland:
   - Corpora arenacea (or brain sand) are calcified structures in the pineal gland and other areas of the brain such as the choroid plexus. It increase with age, so the pineal gland becomes increasingly visible on X-rays over time.

2. **b. Pineal**
   - Corpora arenacea (or brain sand) are calcified structures in the pineal gland which become increasingly visible on X-rays over time.

Special Sense Organs

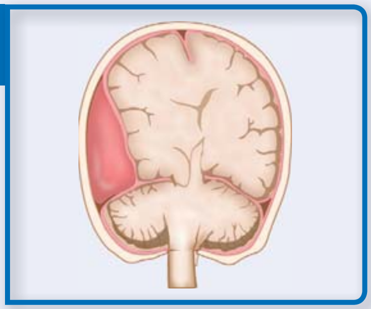
Table 55: Review of special sense organs

Sensory organ	Main and subsidiary structures			Function
Taste buds	Clusters of chemoreceptors in epithelium of tongue, especially in circumval-late papillae			Sweet, bitter, salt, acid
Olfactory receptors (smell)	Olfactory epithelium in roof of nasal formed of chemoreceptor neurones; these connect to olfactory bulbs which are outgrowths of the brain but are called cranial nerve I.			Multiple specific smell molecular shapes recog-nised
Eyes	Retina	Rods	Light-intensity photoreceptors concentrated peripherally	Black and white, night and peripheral vision
		Cones	Light-colour photoreceptors concentrated centrally	Colour receptors in three types: blue, green and red.
		Fovea	Retinal area in central axis, all colour receptors (cones)	Highest acuity vision

Sensory organ	Main and subsidiary structures			Function
		Macula lutea	Retina near to fovea; near–maximum vision; mostly cones, some rods	
		Optic disc	Site of exit of optic nerve: no photoreceptors	Blind spot
	Cornea	Epithelium	Transparent stratified squamous epithelium	Allows light into eye
		Stroma	Densely arrayed specialised collagenous fibers and support cells; no blood vessels	Transparent
	Sclera	Fibrous layer forming the eye globe; continuous with corneal stroma		Support of the globe
	Uvea	Choroid	Intermediate layer between sclera and retina; contians blood vessels and is deeply pigmented	Pigmented to prevent light reflection in globe. Supplies retina by diffusion
		Cilliary body	Secretes aqueous humor (fluid) into posterior chamber	Maintain pressure in globe and globe shape
			Supports lens: smooth muscle exerts tension on lens via zonule	Varies focal length via tension on lens
		Iris	Soft tissue with smooth muscle and pigment, forming variable-sized diaphragm, the pupil	Smooth muscle controls diameter of pupil, varying light entry
		Canal of Schlemm	Removes fluid from anterior chamber following its circulation from posterior chamber	Controls globe pressure
	Lens	Elongated cells containing special proteins which lose their nuclei and form a lens; attached to ciliary body		Tension on lens varies focus
Ear (hearing)	External	Pinna and canal	Reception of sound; hair and wax glands protect canal	Passage for sound into middle ear
	Middle	Middle ear space and Eustachian tube	An air-filled space	Eustachian tube equilibrates air pressure
		Tympanic membrane	Thin fibrous membrane separates external and middle ear	Vibrates with sound waves
		Ossicles	Chain of bones, malleus, incus and stapes, with synovial joints and muscle. Incus covers oval window.	Transfer sound vibrations to oval window, vibrating prilymph
	Inner		Endolymph fluid in a membrane-bound space, often surrounded by fluid (perilymph) and located in bone	Round window dissipates pressure fluctuations
		Cochlea	Conical spiral-shaped structure containing organ of Corti	Converts perilymph vibration to neural signals (i.e hearing)
Ear (balance)	Inner ear	Semicircular canals	Sensory ridges in canals detect fluid flow caused by head movements.	Part of sense of balance/equibrium for static postiton
		Vestibule	Utricle and saccule are perilymph spaces containing sensory areas, maculae with overlying otoliths.	Part of sense of balance/equilibrium for static position

CHAPTER 4

Neuroanatomy



- Nervous system has two major divisions, the **central nervous system** (CNS) and the **peripheral nervous system** (PNS).
- CNS consists of the brain, spinal cord, optic nerve and retina, and contains the majority of neuronal cell bodies.
- PNS includes all nervous tissue outside the CNS and consists of the cranial and spinal nerves, peripheral autonomic nervous system (ANS) and the special senses (taste, olfaction, vision, hearing and balance).
  - It is composed mainly of the axons of sensory and motor neurons that pass between the CNS and the body.
  - ANS is subdivided into **sympathetic** and **parasympathetic** components. It consists of neurones that innervate secretory **glands** and **cardiac** and **smooth** muscle, and is concerned primarily with control of the internal environment.
  - Neurons in the wall of the gastrointestinal tract form the enteric nervous system (ENS) and are capable of sustaining local reflex activity that is independent of the CNS.
  - ENS contains as many intrinsic neurons in its ganglia as the entire spinal cord is often considered as a third division of the nervous system.

BRAIN

- Brain (encephalon) has 12 pairs of cranial nerves through which it communicates with structures of the head and neck and through connections with the spinal cord, it controls the activities of the trunk and limbs.
- The brain is divided into major regions on the basis of ontogenetic growth and phylogenetic principles: **Forebrain** (prosencephalon), **midbrain** (Mesencephalon) **hindbrain** (rhombencephalon).

Primary vesicles	Secondary vesicles	Adult derivatives
Prosencephalon	Telencephalon	Cerebral hemispheres, caudate, putamen, amygdaloid claustrum, lamina terminalis, olfactory bulbs, hippocampus
	Diencephalon	Epithalamus, subthalamus, thalamus, hypothalamus, mammillary bodies, neurohypophysis, pineal gland, retina, iris, ciliary body, optic nerve (CN II), optic chiasm, optic tract
Mesencephalon	Mesencephalon	Midbrain
Rhombencephalon	Metencephalon	Pons, cerebellum
	Myelencephalon	Medulla

- **Prosencephalon** is subdivided into the **telencephalon** and the **diencephalon**.
  - **Telencephalon** is mainly composed of the two **cerebral hemispheres** or cerebrum. Each hemisphere has an outer layer of grey matter, the cerebral cortex, beneath which lies a thick mass of white matter.
  - **Internal capsule** contains nerve fibres that pass to and from the cerebral cortex and lower levels of brain.
  - **Basal ganglia** grey matter nuclei partly embedded in the subcortical white matter.
  - **Corpus callosum** is the nerve fibre connection between corresponding areas on either side of the brain, which cross the midline within commissures.
  - **Diencephalon** equates mostly to the thalamus and hypothalamus, but also includes the smaller epithalamus and subthalamus.
- **Mesencephalon** (midbrain) comprises of the tectum, tegmentum, the cerebral aqueduct, cerebral peduncles, and certain nuclei and fasciculi.
  - Caudally the midbrain adjoins the metencephalon and rostrally the diencephalon.
- **Rhombencephalon** is subdivided into **metencephalon** (pons and the cerebellum) and **myelencephalon** (medulla oblongata).
  - **Pons** lies between the midbrain and the medulla oblongata and in front of the cerebellum. It has two parts: the basilar part ventrally, and pontine tegmentum, dorsally.
  - **Cerebellum** consists of paired hemispheres united by a median vermis and lies within the posterior cranial fossa, dorsal to the brainstem (midbrain, pons and medulla) and connected with cerebellar peduncles.

- ➢ **Medulla oblongata** is the most caudal part of the brainstem and is continuous with the spinal cord below the level of the foramen magnum.
- **Brainstem** is the collective term which includes midbrain, pons and medulla oblongata. It lies upon the basal portions of the occipital and sphenoid bones (**clivus**).

Basic Neuroanatomy

Nervous system has two type of cells: Neuronal and non-neuronal (neuroglial).

Neuron has a cell body, dendrites, and the axon.

- Neuron body is identified by the presence of Nissl substance and rough endoplasmic reticulum.
- Proximal part of axon in a motor neuron is within the CNS and distally in the PNS, as it courses to its effector, e.g. skeletal muscle.
- In the CNS, the myelin for the axon is produced by oligodendrocyte and in the PNS by Schwann cell.

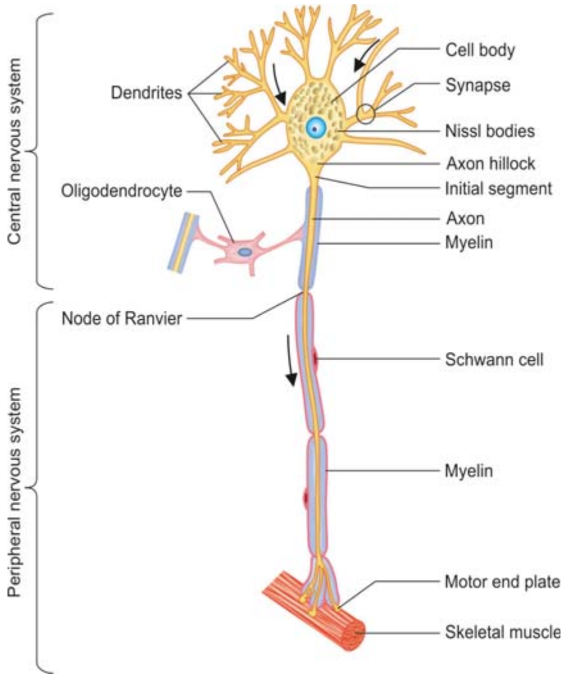


Fig. 1: Motor neuron

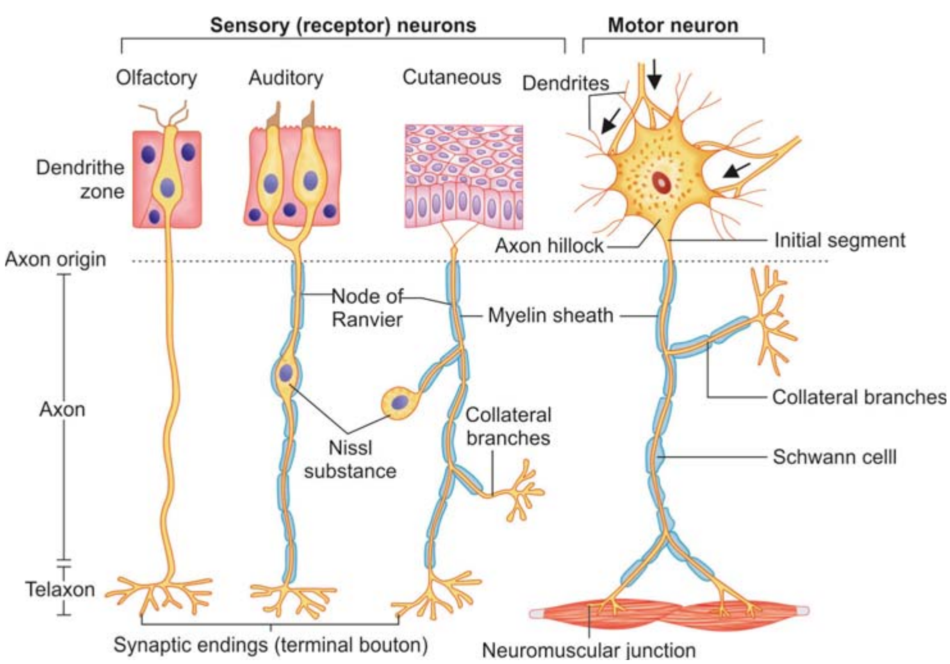


Fig. 2: Types of nerve cells

- Type of nerve cells:
  - Typical **unipolar** brush cells are neurons specific to the cerebellum and the granule region of the dorsal cochlear nucleus.
  - **Pseudounipolar** neurons have dendrite and axon emerging from same process.
    - Found in the spinal (dorsal root) ganglia and sensory ganglia of cranial nerves V, VII, IX and X, all mixed-cranial nerves.
  - **Bipolar** neurons have axon and single dendrite on opposite ends of the soma.
    - Olfactory neurons are bipolar and unmyelinated
    - Bipolar cell of the retina
    - Vestibulocochlear nerve, has the bipolar neuron type in both the spiral (cochlear) ganglion as well as Scarpa's (vestibular) ganglion.
  - **Multipolar** neurons two or more dendrites, separate from the axon and are the largest population of nerve cells in the nervous system.
    - It includes motor neurons, neurons of the autonomic nervous system, interneurons, pyramidal cells of the cerebral cortex, and Purkinje cells of the cerebellar cortex.

Glial cells are non-neuronal cells that maintain homeostasis, form myelin, and provide support and protection for neurons in the CNS and PNS.

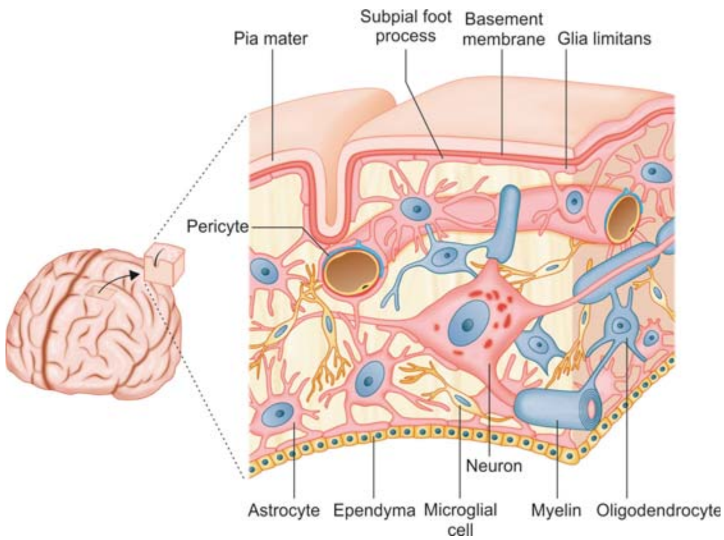


Fig. 3: Glial cells

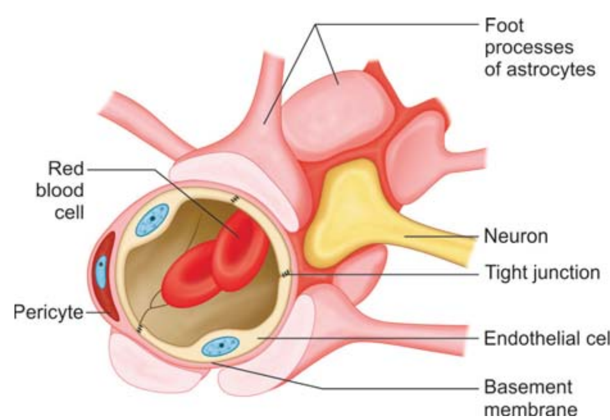


Fig. 4: Blood brain barrier

Table 1: Glial cells in the central nervous system and peripheral nervous system

Cell type	Functions
Central nervous system	
Astrocytes	Maintain blood-brain barrier, regulate ion, nutrient, and dissolved gas concentrations Form scar tissue after injury
Oligodendrocytes	Form myelin around CNS axons
Microglia	Remove cellular debris, and pathogens in CNS by phagocytosis
Ependymal cells	Line ventricles of the brain and central canal of the spinal cord. Assist in production, circulation and monitoring of cerebrospinal fluid
Peripheral nervous system	
Satellite cells	Surround nerve cell bodies in peripheral ganglia
Schwann cells	Surround all axons in PNS Responsible for myelination of axons in PNS Participate in repair process after injury

- **Astrocytes** and their processes interact with the blood vessels as well as with axons and dendrites.
  - Their processes contact the basement membrane of the pia mater on brain surface (forming the glia limitans) and also contact the ependymal lining cells of ventricles.
- **Microglia** are a type of glial cell located throughout the CNS and account for 10–15% of all cells found within the brain.
  - As the resident macrophage cells, they act as the first and main form of active immune defense in the central nervous system (CNS)
  - During hematopoiesis, some of the stem cells differentiate into monocytes and travel from the bone marrow to the brain, where they settle and further differentiate into microglia.

- **Tanycytes** are modified ependymal cells that contact capillaries and neurons. They mediate cellular transport between the ventricles and the neurophil. They project to hypothalamic nuclei that regulate the release of gonadotropic hormone from the adenohypophysis.
- **Blood brain barrier** consists of non-fenestrated endothelial cells joined together by elaborate, complex tight junctions, endothelial basal lamina, and the end foot processes of astrocytes. Infarction of brain tissue destroys the tight junctions of endothelial cells and results in vasogenic edema, which is an infiltrate of plasma into the extracellular space.
- **Blood CSF barrier** consists of the tight junctions between the cuboidal epithelial cells of the choroid plexus. The barrier is permeable to some circulating peptides (e.g., insulin) and plasma proteins (e.g., prealbumin).

Nerve Injury and Response

- **Wallerian degeneration** is anterograde degeneration characterized by the disappearance of axons and myelin sheaths and the secondary proliferation of Schwann cells.
- When a nerve fiber is injured, the neuronal nucleus moves to the cell periphery, and the number of Nissl bodies is greatly reduced.
- The nerve fiber distal to the injury degenerates along with its myelin sheath.
- Schwann cells dedifferentiate and proliferate; myelin debris is phagocytosed by macrophages.
- Proliferated Schwann cells form cellular cords of Bunger that are penetrated by the grooving axonal sprout.
- The axon grows at a rate of 0.5 to 3 mm/day.
- If growing axonal sprout reaches the muscle fiber, the regeneration is successful and new neuromuscular junctions develop.

Effective regeneration does not occur in the CNS, e.g. there is no regeneration of the optic nerve, which is a tract of the diencephalon. There are no basement membranes or endoneural investments surrounding the axons of the CNS.

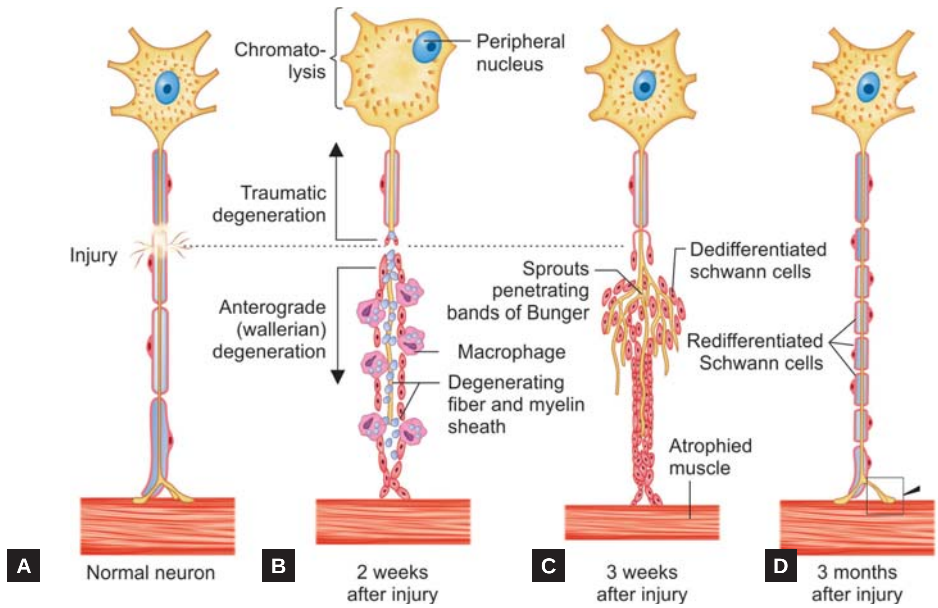


Fig. 5: Nerve injury and response

- **Grey matter** is collection of neuron bodies and **white matter** is collection of axons.
- **Nucleus** is a collection of neuron cell bodies within the CNS and **ganglion** is a collection of neuron cell bodies outside the CNS.
- **Nerve** is collection of axons in the peripheral nervous system, whereas the axon collections in CNS are identified by several terms: Tract, peduncle, lemniscus, fasciculus, capsule etc.

Types of Nerve Fibers

- Somatic sensory fibers carry nerve impulses from skin, muscles, bones, and joints to the CNS.
- Somatic motor fibers carry nerve impulses from CNS to the skeletal muscles.
- Visceral sensory fibres carry the visceral sensations to the CNS.
- Visceral motor fibres covey impulses from CNS to the cardiac muscle, smooth muscles and glands.

Somatosensory Axis

- Sensory information from the receptors enters the central nervous system through peripheral nerves and is conducted to multiple sensory areas in the spinal cord at all levels, reticular substance of the medulla, pons, and mesencephalon of the brain, cerebellum, thalamus and cerebral cortex.

Somatomotor Axis

- Skeletal muscle contraction can be controlled from many levels of the central nervous system, including the spinal cord, reticular substance of the medulla, pons, and mesencephalon, basal ganglia, cerebellum and the motor cortex.T

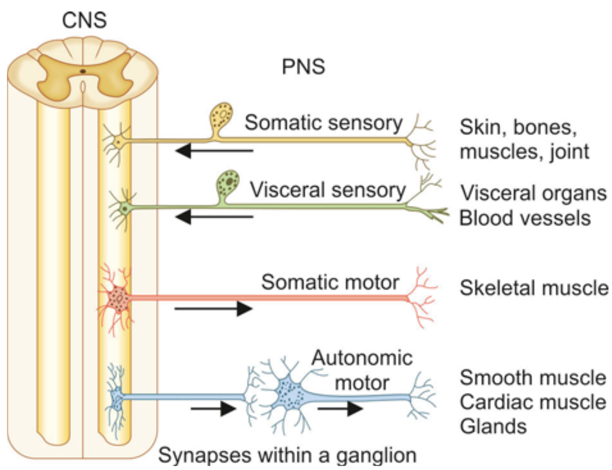


Fig. 6: Types of nerve fibres

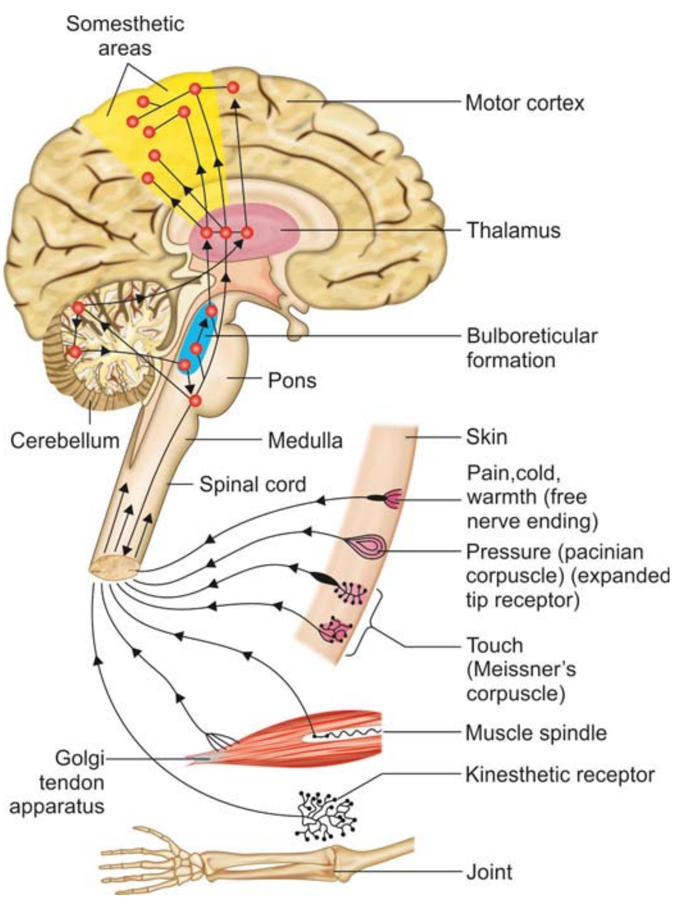


Fig. 7: Somatosensory axis of the nervous system

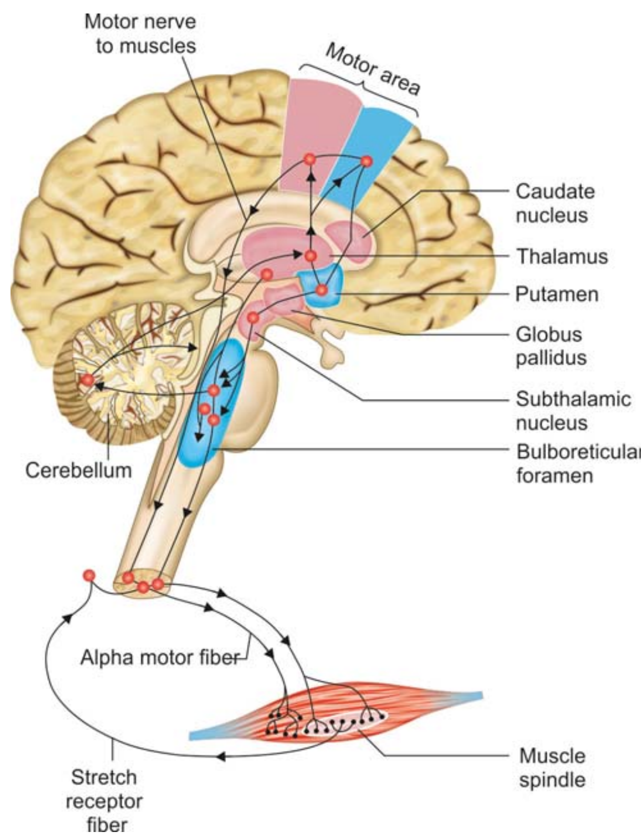


Fig. 8: Skeletal motor nerve axis of the nervous system

White Matter

- **White matter** is constituted by the bundles of **myelinated axons**, which connect various gray matter areas and carry nerve impulses between neurons.
- Collection of axons are categorized on the basis of their course and connection into **association** fibers, **projection** fibers, and **commissural** fibers.
  - **Association fibers** connect cortical regions within the same cerebral hemisphere of the brain.
  - **Projection fibers** project from higher to lower centres (or vice versa) in CNS.
  - **Commissural fibers** are transverse fibers that interconnect similar regions in the left and right sides of CNS (cerebral hemisphere, brainstem, cerebellum, spinal cord).

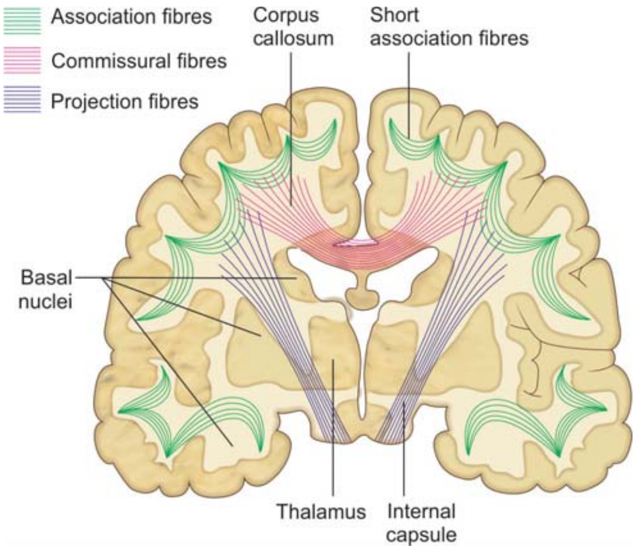


Fig. 9: Types of white matter fibres

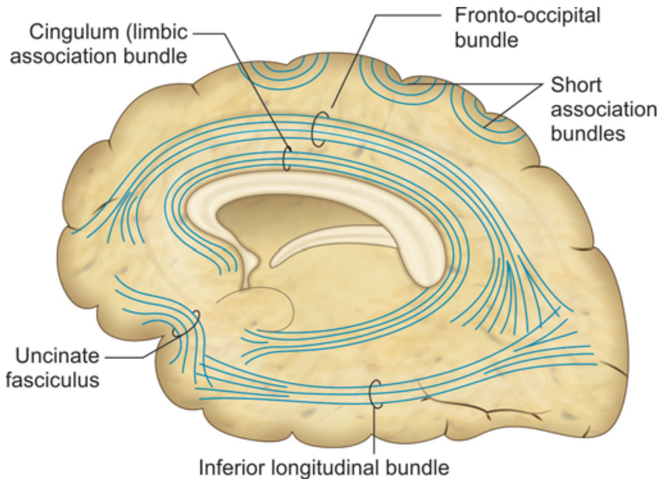


Fig. 10: Bundles of short and long association fibres within the cerebral hemisphere

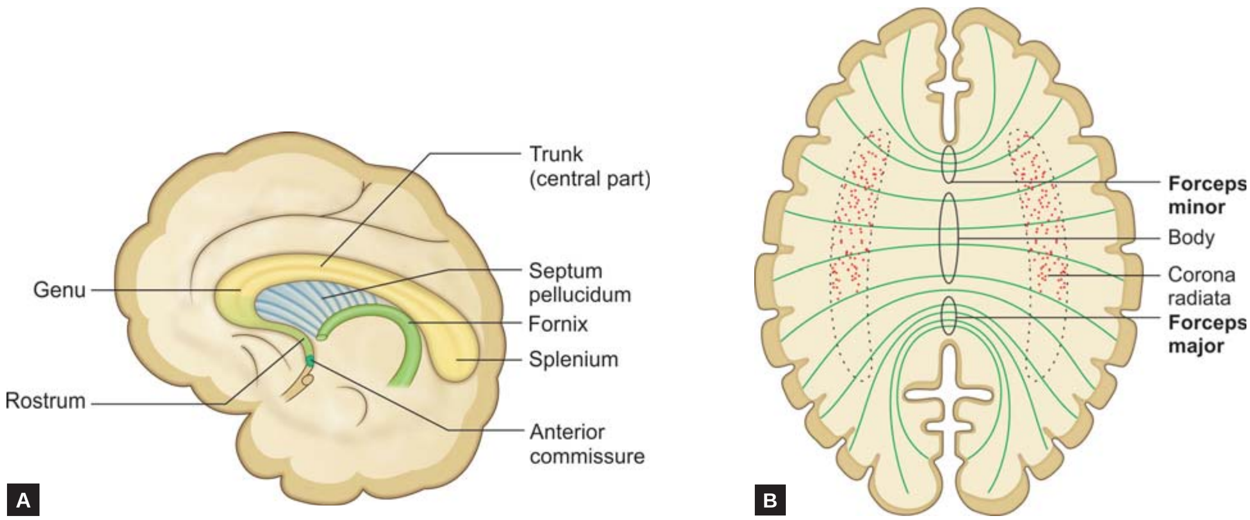
- **Association** fibers:

Name	From	To
Uncinate fasciculus	Frontal lobe	Temporal lobe
Cingulum	Cingulate gyrus	Entorhinal cortex
Superior longitudinal fasciculus	Frontal lobe	Occipital lobe
Inferior longitudinal fasciculus	Occipital lobe	Temporal lobe
Fornix	Hippocampus	Mammillary bodies
Arcuate fasciculus	Frontal lobe	Temporal lobe

- **Projection** fibers: Corona radiata, internal capsule, fimbria
- **Commissural** fibers: Corpus callosum, hippocampal commissure, anterior and posterior commissure, habenular commissure

Corpus Callosum

- The anterior is called the **genu** and posterior part is **splenium**; between the two is the **body** of the corpus callosum.
- The part between the body and the splenium is the **isthmus** and **rostrum**, the part that projects posteriorly and inferiorly from the anterior most genu.
- The fibers curving forward from the genu into the frontal lobe constitute the **forceps minor**, and those curving backward into the occipital lobe, the **forceps major**. Between these two parts is the main body of the fibers which constitute the **tapetum** and extend laterally on either side into the temporal lobe, and cover in the central part of the lateral ventricle



Figs. 11A and B: Parts of corpus callosum. (A) Median sagittal section of the cerebrum showing shape and different parts of corpus callosum, (B) Horizontal section of the cerebrum showing components of the fires of corpus callosum

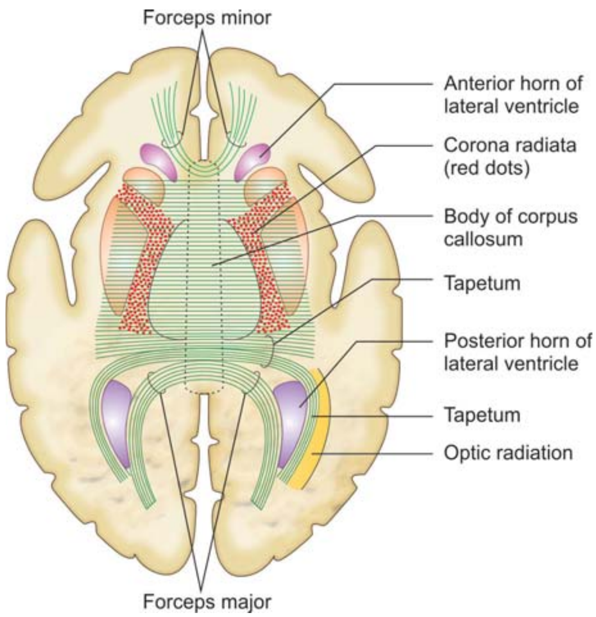


Fig. 12: Horizontal section of the cerebrum (schematic) to show the course and components of the fibres of corpus callosum. Fibres of coronal radiata are seen cut at right angle to their course

ASSESSMENT QUESTIONS

1. Corpus callosum is which type of fibres? *(NEET Pattern 2012)*
a. Projection fibers b. Commissural fibers
c. Association fibers d. None

2. Association fibers are all EXCEPT: *(AIIMS 2014)*
a. Uncinate b. Cingulum
c. Longitudinal fasciculus d. Forceps major

3. All are parts of corpus callosum EXCEPT:
a. Forceps minor b. Forceps major
c. Tapetum d. Indusium griseum

ANSWERS WITH EXPLANATIONS

1. b. Commissural fibers
- Corpus callosum has **commissural fibre**s which connect the left and right cerebral hemispheres and facilitates interhemispheric communication.
- It is the largest white matter structure in the brain.

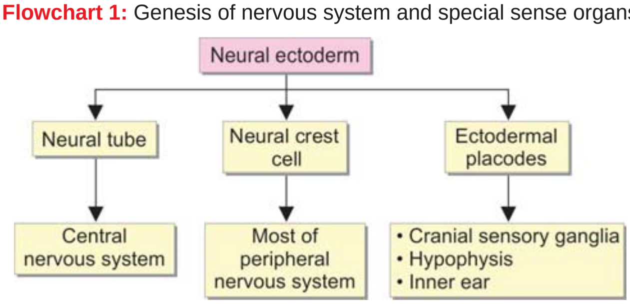
2. d. Forceps major
- **Forceps major** is the collection of commissural fibres in the splenium part of the corpus callosum, communicates somatosensory information between the two halves of the parietal lobe and the visual cortex at the occipital lobe.

3. d. Indusium griseum
- **Indusium griseum** is a thin layer of grey matter in contact with the dorsal surface of the corpus callosum and continuous laterally with the grey matter of the cingulate gyrus.

Development of Nervous System

Nervous system and special sense organs are derivatives of the neuroectoderm and develop from **three sources**:
- **Neural plate**, which forms the CNS (including the preganglionic autonomic nerves).
- **Neural crest** cells appear at the junction of neural plate and peripheral ectoderm, undergo epithelial to mesenchymal transition and migrate away just prior to its fusion of neural plate to form neural tube.
  - Neural crest cells form majority of the neurons and glia outside the CNS.
  - Most of the ganglia (somatic and autonomic) develop from neural crest cells.
  - Neural crest cells also form neurons in adrenal medulla and chromaffin cells.
- **Ectodermal placodes** develop from a common panplacodal ectoderm (PPE) a horseshoe-shaped region of ectoderm surrounding the anterior neural plate and neural crest.

Flowchart 1: Genesis of nervous system and special sense organs



- **Macroglial** cells are derived from neuroectoderm and include: Astrocytes, oligodendrocytes, ependymal cells, Schwann cells.
- During hematopoiesis, some of the stem cells differentiate into monocytes and travel from the bone marrow to the brain, where they settle and further differentiate into **microglia**.
- **Neurulation** begins in the **third week** of development.
  - As the primitive streak regresses caudally, the **notochord** develops in the axial line of the embryo (between the buccopharyngeal membrane and cloacal membrane).
  - Notochord **induces** the overlying ectoderm to form the **neural plate**.
  - By the end of the third week, the lateral margins of the neural plate thicken and become elevated to form the **neural folds** with the neural groove located centrally between the two folds.
  - The neural folds then grow over the midline and begin to fuse to form the **neural tube** which later separate from the surface ectoderm.
  - Closure of the neural tube begins in the **cervical** region and continues cranially and caudally (The recent literature mentions **multiple levels of fusion**).
  - Neural tube has a cavity **neural canal**, which is in continuity with amniotic cavity in the beginning. The cavity gives rise to the central canal of the spinal cord and ventricles of the brain.
  - When neural tube starts closing in the cervical region, the neural canal is still open at the cranial end (anterior neuropore) and caudal end (posterior neuropore).
  - These neuropores gradually shut close the neural canal from the amniotic cavity. The anterior (cranial) neuropore closes earlier (Day 25) than the posterior (caudal) neuropore (day 28).
  - Failure of closure of the neuropores results in **open neural tube defects.** Non-closure anterior neuropore leads to anencephaly and non-closure of posterior neuropore leads to spina bifida. These conditions present with **elevated** levels of alpha-fetoprotein levels (and acetylcholine-esterase).
  - Neural crest cells are the **fourth germ layer** cells, which appear at the margins of the neural folds during closure of the neural tube. (Some authorities consider neural crest cells are derived from **neuro-ectoderm**).
  - **Neural crest cells** contribute to the peripheral nervous system and most of the ganglia are derived from these cells.

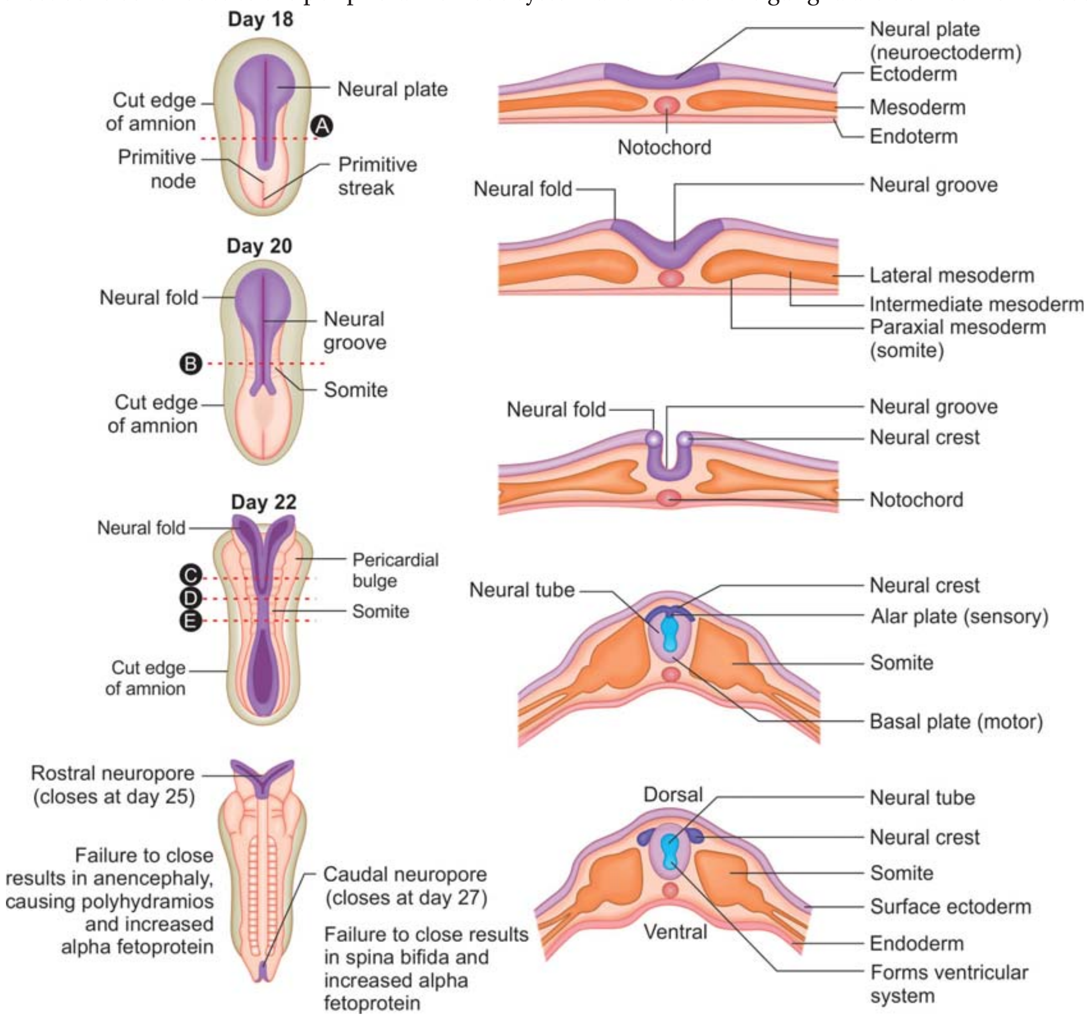


Fig. 13: Nervous system development

- Neural tube closure begins in the **cervical** region and proceeds **bidirectionally** towards cranial and caudal region (Langman's embryology).
- Moore embryology: Fusion of the neural tube starts in embryos with 4–6 somites, at the level of somites 1 and 2, forming the future rhombencephalon.
    - The tube closes caudally and rostrally, forming sequentially cervical and thoracic cord regions, then mesencephalic and prosencephalic brain regions.
    - Rostrally, two sites of fusion can be seen. The initial fusion, termed α, or the dorsal lip of the rostral neuropore, proceeds caudorostrally. A second site, termed β, or the terminal lip of the rostral neuropore, closes from the rostral end of the neural plate and proceeds rostrocaudally.
    - Closure of these lips of the rostral neuropore is completed when 19–20 pairs of somites are present.

Clinical Correlations

Spina bifida is a developmental anomaly characterized by defective closure of the vertebral arch associated with maternal folic acid deficiency and is classified as various types.

- **Alpha fetoprotein** (AFP) is found in the amniotic fluid and maternal serum. It is an indicator of neural tube defects (e.g., spina bifida, anencephaly). AFP levels are reduced in mothers of fetuses with Down syndrome.
- Neural tube defect **Prophylaxis**: Women who may become pregnant are advised to get 400 micrograms of folic acid daily. Women who are pregnant should receive 1.0 mg (1000 mcg), and women who have previously given birth to a child with a neural tube defect should get 4.0 mg/5.0 mg daily, beginning one month before they start trying to get pregnant and continuing through the first three months of pregnancy.

Table 2: Congenital defects of the nervous system

Condition	Clinical features
Spina bifida	• Improper closure of posterior neuropore • Several forms: A. *Spina bifida occulta* (mildest form): Failure of vertebrae to close around spinal cord (tufts of hair often evident). No ↑ AFP B. *Spinal meningocele* (spina bifida cystica): Meninges extend out of defective spinal canal, ↑ AFP C. *Meningomyelocele*: Meninges and spinal cord extend out of spinal canal. ↑ AFP D. *Myeloschisis* (most severe form): Neural tissue is visible externally. ↑ AFP
Anencephaly	• Failure of brain and cranium to develop • Caused by lack of closure of anterior neuropore • Associated with increased maternal α– fetoprotein (AFP) and polyhydramnios • Severe cranial nerve defects
Hydrocephaly	• Accumulation of cerebrospinal fluid (CSF) in ventricles and subarachnoid space • Caused by congenital blockage of cerebral aqueducts • Increased head circumference in neonates
Dandy-Walker malformation	• Dilation of fourth ventricle leading to hypoplasia of cerebellum • Failure of formaina of Luschka and Magendie to open
Arnold-Chiari malformation Type II	• Herniation of the *cerebellar vermis* through the foramen magnum • Hydrocephaly • Myelomeningocele and syringomyelia • Newborn
Fetal alcohol syndrome	• *Most common cause of intellectual disability* • *Cardiac septal defects* • Facial malformations including widely spaced eyes and long philtrum • Growth retardation

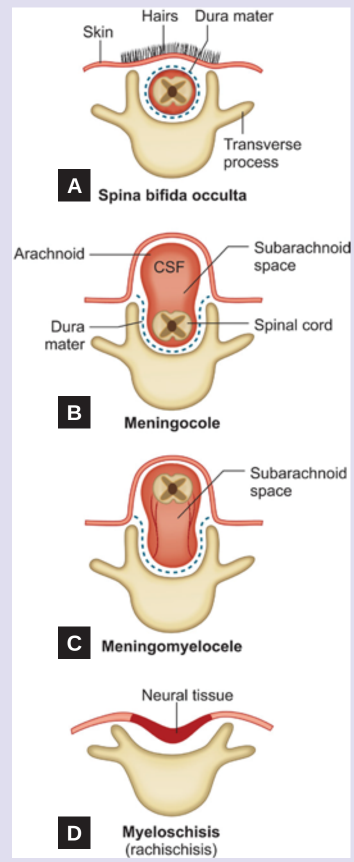


Fig. 14: Spina bifida

Schizencephaly is a neuron migration disorder leading to clefts in the brain, which extend from the CSF cavity (ventricles) and reach till the surface of brain. t

- It is characterized by abnormal continuity of grey matter tissue extending from the ependyma lining of the cerebral ventricles to the pial surface of the cerebral hemisphere surface.

Porencephaly is a type of cephalic disorder involving encephalomalacia, leads to formation of a cyst or cavity in a cerebral hemisphere that are usually the remnants of destructive lesions, but are sometimes the result of abnormal development.

- The disorder can occur before or after birth. In contrast to the schizencephaly lesions, the cysts are lined by white matter and the lesion does not reach the surface of the brain.

Tethered spinal cord (filum terminale syndrome) results from a thick, short filum terminale.
- It leads to weakness and sensory deficits in the lower extremity and a neurogenic bladder.

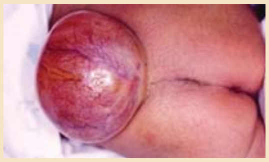
Dandy–Walker syndrome presents with huge cyst in the posterior fossa associated with atresia of the outlet foramina of the fourth ventricle.
- It is accompanied by dilation of the fourth ventricle, agenesis of the cerebellar vermis, occipital meningocele, and frequently agenesis of the splenium of the corpus callosum.

Arnold Chiari malformation is a cerebello medullary malformation where the caudal vermis, cerebellar tonsils, and medulla herniate through the foramen magnum and result in an obstructive hydrocephalus.
- It is frequently associated with spina bifida (meningomyelocele) and platybasia, with malformation of the occipitovertebral joint.
- Patients may present with dysphonia, laryngeal stridor, and respiratory arrest due to involvement of vagus nerve.

ASSESSMENT QUESTIONS

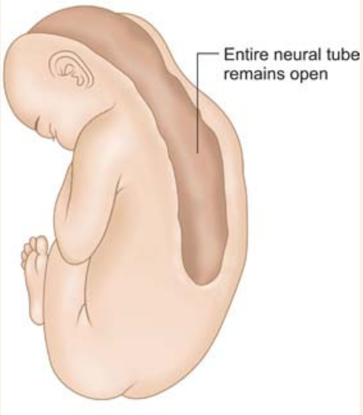
1. **Identify the anomaly:** *(AIIMS 2014)*
   a. Anencephaly
   b. Rachischisis
   c. Craniorachischisis
   d. Meningoencephalocele

2. **Identify the congenital anomaly:** *(AIIMS 2015)*
   a. Rachischisis
   b. Meningocele
   c. Meningomyelocele
   d. Meningoencephalocele



ANSWERS WITH EXPLANATIONS

1. **c. Craniorachischisis**
   - This clinical case is craniorachischisis is the most severe form of dysraphism. It occurs due to total failure of neural tube closure.
   - Brain and spinal cord are exposed to the surrounding amniotic fluid, resulting in necrosis, degeneration or angioma-like formations.

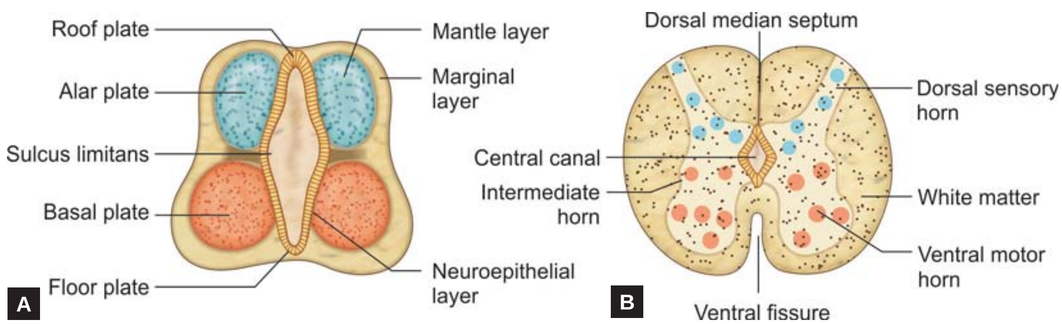


Craniorachischisis

2. **c. Meningomyelocele**
   - The present case shows a cystic swelling in the lumbosacral region, filled with fluid and has visible neural tissue as well, indicative of meningomyelocele.
   - In Myelomeningocele, the skin is intact, and the placode-containing remnants of nervous tissue is observed in the center of the lesion, which is filled with cerebrospinal fluid.

Neural Tube

Layers of the neural tube wall:
- **Neuroepithelial** (ventricular) layer is the innermost layer having ependymal cells that lines the central canal and developing brain ventricles.
- **Mantle** (intermediate) layer is the middle layer consisting of neurons and glial cells, gets organized into a pair of anterior (**basal**) plates and posterior (**alar**) plates.
- **Marginal** layer is the outermost layer containing nerve fibers of neuroblasts of the mantle layer and glial cells. It forms the white matter of the spinal cord through the myelination of axons growing into this layer.



Figs. 15A and B: A. Layers of neural tube and the alar & basal plates giving origin to ventral horn cells and dorsal horn cells (B)

- **Alar plate** is the posterolateral thickening of the mantle layer of the neural tube which give rise to second-order **sensory** neuroblasts of the posterior horn (general somatic afferent and general visceral afferent) cell regions.
  - It becomes the dorsal horn of the spinal cord and receives axons from the spinal ganglion which form the dorsal roots.
- **Basal plate** is the anterolateral thickening of the mantle layer of the neural tube giving rise to the **motor** neuroblasts of the anterior horn (general somatic efferent) and lateral horns (general visceral efferent) cell regions.
  - It becomes the anterior horn of the spinal cord and the axons from motor neuroblasts exiting the spinal cord form the anterior roots.
- **Sulcus limitans** is the longitudinal groove in the lateral wall of the neural tube that appears during the fourth week and **separates** the alar (sensory) and the basal (motor) plates.
  - It extends from rostral midbrain to the spinal cord, disappears in the adult spinal cord but is retained in the rhomboid fossa of the brainstem.
  - **Sulcus limitans** is present between the two plates; dorsally and ventrally, they are connected by non-neurogenic structures (**roof plate** and **floor plate**).
  - Floor plate contains the anterior white commissure.

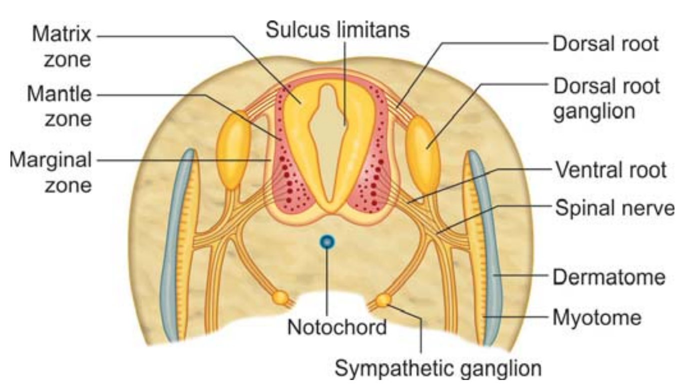


Fig. 16: Differentiation of the neural tube into three distinct layers, zones, and associated structures

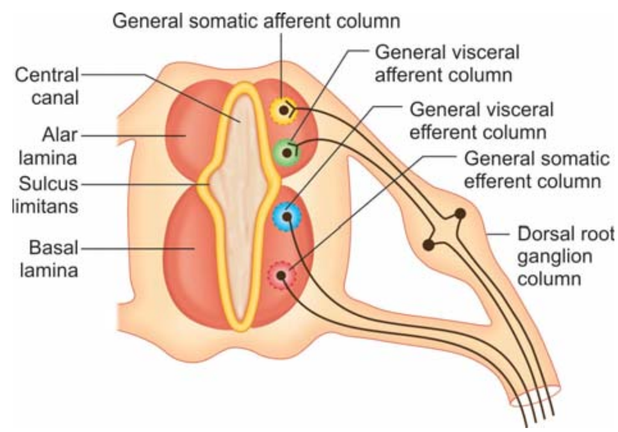


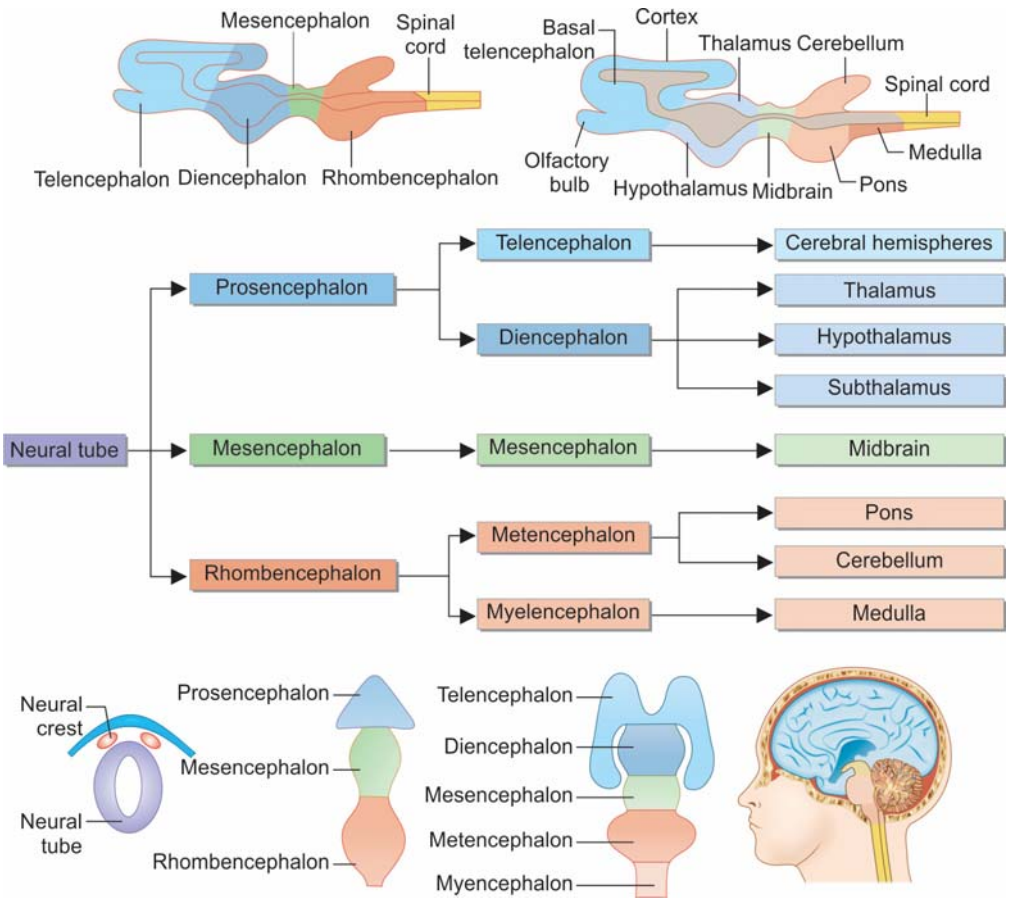
Fig. 17: Transverse section of the developing spinal cord showing four longitudinal cell columns

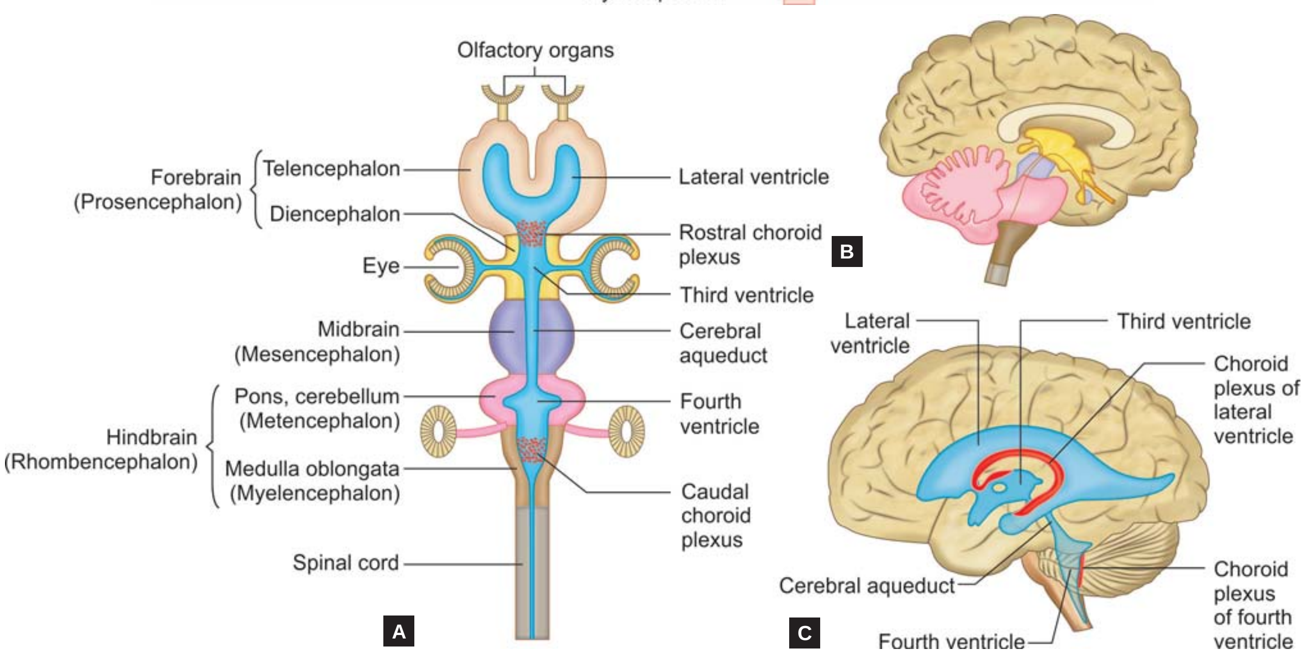
Myelination begins in the fourth month (intrauterine life) in the spinal cord motor roots.
- Myelination of the corticospinal tracts is not complete until the end of the second postnatal year.
- Myelination of the association neocortex extends into the third decade.

Brain Development

- **Three primary** brain vesicles and associated flexures develop during the fourth week.
  - **Prosencephalon** (forebrain) further divides into telencephalon and diencephalon.
  - **Mesencephalon** (midbrain)
  - **Rhombencephalon** (hindbrain) gives rise to metencephalon (pons and cerebellum) and myelencephalon (medulla oblongata).
- **Cephalic** flexure (midbrain flexure) is located between the prosencephalon and the rhombencephalon and **cervical** flexure is located between the rhombencephalon and the future spinal cord.
- **Five secondary** brain vesicles (with four ventricles) appear in the sixth week, which form the five major divisions of brain
  - **Telencephalon** develops an out pocketing that form the **cerebral hemispheres** and olfactory bulbs. its ventricles are called as **lateral ventricles**.
  - **Diencephalon** has the **thalamus** and the related thalami, with **third ventricle**. Its extensions form the optic nerves, neurohypophysis etc.

- **Mesencephalon** presents with the cerebral **aqueduct** of Sylvius.
- **Metencephalon** is separated from the mesencephalon by the **rhombencephalic isthmus** and from the myelencephalon by the **pontine flexure**.
  - It forms the **pons** and has rhombic lips on the dorsal surface that give rise to the **cerebellum**.
  - Rostral half of the **fourth ventricle** is present in metencephalon.
- **Myelencephalon** is present between the pontine and cervical flexures and forms the **medulla oblongata**.
  - Upper half of the medulla oblongata has **fourth ventricle** and lower half has **central canal**.





Figs. 18A to C: Major divisions of the brain. A. The major features of the basic brain plan, including their relationships to the major special sensory organs of the head. B. The corresponding regions in the adult brain, seen in sagittal section. C. The organization of the ventricular system in the brain

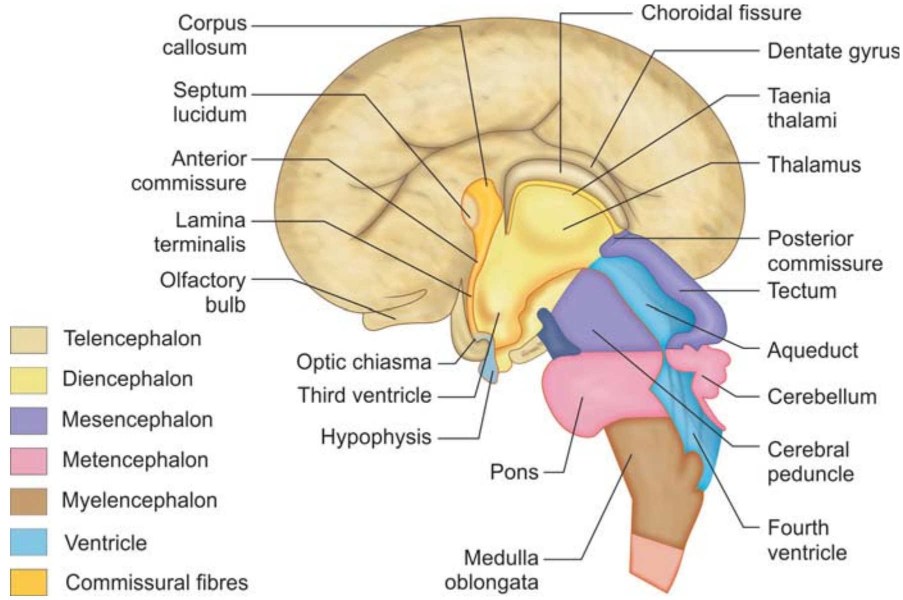
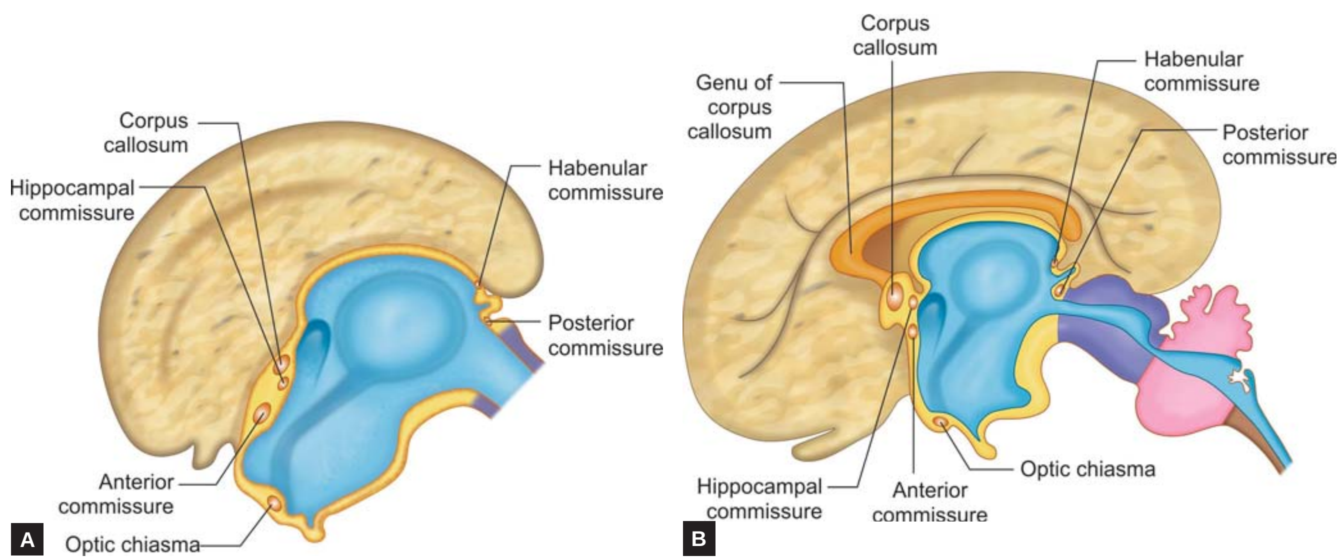


Fig. 19: Sagittal section of brain showing the developing anterior and posterior commissures

Cerebral hemispheres develop further into frontal, parietal, occipital, and temporal lobes.

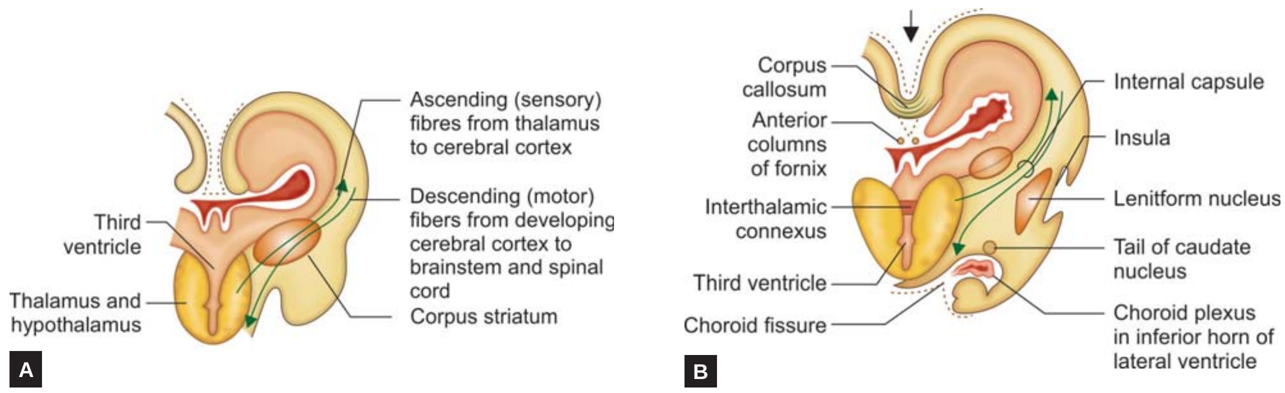
- The temporal lobes overlie the insula and posterior brainstem.
- Telencephalon gives rise to commissural tracts that integrate the activities of the left and right cerebral hemispheres: the corpus callosum, anterior commissure, and hippocampal commissure.
  - **Anterior commissure** is the first commissure to appear and interconnects the olfactory structures and the middle and inferior temporal gyri.
  - **Hippocampal commissure** (fornix) is the second commissure to appear which interconnects the two hippocampi.
  - **Corpus callosum** is the third commissure to appear interconnects the corresponding neocortical areas of the two cerebral hemispheres.
- The small posterior and habenular commissures develop from the epithalamus.



Figs. 20A and B: Sagittal sections showing the formation of commissures

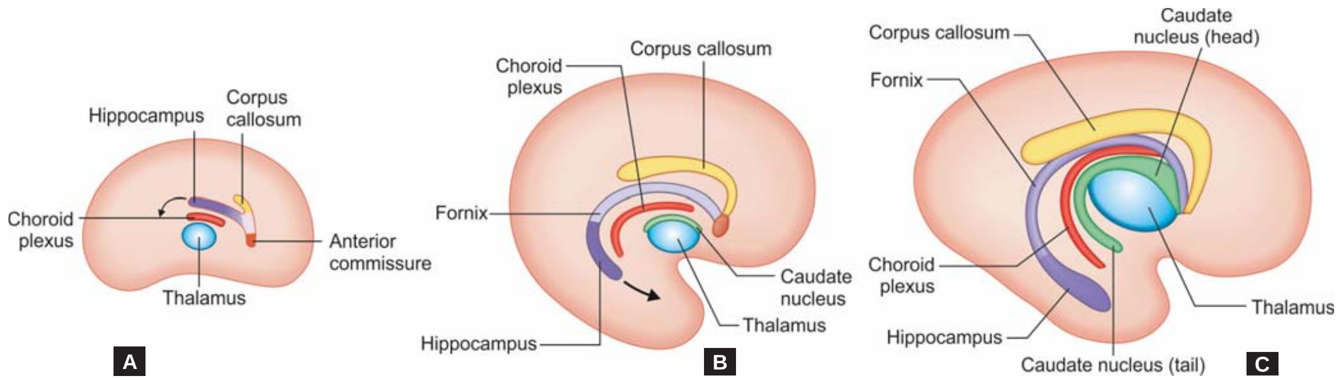
Corpus striatum appears as a bulging eminence on the floor of the lateral **telencephalic** vesicle.

- It forms the **caudate** nucleus, **putamen**, **amygdaloid** nucleus, and **claustrum**.
- The neurons of the **globus pallidus** originate in the subthalamus; they migrate into the telencephalic white matter and become the medial segments of the lentiform nucleus.
- **Corpus striatum** is divided into the **caudate** nucleus (medially) and the **lentiform** nucleus (laterally) by some projection fibres which make up the **internal capsule**.



Figs. 21A and B: Coronal sections of developing forebrain showing development of corpus striatum and internal capsule

Hippocampus which is initially dorsal to the thalamus migrates **into the temporal lobe** and several brain components gradually assume **'C' curvature** with thalamus at the centre: the cerebrum, corpus callosum, choroid plexus, fornix, caudate nucleus. Caudate nucleus has a head, body and tail eventually.



Figs. 22A to C: Coronal section of the developing brain components, showing the 'C' curvature assumed by the cerebrum, corpus callosum, choroid plexus, fornix, caudate nucleus, with thalamus at the centre

Neural Crest Cells

Ectodermal Placodes

- Before the neural tube closes, the elevating neural folds contain two distinctive neuronal populations. The larger population, **neural crest cells**, migrates from the neural epithelium prior to the fusion of neural tube and the smaller population, **neuroepithelial cells**, becomes incorporated into the surface ectoderm after neural tube closure.
- These areas of **neuroepithelium** within the surface ectoderm have been termed **ectodermal placodes**. Majority of the ectodermal placodes form nervous tissue and few of them are non-neurogenic placodes.
- After an appropriate inductive stimulus, placodes present as **localized thickenings** of the cephalic surface ectoderm and either they generate **migratory neuronal cells** that will contribute to the cranial sensory ganglia, or the whole placodal region invaginates to form a **vesicle** beneath the remaining surface ectoderm.
- **Otic placodes** are the first placodes visible on the surface of the embryo and forms the otic pit and the otic vesicle, giving rise eventually to inner ear (hearing and equilibrium).
- **Olfactory** (Nasal) placodes have 2 components (medial and lateral) and form the nose olfactory epithelium.
- **Optic** (Lens) placodes which form the lens, lie on the surface adjacent to the out pocketing of the diencephalon (which forms retina).
- **Trigeminal** placode gives rise to the cells of the trigeminal ganglion
- **Adenohypophyseal** placode forms the anterior lobe of the pituitary gland.

ASSESSMENT QUESTIONS

1. Mesodermal in origin: *(NEET Pattern 2012)*
a. Astrocytes b. Oligodendrocytes
c. Ependymal cells d. Microglial cells

2. All of these arises from neuroepithelial cells EXCEPT: *(NEET Pattern 2013)*
a. Neuron b. Oligodendrocyte
c. Microglial cells d. Ependymal cells

3. Neural tube begin to close from which region? *(AIPG 2009)*
a. Cranial b. Cervical
c. Thoracic d. Lumbar

4. Caudal neuropore closes at day:
a. 20 b. 25
c. 28 d. 30

5. Alpha-fetoprotein levels are elevated in all EXCEPT:
a. Anencephaly
b. Myeloschisis
c. Omphalocele
d. Down syndrome

6. Spinal cord develops from: *(NEET Pattern 2014)*
a. Neural tube
b. Mesencephalon
c. Rhombencephalon
d. Prosencephalon

7. Brainstem nucleus NOT derived from alar plate: *(AIIMS 2008)*
a. Dentate
b. Inferior olivary
c. Hypoglossal
d. Substantia nigra

8. The retina is an outgrowth of the: *(NEET Pattern 2014)*
a. Mesencephalon
b. Diencephalon
c. Telencephalon
d. Pons

9. First commissure is develop: *(NEET Pattern 2013)*
a. Corpus callosum
b. Anterior commissure
c. Hippocampus
d. None of the above

10. All are disorders due to non-migration of neural crest cells all EXCEPT: *(AIIMS 2011)*
a. Porencephaly
b. Lissencephaly
c. Microgyria with ballooning
d. Schizencephaly

ANSWERS WITH EXPLANATIONS

1. d. Microglial cells
- During hematopoiesis, some of the stem cells differentiate into monocytes and travel from the bone marrow to the brain, where they settle and further differentiate into microglia.
- Microglia cells are derived from neuroectoderm and include: Astrocytes, oligodendrocytes, ependymal cells, Schwann cells.

2. c. Microglial cells
- Microglia cells are **mesenchymal** in origin.
- During hematopoiesis, some of the stem cells differentiate into monocytes and travel from the bone marrow to the brain, where they settle and further differentiate into **microglia**.

3. b. Cervical
- Neural tube closure begins in the cervical region and proceeds bidirectionally towards cranial and caudal region (Langman's embryology).

4. c. 28
- Caudal (posterior) neuropore closes three days later (25+3) to cranial (anterior) neuropore.

5. d. Down syndrome
- In Down syndrome Alpha-fetoprotein levels are down.

6. a. Neural tube
- Neural tube develops into brain and spinal cord.
- Brain: Forebrain (Prosencephalon); Midbrain (Mesencephalon); Hindbrain (Rhombencephalon)

7. c. Hypoglossal
- Hypoglossal nucleus is a pure **motor** nucleus derived from the anterior **basal** plate of neural tube.
- Posterior **alar** plate gives **sensory** nuclei.

8. b. Diencephalon
- **Diencephalon** extends into the eyeball to become **retina** and **optic nerve**.

9. b. Anterior commissure
- The first axon tract to develop is the anterior commissure, which forms during the seventh week and interconnects the corresponding areas of the two cerebral hemispheres.
- The anterior commissure connects the 2 olfactory bulbs by its anterior processes and the 2 convolutions of the hippocampus (right and left temporal lobes) by its posterior processes.
- Its fibers pass in the inferior part of the lamina terminalis.

10. a. Porencephaly
- Neuronal migration disorders (NMDs) do not include **porencephaly**.
- Under neuronal migration disorders are **Lissencephaly**, **Microgyria**, **Schizencephaly**.
- **Lissencephaly**, which literally means smooth brain, is a rare brain formation disorder caused by defective neuronal migration during the 12th to 24th weeks of gestation, resulting in a lack of development of brain folds (gyri) and grooves (sulci).
- Terms such as 'agyria' (no gyri) or 'pachygyria' (broad gyri) are used to describe the appearance of the surface of the brain.
- **Microgyria** is a neuronal migration disorder, a developmental anomaly of the brain characterized by development of numerous small convolutions (microgyri), presenting with mental retardation. It is present in a number of specific neurological diseases, notably multiple sclerosis and Fukuyama congenital muscular dystrophy, a specific disease cause by mutation in the Fukutin gene. Alternate names for the condition are polygyria and micropolygyria.

CSF and Ventricles

- CSF (Cerebro Spinal Fluid) is the ultrafiltrate of blood produced in the choroid (capillary) plexuses of the ventricles of the brain.
- The first CSF (cerebro spinal fluid) is formed of amniotic fluid, and is later secreted by the choroid (capillary) plexus in the lateral ventricles (chiefly) and partly in third and fourth ventricles.
- It escapes from the lateral ventricle into third ventricle via **foramen of Monro**, passes through **aqueduct of Sylvius** into the fourth ventricle, then it enters **central canal** eventually.
- It escapes the ventricular space at the roof of fourth ventricles at three foramina (midline Magendie and two lateral Luschka) into the subarachnoid space. (Sub – under).

- CSF absorption from the sub-arachnoid space occurs by the arachnoid villi (granulations) projecting into the dural venous sinuses (e.g. superior sagittal sinus).
- **Dural venous sinus** is the intradural space (between two layers of dura mater), contains venous blood from several tributaries including veins of brain.
- The most important lymphatic CSF absorption pathway is along the **olfactory** nerve route but there are other nerves that may conduct CSF extracranially. Tracers injected into the CSF system appear to exit the cranium along almost all of the cranial nerves including the **optic**, trigeminal, **vestibulo-cochlear**, vagus and hypoglossal nerves.
- The total volume of CSF in the adult ranges from 140–270 mL. The volume of the ventricles is about 25 mL. CSF is produced at a rate of 0.2–0.7 mL per minute (600–700 mL per day), which means that the entire CSF volume is replaced approximately 4 times per day.

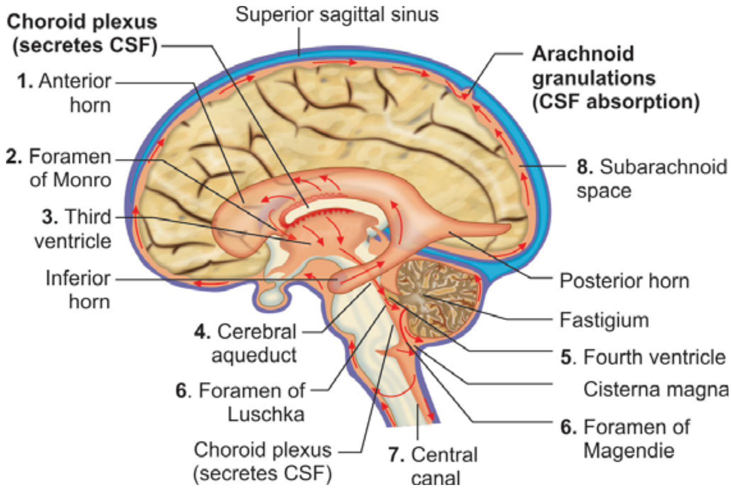


Fig. 23: Circulation of cerebrospinal fluid

CSF in lateral ventricles
↓
Interventricular foramina (of Monro)
↓
Third ventricle
↓
Cerebral aqueduct (of sylvius)
↓
Fourth ventricle
↓

- Central canal of the spinal cord
- Subarachnoid space around spinal cord and cauda equina → Pial veins of the spinal cord
- Foramina in the roof of the ventricle (foramen of magendie and foramina of luschka) → Cerebellomedullary and pontine cisterns → Tentoral notch → Inferior surface of cerebrum → Superolateral surfaces of cerebrum → Arachnoid villi and granulations → Superior sagittal sinus

Fig. 24: Circulation and absorption of CSF

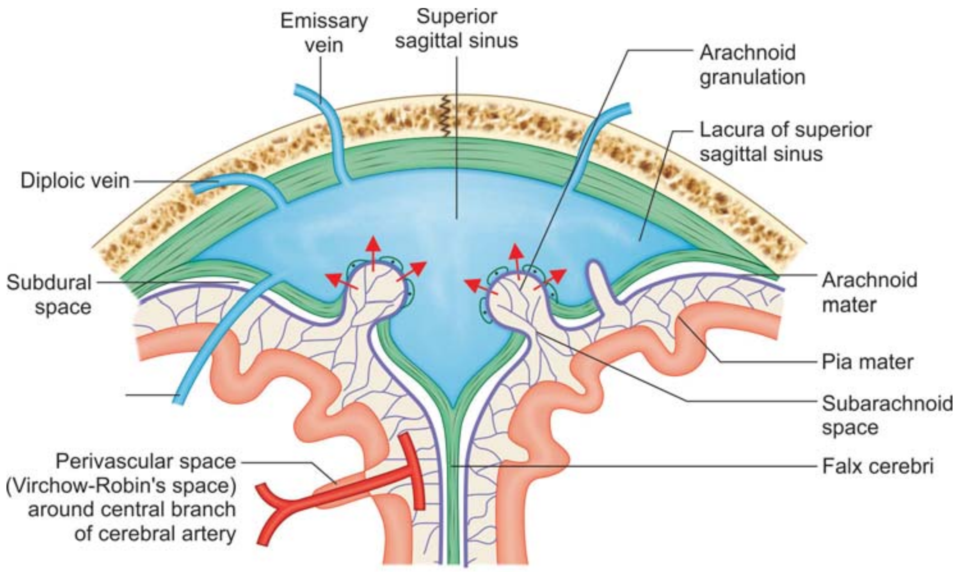


Fig. 25: Schematic coronal section through the superior sagittal sinus showing arachnoid granulations and absorption of the cerebrospinal fluid

Choroid plexus develops by the close apposition of vascular pia mater and ependyma without intervening nervous tissue.

- The vascular layer is infolded into the ventricular cavity and develops a series of small villous projections, each covered by a cuboidal epithelium derived from the ependyma.
- The cuboidal cells display numerous microvilli on their ventricular surfaces.

Clinical Correlations

Hydrocephalus is the dilation of the ventricles due to an excess of CSF. It may result from blockage of CSF circulation or overproduction of CSF.

- **Non-communicating** hydrocephalus may result from obstruction within the ventricles (e.g., congenital aqueductal stenosis).
- **Communicating** hydrocephalus results from blockage distal to the ventricles (e.g., adhesions after tuberculous meningitis).

CSF Cisterns of the Brain

Table 3: Location and vascular contents of various cisterns of the brain

Cistern	Location	Contents
Cerebellomedullary cistern/cisterna magna	In the interval between medulla oblongata and inferior surface of cerebellum	–
Pontine cistern/cisterna pontis	On the ventral surface of pons	Basilar artery and its branches
Interpeduncular cistern/basal cistern	At the base of brain in the interval between two temporal lobes	Circle of Willis (circulus arteriosus)
Cistern of lateral sulcus/sylvian cistern	In the stem of lateral sulcus in front of temporal pole	Middle cerebral artery
Cistern of great cerebral vein of Galen/ clsterna ambiens	In the interval between splenium of corpus callosum and superior surface of cerebellum	Great cerebral vein of Galen

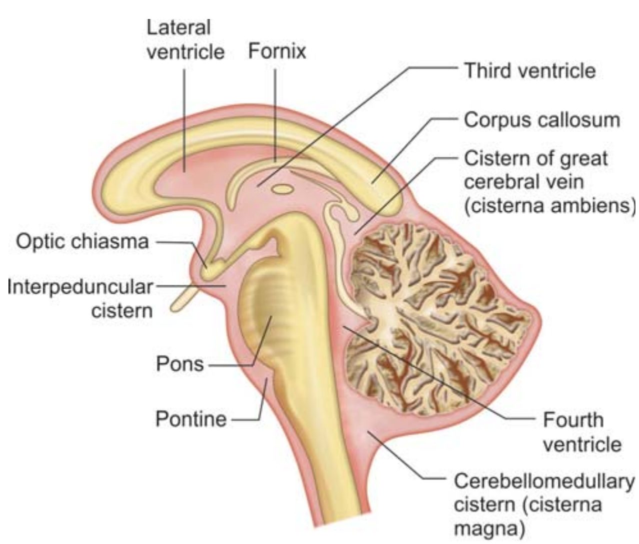


Fig. 26: Sagittal section of brain showing location of principal subarachnoid cisterns

Third ventricle is the ventricle of diencephalon and presents as a median cleft between the two thalami.

- **Thalamus and hypothalamus** are at the **lateral** wall of third ventricle.
- **Lamina terminalis** is at the **anterior** wall of third ventricle.
- The anterior part of the **floor** of the third ventricle is formed mainly by **hypothalamic** structures.
  - Immediately behind the **optic chiasma** lies the thin **infundibular recess**, which extends into the pituitary stalk.
  - Behind this recess, the **tuber cinereum** and the **mammillary bodies** form the floor of the ventricle.
- **Pineal gland** is at the **posterior** wall of third ventricle.
- **Roof** is formed by the **ependyma**, lining the undersurface of the tela choroidea of the third ventricle.
- Certain regions of the lining of the third ventricle become highly specialized, and develop concentrations of tanycytes or other modified cells that are collectively termed the **circumventricular organs**, e.g. the subfornical organ, the organum vasculosum (intercolumnar tubercle) of the lamina terminalis, the subcommissural organ, and the linings of the pineal, suprapineal and infundibular recesses.

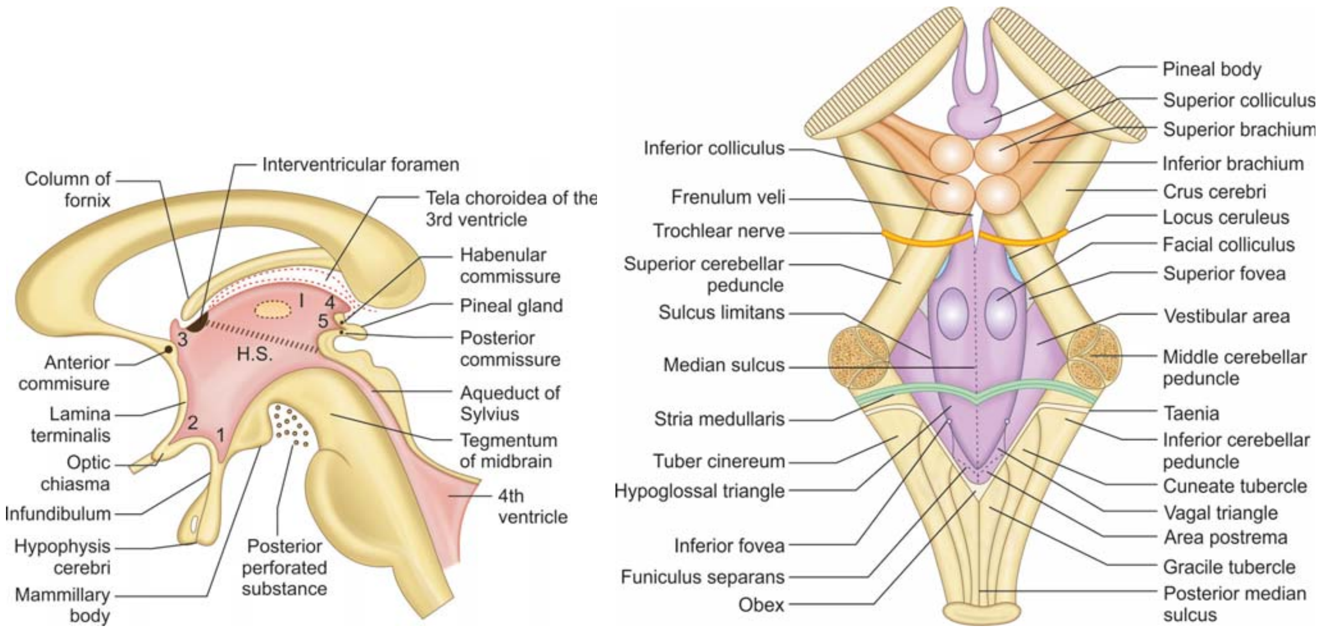


Fig. 27: Boundaries and recesses of the 3rd ventricle as seen in sagittal section (HS - hypothalmic sulcus, I - interthalamic adhesion, 1 - infundibular recess, 2 - optic recess, 3 - anterior recess, 4 - suprapineal recess, 5 - pineal recess)

Fourth ventricle is located within the pons and the upper part of the medulla.

- **Roof** of the fourth ventricle is formed by the **cerebellum** (superior and inferior medullary vela).
- **Floor** of the fourth ventricle is formed by the rhomboid fossa. Structures present at the floor of the fourth ventricle are:
  - **Facial colliculus** is the rounded elevation formed by the axons of facial nerve as they loop around (internal genu) the abducens nucleus in the lower pons.
  - Lesion to the facial colliculus results in ipsilateral facial paralysis and ipsilateral unopposed eye medial deviation.
  - **Obex** represents the caudal tip of the fourth ventricle. It is a marker for the level of the foramen magnum of the skull and the imaginary dividing line between the medulla and spinal cord.
  - **Median sulcus** divides the floor into right and left halves. It extends from cerebral aqueduct of the midbrain to central canal of the spinal cord.
  - **Stria medullaris** are the fibers derived from arcuate nuclei, which emerge from the median sulcus and run transversely across the floor to enter into the inferior cerebellar peduncle.
  - **Medial eminence** are the elevations on either side of the median sulcus and are laterally bounded by sulcus limitans.
  - **Sulcus limitans** represents the border between the alar plate and the basal plate of the developing neural tube.
  - The upper end of the sulcus limitans widens into a triangular depression **superior fovea**. Above the superior fovea sulcus limitans presents a flattened grey area called **locus ceruleus**.
  - The lower end of the sulcus limitans widens into a triangular depression **inferior fovea**.
  - **Vestibular area** is over the vestibular nuclei and lies lateral to sulcus limitans.
  - **Vagal trigone** is the prominence in the floor of the inferior fovea that overlies the dorsal motor nucleus of the vagus.
  - **Hypoglossal trigone** is the slight elevation in the floor of the inferior recess beneath which lies the nucleus of the hypoglossal nerve.

ASSESSMENT QUESTIONS

1. TRUE about cerebrospinal fluid is: *(PGIC 2000)*
a. Produced by choroid plexus
b. Travels from sub-arachnoid space to the fourth ventricle
c. Absorbed by arachnoid villi
d. Drains into the dural venous sinuses
e. Aqueductal stenosis dilates 4th ventricle

2. CSF escapes the fourth ventricle through: *(PGIC 2000)*
a. Foramen of Monro
b. Aqueduct of Sylvius
c. Luschka foramen
d. Magendie foramen
e. Arachnoid granulations

3. The arachnoid villi responsible for cerebrospinal fluid absorption protrude mainly in the: *(AIIMS 2002)*
a. Superior sagittal sinus b. Inferior sagittal sinus
c. Straight sinus d. Transverse sinus

4. Diencephalon represents: *(NEET Pattern 2012)*
a. Lateral ventricle b. 3rd ventricle
c. 4th ventricle d. Aqueduct of Sylvius

5. Cavity of mesencephalon: *(NEET Pattern 2013)*
a. Lateral ventricle b. Third ventricle
c. Cerebral aqueduct d. Fourth ventricle

6. Ventricles of brain are lined by: *(NEET Pattern 2015)*
a. Ependymocytes b. Astrocytes
c. Oligodendrocytes d. Podocytes

7. Anterior horn of lateral ventricle is closed anteriorly by: *(NEET Pattern 2015)*
a. Thalamus b. Septum pellucidum
c. Lamina terminalis d. Corpus callosum

8. Lateral ventricle is connected in third ventricle by: *(NEET Pattern 2013)*
a. Foramen of Monro b. Foramen of Luschka
c. Foramen of Magendie d. Median foramen

9. Pineal gland forms: *(NEET Pattern 2013)*
a. Floor of third ventricle
b. Anterior wall of third ventricle
c. Posterior wall of third ventricle
d. Roof of third ventricle

10. Floor of third ventricle is formed by all EXCEPT: *(NEET Pattern 2015)*
a. Tuber cinereum
b. Posterior perforated substance
c. Tegmentum
d. Anterior pituitary

11. Foramen of Magendie is the central opening of: *(NEET Pattern 2013)*
a. Lateral ventricle b. 4th ventricle
c. 3rd ventricle d. None

12. All are seen in the floor of 3rd ventricles EXCEPT: *(AIIMS 2013)*
a. Infundibulum b. Oculomotor nerve
c. Mammillary body d. Optic chiasma

13. All are seen in the floor of the fourth ventricle EXCEPT:
a. Vagal triangle b. Hypoglossal triangle
c. Vestibular area d. Stria terminalis

14. Floor of 4th ventricle has: *(NEET Pattern 2015)*
a. Infundibulum b. Vagal triangle
c. Mammillary body d. Tuber cinerium

15. Floor of fourth ventricle contains all EXCEPT: *(JIPMER 2011)*
a. Abducent nucleus b. Facial nucleus
c. Dorsal vagal nucleus d. Hypoglossal nucleus

16. Facial colliculus located at: *(AIPG 2008)*
a. Pons b. Medulla
c. Mid brain d. Interpeduncular fossa

17. Which cranial nerve nucleus lies under the facial colliculus: *(AIIMS 2014,15)*
a. Fifth
b. Sixth
c. Seventh
d. Eighth

18. Diagram of fourth ventricle is given with the facial colliculus marked. Damage to the structure producing the elevation marked leads to paralysis of which of the following muscle? *(AIIMS 2016)*
a. Lateral rectus
b. Risorius
c. Levator palpebrae superioris
d. Superior oblique

ANSWERS WITH EXPLANATIONS

1. a. Produced by choroid plexus; c. Absorbed by arachnoid villi; d. Drains into dural venous sinuses.
- CSF moves out of fourth ventricle into the sub-arachnoid space.
- Aqueductal stenosis dilates the proximal ventricles 1 ,2 and 3 (and not 4th).

2. c. Luschka foramen; d. Magendie foramen
- CSF escapes the fourth ventricle into the sub-arachnoid space via three foramina: One midline Magendie and two lateral Luschka.

3. a. Superior sagittal sinus
- CSF absorption from the sub-arachnoid space occurs by the arachnoid villi (granulations) projecting into the dural venous sinuses, mainly into superior sagittal sinus.

4. b. 3rd ventricle
- Third ventricle is the midline ventricle located in diencephalon.

5. c. Cerebral aqueduct
- Cerebral aqueduct of Sylvius is a cavity within the mesencephalon (midbrain), connects the third ventricle in the diencephalon to the fourth ventricle within the region of mesencephalon.

6. a. Ependymocytes
- Ependymocytes are cuboidal or columnar in shape with tuft of cilia on their luminal surfaces and constitute the majority of the ependymal cells that line the ventricles of the brain and central canal of the spinal cord.

7. d. Corpus callosum
- The anterior horn of the lateral ventricle lies anterior to its central part, the two being separated by an imaginary vertical line drawn at the level of the interventricular foramen.
- Anterior horn is closed anteriorly by the genu and rostrum of the corpus callosum.

8. a. Foramen of Monro
- Foramen of Monro allows cerebrospinal fluid (CSF) produced in the lateral ventricles to reach the third ventricle.

9. c. Posterior wall of third ventricle
- The posterior boundary of the ventricle is marked by a suprapineal recess, the habenular commissure, a pineal (epiphyseal) recess, which extends into the pineal stalk, and by the posterior commissure.

10. d. Anterior pituitary
- Floor of third ventricle has infundibular recess, which extends into the pituitary stalk (not anterior pituitary).

11. b. 4th ventricle
- Foramen of Magendie drains cerebrospinal fluid (CSF) from the fourth ventricle into the subarachnoid space (cisterna magna).
- The paired lateral foramina of Luschka drain cerebrospinal fluid from fourth ventricle into the cerebellopontine angle cistern.

12. b. Oculomotor nerve
- Oculomotor nerve is not in the floor of 3rd ventricle, it passes under the floor, in the interpeduncular fossa.
- The anterior part of the floor of the third ventricle is formed mainly by hypothalamic structures.
- Immediately behind the optic chiasma lies the thin infundibular recess, which extends into the pituitary stalk.
- Behind this recess, the tuber cinereum and the mammillary bodies form the floor of the ventricle.

13. d. Stria terminalis
- Abducent (6), vestibular (8), vagus (10), hypoglossal (12) nuclei are at the floor of 4th ventricle.

14. b. Vagal triangle
- Floor of 4th ventricle has areas related to Abducent (6), vestibular (8), vagus (10), hypoglossal (12) nuclei.

15. b. Facial nucleus
- Facial nucleus is not present in the floor of the fourth ventricle.
- Facial colliculus is raised due to the axons of facial nerve winding around the abducent nucleus.

16. a. Pons
- Facial colliculus is a rounded elevation seen in the floor of 4th ventricle, at the posterior aspect of lower pons.
- It is raised due to the axons of facial nerve winding around the abducent nucleus.
- There are 2 facial colliculi in the floor of fourth ventricle.
- Mid brain shows 4 rounded elevations on its posterior aspect: 2 superior and 2 inferior colliculi.
- Interpeduncular fossa shows 2 rounded elevations - mammillary bodies in it.
- Medulla has 2 rounded elevations on the anterior aspect, called as the olives.

17. b. Sixth
- Facial colliculus is raised due to the axons of facial nerve winding around the abducent nucleus.
- It is the facial nerve axons (and not the abducent nucleus) that raises the elevation called facial colliculus.

18. b. Risorius
- Facial colliculus is a rounded elevation formed by the axons of facial nerve (and not by the abducent nucleus deep to it).
- Damage to the facial nerve axons paralyses muscles of facial expression like risorius.

Cerebrum

Cerebrum is the highest and largest part of brain to control and modulate emotions, personality, hearing, vision, and voluntary activities.

It is made up of the two cerebral hemispheres having the outer layers of cortex (grey matter) and the underlying regions of axons (white matter).

- Cerebral cortex is folded into ridges (gyri) and furrows (sulci) to increase the surface area.
- The two cerebral hemispheres are separated from each other by a deep fissure called the longitudinal fissure.
- Cerebral hemisphere is divided into six lobes: frontal, parietal, occipital, temporal, insular and limbic lobes.
- Frontal, parietal, temporal, and occipital lobes named upon their overlying neurocranial bones.
- Dominant hemisphere is responsible for propositional language consisting of grammar, speech and calculations.
  - The left hemisphere is dominant in 95% of cases.
  - Nondominant hemisphere is primarily responsible for three-dimensional or spatial perception and nonverbal ideation (music and poetry).

Cerebral cortex consists of the neocortex (90%) and the allocortex (10%).

- Neocortex has six layers and allocortex three.
- Allocortex itself is two types:
  - Archicortex which includes the hippocampus and the dentate gyrus.
  - Paleocortex which includes the olfactory cortex.

The six layers in the neocortex:

- Layers II and IV of the neocortex are mainly afferent and Layers V and VI are mainly efferent.
- Layer I is the molecular and layer II is the external granular.
- Layer III is the external pyramidal layer which gives rise to association and commissural fibers and is the major source of corticocortical fibers.
- Layer IV is the internal granular layer which receives thalamocortical fibers from the thalamic nuclei of the ventral tier (i.e., ventral posterolateral and ventral posteromedial).
  - In the visual cortex (Brodmann's area 17), layer IV receives input from the lateral geniculate body.
- Layer IV is the internal pyramidal layer and gives rise to corticobulbar, corticospinal, and corticostriatal fibers.
  - It contains the giant pyramidal cells of Betz, which are found only in the motor cortex (Brodmann's area 4).
- Layer VI is the multiform layer and is the major source of corticothalamic fibers.
  - It gives rise to projection, commissural, and association fibers.

Sulci in Cerebrum

Central sulcus (of Rolando) begins by cutting the superomedial border of the hemisphere about 1cm behind the midpoint between the frontal and occipital poles.

- It runs sinuously downwards and forwards at an angle of 70° and ends just above the lateral sulcus.
- Its upper end extends onto the medial surface.
- It is the boundary between the frontal motor area and the parietal sensory area posteriorly.

Lateral sulcus (of Sylvius) begins as a deep cleft on the inferior surface of the cerebral hemisphere at the anterior perforated substance.

- It extends laterally between the temporal pole and the posterior part of the orbital surface of the hemisphere.
- It continues posteriorly and slightly upwards across the lateral surface and ends in the inferior parietal lobule by an upturned posterior end.

Calcarine sulcus develops on the medial surface of the cerebral hemisphere.

- It begins below the posterior end of the splenium part of corpus callosum and follows an arched course with a convexity upwards to the occipital pole and extends upon the superolateral surface.

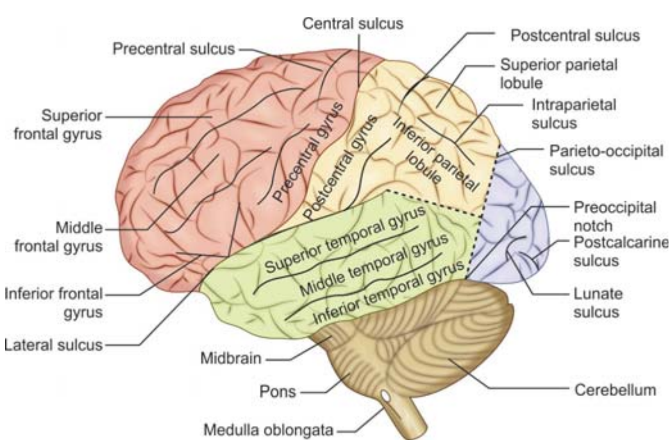


Fig. 28: Lateral aspect of the left side of the brain. Note the four lobes on the superolateral surface of the cerebral hemisphere

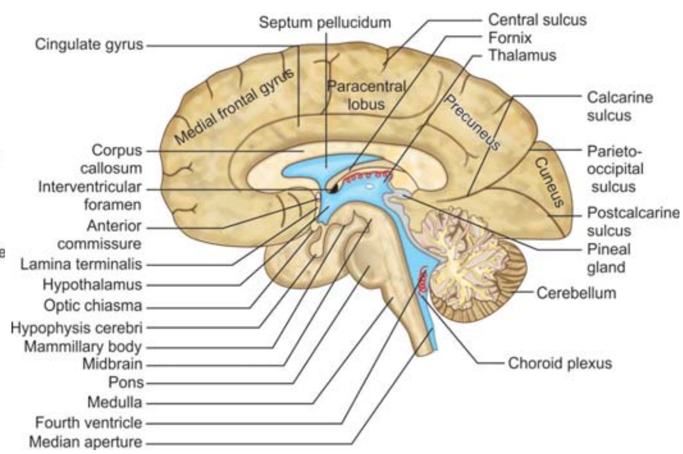


Fig. 29: Median sagittal section of the brain

Types of sulci: **Axial, limiting. operculated,** and **ctomplete**.

- **Axial sulci** develop along the long axis of rapidly growing homogeneous areas. They are longitudinally infolded (as seen in the **posterior part of calcarine sulcus** of the visual cortex).
- **Limiting sulci** develop along planes separating cortical areas, which differ in the functions. **Central sulcus** limiting frontal motor cortex from the parietal sensory cortex.
- **Operculated sulcus** is similar to a limiting sulcus in that it separates structurally and functionally different areas but the transition occurs at the lip and not the floor. Often a third area of function is present in the floor and walls of the sulcus. An example is the **lunate sulcus** (separating the striate and peristriate areas at the surface) which contains the peristriate area within its walls.
- **Complete sulcus** is deep enough to produce an elevation in the wall of a ventricle. For example, the **collateral sulcus** produces collateral eminence in the inferior horn of the lateral ventricle and the **anterior part of the calcarine sulcus** produces calcar avis in the medial wall of the occipital horn of the lateral ventricle.

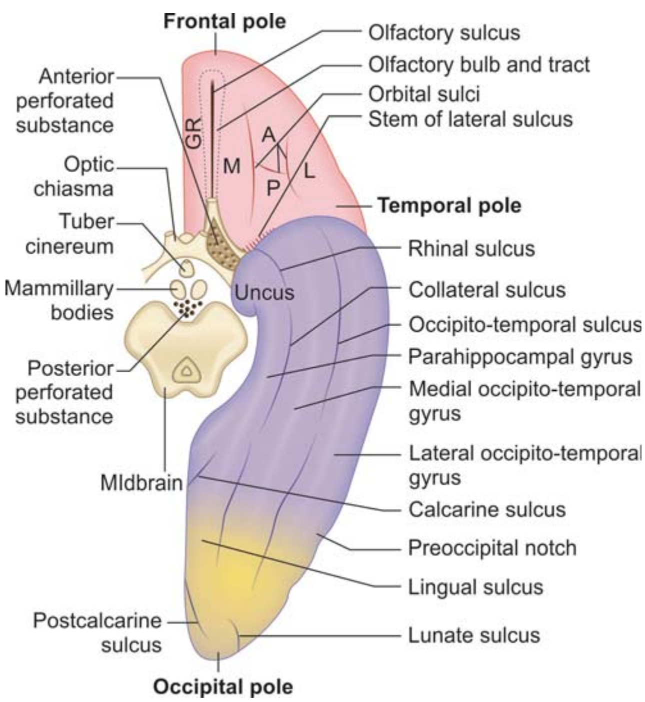


Fig. 30: Inferior surface of the cerebral hemisphere is divided into small anterior part, the orbital surface and large posterior part, the tentorial surface. Midbrain is seen in a transverse section

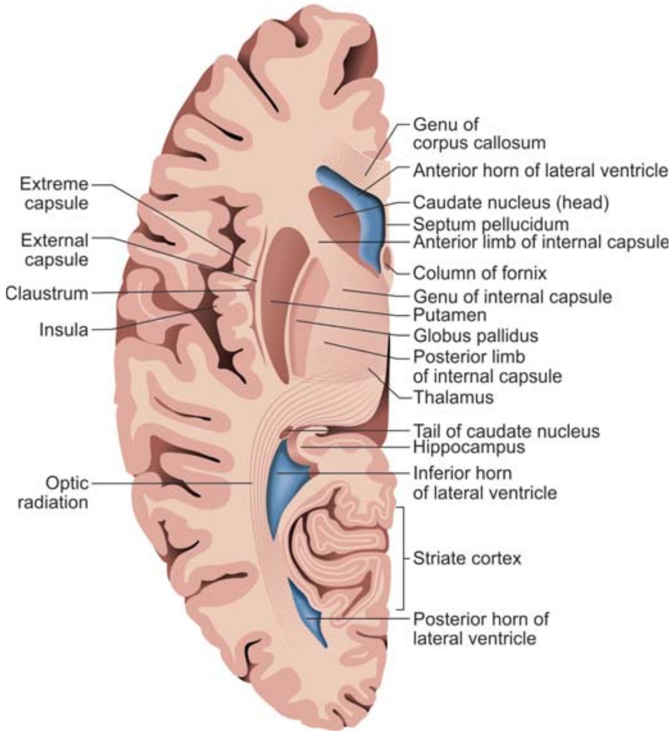


Fig. 31: The superior view of a horizontal section through the left cerebral hemisphere

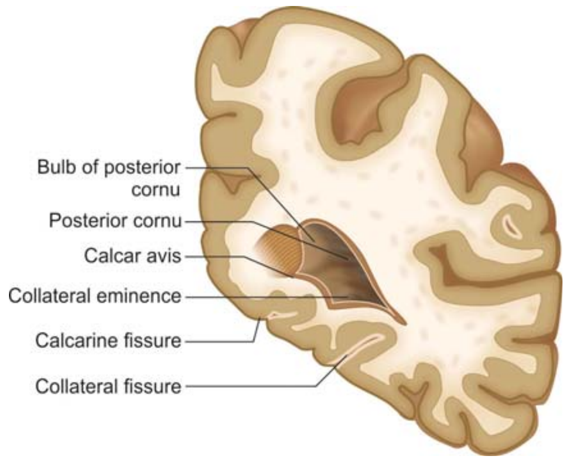


Fig. 32: Cut-section of cerebrum to show calcarine fissure (raising calcar avis) and collateral fissure (raising collateral eminence) into the depths of the cavity of lateral ventricle. These two sulci are thence called complete sulci

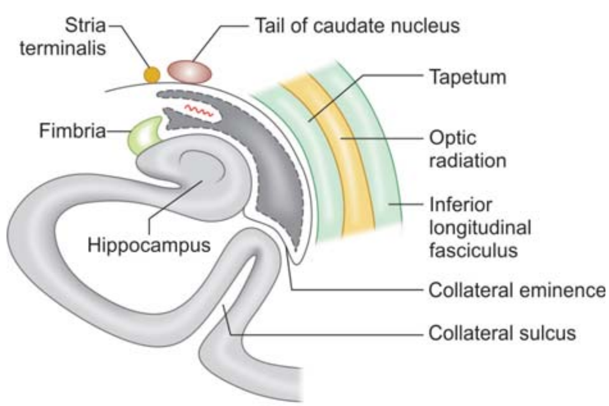


Fig. 33: Coronal section of brain showing boundaries of inferior horn of lateral ventricle

- **Insula** is a portion of the cerebral cortex folded deep within the floor of the lateral sulcus.
  - During development insula becomes hidden due to the overgrowth of the surrounding cortical areas and may be seen by pulling the lips of the lateral sulcus wide apart.
  - It is triangular in shape and surrounded entirely by the circular sulcus except anteroinferiorly at its apex (limen insulae).

High Yield Point

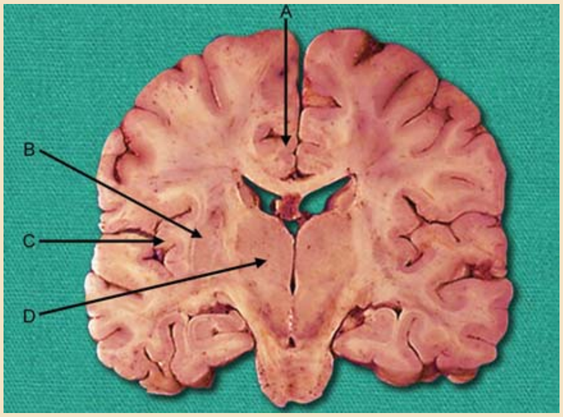
- Hippocampus is concerned with recent memory traces and is related to the inferior (temporal) horn of lateral ventricle.

ASSESSMENT QUESTIONS

1. **Which of the following is a complete sulcus?** *(NEET Pattern 2012)*
   a. Lunate sulcus b. Lateral sulcus
   c. Collateral sulcus d. Calcarine sulcus

2. Which of the following is an operculated sulcus: *(NEET Pattern 2012)*
a. Calcarine
b. Collateral
c. Lunate
d. Central

3. Identify Insula in the coronal section of brain: *(AIIMS 2016)*
a. A b. B
c. C d. D



ANSWERS WITH EXPLANATIONS

1. c. Collateral sulcus > d) Calcarine sulcus
- Complete sulcus is the one which is deep enough to reach the wall of the ventricle and raise an elevation on the interior wall.
- Inside the lateral ventricle, collateral sulcus invaginates to produces an elevation called **collateral eminence** and anterior part of calcarine sulcus (pre-calcarine sulcus) raises the elevation known as **calcar avis**.

2. c. Lunate
- **Operculated sulcus** is similar to a limiting sulcus in that it separates structurally and functionally different areas, but the transition occurs at the lip and not the floor.
- Often a third area of function is present in the floor and walls of the sulcus.
- An example is the **lunate sulcus** (separating the striate and peristriate areas at the surface). which contains the parastriate area within its walls.

3. c. C
- Insula (marker 'C') is the lobe of cerebrum which lies deep to the lateral sulcus of brain.
- Insula is a portion of the cerebral cortex folded deep within the floor of the lateral sulcus.
- Key: A: Frontal cortex (superior longitudinal fissure); B: Basal ganglia; C - Insular cortex; D - Thalamus

Brodmann Areas

Brodmann area is a region of the cerebral cortex defined by its cytoarchitecture, or histological structure and organization of cells correlated closely to specific cortical functions. There are a total of 52 areas grouped into 11 histological areas.

- Brodmann areas 1, 2 and 3 (postcentral gyrus) are the primary somatosensory cortex and area 5 is the somatosensory association cortex.
- Area 4 (pre central gyrus) is the primary **motor** cortex and 6 is the **premotor** cortex and **supplementary** motor cortex (secondary motor cortex).
- Area 17 (occipital cortex) is the **primary** visual area (V1). Area 18 is the **secondary** visual cortex (V2) and Area 19 is **associative** visual cortex (V3, V4, V5).
- Auditory cortex (41 and 42) is located at the anterior part of the superior temporal gyrus (transverse temporal gyri of Heschl's).
- **Wernicke's sensory speech area** (22) is present at the **posterior** part of the **superior temporal gyrus**.
  - There is **uncertainty** about the precise extent of Wernicke's area. Some authorities consider it as a large parietotemporal area that includes areas 22 and 37 to be visuo-auditory areas associated with speech and language respectively.
  - There is a mention of areas 39 (angular gyrus) and 40 (supramarginal gyrus) by few other authors.
  - It is responsible for the **comprehension of language** but its stimulation causes speech arrest.
- **Broca's motor speech area** is part of the inferior frontal gyrus on the left Brodmann areas 44 (pars opercularis), and 45 (pars triangularis).
  - It works for the planning of movement of speech muscles and is involved in production of language.
- **Frontal eye field** (8) is present in the middle frontal gyrus.
  - Frontal eye field is the center for contralateral horizontal gaze. A lesion results in an inability to make voluntary eye movements toward the contralateral side. Since the activity of the intact frontal eye field in the opposite cortex is unopposed in such a lesion, the result is conjugate slow deviation of the eyes toward the side of the lesion.

- Area 43 is the primary gustatory (taste) cortex.
- Area 13 and Area 14 are insular cortex.

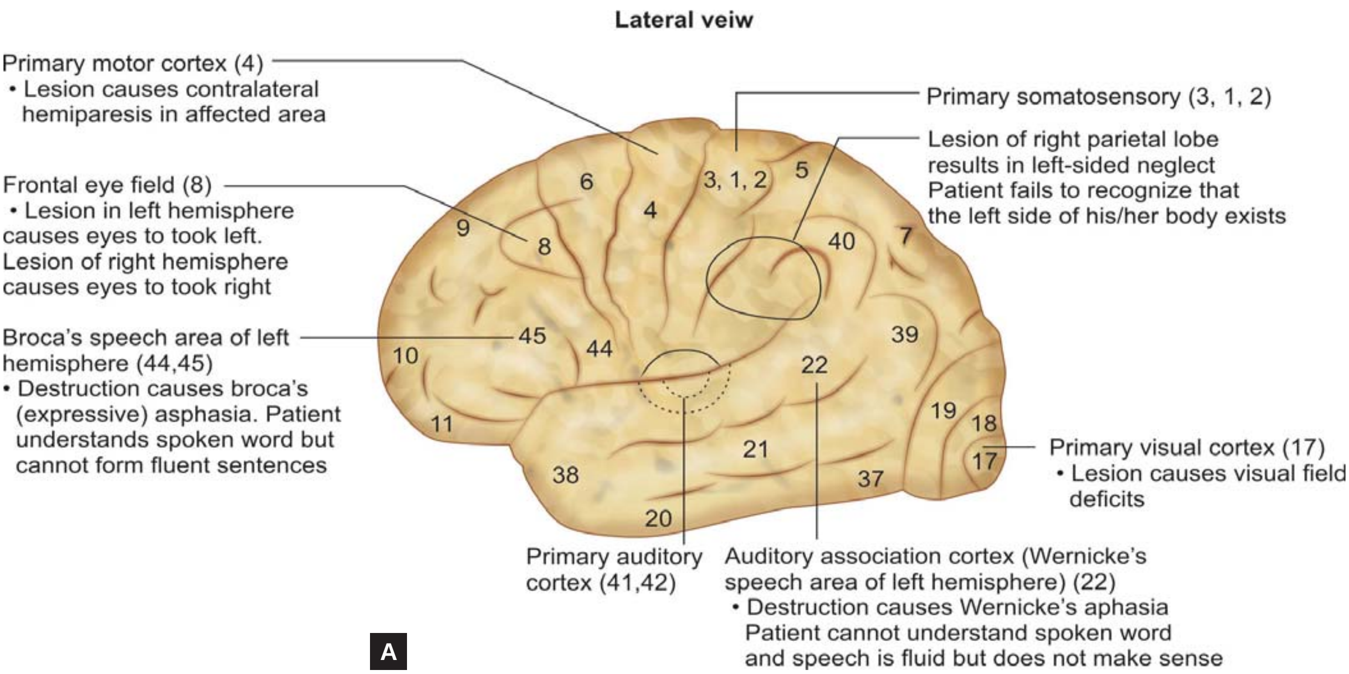
Para-central lobule is present near the midline encroaching upon the medial surface of the hemisphere and is the continuation of the precentral and postcentral gyri.

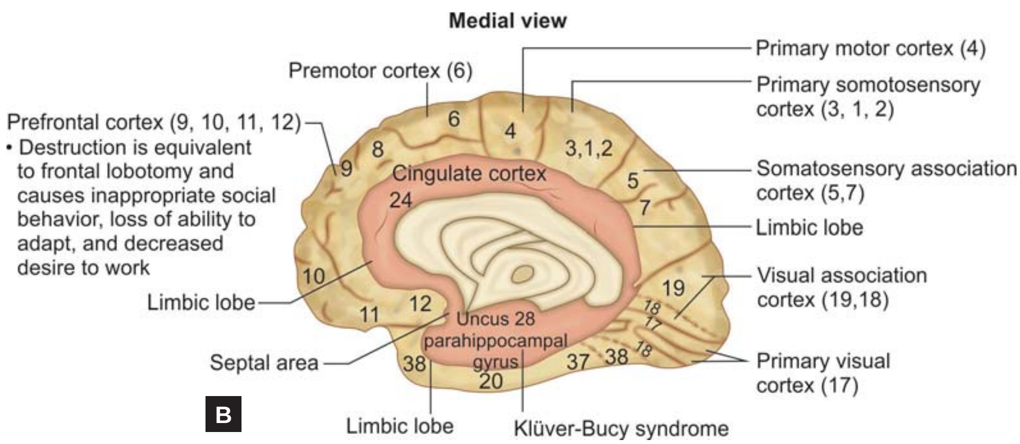
- The paracentral lobule controls motor and sensory innervations of the contralateral **lower limb** and **perineal region**.
- It is also responsible for control of **bladder and bowel** (defecation and urination).

Table 4: Key features of lobes

Lobes	Important regions	Deficit after lesion
Frontal	Primary motor and premotor cortex	Contralateral spastic paresis (region depends on area of homunculus affected), apraxia
	Frontal eye fields	Eyes deviate to ipsilateral side
	Broca speech area* (Areas 44, 45)	Broca aphasia (expressive, nonfluent aphasia): patient can understand written and spoken language, but speech and writing are slow and effortful; patients are aware of their problem; often associated with right arm weakness and right lower face weakness.
	Prefrontal cortex	Frontal lobe syndrome: Symptoms can include poor judgment, difficulty concentrating and problem solving, apathy, inappropriate social behaviour
Parietal	Primary somatosensory cortex	Contralateral hemihypesthesia (region depends on area of homunculus affected)
	Superior parietal lobule	Contralateral astereognosis/apraxia
	Inferior parietal lobule (Angular gyrus; Area 39)	Gerstmann syndrome (If dominant hemisphere): right/left confusion, alexia, dyscalculia and dysgraphia, finger agnosia, contralateral hemianopia or lower quadrantanopia; unilateral neglect (nondominant)
Temporal	Primary auditory cortex	Bilateral damage → deafness Unilateral leads to slight hearing loss
	Wernicke area* (Area 22)	Wernicke aphasia (receptive, fluent aphasia): patient cannot understand any form of language; speech is fast and fluent, but not comprehensible
	Hippocampus	Bilateral lesions lead to inability to consolidate short-term to long-term memory
	Amygdala	Klüver-Bucy syndrome: hyperphagia, hypersexuality, visual agnosia
	Olfactory bulb, tract, primary cortex	Ipsilateral anosmia
	Meyer loop (visual radiations)	Contralateral upper quadrantanopia ("pie in the sky")
Occipital	Primary visual cortex	Cortical blindness if bilateral; macular sparing hemianopia

*In the dominant hemisphere. Eighty percent of people are left-hemisphere dominant.





Figs. 34A and B: Brodmann areas on lateral (A) and medial (B) surfaces of cerebrum.

ASSESSMENT QUESTIONS

1. Primary visual area is located in the walls of:
- a. Parieto occipital sulcus
- b. Superior temporal sulcus
- c. Posterior part of calcarine sulcus
- d. Central sulcus

2. All of the following pairs for Brodmann area are correct EXCEPT:
- a. Superior temporal gyrus: Auditory cortex (41,42)
- b. Superior temporal gyrus: Wernicke's sensory speech area (22)
- c. Inferior frontal gyrus: Broca's motor speech area (44)
- d. Superior frontal gyrus: Frontal eye field (8)

3. Wernicke's Brodmann area is: *(NEET Pattern 2013)*
- a. 22
- b. 37
- c. 39
- d. 40

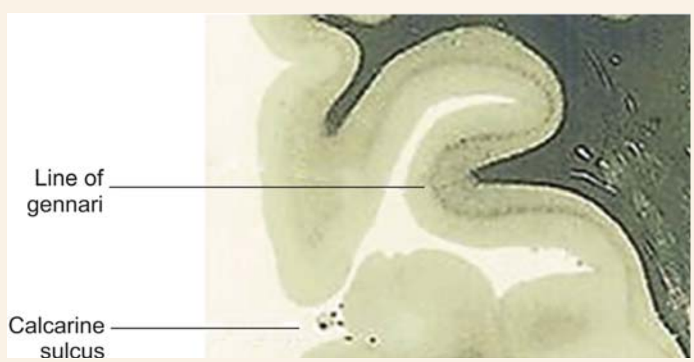
4. Temporal lobe contains: *(NEET Pattern 2015)*
- a. Primary visual area
- b. Primary auditory area
- c. Broca's area
- d. Prefrontal area

5. Broca's area is present in: *(NEET Pattern 2012)*
- a. Superior temporal gyrus
- b. Precentral gyrus
- c. Post central gyrus
- d. Inferior frontal gyrus

6. Heschl's gyrus in brain is located in: *(JIPMER 2016)*
- a. Primary auditory cortex
- b. Medial frontal lobe
- c. Visual cortex
- d. Parietal association area

ANSWERS WITH EXPLANATIONS

1. c. Posterior part of calcarine sulcus
- Primary visual area (Brodmann area 17) is located at the posterior part of the calcarine sulcus.
- This area shows lines (stria) of Gennari and is also called as striate cortex.
- It is supplied by posterior cerebral artery and additionally by middle cerebral artery.



2. d. Superior frontal gyrus: Frontal eye field (8)
- Frontal eye field (8) is located at the middle frontal gyrus.

3. a. 22
- **Wernicke's Brodmann area is** number 22 and is present at the **posterior** part of the **superior temporal gyrus**.
  - There is **uncertainty** about the precise extent of Wernicke's area. Some authorities consider it as a large parietotemporal area that includes areas 22 and 37 to be visuo-auditory areas associated with speech and language respectively.
  - There is a mention of areas 39 (angular gyrus) and 40 (supramarginal gyrus) by few other authors.

4. b. Primary auditory area
- Primary auditory area (41, 42) is present in the superior temporal gyrus (Heschl's gyrus).

5. d. Inferior frontal gyrus
- Broca's motor speech area (44, 45) is present on the inferior frontal gyrus.
- Destruction causes Broca's (expressive) aphasia. Patient understands spoken word but cannot form fluent sentences.

6. a. Primary auditory cortex
- Heschl's gyrus is the transverse temporal gyrus in the area of primary auditory cortex buried within the lateral sulcus occupying Brodmann areas 41 and 42.

Homunculus

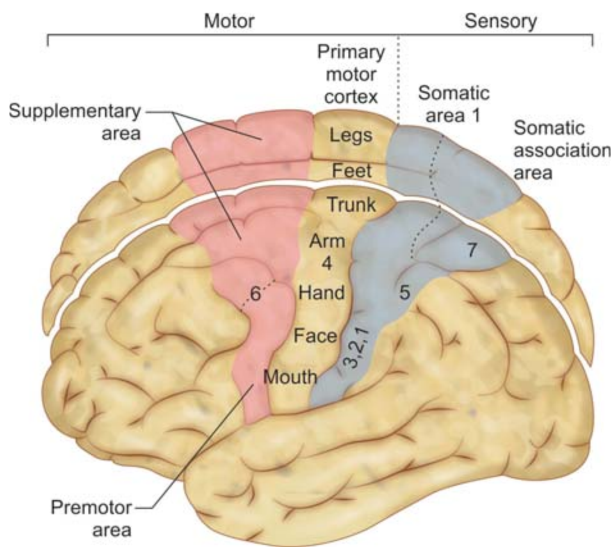
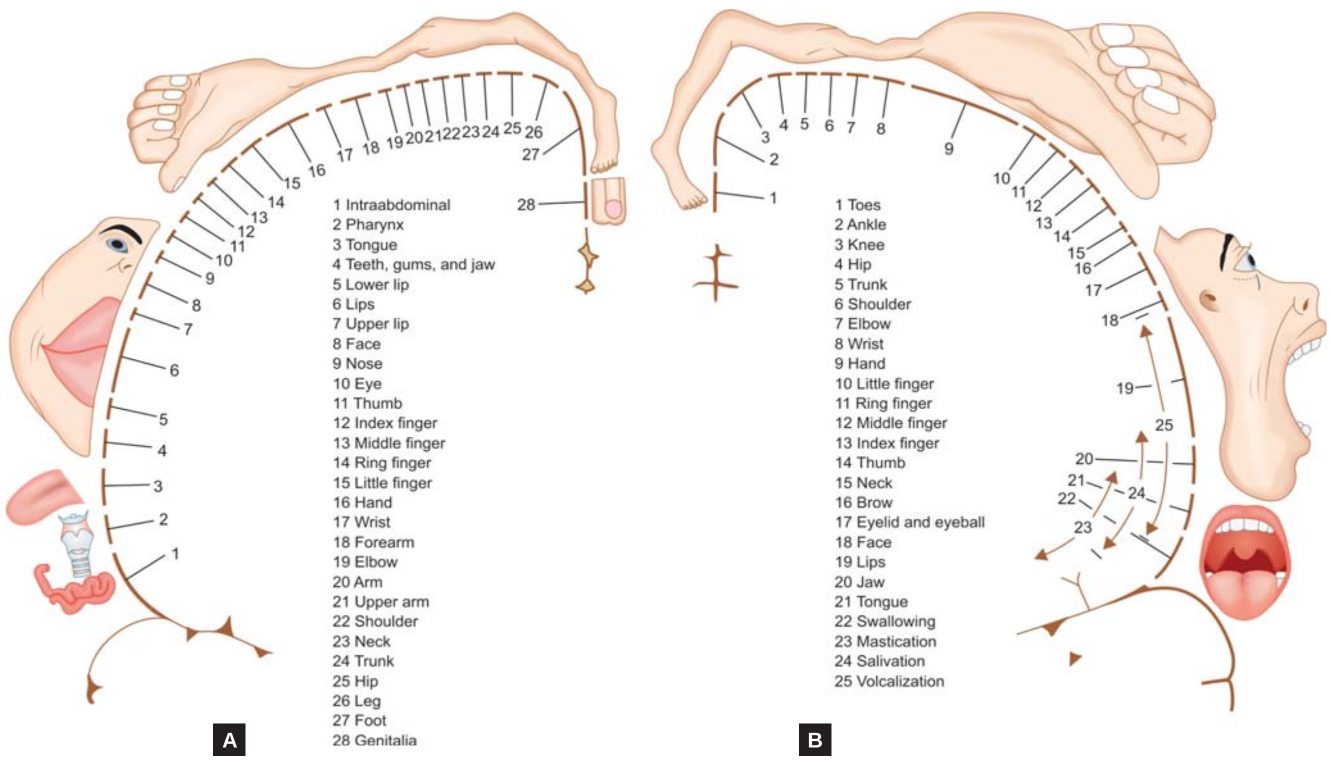


Fig. 35: Motor and somatosensory functional areas of the cerebral cortex (with Brodmann numbers)



Figs. 36A and B: The sensory and motor homunculi. A. Sensory representation in the postcentral gyrus. B. Motor representation in the precentral gyrus

ASSESSMENT QUESTION

1. While doing surgery for meningioma on cerebral hemisphere, there occurred injury to left paracentral lobule, it will lead to paresis of:

a. Left face b. Right neck and scapular region
c. Right leg and perineum d. Right shoulder and trunk

ANSWER WITH EXPLANATION

1. **c. Right leg and perineum**
   - **Para-central lobule** is present near the midline encroaching upon the medial surface of the hemisphere and is the continuation of the precentral and postcentral gyri.
   - The paracentral lobule controls motor and sensory innervations of the contralateral **lower limb** and **perineal region**.
   - It is also responsible for control of **bladder and bowel** (defecation and urination).

Arterial Supply

Language Pathway

- Visual image of a word is projected from the visual cortex (area 17) to the visual association cortices (areas 18 and 19) and next to the angular gyrus (area 39).
- Further processing occurs in Wernicke speech area (area 22), where the auditory form of the word is recalled.
- Arcuate fasciculus carries this information to Broca's speech area (areas 44 and 45), which has motor speech programs to control the vocalization mechanisms of the precentral gyrus (4).

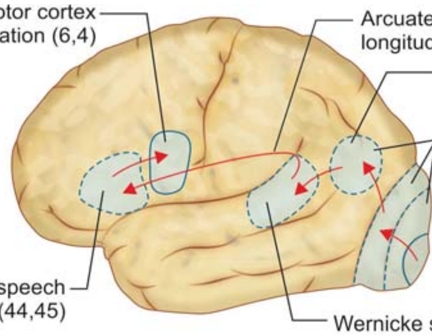


Fig. 37: Cortical areas involved in language production

Clinical Correlations

- **Dysphasia** may occur in lesions of Broca's motor speech area, Wernicke sensory speech area, or the arcuate fasciculus.
- **Broca's expressive aphasia** patient presents with hesitant speech (fluency is decreased), speaks in few words (and not in sentences).
  - The planning of movement of speech muscles is compromised and muscles are unable to articulate properly to produce meaningful voice.
  - Comprehension of language is good.
  - They are aware of their language disorder and may get frustrated by the deficit.
- In **Wernicke's receptive aphasia**, comprehension (understanding) of the language is compromised and the patient incessantly speaks in incoherent (irrelevant) sentences, making little sense.
  - They are often unaware of their mistakes.
- Lesion in the arcuate fasciculus result in **conduction aphasia**, with poor naming and problems in repetition of speech.
  - The comprehension of language and fluency of speech is intact.
  - Patients are aware of their errors but have significant difficulty correcting them.

Table 5: Clinical features of aphasias and related conditions commonly seen in cerebrovascular accidents

	Comprehension	Repetition of spoken language	Naming	Fluency
Wernike's	Impaired	Impaired	Impaired	Preserved or increased
Broca's	Preserved (except grammar)	Impaired	Impaired	Decreased
Global	Impaired	Impaired	Impaired	Decreased
Conduction	Preserved	Impaired	Impaired	Preserved
Noninfluent (anterior) transcortical	Impaired	Preserved	Impaired	Preserved
Isolation	Impaired	Echolalia	Impaired	No purposeful speech
Anomic	Preserved	Preserved	Impaired	Preserved except for word -finding pauses
Pure word deafness	Impaired only for spoken language	Impaired	Preserved	Preserved
Pure alexia	Impaired only for reading	Preserved	Preserved	Preserved

ASSESSMENT QUESTIONS

1. **Speech in words and not in sentence occurs due to the lesion of:**
   a. Wernicke's sensory speech area
   b. Broca's motor speech area
   c. Arcuate fasciculus
   d. Primary auditory area

2. **A man comes with aphasia, is unable to name things and repetition is poor. However, comprehension, fluency and articulation is unaffected. He is probably suffering from:** *(AIIMS 2015)*
   a. Anomic aphasia
   b. Transcortical sensory aphasia
   c. Conduction aphasia
   d. Broca's aphasia

ANSWERS WITH EXPLANATIONS

1. **b. Broca's motor speech area**
   - Speech in words and not in sentences is a feature suggesting **hesitant** speech, which occurs Broca's motor aphasia.

2. **c. Conduction aphasia**
   - A patient with **conduction aphasia** presents with inability to name things and poor repetition of language.
   - These features are evident in other conditions as well but since the comprehension is good, its not a case of **Wernicke's** and on the other hand intact fluency rules out **Broca's** aphasia.

Basal Ganglia

Brain components involved in **control of voluntary movements**

- Idea of voluntary movement originate in **cerebral** cortical association areas.
- The cerebral cortex, **basal ganglia**, and **cerebellum** work cooperatively to plan movements.
- Movement executed by the cortex is relayed via the **pyramidal tract** (corticospinal and corticobulbar tracts) to the motor neurons.
- Cerebellum provides feedback to adjust and smoothen movement.

Basal ganglia is involved in starting (initiation), and stopping of the voluntary motor activity and inhibiting unwanted movements.

- It consists of numerous nuclei, generally mentioned are three structural nuclei deep in the cerebrum (caudate nucleus, putamen, and globus pallidus) and two functional nuclei: Substantia nigra (midbrain) and the subthalamic nucleus (diencephalon).
- Amygdaloid nucleus and claustrum are also considered a part of basal ganglia.

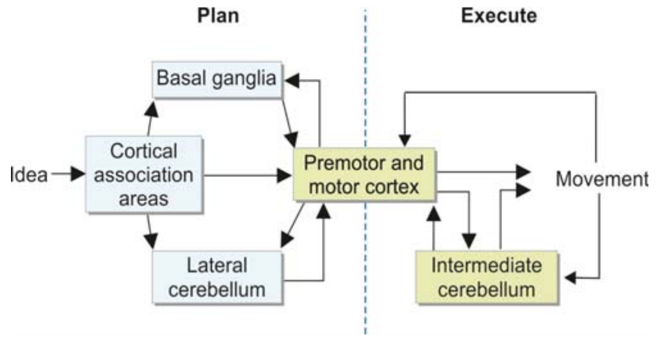


Fig. 38: Brain components involved in control of voluntary movements

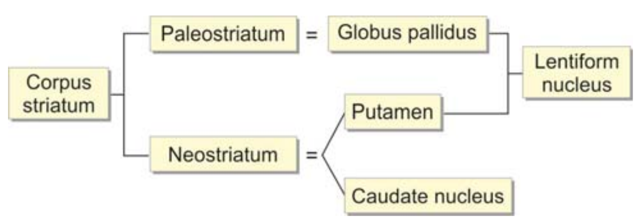


Fig. 39: Components of basal ganglia

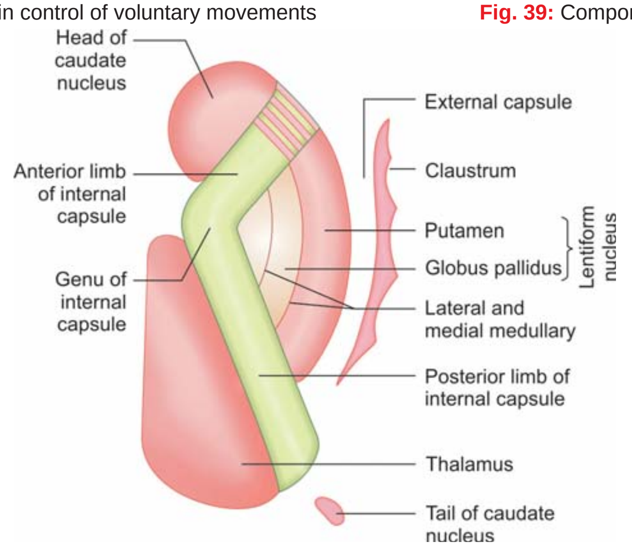
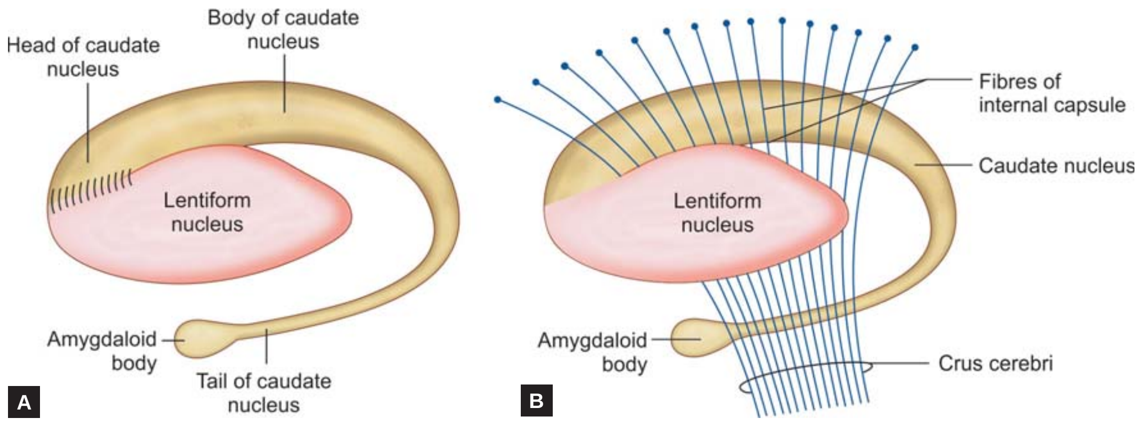


Fig. 40: Basal ganglia components (horizontal section of brain)



Figs. 41A and B: Corpus striatum: (A) as seen from lateral aspect; (B) relationship of the corpus striatum to the internal capsule

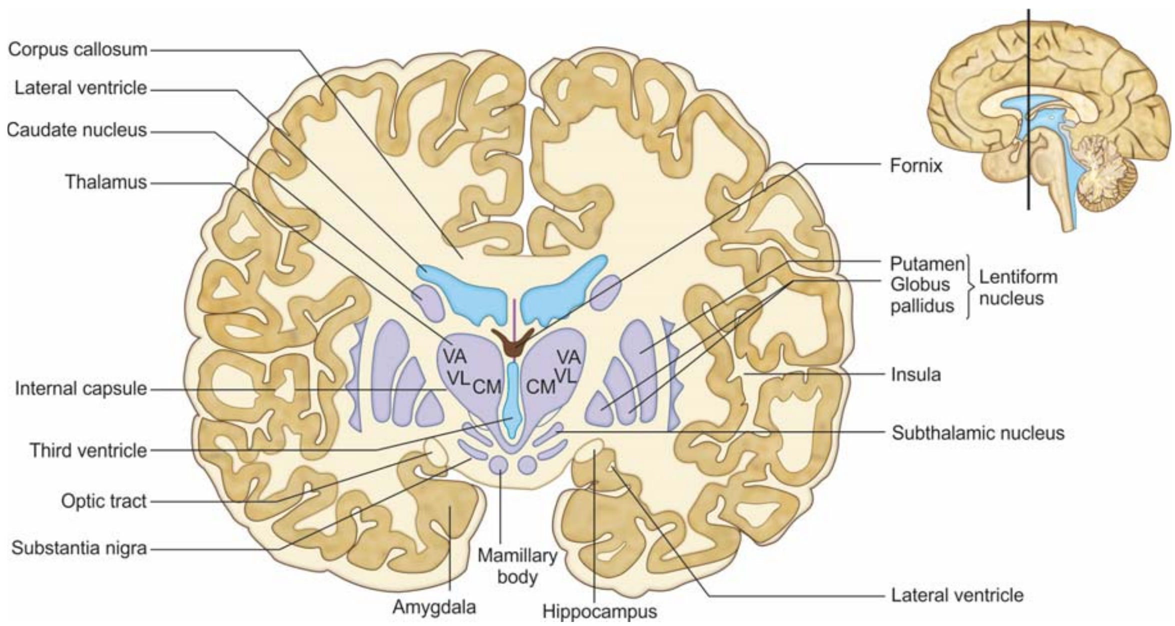


Fig. 42: Basal ganglia components (coronal section of brain)

Basal Ganglia Connections

- The **striatum** receives major input from three sources: the **thalamus**, **neocortex**, and **substantia nigra**.
- The striatum projects to the **globus pallidus** and **substantia nigra**.
- The globus pallidus is the **effector nucleus** of the striatal system; it projects to the **thalamus** and **subthalamic** nucleus.
- The substantia nigra also projects to the thalamus.
- The striatal motor system is expressed through the pyramidal system (corticobulbar and corticospinal tracts).

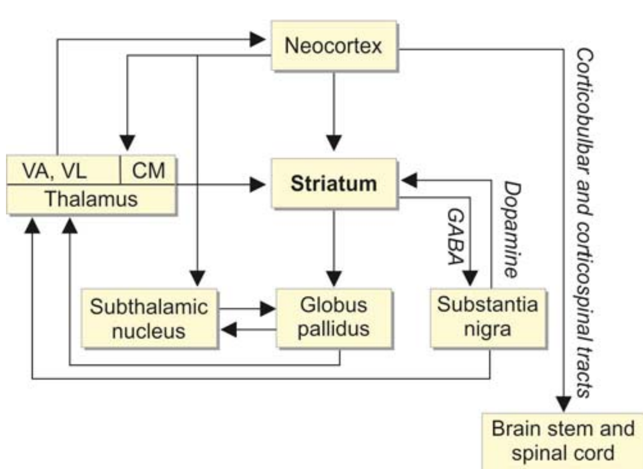


Fig. 43: Basal ganglia: Major afferent and efferent connections. The striatum receives major input from three sources: the thalamus, neocortex, and substantia nigra. The striatum projects to the globus pallidus and substantia nigra. The globus pallidus is the effector nucleus of the strial system; it projects to the thalamus and subthalamic nucleus. The substantia nigra also projects to the thalamus. The striatal motor system is expressed through the corticobulbar and corticospinal tracts. (CM. Centromedian nuclues; GABA. l-aminobutyric acid; VA. Ventral anterior nucleus; VL. Ventral lateral nucleus)

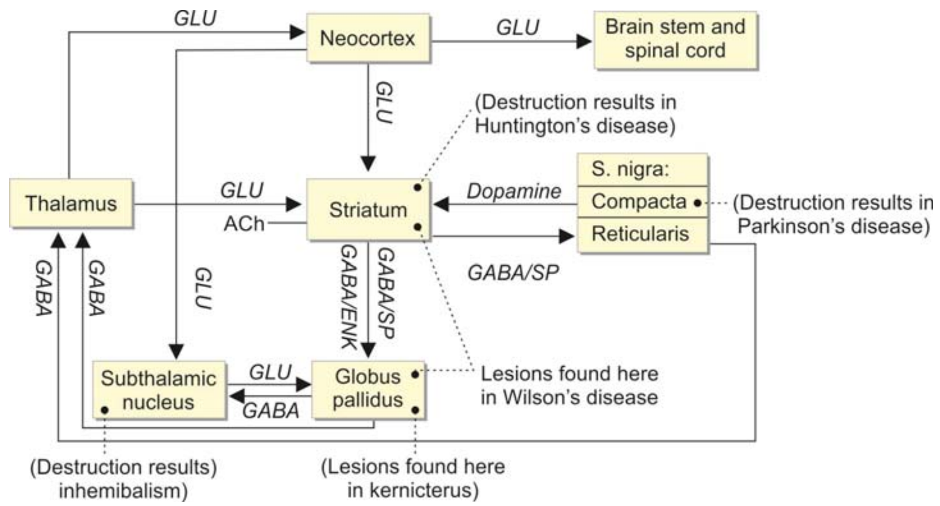


Fig. 44: Basal ganglia: Major neurotransmitters and the disorders. Within the striatum, globus pallidus, and pars reticularis of the substantia nigra (S. nigra), l-aminobutyric acid (GABA) is the predominant neurotransmitter. GABA may coexist in the same neuron with enkephalin (ENK) or substance P (SP). Dopamine-containing neurons are found in the parts compacta of the substantia nigra. Acetylcholine (ACh) is found in the local circuit neurons of the striatum. The subthalamic nucleus projects excitatory glutaminergic fibers to the globus pallidus. (GLU. Glutamate)

Basal Ganglia Functions

- **Planning** and **programming** of movement or, more broadly, in the processes by which an abstract thought is converted into voluntary action.
- Plays a role in the **initiation** and **execution** of voluntary motor activity, especially willed movement.
- It is also involved in **automatic stereotyped** postural and reflex motor activity (e.g., normal subjects swing their arms when they walk).
- Regulate the **muscle tone** and thus helps in smoothening the voluntary motor activities of the body. Decrease muscle tone to inhibit unwanted muscular activity.
- Determine how rapidly a movement is to be performed and how large the movement must be.
- Control group of movements for **emotional expression**.
- Control reflex muscular activity

Lesions

- **Parkinson's disease** is a degenerative disease that affects the **substantia nigra** and its projections to the striatum resulting in depletion of dopamine in the substantia nigra and striatum as well as a loss of melanin-containing dopaminergic neurons in the substantia nigra.
- Patient presents with tremors (pill rolling) , rigidity (cogwheel/lead pipe) and hypokinesia. Stooped posture, shuffling gait and masked facies.
- Lewy bodies are found in the melanin containing neurons of the substantia nigra.
- **Wilson's disease** (hepato-lenticular degeneration) is an autosomal recessive disorder that is caused by a defect in the metabolism of copper, in paediatric patients.
- Deposition of copper in the **lentiform** nucleus and liver (multilobar cirrhosis).
- Clinical signs include choreiform or athetotic movements, rigidity, and wing beating tremor.
- Copper deposition in the limbus of the cornea gives rise to the corneal Kayser-Fleischer ring (pathognomonic sign).
- **Hemiballismus** is a movement disorder that usually results from a vascular lesion of the **subthalamic nucleus**.
- Clinical signs include violent contralateral flinging (ballistic) movements of an entire limb.
- Lesions in the **globus pallidus** frequently lead to spontaneous and often continuous writhing movements of a hand, an arm, the neck, or the face-movements called **athetosis**.
- Multiple small lesions in the **putamen** (of striatum) lead to flicking movements in the hands, face, and other parts of the body, called **chorea**.
- **Huntington's** disease (chorea) is an inherited autosomal dominant movement disorder that is traced to a single gene defect on chromosome 4.
- It is associated with degeneration of the cholinergic and -aminobutyric acid (GABA)-ergic neurons of the **striatum**.
- It is accompanied by gyral atrophy in the frontal and temporal lobes.

ASSESSMENT QUESTIONS

1. All are components of basal ganglia EXCEPT:
   a. Thalamus
   b. Amygdaloid nucleus
   c. Substantia nigra
   d. Globus pallidus

2. INCORRECT matching pair about basal ganglia lesion is:
   a. Wilson's disease: Lentiform nucleus
   b. Athetosis: Globus pallidus
   c. Chorea: Striatum
   d. Hemiballismus: Substantia nigra

3. Nucleus of basal ganglia:
a. Dentate
b. Thalamus
c. Caudate
d. Red nucleus

4. Globus pallidus, putamen are present in: *(NEET Pattern 2012)*
a. Pons
b. Basal ganglia
c. Thalamus
d. Cerebellum

5. Which of the following clearly states the role of basal ganglia in motor function?
a. Planning b. Skilled function
c. Coordinate function d. Balance

6 Hippocampal formation includes all EXCEPT: *(AIPG 2009)*
a. Dentate gyrus b. Subicular complex
c. Amygdaloid nucleus d. Entorhinal cortex

7. The marked structure in the diagram is involved with motor activities. It receives afferents from all of the following EXCEPT: *(AIIMS 2016)*
a. Spinal cord b. Thalamus
c. Cerebral cortex d. Substantia nigra

ANSWERS WITH EXPLANATIONS

1. a. Thalamus
- Basal ganglia is involved in programming and planning of the voluntary motor activity and is constituted by numerous nuclei.
- It has connections with thalamus (but thalamus is not an integral component), whereas subthalamus is definitely considered as the functional component of basal ganglia.

2. d. Hemiballismus: Substantia nigra
- A lesion in the subthalamus often leads to sudden flailing movements of an entire limb, a condition called hemiballismus.
- Lesions of the substantia nigra lead to the common and extremely severe disease of rigidity, akinesia, and tremors known as Parkinson's disease.

3. c. Caudate
- Basal ganglia has three structural (caudate, putamen and globus pallidus) and two functional nuclei (subthalamic and substantia nigra).

4. b. Basal ganglia
- Globus pallidus and putamen together constitute the lentiform nucleus of basal ganglia.

5. a. Planning
- Basal ganglia are involved in the planning and programming of voluntary motor activity, especially in the processes by which an abstract thought is converted into voluntary action.

6. c. Amygdaloid nucleus
- Amygdaloid nucleus is a part of limbic system/basal ganglia, located deep and medially within the temporal lobes and has a primary role in the processing of memory, decision-making, and emotional reactions.
- Hippocampal formation is a compound structure in the medial temporal lobe of the brain which includes the dentate gyrus, the hippocampus proper, the subiculum and entorhinal cortex. It plays a role in memory, spatial navigation and control of attention.

7. a. Spinal cord
- The structure marked in the diagram is **caudate nucleus** (part of basal ganglia).
- Caudate and putamen nucleus constitute striatum part of basal ganglia, which has three major inputs: Thalamus, neocortex, and substantia nigra.

Note: Caudate nucleus do **not** receive any afferent from spinal cord.

Internal Capsule

Internal capsule is the structure composed of collection of axons (**white matter**) in the inferomedial part of cerebral hemisphere.

- It has projection fibres (both **ascending** and **descending**) connecting higher brain centres with the lower and vice versa.
- It **separates** the caudate nucleus and the thalamus from the lentiform nucleus (putamen and globus pallidus).

- In a transverse section, it appears **V shaped**, with an anterior and posterior limb and the bend called as the genu.
- **Anterior limb** lies between the head of the caudate nucleus and lentiform nucleus and the **posterior limb** between the thalamus and lentiform nucleus.
- **Anterior limb** of internal capsule carries fibres connecting the **cerebral cortex** with the **thalamus** and **basal ganglia**.
- **Sensory** and **motor** fibres of the **head region** pass through the **genu.**
- **Sensory** and **motor fibres** of the **body** (neck, trunk and limb regions) pass through the anterior 2/3 of **posterior limb** of internal capsule (upper body fibres are arranged more anterior and lower body fibres more posterior).
- Posterior 1/3 of **posterior limb** carries sensory fibers (including audio-visual pathways).
- **Retrolenticular** portion is caudal to the lentiform nucleus and carries the **optic radiation** (geniculo-calcarine tract) from the lateral geniculate body to the occipital visual cortex (calcarine fissure).
- **Sublentiform** portion is beneath the lentiform nucleus and carries the a**uditory pathway** from the medial geniculate nucleus to the primary auditory cortex (superior temporal gyrus).
- **Pyramidal tract** (corticospinal and corticonuclear tracts) constitutes a significant proportion of the internal capsule, carrying information from the upper motor neurones (in cerebral cortex) to the lower motor neurons (in brainstem and spinal cord) to modulate the **skeletal muscle** activity in the body.
  - Above the basal nuclei the pyramidal tract is a part of the **corona radiata**, below the basal nuclei the tract is called **crus cerebri** (a part of the cerebral peduncle).
  - In **genu** part of internal capsule lies the **corticonuclear tracts**, which carry the upper motor neurone fibres for the skeletal muscles of head region. These fibers undergo decussation and end in the motor nuclei of the cranial nerves of the opposite side.
  - In **posterior limb** runs the **corticospinal tract**, which carry the upper motor neurone fibres for the skeletal muscles of lower body (neck, trunk and limb regions).
- **Sensory** fibres are carried by **trigeminal** system from the **head** region and fibres pass through the **genu** of internal capsule.
- **Sensory** fibres from the **lower body** are carried by various tracts (e.g. dorsal column and spinothalamic tract) and the fibres pass through the **posterior limb** of internal capsule.

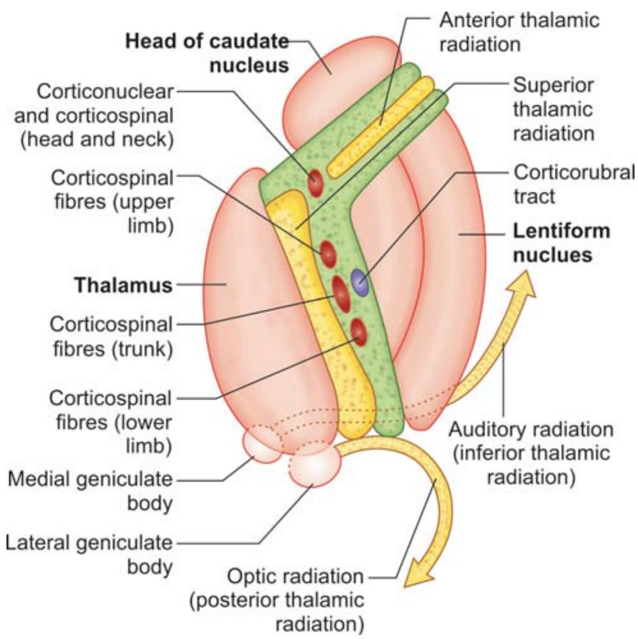


Fig. 45: Main components of internal capsule and their constituent fibres (yellow = thalamocortical, green = corticopontine fibres)

Table 6: Constituent motor and sensory fibres in different parts of the internal capsule

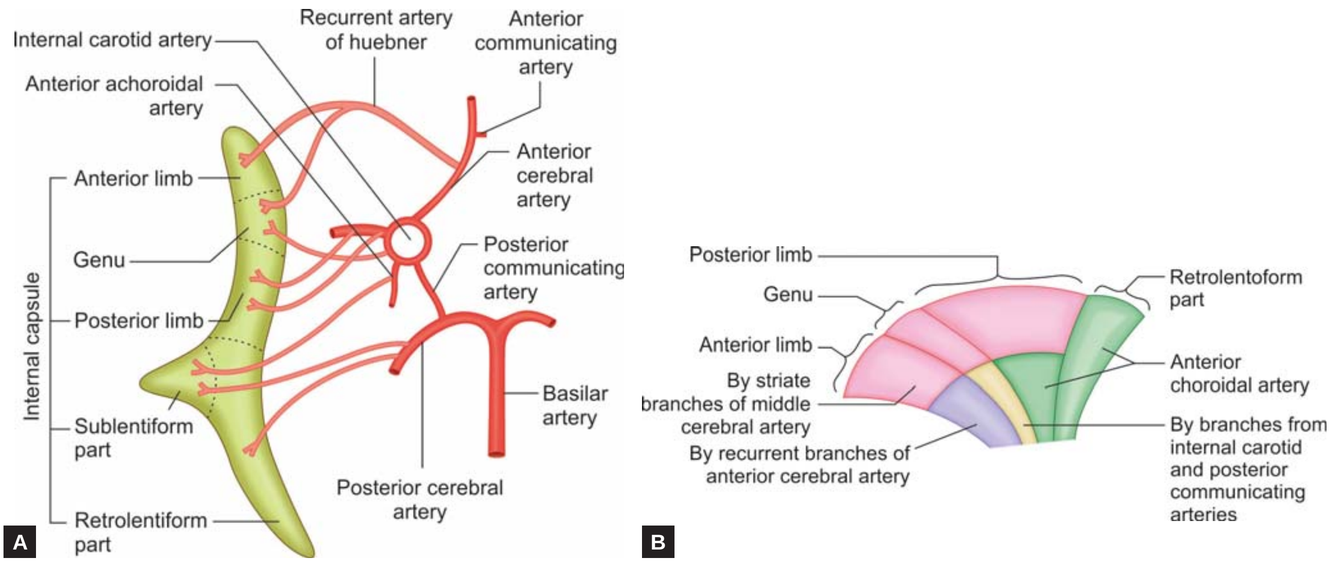
Part	Motor fibres	Sensory fibres
Anterior limb	Corticopontine fibres	Anterior thalamic radiation
Genu	Corticopontine fibres Corticonuclear and corticospinal fibres for head and neck	Superior thalamic radiation (anterior part only)
Posterior limb	Corticopontine fibres Corticospinal (pyramidal) fibres for upper limb, trunk and lower limb Corticorubral (extrapyramidal) fibres	Superior thalamic radiation
Retrolentiform part	Corticopontine fibres	Posterior thalamic radiation (optic radiation)
Sublentiform part	Corticopontine fibres	Inferior thalamic radiation (auditory radiation)

Arterial Supply

- Internal capsule is supplied by arteries that arise from the circle of Willis and its associated vessels. Lateral and medial **striate arteries** from the **middle** and **anterior cerebral arteries** supply major part of internal capsule.
- The arteries supplying internal capsule are:
  - Middle cerebral artery (major supply)
  - Anterior cerebral artery (including recurrent branch of Heubner)
  - Anterior choroidal artery (branch of internal carotid artery)

Note: Internal capsule also receives additional branches from internal carotid artery, posterior communicating artery, and posterior cerebral artery.

- Arterial supply to internal capsule is discussed in two parts: superior (dorsal) and inferior (ventral) part.
  - Superior (dorsal) part of the anterior limb, genu and the posterior limb are supplied by the **lenticulo-striate branches of middle cerebral artery**.
  - Inferior (ventral) part of internal capsule:
    - Anterior limb: Anterior cerebral artery (including recurrent branch of Heubner)
    - Genu: Internal carotid artery
    - Posterior limb: Anterior choroidal artery
    - Sublentiform and retrolentiform parts are chiefly supplied by anterior choroidal artery.
- One of the larger striate branches of the middle cerebral artery is known as 'Charcot's artery of cerebral hemorrhage.'



Figs. 46A and B: Arteries supplying the internal capsule

Clinical Correlations

- Ischaemic injury to internal capsule result in sensory and motor loss (hypesthesia and hemiparesis with the Babinski sign) on the contralateral side of the body.
- Lesion at
  - **Genu** results in sensory and motor loss on the **head** region.
  - **Posterior limb** (anterior 2/3) results in sensory and motor loss in **body** (neck, trunk and limb) region.
  - **Posterior limb** (posterior 1/3) results in audio-visual disturbances (e.g. homonymous hemianopia)

ASSESSMENT QUESTIONS

1. **Relations of internal capsule are:**
   a. Thalamus medially, caudate and lentiform nuclei laterally
   b. Thalamus laterally, caudate and lentiform nuclei medially
   c. Thalamus and caudate nucleus medially and lentiform nucleus laterally
   d. Thalamus and caudate nucleus laterally and lentiform nucleus medially

2. **Which of the following fibres DON'T pass through the posterior limb of internal capsule:**
   a. Sublentiform
   b. Retrolentiform
   c. Corticonuclear
   d. Dorsal column

3. **Corticospinal fibres pass through which part of internal capsule:**
   a. Posterior one-third of anterior limb
   b. Anterior two-third of posterior limb
   c. Posterior two-third of anterior limb
   d. Anterior two-third of anterior limb

4. **Genu of internal capsule carries:** *(NEET Pattern 2014)*
   a. Optic radiation
   b. Corticospinal
   c. Corticorubral tract
   d. Corticonuclear tract

5. **Which of the following parts of the internal capsule are associated with acoustic radiation:**
   a. Genu
   b. Anterior limb
   c. Retrolentiform
   d. Sublentiform

6. **Regarding anterior choroidal artery syndrome, all are true EXCEPT:**
   a. Hemiparesis
   b. Hemi-sensory loss
   c. Predominant involvement of anterior limb of internal capsule
   d. Homonymous hemianopia

7. All of the following pairs are correct for the artery supply to the lower parts of internal capsule EXCEPT:
a. Anterior limb: Recurrent branch of anterior cerebral artery
b. Genu: Internal carotid artery
c. Posterior limb: Anterior choroidal artery
d. Sublentiform part: Heubner's artery

8. Blood supply of posterior limb of internal capsule includes all EXCEPT:
a. Middle cerebral artery
b. Anterior cerebral artery
c. Anterior choroidal artery
d. Posterior cerebral artery

ANSWERS WITH EXPLANATIONS

1. c. Thalamus and caudate nucleus medially and lentiform nucleus laterally
- Internal capsule **separates** the caudate nucleus and the thalamus from the lentiform nucleus (putamen and globus pallidus).
- In a transverse section, it appears **V shaped**, with an anterior and posterior limb and the bend called as the genu.
- **Anterior limb** lies between the head of the caudate nucleus and lentiform nucleus and the **posterior limb** between the thalamus and lentiform nucleus.

2. c. Corticonuclear
- The fibres passing through the posterior limb of internal capsule are corticospinal tract (and **not corticonuclear**).
- **Corticonuclear** fibres pass through the **genu** part of internal capsule.

3. b. Anterior two-third of posterior limb
- **Corticospinal** fibres pass through the **anterior two-third** of the posterior limb of internal capsule.
- Posterior 1/3 of **posterior limb** carries sensory fibers (including **audio-visual** pathways).

4. d. Corticonuclear tract
- **Corticonuclear** tract fibres pass through the **genu** part of internal capsule.

5. d. Sublentiform
- Acoustic (auditory) pathway fibres pass through the **sublentiform** part of the internal capsule.

6. c. Predominant Involvement of anterior limb of internal capsule
- Anterior choroidal artery (branch of internal carotid artery) doesn't supply the anterior limb of internal capsule.
- It supplies inferior (ventral) part of posterior limb of internal capsule.
- Fibres passing through posterior limb of internal capsule are compromised in this syndrome, which include:
  - Sensory and motor fibres from the body
  - Auditory and visual pathway fibres

7. d. Sublentiform part: Heubner's artery
- The sublentiform and retrolentiform parts are chiefly supplied by **anterior choroidal artery**.
- **Heubner's artery** is a recurrent branch of anterior cerebral artery, which supplies the **anterior limb** of internal capsule.

8. b. Anterior cerebral artery
- **Superior** (dorsal) part of the posterior limb of internal capsule is supplied by the striate branches of **middle cerebral artery**.
- **Inferior** (ventral) part of posterior limb is supplied by : **anterior choroidal artery** (branch of internal carotid artery).
- The sublentiform and retrolentiform parts are chiefly supplied by supplied by **anterior choroidal artery**.
- Some authors mention **posterior cerebral artery** as well, as a source of blood supply to posterior limb of internal capsule.

Diencephalon

Diencephalon is the part of the prosencephalon (forebrain), which includes **thalamus** and the related thalami.
- It plays the important role in the **integration** of the sensory and motor systems.
- The ventricle of thalamus is the **third ventricle**, which lies in the midline between the two thalami.
- Components of diencephalon:
  - Thalamus
  - Hypothalamus (neurohypophysis included)
  - Epithalamus which consists of anterior and posterior Paraventricular nuclei, medial and lateral Habenular nuclei, Stria medullaris thalami, Posterior commissure, Pineal body.
  - Subthalamus
  - Metathalamus (medial and lateral geniculate bodies)
- Embryonic diencephalon forms the optic cup, which later forms the retina and optic nerve.

Thalamus

Thalamus is a division of the diencephalon and is a **relay** and **integration centre** for the sensory and motor signals to the cerebral cortex.
- It is also involved in regulation of consciousness, sleep, and alertness.
- The two thalami form the **lateral wall of the third ventricle** and are interconnected by a flattened gray band (**interthalamic adhesion**), which passes through the ventricle.

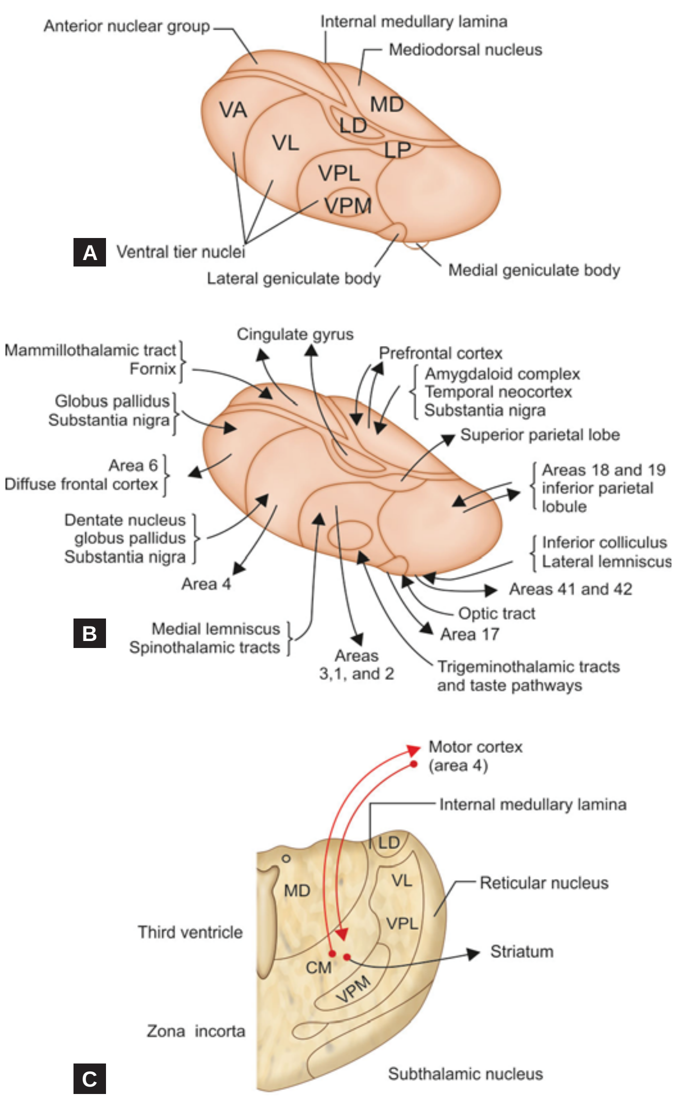
Thalamic Nuclei
- It has a ventral posterior (VP) nucleus, which has two parts: medial and lateral.
  - VPM (Ventero-Posterior-Medial) nucleus receive sensory input from 'head' region, whereas VPL (Ventero-Postero-Lateral) nucleus receive sensory information from the 'body'.

- Trigeminal nerve (first order neurone) carries information from the head region continues in the trigeminal lemniscus (second order neurone in brainstem) and synapses on VPM nucleus of thalamus.
- Thalamus has third order neurones, which in turn project on to the parietal sensory cortex (1,2,3).
- Spinothalamic tract—spinal lemniscal system (pain, temperature) and dorsal column- medial lemniscal system (tactile discrimination, vibration etc.) carry information from the 'body' region to synapse on VPL nucleus of thalamus, which further project the information to area 1,2,3.

Connections

Thalamus receives input from all sensory systems **except** the olfactory system.

- It is connected to the **cerebral cortex** via the thalamocortical radiations and to the **hippocampus** via the mammillo-thalamic tract .
- It has important connections with **basal nuclei.**
- **Spinothalamic tract** in the spinal cord transmits information to the thalamus about crude touch, pressure, pain and temperature.



Figs. 47A to C: Major thalamic nuclei and their afferent connections. A. Oblique dorsolateral aspect of the thalamus and major nuclei. B. The major afferent and efferent connections of the thalamus. C. The transverse section of the thalamus at the level of the arrows in A. Showing the major connections of the centromedian nucleus. CM = centromedian nucleus; MD = mediodorsal nucleus; LD = lateral dorsal nucleus; LP = lateral posterior nucleus; VA = ventral anterior nucleus; VL = ventral lateral nucleus; VPL = ventral posterolateral nucleus; and VPM = ventral posteromedial nucleus

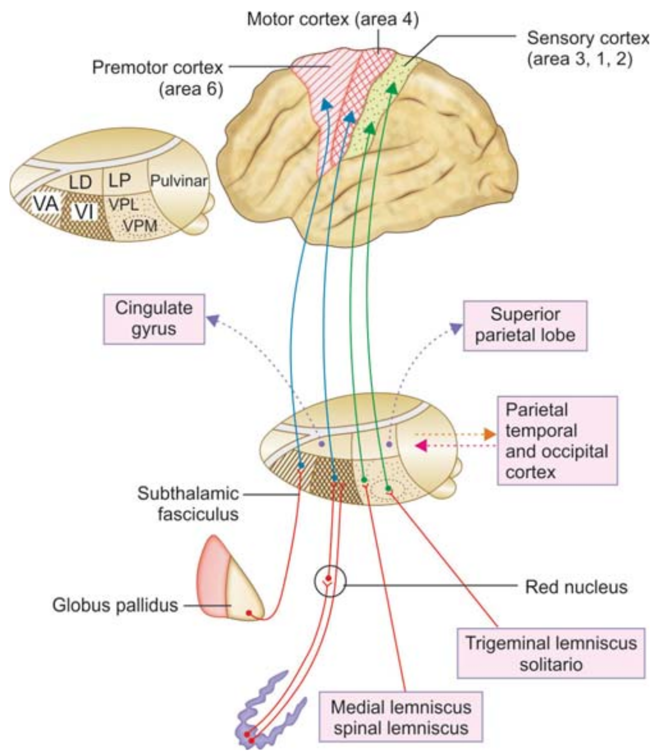


Fig. 48: Scheme to show connections of ventral and lateral groups of thalamic nuclei. The figure inset on left upper corner shows the dorsolateral view of thalamus and its major subdivisions. (LD = lateral dorsal nucleus, LP = lateral posterior nucleus, VA = ventral anterior nucleus, VI = ventral intermediate n, VPL = ventral posterolateral n. VPM = ventral posteromedial n.)

Table 7: Connections of the specific thalamic nuclei			
Nucleus	**Afferents**	**Efferents**	**Functions**
Ventral posterior (VP)			
Ventral posteromedial (VPM)	Trigeminal lemniscus Solitariothalamic tract	To postcentral gyrus (area 3, 1, and 2)	Relay station for impulses from face and head, and taste buds
Ventral posterolateral (VPL)	Medial lemniscus Spinal lemniscus	To postcentral gyrus (area 3, 1 and 2)	Relay station for exteroceptive (pain, touch, and temperature) and proprioceptive sensations from whole of body except face and head
Ventral anterior (VA)	From globus pallidus through subthalamic fasciculus	To premotor cortex (area 6 and 8)	Relay station for striatal impulses
Ventra lateral (VL) (also called ventral intermediate (VI))	From cerebellum (denta-tonubrothalamic fibres and dentatothalamic fibres)	To motor and premotor areas of cerebral cortex (area 4 and 6)	Relay station for cerebellar impulses
Medial geniculate body	Auditory fibres from inferior colliculus	To primary auditory area (area 41 and 42)	Relay station for auditory impulses
Lateral geniculate body	Optic tract	To primary visual cortex (area 17)	Relay station for visual impulses

Arterial Supply

- Posterior communicating artery
- Posterior cerebral artery
- Anterior choroidal artery

Clinical Correlations

- **Thalamic syndrome** leads to contralateral hemiparesis and hemi-anesthesia; elevated pain threshold;
- Spontaneous agonizing, burning pain (hyperpathia); and thalamic hand (athetotic posturing of the hand).
- **Korsakoff's syndrome** may result from damage to the mammillary body or the mammillothalamic tract.
- **Fatal familial insomnia** is a hereditary prion disease in which degeneration of the thalamus occurs, causing the patient to gradually lose his ability to sleep and progressing to a state of total insomnia, and eventual death.

Metathalamus

Metathalamus includes the **medial** and **lateral geniculate bodies**.

- **Lateral geniculate body** is a part of **visual pathway** and serves as a relay nucleus.
  - It receives retinal input through the optic tract and projects to the primary visual cortex (area 17).
  - It has six layered structure.

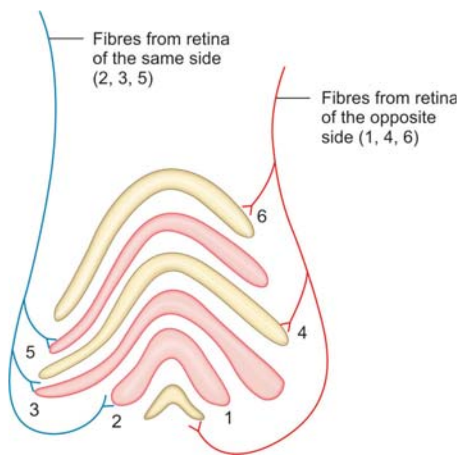


Fig. 49: Six layers (laminae) of the lateral geniculate body and their afferent connections

- **Medial geniculate body** is a part of **auditory pathway** and serves as an auditory relay nucleus.
  - It receives auditory input through the brachium of the inferior colliculus and projects to the primary auditory cortex (areas 41 and 42).

Table 8: Comparison between the medial and lateral geniculate bodies

Medial geniculate body	Lateral geniculate body
Oval-shaped collection of gray matter on the inferior aspect of the pulvinar	Bean-shaped collection of gray matter on the inferior aspect of inferior aspect of the pulvinar
Hilum absent	Hilum present
No lamination	Consists of 6 laminae, numbered 1 to 6 from ventral surface to dorsal surface
Destruction of medial geniculate on one side has little or no effect on hearing	Destruction of lateral geniculate body on one side produces blindness in the opposite half of the field of vision
Last relay station on the auditory pathway	Last relay station on the optic pathway
Sends auditory impulse through auditory radiation to the auditory area of temporal lobe	Sends visual impulses through optic radiation to the visual radiation to the cortex of the occipital lobe

Hypothalamus

- **Hypothalamus** is a division of the diencephalon which lies within the floor and ventral part of the walls of the third ventricle. It helps to maintain homeostasis by regulating the autonomic nervous system, endocrine system, and the limbic system.
- **Hypothalamic nuclei** and their functions.

Anterior	Medial	Posterior
Preoptic	Paraventricular	Posterior
Supraoptic	Dorsomedial	Mammillary
Suprachiasmatic	Lateral	Tuberomammillary
	Ventromedial	Dorsal
	Arcuate	

Table 9: Main hypothalamic nuclei and their functions

Region		Nucleus	Hormone secreted	Function
Chiasmatic	Medial	Median preoptic Periventricular	GnRH GnRH, somatostatin, CRH, TRH	
	Intermediate	Suprachiasmatic Supraoptic Paraventricular	Vasopressin Vasopressin, oxytocin	
Tuberal	Medial	Dorsomedial Ventromedial Arcuate	TRH, ANP TRH GHRH, dopamine	Satiety centre Secrete to portal system
	Lateral	Lateral		Feeding centre
Posterior	Medial	Mammillary body		Memory

Abbreviations: ANP, atrial natriuretic peptide; CRH corticotrophin-releasing hormone; GHRH, growth hormone-releasing hormone; GnRH, gonadotrophin-releasing hormone; TRH, thyrotrophin-releasing hormone.

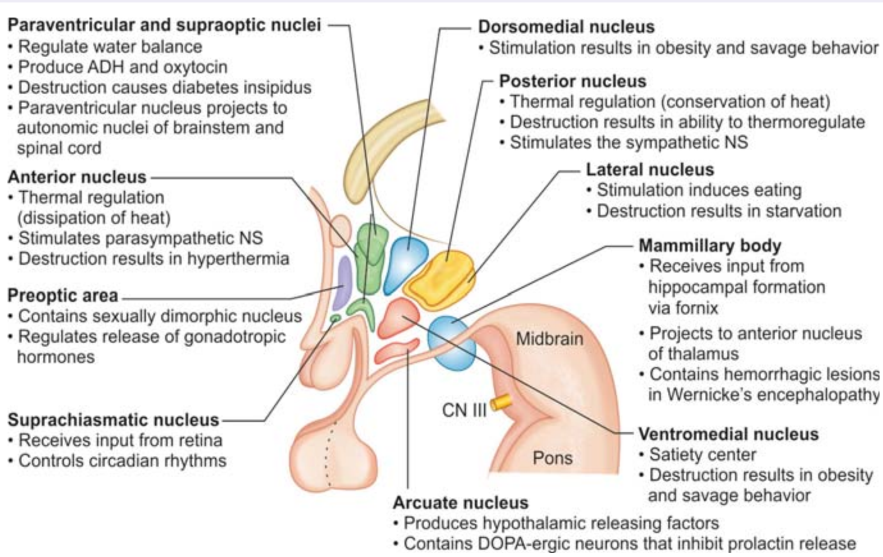


Fig. 50: Hypothalamic nuclei with their functional significance

Connections of Hypothalamus

- **Fornix** has five parts: the alveus, fimbria, crus, body, and columns.
- It projects from the hippocampal formation to the mammillary nucleus, anterior nucleus of the thalamus, and septal area.
- Bilateral transection results in an **acute amnestic syndrome**.
- **Stria terminalis** arises from the amygdaloid complex and interconnects the septal area, the hypothalamus, and the amygdaloid complex.
- It lies in the sulcus terminalis between the caudate nucleus and the thalamus.
- **Mammillothalamic tract** projects from the mammillary nuclei to the anterior nucleus of the thalamus.
- **Hypothalamospinal tract** contains descending autonomic fibers that influence preganglionic sympathetic neurons of the lateral horn cells and preganglionic neurons of the sacral parasympathetic nucleus in the spinal cord.
- The lesion of the tract may result in **Horner syndrome**.

Subthalamus

Subthalamus is a part of diencephalon and is located lies beneath (sub) the thalamus, medial to the internal capsule and dorsolateral to the hypothalamus.

Connections

Subthalamus has efferent connections to:

- Striatum (caudate nucleus and putamen) in the telencephalon
- Dorsal thalamus (medial and lateral nuclear groups) in the diencephalon
- Red nucleus and substantia nigra in the mesencephalon.
- It has afferent connections from the substantia nigra and striatum.
- Its neurons contain glutamate and have excitatory effects over neurons of globus pallidus and substantia nigra.

Reticular Nuclei

Reticular nucleus of the thalamus surrounds the thalamus as a thin layer of gamma-aminobutyric acid (GABA)-ergic neurons.

- It lies between the **external medullary lamina** and the **internal capsule** and receives excitatory collateral input from corticothalamic and thalamocortical fibers.
- It projects inhibitory (GABAergic) fibers to thalamic nuclei, from which it receives input.
- Reticular nuclei have intrathalamic connections and **do not** project to the cortex.

ASSESSMENT QUESTIONS

1. Which of the following is/are projected to ventral posterior nucleus of thalamus? *(PGIC)*

a. Lateral lemniscus
b. Medial lemniscus
c. Corticospinal tract
d. Spinal lemniscus
e. Trigeminal lemniscus

2. Which of the following thalamic nuclei does NOT project to neocortex? *(AIIMS 2003)*

a. Intralaminar nuclei
b. Reticular nuclei
c. Pulvinar nuclei
d. Anterior thalamic nuclei

3. Which of the following is NOT a part of epithalamus?

a. Pineal body
b. Posterior commissure
c. Trigonum habenula
d. Geniculate bodies

4. All of the following pairs are correct for nuclei of hypothalamus EXCEPT:

a. Ventero medial: Hunger
b. Supra-optic: Water conservation
c. Posterior nucleus: Shivering centre
d. Supra-chiasmatic: Circadian rhythm

ANSWERS WITH EXPLANATIONS

1. b. Medial lemniscus; d) Spinal lemniscus; e) Trigeminal lemniscus

- Thalamus has a ventral posterior (VP) nucleus, which has two parts: medial and lateral.
- VPM (Ventero-Posterior-Medial) nucleus receive sensory input from 'head' region, whereas VPL (Ventero-Postero-Lateral) nucleus receive sensory information from the 'body'.
- Trigeminal nerve (first order neurone) carries information from the head region continues in the trigeminal lemniscus (second order neurone in brainstem) and synapses on VPM nucleus of thalamus.
- Thalamus has third order neurones, which in turn project on to the parietal sensory cortex (1,2,3).
- Spinothalamic tract- spinal lemniscal system (pain, temperature) and dorsal column- medial lemniscal system (tactile discrimination, vibration etc.) carry information from the 'body' region to synapse on VPL nucleus of thalamus, which further project the information to area 1,2,3.
- Lateral lemniscus carry auditory pathway and synapses with medial geniculate body (meta-thalamus).

2. b. Reticular nuclei

- Reticular nuclei have intrathalamic connections and do not project to the cortex.
- Reticular nuclei lie between the external medullary lamina and the internal capsule.
- They use the neurotransmitter GABA and have inhibitory control over thalamic nuclei.
- They play important role in normal EEG readings.
- Most of the thalamic nuclei project to the neo-cortex, including intra-laminar, Pulvinar and anterior thalamus.

3. d. Geniculate bodies
- The epithalamus is the dorsal (posterior) segment of the diencephalon.
- It includes the habenula and their interconnecting fibers the habenular commissure, the stria medullaris and the pineal gland.
- The medial and lateral geniculate bodies belong to metathalamus.

4. a. Venteromedial: Hunger
- **Venteromedial** nucleus is the centre for satiety (**not hunger**).
- Anterior hypothalamus has osmoreceptors and centres like **supra-optic nucleus** secrete vasopressin (ADH) for **water conservation**.
- **Posterior** nucleus works for heat conservation (**shivering** centre).
- Supra-chiasmatic regulates the circadian rhythm.

Brainstem

Brainstem includes midbrain, pons and the medulla.
- It extends from the posterior commissure to the pyramidal decussation.
- It contains the nuclei for cranial nerve 3–12 and the nerves fibres exit from it.
- Various motor and sensory pathways (lemnisci) pass through the brainstem: Corticospinal tract (motor), dorsal column-medial lemniscal tract, spinothalamic tract—spinal lemniscal system, trigeminal lemniscus, lateral lemniscus(auditory pathway).
- It contains reticular formation at its central core.
- Brainstem has role in the regulation of cardiac and respiratory function (heart rate, breathing).
- It also regulates the central nervous system and maintains consciousness and regulating the sleep cycle.

Arterial supply to brainstem is from the branches of vertebral arteries and the basilar arteries.

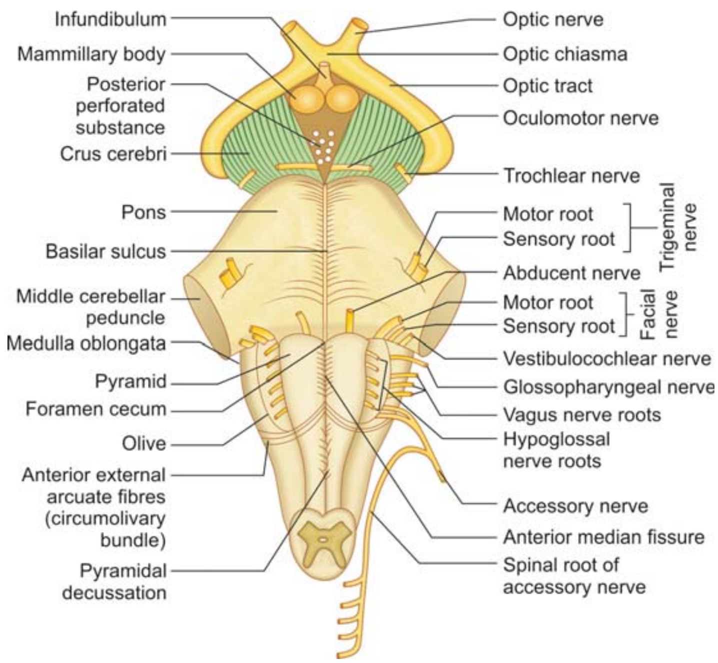


Fig. 51: External features on the anterior (ventral) aspect of the brainstem

Midbrain

- **Mesencephalon** (midbrain) comprises of three parts: the dorsal tectum, intermediate tegmentum, and the base.
- It extends from the posterior commissure to the superior medullary velum.
- It is connected to the cerebellum by the **superior cerebellar peduncle**.
- **Oculomotor** nucleus is present at the level of superior colliculus and **trochlear** nucleus at the level of inferior colliculus.
- It contains a centre for vertical conjugate gaze in its rostral extent.
- Substantia nigra is the largest nucleus of the midbrain.
- Paramedian reticular formation is present along the midline.
- Has four lemnisci (medial to lateral): Medial, trigeminal, spinal and lateral.
- The **ventricle** of midbrain is called the **cerebral aqueduct of Sylvius, which lies** between the tectum and the tegmentum.

A **transverse section** of midbrain shows following structures:
- **Dorsal structures:** Superior and inferior colliculi.
- **Tegmentum**: Oculomotor nucleus, Medial longitudinal fasciculus, Red nucleus, Substantia nigra, Dentatothalamic tract (crossed), Medial lemniscus, Lateral spinothalamic tract (in the spinal lemniscus)
- **Crus cerebri** (cerebral peduncle): Corticospinal tract lies in the middle three-fifths.

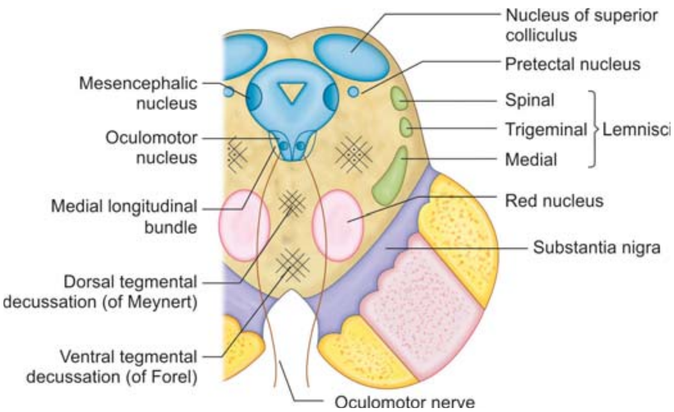


Fig. 52: Transverse section of the midbrain at the level of superior colliculi

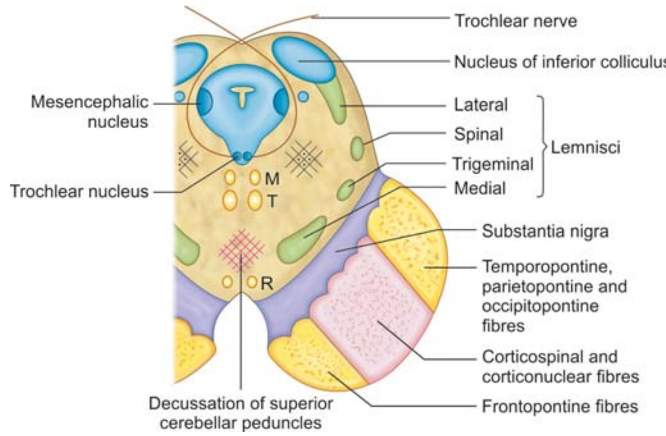


Fig. 53: Transverse section of the midbrain at the level of inferior colliculi (M = medial longitudinal bundle, R = rubrospinal tract, T = tectospinal tract)

Clinical Correlations

- **Weber (Medial midbrain) syndrome** (due to occlusion of paramedian branches of upper basilar and proximal posterior cerebral arteries)
- **Ipsilateral** sign and symptoms (structure involved)
  - 'Down and out eye' with dilated and unresponsive pupil and ptosis (Oculomotor nerve fibres)
    - Eye abduction and depression occurs due to the unopposed action of the lateral rectus (CN 6) and the superior oblique (CN 4)
    - Severe ptosis (paralysis of the levator palpebrae)
    - Fixed and dilated pupil (complete internal ophthalmoplegia)
- **Contralateral** sign and symptoms (structure involved)
  - Weakness of lower face (CN 7), Palate (CN 10) and tongue (CN 12) (**Corticobulbar** tract in crus cerebri)
  - Hemiparesis of trunk and limbs (**Corticospinal** tract in crus cerebri)
  - ? Parkinsonism features (substantia nigra)

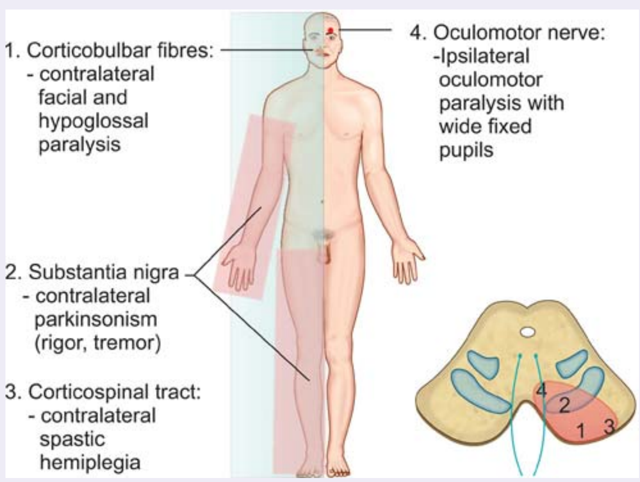


Fig. 54:

- **Lateral** midbrain syndrome (occlusion of posterior cerebral artery branches)
- **Ipsilateral** sign and symptoms (structure involved)
  - 'Down and out eye' with dilated and unresponsive pupil and ptosis (Occulomotor nerve nucleus and fibres)
- **Contralateral** sign and symptoms (structure involved)
  - Hemiataxia, hyperkinesia, tremors (Red nucleus and dentato-rubro-thalamic tract)
- **Benedikt** (paramedian midbrain) syndrome (occlusion of paramedian branches of posterior cerebral artery)
- **Ipsilateral** sign and symptoms (structure involved)
  - 'Down and out eye' with dilated and unresponsive pupil and ptosis (Oculomotor nerve fibres)
    - Eye abduction and depression occurs due to the unopposed action of the lateral rectus (CN 6) and the superior oblique (CN 4)
    - Severe ptosis (paralysis of the levator palpebrae)
    - Fixed and dilated pupil (complete internal ophthalmoplegia)
- **Contralateral** sign and symptoms (structure involved)
  - Hemiataxia, hyperkinesia, tremors (Red nucleus and dentato-rubro-thalamic tract)
  - Loss of proprioception, discriminative touch and vibrations (medial lemniscus)

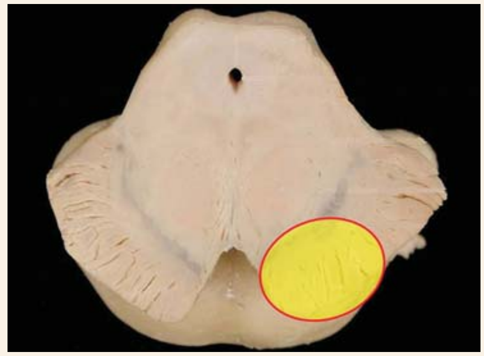
- **Parinaud** (posterior midbrain) syndrome may result due to a pineal tumour
  – Paralysis of upward and downward gaze, pupillary disturbances and absence of convergence (lesion in superior colliculus and pretectal area)
  – Non-communicating hydrocephalus (compression of aqueduct of Sylvius).

ASSESSMENT QUESTIONS

1. **Corpora quadrigemina is present in:**
   a. Midbrain
   b. Upper pons
   c. Lower pons
   d. Medulla

2. **Red nucleus is situated at the level of:**
   a. Mid-brain; superior colliculus
   b. Mid-brain; inferior colliculus
   c. Pons
   d. Medulla

3. **Which of the following is NOT a clinical manifestation of the lesion shown in the diagram?** *(AIIMS- 2016 Pattern)*
   a. Ipsilateral flaccid paralysis of medial rectus
   b. Ipsilateral loss of pain and temperature from face
   c. Contralateral weakness of lower face
   d. Contralateral hemiplegia



ANSWERS WITH EXPLANATIONS

1. **a. Midbrain**
   - **Corpora quadrigemina** (four bodies) are the four colliculi (two superior and two inferior) located at the dorsal aspect of midbrain (tectum).
   - Superior colliculus is related to visual reflexes, and inferior colliculus to auditory.
   - In Parinaud (posterior midbrain) syndrome, superior colliculus is involved leading to disturbances in upward gaze.

2. **a. Midbrain; superior colliculus**
   - A transverse section of midbrain, taken at the level of superior colliculus displays the red nucleus.
   - Weber syndrome: anterior midbrain lesion at this level involving crus cerebri and oculomotor nerve;
   - Benedict's syndrome: anterior and mid region is affected involving red nucleus.
   - Parinaud syndrome: Posterior midbrain lesion involving superior colliculi (upward gaze disturbances).

3. **b. Ipsilateral loss of pain and temperature from face**
   - Weber's syndrome (superior alternating hemiplegia) occurs due to an anterior lesion in the upper mid-brain lesion (level of superior colliculi).
   - It does not present with loss of pain and temperature from face, since the spinothalamic tract—spinal lemniscus system is still intact.

   Note: Weber syndrome may be caused by midbrain infarction as a result of occlusion of the branches of the basilar/posterior cerebral artery.

Pons

The **pons** is part of the brainstem lies between the midbrain (above) and the medulla oblongata (below) and in front of the cerebellum.

- It has two parts: the basilar part of the pons (ventrally) and the pontine tegmentum (dorsally).
  - Basilar part contains corticobulbar, corticospinal, and corticopontine tracts and pontine nuclei
  - Tegmentum contains cranial nerve nuclei, reticular nuclei, and the major ascending sensory pathways.
- Cranial nerve 5-7 nuclei (trigeminal, abducent and facial nerve) are present in pons. Vestibulocochlear nerve nuclei are present at the pontomedullary junction.
- Centre for lateral gaze is present in pons
- It is connected to the cerebellum by the **middle cerebellar peduncle**.

  A **transverse section** of pons shows following structures:
- **Medial structures**: Medial longitudinal fasciculus, internal genu of facial nerve producing facial colliculus, Abducent nucleus (underlies facial colliculus), Medial lemniscus, Corticospinal tract (in the base of the pons)
- **Lateral structures**: Facial nucleus, Descending (Spinal) sensory nucleus and tract of trigeminal nerve, Lateral spinothalamic tract—spinal lemniscus, Vestibular and cochlear nuclei

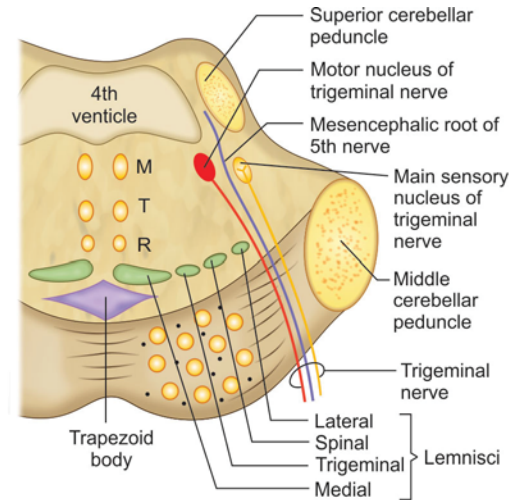


Fig. 55: Transverse section through the upper part of the pons (M = medial longitudinal bundle, R = rubrospinal tract, T = tectospinal tract)

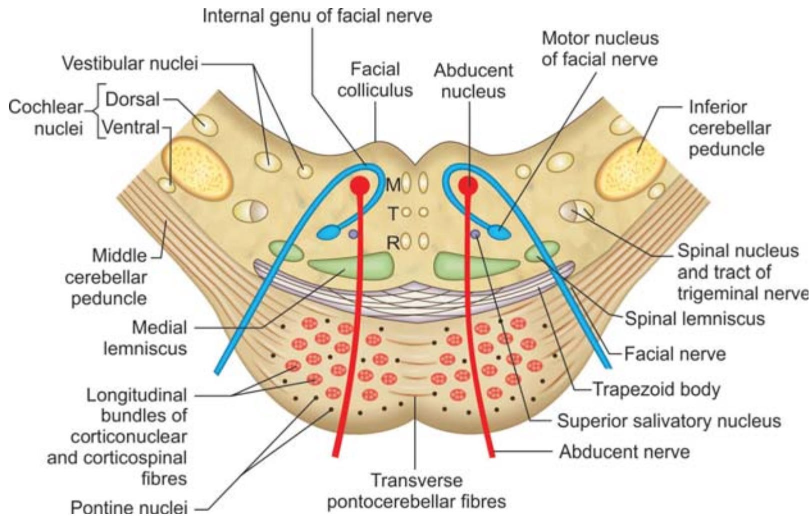


Fig. 56: Transverse section through the lower part of the pons (M = medial longitudinal bundle, T = tectospinal tract, R = rubrospinal tract)

	Lower part	Upper part
Gray matter	Contains: nuclei of VIth, VIIth and VIIIth cranial nerves; and nucleus of spinal tract of trigeminal nerve	Contains: motor and principal sensory nuclei of trigeminal nerve; and caudal part of nucleus ceruleus
White matter	Contains 2 lemnisci: medial and spinal Trapezoid body and nuclei present	Contains 4 lemnisci: medial, trigeminal, spinal and lateral Trapezoid body and nuclei absent

Clinical Correlations

- **Superior pontine syndromes**: Medial and lateral
- **Medial** superior pontine syndrome (occlusion of paramedian branches of upper basilar artery)
- **Ipsilateral** sign and symptoms (structure involved)
  - Cerebellar ataxia (Superior and middle cerebellar peduncles)
  - Internuclear ophthalmoplegia (medial longitudinal fasciculus)
  - Myoclonic syndrome
- **Contralateral** sign and symptoms (structure involved)
  - Paralysis of face, trunk and extremities (Corticobulbar and corticospinal tract)
  - Impaired tactile and proprioceptive sensations (Medial lemniscus)
- **Lateral** superior pontine syndrome (occlusion of superior cerebellar artery)
- **Ipsilateral** sign and symptoms (structure involved)
  - Ataxia (Middle and superior cerebellar peduncles)
  - Dizziness, nausea. Horizontal nystagmus (Vestibular nucleus)
  - Conjugate gaze palsy (pontine centre for gaze)
  - Horner syndrome - miosis, ptosis, anhydrosis (Descending sympathetic fibres)
  - Intention tremors (Dentate nucleus)
- **Contralateral** sign and symptoms (structure involved)
  - Impaired pain and temperature on trunk and limbs (Spinothalamic tract)
  - Impaired touch, vibration and position sense affecting trunk and lower limb (medial lemniscus; lateral portion)
- **Mid-pontine syndromes**: Medial and lateral
- **Medial** mid-pontine syndrome (occlusion of paramedian branches of mid-basilar artery)
- **Ipsilateral** sign and symptoms (structure involved)
  - Ataxia of limbs and gait (Pontine nuclei)
- **Contralateral** sign and symptoms (structure involved)
  - Paralysis of face, trunk and extremities (Corticobulbar and corticospinal tract)
  - Impaired tactile and proprioceptive sensations (Medial lemniscus)
  - **Lateral** mid-pontine syndrome (occlusion of circumferential branch of basilar artery)

- **Ipsilateral** sign and symptoms (structure involved)
  - Ataxia (Middle cerebellar peduncle)
  - Paralysis of muscles of mastication (Trigeminal motor nucleus and nerve)
  - Sensory disturbance on face (Trigeminal sensory nucleus and tract)
- **Contralateral** sign and symptoms (structure involved)
  - Impaired pain and temperature on trunk and limbs (Spinothalamic tract)
- **Inferior pontine syndromes**: Medial and lateral
  - **Medial** inferior pontine syndrome (occlusion of paramedian branches of lower basilar artery)
- **Ipsilateral** sign and symptoms (structure involved)
  - Paralysis of conjugate gaze to the side of lesion; convergence preserved (centre for conjugate lateral gaze)
  - Nystagmus (Vestibular nucleus)
  - Ataxia of limbs and gait (Middle cerebellar peduncle)
  - Diplopia on lateral gaze (Abducent nerve)
- **Contralateral** sign and symptoms (structure involved)
  - Paralysis of face, trunk and extremities (Corticobulbar and corticospinal tract)
  - Impaired tactile and proprioceptive sensations (Medial lemniscus)
  - **Lateral** inferior pontine syndrome (occlusion of anterior inferior cerebellar artery- AICA syndrome)
- **Ipsilateral** sign and symptoms (structure involved)
  - Horizontal and vertical nystagmus, vertigo, nausea, oscillopsia (Vestibular nucleus)
  - Facial nerve paralysis (Facial nerve)
  - Ataxia (Middle cerebellar peduncle and cerebellar hemisphere)
  - Paralysis of conjugate gaze to side of lesion (Centre for conjugate lateral gaze)
  - Deafness and tinnitus (Cochlear nucleus and nerve)
  - Sensory disturbance on face (Descending tract and nucleus of trigeminal nerve)
- **Contralateral** sign and symptoms (structure involved)
  - Impaired pain and temperature on trunk and limbs (Spinothalamic tract)
  - **Locked in syndrome** (pseudocoma) occurs due to infarction at the base of superiro pons.
- Paralysis of muscles supplied by lower cranial nerve and quadriplegia
- Patient is able to communicate by blinking or moving the eyes vertically

Medulla Oblongata

Medulla oblongata is present in the lower part of the brainstem and is continuous with the spinal cord. Its upper part is continuous with the pons.

- It extends from inferior pontine sulcus to the pyramidal decussation.
- Cranial nerve 9-12 nuclei (glossopharyngeal, vagus, cranial accessory nerve and hypoglossal nerve) are present in the medulla.
- Vestibulocochlear nerve nuclei are present at the pontomedullary junction.
- Medulla contains the cardiovascular, respiratory, vomiting and vasomotor centres dealing with heart rate, breathing and blood pressure.
- It is connected to the cerebellum by the **inferior cerebellar peduncle**.

Olive (medulla oblongata)

- Olives are a pair of prominent oval structures in the medulla oblongata containing the olivary nuclei.
- Olive is present on the anterior surface of the medulla lateral to the pyramid, from which it is separated by the antero-lateral sulcus and the fibers of the hypoglossal nerve.
- Posteriorly it is separated from the postero-lateral sulcus by the ventral spinocerebellar fasciculus. In the depression between the upper end of the olive and the pons lies the vestibulocochlear nerve.
- It has two parts:
  - Superior olivary nucleus is considered part of the pons and part of the auditory system, is a part of auditory pathway for sound perception.
  - Inferior olivary nucleus is a part of the olivo-cerebellar system and is mainly involved in cerebellar motor-learning and function.

Pyramid (medulla oblongata)

- Medullary pyramids are paired ridge-like structures present on the ventral aspect of the medulla oblongata.
- It contains motor fibers of the pyramidal tracts (corticospinal and corticobulbar tracts).
- Pyramidal decussation occurs in the lower medulla. Approximately 90% of the fibers decussate and travel down the lateral corticospinal tract while the other 10% travel down the anterior corticospinal tract.
- Anterior median fissure is present in the midline and separates the two pyramids.
- Anterolateral sulcus, which is present along their lateral borders, separates pyramid from olives.

- Hypoglossal nerve fibres emerge from anterolateral sulcus.
  A **transverse section** of medulla shows following structures:
- Medial structures
  - Hypoglossal nucleus, medial lemniscus, pyramid (corticospinal fibers)
- Lateral structures
  - Nucleus ambiguus, vestibular nuclei, inferior cerebellar peduncle (carrying dorsal spinocerebellar, cuneocerebellar, and olivocerebellar tracts), lateral spinothalamic tract—spinal lemniscus, spinal nucleus and tract of trigeminal nerve

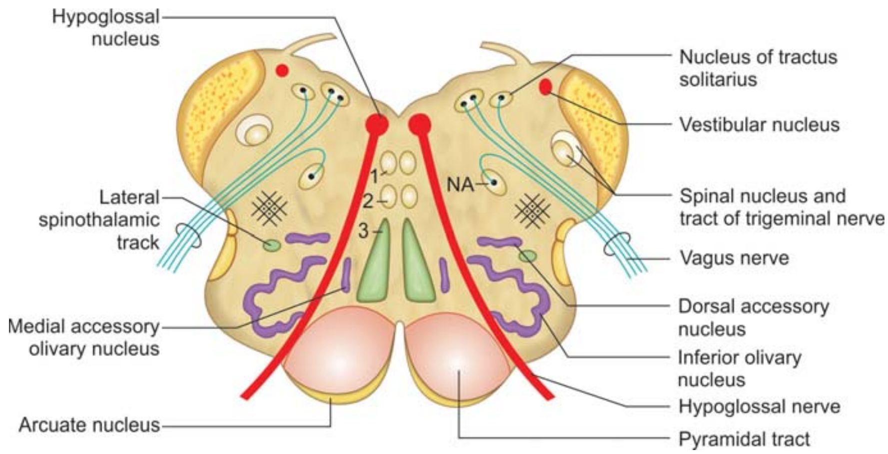


Fig. 57: Transverse section of medulla at the level of olives: 1. Medial longitudinal fasciculus, 2. tectospinal tract, 3. medial lemniscus. (NA = nucleus ambiguus)

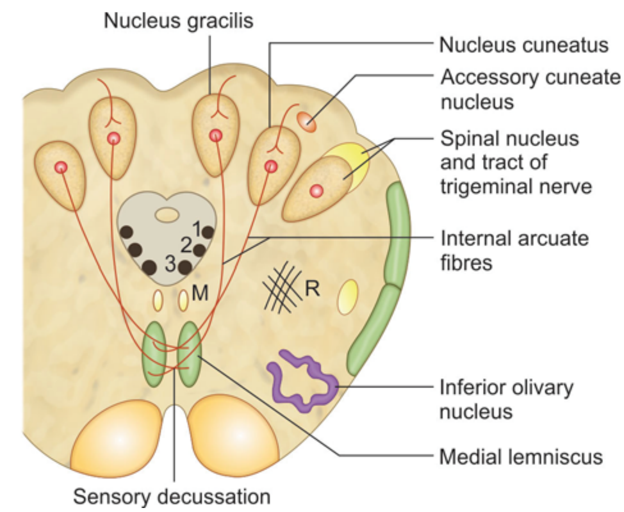


Fig. 58: Transverse section of medulla at the level of sensory decussation (1 = nucleus tractus solitarius, 2 = dorsal nucleus of vagus, 3 = hypoglossal nucleus; M = medial longitudinal fasciculus, R = reticular formation)

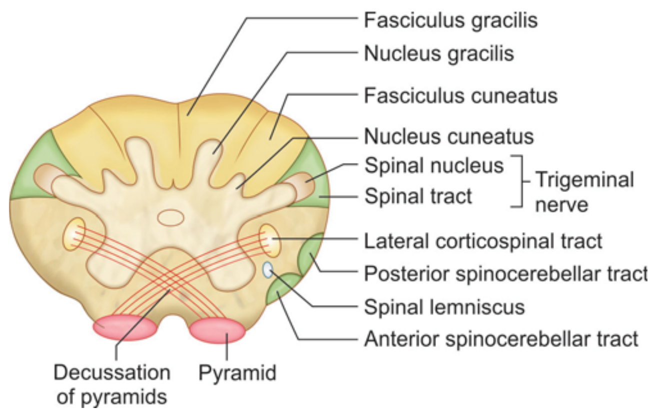


Fig. 59: Transverse section of medulla at the level of pyramidal decussation

- **Medial medullary syndrome** (occlusion of vertebral artery or anterior spinal artery or a branch of basilar artery)
- **Ipsilateral** sign and symptoms (structure involved)
  - **Flaccid** (LMN) paralysis and atrophy of one half of tongue (Hypoglossal nerve)
- **Contralateral** sign and symptoms (structure involved)
  - **Spastic** (UMN) paralysis of trunk and limbs (contralateral corticospinal tract)
  - Impaired tactile, proprioceptive and vibration sense of trunk and limbs (contralateral medial lemniscus)

- **Wallenberg (Lateral medullary)** syndrome (occlusion of vertebral artery > posterior inferior cerebellar artery)
- **Ipsilateral** sign and symptoms (structure involved)
  - Loss of pain and temperature over half face (Descending tract and nucleus of trigeminal nerve)
  - Cerebellar ataxia of limbs, falling to side of lesion (? Spinocerebellar tract)
  - Nystagmus, vertigo, nausea (Vestibular nucleus)
  - Horner's syndrome—miosis, ptosis, anhydrosis (Descending sympathetic tract)

- Paralysis of palate, pharynx and larynx muscles - difficulty in speech and swallowing (Nucleus ambiguus)
- Loss of taste on half of tongue (nucleus tractus solitarius)

- **Contralateral** sign and symptoms (structure involved)
  - Loss of pain and temperature over half of the body (Lateral spinothalamic tract)

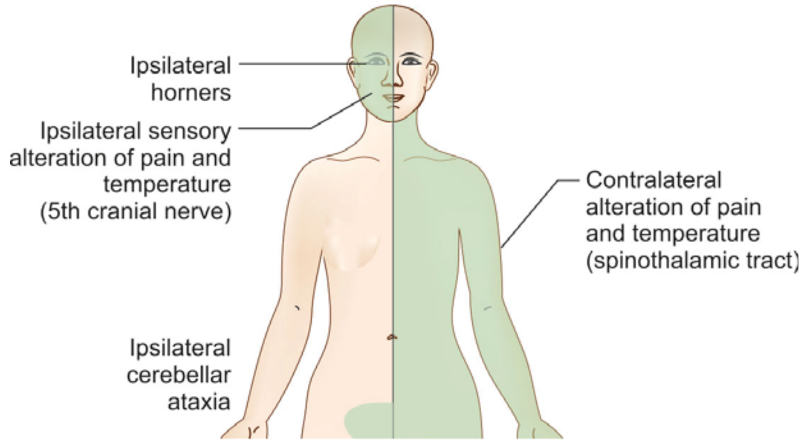


Fig. 60: Right sided Wallenberg syndrome: Clinical features

- Total unilateral medullary syndrome (occlusion of vertebral artery) presents with combination of medial and lateral syndromes

ASSESSMENT QUESTIONS

1. Which nerves does NOT arise from the medulla: *(NEET Pattern 2014)*
a. Facial
b. Glossopharyngeal
c. Vagus
d. Accessory

2. Position of nucleus ambiguus is: *(NEET Pattern 2014)*
a. Anteromedial to olive
b. Anterolateral to olive
c. Posteromedial to olive
d. Posterolateral to olive

3. A 68-year-old woman presents in the emergency room with dizziness and nystagmus. Examination reveals a loss of pain and temperature sensation over the right side of the face and the left side of the body. The patient exhibits ataxia and intention tremor on the right in both the upper and lower extremities and is unable to perform either the finger-to-nose or heel to-shin tasks on the right. In addition, she is hoarse and demonstrates pupillary constriction and drooping of the eyelid on the right. Finally, the right side of her face is drier than the left. Which of the following artery block would explain the patient's condition: *(AIIMS 2016)*
a. Right posterior inferior cerebellar artery
b. Left posterior inferior cerebellar artery
c. Right anterior inferior cerebellar artery
d. Basilar artery

ANSWERS WITH EXPLANATIONS

1. a. Facial
- Facial nerve nuclei are present in the pons and the nerve exits at the pontomedullary junction.
- Nuclei of cranial nerve 9, 10, 11 and 12 are present in the medulla oblongata and their fibres arise from the medulla.

2. c. Posteromedial to olive
- Nucleus ambiguus is a motor nucleus located in the upper medulla oblongata, postero-medial to olive.

3. a. Right posterior inferior cerebellar artery
- This is a case of right sided **Wallenberg syndrome** due to occlusion in the right **posterior inferior cerebellar artery**, leading to lateral medullary ischaemia and lesion of certain nuclei and tracts.
- The patient has alternating hemi-anaesthesia: ipsilateral loss of pain and temperature on face and contralateral loss of pain and temperature on the body. It occurs due to lesion of **lateral spinothalamic tract** and **spinal sensory nucleus of trigeminal**.
- Ataxia and intentions tremors indicate injury to **spinocerebellar tract** in the lateral medulla.
- There is hoarseness of voice which indicates lesion of **nucleus ambiguus** (which controls muscles of larynx).
- Patient also has features of right sided Horner syndrome due to lesion of the **hypothalamo-spinal pathway** in the lateral medulla.

Interpeduncular Fossa

- **Interpeduncular fossa** is a rhomboidal space bounded on either side by crus cerebri of cerebral peduncles, anteriorly by optic chiasma and optic tracts; and posteriorly by the pons.
- It contains (anterior to posterior):
  - A narrow stalk which connects the hypophysis cerebri with the tuber cinereum called **infundibulum**
  - A raised area of gray matter lying anterior to the mammillary bodies called **tuber cinereum**
  - Two small spherical bodies called **mammillary bodies**

- **Posterior perforated substance**, which is a layer of gray matter in the angle between the crus cerebri, and is pierced by central branches of the posterior cerebral arteries
- **Oculomotor nerve** which emerges immediately dorsomedial to the corresponding crus.

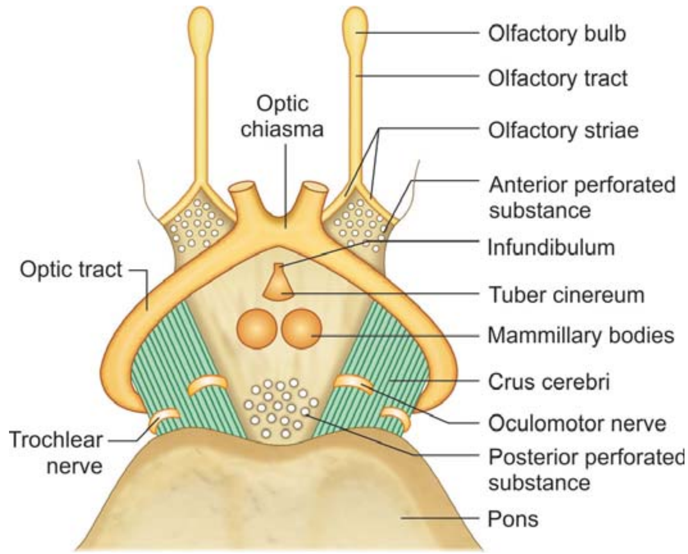


Fig. 61: Boundaries and contents of the interpeduncular fossa

ASSESSMENT QUESTIONS

1. **Olive is seen in which part of brain:** *(NEET Pattern 2014)*
   a. Medulla
   b. Cerebellum
   c. Midbrain
   d. Pons

2. **Internal arcuate fibers of medulla comes from:** *(NEET Pattern 2015)*
   a. Dorsal nucleus of vagus
   b. Hypoglossal nucleus
   c. Nucleus of tractus solitarius
   d. Nucleus gracilis and cuneatus

3. **Fibres passing through crus cerebri are:**
   a. Corticonuclear and corticospinal fibres
   b. Medial lemniscus
   c. Spinothalamic
   d. All

4. **All are contents of interpeduncular fossa EXCEPT:**
   a. Trochlear nerve
   b. Tuber cinerium
   c. Infundibular stalk
   d. Posterior perforated substance

5. **Nucleus fasciculatus is seen in:** *(NEET Pattern 2012)*
   a. Frontal lobe
   b. Medulla
   c. Temporal lobe
   d. Midbrain

ANSWERS WITH EXPLANATIONS

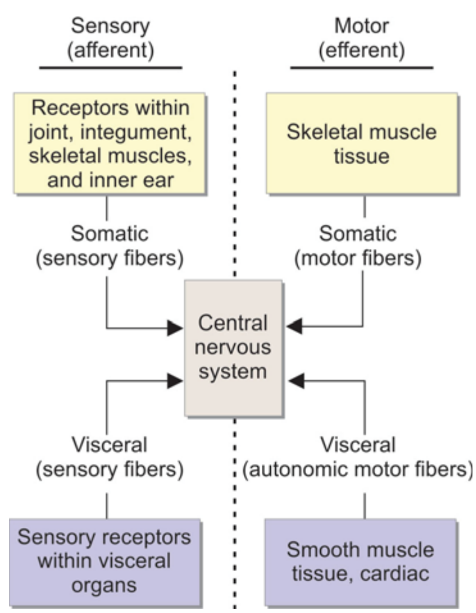
1. **a. Medulla**
   - Olives are a pair oval elevated structures in the medulla oblongata. They contain the olivary nuclei.
   - They are located on the anterior surface of the medulla lateral to the pyramid, from which they are separated by the antero-lateral sulcus and the fibers of the hypoglossal nerve.
2. **d. Nucleus gracilis and cuneatus**
   - The nucleus gracilis and cuneatus give rise to the internal arcuate fibres in the upper medulla.
   - These fibres cross to the opposite side to continue as the medial lemniscus.
   - Internal arcuate fibers are part of the second-order neurons of the dorsal column-medial lemniscus system which relay the sensations like pressure, fine touch, conscious proprioception to the thalamus.
3. **a. Corticonuclear and corticospinal fibres**
   - Crus cerebri is the anterior portion of the cerebral peduncle which contains the motor tracts: corticonuclear and corticospinal tracts.
4. **a. Trochlear nerve**
   - Trochlear nerve is not a content of interpeduncular fossa.
5. **b. Medulla**
   - This appears to be a misprint since there is no such term nucleus fasciculatus.
   - Fasciculus cuneatus and gracilis are components of dorsal column, which ascend up in the spinal cord and synapse with nucleus cuneatus and gracilis in the medulla oblongata.

CNS and BS Nuclei

- Neural tube forms the CNS (central nervous system) and is divided transversely into dorsal (sensory) and ventral (motor) parts by the sulcus limitans. It has a dorsal alar plate which gives origin to the sensory nuclei and a ventral plate separated forming the motor nuclei. The sensory and motor nuclei are separated from each other by the sulcus limitans.
- Cerebellum develops from the rhombic lip of alar plate and hence, Dentate nucleus is a derivative of alar plate. Inferior olivary nucleus is also a derivative of alar plate and is connected to the cerebellum by the climbing fibres. Vestibulo-cochlear nuclei are also derivatives of alar plate and are concerned with the sensations of hearing and balance.
- The tectum of midbrain (superior and inferior colliculi) is derived from dorsal/sensory alar plate. Superior colliculus is related with visual sensations and inferior colliculus is for auditory sensations (auditory pathway). The tegmentum (midbrain) is derived from the basal/motor plate and includes the oculomotor and the trochlear nuclei. These nuclei control the motor movements of eyeball. Red nucleus and substantia nigra are also considered under tegmentum, derived from basal plate and are involved in motor activity (Extra-pyramidal motor tracts).
- Some authors consider Red nucleus and substantia nigra as a derivative of alar plate (? Controversial), which have later migrated to the region of basal plate. But hypoglossal nucleus is definitely a derivative of basal plate. In certain questions we may have more than one answer but have to choose the most appropriate option.
- The main motor (basal plate) nuclei in the brainstem: Oculomotor, Trochlear, Abducent and Hypoglossal (GSE)-for eyeball and tongue muscles. Edinger Westphal, lacrimatory, salivatory, dorsal vagal (GVE)—for smooth/cardiac muscles and glands. Trigeminal, facial, ambiguus (SVE)—for pharyngeal arch muscles.

CRANIAL NERVES

- Cranial nerves are the means by which the brain receives information from, and controls the activities of, the head and neck, and to a lesser extent the thoracic and abdominal viscera.
- There are 12 pairs of cranial nerves that are individually named and numbered (Roman numerals) in a rostrocaudal sequence. Unlike spinal nerves, only some cranial nerves are mixed in function, carrying both sensory and motor fibres; others are purely sensory or purely motor. The first cranial nerve (I; olfactory) has an ancient lineage and is derived from the forerunner of the cerebral hemisphere. It retains this unique position through the connections of the olfactory bulb, and is the only sensory cranial nerve that projects directly to the cerebral cortex rather than indirectly via the thalamus. The areas of cerebral cortex receiving olfactory input have a primitive cellular organization and are an integral part of the limbic system, which is concerned with the emotional aspects of behaviour. The second cranial nerve (II; optic) consists of the axons of second-order visual neurones and these terminate in the thalamus. The other ten pairs of cranial nerves attach to the brainstem and most of their component fibres originate from, or terminate in, the cranial nerve nuclei of the brainstem.



- Neural tube has an anterior basal plate which gives motor neurones (efferent pathways) and a posterior ala plate which forms the sensory neurones (afferent pathways).

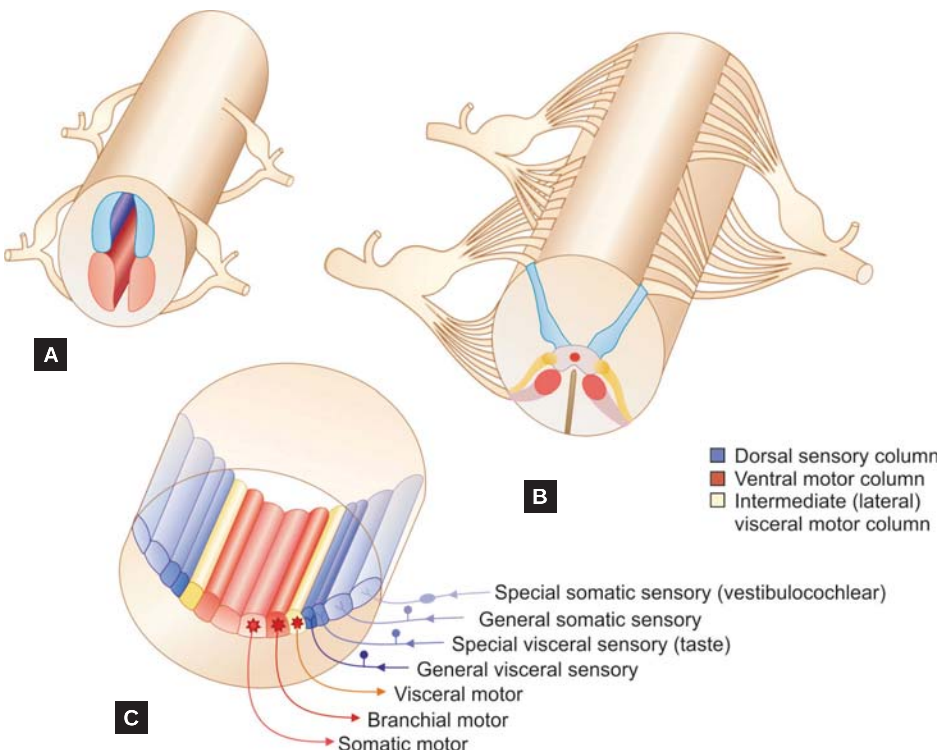
Basal Plate (Ventrolateral Lamina) Cells

- These cells form three elongated, discontinuous, columns that are positioned ventrally and dorsally with an intermediate column between.
- The most ventral column is continuous with the anterior gray column of the spinal cord and will supply muscles considered 'myotomic' in origin. It is represented in the caudal part of the hindbrain by the hypoglossal nucleus, and it reappears at a higher level as the nuclei of the abducens, trochlear and oculomotor nerves (somatic efferent nuclei).

- The intermediate column is represented in the upper part of the spinal cord and caudal brainstem (medulla oblongata and pons), and its neurones supply branchial (pharyngeal) and post branchial musculature. It is discontinuous, forming the elongated nucleus ambiguus in the caudal brainstem, which gives fibres to the ninth, tenth and eleventh cranial nerves, and continues into the cervical spinal cord as the origin of the accessory nerve.
- At higher levels, parts of this column give origin to the motor nuclei of the facial and trigeminal nerves. The nucleus ambiguus and the facial and trigeminal motor nuclei are termed branchial (special visceral) efferent nuclei.
- Neurones in the most dorsal column of the basal plate (represented in the spinal cord by the lateral gray column) innervate viscera. The column is discontinuous; its large caudal part forms some of the dorsal nucleus of the vagus and its cranial part forms the salivatory nucleus. These nuclei are termed general visceral (general splanchnic) efferent nuclei, and their neurones give rise to preganglionic, parasympathetic nerve fibres.
- It is important to note that the neurones of the basal plate and their three columnar derivatives are only motor in the sense that some of their number form either motor neurones or preganglionic parasympathetic neurones.
- The remainder, which greatly outnumber the former, differentiate into functionally related interneurones and, in some loci, into neuroendocrine cells.

Cell Columns of the Alar Plate (Dorsolateral Lamina)

- Cell columns of the alar plate are discontinuous and give rise to general visceral (general splanchnic) afferent, special visceral (special splanchnic) afferent, general somatic afferent, and special somatic afferent nuclei.
- The general visceral afferent column is represented by a part of the dorsal nucleus of the vagus, the special visceral afferent column by the nucleus of the tractus solitarius, the general somatic afferent column by the afferent nuclei of the trigeminal nerve, and the special somatic afferent column by the nuclei of the vestibulocochlear nerve. (The relatively simple functional independence of these afferent columns implied by the foregoing classification is, in the main, an aid to elementary learning.
- The emergent neurobiological mechanisms are, in fact, much more complex and less well understood.) Although they tend to retain their primitive positions, some of these nuclei are later displaced by differential growth patterns, by the appearance and growth of neighbouring fibre tracts, and possibly by active migration.
- It has been suggested that a neurone tends to remain as near as possible to its predominant source of stimulation, and that, to achieve this aim, it will migrate around intervening structures, towards the greatest density of stimuli.
- The curious paths of the axons arising from the facial nucleus and the nucleus ambiguus have been regarded as exemplars of this phenomenon of neurobiotaxis.
- In a 10 mm embryo, the facial nucleus lies in the floor of the fourth ventricle, occupying the position of the special visceral efferent column, and it is placed at a higher level than the abducens nucleus. As growth proceeds, the facial nucleus migrates at first caudally and dorsally, relative to the abducens nucleus, and then ventrally to reach its adult position. As it migrates, the axons to which its somata give rise elongate and their subsequent course is assumed to map out the pathway along which the facial nucleus has travelled.
- Similarly, the nucleus ambiguus initially arises immediately deep to the ventricular floor but, in the adult, it is more deeply placed and its efferent fibres pass first dorsally and medially before curving laterally to emerge at the surface of the medulla oblongata.



Figs. 62A to C: Relative positions of sensory and motor neural columns in brainstem and spinal cord

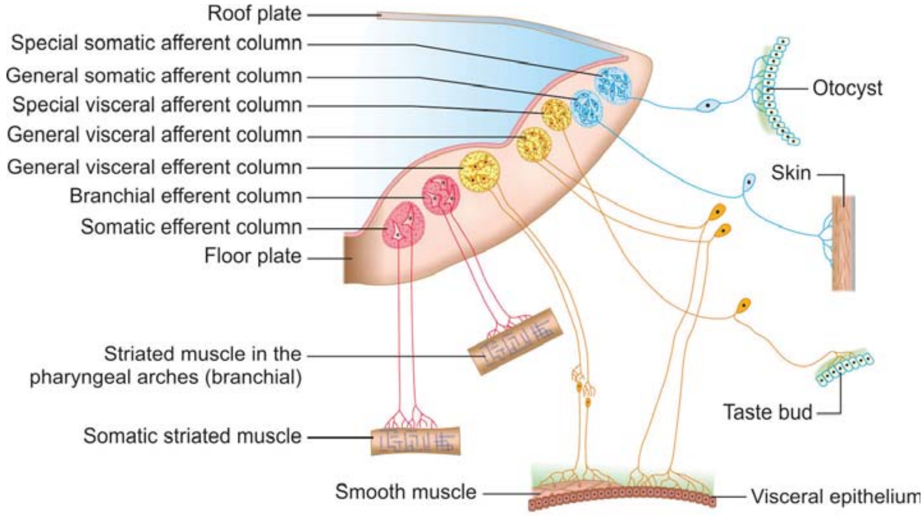


Fig. 63: Transverse section at the level of hindbrain, showing relative positions of sensory and motor neural columns

- Hypoglossal nucleus is a motor nucleus and develops from the Basal plate of neural tube. Neural tube forms the CNS (central nervous system) and is divided transversely into dorsal (sensory) and ventral (motor) parts by the sulcus limitans. It has a dorsal alar plate which gives origin to the sensory nuclei and a ventral plate separated forming the motor nuclei. The sensory and motor nuclei are separated from each other by the sulcus limitans.
- Cerebellum develops from the rhombic lip of alar plate and hence, Dentate nucleus is a derivative of alar plate. Inferior olivary nucleus is also a derivative of alar plate and is connected to the cerebellum by the climbing fibres. Vestibulo-cochlear nuclei are also derivatives of alar plate and are concerned with the sensations of hearing and balance.
- The tectum of midbrain (superior and inferior colliculi) is derived from dorsal/sensory alar plate. Superior colliculus is related with visual sensations and inferior colliculus is for auditory sensations (auditory pathway). The tegmentum (midbrain) is derived from the basal/motor plate and includes the oculomotor and the trochlear nuclei. These nuclei control the motor movements of eyeball. Red nucleus and substantia nigra are also considered under tegmentum, derived from basal plate and are involved in motor activity (Extrapyramidal motor tracts).
- Some authors consider Red nucleus and substantia nigra as a derivative of alar plate (? Controversial), which have later migrated to the region of basal plate. But hypoglossal nucleus is definitely a derivative of basal plate. In certain questions we may have more than one answer but have to choose the most appropriate option.
- The main motor (basal plate) nuclei in the brainstem: Oculomotor, Trochlear, Abducent and Hypoglossal (GSE)-for eyeball and tongue muscles. Edinger Westphal, Lacrimatory, salivatory, Dorsal Vagal (GVE)—for smooth/cardiac muscles and glands. Trigeminal, Facial, Ambiguus (SVE)—for pharyngeal arch muscles.

Table 10: Summary of cranial nerves

No.	Name	Components	Cells of origin	Main central connections	Exit from skull	Distribution and function
I	Olfactory	Special somatic afferent	Olfactory receptor cells in nasal mucosa	To olfactory bulb, anterior perforated substance, piriform cortex	Foramina of cribriform plate	Olfaction
II	Optic	Special somatic afferent	Ganglion cells of retina	To lateral geniculate nucleus of thalamus, pretectal area of midbrain	Optic canal	Vision
III	Oculomotor	Somatic efferent	Oculomotor nucleus	From visual cortical areas, medial longitudinal fasciculus	Superior orbital fissure	Motor to medial rectus, inferior rectus, superior rectus, inferior oblique, levator palpebrae superioris
III	Oculomotor	General visceral efferent	Edinger-Westphal nucleus	From pretectal area of midbrain	Superior orbital fissure	Parasympathetic to sphincter pupillae and ciliary muscles, via ciliary ganglion, mediating pupillary constriction and accommodation

No.	Name	Components	Cells of origin	Main central connections	Exit from skull	Distribution and function
IV	Trochlear	Somatic efferent	T rochlear nucleus	From visual cortical areas, medial longitudinal fasciculus	Superior orbital fissure	Motor to superior oblique
Trigeminal division:						
V	Ophthalmic (V_i)	General somatic afferent	Trigeminal (semilunar) ganglion	To trigeminal sensory nucleus	Superior orbital fissure	Sensation from forehead, scalp, eyelids, nose and eye, including conjunctiva
	Maxillary (V_{ii})	General somatic afferent	Trigeminal (semilunar) ganglion	To trigeminal sensory nucleus	Foramen rotundum	Sensation from mid-face, lower eyelid, nasal cavity and paranasal sinuses, upper lip, maxillary teeth and palate
	Mandibular (V_{iii})	General somatic afferent	Trigeminal (semilunar) ganglion	To trigeminal sensory nucleus	Foramen ovale	Sensation from lower face and scalp, tongue and floor of mouth, mandibular teeth and part of external ear
		General somatic afferent	Mesencephalic part of trigeminal sensory nucleus	To trigeminal sensory nucleus, cerebellum	Foramen ovale	Proprioception from muscles of mastication, temporomandibular joint
	Mandibular (V_{iv})	Branchial (special visceral) efferent	Trigeminal motor nucleus	From precentral gyrus	Foramen ovale	Motor to muscles of mastication (temporalis, masseter, medial and lateral pterygoids), tensor tympani
VI	Abducens	Somatic efferent	Abducens nucleus	From visual cortical areas, medial longitudinal fasciculus	Superior orbital fissure	Motor to lateral rectus
VII	Facial	General somatic afferent	Geniculate ganglion	To trigeminal sensory nucleus, cerebellum	Internal acoustic meatus	Sensation from part of tympanic membrane acoustic meatus and skin behind pinna Proprioception from facial muscles
VII	Facial	Special visceral afferent	Geniculate ganglion	To nucleus solitarius	Internal acoustic meatus	Taste from anterior two-thirds of tongue
VII	Facial	General visceral efferent	Superior salivatory nucleus	From olfactory areas, nucleus solitarius	Internal acoustic meatus	Parasympathetic to lacrimal gland and mucous membrane of nasal and oral cavities (via pterygopalatine ganglion) and submandibular and sublingual salivary glands (via submandibular ganglion) causing secretion and vasodilation
VII	Facial	Branchial (special nucleus)	Facial nucleus	From precentral gyrus	Internal acoustic	Motor to 'muscles of facial expression', stapedius,
VIII	Vestibulocochlear					
	Vestibular division	Special somatic afferent	Vestibular ganglion	To vestibular nuclei, cerebellum	Internal acoustic meatus	Sensations of equilibrium and motion
	Cochlear division	Special somatic afferent	Spiral ganglion	To cochlear nuclei	Internal acoustic meatus	Hearing
IX	Glossopharyngeal	General visceral afferent	Glossopharyngeal ganglia	To trigeminal sensory nucleus	Jugular foramen	General sensation from posterior one-third of tongue, oropharynx and middle ear

No.	Name	Components	Cells of origin	Main central connections	Exit from skull	Distribution and function
IX	Glossopharyngeal	General somatic afferent	Glossopharyngeal ganglia	To nucleus solitarius	Jugular foramen	Sensory from carotid body (chemoreceptors) and carotid sinus (baroreceptors)
IX	Glossopharyngeal	Special visceral afferent	Glossopharyngeal ganglia	To nucleus solitarius	Jugular foramen	Taste from posterior one-third of tongue
IX	Glossopharyngeal	General visceral efferent	Inferior salivatory nucleus	From olfactory areas, nucleus solitarius	Jugular foramen	Parasympathetic to parotid salivary gland (via otic ganglion), causing secretion and vasodilation
IX	Glossopharyngeal	Branchial (special visceral) efferent	Nucleus ambiguus	From precentral gyrus	Jugular foramen	Motor to stylopharyngeus
X	Vagus	General somatic afferent	Superior (jugular) ganglion	To trigeminal sensory nucleus	Jugular foramen	General sensation from pharynx, larynx, trachea, oesophagus, part of auricle and external audiltory meatus
X	Vagus	General visceral afferent	Inferior (no dose) ganglion	To nucleus solitarius	Jugular foramen	Sensory from thoracic and abdominal viscera Sensory from aortic arch (baroreceptors) and aortic bodies (chemoreceptors)
X	Vagus	General visceral efferent	Dorsal motor nucleus of vagus	From hypothalamus, nucleus solitarius	Jugular foramen	Parasympathetic to glands and smooth muscle in the pharynx, larynx, thoracic and abdominal viscera
X	Vagus	Branchial (special visceral) efferent	Nucleus ambiguus	From precentral gyrus, sensory nuclei of brainstem	Jugular foramen	Motor to pharyngeal, external laryngeal and oesophageal striated muscles
XI	*Accessory					
	Cranial root	Branchial (special visceral) efferent	Nucleus ambiguus	From precentral gyrus, sensory nuclei of brainstem	Jugular foramen	Motor to muscles of soft palate and intrinsic muscles of larynx (distributed via vagus)
	Spinal root	Branchial (special visceral) efferent	Spinal cord segments C1-C5	From precentral gyrus	Jugular foramen	Motor to sternocleidomastoid and trapezius
XII	Hypoglossal	Somatic efferent	Hypoglossal nucleus	From precentral gyrus	Hypoglossal canal	Motor to all intrinsic and extrinsic muscles of the tongue, except palatoglossus

Note: *The existence of a 'cranial root' of the accessory nerve with its cell bodies in the nucleus ambiguus is controversial (Gray's Anatomy Ed41). There is a view that the 'spinal root' of the accessory nerve should be regarded as the accessory nerve proper and that the vagus nerve supplies the muscles of the palate, pharynx and larynx.

GSE column	SVE column	GVE column	GVA/SVA column	GSA column	SSA column
• Oculomotor nucleus	• Motor nucleus of trigeminal n.	• Edinger-Westphal nucleus	• Nucleus of solitary tract (nucleus tractus solitarius)	• Sensory nuclei of trigeminal n.	• Vestibular nuclei
• Trochlear nucleus	• Motor nucleus of facial n.	• Lacrimatory nucleus		– Chief	• Cochlear nuclei
• Abducens nucleus	• Nucleus ambiguus	• Superior salivatory nucleus		– Mesencephalic	
• Hypoglossal nucleus		• Inferior salivatory nucleus		– Spinal	
		• Dorsal nucleus of vagus nerve			

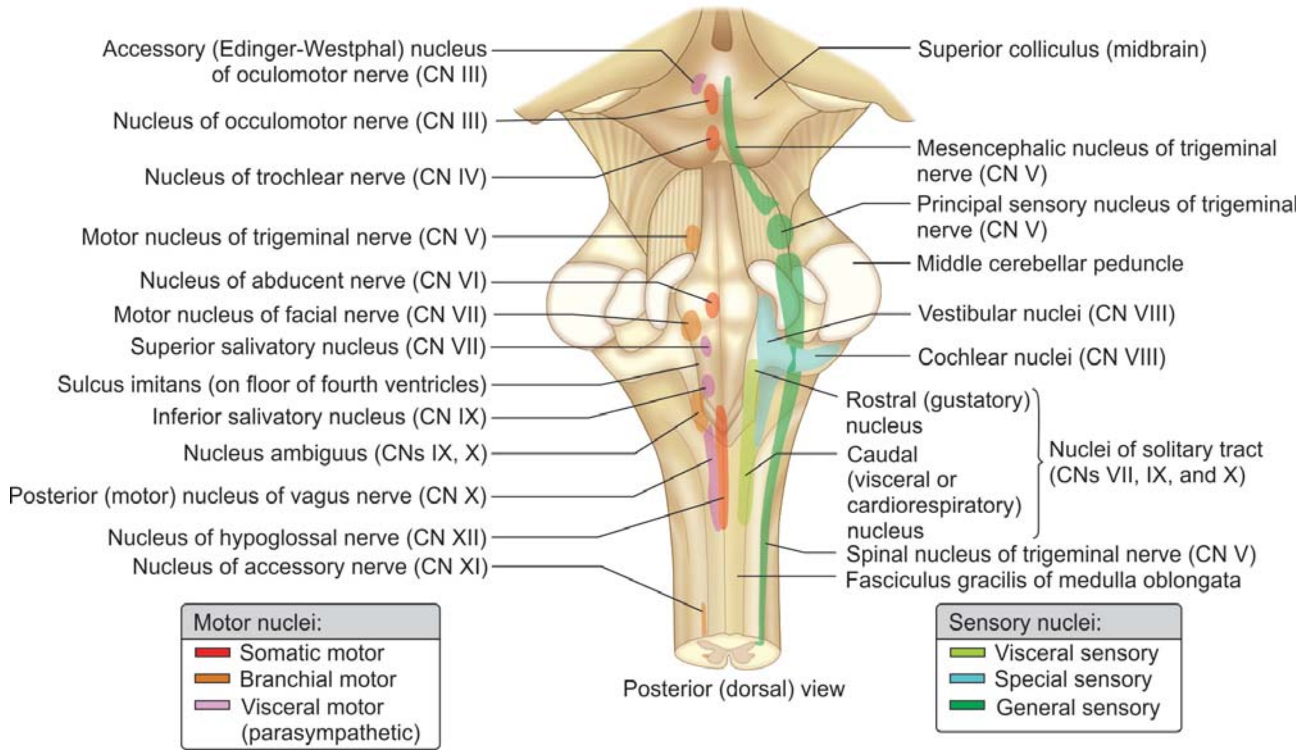


Fig. 64: Cranial nerve nuclei

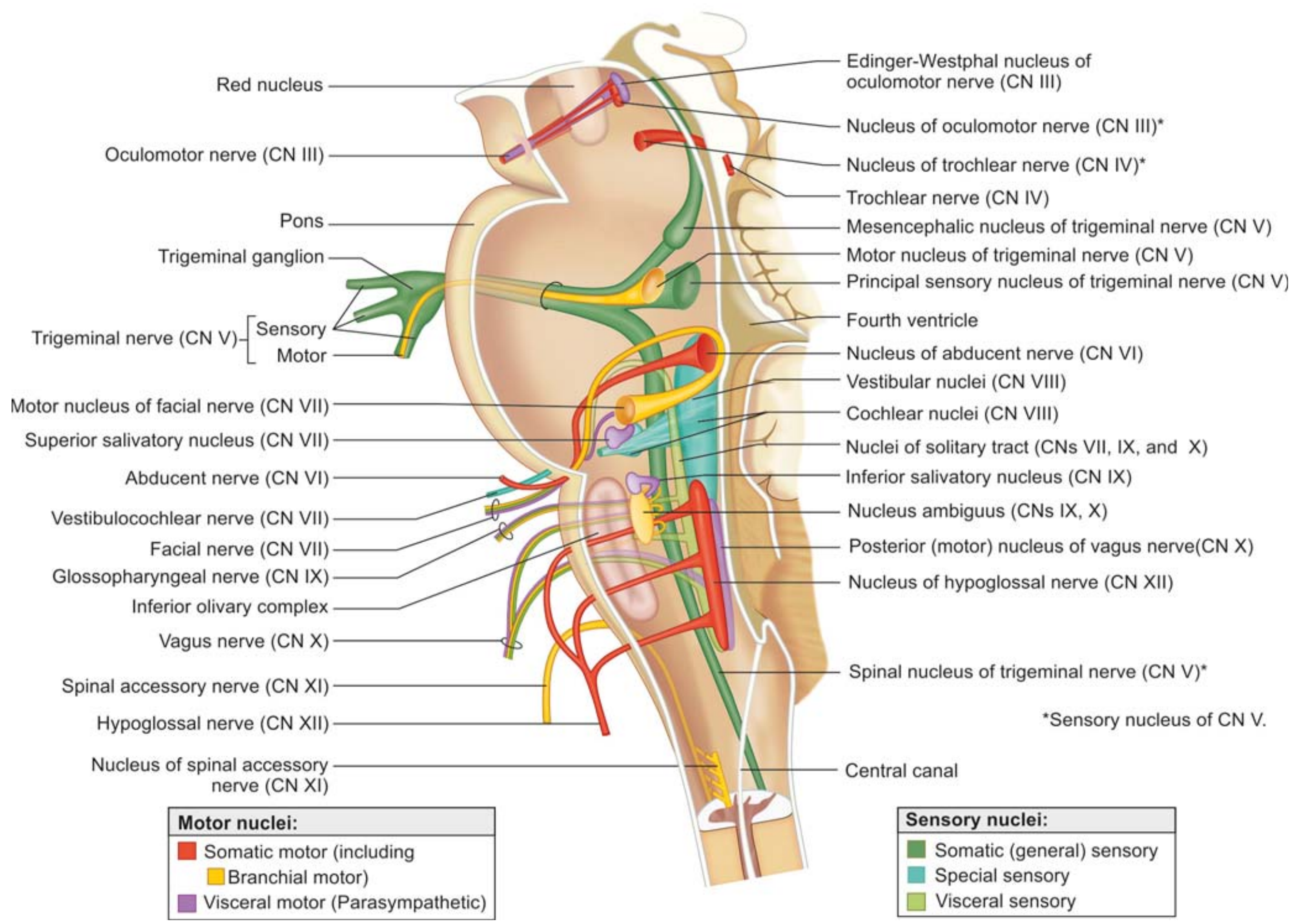


Fig. 65: Brainstem nuclei and the origin and course of cranial nerves

Brain stem has three subdivisions: Mid-brain, Pons and Medulla oblongata and has cranial nerve 3-12 nuclei. Nuclei for CN 3 and 4 (midbrain); CN 5-8 (pons); and 9-12 (medulla). Motor nuclei are located medially (and sensory nuclei are lateral).

- Motor nuclei of cranial nerve are lower motor neurons that innervate the skeletal muscles of the head. These lower motor neurons are under influence of upper motor neurons by corticobulbar fibers. The neuron bodies of corticobulbar fibers are located in the cerebrum (frontal motor cortex).
  - Cranial nerve 1, 2 and 8 are pure sensory nerves.
  - Cranial nerve 3, 4, 6 and 11, 12 are pure motor nerves.
  - Mixed (sensory and motor) nerves are cranial nerve 5, 7, 9 and 10.
- General Somatic Efferent (GSE) fibers conduct motor impulses to the skeletal (somatic) muscles of the body.
- Special Visceral Efferent (SVE) fibers convey motor impulses to the muscles of the head and neck, which develop from pharyngeal arches such as muscles of mastication, muscles of facial expression, and muscles of palate, pharynx and larynx (speech and swallowing).
- General Visceral Efferent (GVE) fibers transmit motor impulses to smooth muscle, cardiac muscle, and glandular tissues (Autonomic Nervous system).
- General Somatic Afferent (GSA) fibers transmit general sensations like touch, pain, temperature, proprioception from the body to the CNS.
- Special Visceral Afferent (SVA) fibers transmit taste sensations to the CNS.
- General Visceral Afferent (GVA) fibers carry sensory impulses from visceral organs to the CNS. For e.g., carotid sinus pressure sensation.

  Special Somatic Afferent (SSA) fibers convey special sensory impulses of smell, vision, hearing and balance to the CNS.
- SVE: Special (S) muscles (E) which develop around the pharynx viscera (V) – pharyngeal arch muscles:
  - Arch – I (Muscles of mastication, 5th nerve)
  - Arch – II (Muscles of facial expression, 7th nerve)
  - Arch – III, IV and VI (Palate, pharynx and larynx muscles), Nucleus Ambiguus (9, 10, 11 nerves).

- GVE and GVA : General Visceral Efferent and Afferent are under ANS (Autonomic nervous system).
  - Motor fibers control three effectors: cardiac, smooth muscles and glands.
  - Sensory fibers receive visceral sensations like angina pain, colicky pain etc.

Nucleus Tractus Solitarius (NTS)

- It is a **sensory** nucleus present in the medulla oblongata and through its center runs the solitary tract axons from the **facial, glossopharyngeal and vagus nerves**.
- It has both SVA and GVA neural columns.
- SVA (Special Visceral Afferent) is related to taste sensations which reach the **upper part** of the nucleus.
- GVA (General Visceral Afferent) is related to sensations like carotid sinus pressure sensations, carotid body chemoreception and information from cardio-respiratory and gastrointestinal processes etc., reach the **lower part** of the nucleus.
- NTS receives taste sensation from three nerves:
  - Anterior two-thirds of the tongue via the chorda tympani nerve of the facial nerve (CN VII).
  - Posterior third of the tongue via the glossopharyngeal nerve (CN IX).
  - Posteriormost tongue (and epiglottic region of the pharynx) via the vagus nerve (CN X).
- Cranial nerve 9 and 10 carry the general visceral sensations (GVA) to lower part of the nucleus. The nucleus mediate the gag reflex, the carotid sinus reflex, the aortic reflex, the cough reflex, the baroreceptor and chemoreceptor reflexes, several respiratory reflexes and reflexes within the gastrointestinal system regulating motility and secretion.
- Information from NTS is projected the paraventricular nucleus of the hypothalamus and the central nucleus of the amygdala, as well as to other nuclei in the brainstem (such as the parabrachial area, the Locus coeruleus, the dorsal raphe nucleus , and other visceral motor or respiratory networks).

Nucleus Ambiguus

- It contains lower motor neurons belonging to cranial nerves 9, 10 and 11 (cranial part).
- It belongs to SVE (Special Visceral Efferent) column and innervate the pharyngeal arch muscles of the palate, pharynx, and larynx involved in the movements of speech and swallowing. It also supplies the muscles of upper esophagus.
- Its 'external formation' contains cholinergic preganglionic parasympathetic neurons for the heart.
- It is located in the upper medulla oblongata, deep in the medullary reticular formation.
- It lies posterior to the inferior olivary nucleus and posteromedial to olive.
- It receives upper motor neuron innervation via the corticobulbar tract.
- Lesions of nucleus ambiguus results in:
  - Difficulty of speech and swallowing—nasal speech, dysphagia, and dysphonia.
  - Uvula towards the contralateral side, due to prominent activity of contralateral (normal side) muscles.

ASSESSMENT QUESTIONS

1. Which of the following brainstem nuclei is not derived from alar plate? *(AIIMS 2008)*
a. Dentate
b. Inferior olivary
c. Hypoglossal
d. Substantia nigra

2. NOT a somatic efferent nerve: *(AIPG 2008)*
a. IIIrd
b. IVth
c. Vth
d. XIIth

3. Visceral efferent column in the lateral horns of spinal cord arises from which plate of the neural tube?
a. Alar
b. Basal
c. Roof
d. Floor

4. All of the following nerves have general visceral fibers EXCEPT: *(AIIMS 2015)*
a. Olfactory
b. Oculomotor
c. Facial
d. Glossopharyngeal

5. Nucleus tractus solitarius receive fibers from all of the following cranial nerves EXCEPT:
a. Facial
b. Glossopharyngeal
c. Vagus
d. Accessory

6. Taste pathway comes under the neural column:
a. SSA
b. GSA
c. SVA
d. GVA

7. All of the following cranial nerves contains somatic efferents EXCEPT: *(NEET Pattern 2013)*
a. VII nerve
b. III nerve
c. IV nerve
d. VI nerve

8. All of the following pairs regarding neural columns and associated nuclei are correct EXCEPT:
a. Hypoglossal nucleus: GSE
b. Nucleus ambiguus: SVE
c. Dorsal nucleus of vagus: GVA
d. Nucleus tractus solitarius: SVA

9. Nuclei cuneatus and gracilis are present in:
a. Spinal cord
b. Medulla oblongata
c. Pons
d. Midbrain

10. Which of the following cranial nerve is associated with special somatic afferent nuclei?
a. V
b. VI
c. VII
d. VIII

11. Which of the following nuclei belongs to the general visceral efferent column? *(AIIMS 2004)*
a. Facial nerve nucleus
b. Trigeminal nerve nucleus
c. Dorsal nucleus of vagus
d. Nucleus ambiguous

12. Nucleus ambiguus doesn't include: *(NEET Pattern 2012)*
a. 7th nerve nucleus
b. 9th nerve nucleus
c. 10th nerve nucleus
d. 11th nerve nucleus

ANSWERS WITH EXPLANATIONS

1. c. Hypoglossal
- Hypoglossal nucleus is a **motor** nucleus and develops from the **basal** plate (and **not alar plate**) of neural tube.
- Neural tube forms the CNS (central nervous system) and is divided transversely into dorsal (sensory) and ventral (motor) plates. Dorsal alar plate give origin to the sensory nuclei and ventral basal plate form the motor nuclei.
- Cerebellum develops from the rhombic lip of alar plate and hence, **Dentate nucleus** is a derivative of alar plate.
- **Inferior olivary nucleus** is also a derivative of alar plate and is connected to the cerebellum by the climbing fibers.
- Some authors consider Red nucleus and **substantia nigra** as a derivative of alar plate (?), which have later migrated to the region of basal plate.

2. c. Vth
- Somatic efferent nerves supply all the skeletal muscles except the branchial arch musculature. Hence, Vth nerve is not a somatic efferent nerve as it supplies the muscles of mastication under the first branchial arch (It comes under special visceral efferent).
- Somatic efferent nerves are the IIIrd , IVth and VIth, which supply the skeletal muscles of eyeball. XIIth nerve also belongs to somatic efferent column and controls the skeletal muscles of tongue.

3. b. Basal
- Visceral efferent column in the lateral horns of spinal cord are sympathetic and parasympathetic motor neurones, which controls cardiac and smooth muscles and the glands.
- Since these are motor neurones they take origin from the anterior **basal** plate of neural tube.

4. a. Olfactory
- **Olfactory** nerve belongs to **SSA** (**Special Somatic** Afferent) neural column.
- Cranial nerve 1, 2, and 8 are under SSA. These nerve brings special sensations (Smell, vision, hearing and balance) from the periphery.
- GVE (General Visceral Efferent) neural column belongs to autonomic nervous system and supplies the three effectors: Cardiac muscles, smooth muscles and glands.
- Oculomotor nerve supplies two smooth muscles under this neural column.
- Facial nerve has superior salivatory nucleus and glossopharyngeal nerve has inferior salivatory nucleus to supply smooth muscles of glands under this column.

5. d. Accessory
- Nucleus tractus solitarius is a **sensory** nucleus present in the medulla oblongata and through its center runs the solitary tract axons from the **facial, glossopharyngeal and vagus nerves**.
- Accessory nerve is a pure motor nerve, its cranial part is included under Special visceral efferent neural column, as it supplies the pharyngeal arch muscles of palate, pharynx and larynx.

6. c. SVA
- Special Visceral Afferent (SVA) fibers transmit taste sensations to the CNS.

7. a. VII nerve
- GSE (General Somatic Efferent) neural column includes supply to all the skeletal muscle, except the pharyngeal arch muscles.
- Muscles of eyeball are supplied by cranial nerve 3, 4 and 6, which are under GSE neural column.
- Pharyngeal arch muscles are under the SVE (Special Visceral Efferent) neural column. Facial nerve supplies muscles of facial expression, which develop in second pharyngeal arch.

8. c. Dorsal nucleus of vagus: GVA
- Dorsal nucleus of vagus is a **motor** nucleus to control cardiac and smooth muscles and glands, hence belongs to GVE (and **not GVA**) neural column.

9. b. Medulla oblongata
- Nuclei cuneatus and gracilis receives the fibers of dorsal column (fasciculus cuneatus and gracilis) and are located in the medulla oblongata.

10. d. VIII
- Special Somatic Afferent (SSA) fibers convey special sensory impulses of smell, vision, hearing and balance to the CNS.

11. c. Dorsal nucleus of vagus
- GVE (General Visceral Efferent) neural column belongs to autonomic nervous system and supplies the three effectors: Cardiac muscles, smooth muscles and glands. Dorsal nucleus of vagus supplies the three effectors of ANS.
- Salivatory (including lacrimatory) nuclei of facial nerve also belong to GVE column.
- Trigeminal nerve nuclei do not have any GVE functionality.
- Nucleus ambiguus belongs to special visceral efferent column and supplies the branchial arch muscles.

12. a. 7th nerve nucleus
- Nucleus ambiguus is contributed by the cranial nerve 9, 10 and cranial part of 11.
- It supplies the pharyngeal arch muscles of palate, pharynx and larynx.

High Yield Point
- Trochlear nerve arises from lower midbrain and Abducent arises from pons.

Cerebellum

Cerebellum is embryologically derived from the rhombic lips, which are the thickened **alar plates** of the mantle layer (neural tube).
- The rostral part of the cerebellum is derived from the caudal mesencephalon.
- Cerebellum is a part of the metencephalon (hindbrain) and lies in the posterior cranial fossa.
- Fourth ventricle, pons and medulla lie anterior to the cerebellum.
- It is separated from the overlying cerebrum (occipital lobes) by a layer of dura mater (**tentorium cerebelli**)
- It has two hemispheres and a narrow midline zone (vermis).
- It has an outer cerebellar **cortex** having tightly folded layer of gray matter, producing gyri (**folia**) and sulci.
- Deep to the gray matter lies white matter, made up largely of myelinated nerve fibers running to and from the cortex. White matter gives the appearance of **arbor vitae** (tree of life) because of its branched, tree-like appearance in cross-section.
- Embedded within the white matter are **four deep cerebellar nuclei** (gray matter).

Structurally, three lobes are distinguished within the cerebellum: the **anterior** lobe (above the primary fissure), the **posterior** lobe (below the primary fissure), and the **flocculonodular** lobe (below the posterior fissure).
- These lobes divide the cerebellum from top to bottom.

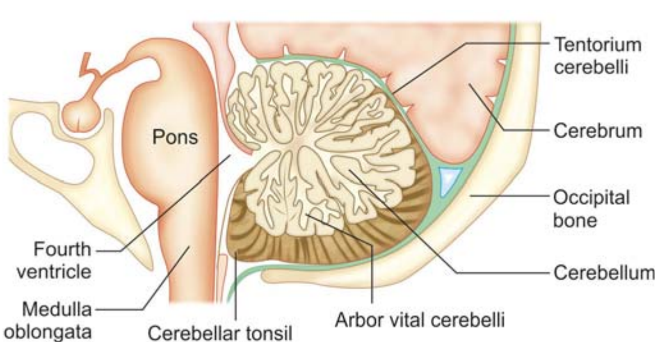


Fig. 66: Structure and relations of cerebellum

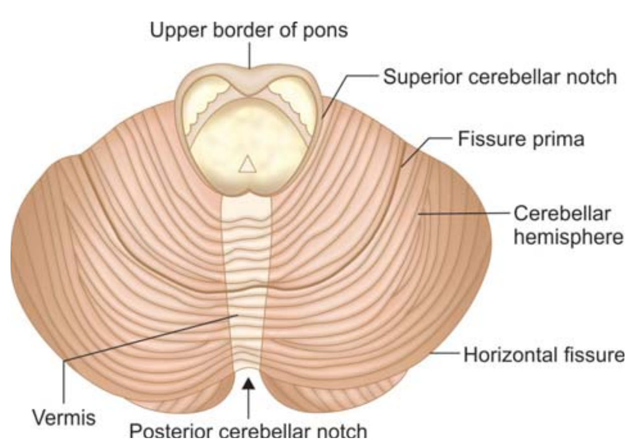


Fig. 67: Superior view of the cerebellum

Functionally the distinction is along the medial-to-lateral direction.

- Medial region : **Spinocerebellum** (paleocerebellum)
  - It includes the medial zone of the anterior and posterior lobes.
  - It works for fine tuning of body and limb movements.
  - It receives proprioceptive input from the dorsal columns of the spinal cord (including the spinocerebellar tract) and from the cranial trigeminal nerve, as well as from visual and auditory systems.
  - It sends fibers to deep cerebellar nuclei that, in turn, project to both the cerebral cortex and the brain stem, thus providing modulation of descending motor systems.
- Lateral region: **Cerebrocerebellum** (neocerebellum)
  - It receives input exclusively from the cerebral cortex (especially the parietal lobe) via the pontine nuclei (**cortico-ponto-cerebellar pathways**), and sends output mainly to the ventrolateral thalamus (in turn connected to motor areas of the premotor cortex and primary motor area of the cerebral cortex) and to the red nucleus.
- Midline region: **Vermis** is a narrow strip of protruding tissue along the midline.

Flocculonodular lobe (vestibulocerebellum) is the oldest part (archicerebellum), participating mainly in balance and spatial orientation.

- Its primary connections are with the **vestibular** nuclei, although it also receives **visual** and other sensory input.

Flowchart 2: Nuclear connection of the cerebellum

Neocerebellum → Dentate nucleus → Red nucleus and thalamus

Paleocerebellum → Globose and emboliform nuclei → Red nucleus

Archicerebellum → Fastigial nucleus → Vestibular nuclei

Table 11: Various subdivisions (lobules) of vermis and cerebellar hemisphere

Lobes	Subdivisions of vermis	Subdivisions of cerebellar hemisphere
Anterior lobe	Lingula Central lobule Culmen	No lateral projection Alae Quadrangular lobe
Posterior lobe	Declive Follum Tuber Pyramid Uvula	Lobulus simplex Superior semilunar lobule Inferior semilunar lobule Biventral lobule Tonsil
Flocculonodular lobe	Nodule	Flocculus

Table 12: Components, nuclei, connections and functions of three morphological subdivisions of the cerebellum

Subdivisions	Components	Nucleus	Chief connections	Functions
Archicerebellum (oldest part)	Flocculonodular lobe + lingula	Nucleus fastigii	Vestibulocerebellar	Maintenance of equilibrium (responsible for maintaining the position of body in space)
Paleocerebellum (in between, i.e. neither oldest nor newest)	Whole of anterior lobe except lingula Pyramid Uvula	Nucleus interpositus consisting of nucleus globosus and nucleus emboliformis	Spinocerebellar	Controls crude movements of the limbs
Neocerebellum (most recent part)	Whole of posterior lobe except pyramid and uvula	Nucleus dentatus	Corticopontocerebellar	Smooth performance of high skilled voluntary movements of precision

- Two neurone types play dominant roles in the cerebellar circuit: **Purkinje** cells and **granule** cells.
- Three types of axons also play dominant roles: **mossy** fibers and **climbing** fibers (afferents to cerebellum), and **parallel** fibers (the axons of granule cells).
- There are two main pathways through the cerebellar circuit, originating from mossy fibers and climbing fibers, both eventually terminating in the deep cerebellar nuclei.
- Cerebellar cortex has **five cell types** arranged in **3 layers**:
  - Outermost molecular layer has inhibitory (GABAergic) interneurons—2 cells (stellate and basket)
  - Middle layer—purkinje cells
  - Inner (deeper/granular) layer—2 cells (granule and Golgi).

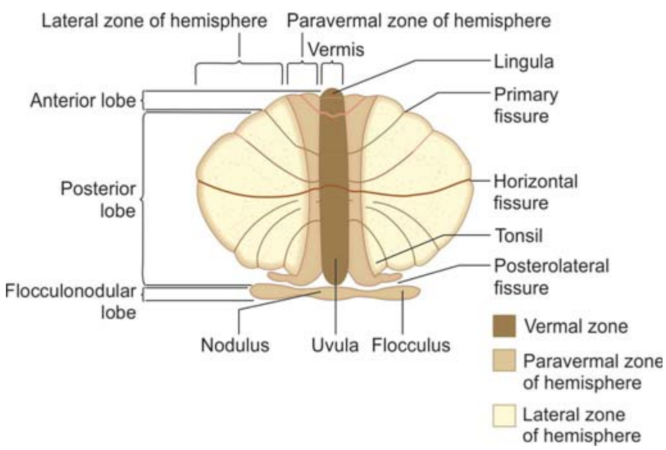


Fig. 68: Schematic diagram of the fissures, lobules, and lobes of the cerebellum. Functional longitudinal zones of the cerebellum are associated with cerebellar nuclei. The vermal (median) zone projects to the fastigial nucleus, the paravermal (paramedian) zone projects to the interposed nucleus, and the lateral zone projects to the dentate nucleus

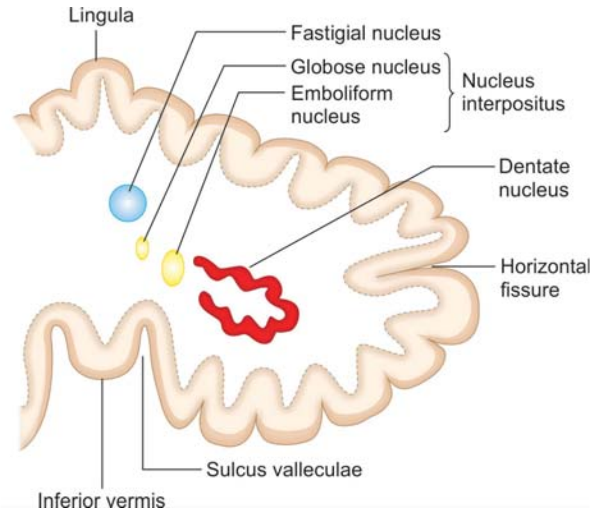


Fig. 69: Transverse section of the cerebellum showing intracerebellar nuclei

Outermost **molecular** layer also contains the array of **parallel fibers** penetrating the **Purkinje cell dendritic trees** at right angles.

Deep nuclei of the cerebellum are collections of gray matter lying within the white matter at the core of the cerebellum.

- Their arrangement is (lateral to medial): Dentate, emboliform, globose, and fastigial.
- Dentate nucleus is the latest in evolution, is the largest and the lateral most. It communicates exclusively with the lateral parts of the cerebellar cortex.
- Flocculonodular lobe is the only part of the cerebellar cortex that does not project to the deep nuclei, instead its efferent reach the vestibular nuclei.
- These nuclei receive collateral projections from mossy fibers and climbing fibers as well as inhibitory input from the Purkinje cells of the cerebellar cortex.
- These nuclei are (with the minor exception of the vestibular nuclei) the sole sources of output (efferents) from the cerebellum.

Climbing fibers (olivocerebellar fibers) originate from the **inferior olivary nucleus** on the contralateral side of the brainstem, pass through inferior cerebellar peduncle and project to Purkinje cells.

- Although the inferior olive **lies in the medulla oblongata** and receives input from the spinal cord, brainstem and cerebral cortex, its output goes entirely to the cerebellum.
- A climbing fiber gives off collaterals to the **deep cerebellar nuclei** before entering the cerebellar cortex, where it splits into about 10 terminal branches, each of which gives input to a single Purkinje cell.

Mossy fibers are the afferent fibers to cerebellum, arising from the pontine nuclei, spinal cord, vestibular nuclei etc.

- They form **excitatory** synapses with the granule cells **and** the cells of the deep cerebellar nuclei.
- Within the granular layer, a mossy fiber generates a series of enlargements called rosettes. The contacts between mossy fibers and granule cell dendrites take place within structures called glomeruli.
- **Cerebellar glomerulus** consists of a mossy fiber rosette, granule cell dendrites, and a Golgi cell axon.

Mossy fibers project directly to the deep nuclei, but also give rise to the following pathway:

Mossy fibers → granule cells → parallel fibers → Purkinje cells → deep nuclei.

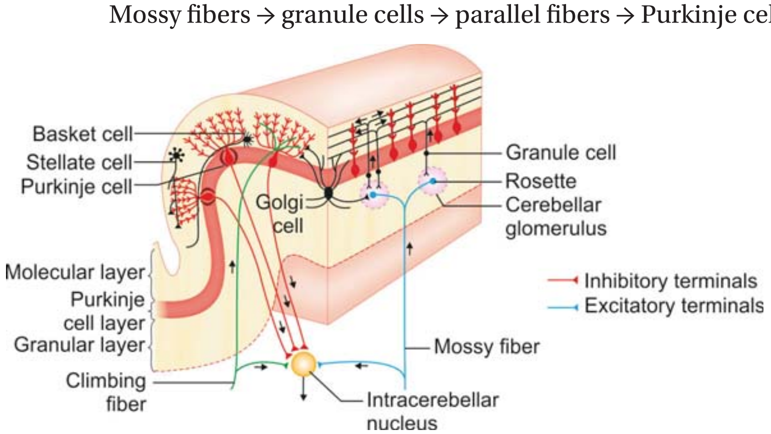


Fig. 70: Triple layers of cerebellar cortex and the triple fiber (mossy, climbing and parallel) neuronal circuitry

Cerebellar Pathways

- Mossy fibers (and climbing fibers) are the afferent fibers reaching the cerebellum via the cerebellar peduncles. These are excitatory in nature and project directly (or indirectly via granule cells) to the Purkinje cells of the cerebellar cortex.
- The axons of the Purkinje cells are inhibitory (GABAergic) and are the only efferent (outflow) from the cerebellar cortex. They project to and inhibit the deep cerebellar nuclei (dentate, interposed, and fastigi) in the medulla.
- From the deep nuclei, efferents project through the superior cerebellar peduncle to the contralateral ventral lateral (and ventral anterior) nuclei of the thalamus, to reach the contralateral cerebrum (precentral gyrus).
- The upper motor neurons of the cerebrum thence influence the contralateral lower motor neurons of the spinal cord via corticospinal tract.

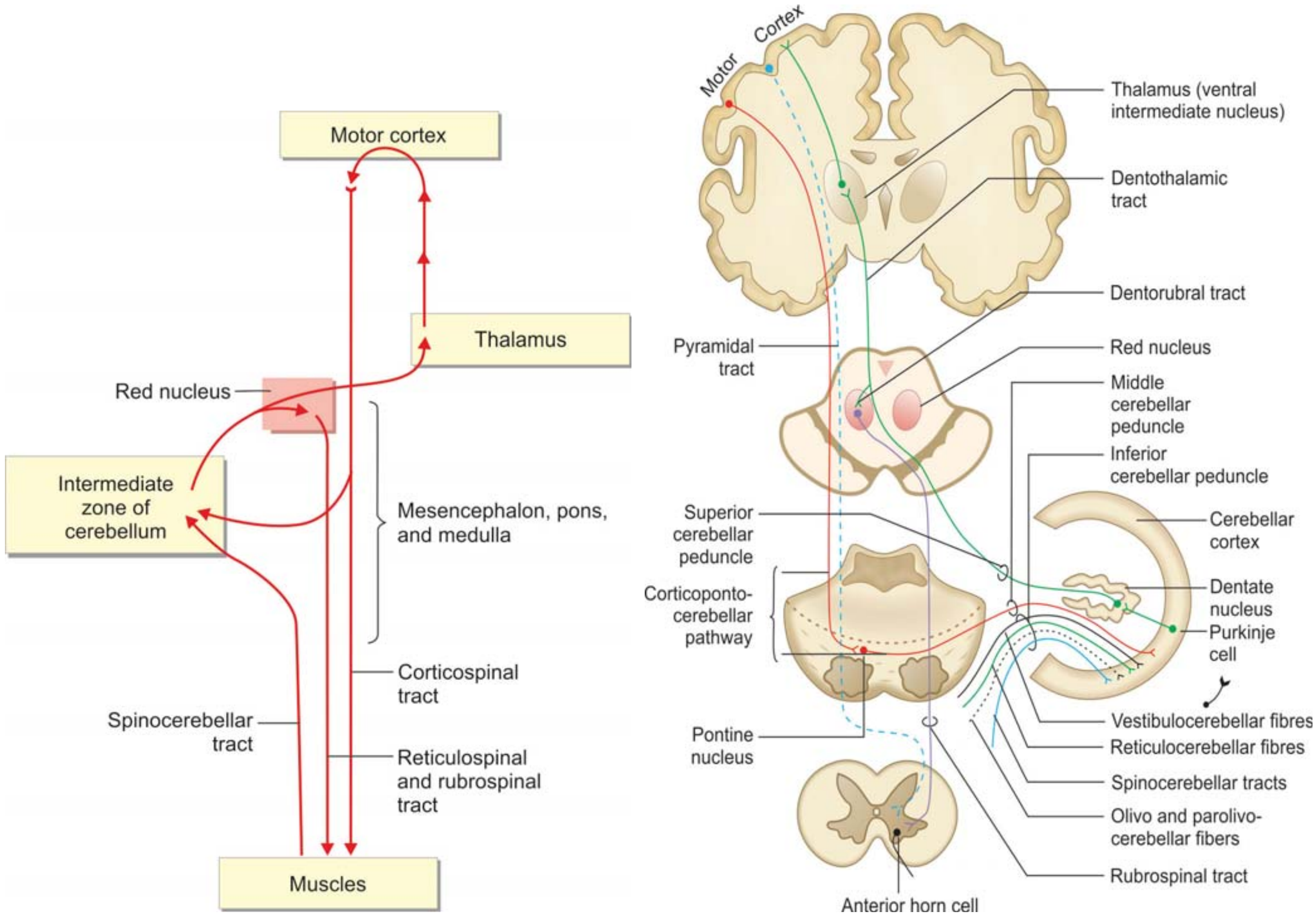


Fig. 71: Cerebral and cerebellar control of voluntary movements, involving especially the intermediate zone of the cerebellum

Three paired **cerebellar peduncles** connect the cerebellum to the brainstem (and different parts of the nervous system).

- These are named according to their position relative to the vermis as the superior, middle and inferior cerebellar peduncle.
- **Superior cerebellar peduncle** is mainly an output to the **cerebral cortex**, carrying efferent fibers to upper motor neurons in the cerebral cortex.
  - The fibers arise from the **deep cerebellar nuclei**.
- **Middle cerebellar peduncle** is the largest and is connected to the **pons.** It receives all of its input from the pons mainly from the pontine nuclei.
  - This input to the pons is **from the cerebral cortex** (Cortico-ponto-cerebellar tract).
- **Inferior cerebellar peduncle** receives input from afferent fibers from the spinal cord, vestibular nuclei and the tegmentum.
  - Cerebellum receives entire modulatory input from the inferior olivary nucleus (via the **climbing fibers** passing through inferior cerebellar peduncle).
  - Output (efferents) from the inferior peduncle is to the vestibular nuclei and the reticular formation.

Cerebellar peduncle	Afferent tracts	Efferent tracts
Superior	Ventral spinocerebellar Tecto-cerebellar	Dentato-rubro-thalamic Dentato-olivary Fastigio-reticular
Middle	Pontocerebellar (cortico-ponto-cerebellar pathway)*	

Cerebellar peduncle	Afferent tracts	Efferent tracts
Inferior	Dorsal spinocerebellar Olivo-cerebellar Parolivo-cerebellar Reticulo-cerebellar Vestibulo-cerebellar Anterior external arcuate fibers Cuneocerebellar (posterior external arcuate fibers) Stria medullaris Trigeminocerebellar	Cerebello-vestibular Cerebello-olivary Cerebello-reticular

*Middle cerebellar peduncle has only one tract: Incoming (afferent) fibers from the contralateral pons (pontocerebellar) fibers.

- **Spinocerebellar tract** originate in the spinal cord and terminate in the ipsilateral cerebellum.
  - It conveys information to the cerebellum about length and tension of muscle fibers (i.e., unconscious proprioceptive sensation)
  - Spinocerebellar tract conveys information from ipsilateral part of trunk and lower limb.
  - Cuneocerebellar tract (posterior external arcuate fibers) carries information form the upper limbs and neck.
- **Dentato-rubro-thalamic tract** is a tract which connects the dentate nucleus and the thalamus (ventral intermediate nucleus) while sending collaterals to the red nucleus. Thalamus further project the information to the cerebral cortex.
- **Cortico-ponto-cerebellar tracts is the** pathway from the cerebral cortex to the contralateral cerebellum. Pontocerebellar fibers are the second order neuron fibers that cross to the other side of the pons and run within the middle cerebellar peduncles, from the pons to the contralateral cerebellum.
- **Olivocerebellar tract** originate at the **olivary nucleus** and pass out through the hilum and decussate with those from the opposite olive in the **raphe nucleus**, then as **internal arcuate fibers** they pass partly through and partly around the opposite olive and enter the inferior peduncle to be distributed to the **cerebellar hemisphere** of the opposite side. They terminate directly on **Purkinje cells** as the **climbing fiber** input system.

Arterial Supply

Three paired major arteries: **Superior** cerebellar artery (SCA), **Anterior inferior** cerebellar artery (AICA), and the **Posterior inferior** cerebellar artery (PICA).

- SCA supplies the upper region of the cerebellum.
- AICA supplies the front part of the undersurface of the cerebellum.
- PICA arrives at the undersurface, where it divides into a medial branch and a lateral branch.
  - The medial branch continues backward to the cerebellar notch between the two hemispheres of the cerebellum.
  - Lateral branch supplies the under surface of the cerebellum, as far as its lateral border, where it anastomoses with the AICA and the SCA.

Functions

- Cerebellum is concerned with **coordination of voluntary motor activity**, controls posture, equilibrium and muscle tone, and is involved learning of repeated motor functions.
- Cerebellum **does not** initiate movement, but contributes to coordination, precision, and accurate timing.

Clinical Correlations

- Cerebellar lesion leads to abnormal gait, disturbed balance, and in-coordination of voluntary motor activity (no paralysis or inability to start or stop movement).There are disorders in fine movement, posture, and motor learning.
- Damage to the **flocculonodular lobe** may show up as a loss of equilibrium and in particular an altered, irregular walking gait, with a wide stance caused by difficulty in balancing.
- Damage to the **lateral zone** typically causes problems in skilled voluntary and planned motor movements which leads to errors in the force, direction, speed and amplitude of movements.
  - Other manifestations include **hypotonia** (decreased muscle tone), **dysmetria** (problems judging distances or ranges of movement), **dysdiadochokinesia** (inability to perform rapid alternating movements such as walking), impaired check reflex or rebound phenomenon, **intention tremor** (involuntary movement caused by alternating contractions of opposing muscle groups) and **dysarthria** (problems with speech articulation).
- Damage to the **midline portion** may disrupt whole-body movements, whereas damage localized more laterally is more likely to disrupt fine movements of the hands or limbs.
- **Cerebellar ataxia**: Damage to the upper part of the cerebellum tends to cause gait impairments and other problems with leg coordination; damage to the lower part is more likely to cause uncoordinated or poorly aimed movements of the arms and hands, as well as difficulties in speed.

ASSESSMENT QUESTIONS

1. Cells present in cerebellar cortex are all EXCEPT: *(AIIMS 2008)*
a. Bipolar b. Purkinje
c. Golgi d. Granule

2. Function of spinocerebellar tract:
a. Equilibrium
b. Coordinates movement
c. Learning induced by vestibular reflexes
d. Planning and Programming

3. Tract NOT present in inferior cerebellar peduncle is:
a. Dentato-rubro-thalamic
b. Posterior spinocerebellar
c. Olivocerebellar
d. Reticulo cerebellar

4. Structures NOT passing through inferior cerebellar peduncle: *(PGIC 07, 08, 09)*
a. Pontocerebellar b. Cuneocerebellar
c. Anterior spinocerebellar d. Posterior spinocerebellar
e. Vestibulocerebellar

5. Which is the lateral most cerebellar nuclei?
a. Dentate
b. Emboliform
c. Fastigi
d. Globose

6. Purkinje cells fibers from the cerebellum end in: *(NEET Pattern 2014)*
a. Extrapyramidal system b. Cranial nerve nuclei
c. Cerebellar nuclei d. Cerebral cortex

7. Efferents from cerebellum arise from:
a. Purkinje cells b. Stellate neurons
c. Deep nuclei d. Grade III fibers

8. Tract present in middle cerebellar peduncle is: *(NEET Pattern 2015)*
a. Dentato-thalamic b. Posterior spinocerebellar
c. Olivocerebellar d. Pontocerebellar

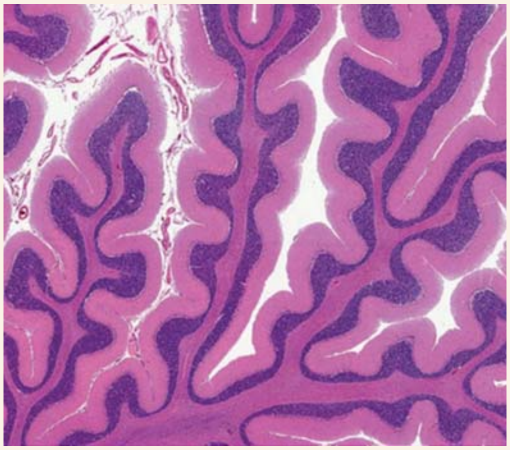
9. Tract ABSENT in superior cerebellar peduncle:
a. Tecto-cerebellar b. Dentato thalamic
c. Dorsal spinocerebellar d. Ventral spinocerebellar

10. In cerebellar lesion NOT seen is:
a. Ataxia b. Nystagmus
c. Resting tremors d. Hypotonia

11. NOT included in cerebellar nuclei:
a. Dentate nuclei
b. Emboliform nuclei
c. Fastigial nuclei
d. Caudate nuclei

12. By three cerebellar peduncles, the cerebellum is attached to: *(PGIC)*
a. Spinal cord b. Medulla
c. Cerebrum d. Midbrain
e. Pons

13. Pathology of the given structure will lead to which of the following speech disorder: *(AIIMS 2016)*
a. Visual agnosia
b. Sensory aphasia
c. Dysarthria
d. Verbal apraxia



ANSWERS WITH EXPLANATIONS

1. a. Bipolar
- Cerebellar cortex has **five** cell types and **bipolar cells** are not among them.
- Bipolar cells can be seen in the **cerebral** cortex and retina.
- Cerebellar cortex has 3 layers: Outermost molecular layer – 2 cells (stellate and basket); middle layer – purkinje cells and inner (deeper/granular) layer– 2 cells (granule and Golgi).

2. b. Coordinates movement
- Spinocerebellar tract carries the unconscious proprioception to the higher brain centers, for co-ordination of voluntary motor activity.

3. a. Dentato-rubro-thalamic
- Dentato-rubro-thalamic tract passes through the **superior** cerebellar peduncle to reach the contralateral thalamus.

4. a. Pontocerebellar, c. Anterior spinocerebellar
- **Pontocerebellar** tract passes through the **middle** cerebellar peduncle and **anterior spinocerebellar** tract passes through the **superior** peduncle.

5. a. Dentate
- Evolution wise, the latest and the lateral-most nucleus is dentate and the oldest and medial most is Fastigi nucleus.

6. c. Cerebellar nuclei
- Purkinje cells are the only cells in cerebellar cortex, which carry the information out (efferents).
- The fibers are neuroinhibitory and synapse in the deep cerebellar nuclei.

7. c. Deep nuclei
- Efferents from cerebellum arise from the deep cerebellar nuclei.
- Efferents from the cerebellar cortex arise from the purkinje cells.

8. d. Pontocerebellar
- Middle cerebellar peduncle has incoming (afferent) fibers from the contralateral pons (ponto-cerebellar) fibers.
- Dentato-thalamic fibers pass through superior cerebellar peduncle from the dentate nucleus to synapse in thalamus.
- Posterior spino-cerebellar and the olivo cerebellar fibers pass through the inferior cerebellar peduncle.

9. c. Dorsal spinocerebellar
- Dorsal spinocerebellar fibers pass through **inferior** cerebellar peduncle.
- Ventral spinocerebellar tract send fibers through superior cerebellar peduncle.
- Superior colliculus (visual reflexes) and inferior colliculus (auditory) are present in the tectum (midbrain).Tectocerebellar fibers in superior cerebellar peduncle carry visual and auditory information from the colliculi towards cerebellum.
- Dentatothalamic tract passes through the superior cerebellar peduncle to reach the contralateral thalamus.

10. c. Resting tremors
- Cerebellar lesions present with intention (and not resting) tremors.
- Resting tremor is a feature of basal ganglia disorder like Parkinson's disease.
- Ataxia (incoordination of voluntary motor activity), hypotonia and nystagmus may be the accompanying features.

11. d. Caudate nuclei
- Deep cerebellar nuclei are DEFG: Dentate, Emboliform, Fastigi and Globose.
- Caudate nucleus is a part of basal ganglia.

12. b. Medulla; d. Midbrain; e. Pons
- Cerebellum attaches to the brainstem with the help of cerebellar peduncles.
- Superior cerebellar peduncle is attached to midbrain; middle to pons and inferior to medulla oblongata.

13. c. Dysarthria
- It is the histology slide of cerebellum, lesion of which may lead to **dysarthria**. As speech production requires the coordinated and simultaneous contraction of a large number of muscle groups, cerebellar disorders could disrupt speech production and cause ataxic dysarthria.
- **Identification point**: Cerebellar cortex forms a series of deeply convoluted folds (folia) supported by a branching central white matter (Arbor vitae).
- Cerebellar outer molecular layer (ML) contains relatively few neurones and large numbers of unmyelinated fibers.
- The inner granular cell layer (GL) is extremely cellular.
- Between the two is a single layer of huge neurones called Purkinje cells (PL).

Limbic System

Limbic system is a collection of components from the telencephalon, diencephalon, and mesencephalon.
- It is located on both sides of the thalamus, immediately beneath the cerebrum.
- It is the limbus, where the subcortical structures meet the cerebral cortex.
- It expresses itself through the **hypothalamus** via the autonomic nervous system (ANS) and endocrine system.

Components:
- **Cortical areas**:
  - Orbitofrontal cortex
  - Limbic lobe
  - Piriform cortex (olfactory system)
  - Entorhinal cortex (memory and associative components)
  - Hippocampal formation
  - Fornix (Axons connecting the hippocampus with the mammillary bodies and septal nuclei)
- **Subcortical areas:**
  - **Septal nuclei**
  - **Amygdala**
  - Nucleus accumbens (associated with reward, pleasure, addiction)
- **Diencephalic structures:**
  - Hypothalamus
  - Mammillary bodies (components of hypothalamus which receives information from the hippocampus via the fornix and projects it to the thalamus).

- Anterior nuclei of thalamus
- Dorsomedial nucleus of the thalamus

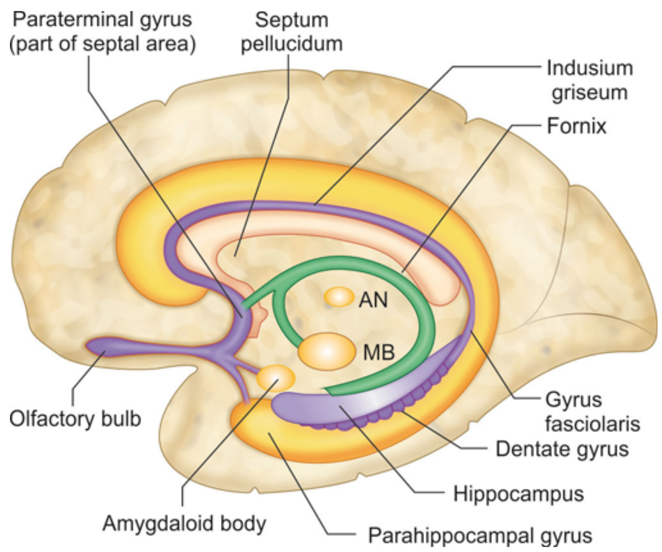


Fig. 72: Structures forming hippocampal formation (viz. hippocampus, dentate gyrus, gyrus fasciolaris and indusium griseum) and associated structures. (MB = mammillary body of hypothalamus, AN = anterior nucleus of thalamus)

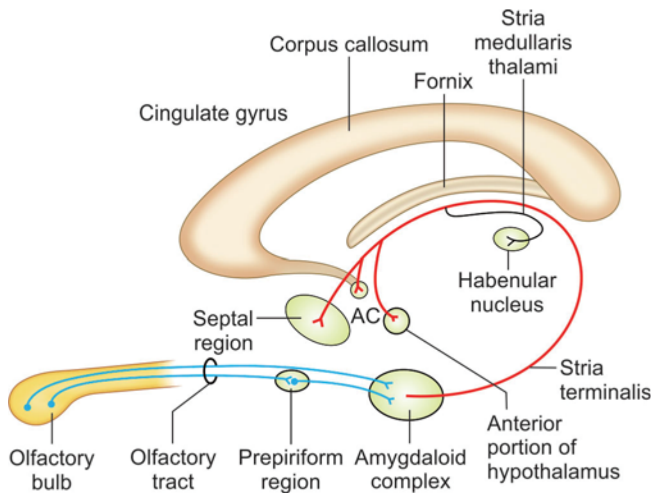


Fig. 73: Main afferent and efferent connections of the amygdaloid complex. Note the course of the stria terminalis (AC = anterior commissure)

- **Orbitofrontal cortex** mediates the conscious perception of **smell** and is also associated with **decision-making**.
  - It is interconnected via the medial forebrain bundle with the septal area and hypothalamic nuclei.
- **Limbic lobe** includes the subcallosal area, the paraterminal gyrus, the cingulate gyrus and isthmus, and the parahippocampal gyrus, which includes the uncus.
  - It contains, buried in the parahippocampal gyrus, the hippocampal formation and the amygdaloid nuclear complex.
- **Anterior nucleus of the thalamus**
  - It receive input from the mammillary bodies via the mammillothalamic tract and fornix and projects to the cingulate gyrus (Papez circuit).
  - It is involved in memory processing.
- **Septal nuclei** lie in front of the lamina terminalis
  - Have reciprocal connections with the hippocampal formation via the fornix.
  - Have reciprocal connections with the hypothalamus via the medial forebrain bundle.
  - They projects via the stria medullaris (thalami) to the habenular nucleus.
  - Considered as a pleasure zone.
- **Hippocampal formation** has major input via the entorhinal cortex and the major output via the fornix.
  - There are three major structures in hippocampal formation:
    - **Dentate gyrus** has a three-layered archicortex. It contains granule cells that receive hippocampal input and project it to the pyramidal cells of the hippocampus and subiculum.
    - **Hippocampus** (cornu ammonis) also has a three-layered archicortex. It contains pyramidal cells that project via the fornix to the septal area and the hypothalamus.
    - **Subiculum** receives input via the hippocampal pyramidal cells. It projects via the fornix to the mammillary nuclei and the anterior nucleus of the thalamus.
  - Hippocampal formation functions in learning, memory, and recognition of novelty. In Alzheimer's disease, loss of cells in the HF and entorhinal cortex leads to loss of memory and cognitive function.
- **Dorsomedial nucleus of the thalamus** has reciprocal connections with the orbitofrontal and prefrontal cortex and hypothalamus.
  - It receives input from the amygdala.
  - It plays a role in affective behavior and memory.
- **Hypothalamus** is a component of the limbic system and regulates various autonomic processes.
  - It is connected with:
    - Frontal lobes, septal nuclei and the brain stem reticular formation via the medial forebrain bundle.
    - Hippocampus via the fornix
    - Thalamus via the mammillothalamic fasciculus.

- **Amygdala** is a basal nucleus that underlies the parahippocampal uncus (temporal lobe)
  - It modulates hypothalamic and endocrine activities.
  - The input is from the sensory association cortices, olfactory bulb and cortex, hypothalamus and septal area, and hippocampal formation.
  - The major pathway from the amygdaloid nucleus is the **stria terminalis**, which terminates in the septal nuclei and in the hypothalamus.
  - Bilateral lesions result in placidity, with loss of fear, rage, and aggression.

Connections

- **Fornix** projects from the hippocampal formation to the septal nuclei (pre-commissural fornix) and to the mammillary body (post-commissural fornix).
- **Stria terminalis** lies between the thalamus and the caudate nucleus.
  - Projects from the amygdala to the hypothalamus and the septal area.
- **Stria medullaris** of the thalamus connects the septal nuclei to the habenular nucleus.
- **Papez circuit**:
  - It is a loop pathway that interconnects the major limbic structures.
  - Hippocampal formation projects (via the fornix) to the mammillary nucleus , which itself projects to the anterior nucleus of the thalamus (via the mammillothalamic tract).
  - Anterior nucleus of the thalamus projects to the cingulate gyrus, which itself projects (via the entorhinal cortex) to the hippocampal formation.
  - Hippocampal formation consists of three components:
    - Hippocampus proper (cornu ammonis), subiculum, and the dentate gyrus.
    - Hippocampus projects to the septal area, the subiculum projects to the mammillary bodies, whereas the dentate gyrus does not project beyond the hippocampal formation.
    - Papez circuit: Hippocampal formation → mammillary bodies → anterior nucleus of thalamus → cingulate gyrus → Hippocampal formation.

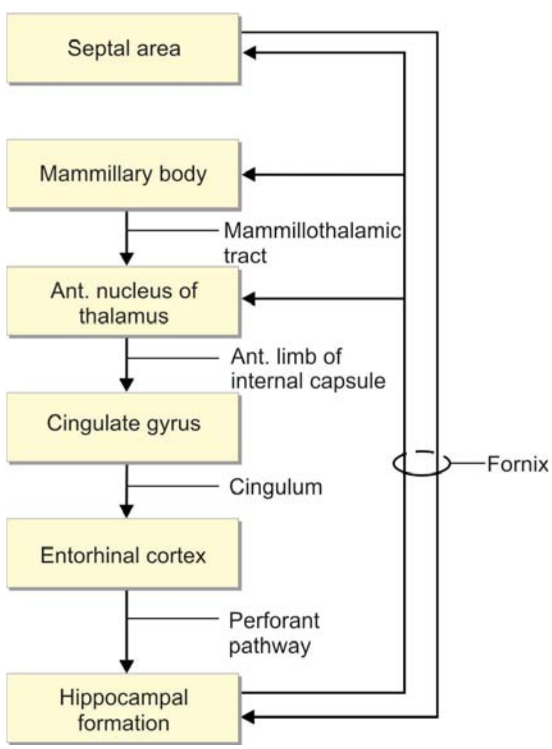


Fig. 74: Connections of Limbic system: Major afferent and efferent connections of the hippocampal formation.

Functions

- **Limbic system** is associated with **behavior**, **emotions**, motivation, olfaction and memory. E.g., **Papez circuit**.
- Plays a role in feeling, feeding, fighting, fleeing, and mating.

Clinical Correlations

- **Kluver–Bucy syndrome**
  – Results from ablation of the temporal poles, including the amygdalae, the hippocampal formations, and the anterior temporal neocortex.
  – Presents with the **triad** of hyperphagia, hyper-sexuality, and psychic blindness.
- **Foster Kennedy syndrome** results from meningioma of the olfactory groove.
  – The meningioma compresses the olfactory tract and optic nerve.
  – Ipsilateral anosmia and optic atrophy and contralateral papilledema occur as a result of increased intracranial pressure.
- **Wernicke's encephalopathy** results from **thiamine** (vitamin B1) deficiency (chronic alcoholism).
  – The clinical **triad** includes ocular disturbances and nystagmus, gait ataxia, and mental dysfunction.
- **Korsakoff's syndrome** (amnestic–confabulatory syndrome). Clinical signs include memory disturbances (amnesia), confabulation, and temporo-spatial disorientation.
  – Pathologic features include mammillary nuclei, dorsomedial nuclei of the thalamus, and periaqueductal gray and pontine tegmentum.

ASSESSMENT QUESTION

1. **In the Papez circuit of the limbic system, between which combination is the hypothalamus placed on the basis of function?** *(AIIMS Pattern 2007)*
   a. Cingulate cortex - hippocampus
   b. Hippocampus - Thalamus
   c. Thalamus - Hippocampus
   d. Parahippocampal gyrus - Thalamus

ANSWER WITH EXPLANATION

1. **b. Hippocampus - Thalamus**
   - The sequence of connections is **H**ippocampus → **M**ammillary body → **T**halamus. (**Mnemonic**: **HMT**)

   Note: Mammillary body is a component of hypothalamus.

Reticular System

- The reticular formation is a set of interconnected nuclei that are located throughout the brainstem. The reticular formation is not anatomically well defined because it includes neurons located in diverse parts of the brain. The neurons of the reticular formation all play a crucial role in maintaining behavioral arousal and consciousness. The functions of the reticular formation are modulatory and premotor. The modulatory functions are primarily found in the rostral sector of the reticular formation and the premotor functions are localized in the neurotns in more caudal regions.
- The reticular formation is divided into three columns: raphe nuclei (median), gigantocellular reticular nuclei (medial zone), and parvocellular reticular nuclei (lateral zone). The raphe nuclei are the place of synthesis of the neurotransmitter serotonin, which plays an important role in mood regulation. The gigantocellular nuclei are involved in motor coordination. The parvocellular nuclei regulate exhalation.
- It is essential for governing some of the basic functions of higher organisms and is one of the phylogenetically oldest portions of the brain.
- The reticular formation has been functionally cleaved both sagittally and coronally.
- Traditionally the nuclei are divided into three columns:
  - In the median column – the raphe nuclei
  - In the medial column – gigantocellular nuclei (because of larger size of the cells)
  - In the lateral column – parvocellular nuclei (because of smaller size of the cells)
- The original functional differentiation was a division of caudal and rostral, this was based upon the observation that the lesioning of the rostral reticular formation induces a hypersomnia in the cat brain. In contrast, lesioning of the more caudal portion of the reticular formation produces insomnia in cats. This study has led to the idea that the caudal portion inhibits the rostral portion of the reticular formation.
- Sagittal division reveals more morphological distinctions. The raphe nuclei form a ridge in the middle of the reticular formation, and, directly to its periphery, there is a division called the medial reticular formation. The medial RF is large and has long ascending and descending fibers, and is surrounded by the lateral reticular formation. The lateral RF is close to the motor nuclei of the cranial nerves, and mostly mediates their function.

Medial and Lateral Reticular Formation

- The medial reticular formation and lateral reticular formation are two columns of neuronal nuclei with ill-defined boundaries that send projections through the medulla and into the mesencephalon (midbrain). The nuclei can be differentiated by function, cell type, and projections of efferent or afferent nerves.

Functions

The reticular formation consists of more than 100 small neural networks, with varied functions including the following:

- Somatic motor control – Some motor neurons send their axons to the reticular formation nuclei, giving rise to the reticulospinal tracts of the spinal cord. These tracts function in maintaining tone, balance, and posture—especially during body movements. The reticular formation also relays eye and ear signals to the cerebellum so that the cerebellum can integrate visual, auditory, and vestibular stimuli in motor coordination. Other motor nuclei include gaze centers, which enable the eyes to track and fixate objects, and central pattern generators, which produce rhythmic signals to the muscles of breathing and swallowing.
- Cardiovascular control – The reticular formation includes the cardiac and vasomotor centers of the medulla oblongata.
- Pain modulation – The reticular formation is one means by which pain signals from the lower body reach the cerebral cortex. It is also the origin of the descending analgesic pathways. The nerve fibers in these pathways act in the spinal cord to block the transmission of some pain signals to the brain.
- Sleep and consciousness – The reticular formation has projections to the thalamus and cerebral cortex that allow it to exert some control over which sensory signals reach the cerebrum and come to our conscious attention. It plays a central role in states of consciousness like alertness and sleep. Injury to the reticular formation can result in irreversible coma.
- Habituation – This is a process in which the brain learns to ignore repetitive, meaningless stimuli while remaining sensitive to others. A good example of this is a person who can sleep through loud traffic in a large city, but is awakened promptly due to the sound of an alarm or crying baby. Reticular formation nuclei that modulate activity of the cerebral cortex are part of the reticular activating system.

Clinical Significance

Mass lesions in the brainstem cause severe alterations in level of consciousness (such as coma) because of their effects on the reticular formation. Bilateral damage to the reticular formation of the midbrain may lead to coma or death.

Lesions in the reticular formation have been found in the brains of people who have post-polio syndrome, and some imaging studies have shown abnormal activity in this area in people with chronic fatigue syndrome, indicating a high likelihood that damage to the reticular formation is responsible for the fatigue associated with these syndromes.

History

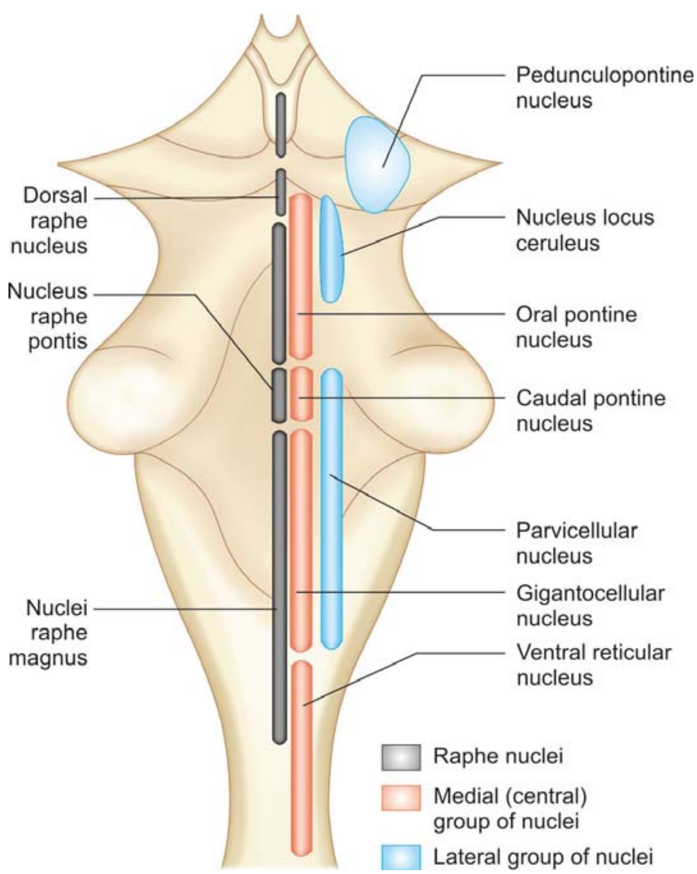


Fig. 75: Schematic diagram to show the reticular nuclei in the brainstem

SC - Vertebral Canal

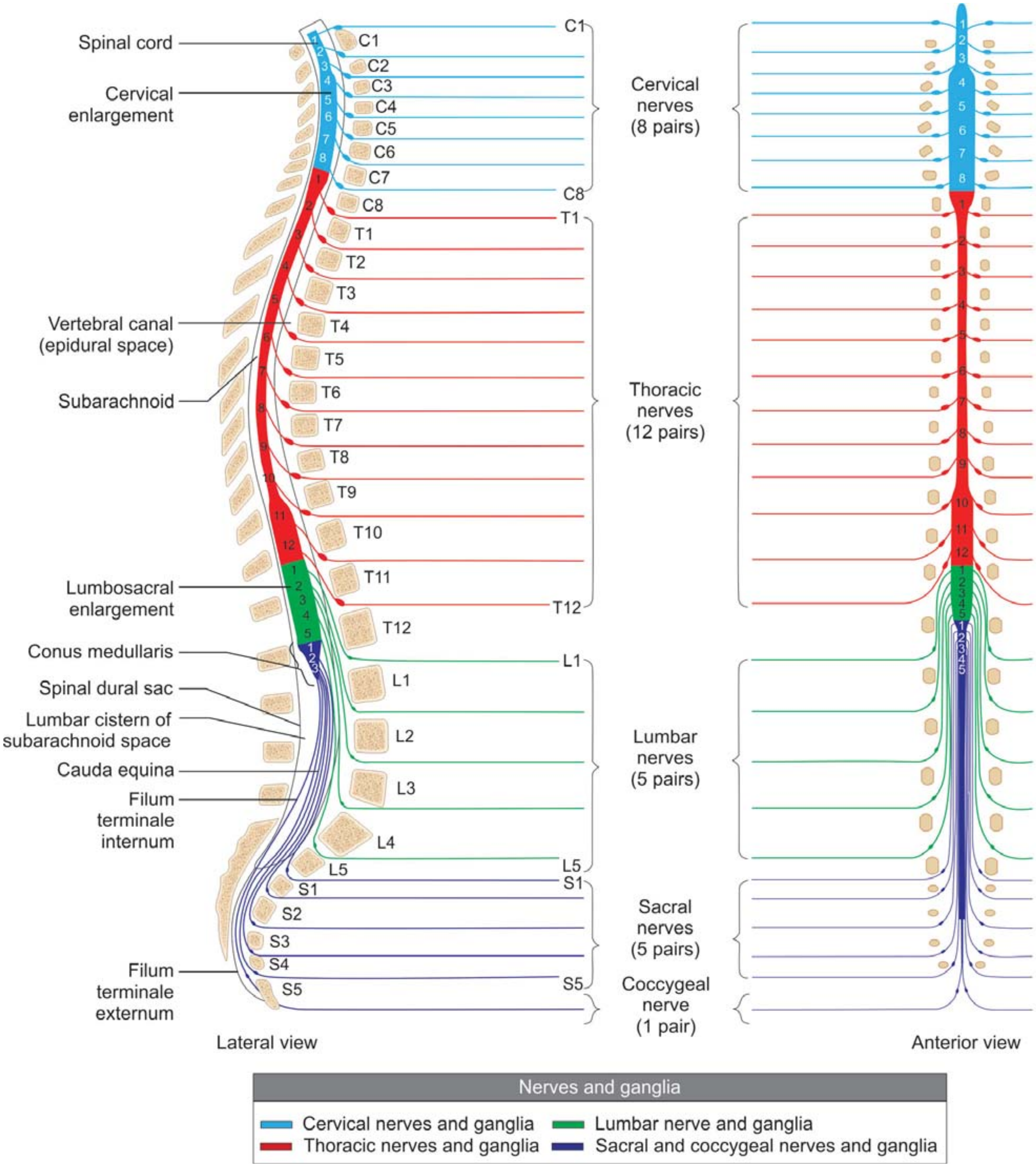


Fig. 76: Spinal nerves and their relation with various vertebral level and intervertebral foramina

- The cervical enlargement gives axons to the brachial plexus to supply the upper limbs.
  - It extends from the C3-T2 segments.
  - The maximum circumference is in the C6 segment.
- Lumbar enlargement gives axons to the lumbar and sacral plexus to supply the lower limbs.
  - It extends from the L1-S3 segments.
  - The equivalent vertebral levels are last four thoracic vertebra (T9-12).
  - The maximum circumference is at the lower part of T12 vertebra.

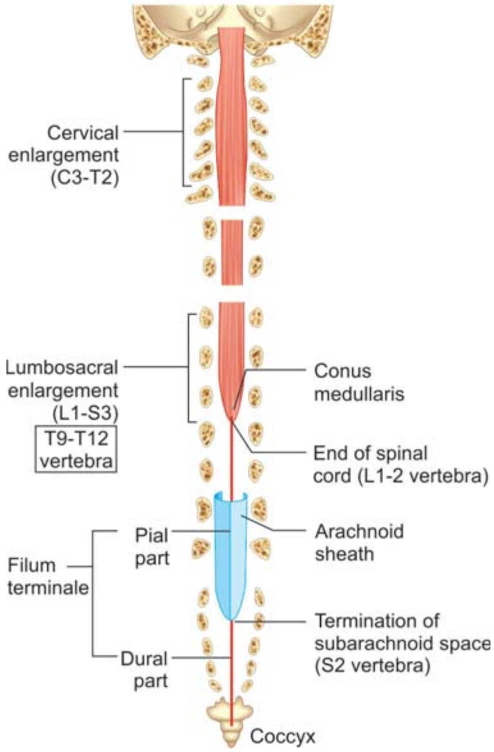


Fig. 77: Cervical and lumbosacral enlargements in the spinal cord. Terminal extent of various structures in relation to veretbral level is also evident

Table 13: Characteristic features of the spinal segments as seen in transverse sections at cervical, thoracic, and lumbar regions of the spinal cord

		Levels	
Features	**Cervical**	**Thoracic**	**Lumbar**
Grey matter	Large	Small	Large
Posterior horn	Slender and extends far posteriorly	Slender	Bulbous
Anterior horn	Massive	Slender	Bulbous
Lateral horn	Absent	Present	Present only in tL1 and L2 segments
Reticular formation	Well developed	Poorly developed	Absent
Amount of white matter	Massive + + + +	Large (less than in the cervical region)+++	Less (but slightly less than in the thoracic region) + + +

Numbering of Spinal Nerves and Vertebrae

- The peripheral nerves emerge through the intervertebral foramina.
  - At thoracic, lumbar, sacral and coccygeal levels, the numbered nerve exits the vertebral canal by passing below the pedicle of the corresponding vertebra, e.g. L4 nerve exits the intervertebral foramen between L4 and L5.
  - However, in the cervical region, nerves C1–7 pass above their corresponding vertebrae.
  - C1 leaves the vertebral canal between the occipital bone and atlas (termed suboccipital nerve).
  - The last pair of cervical nerves does not have a correspondingly numbered vertebra and C8 passes between the seventh cervical and first thoracic vertebrae.

Table 14: Numbering of S and vertebrae

Segmental level	Number of nerves	Level of exit from vertebral column
Cervical	8 (C1-C8)	Nerve C1[a] (suboccipital nerve) passes superior to arch of vertebra C1 Nerves C2-C7 pass through IV foramina superior to the corresponding vertebrae Nerve C8 passes through the IV foramen between vertebra C7 and T1
Thoracic	12 (T1-T12)	Nerves T1-L5 pass through IV foramina inferior to the corresponding vertebrae
Lumbar	5 (L1-L5)	
Sacral	5 (S1-S5)	Nerves S1-S4 branch into anterior and posterior rami within the sacrum, with the respective rami passing through the anterior and posterior sacral foramina
Coccygeal[a]	1 (Co1)	5th sacral and coccygeal nerves pass through the sacral hiatus

[a]The first cervical nerves lack posterior roots in 50% of people, and the coccygeal nerves may be absent. (Modified from *Barr's The Human Nervous System*).

- First and second cervical spinal roots are short, running almost horizontally to their exits from the vertebral canal, and that from the third to the eighth cervical levels the roots slope obliquely down.
  - Lumbar, sacral and coccygeal roots descend with increasing obliquity to their exits.
  - Approximate vertebral levels of the spinal cord segments are shown in Table.
  - In the cervical region, the tip of a vertebral spinous process corresponds to the succeeding cord segment (i.e. the sixth cervical spine is opposite the seventh spinal segment).
  - At upper thoracic levels, the tip of a vertebral spine corresponds to the cord two segments lower (i.e. the fourth spine is level with the sixth segment), and in the lower thoracic region, there is a difference of three segments (i.e. the tenth thoracic spine is level with the first lumbar segment).
  - The eleventh thoracic spine overlies the third lumbar segment and the twelfth is opposite the first sacral segment.

Table 15: Approximate vertebral levels of the spinal cord segments

Regions	Spinal segments	Vertebral level	General rule
Upper cervical	C2	C2	Same level
Lower cervical	C6	C5	One vertebra above
Upper thoracic	T5	T3	Two vertebrae above
Lower thoracic	T10	T7	Three vertebrae above
Lumbar	L1-L5	T10-T11	Three to five vertebrae above
Sacral and coccygeal	S1-S5 and C × 1	T12-L1	Six to ten vertebrae above

Table 16: Spaces associated with spinal meninges*

Space	Location	Contents
Epidural	Space between periosteum lining bony wall of vertebral canal and spinal dura mater	Fat (loose connective tissue); internal vertebral venous plexuses; inferior to L2 vertebra, ensheathed roots of spinal nerves
Subarachnoid (leptomeningeal)	Naturally occurring space between arachnoid mater and pia mater	CSF; radicular, segmental, medullary, and spinal arteries; veins; arachnoid trabeculae

*Although it is common to refer to a "subdural space," there is no naturally occurring space at the arachnoid-dura junction (Haines, 2006).

- Epidural space lies between the spinal dura mater and the tissues that line the vertebral canal.
- It is closed above by fusion of the spinal dura with the edge of the foramen magnum, and below by the posterior sacrococcygeal ligament that closes the sacral hiatus.

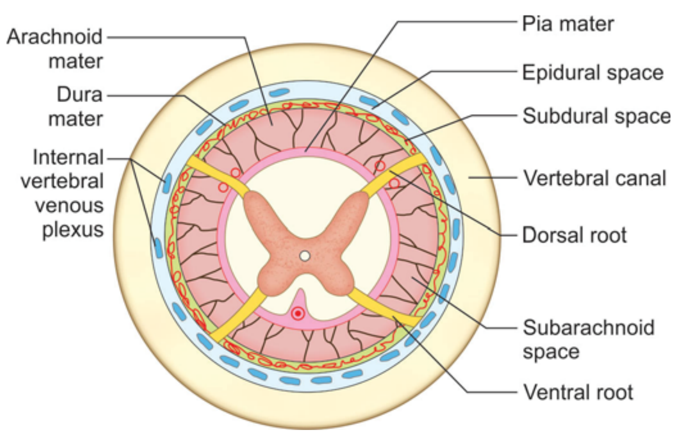


Fig. 78: Schematic transection of the vertebral canal showing its contents

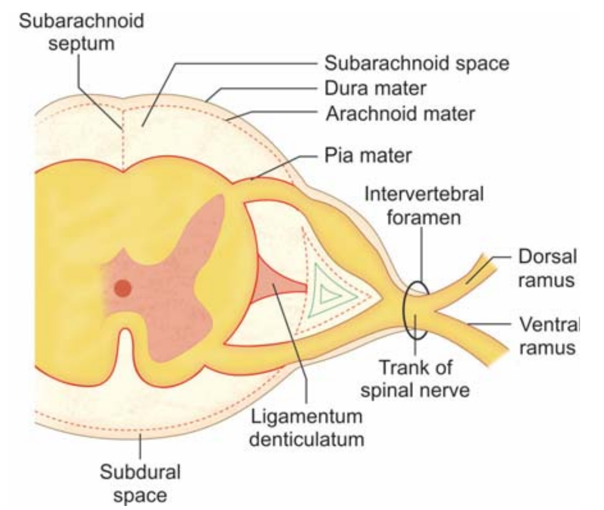
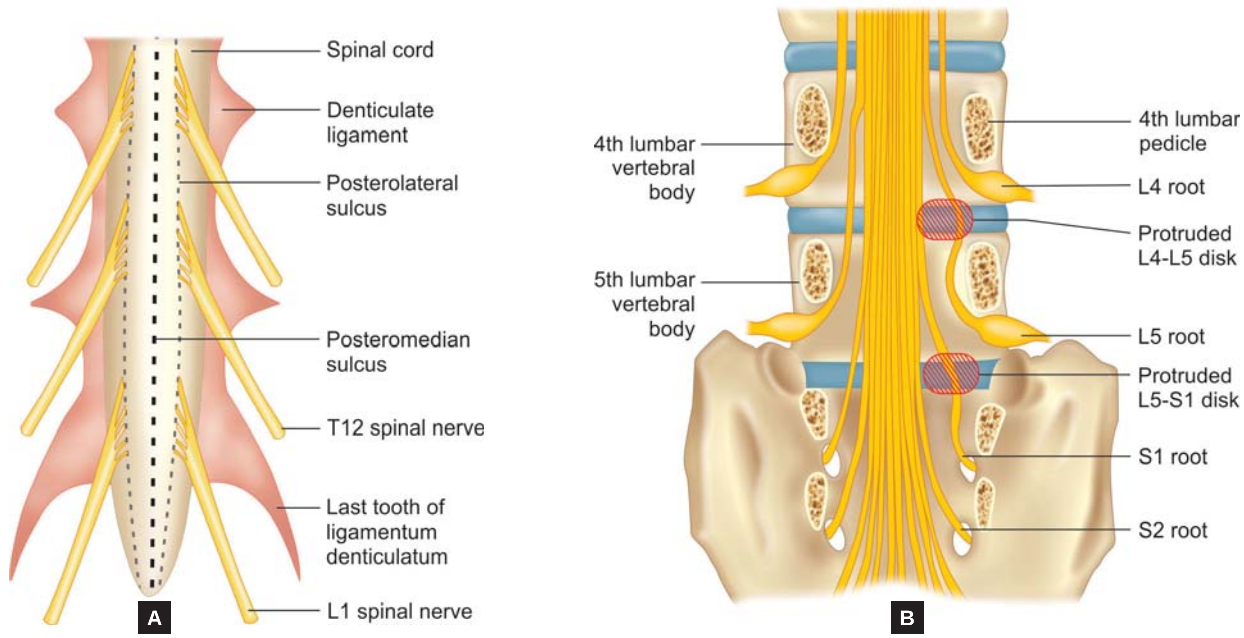


Fig. 79: Schematic transverse section of the spinal cord showing meninges and formation of meningeal sheaths onto the spinal nerve roots

- **Ligamenta denticulatum** is made up of piamater and attaches to duramater.
  - It lies on each side between the dorsal and ventral nerve roots, forming narrow ribbon-like transparent bands.
  - The lateral margin of each ligamentum denticulatum sends 21 teeth-like projections, which pass through subarachnoid space and arachnoid mater to gain attachment on the inner surface of the dural tube between the points of emergence of two adjacent spinal nerves.

- It helps to anchor the spinal cord in the middle of the subarachnoid space.
- The first tooth of ligamentum denticulatum is above the rim of the foramen magnum, while the last tooth lies between the exiting twelfth thoracic and first lumbar spinal nerves.



Figs. 80A and B: (A) Posterior view of part of the spinal cord showing ligamenta denticulata, (B) Posterolateral herniation of the nucleus pulposus in the lumbosacral region , doesn't affect the nerve root exiting at the same level, but the next subsequent nerve root

Spinal Cord/Nerve Injuries

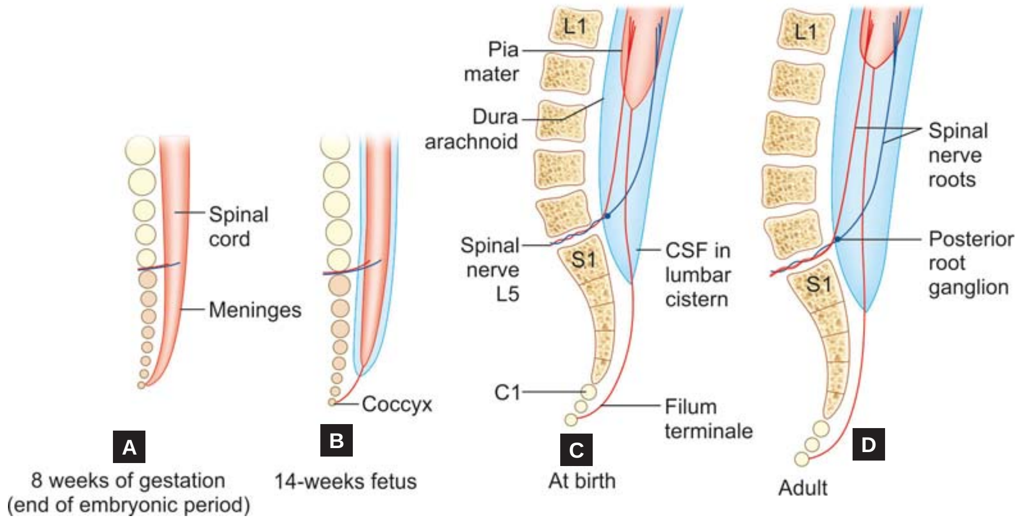
- Complete division above the C4 segment causes respiratory failure due to loss of activity in the phrenic and intercostal nerves.
- Lesions between C5 and T1 paralyze all four limbs (quadriplegia).
- In lesion at the C5 segment, upper limb goes into complete paralysis; lesion at C6, leads to arm positioned in abduction and lateral rotation, with the elbow flexed and the forearm supinated, due to unopposed activity in deltoid, supraspinatus, rhomboid and the brachial flexors (all supplied by the fifth cervical spinal nerves).
- Lesions of the T1 segment paralyze small muscles in the hand and damage the sympathetic outflow to the head and neck, resulting in Horner's syndrome.
  - Sensation is retained in areas innervated by segments above the lesion; thus cutaneous sensation is retained in the neck and chest down to the second intercostal space because this area is innervated by the supraclavicular nerves (C3 and C4).
- At thoracic levels, division of the cord paralyzes the trunk below the segmental level of the lesion, and both lower limbs (paraplegia).
- The first sacral neural segment is approximately level with the thoracolumbar vertebral junction; injury paralyzes the urinary bladder, the rectum and muscles supplied by the sacral segments, and cutaneous sensibility is lost in the perineum, buttocks, the back of the thighs and the legs, and soles of the feet.
  - The roots of lumbar nerves descending to join the cauda equina may be damaged at this level, causing complete paralysis of both lower limbs.
- Lesions below the first lumbar vertebra may divide or damage the cauda equina and affect the lower limb region.

Herniated disc between	Compressed nerve root	Dermatome affected	Muscles affected	Movement weakness	Nerve and reflex involved
C4 and C5	C5	C5 Lateral surface of the arm	Deltoid	Abduction of arm	Axillary nerve ↓ biceps jerk
C5 and C6	C6	C6 Lateral surface of the forearm Thumb index finger	Biceps Brachialis Brachioradialis	Flexion of forearm Supination/pronation	Musculocutaneous nerve ↓ biceps reflex ↓ brachioradialis (supinator) reflex
C6 and C7	C7	C7 Middle finger	Triceps Wrist extensors	Extension of forearm Extension of wrist	Radial nerve ↓ triceps jerk

Herniated disc between	Compressed nerve root	Dermatome affected	Muscles affected	Movement weakness	Nerve and reflex involved
L3 and L4	L4	L4 Medial surface of the leg	Quadriceps	Extension of Knee	Femoral nerve ↓ knee jerk
L4 and L5	L5	L5 Lateral surface of leg Dorsum of foot Big toe	Tibialis anterior Extensor hallucis longus Extensor digitorum longus	Dorsiflexion of ankle (patient cannot stand on heels) Extension of toes	Common fibular Nerve No reflex loss
L5 and S1	S1	S1 Heel Little toe	Gastrocnemius Soleus	Plantar flexion of ankle (patient cannot stand on toes) Flexion of toes	Tibial nerve ↓ ankle jerk

Spinal Cord Termination

- Spinal cord occupies the upper two-thirds of the vertebral canal.
  - It is continuous cranially with the medulla oblongata, just below the level of the foramen magnum, at the upper border of the atlas.
  - It terminates caudally as the conus medullaris at lower border of L1 vertebra.
- During development, the vertebral column elongates more rapidly than the spinal cord, so that there is an increasing discrepancy between the anatomical level of spinal cord segments and their corresponding vertebrae.
  - At week 8, the vertebral column and spinal cord are the same length and the cord ends at the last coccygeal vertebra.
  - At birth, the conus medullaris extends to the upper border of third lumbar vertebra.
  - With growth of the spine, the conus typically reaches the adult level (L1) by 2 years of age.
  - In adults, the conus medullaris terminates at the lower border of L1 vertebra.
- Disproportionate growth results in formation of the cauda equina, consisting of posterior and anterior roots (L3–Co) that descend inferior to the conus medullaris, and in formation of the filum terminale, which anchors the spinal cord to the dura mater and coccyx.
- Due to rostral shift of the spinal cord during development, the spinal nerve roots become progressively oblique from above downwards.
- In upper cervical region the spinal nerve roots are **short and run almost horizontally** but the roots of the lumbar and sacral nerves are long and run obliquely (**almost vertically**).
- The spinal cord and its blood vessels and nerve roots lie within a meningeal sheath (theca), which extends from the foramen magnum to the level of the second sacral vertebra in the adult.
- Distal to this level, the dura extends as a fine cord, the filum terminale externum, which fuses with the posterior periosteum of the first coccygeal segment.
- The filum terminale is a filament of connective tissue approximately 20 cm long, descends from the apex of the conus medullaris.
  - The upper 15 cm, the filum terminale internum, is continued within extensions of the dural and arachnoid meninges and reaches the caudal border of the second sacral vertebra.
  - The final 5 cm, the filum terminale externum, fuses with the investing dura mater, and then descends to the dorsum of the first coccygeal vertebral segment.
  - The filum is continuous above with the spinal pia mater.



Figs. 81A to D: (A, B) Regression of coccygeal segments of the spinal cord creates the filum terminale. (C,D) Ascent of the spinal cord

Gray's Anatomy; Ed41

- In late fetal period, the conus medullaris lies between the L3 and S5 vertebrae.
- In premature and term neonates, it lies between the L1-3 vertebrae, and in children between the ages of 1 and 7 years, it lies between the T12-L3 vertebrae.
- In the adult, the spinal cord terminates on average at the level of the middle third of the body of the L1 vertebra, which corresponds approximately to the transpyloric plane.
- However, it may end as high as the middle third of the body of the T11 vertebra or as low as the middle third of the body of the L3 vertebra.

Structure/Space	Terminal extent
Spinal cord at birth	L3 vertebrae (upper border)
Spinal cord in 2 year infant	L1 vertebra (lower border)
Adult spinal cord	L1 vertebra (lower border) or L2 vertebra (upper border)
Filum terminale	Attached to first coccygeal segment
Filum terminale internum	S2 vertebra (lower border)
Filum terminale externum	Attached to first coccygeal segment
Piamater and duramater	Attached to first coccygeal segment
Subarachnoid sheath Subarachnoid space Subdural space	S2 vertebra (lower border)

ASSESSMENT QUESTIONS

1. **Subarachnoid space ends at:** *(NEET Pattern 2012)*
   a. D12
   b. L2
   c. L5
   d. S2

2. **In adults, the spinal cord normally ends at:** *(NEET Pattern 2015)*
   a. Lower border of L1
   b. Lower border of L3
   c. Lower border of S1
   d. Lower border of L5

3. **Ligamentum denticulatum has how many pair of teeth like projections?** *(NEET Pattern 2016)*
   a. 19
   b. 21
   c. 28
   d. 33

4. **The spinal cord in infants ends at the level of:**
   a. L1
   b. L2
   c. L3
   d. L4

ANSWERS WITH EXPLANATIONS

1. **d. S2**
   - Both subarachnoid space and subdural spaces terminate approximately at the lower border of S2 vertebra.

2. **a. Lower border of L1**
   - In adults the spinal cord normally ends at the lower border of the L1 vertebra.
   - In a neonate, spinal cord ends at the upper border of L3 vertebra.
   - Dural and the subarachnoid sheath ends at the caudal (lower) border of the S2 vertebra.

3. **b. 21**
   - The pia mater of the spinal cord has a pair of denticulate ligaments (one on each side of the spinal cord) with 21 attachments which attach it to the arachnoid and dura mater.

4. **c. L3**
   - Spinal cord termination in a baby at birth is at upper border of L3 vertebra.

Spinal Nerve

- Spinal nerves are the means by which the CNS receives information from, and controls the activities of, the trunk and limbs. Spinal nerves are considered in detail elsewhere on a regional basis.
- There are 31 pairs of spinal nerves (8 cervical, 12 thoracic, 5 lumbar, 5 sacral, 1 coccygeal) and these contain a mixture of sensory and motor fibers.
- They originate from the spinal cord as continuous series of dorsal and ventral nerve rootlets. Adjacent groups of rootlets fuse to form dorsal and ventral roots, which then merge to form the spinal nerves proper.
- The dorsal roots of spinal nerves contain afferent nerve fibers from cell bodies located in dorsal root ganglia. These cells give off both centrally and peripherally directed processes and do not have synapses on their cell bodies. The ventral roots of spinal nerves contain efferent fibers from cell bodies located in the spinal grey matter. These include motor neurones innervating skeletal muscle and preganglionic autonomic neurones.

- Spinal nerves exit from the vertebral canal via their corresponding intervertebral foramina. They then divide to form a large ventral (anterior) ramus and a smaller dorsal (posterior) ramus. In general terms, the ventral ramus innervates the limbs together with the muscles and skin of the anterior part of the trunk. The dorsal ramus innervates the post-vertebral muscles and the skin of the back. The nerve fibers within the ventral rami serving the upper and lower limbs are redistributed within brachial and lumbosacral plexuses, respectively.

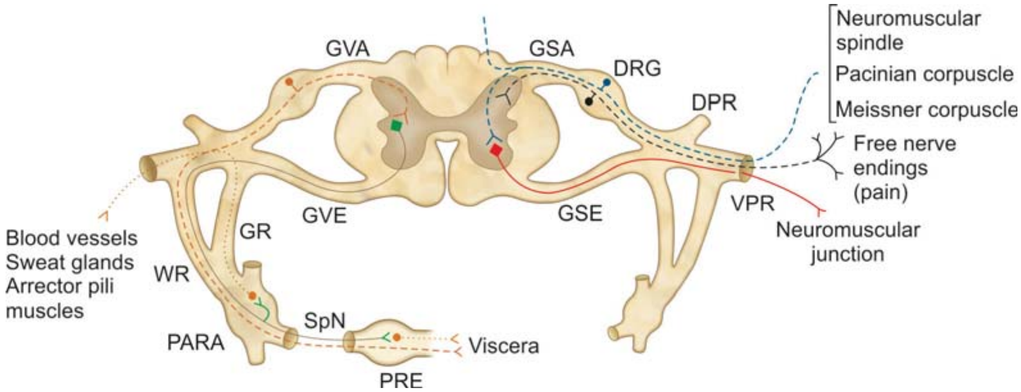


Fig. 82: Arrangement of somatic nervous system (GSA and GSE) on the right half of the diagram and autonomic nervous system (GVE and GVA) on the left half of the diagram.

Spinal Nerves

- Consist of 31 pairs: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, and 1 coccygeal.
- Are formed from dorsal and ventral roots; each dorsal root has a ganglion that is within the intervertebral foramen.
- Are connected with the sympathetic chain ganglia by rami communicantes.
- Contain sensory fibers with cell bodies in the dorsal root ganglion (general somatic afferent,GSA and general visceral afferent,GVA fibers), motor fibers with cell bodies in the anterior horn of the spinal cord (general somatic efferent,GSE fibers), and motor fibers with cell bodies in the lateral horn of the spinal cord (general visceral efferent, GVE fibers) between T1 and L2.
- Are divided into the ventral and dorsal primary rami. The ventral primary rami enter into the formation of plexuses (i.e., cervical, brachial, and lumbosacral); the dorsal primary rami innervate the skin and deep muscles of the back.

Sympathetic Nerve Fibers

- Have preganglionic nerve cell bodies that are located in the lateral horn of the thoracic and upper lumbar levels of the spinal cord.
- Have preganglionic fibers that pass through ventral roots, spinal nerves, and white rami communicantes. These fibers enter adjacent sympathetic chain ganglia, where they synapse or travel up or down the chain to synapse in remote ganglia or run further through the splanchnic nerves to synapse in collateral ganglia, located along the major abdominal blood vessels.
- Have postganglionic fibers from the chain ganglia that return to spinal nerves by way of gray rami communicantes and supply the skin with secretory fibers to sweat glands (sudomotor), motor fibers to smooth muscles of the hair follicles (arrectores pilorum – pilomotor), and vasomotor fibers to the blood vessels.
- White rami communicantes contain preganglionic sympathetic GVE fibers with cell bodies located in the lateral horn of the spinal cord and GVA fibers with cell bodies located in the dorsal root ganglia. They are connected to the spinal nerves and limited to spinal cord segments between T1 and L2.
- Gray rami communicantes contain postganglionic sympathetic GVE fibers with cell bodies located in the sympathetic chain ganglia. They are connected to every spinal nerve and supply the blood vessels, sweat glands, and arrector pili muscles of hair follicles.

Lesions

- Complete division above the fourth cervical segment causes respiratory failure because of the loss of activity in the phrenic and intercostal nerves. Lesions between C5 and T1 paralyze all four limbs (quadriplegia), the effects in the upper limbs varying with the site of injury: at the fifth cervical segment, paralysis is complete; and at the sixth, each arm is positioned in abduction and lateral rotation, with the elbow flexed and the forearm supinated, due to unopposed activity in deltoid, supraspinatus, rhomboid and the brachial flexors (all supplied by the fifth cervical spinal nerves). Upper limb paralysis is less marked in lower cervical lesions. Lesions of the first thoracic segment paralyze small muscles in the hand and damage the sympathetic outflow to the head and neck, resulting in contraction of the pupil, recession of the eyeball, narrowing of the palpebral fissure and loss of sweating in the face and neck (Horner's syndrome). However, sensation is retained in areas innervated by segments above the lesion; thus cutaneous sensation is retained in the neck and chest down to the second intercostal space because this area is innervated by the supraclavicular nerves (C3 and C4). At thoracic levels, division of the cord paralyses the trunk below the segmental level of the lesion, and both lower limbs (paraplegia). The first sacral neural segment is approximately level with the thoracolumbar vertebral junction; injury, which commonly occurs here, paralyses the urinary bladder, the rectum and muscles supplied by the sacral segments, and cutaneous sensibility is lost in the perineum, buttocks, the back of the thighs and the legs, and soles of the feet. The roots of lumbar nerves descending to join the cauda equina may be damaged at this level, causing complete paralysis of both lower limbs. Lesions below the first lumbar vertebra may divide or damage the cauda equina, but severe nerve damage is uncommon and is usually confined to the spinal roots at the level of the trauma.

- Lesions of the conus and cauda equina, e.g. tumors, cause bilateral deficit, often with pain in the back extending into the sacral segments and to the legs. Loss of bladder and erectile function can be early features. There are lower motor neuron signs in the legs with fasciculation and muscle atrophy. Sensory loss usually involves the perineal or 'saddle area,' as well as other lumbar and sacral dermatomes. There may be congenital abnormalities, e.g. spina bifida, lipomata or diastematomyelia, and the conus may extend below the lower border of L1, often with a tethered filum terminale. Extramedullary lesions include prolapsed intervertebral discs. A midline (central) disc protrusion in the lumbar region may present with involvement of the sacral segments only.
- Two distinct clinical syndromes, conus medullaris syndrome and cauda equina syndrome, have been described, the latter being much more common. Cauda equina syndrome typically presents in men who have a lumbar disc herniation in the setting of lumbar spinal stenosis, with symptoms of asymmetric saddle anesthesia and asymmetric lower extremity weakness, and delayed presentation of atonic bladder and flaccid anal sphincter. Conus medullaris syndrome typically presents with symmetric saddle anesthesia, symmetric motor deficit and earlier atonic bladder and sphincter dysfunction. The usual causes are intradural tumors or vascular lesions (Radcliff et al 2011). Tethered cord syndrome may be associated with occult or non-occult spinal dysraphism. In its classic form, it refers to an unusually low conus medullaris (although in some 14–18% of cases the position of the conus is anatomically normal). There is some debate as to what constitutes an abnormally low conus, whether below the L1–2 disc space or below the lower border of the body of the L2 vertebra. Most commonly, tethered cord syndrome is associated with a short filum terminale more than 2 mm wide, but it also may be related to an intradural lipoma. Traction on the caudal cord and loss of filum terminale elasticity are thought to predispose to decreased blood flow in the cord, leading to symptoms (Filippidis et al 2010). The clinical presentation varies according to age. In children, the most common presentation includes foot deformities, neurological deficits, spinal deformity and various cutaneous findings such as a lumbar capillary angioma. In adults, the syndrome more commonly presents with perianal pain and leg weakness.

Slip Disc

ASSESSMENT QUESTIONS

1. **The spinal nerve pairs are:** *(NEET Pattern 2013)*
   a. 28
   b. 30
   c. 31
   d. 33
2. **All is true about sympathetic nervous system fibers arising from the spinal cord EXCEPT:**
   a. Neurons are located in the intermedio-lateral column
   b. Pre-ganglionic fibers are myelinated and shorter in length
   c. Splanchnic nerves carry GVE and GVA neural columns
   d. Splanchnic fibers carry postganglionic fibers
3. **These ventral spinal rootlets are more prone to injury during decompressive operations because they are shorter and exit in a more horizontal direction:** *(AIIMS 2002)*
   a. C5 b. C6
   c. C7 d. T1

ANSWERS WITH EXPLANATIONS

1. **c. 31**
   - There are 31 pairs of spinal nerves, one on each side of the vertebral column.
   - These are grouped into the corresponding cervical (7), thoracic (12), lumbar (5), sacral (5) and coccygeal (1) regions of the spine.
2. **d. Splanchnic fibers carry postganglionic fibers**
   - *Splanchnic nerves carry preganglionic fibres.
3. **a. C5**
   - In upper cervical region the spinal nerve roots are short and run almost horizontally and are more prone to injury during decompressive operations.
   - Roots of the lumbar and sacral nerves are long and run obliquely (almost vertically).

Laminae and Reflex Arc

Table 17: Rexed laminae and nuclear groups

Laminae	Corresponding grey column nuclei
I	Posteromarginal nucleus
II	Substantia gelatinosa
III and IV	Nucleus proprius

Laminae	Corresponding grey column nuclei
V and VI	Base of dorsal column
VII	Nucleus dorsalis (Clarke's column) and intermediolateral nuclei of lateral horn
VIII and IX	Medial and lateral groups of nuclei of anterior grey column
X	Surrounds the central canal and composed of the grey commissure and substantia gelatinosa centralis

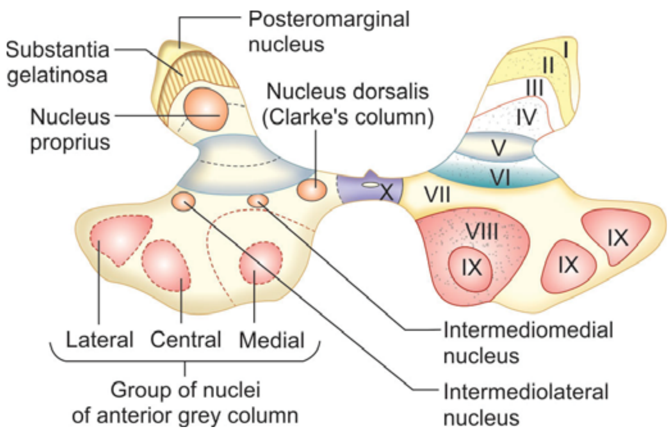


Fig. 83: The laminae of Rexed and related nuclear groups

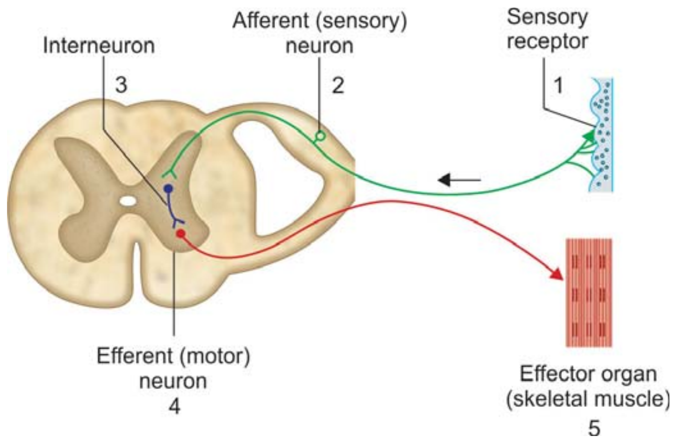


Fig. 84: Polysynaptic spinal reflex arc involved in withdrawal reflex. Note the five components: (1) a sensory receptor, (2) an afferent or sensory neuron, (3) an association neuron, (4) an efferent or motor neuron, and (5) an effector organ

Lumbar Puncture

- A line is drawn between the highest points of the iliac crests (intercristal or Tuffier's line) which intersects the vertebral column at the L4 vertebral body or; corresponding to the L4-5 interspace.
- **Tuffier's line** is drawn by joining the most superior aspects of the iliac crests almost always crosses the L4 body or L4/L5 intervertebral disc. This line is used as a landmark when performing a **lumbar puncture**; localization via palpation, especially in females and patients with a greater body mass index (BMI), often places it at a higher vertebral level, up to the L2–L3 interspace. In neonates, Tuffier's line sits at the L4/L5 interlaminar space level whilst prone, moving to the upper third of L5 during vertebral column flexion.
- The needle is inserted between the spines of L3 and L4 (or L4 and L5).
  - It pierces the structure in order: Skin → subcutaneous tissue → supraspinous ligament → interspinous ligament → ligamentum flavum (first 'pop' sensation) → epidural space (containing internal vertebral venous plexus) → duramater (second 'pop' sensation) → arachnoid mater → subarachnoid space.
  - Note: Pop sensation is felt after piercing ligamentum flavum, due to loss of resistance as the needle enters the epidural space. Another pop sensation is felt after piercing duramater as the needle enters the subarachnoid space.

Lumbar Puncture in Neonate and Infant

- In premature and term neonates, the spinal cord usually terminates between the first and third lumbar (L1-3) vertebrae.
- With growth of the spine, the conus typically reaches the adult level (L1) by 2 years of age.
- In children between the ages of 1 and 7 years, the conus medullaris lies between the twelfth thoracic and third lumbar vertebrae.
- The supracristal plane intersects the vertebral column slightly higher (L3–4).
- A needle with trocar is inserted into the back between the spines of the third and fourth lumbar (L3/L4) vertebrae or L4/L5 interspinous levels below the level of the conus medullaris.
- The space between l3 and l4 is approximately level with the iliac crests and it is usual to insert the needle and trocar into the intervertebral space immediately above or below the iliac crests.
- The ligamentum flavum and dura mater are **not as thick** in infants and children as they are in adults. therefore, it is difficult to assess when the needle passes through them into the subarachnoid space because the characteristic "**pop**" or "give" may be subtle or nonexistent in the pediatric lumbar puncture.

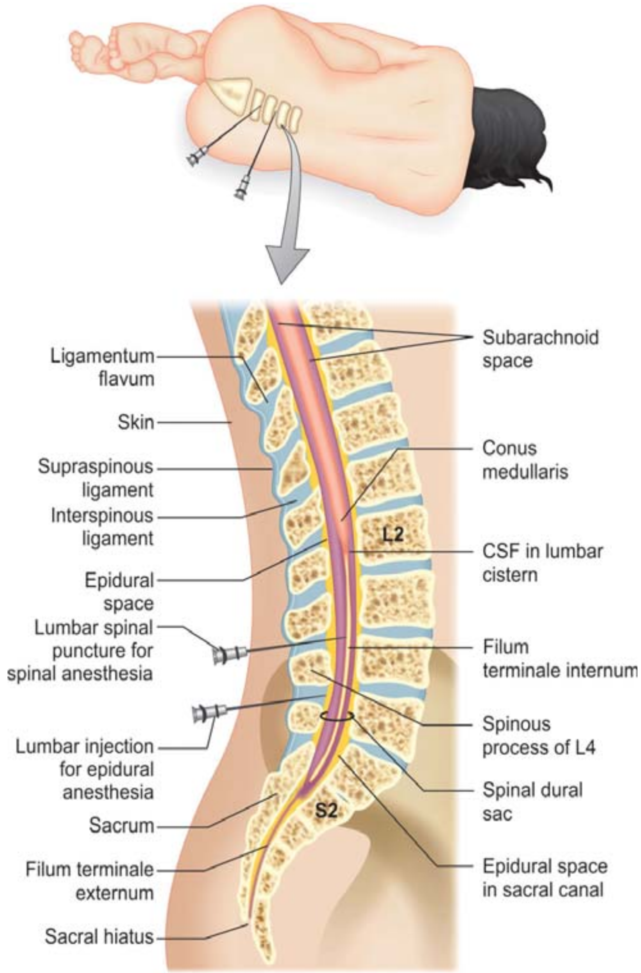


Fig. 85: Spinal and epidural anaesthesia

Spinal Chord - Vascular Supply

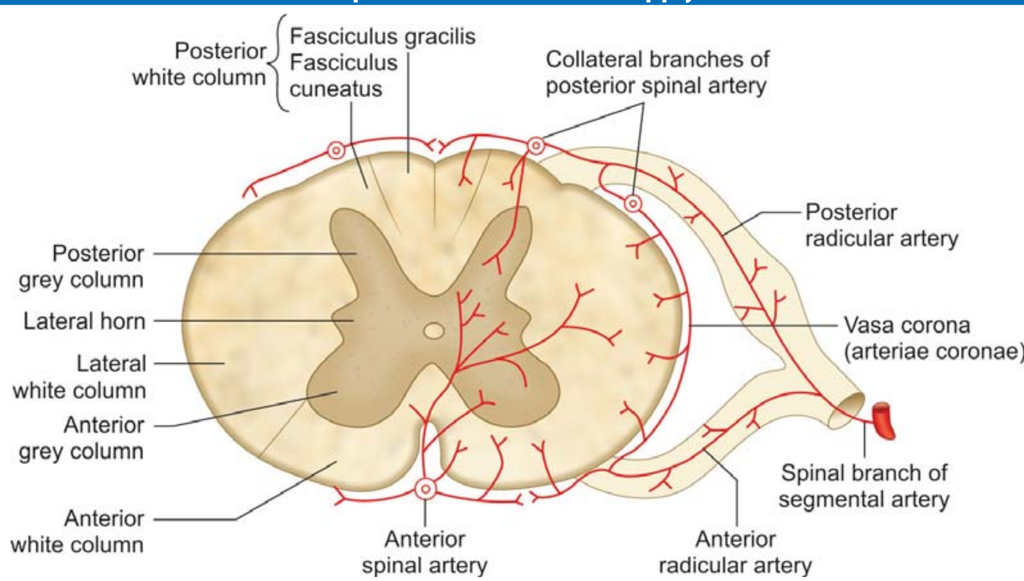
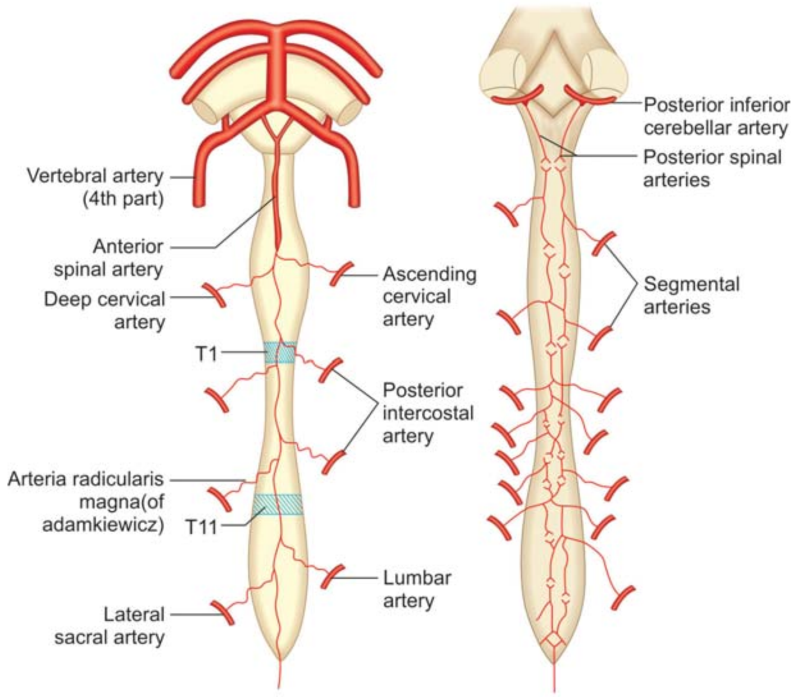


Fig. 86: Arterial supply of the interior part of spinal cord

- Arterial supply: Spinal cord is supplied by three major longitudinal vessels, a midline anterior and two posterior spinal arteries originating intracranially from the vertebral artery and terminating in a plexus around the conus medullaris.
  - The anterior spinal artery is a midline structure formed by the union of anterior spinal branches of the vertebral artery, and descends in the ventral median fissure of the cord.

- Two posterior spinal arteries originates from the vertebral artery (or posterior inferior cerebellar artery) and descends in the posterolateral sulcus of the cord.
- The segmental arteries are derived in craniocaudal sequence from spinal branches of the vertebral, deep cervical, intercostal and lumbar arteries.
  - These vessels enter the vertebral canal through the intervertebral foramina and anastomose with branches of the longitudinal vessels to form a pial plexus on the surface of the cord.
- The great anterior radiculo-medullary artery (of Adamkiewicz) is the largest anterior medullary feeder.
  - It may arise from a spinal branch of either one of the lower posterior intercostal arteries (T9–11), or of the subcostal artery (T12), or less frequently of the upper lumbar arteries (L1 and L2).
  - It is mostly seen on the left side and may be the main supply to the lower two-thirds of the cord.



Figs. 87A and B: Arterial supply of the spinal cord: (A) viewed from anterior aspect, and (B) viewed from the posterior aspect

- **Venous drainage**: Intramedullary veins within the substance of the spinal cord drain into a circumferential plexus of surface veins, the coronal plexus (venous plexus of the pia mater).
  - Six tortuous longitudinal channels are present in this plexus: anterior and posterior spinal veins (anterior and posterior median veins) and four others that run on either side of the ventral and dorsal nerve roots.
  - These vessels connect freely and drain superiorly into the cerebellar veins and cranial sinuses, and segmentally into medullary veins mainly.
  - The segmental veins drain into the intervertebral veins and thence into the external vertebral venous plexuses, the caval and azygos systems.

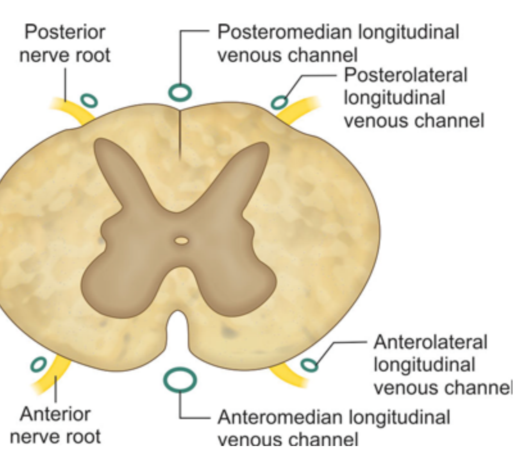


Fig. 88: Venous drainage of spinal cord

Pain

- Radicular pain is caused by disorders that affect a spinal nerve or its dorsal root ganglion. This type of pain characteristically radiates, along a narrow band, into the area of the limb (or trunk wall) that the spinal nerve supplies, and is typically (although not always) lancinating in quality, not unlike an electric shock.
- Referred pain is pain felt in the distribution of a nerve that is not the nerve that innervates the source of pain, although typically these nerves are derived from the same spinal cord segment. Referred pain is felt deeply across a broad area, and is usually aching in quality; although it may radiate into a limb (or around the trunk wall), it is typically constant in location. Patients may find it hard to define the outer boundaries of this pain but they can clearly identify the centre of its distribution. Referred pain can be subdivided into somatic referred pain and visceral referred pain, according to its origin. As its name implies, visceral referred pain is caused by disorders in viscera; in some cases, the referral can be quite remote from the viscus, e.g. cardiac pain that radiates into the neck. Somatic referred pain is caused by disorders of muscular and skeletal structures. Examples include lumbar spinal pain referred to the gluteal region, thigh or leg; cervical spinal pain referred to the upper limb girdle; and cervical or thoracic spinal pain referred to the chest wall, where it may mimic cardiac pain. Often the source of somatic referred pain cannot be determined by clinical examination, and invasive tests are required to pinpoint its location.

Neural Pathways

Neural pathway is a series of neurons connected together to enable a signal to be sent from one part of CNS to another.

- It involves a single axon or a sequence of axons designated by terminologies: **Tract**, **lemniscus**, **capsule**, **fasciculus**, etc.
- They are classified as **ascending** and **descending**.

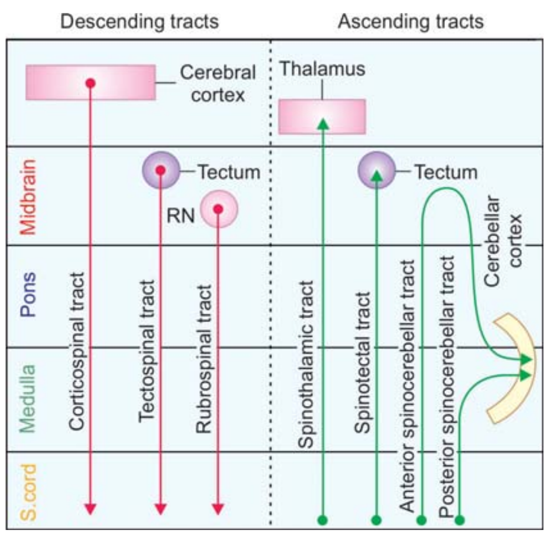
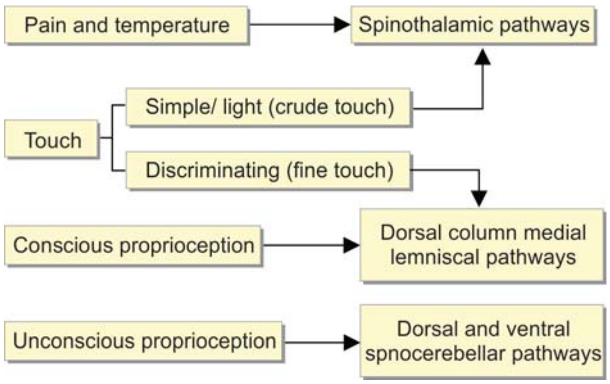


Fig. 89: Major ascending and descending tracts. (RN = Red nucleus)

Sensory modalities are either special senses or general senses.

- The **special senses** are olfaction, vision, taste, hearing and vestibular function.
  - Afferent information is encoded by highly specialized sense organs and transmitted to the brain in cranial nerves I, II, VII, VIII and IX.
- The **general senses** include touch, pressure, vibration, pain, thermal sensation and proprioception (sense of posture and movement).
- Afferent impulses from the trunk and limbs are conveyed to the spinal cord in **spinal nerves**, while those from the head are carried to the brain in **cranial nerves**.
- **Generally** ascending sensory projections related to the general senses consist of a sequence of **three neurons** that extends from peripheral receptor to contralateral cerebral cortex.
  - These are referred to as first, second and third order neurons.
- **First order neuron** afferents have peripherally located sensory endings and cell bodies that lie in dorsal root ganglia or the sensory ganglia associated with certain cranial nerves.
  - Their axons enter the CNS through spinal or cranial nerves and terminate by synapsing on the cell bodies of ipsilateral second-order neurons.
- Primary afferent fibres carrying **pain**, **temperature** and coarse **touch and pressure** information from the trunk and limbs are carried by **spinothalamic tract**.
  - Homologous fibres from the head terminate in the **trigeminal** sensory nucleus of the brainstem.
- Primary afferent fibres carrying **proprioceptive** information and **fine (discriminative) touch** from the trunk and limbs ascend ipsilaterally in the spinal cord as the **dorsal column - medial lemniscal system.**
  - A similar homologous projection exists for afferents derived from the head.

Flowchart 3: Sensations carried by different somatic sensory pathways



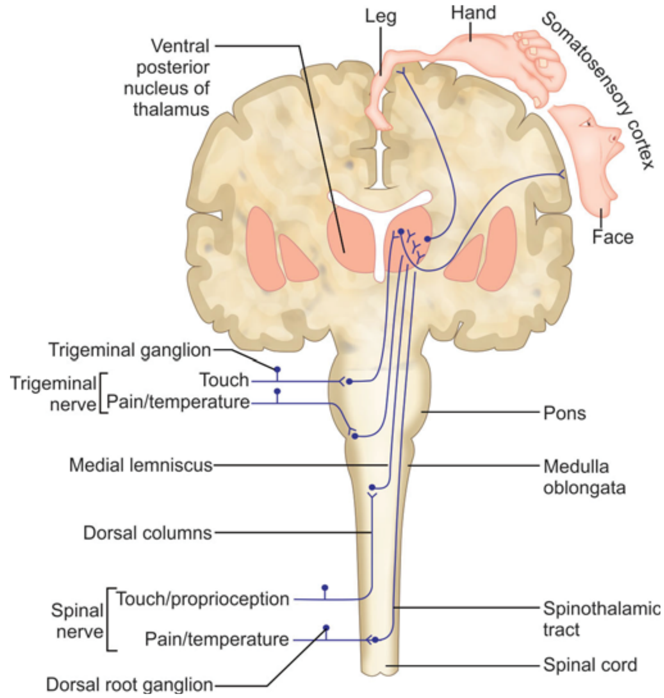


Fig. 90: The organization of general sensory pathways showing first-order, second-order and third-order neurons

Table 18: Major ascending tracts in the spinal cord				
Tract	**Location**	**Origin***	**Termination**	**Functions**
Lateral spinothalamic tract	Lateral white column	Posterior horn cells of spinal cord of opposite side	Ventral posterolateral (VPL) nucleus of thalamus	Carry pain and temperature from opposite side of the body
Anterior spinothalamic tract	Anterior white column	Posterior horn cells of spinal cord of opposite side	Ventral posterolateral (VPL) nucleus of thalamus	Carry light touch, pressure, tickle, and itch sensation from opposite side of the body
Spinotectal tract	Lateral white column	Posterior horn cells of spinal cord of opposite side	Superior colliculus of tectum of midbrain	Visuomotor reflexes, head and eye movements towards the source of stimulation
Spinocerebellar (anterior and posterior) tracts	Lateral white column (superficially)	Posterior horn cells of spinal cord of same side	Cerebellum	Unconscious kinaesthesia (proprioception)
Fasciculus gracilis and fasciculus cuneatus (tracts of Gall and Burdach)	Posterior white column of spinal cord	Dorsal root ganglia of spinal nerves of the same side	Nucleus gracilis and nucleus cuneatus in medulla of the same side	Joint sense, vibration sense, two-point discrimination, stereognosis, conscious kinaesthesia

*Location of cell bodies of neurons from which the axons of tract arise

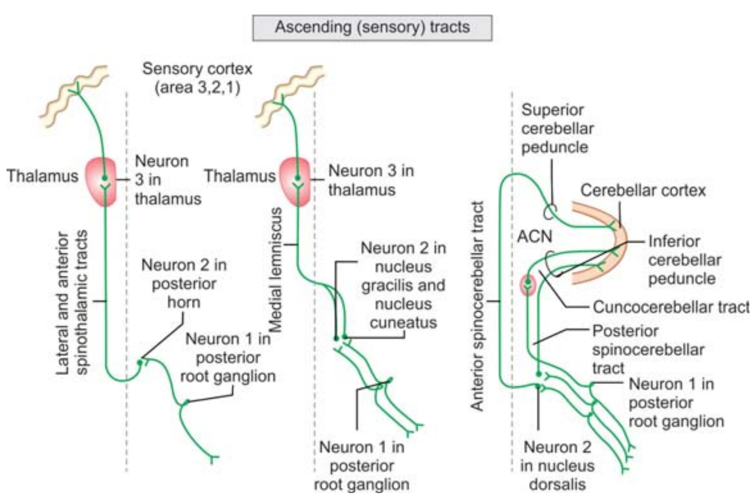


Fig. 91: Sensory pathways (ascending tracts): Spinothalamic tract, dorsal column-medial lemniscal system and spinocerebellar tract

Dorsal Column – Medial Lemniscal System (DC-MLS)

- It carries the following sensory modalities - **fine (discriminative) touch**, pressure, vibration, conscious proprioception and stereognosis.
- **First order neurons** (dorsal root ganglion) carry the information ipsilaterally in the dorsal column (fasciculus cuneatus and gracilis) to synapse on **second order neurons** located in the gracile and cuneate nuclei of the caudal medulla.
- They give rise to axons (internal arcuate fibers) that **decussate** and form medial lemniscus.
- The **medial lemniscus** crosses midline and ascends through the **contralateral brain stem** and terminates in the **ventral posterolateral** (VPL) nucleus of the thalamus.
- **Third order neurons** are located in the VPL nucleus of the thalamus.
- They project through the posterior limb of the **internal capsule** to the **primary** somatosensory cortex - postcentral gyrus (Brodmann's areas 3, 1, and 2).

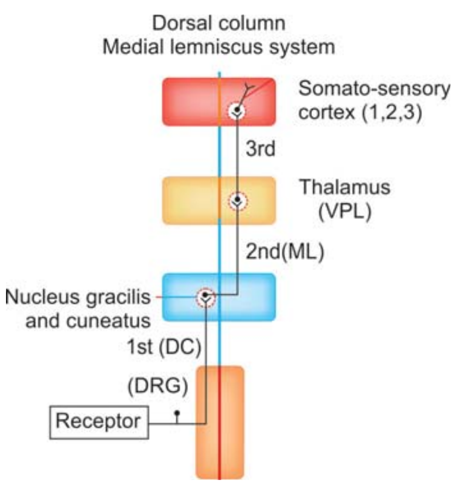


Fig. 92: Dorsal column- medial lemniscal system (overview)

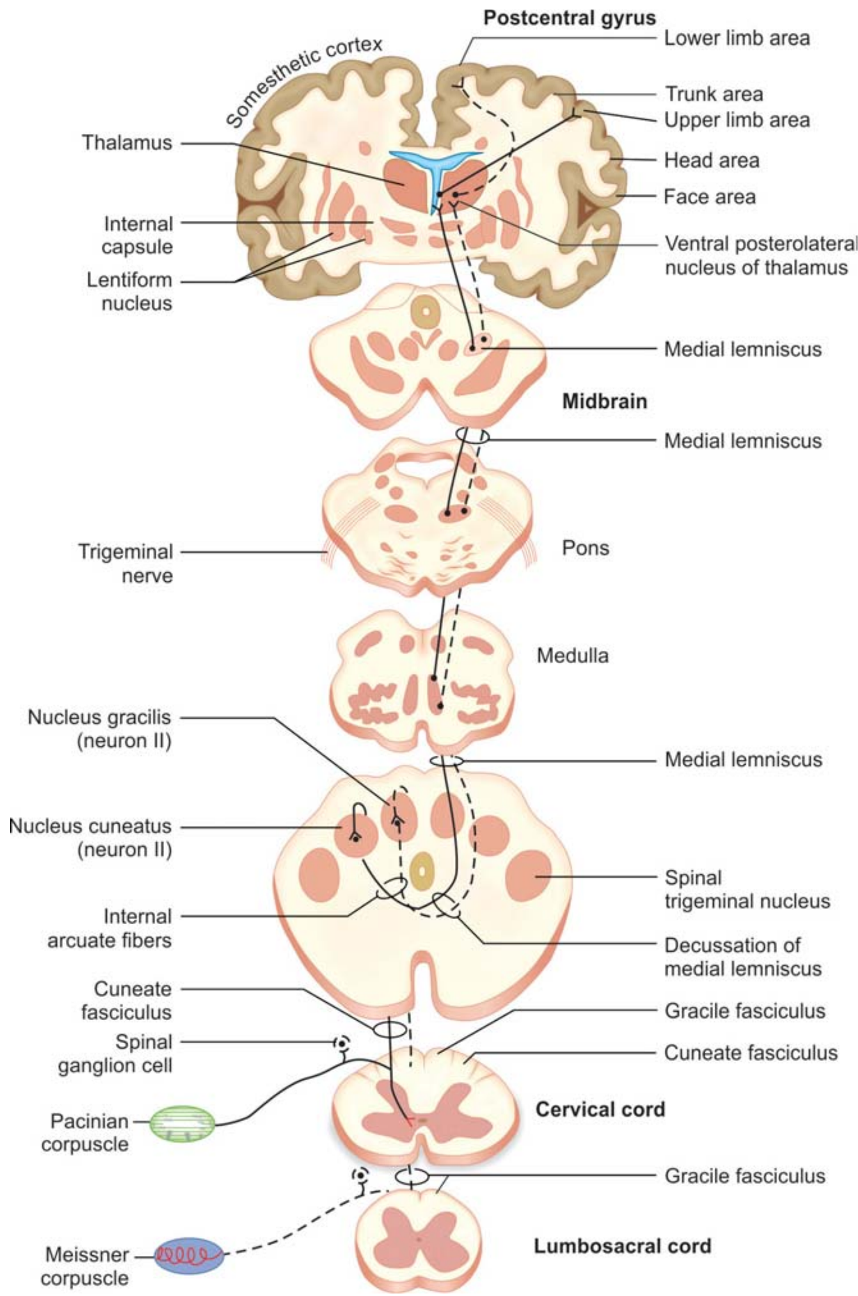


Fig. 93: Dorsal column- medial lemniscal system (detailed)

Spinothalamic Tract (STT)

- Primary afferent fibres carrying **pain** and **temperature** information from the trunk and limbs are carried by **lateral spinothalamic tract** and coarse **touch** and **pressure** information by **anterior spinothalamic tract**.

Lateral Spinothalamic Tract – Spinal Lemniscal System

- **First order neurons** (dorsal root ganglion) fibres **ascend up** by one or two spinal segments, before they terminate in the dorsal horn of the spinal grey matter.
- They synapse on the posterior horn cells (**second order neuron**), which further send the fibres decussating in the anterior white commissure and run as **lateral spinothalamic tract** (spinal cord) and further as **spinal lemniscus** (in the brainstem).
- **Third order neurons** are located in the **VPL nucleus of the thalamus**. They project through the **posterior limb** of the internal capsule to terminate in the postcentral gyrus of the parietal lobe, which is also known as the **primary** somatosensory cortex (Brodmann area 1,2,3).

Anterior spinothalamic tract has a minor role in carrying the touch and pressure of light and crude (coarse) nature. It carries the sensations of itch, tickling etc.

- It has almost the same course as lateral spinothalamic tract and joins it in the brainstem at the level of **spinal lemniscus**, before it reaches the thalamus.
- Some of the axons carrying touch sensations may join **medial lemniscus**, before reaching the thalamus.

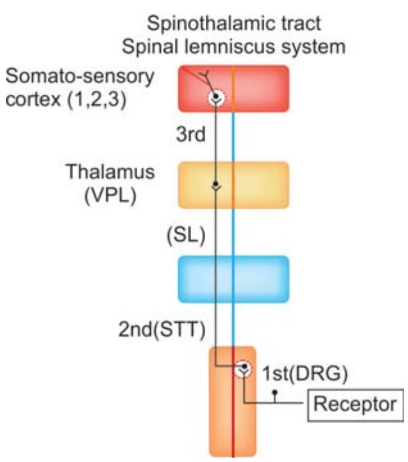


Fig. 94: Spinothalamic - spinal lemniscal system (overview)

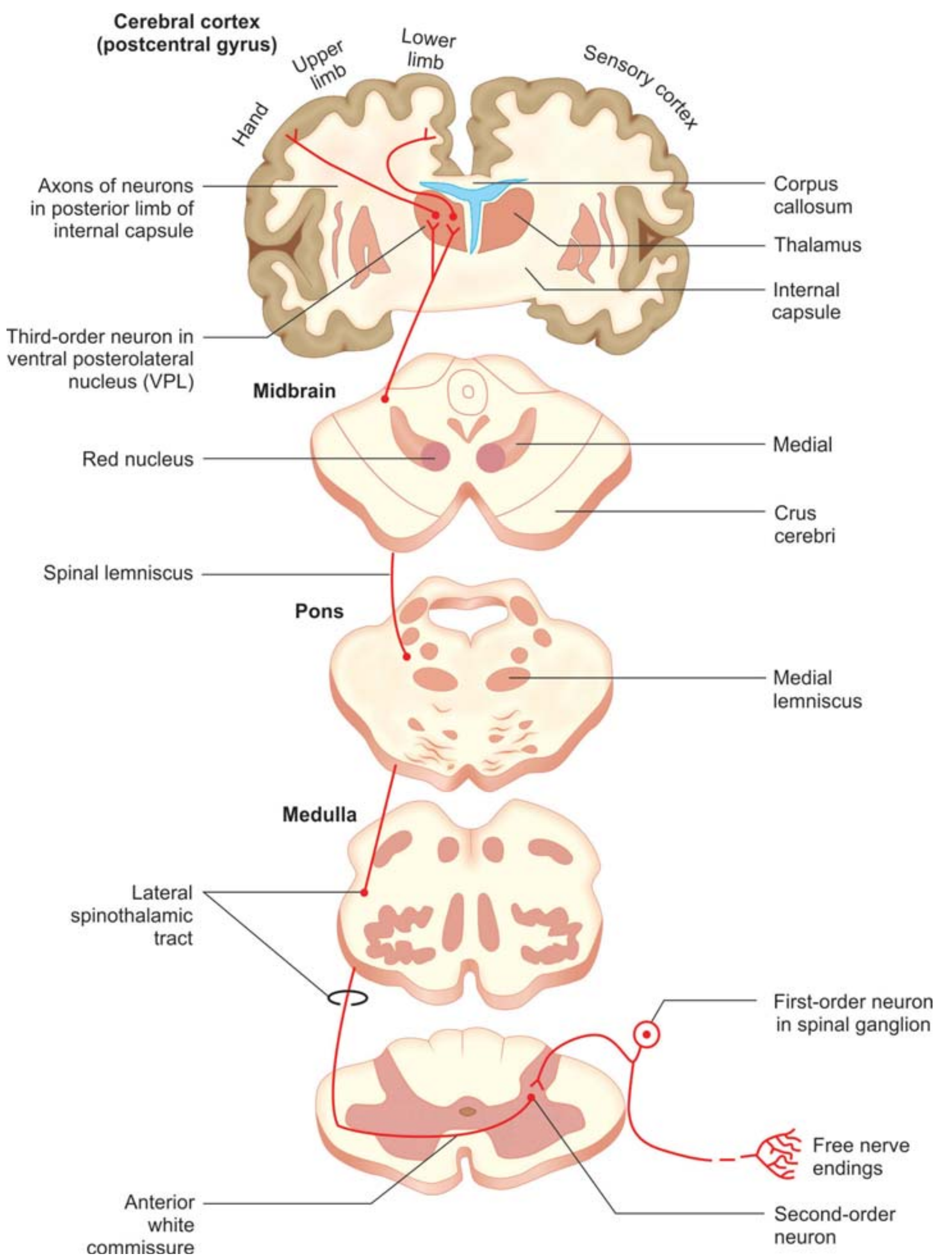


Fig. 95: Spinothalamic - spinal lemniscal system (detailed)

ASSESSMENT QUESTIONS

1. **Which of the following is NOT carried by posterior column tract?** *(AIIMS 2014)*
   a. Position sense
   b. Pain
   c. Touch
   d. Vibration

2. **Which of the following pathway is involved in the ability to recognize an unseen familiar object placed in the hand?** *(AIPG)*
   a. Dorsal spinocerebellar tract
   b. Anterior spinothalamic tract
   c. Posterior spinothalamic tract
   d. Dorsal column

3. **An anterolateral cordotomy relieving pain in left leg is effective because it interrupts the:**
   a. Left dorsal column
   b. Right lateral spinothalamic tract
   c. Left corticospinal tract
   d. Left spinocerebellar tract

4. **TRUE about medial lemniscus system:**
   a. Formed from fasciculus gracilis and cuneatus
   b. Carries discriminative touch and proprioception
   c. Convey pain and temperature
   d. Joins spinothalamic tract
   e. Decussates at lower medulla

ANSWERS WITH EXPLANATIONS

1. **b. Pain**
   - Posterior (**dorsal**) column carries sensations like pressure, vibration, tactile discrimination, proprioception, stereognosis, conscious proprioception.
   - Pain and temperature is carried by the **lateral spinothalamic tract**.
2. **d. Dorsal column**
   - Ability to recognise an unseen familiar object is known as **stereognosis** and is carried by the **dorsal column**.
3. **b. Right lateral spinothalamic tract**
   - Pain from the left is carried by **lateral spinothalamic tract**, contralaterally on the right side of the spinal cord.
4. **a. Formed from fasciculus gracilis and cuneatus; b. Carries discriminative touch and proprioception; e. Decussates at lower medulla**
   - Five sensations (pressure, touch, vibration, stereognosis and proprioception) are carried by dorsal column (fasciculus gracilis and cuneatus) of spinal cord and synapse in the respective nuclei in the lower medulla.
   - Second order neurons begin as medial lemniscus and cross the midline (internal arcuate fibres) in the medulla and ascend up to synapse in thalamus (VPL nucleus).
   - Pain and temperature is carried by lateral spinothalamic tract – spinal lemniscal system.

Descending Tracts

- Corticofugal fibres descend through the internal capsule and pass into the brainstem, where many of them terminate, innervating the cranial nerve nuclei and other brainstem nuclei such as the red nucleus, reticular nuclei, olivary nuclei, etc. The term 'corticobulbar' has been used for many years to describe cortical projections to brainstem nuclei but it is a misnomer. The suffix 'bulbar' is derived from 'bulb', an obsolete name for the medulla oblongata: clearly, corticofugal fibres that terminate in the midbrain and/or pons cannot be described as corticobulbar. The term 'corticobulbar' has been replaced by 'corticonuclear'. Terminologia Anatomica specifies cortical axons that innervate motor or sensory nuclei of cranial nerves according to their connections as follows: fibrae corticonucleares bulbi (medullary corticonuclear fibres); fibrae corticonuclearis pontinis (pontine corticonuclear fibres); and fibrae corticonuclearis mesencephali (mesencephalic corticonuclear fibres).
- Corticospinal (pyramidal tract) fibres originate from widespread regions of the cerebral cortex, including the primary motor cortex of the frontal lobe where the opposite half of the body is represented in a detailed somatotopic fashion. The fibres descend throughout the length of the brainstem. The majority then cross to the contralateral side in the motor decussation of the pyramids in the medulla. Thereafter, they continue caudally as the lateral corticospinal tract of the spinal cord, which terminates in association with interneurons and motor neurons of the spinal grey matter. The principal function of the corticonuclear and corticospinal tracts is the control of fine, fractionated movements, particularly of those parts of the body where delicate muscular control is required. These tracts are particularly important in speech (corticonuclear tract) and movements of the hands (corticospinal tract).
- Basal ganglia/nuclei appear to be involved in the selection of appropriate behavioural patterns/movements and the suppression of inappropriate ones. Disorders of the basal ganglia cause either too little movement (akinesia) or abnormal involuntary movements (dyskinesias), as well as tremor and abnormalities of muscle tone. The basal ganglia are sometimes described as being part of the so-called 'extrapyramidal (motor) system'. This term is used to distinguish between the effects of basal ganglia disease and those of damage to the 'pyramidal' (corticospinal) system. However, the progressive elucidation of the anatomy of the basal ganglia and of the pathophysiology of motor disorders has revealed the close functional interrelationship between the two 'systems', and has rendered the terms that distinguish them largely obsolete. The cerebellum has rich connections with the brainstem, particularly the reticular and vestibular nuclei, and with the thalamus. It is concerned with the coordination of movement; cerebellar disorders cause ataxia, intention tremor and hypotonia.

Table 19: Major descending tracts in the spinal cord				
Tract	**Location**	**Origin**	**Termination**	**Functions**
Lateral corticospinal (crossed pyramidal) tract	Lateral white column of spinal cord	Primary motor cortex (area 4), premotor cortex (area 6) of the opposite cerebral hemisphere (upper motor neurons)	Anterior horn cells of the spinal cord (lower motor neurons)	Controls conscious skilled movements especially of hands (contraction of individual or small group of muscles particularly those which move hands, fingers, feet and toes)
Anterior corticospinal (uncrossed pyramidal) tract	Anterior white column	Primary motor cortex (area 4) premotor cortex (area 6) of the opposite cerebral hemisphere (upper motor neurons)	Anterior horn cells of the spinal cord (lower motor neurons)	Same as that of lateral corticospinal tracts
Rubrospinal tract	Lateral white column	Red nucleus of the opposite side located in midbrain	Anterior horn cells of the spinal cord	Unconscious coordination of movements (controls muscle tone and synergy)
Vestibulospinal tract	Anterior white column	Vestibular nucleus	Anterior horn cells of the spinal cord	Unconscious maintenance of posture and balance
Tectospinal tract	Anterior white column	Superior colliculus of the opposite side	Cranial nerve nuclei in medulla and anterior horn cells of the upper spinal segments	Controls movements of head, neck and arms in response to visual stimuli
Lateral reticulospinal tract	Lateral white column	Reticular formation in midbrain, pons and medulla	Anterior horn cells of the spinal cord	Mainly responsible for facilitatory influence on the motor neurons to the skeletal muscles
Medial reticulospinal tract	Anterior white column	Reticular formation in medulla	Anterior horn cells of the spinal cord	Mainly responsible for inhibitory influence on the motor neurons to the skeletal muscles

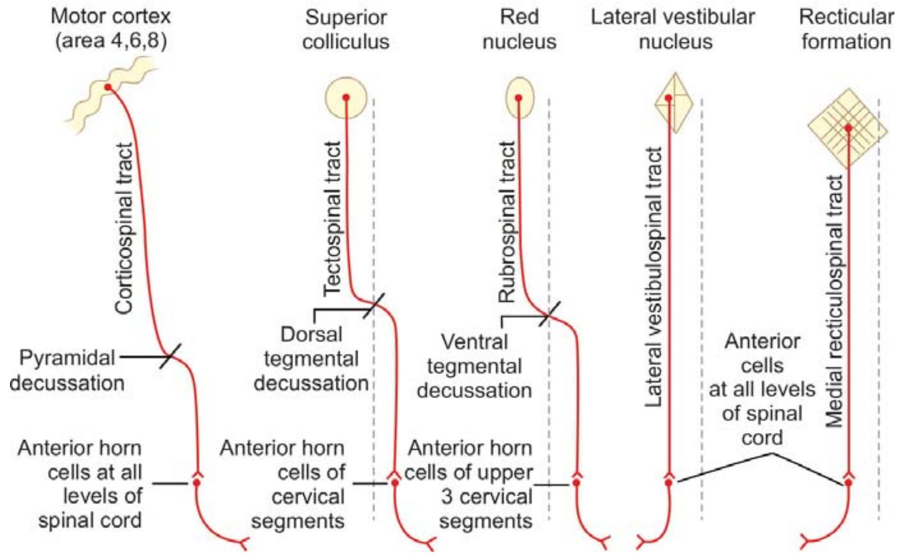


Fig. 96: Descending (motor) tracts

Pyramidal System

Pyramidal tract: Fibers arise from pyramidal neurons in layer 5 of the precentral gyrus, premotor areas and somatic sensory cortex and descend through the posterior limb of internal capsule and basis pedunculi, cross at the spinomedullary junction and form the lateral corticospinal tract in the lateral funiculus of the spinal cord. They terminate on lower motor neurons in the ventral horn or on interneurons.

- Most muscles are represented in the contralateral motor cortex. However, some (such as the muscles of the upper face, the muscles of mastication, and muscles of the larynx) are represented bilaterally.
- With the noted bilateral exceptions, lesion of the pyramidal tract above the decussation results in spastic paralysis, loss of fine movements, and hyper-reflexia on the contralateral side.
- Lesion of the corticospinal tract in the spinal cord results in ipsilateral symptomology.

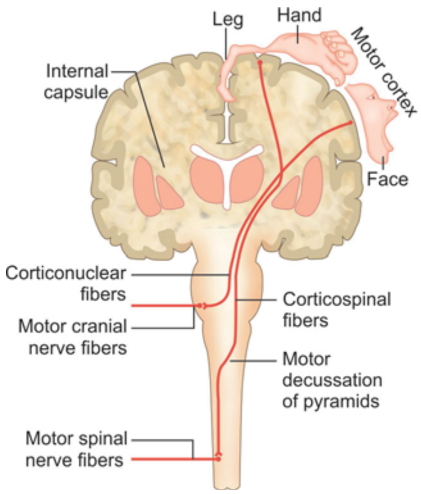


Fig. 97: The corticospinal and corticonuclear tracts

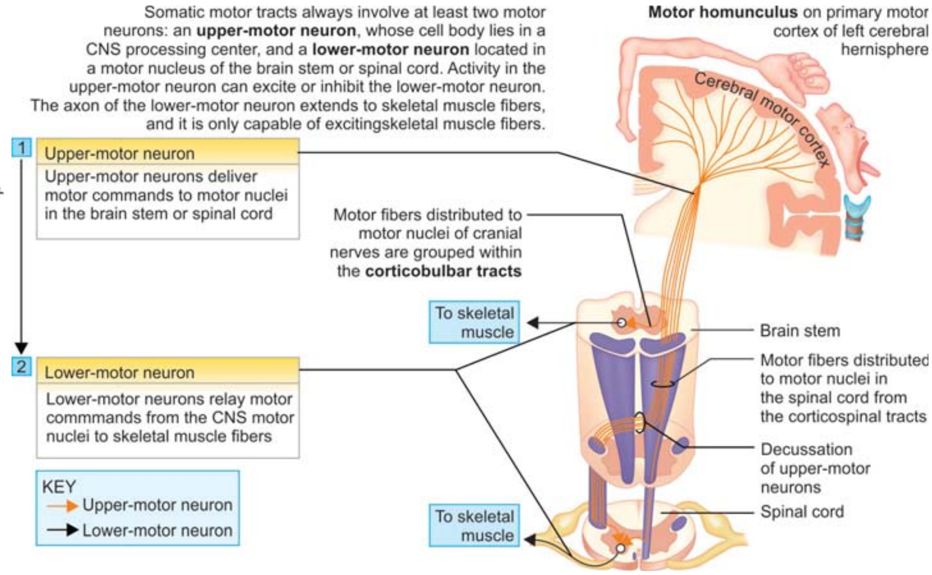


Fig. 98: Pyramidal system showing corticobulbar and corticospinal tracts. Upper motor neurones in the cerebrum modulate the lower motor neurones located in brainstem (cranial nerves) and spinal cord (spinal nerves), which themselves control the skeletal muscles

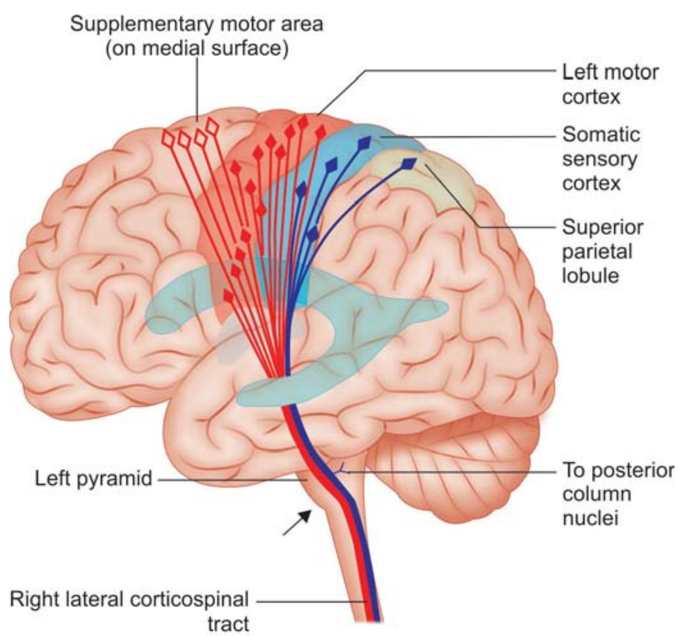


Fig. 99: Pyramidal tract visualised from the left side. The supplementary motor area is on the medial surface of the hemisphere. The arrow indicates the level of pyramidal decussation. Non-motor neurons are shown in blue. Pyramidal tract has 60% motor fibres and 40% sensory fibres. 30% motor fibres arise from the primary motor area and 30% motor fibres from the supplemental motor area. 40% sensory fibres arise from the parietal sensory cortex and follow the motor fibres in pyramidal tract

Medial Longitudinal Fasciculus (MLF)

- Subcortical centre for horizontal conjugate gaze lies in the abducent nucleus in pons.
- It receives input from the contralateral frontal eye field and controls ipsilateral lateral rectus and contralateral medial rectus muscle via projections of **medial longitudinal fasciculus** (MLF).
- MLF connects the nuclei controlling eyeball muscles and mediates nystagmus and lateral conjugate gaze.
- Its fibres originate in vestibular nucleus and terminate in abducent, trochlear and occulomotor nuclei.
- It coordinates eyeball movements with the head. Trochlear nucleus is mainly concerned with vertical gaze movements.

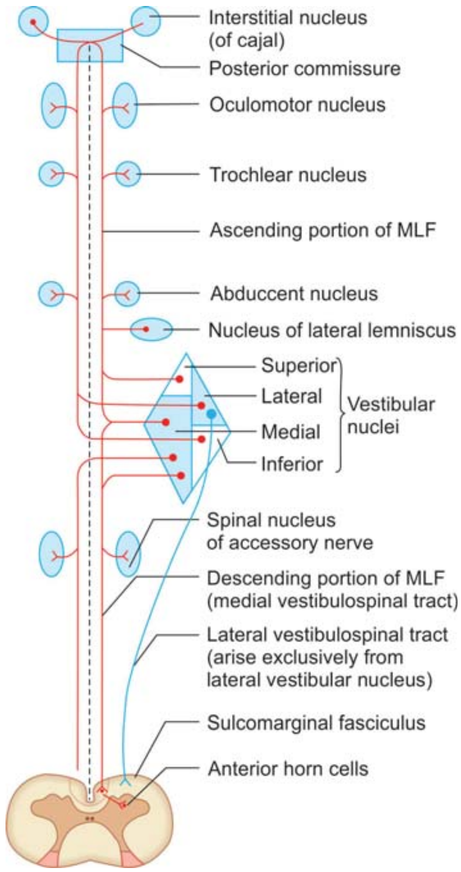


Fig. 100: Medial longitudinal fasciculus (MLF) and distribution of its fibres to cranial nerve nuclei

Transverse section of spinal cord showing various neural pathways passing through it.

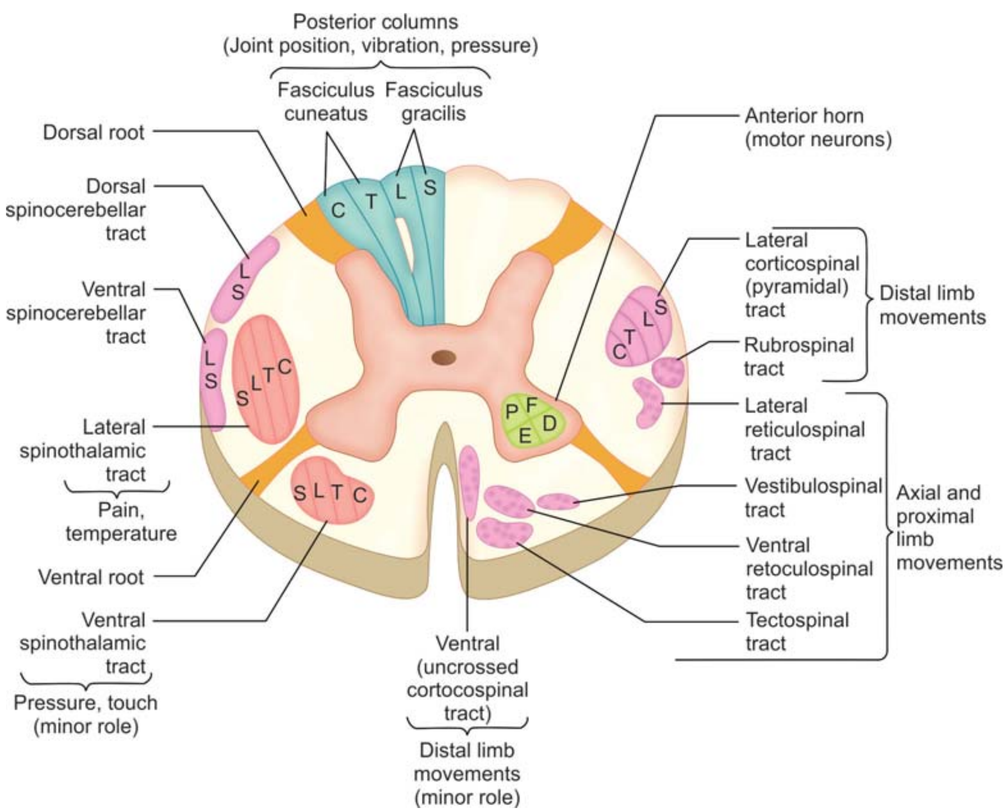


Fig. 101: Transverse section of spinal cord showing sensory tracts on left half and motor tracts on the right half

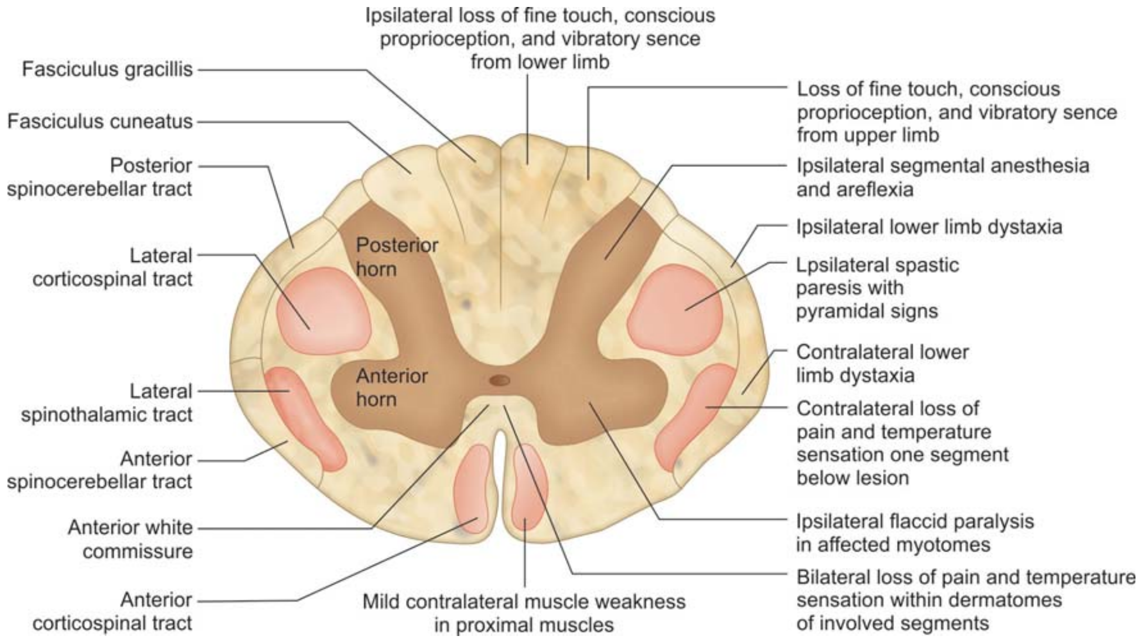


Fig. 102: Transverse section of the cervical spinal cord. Clinically important pathways are shown on the left side; clinical deficits resulting from the interruption of these pathways are shown on the right side. Destructive lesions of the posterior horns result in anesthesia and areflexia, and destructive lesions of the anterior horns result in LMN lesions and areflexia. Destruction of the anterior white commissure interrupts the central transmission of pain and temperature impulses bilaterally via the anterolateral system.

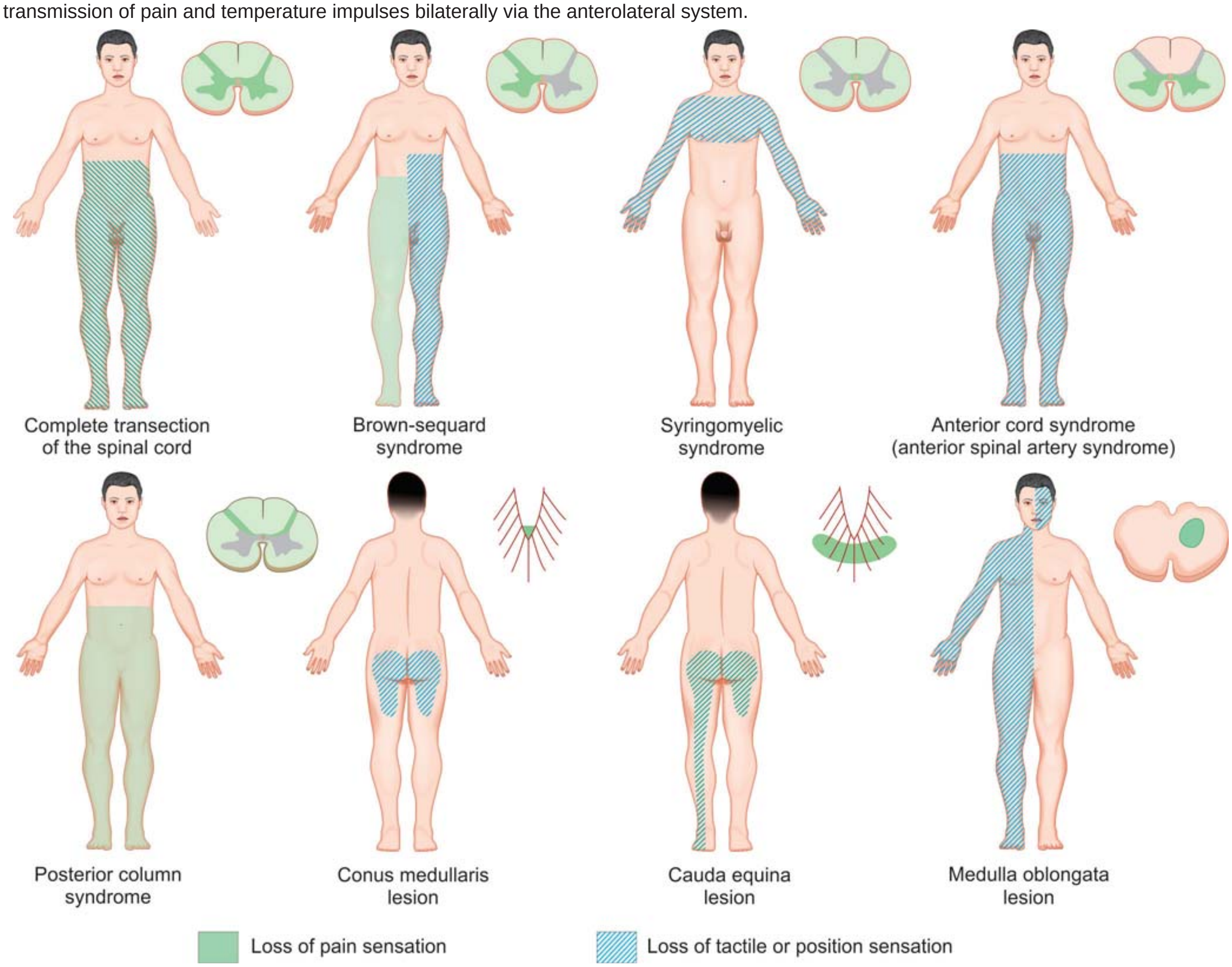


Fig. 103: Localization of sensory disorders

Table 20: Differences between conus medullaris syndrome and cauda equina syndrome		
Features	**Conus medullaris syndrome**	**Cauda equina syndrome**
Part affected	Conus medullaris containing sacral segments of the cord and may be lumbar nerves	Sacral nerve roots
Presentation	Both upper motor neuron and lower motor neuron type paralysis	Only lower motor neuron type of paralysis
Onset	Sudden	Gradual
Laterality	Bilateral	May be unilateral
Low back pain	Severe	Not severe
Root pain	Not severe	Severe
Anesthesia	Perianal region	Saddle anesthesia
Paralysis	Bilateral upper motor neuron type with exaggerated tendon reflexes, increased tone below the level of lesion and lower motor neuron type paralysis at the level of lesion	Unilateral, lower motor neuron type paralysis with hypotonia, loss of reflexes and atrophy of muscles
Bladder and bowel involvement	Early, urinary retention with overflow urinary and bowel incontinence	Late, urinary and bowel retention
Sexual dysfunction	More frequent	Less frequent

- **Cauda equina syndrome** is usually unilateral may result from a lumbar disc herniation involving lower lumbar and sacro-coccygeal spinal root values.
  - The presenting complaint of the patient is severe unilateral pain in the back extending into the sacral segments and to the legs (sciatica).
  - Lower motor neuron signs are present in the leg with fasciculation and muscle atrophy.
  - Knee reflex (L-2, 3 and 4) ankle reflex (S-1) is lost on the affected side and plantar reflex is extensor.
  - Saddle anaesthesia and lower extremity weakness is asymmetric.
  - Delayed presentation of atonic bladder and flaccid anal sphincter.
- **Conus medullaris syndrome** is usually midline lesion, may result from intradural tumours or vascular lesions.
  - It is a lower motor neuron lesion and involves the lower 3 sacral and coccygeal segments.
  - It presents with earlier atonic bladder and sphincter dysfunction, symmetric saddle anaesthesia (S2-5) and late symmetric motor deficit in lower limbs.
  - Knee reflex (L-2, 3 and 4) ankle reflex (S-1) are intact since the spinal segments involved in knee and ankle jerks are at higher level than the level of lesion.
  - Plantar reflex (S1-2) remains flexor in this syndrome, since its spinal arc is also above the level of lesion and is unaffected.

Cauda equina syndrome typically presents in men who have a lumbar disc herniation in the setting of lumbar spinal stenosis, with symptoms of asymmetric saddle anaesthesia and asymmetric lower extremity weakness, and delayed presentation of atonic bladder and flaccid anal sphincter. Conus medullaris syndrome typically presents with symmetric saddle anaesthesia, symmetric motor deficit and earlier atonic bladder and sphincter dysfunction. The usual causes are intradural tumours or vascular lesions.

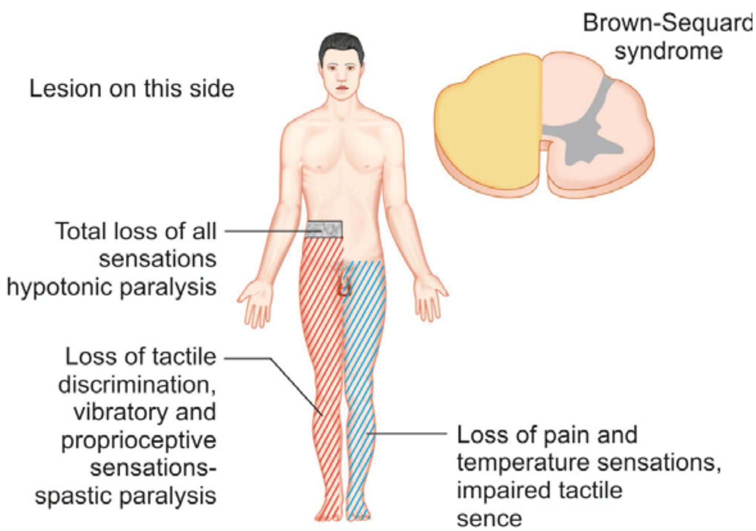


Fig. 104: Brown-Séquard syndrome with a spinal cord lesion at the right 10th thoracic level

Cauda equina syndrome: It is caused due to compression of cauda equina—a leash of nerve roots of L2 to S1 around the filum terminale. Clinically, it presents as:

a. Flaccid paraplegia
b. Saddle-shaped anesthesia
c. Late bladder and bowel involvement leading to incontinence of urine and feces
d. Impotence
e. Absence of knee and ankle jerks

ASSESSMENT QUESTIONS

1. **All true about conus syndrome EXCEPT:** *(AIPG 2008)*
   a. Begins at the level of lower 3 sacral and coccygeal segment
   b. Absent knee and ankle jerks
   c. Flexor planter reflex
   d. Saddle anesthesia

2. **Which of the following is concerned with pain and temperature?** *(AIPG 2008)*
   a. Pyramidal tract
   b. Anterior spinothalamic tract
   c. Lateral spinothalamic tract
   d. Dorsal spinocerebellar tract

3. **Which of the following is NOT carried by posterior column tract?** *(AIPG 2008)*
   a. Position sense
   b. Temperature
   c. Pressure
   d. Vibration

4. **The final common pathway for horizontal gaze is nucleus:** *(AIPG 2008)*
   a. Abducent
   b. Occulomotor
   c. Trochlear
   d. Vestibular

5. **Which of the following tracts is seen in the posterior column of spinal cord?** *(PGIC)*
   a. Lateral spinothalamic tract
   b. Fasciculus gracilis
   c. Fasciculus cuneatus
   d. Rubrospinal tract
   e. Posterior spinocerebellar

6. **Most of the fibres in Pyramidal tract originate from:**
   a. Primary motor cortex
   b. Pre-motor cortex
   c. Primary somato-sensory cortex
   d. Supplementary motor cortex

7. **All is true about Brown Sequard syndrome EXCEPT:**
   a. Hemisection of spinal cord
   b. Ipsilateral loss of vibration sensations
   c. Ipsilateral loss of crude touch sensations
   d. Ipsilateral paralysis below the level of lesion

ANSWERS WITH EXPLANATIONS

1. **b. Absent knee and ankle jerks**
   - Since the spinal segments involved in knee and ankle jerks are at higher level than the level of lesion, they are preserved, and not lost.
   - Root value of knee reflex is L-2, 3 and 4 and for the ankle reflex is S-1.
   - Conus medullary syndrome is a lower motor neuron lesion and involves the lower 3 sacral and coccygeal segments.
   - Plantar reflex remains flexor in this syndrome, since its spinal arc is also above the level of lesion and is unaffected.
   - Root value of plantar reflex is S-1, 2.
   - Conus medullary syndrome produces saddle anaesthesia in the perineal region as per the dermatomal pattern.

2. **c. Lateral spinothalamic**
   - Pain and temperature is carried by the lateral spinothalamic tract, whereas, anterior spinothalamic tract carries the crude touch.
   - Pyramidal tract is a motor tract and is concerned with control of fine and skilled voluntary motor activity.
   - Dorsal spinocerebellar tract is concerned with unconscious proprioception, mainly from the lower limbs.
   - Upper limb proprioception is carried by the cuneocerebellar tract.

3. **b. Temperature**
   - Posterior column tract does not carry the temperature sensations, which is carried by the lateral spino-thalamic tract.
   - Pressure, fine touch and vibration is carried by the posterior column.
   - It also carries the conscious proprioception—the knowledge of position and movement of body parts.

4. **a. Abducent**
   - Subcortical centre for horizontal conjugate gaze lies in the abducent nucleus in pons.
   - It receives input from the contralateral frontal eye field and controls ipsilateral lateral rectus and contralateral medial rectus muscle via projections of medial longitudinal fasciculus (MLF).
   - MLF connects the nuclei controlling eyeball muscles and mediates nystagmus and lateral conjugate gaze.
   - Its fibres originate in vestibular nucleus and terminate in abducent, trochlear and occulomotor nuclei.
   - It coordinates eyeball movements with the head. Trochlear nucleus is mainly concerned with vertical gaze movements.

5. **b. Fasciculus gracilis; c. Fasciculus cuneatus**
   - Posterior column (dorsal column) of spinal cord has two fasciculi: gracilis and cuneatus.

6. **c. Primary somato-sensory cortex**
   - About 31% of the corticospinal tract neurons arise from the primary motor cortex.
   - The premotor cortex and supplementary motor cortex account for 29% of the corticospinal tract neurons.
   - The largest percentage of 40% originate in the parietal lobe and primary somatosensory area in the postcentral gyrus.

7. **c. Ipsilateral loss of crude touch sensations**
   - Brown Sequard syndrome presents with **contralateral** loss of crude touch sensations, since **anterior spinothalamic tract** carrying these sensations, crosses the midline and runs on the opposite half of spinal cord.

Autonomic Nervous System

Autonomic nervous system (ANS) is responsible for the motor innervation of **three effectors**: Cardiac muscle, smooth muscle, and glands, and is divided into **three components**: Sympathetic, parasympathetic, and enteric divisions.

- It includes general visceral efferent (GVE) and general visceral afferent (GVA) fibers.
- Its motor (GVE) component is a ganglionated system involving **two neurons**: preganglionic and postganglionic.
- Preganglionic neurons with cell bodies are in the CNS (brainstem and in the lateral grey columns of the spinal cord). Their axons are usually finely **myelinated**, exit from the CNS in certain cranial and spinal nerves, and then pass to peripheral ganglia, where they synapse with postganglionic neurons.
- The axons of postganglionic neurons are usually **unmyelinated**. Postganglionic neurons are **more numerous** than preganglionic ones; one preganglionic neuron may synapse with 15–20 postganglionic neurons, which permits the wide distribution of many autonomic effects.

Location and Distribution

- Sympathetic flow is **thoracolumbar** outflow and **parasympathetic** is craniosacral outflow.
- Autonomic activity is not initiated or controlled solely by the reflex connections of general visceral afferent pathways; nor do impulses in these pathways necessarily activate general visceral efferents.
- Peripheral autonomic activity is integrated at higher levels in the **brainstem** and **cerebrum**, including various nuclei of the brainstem **reticular formation**, **thalamus** and **hypothalamus**, the **limbic lobe** and **prefrontal** neocortex, together with the ascending and descending pathways that interconnect these regions.
- The parasympathetic system is **restricted** in its distribution to the head, neck and body cavities (except for erectile tissues of genitalia), otherwise, parasympathetic fibres are **never** found in the body wall and limbs. Sympathetic fibres by comparison are distributed to all the vascularized portions of body.

Neurotransmitters

- Generally preganglionic neurons of both sympathetic and parasympathetic systems are **cholinergic** and postganglionic parasympathetic neurons are also **cholinergic** while those of the sympathetic nervous system are **noradrenergic** (with few exceptions).
- The principal co-transmitters in sympathetic nerves are **ATP** and **neuropeptide Y**; in parasympathetic nerves **vasoactive intestinal polypeptide (VIP)**; and in enteric nerves ATP, VIP and **substance P**.
- **Acetylcholine** (ACh) is the preganglionic neurotransmitter for both divisions of the ANS as well as the postganglionic neurotransmitter of the parasympathetic neurons; the preganglionic receptors are nicotinic, and the postganglionic are muscarinic in type.
- **Norepinephrine** (NE) is the neurotransmitter of the postganglionic sympathetic neurons, except for cholinergic neurons innervating the eccrine sweat glands.

Functions of Autonomic Nervous System (ANS)

- Sympathetic nervous system functions in **emergencies** (energy consumption), preparing for fight or flight, whereas the parasympathetic nerve functions in **homeostasis** (energy conservation), tending to promote quiet and orderly processes of the body.

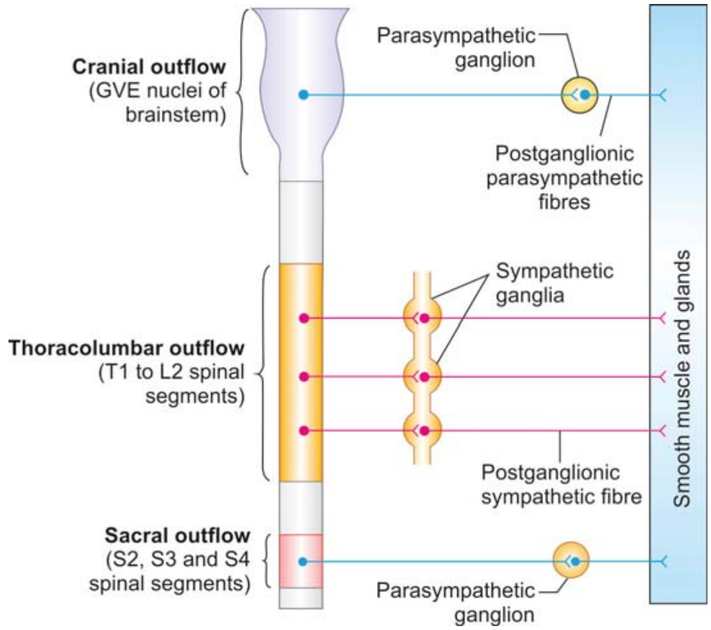


Fig. 105: ANS showing two components: sympathetic and parasympathetic

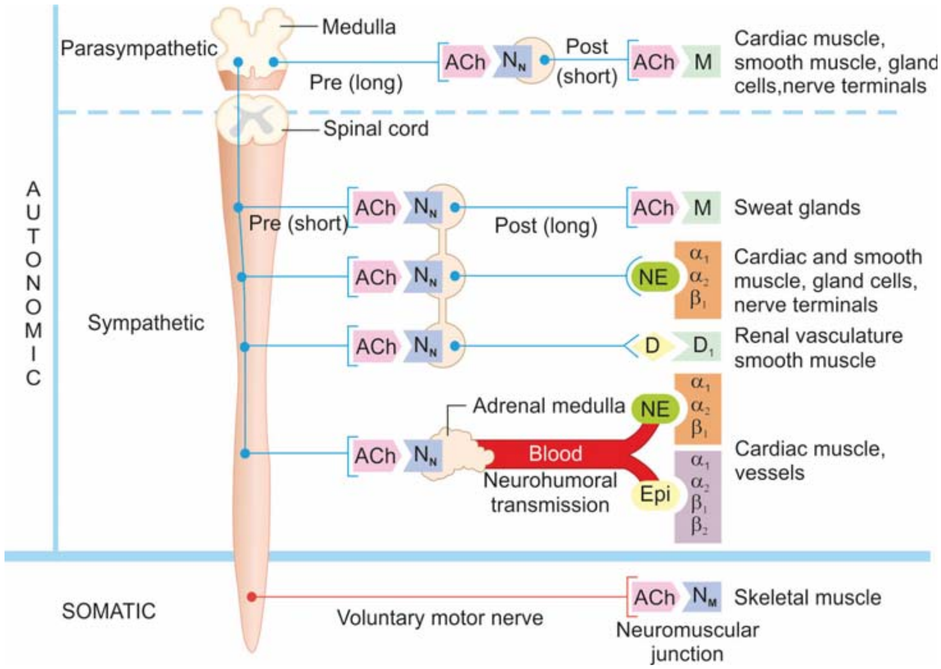


Fig. 106: ANS showing the various neurotransmitters at ganglion and effector levels

- Sympathetic activity, in general, results in the constriction of cutaneous arteries (increasing blood supply to the heart, muscles and brain), cardiac acceleration, an increase in blood pressure, contraction of sphincters and depression of peristalsis, all of which mobilize body energy stores for dealing with increased activity.
- Parasympathetic activity leads to cardiac slowing and an increase in intestinal glandular and peristaltic activities, which may be considered to conserve body energy stores.
- With the exception of coronary arteries, vasoconstriction is sympathetically stimulated; the effects of sympathetic stimulation on glands (other than sweat glands) are the indirect effect of vasoconstriction.
- **Sympathetic** nervous system works for bladder and bowel **storage** (decrease in peristalsis and sphincter constriction), whereas **parasympathetic** system is involved in bladder and bowel **evacuation** (increased peristalsis and relaxed sphincters).
- Pelvic viscera like urinary bladder and rectum are supplied by T10 - 12; L1-2 (sympathetic splanchnic nerves) supply which decrease the peristalsis of detrusor and constrict the urethral sphincters for **storage** of urine.
- Parasympathetic nervi erigentes (S2-4) increase the peristalsis of detrusor and relax the urethral sphincters for **evacuation** of urine.
- Somatic nervous system allows for the bladder and bowel continence by S-2-4 (somatic pudendal nerve) which constricts the external urethral sphincter (skeletal muscle) for voluntary holding of urine or faecal matter.
- Pain fibres from the bladder and proximal urethra (GVA) traverse both the **pelvic splanchnic nerves** and the inferior hypogastric plexus, hypogastric nerves, superior hypogastric plexus and lumbar splanchnic nerves to reach their cell bodies in ganglia on the **lower thoracic and upper lumbar dorsal spinal roots** (T10 - 12; L1-2).

Table 21: Functions of autonomic nervous system (ANS)

Organ, tract, or system		Effect of sympathetic stimulation	Effect of parasympathetic stimulation
Eyes	Pupil	Dilates pupil (admits more fight for increased acuity at a distance)	Constricts pupil (protects pupil from excessively bright light)
	Ciliary body		Contracts ciliary muscle, allowing lens to thicken for near vision (accommodation)
Skin	Arrector muscles of hair	Causes hairs to stand on end ("goose-flesh" or "goose bumps")	No effect (does not reach)
	Peripheral blood vessels	Vasoconstricts (blanching of skin, lips, and turning fingertips blue)	No effect (does not reach)
	Sweat glands	Promotes sweating	No effect (does not reach)
Other glands	Lacrimal glands	Slightly decreases secretion	Promotes secretion
	Salivary glands	Secretion decreases, becomes thicker, more viscous	Promotes abundant, watery secretion

Organ, tract, or system	Effect of sympathetic stimulation	Effect of parasympathetic stimulation
Heart	Increases the rate and strength of contraction; inhibits the effect of parasympathetic system on coronary vessels, allowing them to dilate	Decreases the rate and strength of contraction (conserving energy); constricts coronary vessels in relation to reduced demand
Lungs	Inhibits effect of parasympathetic system, resulting in bronchodilation and reduced secretion, allowing for maximum air exchange	Constricts bronchi (conserving energy) and promotes bronchial secretion
Digestive tract	Inhibits peristalsis, and constricts blood vessels to digestive tract so that blood is available to skeletal muscle; contracts internal anal sphincter to aid fecal continence	Stimulates peristalsis and secretion of digestive juices Contracts rectum, inhibits internal anal sphincter to cause defecation
Liver and gallbladder	Promotes breakdown of glycogen to glucose (for increased energy)	Promotes building/conservation of glycogen; increases secretion of bile
Urinary tract	Vasoconstriction of renal vessels slows urine formation; internal sphincter of bladder contracted to maintain urinary continence	Inhibits contraction of internal sphincter of bladder, contracts detrusor muscle of the bladder wall causing urination
Genital system	Causes ejaculation and vasoconstriction resulting in remission of erection	Produces engorgement (erection) of erectile tissues of the external genitals
Suprarenal medulla	Release of adrenaline into blood	No effect (does not innervate)

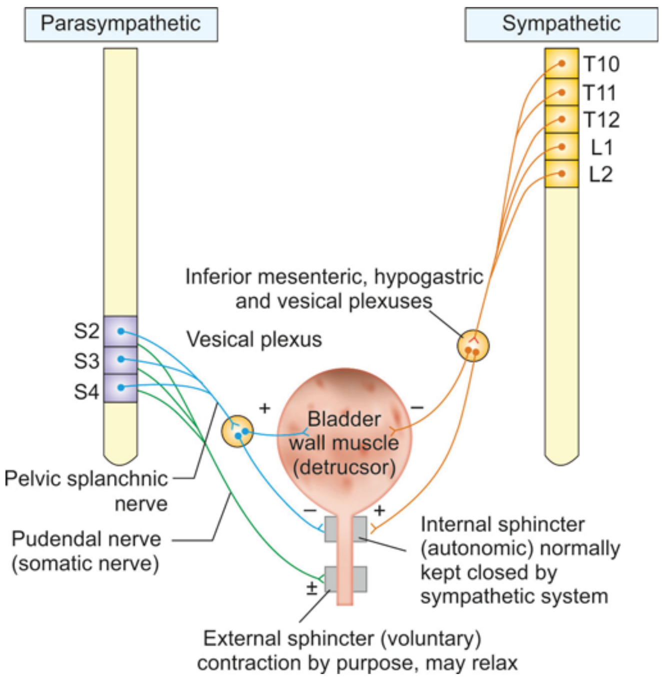


Fig. 107: Autonomic and somatic nervous system control in urine storage and evacuation

Parasympathetic Nervous System

Parasympathetic Nervous System is an energy conserving (**anabolic**) system, concerned with homeostasis and promoting quiet and orderly processes of the body.

- Preganglionic parasympathetic neuronal cell bodies are located in certain **cranial nerve nuclei** of the brainstem and in the **intermedio-lateral horn cells** of the second to fourth sacral segments of the spinal cord.
- Efferent fibres (GVE), which are **myelinated**, emerge from the CNS only in the **oculomotor**, **facial**, **glossopharyngeal** and **vagus** nerves, and in the **nervi erigentes** (S2-4) spinal nerves.
- Both the preganglionic and postganglionic parasympathetic neurons are **cholinergic**.

- The cell bodies of postganglionic parasympathetic neurons are mostly located **distant** from the CNS, either in discrete ganglia located near the structures innervated, or dispersed in the walls of viscera.
- In the cranial part of the parasympathetic system there are **four** small peripheral ganglia: **ciliary**, **pterygopalatine**, **submandibular** and **otic**.
- These ganglia are **efferent** parasympathetic ganglia, **unlike** the trigeminal, facial, glossopharyngeal and vagal sensory ganglia, all of which are concerned exclusively with afferent impulses and contain the cell bodies of sensory neurons.
- The cranial parasympathetic ganglia are also traversed by afferent fibres, postganglionic sympathetic fibres and, in the case of the otic ganglion, by branchial efferent fibres; however, **none of these fibres synapse** in the ganglia.
- Postganglionic parasympathetic fibres are usually **unmyelinated** and **shorter** than their counterparts in the sympathetic system because the ganglia in which the parasympathetic fibres synapse are either in or near the viscera they supply.
- **Vagus** nerve has the **largest distribution** in the body and contains the parasympathetic preganglionic **GVE** fibers with cell bodies located in the medulla oblongata and the **GVA** fibers with cell bodies located in the inferior (nodose) ganglion.
- Parasympathetic fibers in the vagus nerve (CN X) that supply all of the thoracic and abdominal viscera, **except** the descending and sigmoid colons and other pelvic viscera (which are supplied by nervi erigentes).

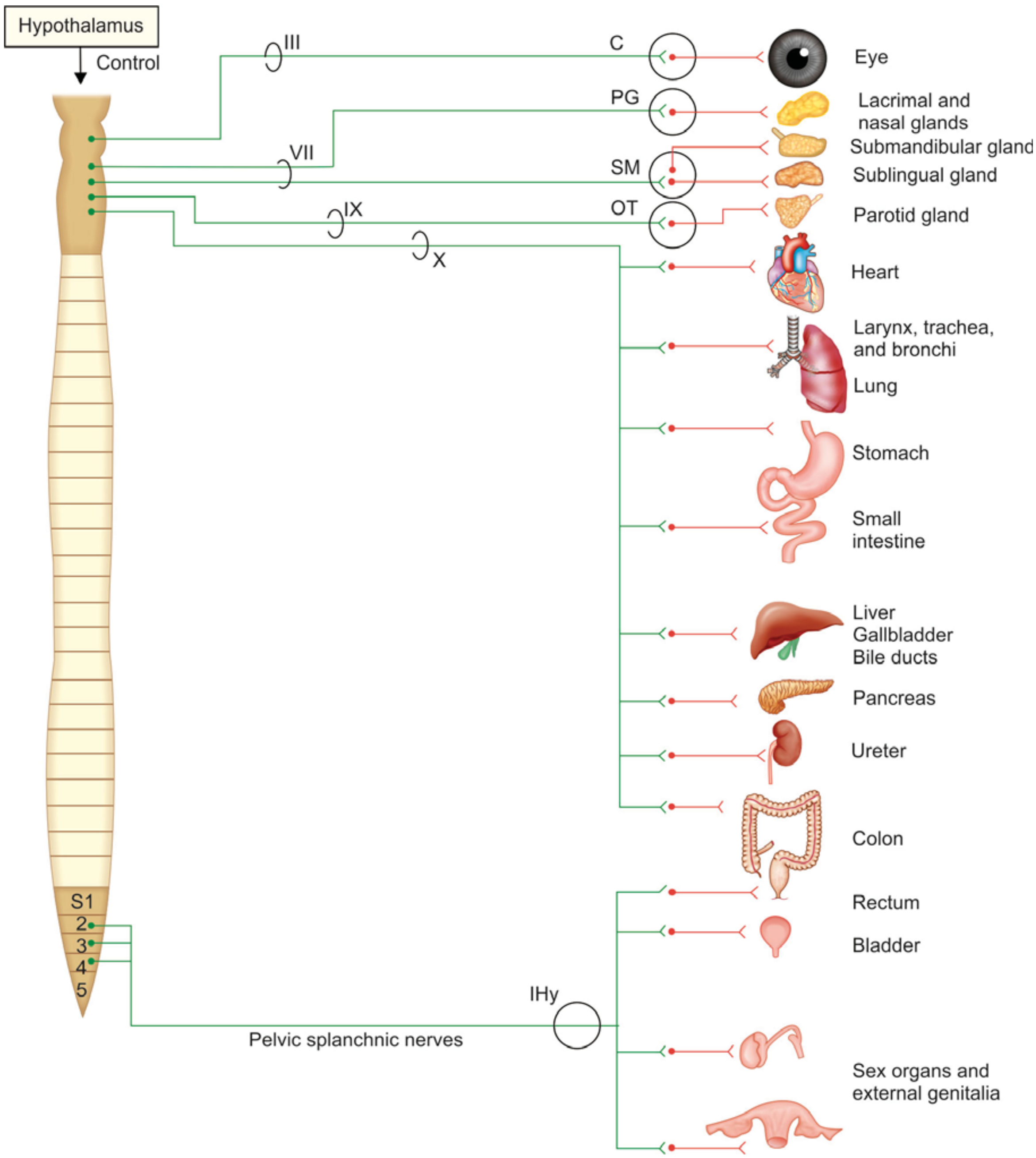


Fig. 108: Diagram of the visceromotor component of the parasympathetic nervous system. Preganglionic parasympathetic neurons (solid line; green), postganglionic parasympathetic neurons (solid line; red). C, ciliary ganglion; PG, pterygopalatine ganglion; SM, submandibular ganglion; OT, otic ganglion; IHy, inferior hypogastric plexus

Sympathetic Nervous System

Sympathetic Nervous System is a catabolic (energy-consuming) system that enables the body to cope with emergencies, with a fight-or-flight reaction.

- It contains preganglionic cell bodies that are located in the intermediolateral horn cells of the spinal cord segments between T1 and L2 (thoracolumbar flow).

Sympathetic trunks are two ganglionated nerve cords that extend on either side of the vertebral column from the cranial base to the coccyx.

- The trunk is composed primarily of ascending and descending preganglionic sympathetic fibers and visceral afferent fibers and contains the cell bodies of the postganglionic sympathetic fibers.
- The ganglia are joined to spinal nerves by short connecting nerves called **white** and g**rey rami communicantes**.
- Preganglionic axons join the trunk through the white rami communicantes while postganglionic axons leave the trunk in the grey rami.
- In the neck, each sympathetic trunk lies posterior to the carotid sheath and anterior to the transverse processes of the cervical vertebrae.
- In the thorax, the trunks are anterior to the heads of the ribs and the posterior intercostal vessels and gives rise to cardiac, pulmonary, mediastinal, and splanchnic branches.
- Sympathetic trunks enter the abdomen through the crus of the diaphragm or behind the medial lumbocostal arch and in the abdomen they lie anterolateral to the bodies of the lumbar vertebrae.
- In the pelvis they are anterior to the sacrum and medial to the anterior sacral foramina.
- Anterior to the coccyx the two trunks meet in a single, median, terminal ganglion.
- Cervical sympathetic ganglia are usually reduced to three by fusion. The internal carotid nerve, a continuation of the sympathetic trunk arises from the cranial pole of the superior ganglion and accompanies the internal carotid artery through its canal into the cranial cavity.
- There are between 10 and 12 (usually 11) thoracic ganglia, 4 lumbar ganglia, and 4 or 5 ganglia in the sacral region.
- The cell bodies of preganglionic sympathetic neurons are located in the lateral horn of the spinal grey matter of all thoracic segments and the upper two or three lumbar segments.
- Their axons are myelinated and leave the cord in the corresponding ventral nerve roots and pass into the spinal nerves, but soon leave in white rami communicantes to join the sympathetic trunk.
- Neurons like those in the lateral grey column exist at other levels of the cord above and below the thoracolumbar outflow and small numbers of their fibres leave in other ventral roots.
- On reaching the sympathetic trunk, preganglionic fibres behave in one of several ways. They may synapse with neurons in the nearest ganglion, or traverse the nearest ganglion and ascend or descend in the sympathetic chain to end in another ganglion.
- A preganglionic fibre may terminate in a single ganglion or, through collateral branches, synapse with neurons in several ganglia.
- Preganglionic fibres may traverse the nearest ganglion, ascend or descend and, without synapsing, emerge in one of the medially directed branches of the sympathetic trunk to synapse in the ganglia of autonomic plexuses (mainly situated in the midline, e.g. around the coeliac and mesenteric arteries).
- More than one preganglionic fibre may synapse with a single postganglionic neurone.
- Uniquely, the suprarenal gland is innervated directly by preganglionic sympathetic neurons that traverse the sympathetic trunk and coeliac ganglion without synapse.
- The neuron bodies of sympathetic postganglionic neurons are located mostly either in the ganglia of the sympathetic trunk or in ganglia in more peripheral plexuses.
- The axons of postganglionic neurons are, therefore, generally longer than those of preganglionic neurons, an exception being some of those that innervate pelvic viscera.
- The axons of ganglionic cells are unmyelinated. They are distributed to target organs in various ways.
- Those from a ganglion of the sympathetic trunk may return to the spinal nerve of preganglionic origin through a grey ramus communicans, which usually joins the nerve just proximal to the white ramus, and are then distributed through ventral and dorsal spinal rami to blood vessels (vasomotor), sweat glands (sudomotor), hair (pilomotor) in their zone of supply.
- Alternatively, postganglionic fibres may pass in a medial branch of a ganglion direct to particular viscera, or innervate adjacent blood vessels, or pass along them externally to their peripheral distribution. They may ascend or descend before leaving the sympathetic trunk as described above.
- Many fibres are distributed along arteries and ducts as plexuses to distant effectors.
- The sympathetic system has a much wider distribution than the parasympathetic. It innervates all sweat glands, the arrector pili muscles, the muscular walls of many blood vessels, the heart, lungs and respiratory tree, the abdominopelvic viscera, the oesophagus, the muscles of the iris, and the non-striated muscle of the urogenital tract, eyelids etc.
- Postganglionic sympathetic fibres that return to the spinal nerves are vasoconstrictor to blood vessels, secretomotor to sweat glands and motor to the arrector pili muscles within their dermatomes.
- Those that accompany the motor nerves to voluntary muscles are probably only dilatory.
- Most, if not all, peripheral nerves contain postganglionic sympathetic fibres. Those reaching the viscera are concerned with general vasoconstriction, bronchial and bronchiolar dilation, modification of glandular secretion, pupillary dilation, inhibition of gastrointestinal muscle contraction, etc.

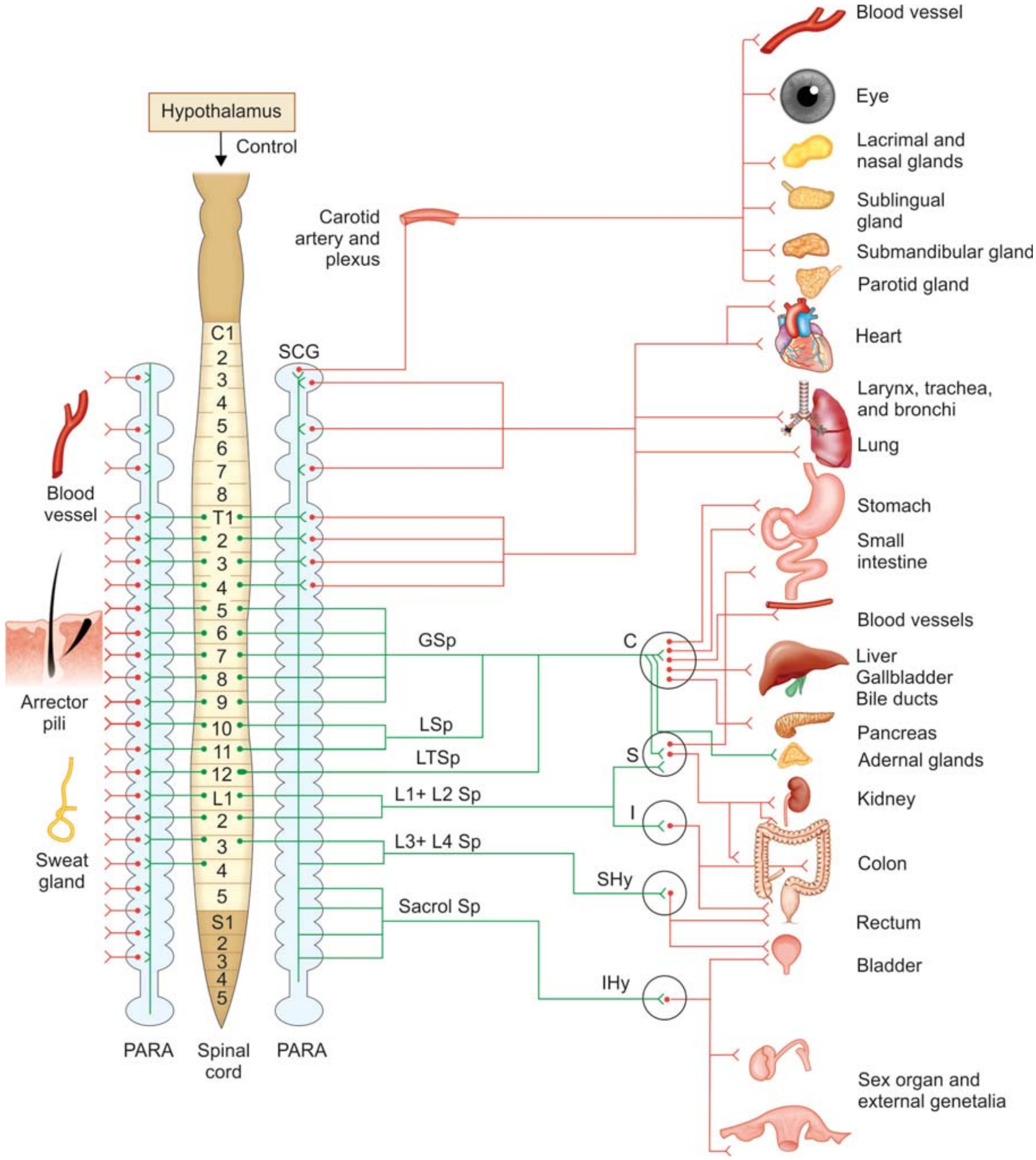


Fig. 109: Diagram of the visceromotor component of the sympathetic nervous system. Preganglionic sympathetic neurons (solid line; green), postganglionic sympathetic neurons (solid line; red). PARA, paravertebral chain ganglia; C, celiac ganglion; S, superior mesenteric ganglion; I, inferior mesenteric ganglion; SHy, superior hypogastric plexus; IHy, inferior hypogastric plexus; GSp, greater thoracic splanchnic nerve; LSp, lesser thoracic splanchnic nerve; LTSp, least thoracic splanchnic nerve; Sp, splanchnic nerve

- Sympathetic fibres have a typical relation with the spinal nerves. The preganglionic sympathetic fibres may relay in their corresponding (or higher and lower) ganglion and pass to their corresponding spinal nerve for distribution or pass without synapse to a peripheral (prevertebral) ganglion for relay.
- **White Rami Communicantes** contain preganglionic sympathetic GVE (myelinated) fibers with cell bodies located in the lateral horn (intermediolateral cell column) of the spinal cord and GVA fibers with cell bodies located in the dorsal root ganglia. They are connected to the spinal nerves, limited to the spinal cord segments between T1 and L2.
- **Gray Rami Communicantes** contain postganglionic sympathetic GVE (unmyelinated) fibers that supply the blood vessels, sweat glands, and arrector pili muscles of hair follicles. They are connected to every spinal nerve and contain fibers with cell bodies located in the sympathetic trunk.
- **Thoracic Splanchnic Nerves** contain sympathetic preganglionic GVE fibers with cell bodies located in the lateral horn (intermediolateral cell column) of the spinal cord and GVA fibers with cell bodies located in the dorsal root ganglia. They include: **Greater** Splanchnic Nerve, **Lesser** Splanchnic Nerve and **Least** Splanchnic Nerves.

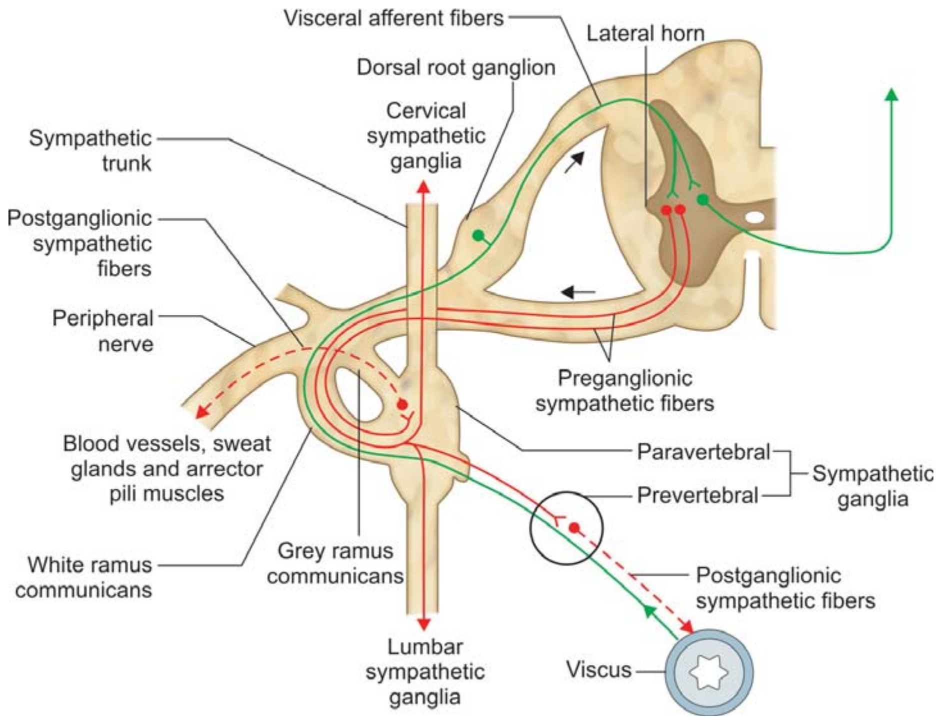


Fig. 110: Sympathetic nervous system showing efferent and afferent fibres. The preganglionic fibres are shown by solid red lines and postganglionic fibres by interrupted red lines. The afferent fibres are shown by green lines

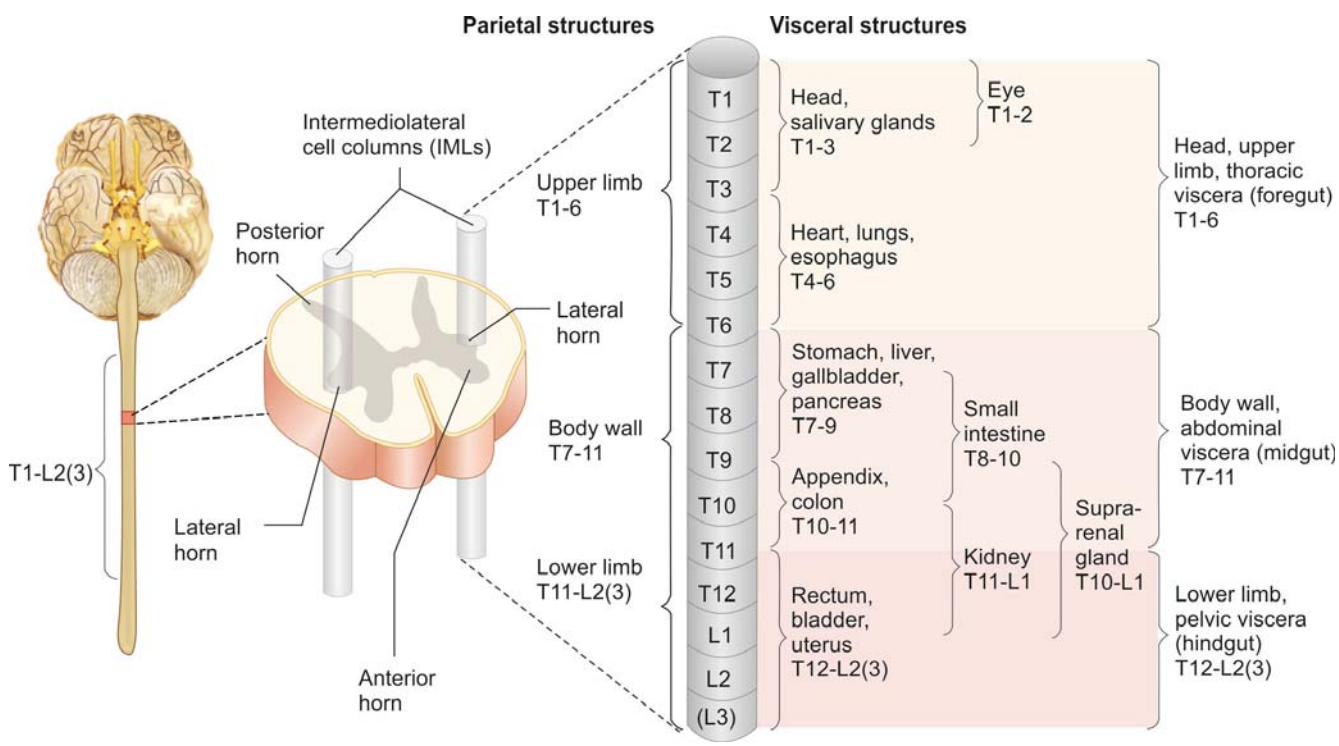


Fig. 111: Sympathetic nervous system, showing distribution of various root values to the viscera

- Oculosympathetic pathway: Hypothalamus (first order neuron) send fibers which project to the ipsilateral ciliospinal center of the intermediolateral cell column at T1 (second order neurons).
  - The ciliospinal center projects preganglionic sympathetic fibers to the superior cervical ganglion (third order neuron).
  - The superior cervical ganglion projects perivascular postganglionic sympathetic fibers through the tympanic cavity, cavernous sinus, and superior orbital fissure to the dilator pupillae and superior tarsal muscle (part of Muller muscle).
  - Interruption of this pathway at any level results in **Horner syndrome**.

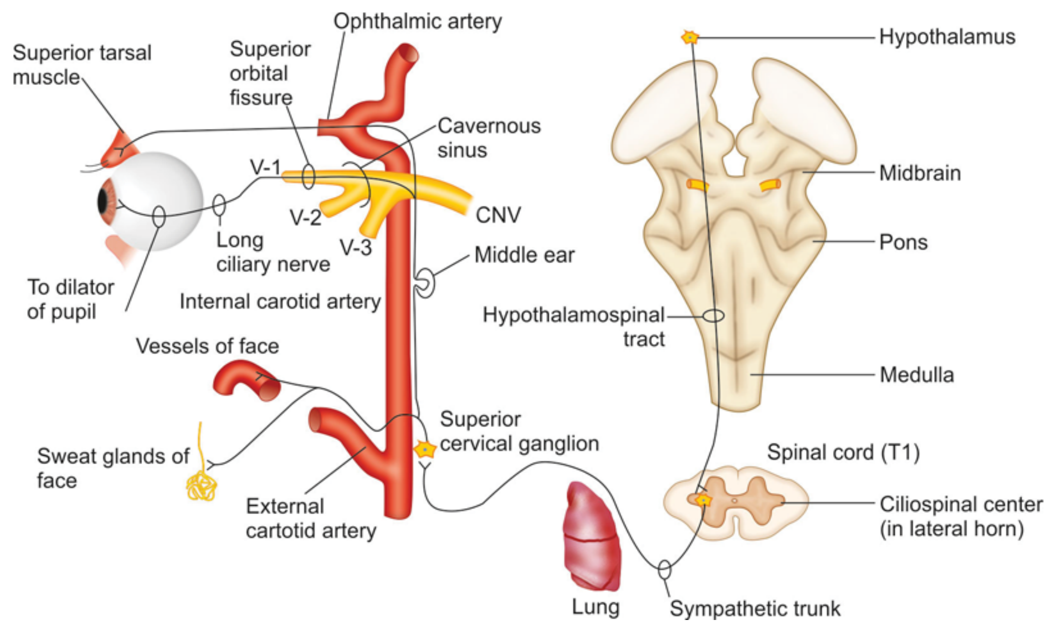


Fig. 112: Sympathetic pathway for controlling smooth muscles of eyeball, namely superior tarsal muscle and dilator pupillae muscle. It is three order neurone pathway and injury at any level leads to features of Horner syndrome

Clinical Correlations

Horner syndrome

Etiology

- **First order** neuron injury, e.g. Wallenberg syndrome. The hypothalamospinal pathway is lesioned in the lateral medullary ischemia.
- **Second order** neuron, e.g. Pancoast tumour (apical lung cancer like bronchial carcinomas) that invades the sympathetic trunk and is also a recognized complication of cervical sympathectomy or a radical neck dissection.
- **Third order** neuron, e.g. Carotid artery dissection

Clinical Features

- **Partial ptosis** (drooping eyelid) due to paralysis of *superior tarsal muscle* (part of Muller muscle) and unopposed (**over-activity) of orbicularis muscle**. Upside-down ptosis (slight elevation of the lower lid).
- **Enophthalmos** (sunken globe) due to paralysis of orbitalis muscle. Enophthalmos may be absent or patient may present with apparent enophthalmos (the impression that the eye is sunken, caused by a narrow palpebral aperture)
- **Miosis** (paralysed contracted pupil) occurs as the *dilator pupillae* is paralysed and sphincter pupillae is **unopposed**. If dilator pupillae is partly functional a pupillary dilatation lag is observed and pupil's light reflex may be elicited.
- **Vasodilation** occurs, since T-1 sympathetic vasoconstrictive fibres are lesioned—hyperemia and flushing on face, bloodshot conjunctiva and nasal congestion.
- **Anhydrosis** (lack of thermal sweating)
- **Loss of ciliospinal reflex** (The ciliospinal reflex is a pupillary-skin reflex, which consists of dilation of the ipsilateral pupil in response to pain applied to the neck, face, and upper limb).

Congenital Horner syndrome: Difficult labour and hyper-abduction injury during birth may lead to avulsion of the first thoracic nerve from the spinal cord (**Klumpke's palsy**) presenting with heterochromia and unilateral straight hair.

Heterochromia iris is a difference in colour between the two eyes that results from interference with melanocyte pigmentation of the iris by a lack of sympathetic stimulation during development.

- The affected iris colour may remain blue while the other iris changes to brown.
- The colour of iris at birth is deep blue and changes to green and brown eventually (decided by the sun exposure in various races).
- Iris pigmentation is under sympathetic control during development, which is completed by age 2 years.
- Heterochromia is uncommon in patients with Horner syndrome acquired later in life.

Fig. 113: Right sided Horner syndrome showing partial ptosis (paralysed superior tarsal muscle), miosis (paralysed dilator pupillae) and enophthalmos (paralysed orbitalis muscle). Also note blue green colur of right iris as compared to left normal brown iris (heterochromia iridis)

ASSESSMENT QUESTIONS

1. **All of the following statements about the vagus nerve are true EXCEPT that it:** *(AIIMS 2005)*
   a. Supplies heart and lung
   b. Carries postganglionic parasympathetic fibers
   c. Innervates right two third of transverse colon
   d. Stimulates peristalsis and relaxes sphincters
2. **General visceral fibres do NOT supply:** *(NEET Pattern 2013)*
   a. Smooth muscles
   b. Skeletal muscles
   c. Cardiac muscles
   d. Glands
3. **Intraocular muscle supplied by Edinger Westphal nucleus is:** *(NEET Pattern 2014)*
   a. Superior oblique
   b. Ciliary muscle
   c. Lateral rectus
   d. Medial rectus
4. **All of the following nuclei belong to GVE (General Visceral Efferent) EXCEPT:**
   a. Edinger Westphal nucleus
   b. Lacrimatory nucleus
   c. Dorsal nucleus of vagus
   d. Abducent
5. **Sweating is mediated by:**
   a. Adrenal hormones
   b. Sympathetic adrenergic system
   c. Sympathetic cholinergic system
   d. Parasympathetic cholinergic system
6. **Synaptic transmission in autonomic ganglia is due to:**
   a. Nicotinic
   b. Cholinergic
   c. Muscarinic
   d. Dopaminergic
7. **Preganglionic parasympathetic neurons are located in:**
   a. Cervical and sacral spinal cord
   b. Thoracic and lower lumbar spinal cord
   c. Brainstem and sacral spinal cord
   d. Thoracic spinal cord
8. **Dilator pupillae is supplied by:**
   a. Oculomotor nerve
   b. Sympathetic fibers from the fronto-orbital branch of trigeminal nerve
   c. Postganglionic sympathetic fibers from cervical sympathetic chain
   d. Postganglionic parasympathetic fibers
9. **Superior salivatory nucleus controls all of the following glands EXCEPT:**
   a. Lacrimal
   b. Palatine
   c. Sublingual salivary gland
   d. Parotid salivary gland
10. **A 19-year-old woman met with a car accident and sustained crushed internal injury in the abdomen. The fibers in the vagus nerve are lesioned, which interferes with the functions of, which of the following structure?**
    a. Urinary bladder
    b. Splenic flexure of colon
    c. Kidney
    d. Uterus
11. **All are seen in Horner's syndrome EXCEPT:** *(AIIMS 2008)*
    a. Heterochromia iridis b. Ptosis
    c. Miosis d. Apparent exophthalmos
12. **Which of the following is NOT a sign of stellate ganglion block?** *(AIPG 2006)*
    a. Meiosis b. Exophthalmos
    c. Nasal congestion d. Conjunctival redness
13. **Features of stellate ganglion lesions include:** *(PGIC 2014)*
    a. Miosis
    b. Vasodilation in ipsilateral arm
    c. Mydriasis in contralateral eye
    d. Mydriasis in ipsilateral eye
    e. Visual loss
14. **Nerve carrying parasympathetic fibres are:** *(AIIMS 2016)*
    a. Cranial nerves 3, 5, 7, 10 and S1-5
    b. Cranial nerves 3, 7, 9, 10 and S1-5
    c. Cranial nerves 5, 7, 9, 10 and S2-4
    d. Cranial nerves 3, 5, 7, 10 and S2-4

ANSWERS WITH EXPLANATIONS

1. **b. Carries postganglionic parasympathetic fibers:**
   - **Vagus nerve carries preganglionic (and not post-ganglionic) fibres from the dorsal nucleus of vagus in the medulla oblongata.**
   - Vagus nerve is the **longest** cranial nerve with **largest distribution** in the body. It supplies head and neck region, thorax, abdomen and some pelvic viscera as well.
   - It causes bradycardia (heart) and bronchoconstriction (lung).
   - It supplies **till the right 2/3 of transverse colon** (mid-gut). Splenic flexure is innervated by nervi erigentes.
   - Vagus nerve is a parasympathetic nerve, which **increases peristalsis** and **relaxes the sphincters** for viscus evacuation.
2. **b. Skeletal muscles**
   - General visceral efferent (GVE) includes the fibres under autonomic nervous system, which control three effectors: **Cardiac** muscle, **smooth** muscles and **glands**.
   - General somatic efferent (GSE) neural column controls skeletal muscles.
3. **b. Ciliary muscle**
   - Edinger Westphal nucleus sends the preganglionic parasympathetic fibres through occulomotor nerve to ciliary ganglion, which further supply two smooth muscles of the eyeball: ciliaris and sphincter pupillae.

4. d. Abducent
- General visceral efferent (GVE) includes the fibres under autonomic nervous system, which control three effectors: Cardiac muscle, smooth muscles and glands.
- Abducent nucleus is under general somatic efferent (GSE) neural column, which controls skeletal muscles, like lateral rectus.

5. c. Sympathetic cholinergic system > b. Sympathetic adrenergic system
- Sweat glands are two types: Eccrine and apocrine.
- Eccrine sweat glands are more common in occurrence and are supplied by sympathetic cholinergic fibres.
- Apocrine sweat glands (less common in occurrence) are supplied by adrenergic sympathetic fibres.

6. b. Cholinergic
- Synaptic transmission in autonomic ganglia (sympathetic and para-sympathetic) is chiefly mediated by acetylcholine (cholinergic pathway).

7. c. Brainstem and sacral spinal cord
- Preganglionic fibres arise from CNS and parasympathetic fibres from brainstem and sacral spinal cord (craniosacral flow).
- Sympathetic fibres arise from the intermediolateral horns of spinal cord segment T-1 to L2/3 (thoracolumbar flow).

8. c. Postganglionic sympathetic fibers from cervical sympathetic chain
- Dilator pupillae is supplied by sympathetic fibres, which arise from the inter-medio-lateral horn of spinal cord segment T-1.
- These pre-ganglionic T-1 sympathetic fibres climb up the cervical sympathetic chain and synapse in the superior (highest) cervical ganglion.
- Post ganglionic fibres make sympathetic plexus around the internal carotid artery and reach the dilator pupillae muscle.

9. d. Parotid salivary gland
- Inferior salivatory nucleus located at the lower pons supply parotid salivary gland.

10. c. Kidney
- Vagus nerve supplies till the kidney level. Pelvic viscera like urinary bladder, uterus are supplied by nervi erigentes.
- Splenic flexure of colon belongs to hind gut, supplied by nervi erigentes.

11. d. Apparent exophthalmos
- Horner syndrome presents with enophthalmos (and not exophthalmos).
- This is due to paralysis of **ciliaris** muscle which normally protrude the eyeball out of the socket. It's paralysis leads to eyeball staying back in the orbit, giving the appearance of **sunken eyeball** (enophthalmos).
- **Heterochromia iridis** may be present if the lesion occurred in a child younger than 2 years (congenital Horner syndrome).

12. b. Exophthalmos
- Stellate ganglion block produces enophthalmos (not exophthalmos), due to the paralysis of ciliaris muscle (supplied by T1 sympathetic fibres).
- Stellate ganglion has the sympathetic fibres and with root value T-1 and it supplies the head and neck region like skin over the face, muscles of the iris-dilator pupillae etc.
- Stellate ganglion block produces the symptomology of Horner's syndrome i.e., loss of papillary dilatation –meiosis; loss of sympathetic vasoconstrictive tone resulting in dilated vessels-conjunctival redness. Loss of vasoconstrictive tone leads to dilatation of blood vessels in the nose region also and thus increasing nasal secretions – nasal congestion.

13. a. Miosis
- Stellate ganglion block leads to paralysis of dilator pupillae muscle resulting in miosis, due to unopposed action of sphincter pupillae.

14. b. Cranial nerves 3, 7, 9, 10 and S1-5
- There appears to be a misprint in the given options.
- The most appropriate option has been taken as the answer.
- Parasympathetic flow is cranio-sacral flow carried by cranial nerves: 3, 7, 9, 10 and the sacral nerves: S-2, 3, 4. These nerves carry the preganglionic fibres to their respective ganglia.

Visceral Afferent Pathways

Visceral afferent (GVA) pathways in many ways resemble somatic afferent (GSA) pathways.

- The peripheral processes of **visceral afferents** run through autonomic ganglia or plexuses, and also through somatic nerves.
- Their central processes accompany somatic afferent fibres through cranial nerves or dorsal spinal roots into the CNS, where they establish connections that mediate autonomic reflexes and visceral sensation.
- General visceral afferent (GVA) fibres from the viscera and blood vessels accompany their efferent counterparts, and are the peripheral processes of unipolar cell bodies located in some **cranial nerve ganglia** and **dorsal root ganglia**.
- They are contained in the **vagus**, **glossopharyngeal** and few other cranial nerves; the second to fourth sacral spinal nerves, distributed with the nervi erigentes (pelvic splanchnic nerves); and thoracic and upper lumbar spinal nerves, distributed through rami communicantes and alongside the efferent sympathetic innervation of viscera and blood vessels.
- The cell bodies of vagal general visceral afferent (GVA) fibres are in the superior and inferior **vagal ganglia**. Their peripheral processes are distributed to terminals in the **pharyngeal** and **oesophageal** walls where, acting synergistically with **glossopharyngeal** visceral afferents in the pharynx, they are concerned with **swallowing reflexes**.
- **Heart**: The vagal afferents innervate the walls of the great vessels, the aortic bodies and pressor receptors, where they are stimulated by raised intravascular pressure.
- **Lungs:** The vagal fibres are distributed via the pulmonary plexuses. They supply bronchial mucosa (involved in cough reflexes) and pulmonary vessels (chemoreceptors).
- Vagal visceral afferent fibres also end in the gastric and intestinal walls, digestive glands and the kidneys.

  - Fibres ending in the gut and its ducts respond to stretch or contraction. Gastric impulses may evoke sensations of hunger and nausea.
- The cell bodies of glossopharyngeal general visceral afferents are in the glossopharyngeal ganglia.
  - Their peripheral processes innervate the posterior lingual region, the palatine tonsils and pharynx, but they do not innervate taste buds.
  - They also innervate the carotid sinus and the carotid body, which contain receptors which detect tension and changes in chemical composition of the blood.
  - Impulses from these receptors are essential to circulatory and respiratory reflexes.
- Visceral afferents that enter the spinal cord through spinal nerve roots terminate in the spinal grey matter.
- The central processes of vagal and glossopharyngeal afferent (GVA) fibres end in the lower part of **nucleus tractus solitarius** of the medulla oblongata.
- About 5% of the vagal afferents project directly to, and terminate in, the upper cervical spinal cord (C1–2), where they are believed to contribute to referred sensations, as well as to propriospinal mechanisms of nociceptive modulation.
- Visceral afferents establish connections within the CNS that mediate autonomic reflexes. In addition, afferent impulses probably mediate visceral sensations such as hunger, nausea, sexual excitement, vesical distension, etc.

Pain Pathways

- Visceral pain fibres may follow these routes. Although viscera are **insensitive** to cutting, crushing or burning, excessive **tension** in smooth muscle and some pathological conditions like accumulation of metabolites due to **ischaemia** produce visceral pain.
- In general, afferent fibres that accompany pre- and postganglionic sympathetic fibres have a segmental arrangement and end in spinal cord segments from which preganglionic fibres innervate the region or viscus concerned.
- In visceral disease, **vague dull pain** may be felt near the viscus itself (visceral pain) or in a cutaneous area or other tissue whose somatic afferents enter spinal segments receiving afferents from the viscus, a phenomenon known as **referred pain**. Referred pain is often associated with local cutaneous tenderness.
- If inflammation spreads from a diseased viscus to the adjacent parietal serosa (e.g. the peritoneum), somatic afferents will be stimulated, causing local **somatic pain**, which is commonly spasmodic.
- Nociceptive impulses from the pharynx, oesophagus, stomach, intestines, kidneys, ureter, gallbladder and bile ducts seem to be carried in sympathetic pathways.
- **Cardiac** nociceptive impulses enter the spinal cord in the first to fifth thoracic spinal nerves, mainly via the **middle and inferior cardiac nerves**, but some fibres pass directly to the spinal nerves.
  - Peripherally, the fibres pass through the cardiac plexuses and along the coronary arteries.
  - Myocardial ischaemia produce symptoms of angina pectoris in which pain is typically presternal, and is also referred to much of the left chest, and radiates to the left shoulder, the medial aspect of the left arm, along the left side of the neck to the jaw and occiput, and down to the epigastrium.
  - Cardiac afferents carried in vagal cardiac branches are concerned with the reflex depression of cardiac activity.
- General visceral afferents (GVA) entering thoracic and upper lumbar spinal segments (T10 - 12; L1-2) are **largely concerned with pain**.
- **Urinary bladder and proximal urethra** pain fibres traverse both the **pelvic splanchnic nerves** and the **inferior hypogastric plexu**s, hypogastric nerves, **superior hypogastric plexus** and lumbar splanchnic nerves to reach their cell bodies in ganglia on the lower thoracic and upper lumbar dorsal spinal roots (**T10 - 12; L1-2**).
  - Lesions of the cauda equina abolish pain from vesical overdistension, but hypogastric section is ineffective.
- **Uterus** pain is carried by the hypogastric plexus and **lumbar splanchnic nerves** to reach neuron bodies in the lowest thoracic and upper lumbar spinal ganglia (**T10 - 12; L1-2**).
  - Hypogastric division may relieve dysmenorrhoea.
- **Uterine cervix** pain fibres are carried by the nervi erigentes (**pelvic splanchnic nerves**) to reach their neuron bodies in the upper sacral (S2-4) spinal ganglia; stretching the cervix uteri causes pain but cauterization and biopsy excisions do not.
- **Ureteric pain** fibres, also running with sympathetic fibres, are presumably involved in the agonizing renal colic that follows obstruction by calculi.
- **Gonadal** (testis and ovary) pain fibres run through the corresponding plexuses to neurone bodies in the tenth and eleventh thoracic dorsal root ganglia.
- Afferent fibres in **pelvic splanchnic nerves** innervate pelvic viscera and the distal part of the colon.
- Some primary afferent neurons, innervating the gut, lungs, heart and blood vessels, also appear to have an efferent function in that they release transmitters from their peripheral endings during the axon reflex.
  - The primary substances released in this way are **substance P**, **calcitonin gene-related peptide** (CGRP) and **ATP**.
  - These act on target cells to produce vasodilation, increased venular permeability, changes in smooth muscle contractility, degranulation of mast cells and a variety of effects on leukocytes and fibroblasts, a process collectively known as **'peripheral neurogenic inflammation**'.
  - It has a **trophic role** in the maintenance of tissue integrity and repair in response to injury.

Enteric Nervous System

- Several peripheral **autonomic ganglia** contain neurons **derived from the neural crest** during embryonic development that are anatomically distinct from classical sympathetic and parasympathetic neurons.
- Enteric nervous system consists of neurons and enteric glial cells grouped into ganglionated plexuses lying in the wall of the gastrointestinal tract to form **myenteric** and **submucous** plexuses that extend from the oesophagus to the anal sphincter.
- This intrinsic circuitry mediates numerous **reflex functions** including the **contractions** of the muscular coats of the gastrointestinal tract, **secretion** of gastric acid, intestinal transport of water and electrolytes, and the **regulation** of mucosal blood flow.
- Although complex interactions occur between the enteric and sympathetic and parasympathetic nervous systems, the enteric nervous system is capable of sustaining local reflex activity independent of the CNS and keeps working despite denervation of sympathetic and parasympathetic fibres.
- **Peristalsis** wave in ureter is generated in smooth muscle cells of the minor calyces (**pacemaker**). The sympathetic and parasympathetic nerves are not essential for the initiation and propagation of ureteric contraction waves, they are just **modulatory** in function.

Arterial Supply

Brain is supplied by t**wo arterial systems**: Carotid and vertebrobasilar. Major arteries supplying the brain are given in Table.

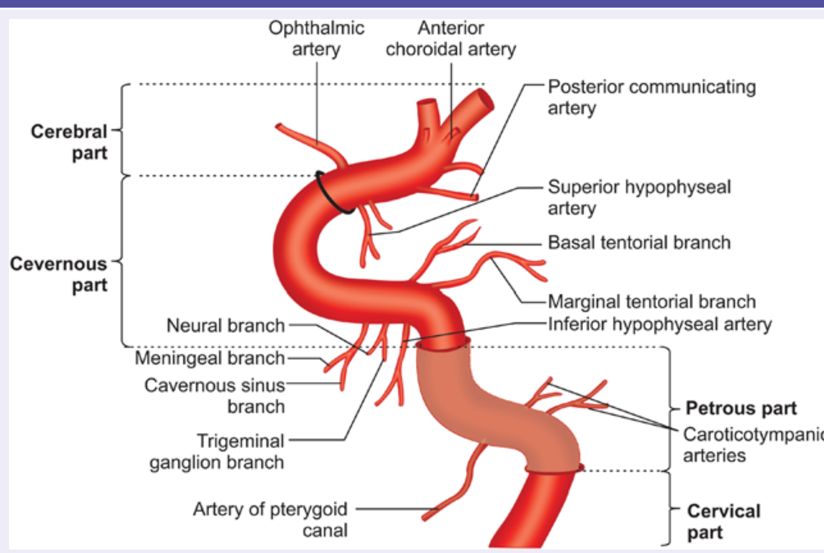
Table 22: Arterial blood supply of cerebral hemispheres

Artery	Origin	Distribution
Internal carotid:	Common carotid artery at superior border of thyroid cartilage	Gives branches to walls of cavernous sinus, pituitary gland, and trigeminal ganglion; provides primary supply to brain
Anterior cerebral	Internal carotid artery	Cerebral hemispheres, except for occipital lobes
Anterior communicating	Anterior cerebral artery	Cerebral arterial circle (of Willis)
Middle cerebral	Continuation of internal carotid artery distal to anterior cerebral artery	Most of lateral surface of cerebral hemispheres
Vertebral:	Subclavian artery	Cranial meninges and cerebellum
Basilar	Formed by union of vertebral arteries	Brainstem, cerebellum, and cerebrum
Posterior cerebral	Terminal branch of basilar artery	Inferior aspect of cerebral hemisphere and occipital lobe
Posterior communicating	Posterior cerebral artery	Optic tract, cerebral peduncle, internal capsule, and thalamus

Internal Carotid Artery is a branch of common carotid artery and enters the **carotid canal** in the petrous part of the temporal bone.

- It is separated from the tympanic cavity by a thin bony structure, lies within the cavernous sinus and gives branches to the pituitary (hypophysis) and trigeminal (semilunar) ganglion.
- Next it pierces the dural roof of the cavernous sinus between the anterior clinoid process and the middle clinoid process, which is a small projection posterolateral to the tuberculum sellae.
- The artery forms a carotid siphon (a bent tube with two arms of unequal length), which is the petrosal part just before it enters the cranial cavity.
- The four parts of internal carotid artery in its course and their branches are shown in the following table and Fig.

Part	Branches
Cervical	No branches
Petrous	Caroticotympanic Pterygoid
Cavernous	Cavernous Superior and inferior hypophyseal
Cerebral	Anterior cerebral Middle cerebral Ophthalmic Anterior choroidal Posterior communicating Mnemonic: AM-OCP



Five branches given in the cerebral part (AM-OCP): **Anterior Cerebral, Middle Cerebral, Ophthalmic, Choroidal and Posterior Communicating arteries.**

- **Anterior Cerebral Artery** enters the longitudinal fissure of the cerebrum, supplies the optic chiasma and medial surface of the frontal and parietal lobes of the brain.
  - It is the major artery on the medial surface of cerebrum.
  - It supplies the lower body representation on the brain homunculus.
  - An occlusion/haemorrhage in the artery presents with sensory motor disturbances in lower limb and pelvis perineum area.
- **Middle Cerebral Artery** passes laterally in the lateral cerebral fissure and supplies the lateral convexity of the cerebral hemisphere.
  - It is the major artery on the supero-lateral surface of cerebrum.
  - It supplies the upper body representation on the brain homunculus.
- **Ophthalmic Artery** enters the orbit via the optic canal with the optic nerve and supplies the eyeball and structures in the orbit and forehead.
  - Its occlusion results in monocular blindness.
- **Posterior Communicating Artery** arises from the carotid siphon and joins the posterior cerebral artery.
  - It connects the anterior circulation of the circle of Willis with the posterior circulation.
  - It runs backward below the optic tract and supplies the optic chiasma and tract and hypothalamus.
  - It is the second most common site of an aneurysm, which, if ruptured, will result in a subarachnoid hemorrhage and oculomotor nerve (CN III) paralysis.
- **Anterior Choroidal Artery** supplies the choroid plexus of the lateral ventricles, optic tract and radiations, lateral geniculate body and the posterior limb of internal capsule.
- **Circle of Willis** lies at the base of the brain, in the **interpeduncular fossa** (in sub-arachnoid space).
- It serves as a channel of collateral circulation in the events of arterial occlusions and is formed by the nine arteries:
  - Anteriorly: Anterior communicating artery
  - Anterolaterally: Paired anterior cerebral artery
  - Laterally: Proximal segments of both internal carotid arteries
  - Postero-laterally: Paired posterior communicating arteries
  - Posteriorly: Proximal segments of both posterior cerebral arteries

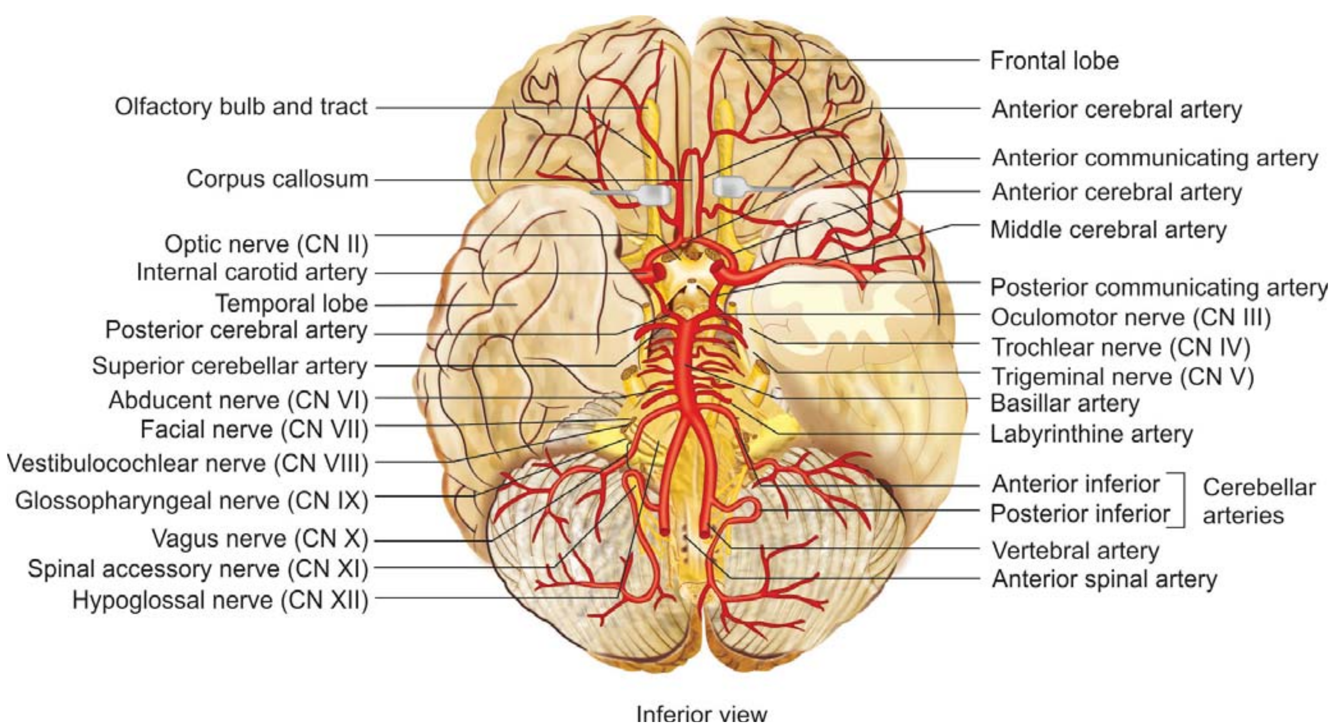


Fig. 114: Base (inferior view) of brain showing the contributing arteries and branches of circle of Willis

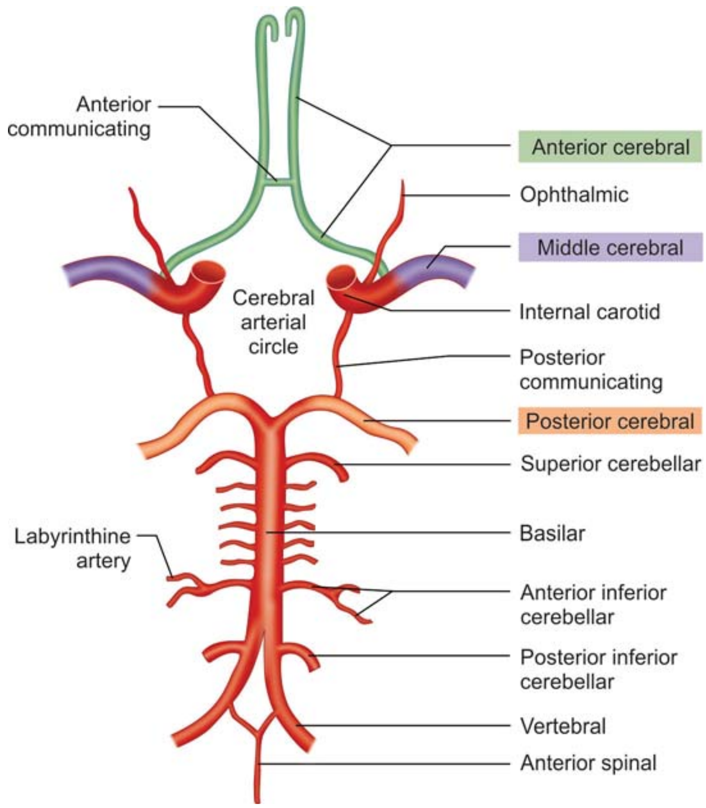
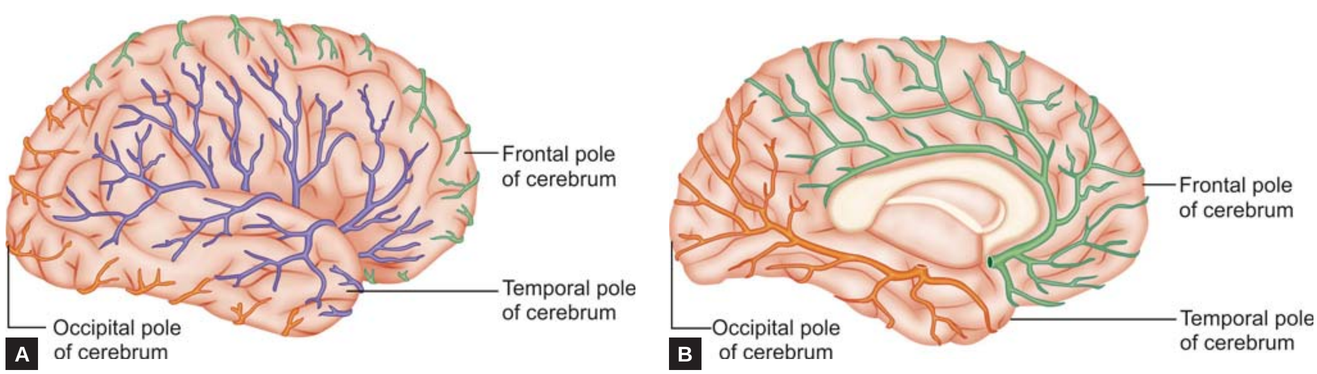


Fig. 115: Circle of Willis: Contributing arteries and branches

Cerebral hemispheres are supplied by three cerebral arteries : anterior cerebral artery is a chief artery on medial surface, middle cerebral artery on superolateral surface and posterior cerebral artery on the inferior surface.



Figs. 116A and B: (A) Right lateral view of right hemisphere, (B) medial view of left hemisphere. (Blue: Middle cerebral artery; Green: Anterior cerebral artery; Orange: Posterior cerebral artery)

Vertebral Artery arise from the first part of the subclavian artery and ascend through the foramen transversium of upper six cervical vertebra (C1 to C6).

- Next it curve posteriorly winds around the superior articular process of the atlas, pierce the dura mater into the vertebral canal, and then enter the cranial cavity through the foramen magnum.
- The two vertebral arteries join to form the basilar artery.
- Branches:
  - **Anterior Spinal Artery** arises as two roots from the vertebral arteries shortly before the junction of the vertebral arteries. It descends in front of the medulla, and the two roots unite to form a single median trunk at the level of the foramen magnum. It supplies medial medulla and anterior 2/3 of spinal cord.
  - **Posterior Spinal Artery** is a branch given by vertebral artery (or the posterior inferior cerebellar artery), descends on the side of the medulla, and the right and left roots unite at the lower cervical region. It supplies posterior 1/3 of spinal cord.
  - **Posterior Inferior Cerebellar Artery (PICA)** is the largest branch of the vertebral artery, supplies the lateral medulla and distributes to the posterior–inferior surface of the cerebellum, and gives rise to the posterior spinal artery.

Basilar Artery is formed by the union of the two vertebral arteries at the lower border of the pons.

- It terminates near the upper border of the pons by dividing into the right and left posterior cerebral arteries. Branches:
  - **Pontine Arteries** are multiple in number and supply the pons.
  - **Labyrinthine Artery** is an occasional branch, enters the internal auditory meatus and supplies the cochlea and vestibular apparatus.
  - **Anterior Inferior Cerebellar Artery (AICA)** supplies the anterior part of the inferior surface of the cerebellum. It gives the labyrinthine artery in 85% of the population.
  - **Superior Cerebellar Artery** passes laterally just behind the oculomotor nerve and supplies the superior surface of the cerebellum.
  - Basilar artery bifurcates into two **posterior Cerebral Arteries** which pass laterally in front of the oculomotor nerve, wind around the cerebral peduncle, and supplies the midbrain, thalamus and the temporal and occipital lobes of the cerebrum, with visual cortex.

Brief overview of arterial supply to various parts of brain:

- Cerebrum
  - Cerebral hemispheres are supplied by three cerebral arteries : anterior cerebral artery is a chief artery on medial surface, middle cerebral artery on superolateral surface and posterior cerebral artery on the inferior surface.
- Basal ganglia
  - The components are supplied by the striate (medial and lateral) arteries, which are branches from the roots of the anterior and middle cerebral arteries.
  - The posteroinferior part of the lentiform complex is supplied by the thalamostriate branches of the posterior cerebral artery.
  - Additional contributions are from anterior choroidal artery (branch of internal carotid artery).
- Thalamus
  - Branches of the posterior communicating, posterior cerebral and basilar arteries.
  - Some authors mention anterior choroidal artery as well.
- Medulla oblongata
  - Branches of the vertebral, anterior and posterior spinal, posterior inferior cerebellar and basilar arteries.
- Pons
  - Branches of basilar artery and the anterior inferior and superior cerebellar arteries.
- Mid brain
  - Branches of posterior cerebral, superior cerebellar and basilar arteries
- Cerebellum
  - Branches of posterior inferior, anterior inferior and superior cerebellar arteries.
- Choroid plexus
  - In third and lateral ventricles is supplied by branches of the internal carotid and posterior cerebral arteries
  - In fourth ventricle is supplied by the posterior inferior cerebellar arteries

Clinical Correlations

- Berry aneurysms are balloon (sac) like dilatations in the vessel wall and are common in the circle of Willis (at the base of the brain). These might rupture sometime and lead to subarachnoid haemorrhage.
- The most common sites for aneurysms include the anterior cerebral artery and anterior communicating artery (30–35%), the bifurcation, division of two branches, of the internal carotid and posterior communicating artery (20–25%), the bifurcation of the middle cerebral artery (20%), the bifurcation of the basilar artery, and the remaining posterior circulation arteries.
  - **Anterior communicating artery** is a short vessel connecting the two anterior cerebral arteries.
  - It is the most common site of an aneurysm (e.g., congenital berry aneurysm), which, if ruptured, will result in a subarachnoid hemorrhage and bitemporal lower quadrantanopia due to compression of optic chiasma.
  - **Posterior communicating artery** is the second most common site of an aneurysm (e.g., congenital berry aneurysm), which, if ruptured, will result in a subarachnoid hemorrhage and possibly oculomotor nerve (down and out eye with, fixed dilated pupil and ptosis).
- Aneurysms on the posterior communicating artery, superior cerebellar artery, or the tip of the basilar artery, can cause oculomotor nerve palsy by compression. Aneurysms on the internal carotid artery near its termination may compress the lateral aspect of the optic chiasma, and compromise axons derived from the temporal side of the ipsilateral retina, which causes a defect in the nasal visual field.

Cause	Abducens nerve (%) (n = 1918)	Trochlear nerve (%) (n = 578)	Oculomotor nerve (%) (n = 1130)
Undetermined	26	32	23
Neoplasm	22	5	12
Head trauma	15	29	14
Aneurysm	3	1	16
Vascular	13	18	20
Other	21	15	15

- **Posterior cerebral artery** occlusion results in contralateral sensory loss of all modalities with concomitant severe pain (i.e., thalamic syndrome) due to damage to the thalamus and contralateral homonymous hemianopia with macular sparing.
- **Middle cerebral artery** occlusion of leads to the following Signs and symptoms:

- Contralateral paralysis and contralateral anesthesia of the face, neck, trunk and arm region along with and sensory impairment over the same area.
- Homonymous hemianopia and aphasia if the dominant hemisphere is involved.

Lenticulostriate arteries (branches of middle cerebral artery) supply the basal ganglia and the internal capsule.

- Occlusion results in contralateral hemiplegia due to destruction of descending motor fibers in the posterior limb of the internal capsule
- Contralateral hemi-anesthesia due to lesion of ascending sensory thalamocortical fibers in the internal capsule.

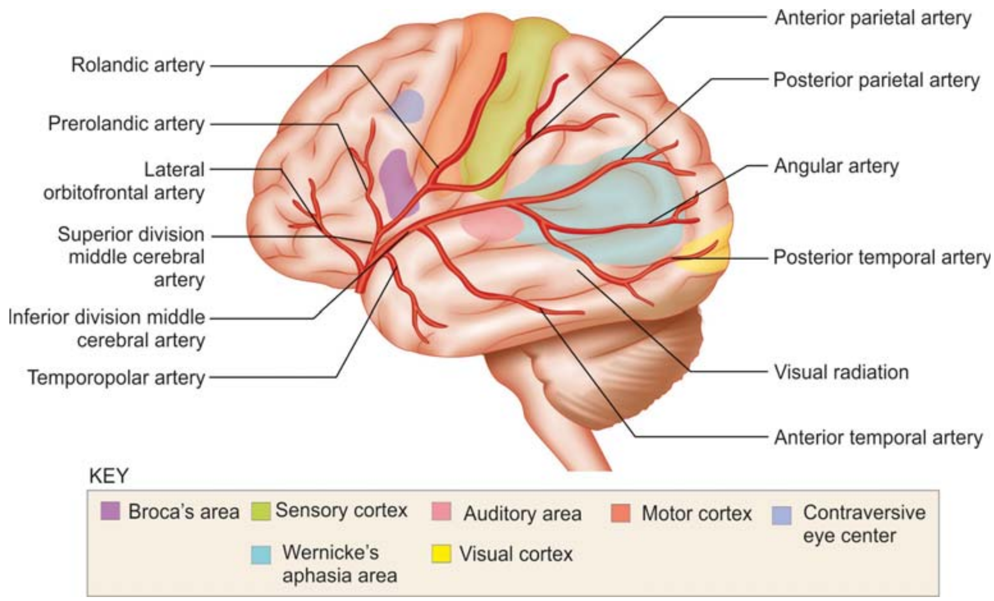


Fig. 117: Lateral view of cerebrum showing branches of middle cerebral artery supplying the various Brodmann areas

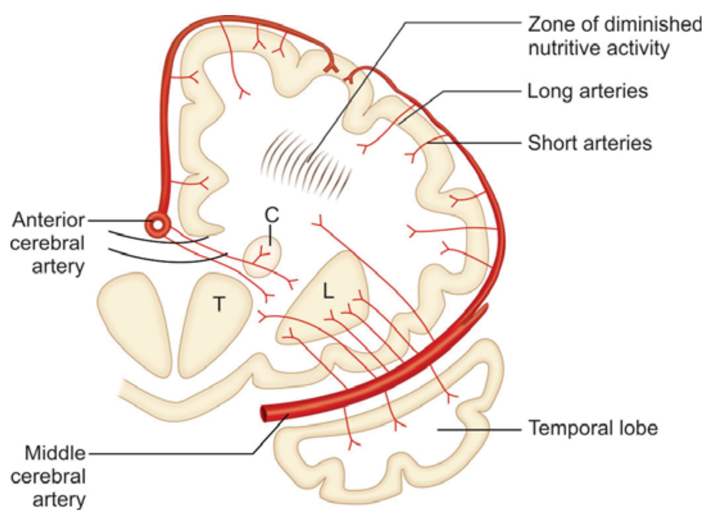


Fig. 118: Coronal section of brain showing arterial supply of the basal ganglia region by middle and anterior cerebral arteries. (T = thalamus, C = caudate nucleus, L = lentiform nucleus

ASSESSMENT QUESTIONS

1. Primary motor area (Area no. 4) of brain is supplied by:
a. Anterior cerebral artery
b. Middle cerebral artery
c. Anterior and middle cerebral artery
d. Anterior and posterior cerebral artery

2. Which of the following is NOT a branch of the cavernous segment of internal carotid artery? *(AIPG 2007; AIIMS 2008)*
a. Inferior hypophyseal artery
b. Branches to cavernous sinus
c. Ophthalmic artery
d. Meningeal artery

3. NOT affected in posterior cerebral artery infarct is:
a. Midbrain
b. Pons
c. Thalamus
d. Striate cortex

4. All of the following arteries supply medulla EXCEPT:
a. Anterior spinal artery
b. Anterior inferior cerebellar artery
c. Superior cerebellar
d. Basilar

5. All of the following arteries supply medulla EXCEPT: *(AIPG 2009)*
a. Post inferior cerebellar
b. Basilar
c. Anterior spinal
d. Bulbar

6. Which is NOT a branch of the vertebral artery:
a. Anterior spinal
b. Posterior spinal
c. Posterior inferior cerebellar artery
d. Anterior inferior cerebellar artery

7. A block in the posterior cerebral artery supplying occipital lobe results in:
a. Ipsilateral homonymous hemianopia
b. Contralateral homonymous hemianopia
c. Ipsilateral homonymous hemianopia with macular sparing
d. Contralateral homonymous hemianopia with macular sparing

8. Most common site of berry aneurysm:
a. Internal carotid bifurcation
b. Anterior cerebral circulation
c. Middle cerebral circulation
d. Anterior choroidal circulation

9. Most commonly lesioned nerve in intracranial aneurysms is: *(AIPG 2007)*
a. Optic
b. Oculomotor
c. Trochlear
d. Abducent

10. Berry aneurysm of the posterior communicating artery causes compression of: *(AIIMS 2008)*
a. Optic nerve
b. Oculomotor nerve
c. Trochlear nerve
d. Hypophysis cerebri

11. All is true about branches of internal carotid artery EXCEPT:
a. Anterior choroidal artery is given in cerebral part
b. Ophthalmic artery is given in cerebral part
c. Posterior communicating artery is given in petrous part
d. Caroticotympanic artery is given in petrous part

12. Posterior communicating artery is a branch of:
a. Internal carotid
b. External carotid
c. Middle cerebral
d. Posterior superior cerebellar

13. In Posterior communicating artery aneurysm, which structure may be compressed: *(AIIMS 2012)*
a. Olfactory
b. Optic
c. Oculomotor
d. Trochlear

14. Vertebral arteries of both sides unite to form: *(NEET Pattern 2015)*
a. Anterior spinal artery
b. Posterior spinal artery
c. Medullary artery
d. Basilar artery

15. Branch of basilar artery include: *(PGIC 2002)*
a. Posterior inferior cerebellar artery
b. Posterior cerebral artery
c. Middle cerebral artery
d. Posterior communicating artery
e. Anterior cerebral artery

16. Posterior cerebral artery supplies all EXCEPT: *(AIIMS 2010)*
a. Pons
b. Midbrain
c. Thalamus
d. Striate cortex

17. Visual area of cortex is supplied by: *(PGIC 2008)*
a. Anterior cerebral artery
b. Middle cerebral artery
c. Posterior cerebral artery
d. Posterior inferior cerebellar artery
e. Posterior choroidal artery

18. Artery/arteries supplying occipital cortex is/are:
a. PCA
b. MCA
c. MCA+ PCA
d. ACA

19. Which of the following does NOT supply medulla oblongata? *(AIIMS 2013)*
a. Anterior spinal artery
b. Posterior spinal artery
c. Posterior inferior cerebellar artery
d. Superior cerebellar artery

20. Major supply of medial surface of cerebral hemisphere: *(NEET Dec. 12 Pattern)*
a. Anterior cerebral artery
b. posterior cerebral artery
c. Middle cerebral artery
d. Posterior inferior cerebellar artery

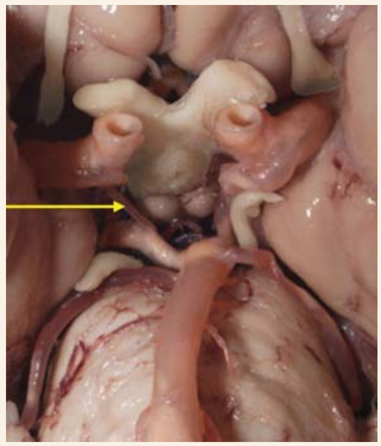
21. Chief artery of lateral surface of cerebral hemisphere: *(NEET Pattern 2013)*
a. Anterior cerebral artery
b. Posterior cerebral artery
c. Middle cerebral artery
d. Posterior inferior cerebellar artery

22. Circle of Willis does not get contribution from:
a. Anterior cerebral artery
b. Middle cerebral artery
c. Posterior communicating artery
d. Posterior cerebral artery

23. Posterior communicating artery connects: *(NEET Pattern 2015)*
a. Two posterior cerebral arteries
b. Posterior cerebral artery with middle cerebral artery
c. Posterior cerebral artery with internal carotid artery
d. Anterior cerebral artery with middle cerebral artery

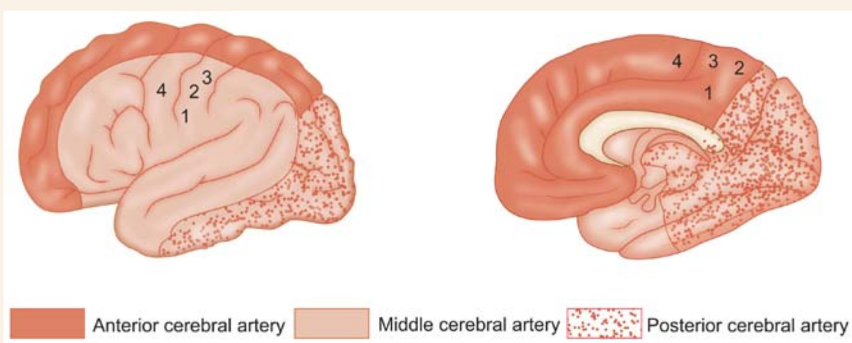
24. Blood supply of putamen includes all EXCEPT: *(NEET Pattern 2015)*
a. Medial striate arteries
b. Lateral striate arteries
c. Anterior choroidal artery
d. Posterior communicating artery

25. Identify the marked artery in the diagram: *(AIIMS 2016)*
a. Anterior communicating artery
b. Posterior communicating artery
c. Superior cerebellar artery
d. Anterior inferior cerebellar artery



ANSWERS WITH EXPLANATIONS

1. c. Anterior and middle cerebral artery
- Greater part of the lateral surface receives supply from middle cerebral artery, whereas medial surface of cerebrum is majorly supplied by anterior cerebral artery.
- The upper limb and head are represented on the lateral surface of the cortex in homunculus, whereas pelvis and lower limb are on the medial surface of the hemispheres.
- Therefore, the motor and sensory functions of the lower limb are supplied by the anterior cerebral artery while the motor and sensory functions of the upper limb and head are supplied by the middle cerebral artery.



2. c. Ophthalmic branch
- Internal carotid artery gives ophthalmic branch in its cerebral part (**not** in cavernous segment).
- Cavernous branches supply the trigeminal ganglion, the walls of cavernous sinus and the nerves contained in it.
- The hypophyseal branches form pituitary portal system and meningeal branch supplies the bone and duramater of anterior cranial fossa.

3. b. Pons
- **Pons** are supplied by basilar artery.
- **Midbrain** is supplied by branches of posterior cerebral artery and basilar artery.
- **Thalamus** is supplied by numerous arteries including posterior cerebral artery and posterior communicating artery.
- **Striate cortex** is supplied by posterior cerebral artery and additionally by middle cerebral artery (macular area on brain).

4. c. Superior cerebellar
- Medulla oblongata is supplied by numerous arteries (but **not** superior cerebellar).
- The arteries supplying medulla are: Vertebral, anterior spinal, posterior spinal, posterior inferior cerebellar, anterior inferior cerebellar, basilar etc.

5. d. Bulbar
- There is no artery by the name of bulbar artery in literature.
- Medulla oblongata is supplied by the branches of vertebral, anterior spinal and posterior spinal, posterior inferior cerebellar and basilar arteries.
- Lesion of vertebral artery or Posterior inferior cerebellar artery leads to Lateral medullary (Wallenberg) syndrome.
- Lesion of anterior spinal artery leads to medial medullary syndrome where pyramidal tract is mainly involved and contralateral spastic paralysis is observed.

6. d. Anterior inferior cerebellar artery
- Anterior inferior cerebellar artery is a branch of basilar artery.
- It gives labyrinthine artery, which passes through internal auditory meatus (along with facial and vestibulo-cochlear nerve) and supply the inner ear.
- Occasionally labyrinthine artery is a direct branch of basilar artery.

7. d. Contralateral homonymous hemianopia with macular sparing
- Posterior cerebral artery supplies occipital visual (striate) cortex, and a block results in loss of visual field on the opposite side - contralateral homonymous hemianopia.
- Left half of each eye is blind in right posterior cerebral artery infarct.
- There is associated macular sparing, since the macular area on brain is additionally supplied by branch of middle cerebral artery.

8. b. Anterior cerebral circulation
- Berry aneurysms are more common at the site where anterior communicating artery is given by anterior cerebral artery (~30%), whereas, the incidence is ~25% at the origin of posterior communicating artery (from internal carotid artery). Bifurcation of middle cerebral artery presents with an incidence of ~20 %.

9. b. Oculomotor
- Intracranial aneurysms may involve oculomotor ,abducent and optic nerve in descending order.
- Trochlear nerve is involvement is highest in head trauma.

Cause	Abducens nerve (%)(n = 1918)	Trochlear nerve (%) (n = 578)	Oculomotor nerve (%) (n = 1130)
Undetermined	26	32	23
Neoplasm	22	5	12
Head trauma	15	29	14
Aneurysm	3	1	16
Vascular	13	18	20
Other	21	15	15

10. b. Oculomotor nerve
- Berry aneurysm in the vicinity of posterior communicating artery can compress the third cranial nerve and cause oculomotor nerve palsy.
- Aneurysms of superior cerebellar artery or tip of the basilar artery can also compress the oculomotor nerve and produce its palsy.
- Berry aneurysm on the internal carotid artery (near its termination) compresses the lateral aspect of optic chiasma and hence damages the visual information from the ipsilateral nasal visual field.

11. c. Posterior communicating artery is given in petrous part:
- Posterior communicating artery is given in cerebral part

12. a. Internal carotid
- Posterior communicating artery is a branch of internal carotid artery and joins the posterior cerebral artery to form circle of Willis.
- External carotid artery supplies mainly the structures on the exterior of cranial cavity with few branches inside it like middle meningeal artery.
- Middle cerebral and anterior cerebral arteries are the other branches of internal carotid artery.
- There is no artery by the name posterior superior cerebellar.

13. c. Oculomotor nerve
- The most commonly damaged nerve in posterior communicating artery aneurysm is oculomotor nerve.
- A complete oculomotor nerve palsy results in a characteristic down and out position in the affected eye, accompanied by ptosis and pupil dilation.

14. d. Basilar artery
- The two vertebral arteries enter the cranial cavity through foramen magnum and unite at the pontomedullary junction to form the basilar artery.
- It ascends superiorly anterior to the pons and divides at the junction of pons and midbrain into two posterior cerebral arteries.

15. b. Posterior cerebral artery
- Branches of basilar artery: Paramedian, Anterior inferior cerebellar artery, Labyrinthine artery, Superior cerebellar artery, Posterior cerebral artery

16. a. Pons
- Posterior cerebral artery gives branches to only the midbrain part of brainstem (not pons or medulla oblongata).
- Thalamus has multiple artery's supplying, few arise from posterior cerebral artery.
- Posterior cerebral artery supplies the posterior cerebrum, including the occipital visual (striate) cortex.

17. b. Middle cerebral artery; c. Posterior cerebral artery
- The major artery to supply occipital visual cortex is posterior cerebral artery.
- An additional branch to the macular area on the brain is given by the middle cerebral artery.

18. c. MCA + PCA
- The major artery to supply occipital cortex is posterior cerebral artery.
- An additional branch to the macular area on occipital visual cortex is given by the middle cerebral artery.

19. d. Superior cerebellar artery
- Medulla oblongata is supplied by branches of the vertebral, anterior and posterior spinal, posterior inferior cerebellar and basilar arteries.

20. a. Anterior cerebral artery
- Cerebral hemispheres are supplied by three cerebral arteries: anterior cerebral artery is a chief artery on medial surface, middle cerebral artery on superolateral surface and posterior cerebral artery on the inferior surface.

21. c. Middle cerebral artery
- Middle cerebral artery runs in the lateral sulcus of brain and is the major artery on the superolateral surface of cerebrum.

22. b. Middle cerebral artery
- Circle of Willis is contributed by paired posterior cerebral arteries, posterior communicating arteries, internal carotid arteries, anterior cerebral arteries and one anterior communicating artery.

23. c. Posterior cerebral artery with internal carotid artery
- Posterior communicating artery is a branch of internal carotid artery which anastomoses with posterior cerebral artery and contribute to the circle of Willis.

24. d. Posterior communicating artery
- Basal ganglia components (including putamen) are supplied by the striate (medial and lateral) arteries, which are branches from the roots of the anterior and middle cerebral arteries.
- The posteroinferior part of the lentiform complex is supplied by the thalamostriate branches of the posterior cerebral artery.
- Additional contributions are from anterior choroidal artery (branch of internal carotid artery).

25. b. Posterior communicating artery
- The marked artery is posterior communicating artery, branch of internal carotid artery, anastomosing with posterior cerebral artery, contributing to circle of Willis.
- This is inferior view of brain, showing the circle of Willis in the interpeduncular fossa at the base of the brain.

Applied Anatomy

Table 23: Differences between the pyramidal and extrapyramldal systems

	Pyramidal system	Extrapyramidal system
Phylogeny	Phylogenetically recent in acquisition, present only in mammals and achieving its greatest development in man	Phylogenetically older than pyramidal system
Function	Responsible for non-postural, precise movements of small muscles involved in skilful activity	Responsible for gross postural (stereotyped) movements involving large groups of muscles
Pathways	Connected directly to the lower motor neurons. Therefore impulses reach the LMNs, through a direct route	Connected indirectly (polysynaptic pathway) to lower motor neurons. Therefore, impulses reach the LMNs through a circuitous route
Effects of lesion	No increase in muscle tone	Muscle tone increased (spasticity)
Cortical fibres	Arise predominantly in primary motor area (Brodmann's area 4)	Arise predominantly in premotor area (Brodmann's area 6)
Subcortical centres and basal ganglia	Play no role in pyramidal system	Play a key role in extrapyramidal system

N.B. Naturally occurring lesions in man rarely, if ever involve pyramidal pathway without simultaneous involvement of extrapyramidal pathways, therefore the division of motor pathways into pyramidal and extrapyramidal systems is of little or no clinical relevance.

Site of lesion	Clinical features
Cortex	• Contralateral hemiplegia
(cortical hemiplegia)	• Aphasia (if lesion in dominant hemisphere)
Internal capsule	• Contralateral hemiplegia
(capsular hemiplegia)	• Ipsilateral UMN-type of facial palsy
Midbrain/crus cerebri	• Contralateral hemiplegia

Site of lesion	Clinical features
(midbrain hemiplegia)	• Ipsilateral LMN type of 3rd nerve palsy
Pons	• Contralateral hemiplegia
(pontine hemiplegia)	• Ipsilateral LMN type of 6th nerve palsy
	• Ipsilateral LMN type of 7th nerve palsy
Medulla	• Contralateral hemiplegia
(medullary hemiplegia)	• Ipsilateral LMN type of tongue paralysis (12th nerve palsy)
Spinal cord	• Contralateral hemiplegia
(spinal hemiplegia)	• No cranial nerve involvement

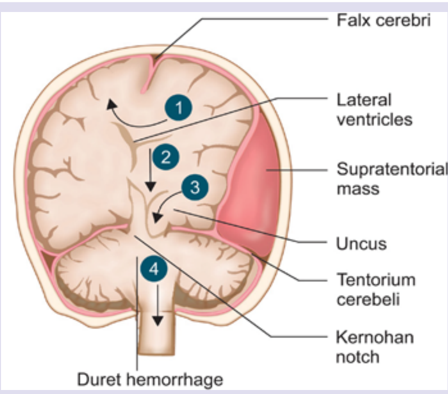
Table 24: Differences In clinical features of upper and lower motor neuron lesions

Features	Upper motor neuron lesion	Lower motor neuron lesion
Muscle tone	Increased (hypertonia or spasticity)	Decreased (hypotonia or flaccidity)
Muscle wasting	Absent (except due to disuse atrophy)	Present (atrophy)
Extent of paralysis	Widespread	Localized
Babinski's sign*	Present	Absent
Tendon reflexes, viz. knee and ankle jerks	Exaggerated	Diminished or lost
Muscle clonus†	Present	Absent

*When outer border of plantar surface of the foot is scratched with a blunt object in patient with a pyramidal (UMN) lesion it results in slow dorsiflexion of great toe accompanied by fanning of lateral toes. In normal person it results in plantar flexion of toes; †A quick and continued stretch of a tendon, e.g. by sudden downward pulling of patella in patient with upper motor neuron lesion results in appearance of repetitive, rhythmical contraction and relaxation of quadriceps instead of single contraction as in normal individuals.

Table 25: Signs that distinguish the origin of weakness

Sign	Upper motor neuron
Atrophy	None
Fasciculations	None
Tone	Spastic
Distribution of weakness	Pyramidal/regional
Muscle stretch reflexes	Hyperactive
Babinski sign	Present



1 Cingulate (subfalcine) herniation under falx cerebri	Can compress anterior cerebral artery.
2 Downward transtentorial (central) herniation	Caudal displacement of brain stem → rupture of paramedian basilar artery branches → Duret hemorrhages. Usually fatal
3 Uncal herniation	Uncus = medial temporal lobe. Compresses ipsilateral CN III (blown pupil, "down-and-out" gaze), ipsilateral PCA (contralateral homonymous hemianopia with macular sparing), contralateral crus cerebri at the Kernohan notch (ipsilateral paresis; a "false localization" sign)
4 Cerebellar tonsillar herniation into the foramen magnum	Coma and death result when these herniations compress the brain stem

Multiple sclerosis	Autoimmune inflammation and demyelination of CNS (brain and spinal cord. Patients can present with optic neuritis (sudden loss of vision resulting in Marcus Cunn pupils), INO, hemiparesis, hemisensory symptoms, bladder/bowel dysfunction. Relapsing and remitting course. Most often affects women in their 20s and 30s; more common in whites living further from equator.
	Charcot triad of MS is a SIN:
	• Scanning speech
	• Intention tremor (also incontinence and internuclear ophthalmoplegia)
	• Nystagmus

Miscellaneous

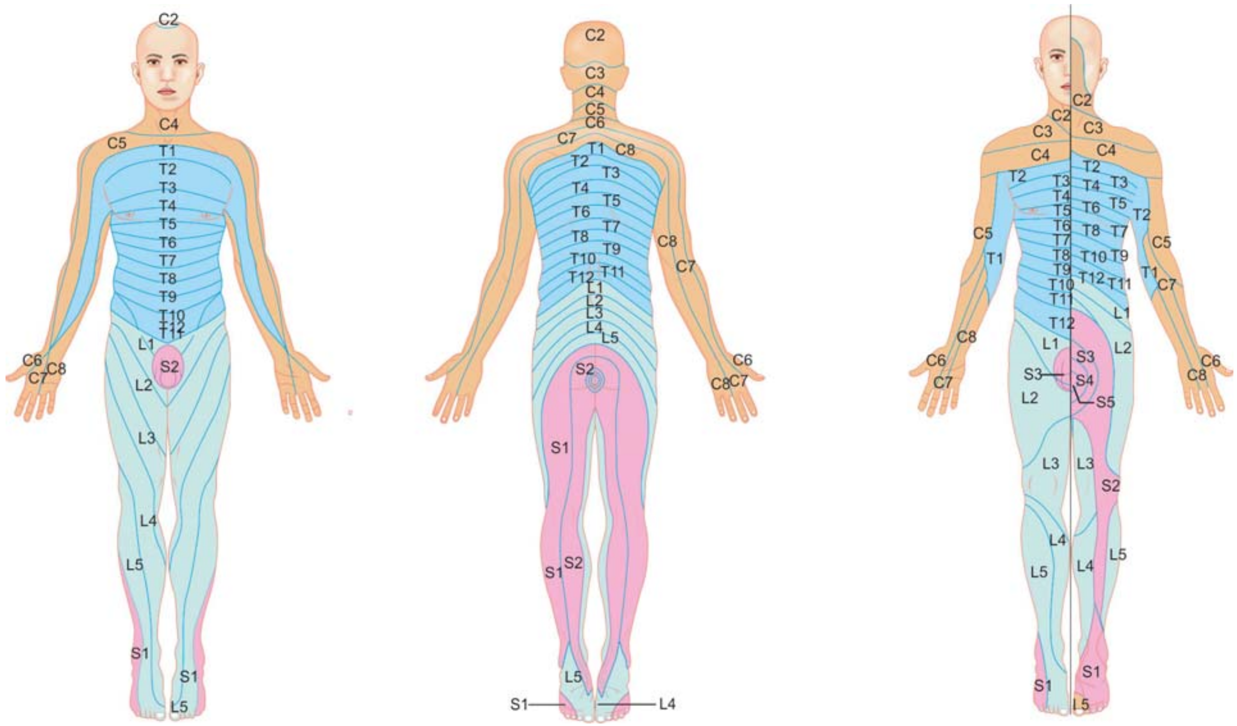


Fig. 119: Typical dermatome maps, illustrating some of the variations reported by different authors

Reflexes

Ankle jerk – Spinal segment **S-1**; Nerve: Tibial; Muscle: Gastrocnemius.
Knee jerk – Spinal segment **L- 2, 3, 4**; Nerve: Femoral; Muscle: Quadriceps.
Biceps jerk – Spinal segment **C-5, 6**; Nerve: Musculocutaneous: Muscle – Biceps.
Supinator reflex – Spinal segment **C-5, 6**; Nerve Radial; Muscle: Brachioradialis.
Triceps reflex – Spinal segment **C-7, 8**; Nerve: radial; Muscle: Triceps.
Memory aid: S-**1**; L-**2, 3, 4**; C-**5, 6**; C-**7, 8**.

MISCELLANEOUS QUESTIONS

1. **All are pain sensitive area of brain EXCEPT:** *(AIPG 2009)*
   a. Dural sheath surrounding vascular sinuses
   b. Middle meningeal artery
   c. Falx cerebri
   d. Choroid plexus

2. **Which structure is just lateral to anterior perforated substance?** *(AIPG 2009)*
   a. Uncus
   b. Limen insulae
   c. 3rd Ventricle
   d. Optic chiasma

ANSWERS WITH EXPLANATIONS

1. **d. Choroid plexus**
   - Choroid plexus is not a pain producing structure. Much of the brain parenchyma, Ventricular ependyma, pial veins and choroid plexus are not pain-producing structures.
   - Few cranial structures are pain producing: The scalp, middle meningeal artery, dural sinuses, falx cerebri and proximal segments of large pial arteries.
   - The structures involved in headache are few and the large intracranial vessels and dura mater innervated by the trigeminal nerve.

2. **b. Limen insulae**
   - Limen insulae lies in the lateral relation of anterior perforated substance.
   - Uncus lies in the postero-lateral relation of anterior perforated substance, optic chiasma is medial and 3rd ventricle lies postero-superior to it.
   - Anterior perforated substance lies on the base of the brain situated between the olfactory trigone anteriorly and optic tract posteriorly bounded by the lateral and medial olfactory stria (of the olfactory pathway) on sides.
   - Limen insulae is the point at which the cortex of the insula is continuous, on the inferior surface of the cerebral hemisphere, with the cortex of the frontal lobe.
   - Uncus is the blunt end of the temporal lobe in inferior view. It is the medially curved anterior end of the parahippocampal gyrus observed on the inferior surface of the cerebral hemisphere.
   - Limen insulae, Uncus and the entorhinal area (anterior part of parahippocampal gyrus) are collectively called as Pyriform cortex and are connected to the olfactory pathway.

High Yield Points

In adults the weight ratio of cerebellum to cerebrum is approximately 1:10 and in infants 1:20.

- Traditionally the reticular nuclei are divided into three columns
  - In the median column – the raphe nuclei
  - In the medial column – magnocellular nuclei
  - In the lateral column – parvocellular nuclei (because of smaller size of the cells)
- Bipolar neurons are found in the olfactory nerve (CN I), in the retina and cochlear and vestibular ganglia of CN VIII.
- Pseudo-unipolar neurons are located in the spinal (dorsal root) ganglia and sensory ganglia of cranial nerves (CN) V, VII, IX, and X.
- Light Reflex: Optic nerve carries the visual information to pretectal nucleus. Cells in the pretectal area send axons to the Edinger-Westphal nuclei on both sides. The Edinger-Westphal nucleus sends preganglionic parasympathetic fibers in the occulomotor nerve to the ciliary ganglion. Due to bilateral connection with Edinger-Westphal nuclei, shining light into one eye results in constriction of both the ipsilateral pupil (direct light reflex) and contralateral pupil (consensual light reflex).
- Pancoast tumor (superior pulmonary sulcus tumor) is a malignant neoplasm of the lung apex which may cause a lower trunk brachial plexopathy (which causes severe pain radiating toward the shoulder and along the medial aspect of the arm and atrophy of the muscles of the forearm and hand) and a lesion of cervical sympathetic chain ganglia with Horner syndrome (ptosis, enophthalmos, miosis, anhidrosis, and vasodilation).
- Multiple sclerosis (MS) is a nervous system disease that causes destruction of myelin in the spinal cord and brain, leading to sensory disorders and muscle weakness. Signs and symptoms include numbness or tingling, visual disturbances (swelling of the optic nerve), cognitive impairments, muscle weakness, difficulty with coordination and balance, slurred speech, bladder incontinence etc.
- Portal venous system consists of the hypophyseal portal system in which blood from the hypothalamic capillaries passes through the hypophyseal portal veins and then the pituitary capillary sinusoids to the hypophyseal veins.

Radiology

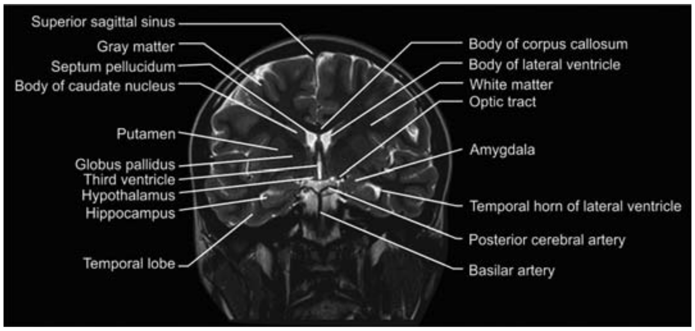


Fig. 120: MRI Coronal view of brain

MRI Coronal Brain Anatomy

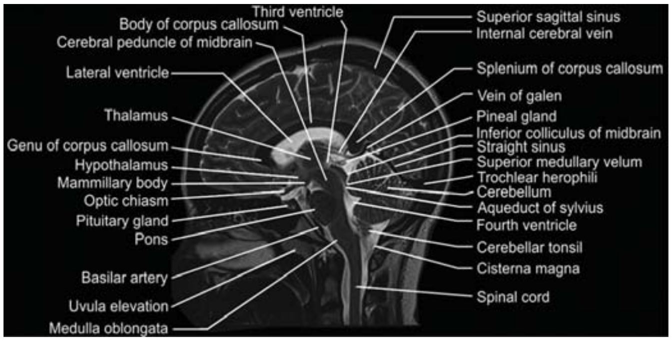


Fig. 121: MRI Sagittal view of brain

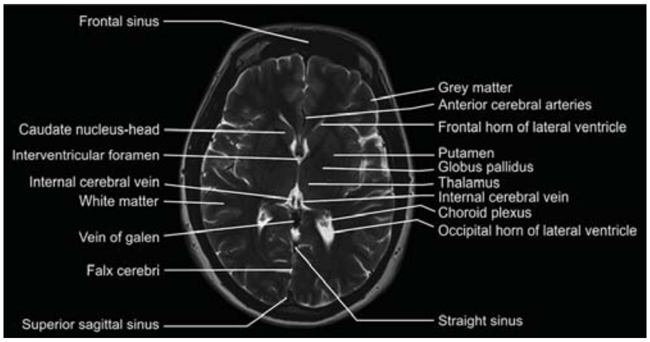


Fig. 122: MRI Transverse view of brain

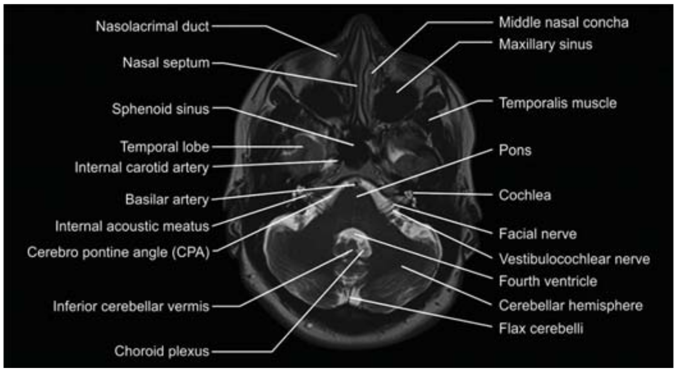
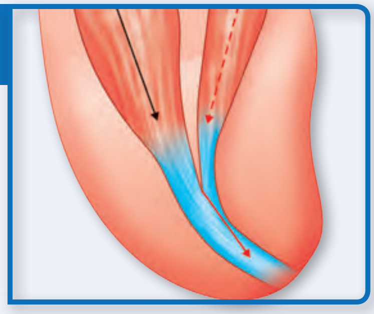


Fig. 123: MRI Transverse view of brain

CHAPTER 5



Head and Neck

Surface Marking

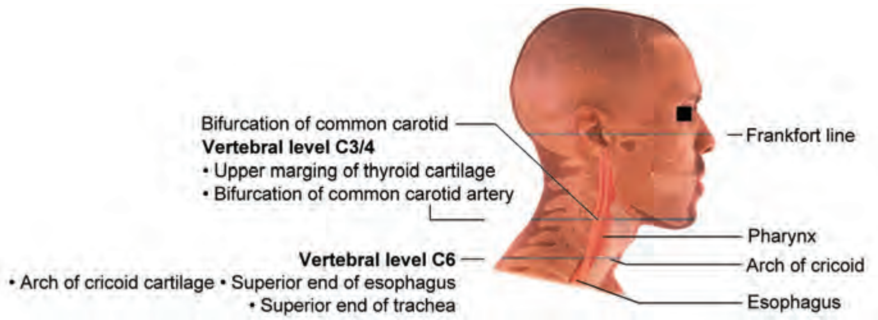


Fig. 1: Lateral view of head and neck to show structures at the C3/C4 and C6 vertebral levels.

Vertebral level	Structures
C3	Level of greater cornu of hyoid bone
C3- C4 junction	Level of upper border (and notch) of thyroid cartilage and bifurcation of common carotid artery
C4-C5 Junction	Level of thyroid cartilage
C6	Level of cricoid cartilage

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- The upper border of the thyroid cartilage usually lies between the fourth and fifth cervical vertebrae *(Mirjalili et al. 2012b).*
- The body of the hyoid bone sits level with the **fourth cervical vertebra** (higher in children).

Craniometric Points

The lateral (**Sylvian**) fissure of the brain aligns with the anterior part of squamosal suture in a zone 2.5–4.0 cm anterior to the external acoustic meatus.

- The **pterion** represents the junction of the four bones: the frontal, parietal, and temporal bones and the great wing of the sphenoid bone.
  - It is situated within a 1 cm diameter circle centered approximately 2.6 cm posterior and 1.3 cm superior to the posterolateral margin of the zygomaticofrontal suture.
  - Alternatively, the pterion is located approximately 4 cm above the midpoint of the zygomatic arch.
  - The central point of pterion is known as Sylvian point, the cranium is very thin at this point. Its immediate deep relations are fontal branch of middle meningeal artery, its accompanying vein and stem of lateral sulcus of brain.
  - Fracture at this point may injure middle meningeal artery and give rise to extradural hemorrhage.
  - Pterion helps in the positioning of burr-holes to evacuate extradural haematomas.

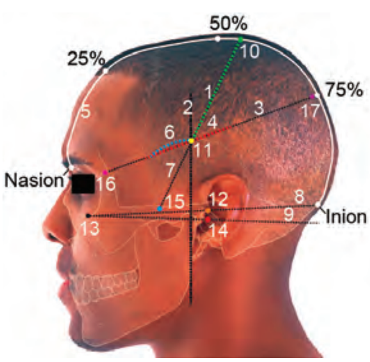
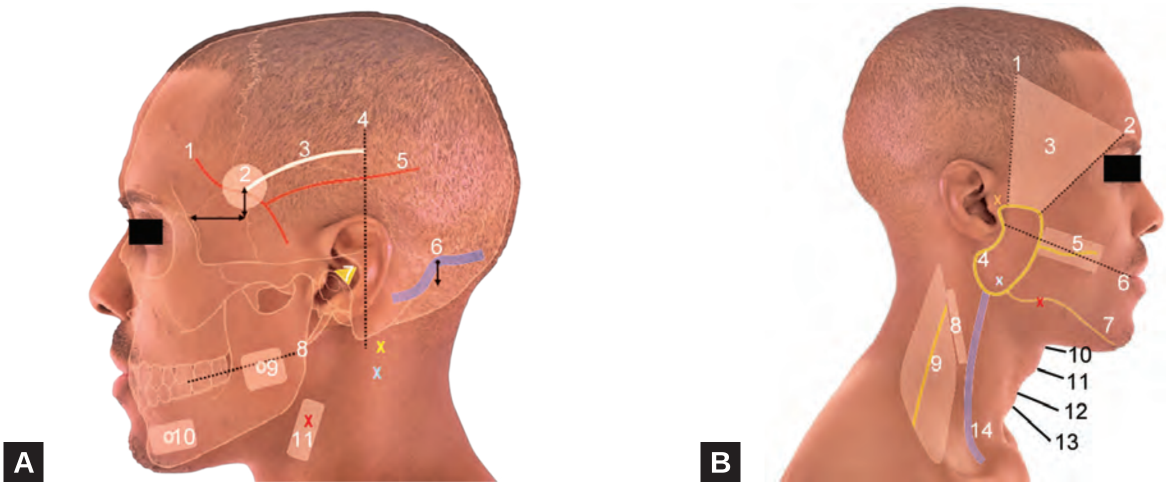


Fig. 2: Craniometric points and cerebral sulci: 1, Rolandic line/central sulcus (green line); 2, pre-auricular/ mandibular condylar line orientated perpendicular to the infra-orbitomeatal line; 3, frontozygomatic/ Sylvian line passing from the frontozygomatic suture (16) to a point 75% of the way along the nasion-inion midsagittal line; 4, lateral sulcus/Sylvian fissure (red line); 5, nasion-inion midsagittal line; 6, lateral sulcus/Sylvian fissure alternative location (blue line): aligns anteriorly with the anterior part of the squamosal suture in a zone 2.5–4.0 cm anterior to the external acoustic meatus; 7, line from the (superior Rolandic point (green dot) to the midpoint of the zygomatic arch (15, blue dot); 8, Reid's baseline/Frankfort plane; 9, infra-orbitomeatal line; 10 (green dot), superior Rolandic point 2 cm posterior to the midpoint of the nasion-inion line (at the 53– 55% point of the nasion-inion line); 11 (yellow dot), inferior Rolandic point; 12 (orange dot), portion; 13 (black dot), orbitale; 14 (red dot), frontozygomatic suture; 17 (purple dot), superior extent of the parieto-ocipital sulcus.



Figs. 3A and B: Lateral view of the head and neck (A) Pterion, meningeal arteries, carotid bifurcation, mental and mandibular foramen: 1, anterior branch of the middle meningeal artery: sits deep to the pterion in over half of subjects; 2, zone of location of the pterion: in a 1 cm diameter circle centerd 2.5 cm posterior and 1.5 cm superior (black arrows) to the frontozygomatic suture; 3, lateral (Sylvian) fissure: aligns anteriorly with the anterior meningeal artery: runs parallel to the zygomatic arch and sits level with the supraorbital margin on the mastoid line; 6, asterion: sits almost always over or sometimes just below (black arrow) the transverse-sigmoid sinus junction; 7, suprameatal triangle; 8, occlusal plane; 9, zone of location (white) of the mandibular foramen: in the majority of cases, the foramen sits level with or below the occlusal plane (8), an average of 2 cm posteior to tooth 8; 10, zone of location (white) of the mental foramen: the foramen commonly sits between the roots of teeth 4 and 5 (range 3–6), usually level with or inferior to the tooth root apex; X (green), transverse process of C1 (atlas); X (blue), transverse process of C2 (axis); 11, zone of location (white) of the bifurcation of the common carotid artery: usually above the level of the thyroid lamina; X (red), most common level of common carotid bifurcation (C3), (B) Parotid gland and duct, CN 7 & 11, cutaneous branches of cervical plexus and internal jugular vein : 1, portion line; 2, zygomatic sutural line; 3, zone of location of the (fronto)temporal nerve; 4, parotid gland; 5, zone of location (white) of the parotid duct (green line): sits within 1.5 cm of the middle half of a line passing from the lower tragus to the chelion; 6, lower tragus-chelion line; 7, marginal mandibular nerve; 8; zone of emergence of the cutaneous branches of the cervical plexus (white), posterior to the middle third of sternocleidomastoid; 9, zone of location of the accessory nerve, from 3–10 cm below the tip of the mastoid process to 1–10 cm above the insertion of trapezius into the clavicle; 10, hyoid bone; 11, thyroid cartilage (laryngeal prominence); 12, cricothyroid ligament/membrane; 13, cricoid cartilage; 14, external jugular vein; X (blue), angle of the mandible; X (red), facial artery and anterior border of masseter crossing the lower border of the mandible; X (orange), superficial temporal artery.

- The lateral wall of mastoid antrum corresponds to the **suprameatal triangle of Macewen** on the outer surface of the skull, palpable through the cymba conchae.
- This triangle is a small depression posterosuperior to the external auditory meatus on squamous part of the temporal bone.
- It is bounded superiorly by **supramastoid crest**, which is level with the floor of the middle cranial fossa; the anteroinferior side, which forms the posterosuperior margin of the external acoustic meatus, indicates approximately the position of the descending part of the facial nerve canal; and posteriorly by a vertical tangent to the posterior margin of the meatus, is anterior to the sigmoid sinus.
- A small bony projection - suprameatal spine of Henle may be present in the anteroinferior part of this triangle.
- It is an important landmark when performing a cortical mastoidectomy.
- The **mastoid antrum** lies 1.25 cm deep to this triangle. The lateral wall of mastoid antrum is only 2 mm thick at birth but increases at an average rate of 1 mm a year, attaining a final thickness of 12–15 mm.
- The adult capacity of the mastoid antrum is 1 mL, with a general diameter of 10 mm.
- Unlike the other air sinuses in the skull, it is **present at birth, and almost adult in size**, although it is at a higher level relative to the external acoustic meatus than it is in adults.
- In the young the lateral antral wall is very thin, mastoid process is absent and the stylomastoid foramen and emerging facial nerve are very superficially situated.

Table 1: Craniometric points of cranium

Landmark	Shape and Location
Pterion	Junction of greater wing of sphenoid, squamous temporal, frontal, and parietal bones; overlies course of anterior division of middle meningeal artery
Lambda	Point on calvaria at junction of lambdoid and sagittal sutures
Bregma	Point on calvaria at junction of coronal and sagittal sutures
Vertex	Superior point of neurocranium, in middle with cranium oriented in anatomical (orbitomeatal or Frankfort plane.
Asterion	Star shaped; located at junction of three sutures: parietomastoid, occipitomastoid, and lambdoid

Landmark	Shape and Location
Glabella	Smooth prominence; most marked in males; on frontal bones superior to root of nose; most anterior projecting part of forehead
Inion	Most prominent point of external occipital protuberance
Nasion	Point on cranium where frontonasal and internasal sutures meet

Skeletal Landmarks

- The **pericraniocervical** line, demarcates the head from the neck, and runs from the midpoint of the chin anteriorly to the external occipital protuberance posteriorly.
- The external occipital protuberance (**inion**) is a palpable bony protuberance located on the posterior midline of the occipital bone. The confluence of the dural venous sinuses sits mainly to the upper right side of the inion.
- The superior nuchal lines are palpable passing laterally from the inion.
- The **asterion** can be palpated as a slight depression 1–2 cm behind the pinna at a level approximately at the junction of the upper third and lower two-thirds of the pinna. It is commonly employed to define the location of transverse-sigmoid sinus junction.

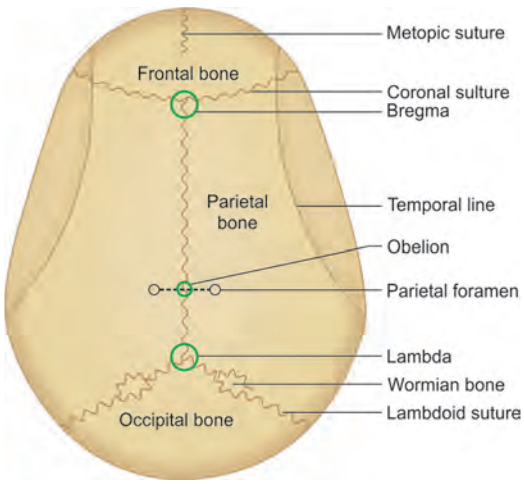


Fig. 4: Skeletal landmarks on skull (Norma verticalis).

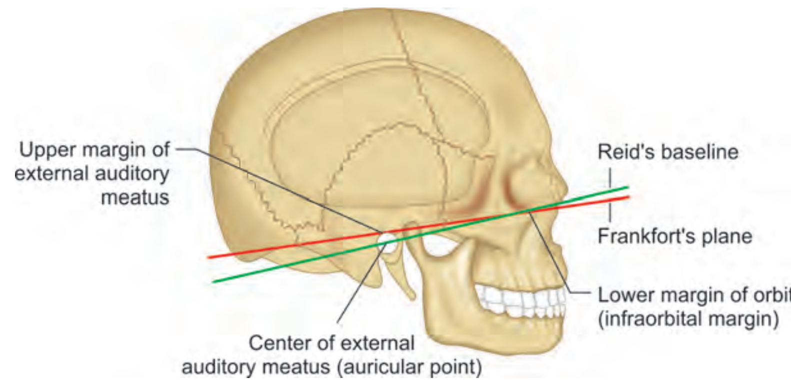


Fig. 5: Lateral view of skull showing Reid's baseline and Frankfurt's plane.

- **Reid's baseline** extends from infraorbital margin to center of external acoustic meatus.
- **Frankfort's horizontal plane** extends from infraorbital margin to superior margin of external meatus.

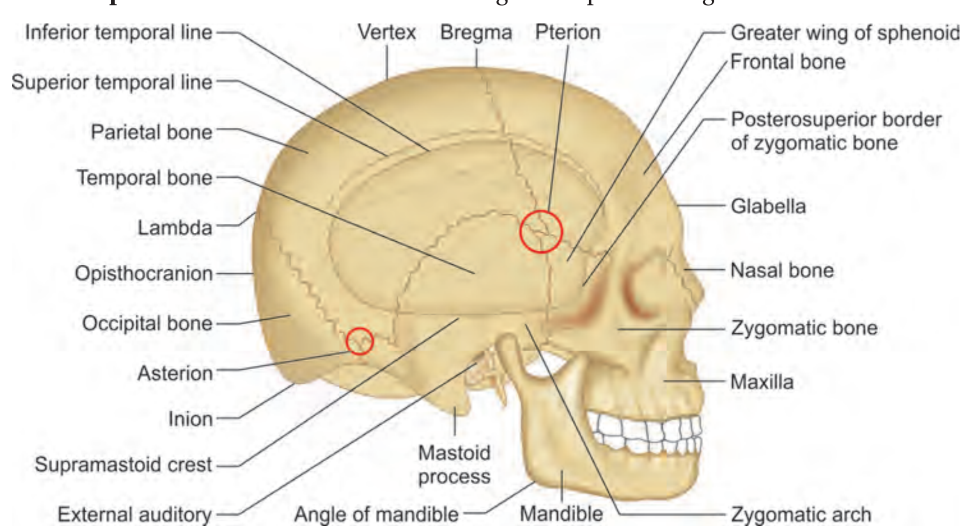


Fig. 6: Skeletal landmarks on skull (norma lateralis).

Mandible

- The lower border of the mandible can be traced to the angle at vertebral level C2.
- The **mental foramen**, which transmits the mental nerve and vessels lies an average of 2.5 cm from the midline face between the root apices of mandibular teeth 4 and 5 (range: teeth 3–6).
- The **mandibular foramen** sits on the medial surface of the ramus an average of 1.9 cm posterior to the third molar.

ASSESSMENT QUESTIONS

1. **Upper border of thyroid cartilage is at:** *(NEET Pattern 2012)*
   a. C2
   b. C4
   c. C6
   d. T1

2. **Cricoid cartilage lies at which vertebral level:** *(NEET Pattern 2012)*
   a. C2
   b. C4
   c. C6
   d. T1

3. **Hyoid lies at the level of:** *(NEET Pattern 2013)*
   a. C3
   b. C5
   c. C7
   d. T2

4. **Sylvian point is related to which part of temporal bone:** *(NEET Pattern 2015)*
   a. Squamous part
   b. Petrous part
   c. Tympanic part
   d. Mastoid part

5. **Reid's line extends from:** *(NEET Pattern 2014)*
   a. Infraorbital margin to superior margin of external acoustic meatus
   b. Infraorbital margin to center of external acoustic meatus
   c. Infraorbital margin to inferior margin of external acoustic meatus
   d. None of the above

ANSWERS WITH EXPLANATIONS

1. **b. C4**
   - Upper border of thyroid cartilage lies at C3-4 vertebral level. Common carotid artery bifurcates into two branches at this level.
2. **c. C6**
   - Cricoid cartilage of larynx lies at the C6 vertebra level, which marks the termination of larynx and pharynx and beginning of trachea and oesophagus.
3. **a. C3**
   - Hyoid bone is located at the level of C3 vertebra.
4. **a. Squamous part**
   - Sylvian point practically corresponds to the pterion, which is an H-shape suture, contributed by four bones, including the squamous part of temporal bone.
5. **b. Infraorbital margin to center of external acoustic meatus**
   - Reid's base line extends from infraorbital margin to center of external acoustic meatus.

Embryology

Pharyngeal Apparatus

- **Pharyngeal apparatus** consists of the pharyngeal arches, pouches, grooves, and membranes.
- Pharyngeal (Branchial) arches are composed majorly of secondary mesenchyme (neural crest origin) and partly primary mesenchyme.
- The mesenchymal core is covered externally by ectoderm and internally by endoderm.
- Pharyngeal arches develop in the lateral wall of the primitive pharynx and later extend ventrally and fuse with their counterparts of the opposite side in floor of the primitive pharynx to form horseshoe-shaped cylindrical bars.
- Initially there are six arches, but **fifth arch is rudimentary**.
- Pharyngeal (branchial) arches give the head and neck their typical appearance in the fourth week.
- Each arch contains its own artery, cranial nerve, muscle element, and cartilage bar or skeletal element.
- Ectoderm lined pharyngeal clefts give rise to only one structure, the external auditory meatus.
- Endoderm of the pharyngeal pouches gives rise to a number of endocrine glands and part of the middle ear.
- The dorsal end of the first pouch with a contribution from the dorsal part of the second pharyngeal pouch, constitutes the **tubotympanic recess**. The recess forms the middle ear cavity, the pharyngotympanic tube and their extensions.
- Patterning of the skeletal elements of the pharyngeal arches is regulated by gene expression in pharyngeal pouch endoderm.
- Neural crest cells originate from the caudal midbrain and from segments in the hindbrain called rhombomeres and dictate the type of skeletal elements that form in the arch region.

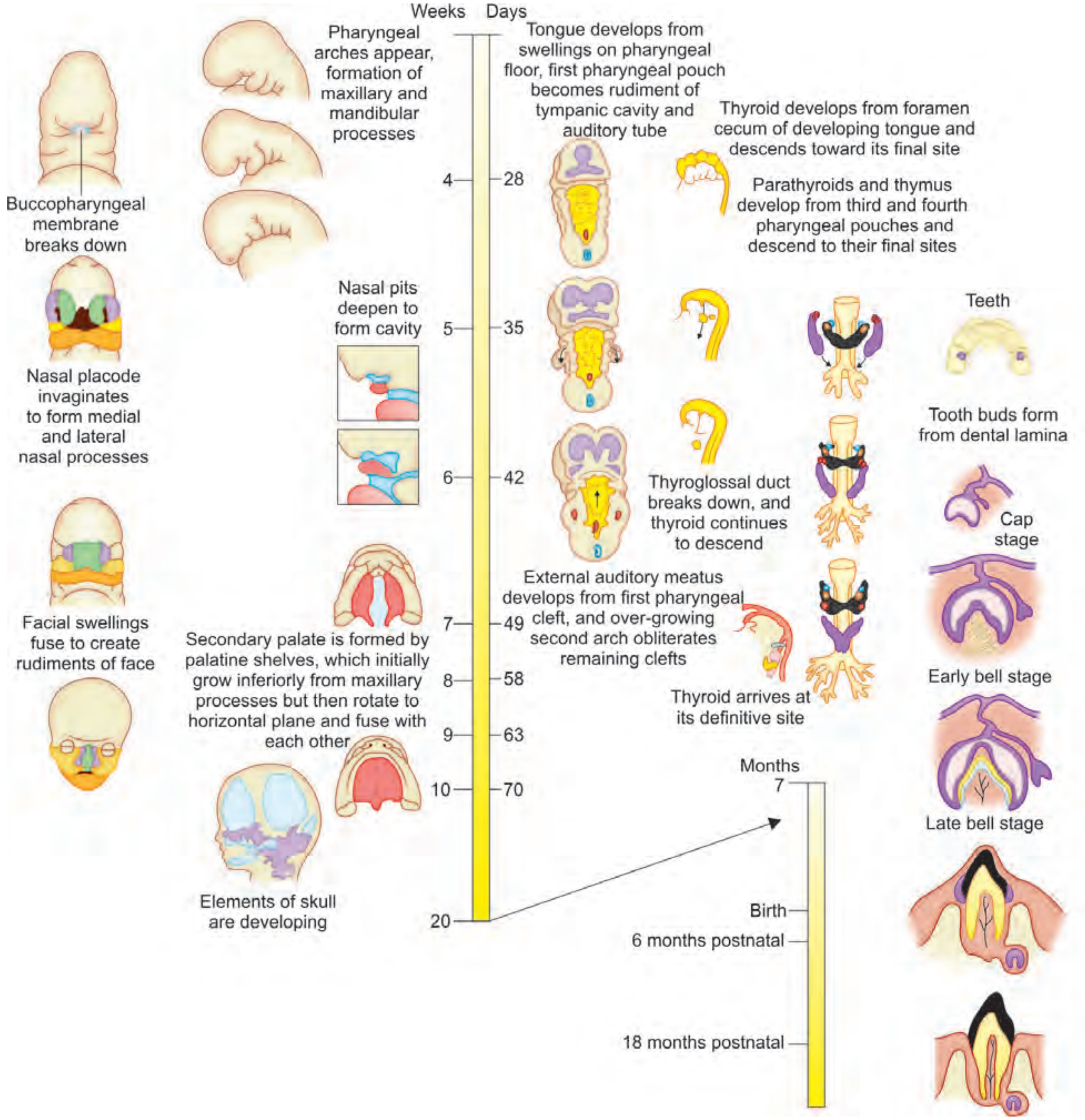
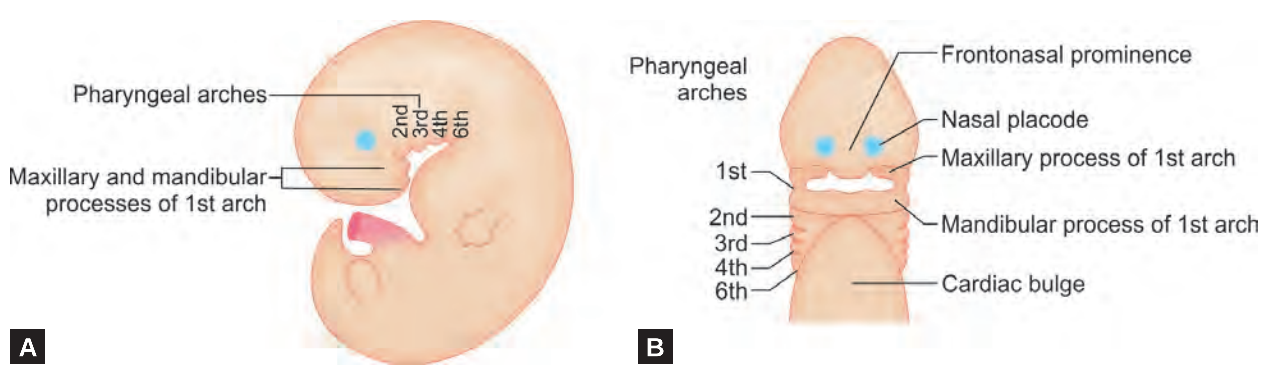


Fig. 7: Time line. Development of the head, neck, and pharyngeal apparatus



Figs. 8A and B: Formation of pharyngeal arches. (A) Lateral view. (B) Frontal view. Note that first pharyngeal arch consists of maxillary and mandibular processes.

Table 2: Derivatives of the pharyngeal arches

Arch No.	Nerve	Embryonic cartilage	NCCs/Mesoderm	Mesoderm (Muscles)	Misc	Artery
1.	CNV_3	Quadrate/Meckel's	Maxilla Mandible (GT) Incus Malleus Anterior ligament of malleus Sphenomandibular ligament	Tensor tympani Tensor veli palatini Muscles of mastication Mylohyoid Anterior belly digastric	Anterior 2/3 of tongue	Maxillary (transitory)
2.	CN VII	Reichert's	Stapes Styloid process Stylohyoid ligament Lesser horn and upper part of body of hyoid bone	Stapedius Stylohyoid Facial muscles (incl. Buccinatory/ Platysma, auricular, occipitofrontalis) Posterior belly digastric		Stapedial/Hyoid artery (transitory)
3.	CN IX		Greater horn and lower part of body of hyoid	Stylopharyngeus	Posterior 1/3 of tongue	Common caroitd artery Internal carotid artery (first part)
4.	CN X Pharyngeal branch supe- rior laryngeal branch		NCSs: none Thyroid Cartilage Epiglottis	Palate (Levator, etc.) Pharynx Cricothyroid	Root of tongue	Right subclavian artery (proximal part) Arch of aorta (between origins of left common carotid and left subclavian arteries)
6	CN X Recurrent laryngeal branch		NCCs: none Cricoid Arytenoid cartilages	Larynx		Pulmonary arteries D arteriosus

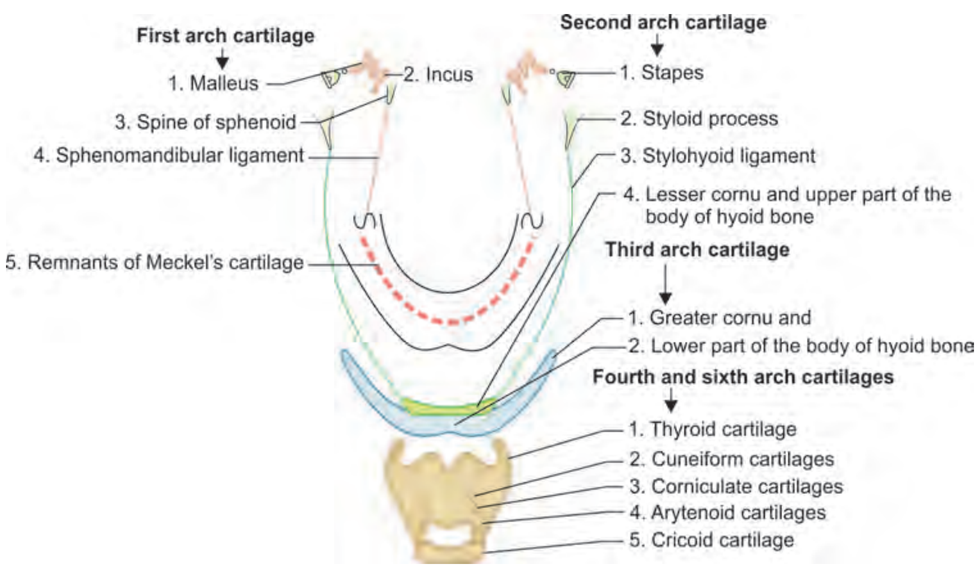


Fig. 9: Skeletal derivatives of pharyngeal arch cartilages. Bones are derived from the neural crest cells and larynx cartilages are derived from lateral plate mesoderm.

Pharyngeal Arch Muscles: Myoblasts from the pharyngeal arches, which originate from the **unsegmented paraxial mesoderm** and prechordal plate form the muscles of mastication, facial expression, pharynx, and larynx.

- These muscles are innervated by pharyngeal arch nerves.
- **Ocular Muscles:** Extrinsic eye muscles are derived from mesenchymal cells near the prechordal plate.
- Three preotic myotomes, each supplied by its own nerve (cranial nerve Ill, IV and VI), form the extrinsic muscles of the eye.
- **Tongue muscles** develop in the myoblasts from three postotic **(occipital) myotomes** innervated by the hypoglossal nerve (CN Xll).
- One tongue muscle (palatoglossus) develops in pharyngeal arch mesoderm (supplied by vago-accessory complex).

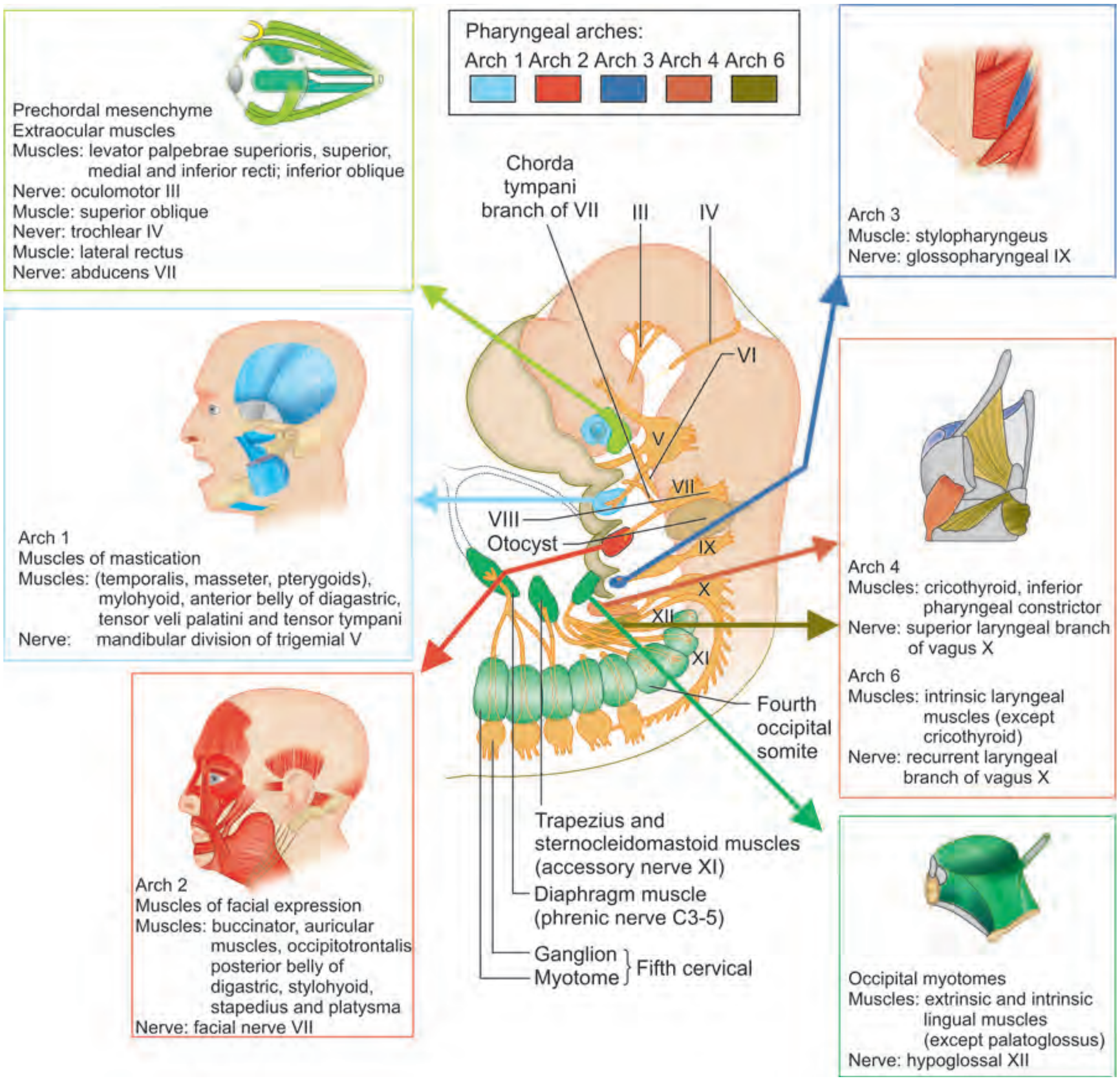


Fig. 10: Muscular derivatives in the region of pharyngeal arches.

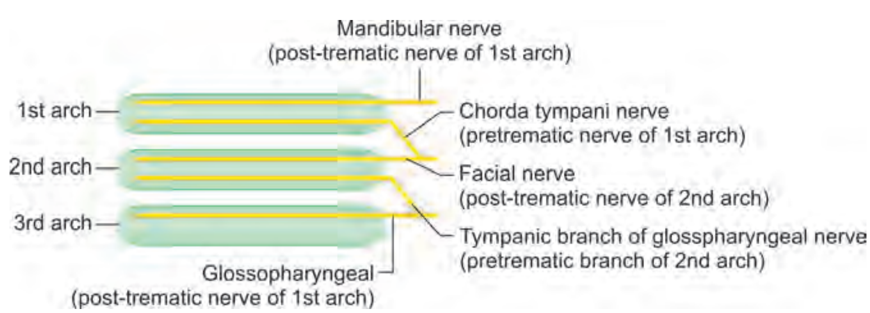


Fig. 11: Arrangement of post-trematic and pretrematic nerve

ASSESSMENT QUESTIONS

1. **Nerve of 6th arch is:** *(NEET Pattern 2013)*
   a. Trigeminal
   b. Facial
   c. Glossopharyngeal
   d. Vagus

2. **Which of the following is derived from 1st pharyngeal arch:** *(NEET Pattern 2015)*
   a. Frontonasal process
   b. Maxillary process
   c. Mandibular process
   d. Both maxillary and mandibular processes

3. **Epiglottis develops from which branchial arch:** *(NEET Pattern 2013)*
   a. Third
   b. Fourth
   c. Fifth
   d. Sixth

4. **Tensor tympani is supplied by the nerve:** *(AIIMS 2010)*
   a. Facial
   b. Glossopharyngeal
   c. Trigeminal
   d. Vagus

5. **Which of the following laryngeal muscle arise 4th arch:**
   a. Cricothyroid
   b. Transverse arytenoids
   c. Posterior cricoarytenoid
   d. Lateral arytenoids

6. **Which of the following muscle is derivative of 1st arch:** *(NEET Pattern 2015)*
   a. Stylopharyngeus
   b. Tensor tympani
   c. Platysma
   d. Cricothyroid

7. **Pharyngeal muscles are derived from which pharyngeal arch:** *NEET Pattern 2015)*
   a. 1st
   b. 2nd
   c. 3rd
   d. 4th

8. **Wrong match about the bone and cartilages in pharyngeal arches**
   a. Meckel's cartilage: Mandible
   b. Reichert's cartilage: Stapes
   c. Second arch cartilage: Styloid process
   d. Third arch: Lesser cornu of hyoid bone

ANSWERS WITH EXPLANATIONS

1. **d. Vagus**
   - Recurrent laryngeal nerve (branch of vagus) is the nerve of sixth pharyngeal arch.
2. **d. Both maxillary and mandibular processes**
   - Both maxillary and mandibular processes develop in first pharyngeal arch.
3. **b. Fourth**
   - Epiglottis and upper part of thyroid cartilage develop in the fourth pharyngeal arch.
4. **c. Trigeminal**
   - Tensor tympani muscle develops in the first pharyngeal arch and is hence, supplied by the mandibular branch of trigeminal nerve.
   - Facial nerve supplies the muscles developing in the second pharyngeal arch, which are mainly the muscles of facial expression.
   - Glossopharyngeal nerve supplies the muscle stylopharyngeus developing in the third pharyngeal arch.
   - Vagus nerve (along with cranial accessory nerve) supply the muscles developing in the fourth and sixth arch (muscles of palate, pharynx and larynx).
5. **a. Cricothyroid**
   - Most of the laryngeal muscles develop in sixth arch, with few exceptions.
   - Cricothyroid muscle develops in fourth pharyngeal arch.
6. **b. Tensor tympani**
   - Tensor tympani muscle develops in the first pharyngeal arch.
   - Stylopharyngeus develops in 3rd arch, platysma in 2nd and cricothyroid in 4th arch, respectively.
7. **d. 4th**
   - Most of the pharyngeal muscles develop in fourth arch, with few exceptions.
   - Stylopharyngeus muscle develops in third pharyngeal arch.
8. **d. Third arch: Lesser cornu of hyoid bone**
   - Third pharyngeal arch forms the lower body and greater (and not lesser) cornu of hyoid bone.

Pharyngeal Cleft and Pouches

- Pharyngeal pouches are formed in the lateral wall of the pharynx and are lined by endoderm.
- Pharyngeal clefts (grooves) develop on the outer aspect and are lined by ectoderm.
- Pharyngeal membranes lie between the two.

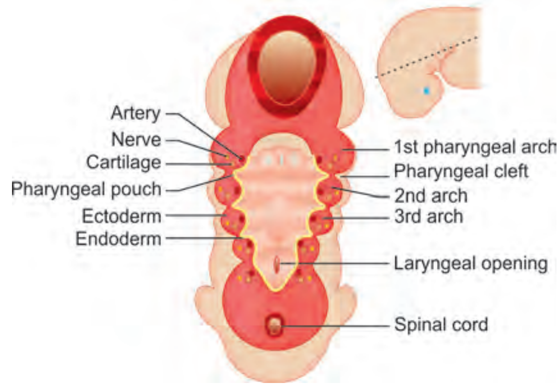
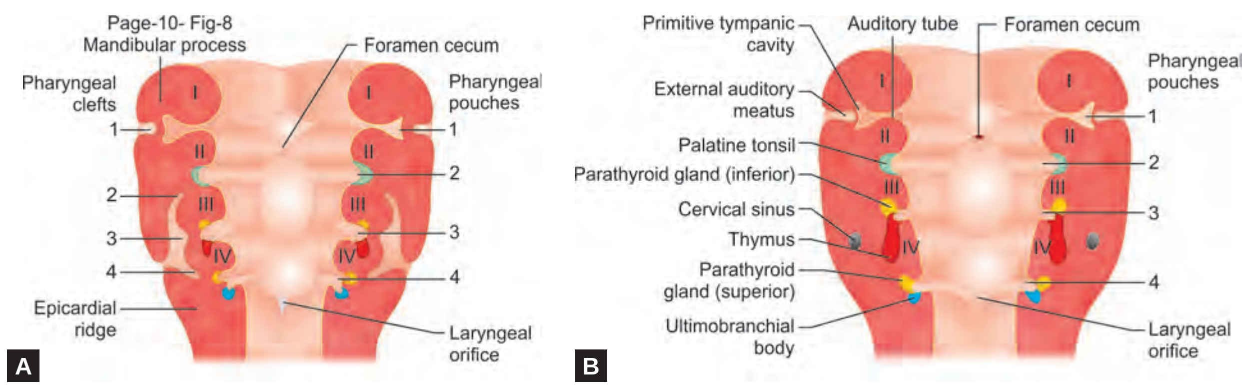


Fig. 12: Cut section of pharyngeal arches. Each arch consists of a mesenchymal core derived from mesoderm and neural crest cells and each is lined internally by endoderm and externally by ectoderm. Each arch also contains an artery (one of the aortic arches) and a cranial nerve and each will contribute specific skeletal and muscular components to the head and neck. Between the arches are pouches on the inner surface and clefts externally.



Figs. 13A and B: (A) Development of the pharyngeal clefts and pouches. The second arch grows over the third and fourth arches, burying the second, third, and fourth pharyngeal clefts. (B) Remnants of the second, third, and fourth pharyngeal clefts form the cervial sinus, which is normally obliterated.

Pouch	Adult derivatives
1.	Epithelium of middle ear cavity and Eustachian tube
2.	Epithelium of palatine tonsil crypts
3.	Thymus (ventral) Inferior parathyroid (dorsal)
4.	Superior parathyroid (dorsal) Ultimobranchial body (ventral) – Parafollicular C cells of thyroid

Groove	Adult derivatives
1	Epithelium of external auditory meatus
2–4	Obliterated

Membrane	Adult derivatives
1	Tympanic membrane
2–3	Obliterated

Tonsil develops in the region of 2nd pharyngeal pouch.

- The **endoderm of the second pouch** proliferates and grows into the underlying secondary mesenchyme (**neural crest** cell derived).
- The central parts of these buds break down, forming tonsillar crypts (pit-like depressions).
- The pouch endoderm forms the surface epithelium and lining of the tonsillar crypts.

- At approximately 20 weeks, the mesenchyme around the crypts differentiates into lymphoid tissue, which soon organizes into the lymphatic nodules of the palatine tonsil.
- The remnant of 2nd pharyngeal pouch is seen as supratonsillar/intratonsillar cleft.

Clinical Correlations

- The mesenchyme of second pharyngeal arch rapidly grows downward, overlaps the second, third, and fourth pharyngeal clefts (grooves), and fuses with the epicardial ridge.
- Thus, second, third, and fourth pharyngeal clefts get buried under the surface and form a slit-like cavity—the **cervical sinus** that is lined by ectoderm.
- The cervical sinus later disappears, if it fails to obliterate, it leads to the formation of **branchial cyst**.
- The branchial cyst is present at the anterior border of the sternocleidomastoid at the junction of its upper one-third and lower two-third, below and behind the angle of mandible.
- In some cases, branchial cyst may open externally on the surface of the neck forming **external branchial sinus**.
- Rarely the branchial cyst may communicate internally with tonsillar fossa, leading to **internal branchial sinus**.
- **Branchial fistula** may develop due to rupture of membrane between the second pharyngeal cleft and second pharyngeal pouch, which passes deep between the external and internal carotid arteries (carotid fork) and opens into the tonsillar sinus.

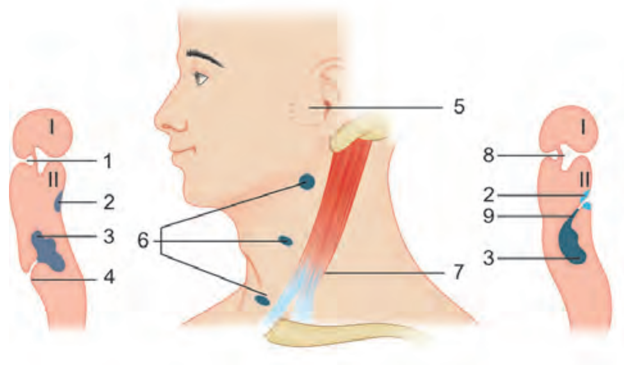


Fig. 14: 1. External auditory meatus; 2, Palatine tonsil; 3. Lateral cervical (branchial) cyst; 4. External branchial sinus; 5. Region of preauricular fistulae; 6. Region of lateral cervical cysts and fistulae; 7. Sternocleidomastoid muscle; 8. Tubotympanic recess: 9. Internal branchial sinus.

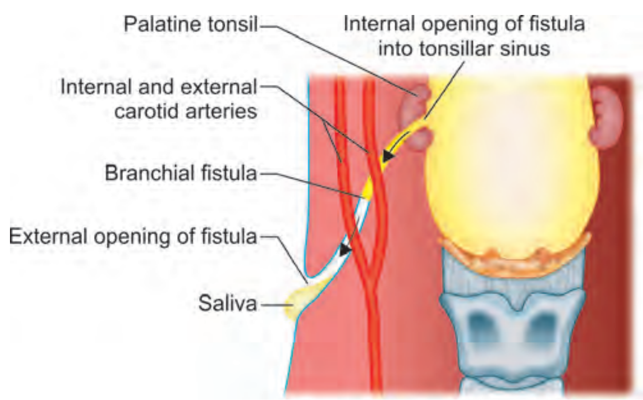


Fig. 15: Branchial fistula connects tonsilar fossa to the skin of the lower neck and may bring saliva to the exterior. The fistula track passes between the carotid fork (between external and internal carotid artery).

DiGeorge syndrome presents with chromosome 22q11 deletion.

- Neural crest cell migration is affected and patients lack mature T cells (due to **absence of thymus**).
- There is defective development of pharyngeal pouch three and four.
- Most common cause of death is cardiovascular defects, though severe bacterial infections, **hypocalcemic** tetany may also lead to grave consequences.
- Presentation: Positive Chvostek sign (and Trousseau sign); recurrent infections (viral, fungal, and protozoal); characteristic facies (micrognathia, broad nasal bridge, long face, narrow palpebral fissures, asymmetric crying face).
- Diagnostics: Hypocalcemia, lymphopenia, absent thymic silhouette on neonatal imaging.

ASSESSMENT QUESTIONS

1. **Palatine tonsil develops from which pharyngeal pouch?** *(NEET Pattern 2012)*
   a. First
   b. Second
   c. Third
   d. Fourth

2. **Which of these is CORRECT about the development of tonsil:** *(NEET Pattern 2012)*
   a. Is a derivative of the first pharyngeal arch
   b. Develops from the second pharyngeal pouch
   c. Develops from the third pharyngeal pouch
   d. Is a derivative of the neural crest cells

3. **Thymus develops from:**
   a. Second pharyngeal pouch (ventral portion)
   b. Third pharyngeal pouch (ventral portion)
   c. Third pharyngeal pouch (dorsal portion)
   d. Fourth pharyngeal pouch (ventral portion)

4. **During 4th week, endoderm and ectoderm approach each other in the head and neck region at:** *(AIIMS)*
   a. Pharyngeal groove
   b. Pharyngeal pouch
   c. Pharyngeal membrane
   d. Pharyngeal arch

5. **Which structure develops from all the 3 germ layers?**
   a. Tympanic membrane
   b. External acoustic meatus
   c. Auditory tube
   d. Middle ear

6. **TRUE statement regarding branchial anomalies:** *(AIIMS 2010)*
   a. Most commonly second arch is involved
   b. Cyst is more common than sinus
   c. Sinus should always be excised
   d. Cyst cause dysphagia and hoarseness

ANSWERS WITH EXPLANATIONS

1. **b. Second**
   - Second pharyngeal pouch gives the tonsillar epithelium.

2. **d. Is a derivative of the neural crest cells > b. Develops from the second pharyngeal pouch**
   - Neural crest derived (secondary) mesenchyme (in the region of second pharyngeal pouch) differentiates into lymphoid tissue, which organizes into the lymphatic nodules of the palatine tonsil.
   - Endoderm of pharyngeal pouch contributes to the tonsillar epithelium.

3. **b. Third pharyngeal pouch (ventral portion)**
   - Thymus gland develops in the ventral portion of third pharyngeal pouch, whereas in the dorsal region develops inferior parathyroid.

4. **c. Pharyngeal membrane**
   - During 4th week, at the lateral wall of primitive pharynx, inner endoderm (of pharyngeal pouch) and outer ectoderm (of pharyngeal cleft) approach each other and sandwich the pharyngeal membrane between the two.
   - The membrane is made up of mesenchyme (connective tissue) lined by outer ectodermal epithelium and inner endodermal epithelium.

5. **a. Tympanic membrane**
   - Tympanic membrane has an outer epithelial layer (ectodermal) and inner epithelial layer (endodermal) and sandwiched between the two is mesenchyme, forming the connective tissue.

6. **a. Most commonly second arch is involved**
   - This is a controversial question, since all the statements can be proven correct. The most appropriate option has been chosen as the answer.
   - Branchial arch anomalies are the most commonly associated with second arch, comprising more than 90% of the arch anomalies.
   - Branchial cysts are more common than the branchial sinus statistically - nearly 74% of the branchial arch anomalies present as a branchial cyst (though in pediatric age group sinuses are more common than cysts).
   - Branchial sinuses should always be excised (though some of the authors believe that excision should be done if they present with chronic inflammation, recurrent infections or have potential for malignant degeneration).
   - Pressure symptoms like dysphagia and hoarseness are rarely seen with branchial cyst (though few cases have been documented in neonates).

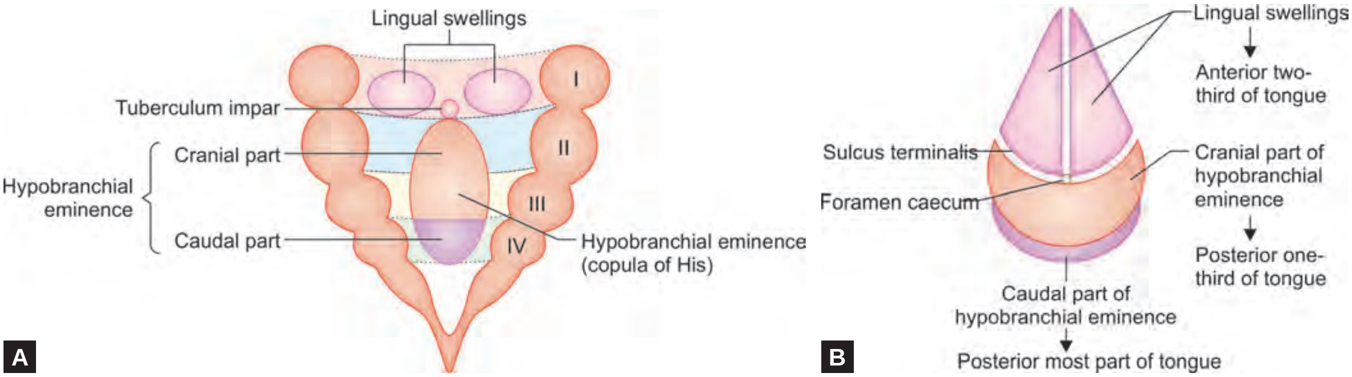
Development: Tongue and Thyroid

Tongue develops at the anterior wall of the primitive pharynx, which later becomes the floor of pharynx.

- Anterior two-thirds of the tongue develops in first pharyngeal arch from one median swelling (**tuberculum impar**) and two lateral **lingual swellings**.
- Posterior one-third of the tongue develops from the cranial part of **copula or hypobranchial eminence** that is formed by mesoderm of the pharyngeal arches 3 and 4.
- Posteriormost part of tongue develops from the **caudal part** of hypobranchial eminence.
- Intrinsic and extrinsic muscles of tongue are derived from myoblasts that migrate to the tongue region from **occipital somites** (except palatoglossus, which develops in pharyngeal arches).

Component	Developmental origin
Connective tissue	Pharyngeal arches 1, 3 and 4
Muscles	Occipital somites
Epithelium	Ectoderm (anterior 2/3) Endoderm (posterior tongue)*

*The endoderm-ectoderm junction is at sulcus terminalis.

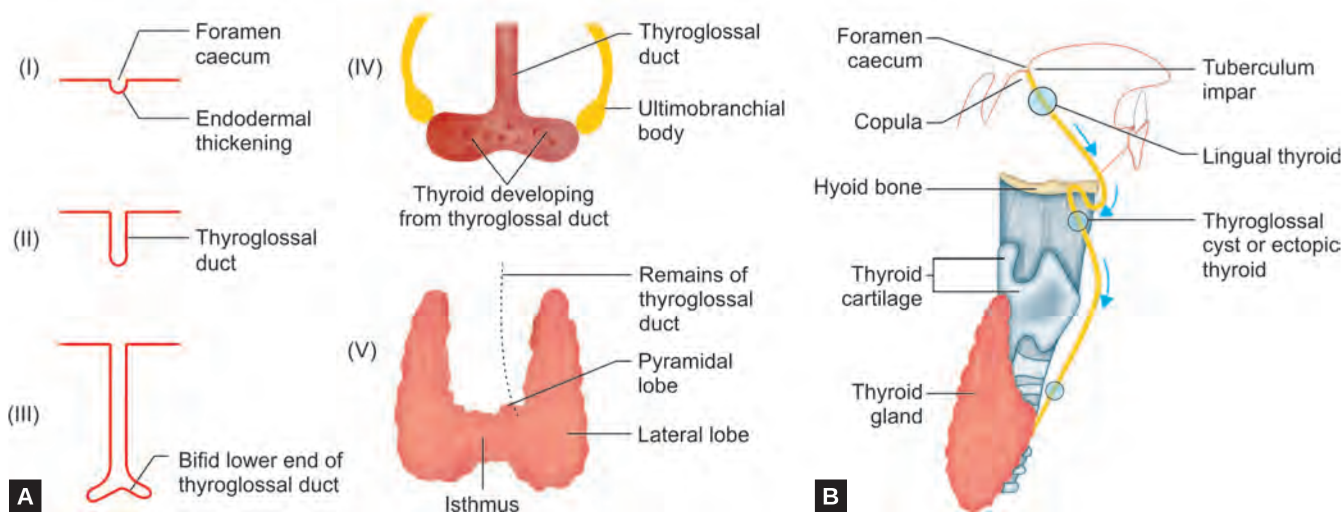


Figs. 16A and B: Tongue development at the floor of primitive pharynx. (A) Four swellings appear in the floor of pharynx. (B) Anterior two-third of tongue is derived by the growth and fusion of two lingual swellings and posterior one-third by the growth and fusion of cranial part of the hypobranchial eminence. Posteriormost part of tongue is contributed by he caudal part of hypobranchial eminence.

- **Thyroid Gland** develops from the thyroid diverticulum, which forms from the endoderm in the floor of the foregut (pharynx) and divides into right and left lobes that are connected by the isthmus of the gland.
- It descends caudally into the neck, passing ventral to the hyoid bone and laryngeal cartilages.
- During migration, the developing gland remains connected to the tongue by the thyroglossal duct, which is an endodermal tube and extends between the thyroid primordium and posterior part of the tongue.
- This duct is later obliterated, and the site of the duct is marked by the foramen cecum.
- Parafollicular C cells of thyroid are derived from the neural crest cells via the ultimobranchial body in the fourth pharyngeal pouch and then migrate into the thyroid gland.
- **Ultimobranchial body** is a remnant of the fifth pharyngeal pouch (which regresses) and attaches to the fourth pharyngeal pouch later.
- It receives the neural crest cells, which get transformed into parafollicular C cells of thyroid.
- Later these cells migrate to the thyroid gland and secrete thyrocalcitonin hormone.

Clinical Correlations

- **Thyroglossal duct cyst** is a cyst in the midline of the neck, resulting from lack of closure of a segment of the thyroglossal duct. It occurs most commonly in the region below the hyoid bone.
- As the cyst enlarges, it is prone to infection.
- Occasionally, a thyroglossal cyst ruptures spontaneously, producing a sinus as a result of an infection of the cyst.



Figs. 17A and B: Development of the thyroid gland. (A) Thyroid gland develops from the endoderm of the foramen caecum, by the formation of a thyroglossal duct. Neural crest cells in the ultimobranchial body contributes to the parafollicular C cells of thyroid. (B) Path taken by thyroglossal duct as it migrates inferiorly. from the foramen caecum in the tongue towards the adult position in the anterior triangle of neck.

ASSESSMENT QUESTIONS

1. **Parafollicular C cells are derived from:**
   a. Ultimobranchial body
   b. Pharyngeal pouch 4
   c. Pharyngeal pouch 5
   d. Neural crest cells

2. **Tongue muscles develops from:** *(NEET Pattern 2012)*
   a. Occipital somites
   b. Hypobranchial eminence
   c. Neural crest cells
   d. Pharyngeal pouches

3. Tongue muscle which is NOT developed from occipital myotome: *(NEET pattern 2015)*
a. Styloglossus
b. Hyoglossus
c. Genioglossus
d. Palatoglossus

4. Tongue develops from all EXCEPT:
a. Tuberculum impar
b. Hypobranchial eminence
c. Second arch
d. Lingual swellings

5. Posterior one-third of the tongue develops from: *(NEET pattern 2012)*
a. Lingual swellings
b. Tuberculum impar
c. Hypobranchial eminence
d. Tongue bud

6. The parafollicular C cells of thyroid develops from: *(JIPMER 2016)*
a. 1st and 2nd pharyngeal pouch
b. 2nd and 3rd pharyngeal pouch
c. 3rd and 4th pharyngeal pouch
d. 4th and 5th pharyngeal pouch

7. Maxillary prominence develops in: *(JIPMER)*
a. 1st pharyngeal arch
b. 1st pharyngeal groove
c. 1st pharyngeal pouch
d. 1st pharyngeal membrane

8. True about development all EXCEPT: *(PGIC)*
a. Parathyroid glands develop from 3rd and 4th pharyngeal pouch
b. Tongue muscles develop from occipital myotome
c. Superior parathyroid gland develops from 4th pharyngeal pouch
d. Inferior parathyroid gland develops from 2nd pharyngeal pouch
e. Thyroid develops form foramen caecum

ANSWERS WITH EXPLANATIONS

1. d. Neural crest cells
- Parafollicular C cells of thyroid gland develop from the neural crest cells.
- The Fifth pharyngeal pouch is rudimentary and disappears, leaving behind ultimobranchial body, which attaches to the fourth pharyngeal pouch.
- Neural crest cells reach the ultimobranchial body and get converted into parafollicular C cells of thyroid.

2. a. Occipital somites
- Tongue muscles develop from occipital myotomes and are innervated by the hypoglossal nerve.
- One tongue muscle (palatoglossus) develops in pharyngeal arch mesoderm.

3. d. Palatoglossus
- Tongue muscles develop from occipital myotomes except palatoglossus, which develop in pharyngeal arches.
- All tongue muscles are supplied by hypoglossal nerve except palatoglossus (supplied by the vagus accessory complex).

4. c. Second arch
- Second arch has negligible contribution in the adult tongue.

5. c. Hypobranchial eminence
- Posterior one-third of the tongue develops from the cranial part of hypobranchial eminence (copula of His).

6. d. 4th and 5th pharyngeal pouch
- Parafollicular C cells of thyroid gland develop from the neural crest cells.
- The fifth pharyngeal pouch is rudimentary and disappears, leaving behind ultimobranchial body, which attaches to the fourth pharyngeal pouch.
- Neural crest cells reach the ultimobranchial body and get converted into parafollicular C cells of thyroid.

7. a. 1st pharyngeal arch
- Two prominences develop in 1st pharyngeal (mandibular) arch.
- Maxillary prominence, which forms maxilla, zygomatic bone, squamous part of temporal bone.
- Mandibular prominence, which has Meckel's cartilage and forms mandible.

8. d. Inferior parathyroid gland develop from 2nd pharyngeal pouch
- Inferior parathyroid gland develops from 3rd pharyngeal pouch.

Development of Skull Bones

- **Neural crest cells** contribute to secondary mesenchyme which forms most of the skull bones.
- Additionally there are two contributions from primary mesenchyme: **Cranial paraxial mesenchyme** and **sclerotome** (paraxial mesenchyme), which give parietal and occipital bone components.
- Skull has three types of bones developmentally: **Cartilagenous**, **membranous** and **membranocartilaginous**

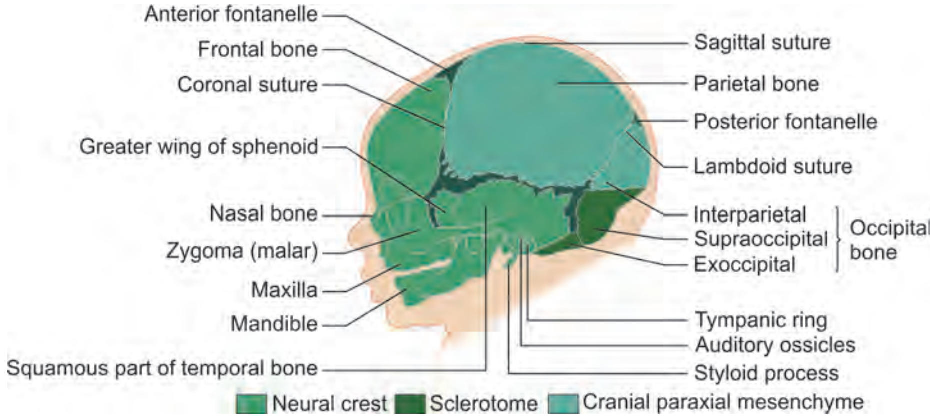
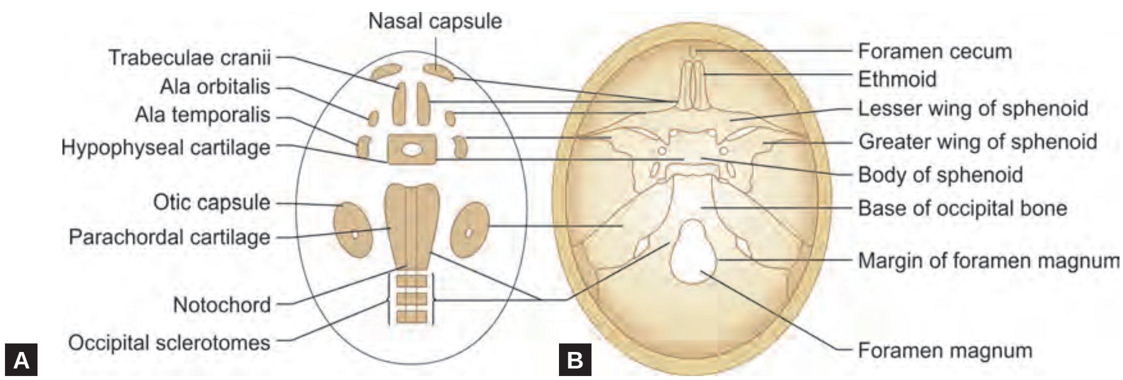


Fig. 18: The newborn skull, showing the tissue origins of the bones (based on combined mouse and human data). The darker green represents the sites of fontanelles.



Figs. 19A and B: Development of the base of the skull (dorsal view). (A) Cartilages that form cartilaginous neurocranium. (B) Bones of the base of the skull formed by various cartilages of neurocranium by endochondral ossification.

Table 3: Types of bones of skull according to their development (ossification)

Membranous bones (ossify in membrane)	Cartilaginous bones (ossify in cartilage)	Membranocartilaginous bones (ossify both in membrane and cartilage)
Frontal Parietal	Ethmoid Inferior nasal concha	Occipital (part above the superior nuchal line is membranous and the remaining part is cartilaginous)
Maxilla (Excluding premaxilla) Zygomatic Nasal		Sphenoid (Lateral parts of greater wings and pterygoid processes are membranous and rest is cartilaginous)
Lacrimal		Temporal (squamous) and tympanic parts are membranous while petromastoid part and styloid process are cartilaginous
Vomer		Mandible (condylar and coronoid proesses are cartilaginous and the rest of the mandible is membranous)

Skull at Birth

- The skull at birth, has **large calvaria** in proportion to other skeletal parts due to fast development of the brain, reaching 25% of its adult size at birth and 75% by the age of 4 years.
- Facial region is small and constitutes only about one-eighth of the neonatal skull (about half in the adult skull).
- Face is small due to the rudimentary stage of development of the mandible and maxillae; the teeth are unerupted and the maxillae are not yet pneumatized.
- Bones of the calvaria are **unilaminar** and **lack diploe**.
- The fibrous membrane that forms the calvaria remains unossified at the six angles of the parietal bones, producing **six fontanelles**: two single midline (anterior and posterior) and two lateral pairs: Sphenoidal (anterolateral) and mastoid (posterolateral).
- The **anterior fontanelle** is the largest, measuring approximately 4 cm in anteroposterior and 2.5 cm in transverse dimensions.
  - It occupies the junction between the sagittal, coronal and frontal sutures and is rhomboid in shape.
  - It pulsates because of the underlying cerebral arteries and can be used to obtain a blood sample from the underlying superior sagittal sinus.
- The **posterior fontanelle** lies at the junction between the sagittal and lambdoid sutures and is triangular in shape.

- The **sphenoidal** (anterolateral) and **mastoid** (posterolateral) fontanelles lie at the sphenoidal and mastoid angles of the parietal bones, respectively.
- Posterior fontanelle closes soon after birth, lateral fontanelles close within a few weeks of birth and anterior fontanelle closes by 2 years of age.

Figs. 20A and B: Foetal skull. (A) Lateral view. (B) Superior view.

- During fetal life and infancy, the flat bones of the skull are separated by dense connective tissue called **sutures**, which are immovable in adult life.
- **Coronal** Suture lies between the frontal bone and the two parietal bones.
- **Sagittal** Suture is present between the two parietal bones.
- Squamous (**Squamoparietal**) Suture lies between the parietal bone and the squamous part of the temporal bone.
- **Lambdoid** Suture is present between the two parietal bones and the occipital bone.
- **Metopic** suture lies in the median plane and separates the two halves of the frontal bone.
- At birth, the **orbits are relatively large**, the internal ear, tympanic cavity, auditory ossicles and mastoid antrum are all **almost adult in size**, and the **mastoid process is absent**.
- The external acoustic meatus is short, straight and wholly cartilaginous.
- The external aspect of the tympanic membrane faces more inferiorly than laterally.
- The **styloid process** has not yet commenced ossification, paranasal sinuses are rudimentary or absent and only the **maxillary sinuses** are usually identifiable.
- Mandible at birth is in two halves, united by the fibrous tissue at the symphysis menti.
- **Postnatal growth** of skull: Growth of the brain continues to be extremely rapid in the first 2 years.
- The **metopic suture** (between two halves of frontal bones) fuses during the first year (between 3 and 9 months of age).
- The inner ear and the **petrous temporal bone** around it grow very little after birth, so the increasing breadth of the skull draws the petrous temporal bone out laterally, creating the bony **external acoustic meatus**.
- Use of sternocleidomastoid to lift the head results in formation of the **mastoid process** of the temporal bone (during the later part of 2nd year), which develops air-filled spaces (**mastoid air cells**) during 6th year.
- The **paranasal sinuses** begin to form in late fetal life as diverticula from the nasal cavity that gradually invade the maxilla, frontal, ethmoid and sphenoid bones.
- Paranasal sinuses are rudimentary at birth. The maxillary sinus is the 1st PNS to develop and is identifiable at birth. Maxillary antrum enlarges with age.
- At birth, small **ethmoidal** sinuses are also present, but the **frontal** sinus is nothing more than an out-pouching from the nasal cavity, and there is no pneumatization of the **sphenoid** bone.
- Diploe (and diploic veins) are present in the skull at birth – they appear by 4th year of age.

Structures at adult size (at birth)	Structures not at adult size (at birth)
• Tympanic membrane • Tympanic cavity • Ear ossicles (malleus, incus and stapes) • Tympanic (mastoid. antrum • Internal ear: Cochlea, vestibule, semicircular canal	• Tegmen tympani • Mastoid process • External ear and external auditory canal • Eustachian tube

ASSESSMENT QUESTIONS

1. **Facial skeleton develops form:** *(NEET Pattern 2013)*
   a. Neural crest
   b. Paraxial mesoderm
   c. Intermediate mesoderm
   d. Lateral plate mesoderm

2. **All are of adult size at birth EXCEPT:** *(AIIMS 2009)*
   a. Mastoid antrum
   b. Ear ossicles
   c. Tympanic cavity
   d. Maxillary antrum and orbit

3. **Which of the following attains adult size before birth:** *(AIIMS 2010)*
   a. Ear ossicles
   b. Maxilla
   c. Mastoid
   d. Parietal bone

4. **Suture present between parietal and occipital bones is:** *(NEET Pattern 2012)*
   a. Lambdoid suture
   b. Coronal suture
   c. Sagittal suture
   d. Metopic suture

ANSWERS WITH EXPLANATIONS

1. **a. Neural crest**
   - The viscerocranium consists of the bones of the face that develop from the secondary mesenchyme, derived from neural crest cells in the 1st and 2nd pharyngeal arches.
2. **d. Maxillary antrum and orbit**
   - **Tympanic cavity**, **mastoid (tympanic) antrum**, **ear ossicles** and the Internal ear are of adult size in the foetal skull.
   - Mastoid process is absent at birth - appears during the later part of 2nd year and the mastoid air cells appear during 6th year.
   - Paranasal sinuses are rudimentary at birth. The maxillary sinus is the 1st PNS to develop and is identifiable at birth. Maxillary antrum enlarges with age.
   - At birth the orbits appear relatively large. Growth of the orbits is complete by 7th year.
3. **a. Ear ossicles**
   - Ear ossicles are almost of adult size at birth. Maxilla, mastoid and parietal bones change their features significantly after birth.
4. **a. Lambdoid suture**
   - **Lambdoid** Suture is present between the two parietal bones and the occipital bone
   - **Coronal** Suture lies between the frontal bone and the two parietal bones.
   - **Sagittal** Suture is present between the two parietal bones.
   - **Metopic** suture lies in the median plane and separates the two halves of the frontal bone.

Skull Bones

- The **skull** is composed of 28 separate bones and is divided into two parts: The neurocranium and viscerocranium.
- **Neurocranium** consists of the flat bones of the skull (i.e. cranial vault) and the base of the skull, which include the **eight cranial bones** for enclosing the brain (unpaired frontal, occipital, ethmoid, and sphenoid bones and paired parietal and temporal bones), which can be seen in the cranial cavity.
- **Viscerocranium:** The viscerocranium consists of the bones of the face that develop from the pharyngeal arches in embryologic development, which include the following **Fourteen facial bones** (paired lacrimal, nasal, palatine, inferior turbinate, maxillary, and zygomatic bones and unpaired vomer and mandible).
- **Cranium** is the skull without the mandible.
- **Calvaria** is the skullcap, which is the vault of the skull without the facial bones. It consists of the superior portions of the frontal, parietal, and occipital bones. Its highest point on the sagittal suture is the vertex.

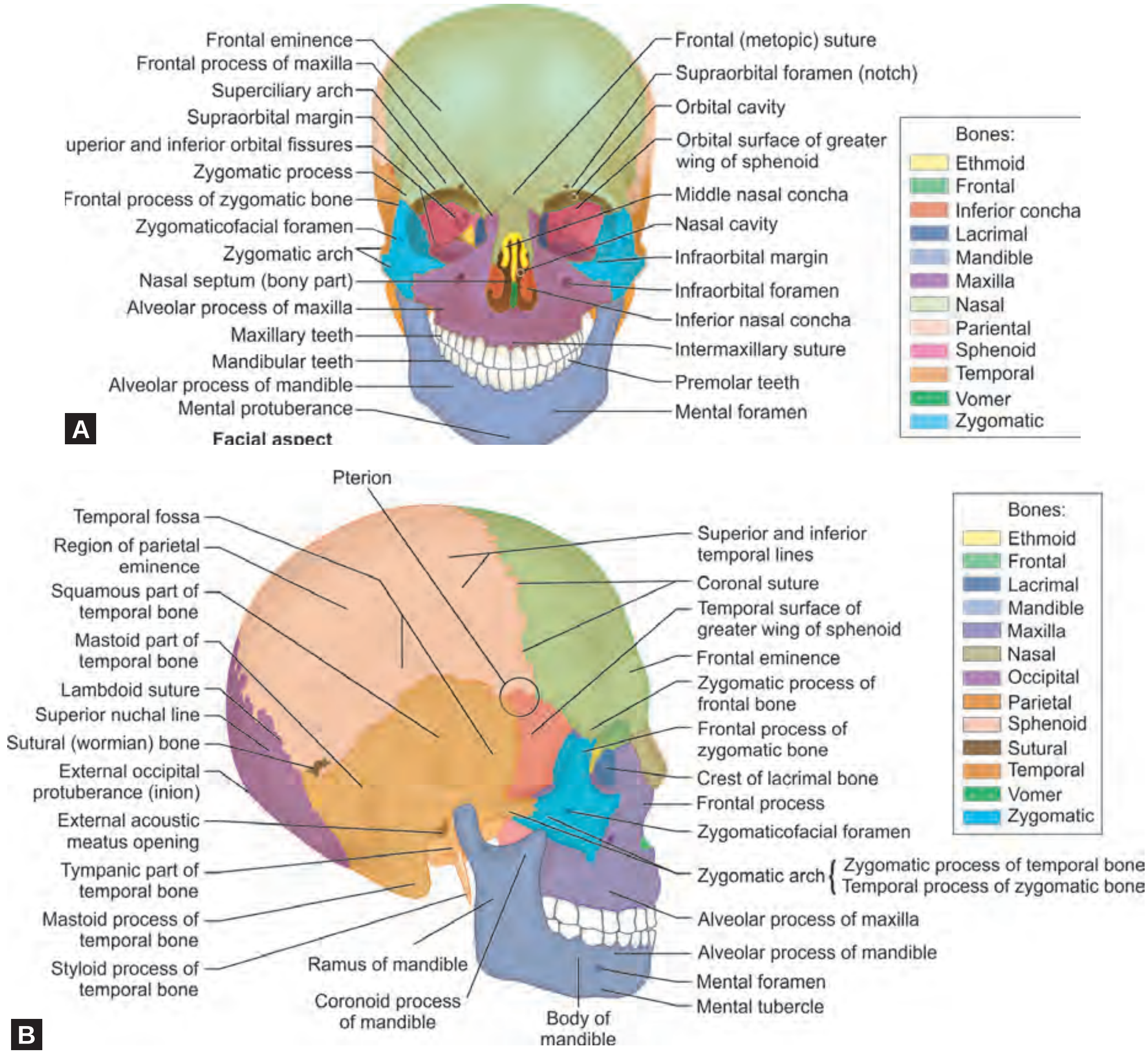
Bones of cranium:

- **Frontal bone** is a pneumatic bone which underlies the forehead and the superior margin and roof of the orbit and has a smooth median prominence called the glabella.
- **Parietal bone** forms part of the superior and lateral surface of the skull.
- **Temporal bone** consists of the squamous part, which is external to the lateral surface of the temporal lobe of the brain; the petrous part, which encloses the internal and middle ears; the mastoid part, which contains mastoid air cells; and the tympanic part, which houses the external auditory meatus and the tympanic cavity.
- **Occipital bone** consists of squamous, basilar, and two lateral condylar parts. It encloses the foramen magnum and forms the cerebral and cerebellar fossae.
- **Sphenoid** is a pneumatic bone, consists of the body (with sphenoid air sinus), the greater and lesser wings, and the pterygoid process.
- **Ethmoid** is a pneumatic bone located between the orbits and consists of the cribriform plate, perpendicular plate, and two lateral masses enclosing ethmoid air cells.
- Air sinuses are present in the paranasal (around the nose) bones like maxilla and ethmoidal.
- Mastoid bone belongs to temporal bone and has mastoid air sinuses related to middle ear, which itself contains air.
- Pneumatic (air) bones work as air-conditioners by increasing or decreasing the temperature of inhaled air and adding moisture (conditioning) to it, if needed.
- These bones also work as resonance chambers and improve the quality of voice output.
- They keep the skull lighter—common cold leads to fluid accumulation in their sinuses and lead to the feeling of 'heavy head.'

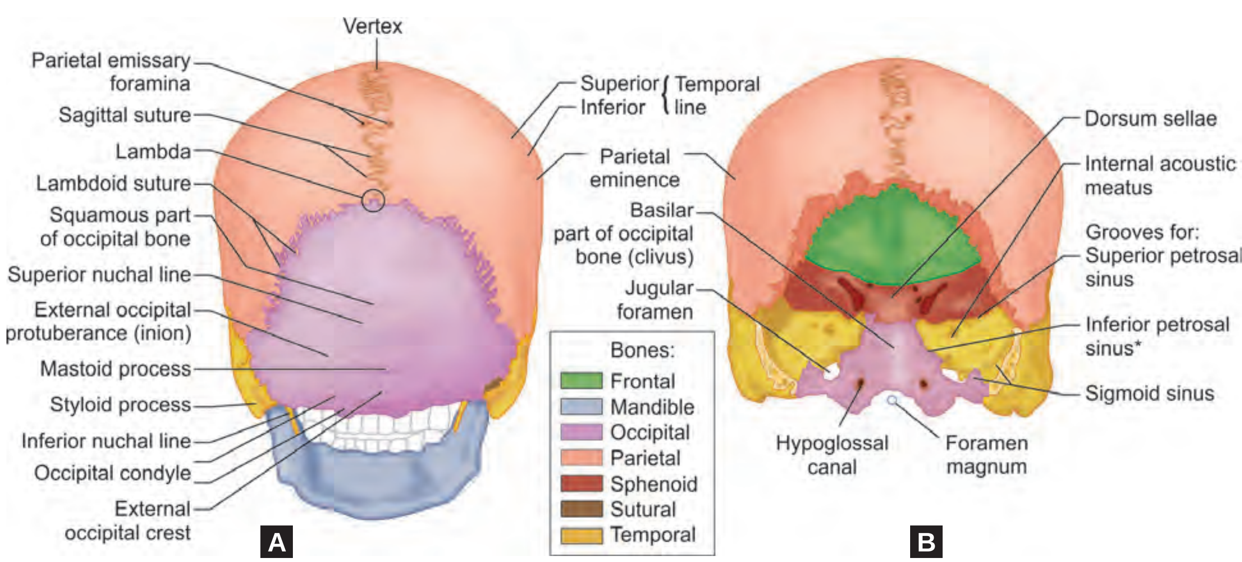
Clinical Correlations

- Skull fracture of anterior cranial fossa causes anosmia, periorbital bruising (raccoon eyes), and CSF leakage from the nose (rhinorrhea).

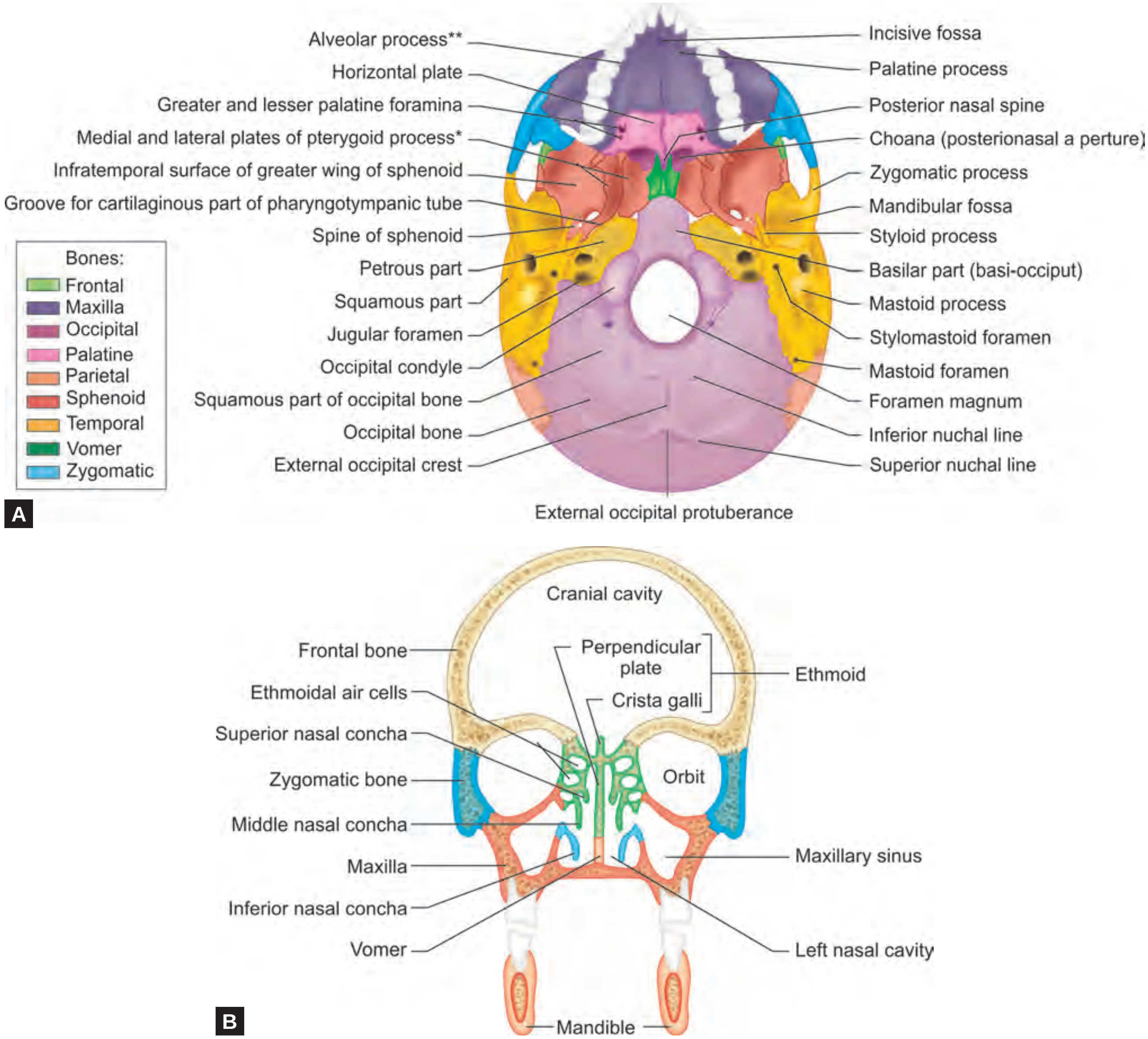
- Fracture of the of the petrous portion of the temporal bone may cause blood or cerebrospinal fluid (CSF) to escape from the ear, hearing loss, and facial nerve damage.



Figs. 21A and B: (A) Norma frontalis with colour coded skull bones. (B) Norma lateralis.



Figs. 22A and B: Cranium: Occipital aspect. (A) The posterior aspect of the neurocranium, or occiput, is composed of parts of the parietal bones, the occipital bone, and the mastoid parts of the temporal bones. The sagittal and lambdoid sutures meet at the lambda, which can often be felt as a depression in living person. (B) The squamous part of the occipital bone has been removed to expose the anterior part of the posterior cranial fossa.



Figs. 23: Skull: (A) Norma basalis. (B) coronal section of skull bones, anterior view.

*Collectively form pterygoid process of spherinoid

**The U. shapted (inverted here) ridge formed by the free border of the adveolar processes of the right and left maxillae make up the adveolar arch

Styloid Process extends downward and forward from the temporal bone and gives origin to three muscles (stylohyoid, styloglossus, and stylopharyngeus) and two ligaments (stylohyoid and stylomandibular).

ASSESSMENT QUESTIONS

1. Metopic sutures closes at: *(NEET Pattern 2013)*

a. 6 months
b. 3 years
c. 6 years
d. 60 years

2. Suture present between parietal and occipital bones is: *(NEET Pattern 2012)*

a. Lambdoid
b. Sagittal
c. Coronal
d. Metopic

3. Thinnest bone is a part of which bone: *(NEET Pattern 2014)*

a. Frontal
b. Ethmoid
c. Sphenoid
d. Temporal

4. All of the following are pneumatic bones EXCEPT: *(AIIMS 2003)*

a. Maxilla
b. Parietal
c. Ethmoid
d. Mastoid

ANSWERS WITH EXPLANATIONS

1. **a. 6 months**
    - Metopic suture is the frontal suture between the two halves of frontal bone, runs through the midline across the frontal bone from the nasion to the bregma. It completely fuses between 3 and 9 months of age.
    - Forensic books mention the closure between the age of 2–8 years. (?)
2. **a. Lambdoid**
    - Lambdoid suture is on the posterior aspect of the skull that connects the parietal bones with the occipital bone.
    - It is continuous with the occipitomastoid suture.
3. **b. Ethmoid**
    - Ethmoid bone is papery thin.
4. **b. Parietal**
    - Parietal bone is not related to nose or ear and hence it does not show air spaces, i.e. it is not a pneumatic bone.
    - Air sinuses are present in the paranasal (around the nose) bones like maxilla and ethmoidal.
    - Mastoid bone belongs to temporal bone and has mastoid air sinuses related to middle ear, which itself contains air.

Cranial Cavity/Skull Foramina

- The floor of the cranial cavity is divided into three cranial fossa: anterior, middle and posterior, all of which contain foramina and fissures through which blood vessels and cranial nerves are transmitted.

Structures seen inside the cranial fossa:

- **Foramen Cecum** is a small pit in front of the crista galli between the ethmoid and frontal bones.
- **Crista Galli** is the triangular midline projection of the ethmoid bone extending upward from the cribriform plate, provides attachment for the dural fold falx cerebri.
- **Cribriform Plate** of the Ethmoid Bone is at roof of nasal cavity, perforated by 15 to 20 foramina, supports the olfactory bulb, and transmits the axons of olfactory nerve from the olfactory mucosa to the olfactory bulb.
- **Anterior Clinoid Processes** are two anterior processes of the lesser wing of the sphenoid bone, in the middle cranial fossa, provide attachment for the free border of the tentorium cerebelli.
- **Middle Clinoid Process** is a small inconstant eminence on the body of the sphenoid, posterolateral to the tuberculum sellae.
- **Posterior Clinoid Processes** are two tubercles from each side of the dorsum sellae, provide attachment for the attached border of the tentorium cerebelli.
- **Lesser Wing of the Sphenoid** Bone forms the anterior boundary of the middle cranial fossa, forms the sphenoidal ridge separating the anterior from the middle cranial fossa, contributes to the boundary of the superior orbital fissure.
- **Superior orbital fissure** is a gap between the lesser wing of sphenoid and greater wing of sphenoid.
- **Greater Wing of the Sphenoid** Bone forms the anterior wall and the floor of the middle cranial fossa. It has several openings: the foramen **rotundum**, foramen **ovale**, canaliculus innominatus and foramen **spinosum**.
- **Sella Turcica** (Turkish Saddle) of the Sphenoid Bone is bounded anteriorly by the tuberculum sellae and posteriorly by the dorsum sellae.
- It has a deep central depression known as the pituitary (hypophyseal) fossa, which accommodates the pituitary gland or the hypophysis.
    - It lies directly above the sphenoid sinus located within the body of the sphenoid bone; its dural roof is formed by the diaphragma sellae.
- **Jugum Sphenoidale** is a portion of the body of the sphenoid bone connecting the two lesser wings and forms the roof for the sphenoidal air sinus.
- **Clivus** is the downward sloping surface from the dorsum sellae to the foramen magnum.
- It is formed by a part of the body of the sphenoid and a portion of the basilar part of the occipital bone.
- The spheno-occipital joint is a synchondrosis.
- It is related to the anterior aspect of brainstem.

Anterior Cranial Fossa

Foramen	Contents
Cribriform plate	Olfactory nerve
Foramen cecum	Emissary vein from nasal mucosa to superior sagittal sinus
Anterior and posterior ethmoidal foramina	Anterior and posterior ethmoidal nerves, arteries, and veins

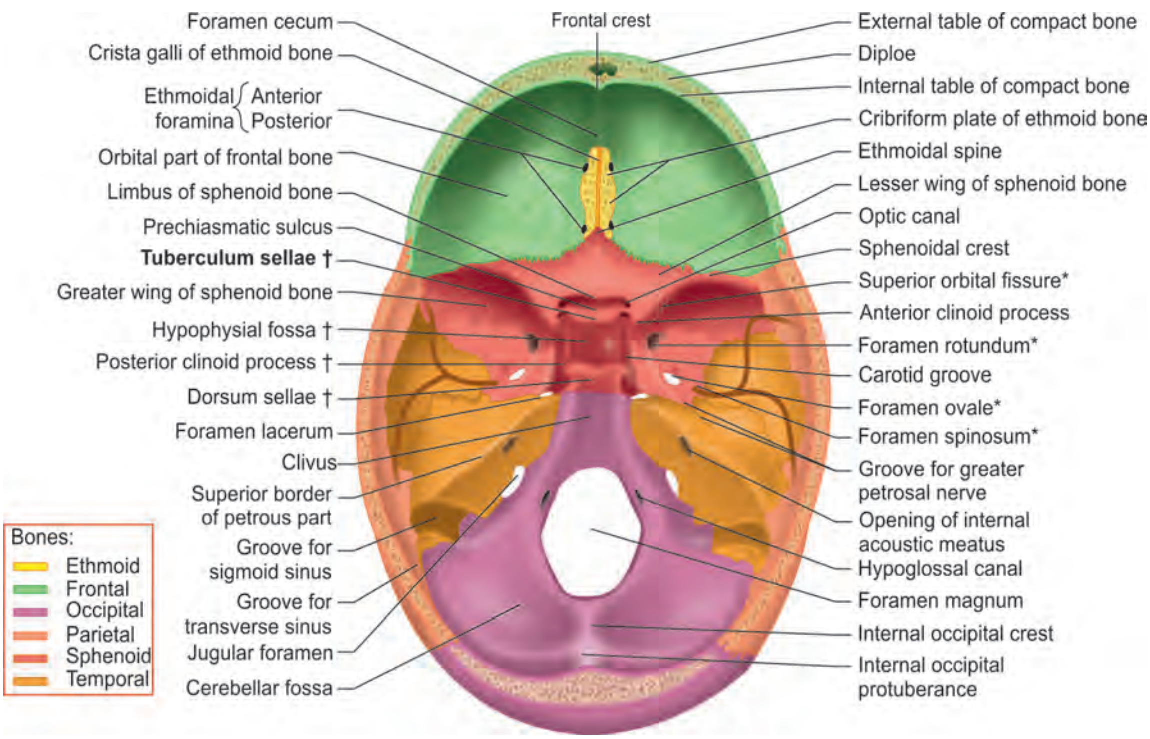


Fig. 24: Superior view, internal surface of cranial base

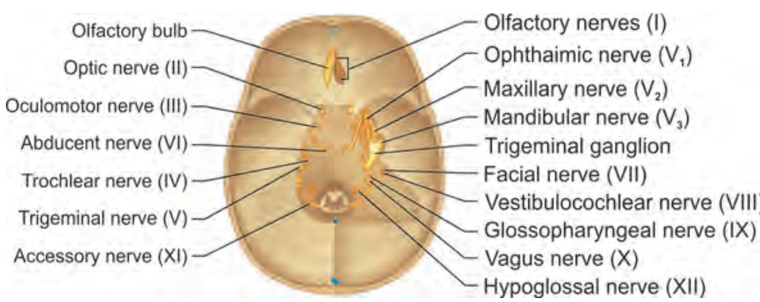


Fig. 25: Cranial cavity showing the relation of cranial nerves with corresponding foramina.

Middle Cranial Fossa

Foramen	Contents
Optic canal	Optic nerve, ophthalmic artery, and central artery and vein of the retina
Superior orbital fissure (through CTRZ*)	Oculomotor nerve (superior and inferior division), abducent nerves and nasociliary nerve (branch of ophthalmic division of trigeminal nerve)
Superior orbital fissure (left outside the ring)	LFT* nerves: Lacrimal and frontal nerves (branches of ophthalmic division of trigeminal nerve), trochlear nerve and ophthalmic (superior and inferior) veins
Foramen rotundum	Maxillary division of trigeminal nerve
Foramen ovale	Mandibular division of trigeminal nerve, accessory meningeal artery, Lesser petrosal nerve, Emissary vein. Mnemonic: MALE
Canaliculus innominatus	Lesser petrosal nerve (occasionally)
Foramen spinosum	Middle meningeal artery, nervus spinosus
Foramen lacerum	No structure passes through this foramen, but the upper part is traversed by the internal carotid artery (and sympathetic plexus around), deep petrosal nerves and greater petrosal nerves joining to form vidian nerve of pterygoid canal
Carotid canal	Internal carotid artery and sympathetic nerves (carotid plexus)
Hiatus of facial canal	Greater petrosal nerve
*CTRZ: Common tendinous ring of Zinn	

Note: *LFT nerves are LeFT outside the common tendinous ring of Zinn.

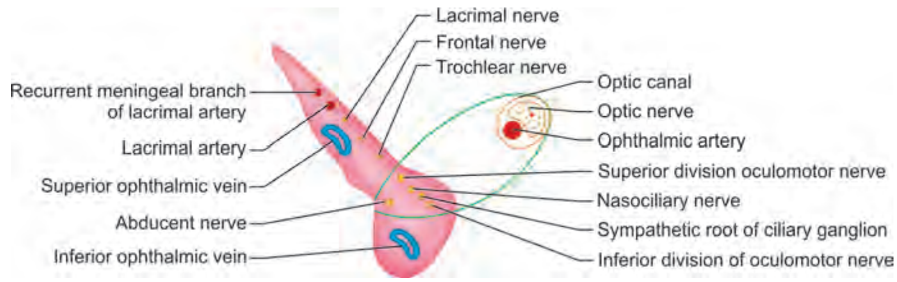


Fig. 26: The superior orbital fissure.

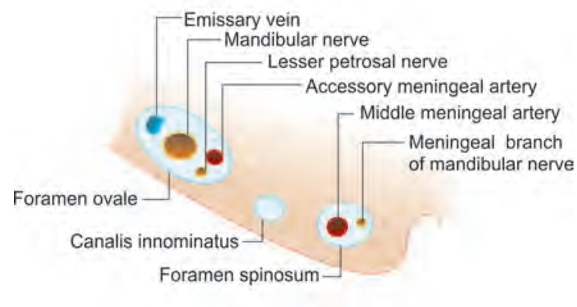


Fig. 27: Structures passing through foramen oval and spinosum.

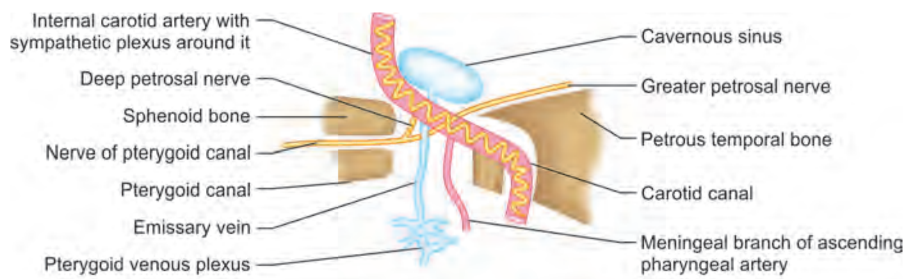


Fig. 28: Structures at the base and passing through the foramen lacerum.

Posterior Cranial Fossa

Foramen	Contents
Internal auditory meatus	Facial and vestibulocochlear nerves and labyrinthine artery
Jugular foramen (anterior part)	Inferior petrosal sinus
Jugular foramen (middle part)	Cranial nerves 9, 10, 11 (cranial and spinal)
Jugular foramen (posterior part)	Junction of sigmoid sinus and internal jugular vein Meningeal branch of occipital artery
Hypoglossal canal	Hypoglossal nerve and meningeal artery.
Foramen magnum (Anterior part)	Apical ligament of dens Membrana tectoria Vertical band of cruciate ligament
Foramen magnum (posterior part)	Lower part of medulla oblongata Meninges (dura, arachnoid and pia mater) In subarachnoid space: Spinal root of accessory nerves Vertebral arteries and sympathetic plexus Anterior and posterior spinal arteries Venous plexus of vertebral canal
Condyloid foramen	Condyloid emissary vein
Mastoid foramen	Branch of occipital artery to dura mater and mastoid emissary vein

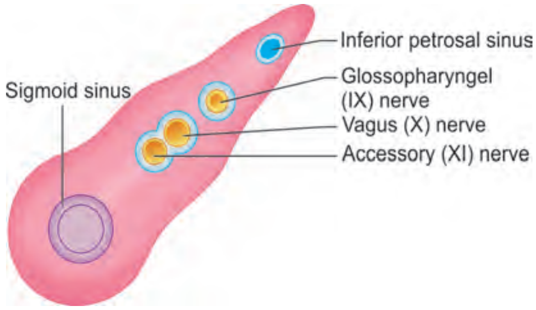


Fig. 29: Structures passing through the jugular foramen

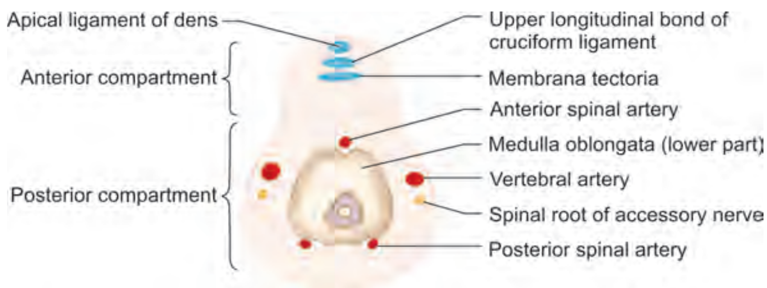


Fig. 30: Structures passing through the foramen magnum

Foramina in the Base of the Skull

Foramen	Contents
Petrotympanic fissure	Chorda tympani and often anterior tympanic artery
Stylomastoid foramen	Facial nerve
Incisive canal	Nasopalatine nerve and terminal part of the sphenopalatine or greater palatine vessels
Greater palatine foramen	Greater palatine nerve and vessels
Lesser palatine foramen	Lesser palatine nerve and vessels
Palatine canal	Descending palatine vessels and the greater and lesser palatine nerves
Pterygoid canal	Runs from the anterior wall of the foramen lacerum to the pterygopalatine fossa and transmits the nerve of the pterygoid canal (vidian nerve)
Sphenopalatine foramen	Sphenopalatine vessels and nasopalatine nerve

Foramina in the Front of the Skull

Foramen	Contents
Zygomaticofacial foramen	Zygomaticofacial nerve
Supraorbital notch or foramen	Supraorbital nerve and vessels
Infraorbital foramen	Infraorbital nerve and vessels
Mental foramen	Mental nerve and vessels

High Yield Point

- Membrana tectoria is continuation of posterior longitudinal ligament on vertebral column and enters cranial cavity passing through foramen magnum.

ASSESSMENT QUESTIONS

1. Which of the following cranial nerves present in the posterior fossa: *(AIIMS 2006)*
   a. 3rd to 12th
   b. 4th to 12th
   c. 5th to 12th
   d. 6th to 12th

2. Duramater is supplied by all cranial nerves EXCEPT: *(AIIMS 2009)*
   a. 12
   b. 10
   c. 5
   d. 4

3. CSF rhinorrhea leakage occurs through:
   a. Frontal sinus
   b. Sphenoid sinus
   c. Ethmoid sinus
   d. Tegmen tympani

4. All structures pass through foramen ovale EXCEPT:
   a. Accessory meningeal artery
   b. Middle meningeal artery
   c. Lesser petrosal nerve
   d. Emissary vein

5. Structure passing through the tendinous ring of Zinn
   a. Superior ophthalmic vein
   b. Trochlear nerve
   c. Nasociliary nerve
   d. Lacrimal nerve

6. Mass in jugular foramen may result in all EXCEPT:
   a. Difficulty in swallowing
   b. Hoarseness
   c. Difficulty in turning the neck to opposite side
   d. Tongue deviates to same side

7. Lesser petrosal nerve passes through
a. Foramen rotundum
b. Foramen ovale
c. Canaliculus innominatus
d. Foramen spinosum

8. Incisive foramen transmits: *(NEET Pattern 2015)*
a. Greater palatine artery and greater palatine nerve
b. Greater palatine artery and lesser palatine nerve
c. Greater palatine artery and sphenopalatine nerve
d. Greater palatine artery and nasopalatine nerve

9. Choose the incorrect pair regarding the skull foramina and the structures passing through: *(PGIC)*
a. Maxillary nerve: Foramen rotundum
b. Vestibulocochlear nerve: Internal acoustic meatus
c. Anterior part of jugular foramen: Inferior petrosal sinus
d. Foramen spinosum: Middle meningeal artery
e. Superior orbital fissure: Optic nerve

10. Structures which passes through the internal auditory meatus are all EXCEPT: *(NEET Pattern 2014)*
a. Nerve of Wrisberg
b. Anterior inferior cerebellar artery
c. Superior vestibular nerve
d. Cochlear nerve

11. Dorello's canal transmits: *(NEET Pattern 2015)*
a. Middle meningeal artery
b. Mandibular nerve
c. Superior alveolar branch of maxillary
d. Abducent nerve

12. Cranial nerve related to apex of the petrous temporal bone: *(PGIC 2005)*
a. IX
b. VIII
c. VII
d. VI
e. V

13. All is true for Sternberg canal EXCEPT: *(AIPG 2009)*
a. Interior and medial to foramen rotundum
b. Posterior and lateral to foramen rotundum
c. Cause of intra-sphenoidal meningocele
d. Can carry infection to sphenoidal sinus

14. Which structure passes through foramen magnum: *(AIPG 2010)*
a. Vertebral artery
b. Internal carotid artery
c. Hypoglossal nerve
d. Sympathetic chain

ANSWERS WITH EXPLANATIONS

1. a. 3rd to 12th
- Posterior cranial fossa has the brainstem which gives cranial nerve 3–12, hence these nerves are present in the fossa.
- The last six nerves (7–12) enter/exit through the foramina present in the posterior cranial fossa.

2. d. 4
- Cranial nerve 4 (trochlear) do not supply dura mater.
- It is a pure motor nerve which supply the skeletal muscle superior oblique in the eyeball.

3. c. Ethmoid sinus
- In fracture of anterior cranial fossa, cribriform plate of ethmoid bone may be involved, leading to CSF rhinorrhea.
- The ethmoid air sinuses are filled with CSF in this case.

4. b. Middle meningeal artery
- '**MALE**' structures pass through foramen ovale: **M**andibular division of trigeminal nerve, **A**ccessory meningeal artery, **L**esser petrosal nerve, **E**missary vein.
- Middle meningeal artery passes through foramen spinosum, along with nervus spinosus (branch of mandibular nerve).

5. c. Nasociliary nerve
- Nasociliary nerve passes inside (though) the common tendinous ring of Zinn.
- LFT nerves are left outside the ring (L - Lacrimal, F - Frontal, T - Trochlear).
- Superior and inferior ophthalmic veins usually remain outside the ring of Zinn.

6. d. Tongue deviates to same side
- Hypoglossal nerve passes through hypoglossal canal (and not jugular foramen).
- Jugular foramen has cranial nerves 9, 10, and 11 passing through it, which supply the muscles of palate, pharynx and larynx (for speech and swallowing).
- A mass in the foramen leads to paralysis of these muscles and difficulty in speech and swallowing.
- Injury to spinal part of accessory nerve leads to paralysis of sternocleidomastoid muscle and difficulty in turning the neck to opposite side.

7. b. Foramen ovale > c. Canaliculus innominatus
- Lesser petrosal nerve passes through the foramen ovale (and canaliculus innominatus in small percentage of population).

8. d. Greater palatine artery and nasopalatine nerve
- Incisive foramina is located behind the central incisor teeth in the incisive fossa of the maxilla (hard palate).
- It receives the nasopalatine nerves from the floor of the nasal cavity along with the greater palatine vessels supplying the mucous membrane covering the hard palate of the mouth.

9. e. Superior orbital fissure: Optic nerve
- Optic nerve passes through the optic canal.

10. b. Anterior inferior cerebellar artery
- Labyrinthine vessels passing through internal auditory meatus.
- Vestibulocochlear and facial nerves also pass through the meatus.
- Nerve of Wrisberg (nervus intermedius) is sensory component of facial nerve.

11. d. Abducent nerve
- Dorello's Canal is the bow-shaped enclosure surrounding the abducens nerve as it enters the cavernous sinus.
- It is present at the medial most end of the petrous ridge at the confluence of the inferior petrosal sinus and cavernous sinus.

12. d. VI, e. V
- Apex of petrous temporal bone is related to cranial nerve V and VI.

13. b. Posterior and lateral to foramen rotundum
- Sternberg's canal is anteromedial to the foramen rotundum and not posterolateral.
- It is situated at the attachment of posterior root of lesser wing to the body of sphenoid.
- Sternberg's canal is the lateral craniopharyngeal canal connecting middle cranial fossa with the nasopharynx.
- This canal is considered as the congenital origin for the intrasphenoidal meningocele.
- Sometimes a medial craniopharyngeal canal may be observed, running from the anterior part of the hypophyseal fossa to the exterior of the skull.
- The Sternberg's canal is in the para-sellar region of middle cranial fossa and communicates with the sphenoidal sinus as well as with the pterygopalatine fossa and/or the nasopharynx depending upon the course of the canal. Infection may be carried from the nasopharynx towards the sphenoidal sinus via the canal.

14. a. Vertebral artery
- Foramen magnum has the two vertebral arteries and three spinal arteries passing through it.
- Major structures passing foramen magnum are: Medulla oblongata with the 3 meninges, Two vertebral arteries, Three spinal arteries (one anterior and two posterior), Spinal part of accessory nerve, few ligaments.
- Internal carotid artery passes through the carotid canal in the petrous temporal bone at the base of the skull.
- Hypoglossal nerve passes the hypoglossal canal present in the occipital bone.
- Sympathetic chain begins at the foramen magnum and continues till the coccyx. The superior end of it is continued upward through the carotid canal into the skull, and forms a plexus on the internal carotid artery; the inferior part travels in front of the coccyx, where it converges with the other trunk at a structure known as the ganglion impar.

High Yield Points

- Tumours of anterior cranial fossa damage the olfactory bulb *(NEET Pattern 2015)*
- Vertical crest in fundus of the *internal auditory canal* is called **Bill's bar.** *(AIIMS 2011)*
- **Maxillary nerve** arises in the trigeminal ganglion (middle cranial fossa), passes through lateral wall of cavernous sinus and leaves the skull through **foramen rotundum** to enter the pterygopalatine fossa.
- **Bill's bar**: A vertical crest that separates the superior fundus in the **internal auditory canal** into anterior and posterior portions containing the **facial nerve** (and nervus intermedius) and the **superior vestibular nerve**, respectively. **(AIIMS 2011)**

Intracranial Haemorrhage

- Hemorrhages within the head area include: **Epidural** hemorrhage, **subdural** hemorrhage, **subarachnoid** hemorrhage.
- **Epidural Hemorrhage** is caused by a skull fracture near the pterion and is associated with the middle cranial fossa.
- Middle meningeal artery is ruptured and blood is collected between the skull and dura mater.
- It presents with a medical emergency and a lucid interval for a few hours is followed by death if not attended to.
- CT scan reveals a lens-shaped (biconvex) hyperdensity adjacent to bone.
- It may cause a transtentorial herniation that compresses oculomotor nerve causing ipsilateral dilated pupil and compresses the cerebral peduncles causing contralateral hemiparesis.
- It is a classic medical emergency that requires a craniotomy (burr holes) for blood clot evacuation and coagulation of the ruptured vessel.
- **Subdural Hemorrhage** is caused by a violent shaking of the head and commonly occurs in alcoholics and elderly.
- It is venous bleed from superior cerebral veins (bridging veins) and blood is located between the dura and arachnoid.
- CT scan shows a thin, crescent-shaped hyperdensity that hugs the contours of the brain; blood accumulates slowly (days to weeks after trauma).
- **Subarachnoid Hemorrhage** is caused by a contusion or laceration injury to the brain or a berry aneurysm.
- CT scan shows a hyperdensity in the cisterns, fissures, and sulci of the brain; arterial blood with the subarachnoid space; irritation of the meninges causes a sudden onset of the 'worst headache of my life,' blood is found within the CSF in lumbar puncture.

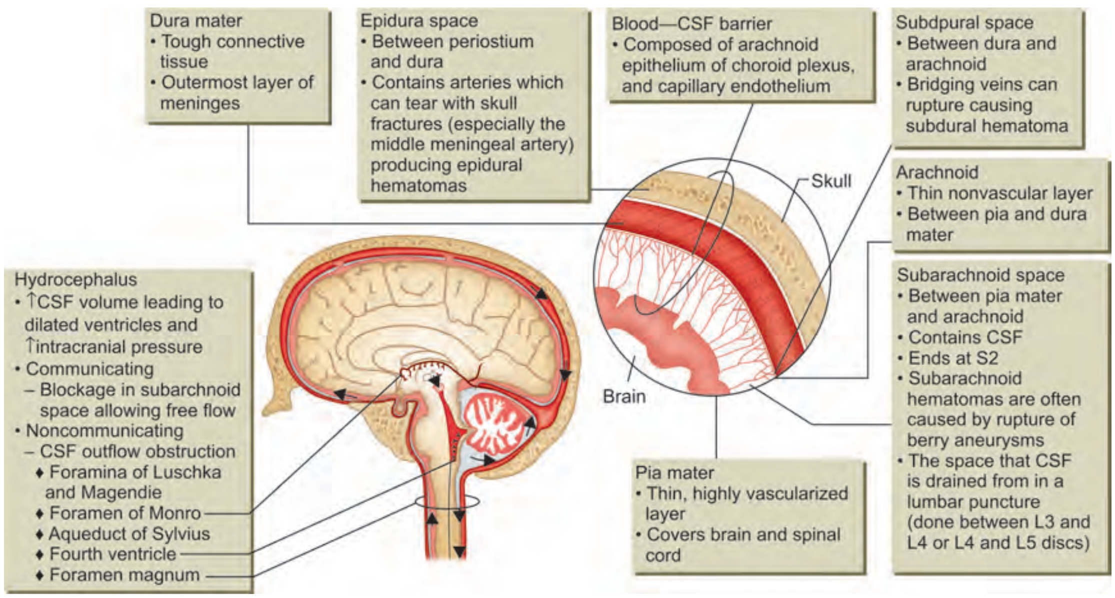
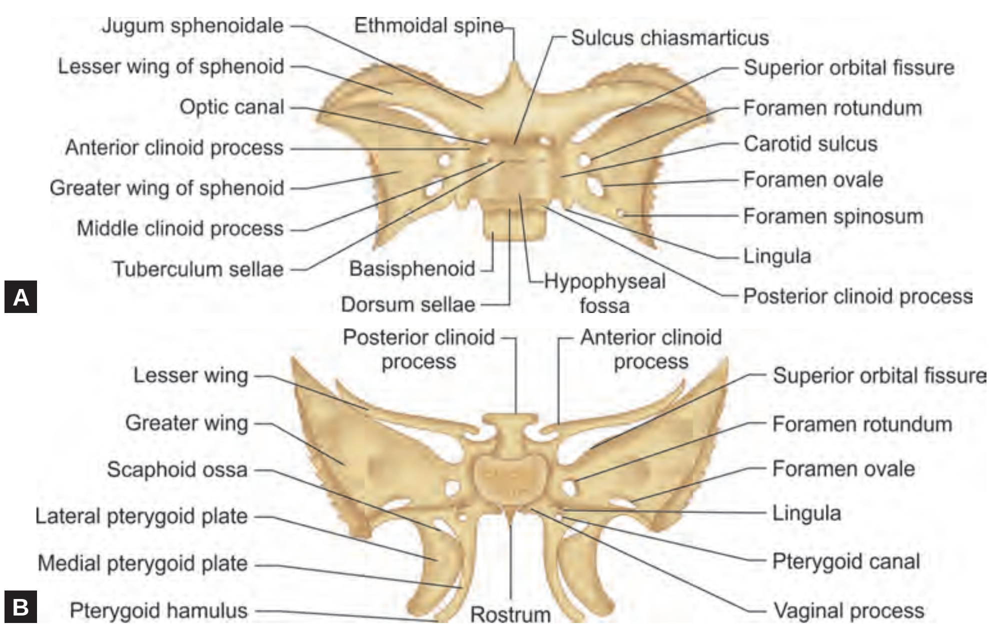
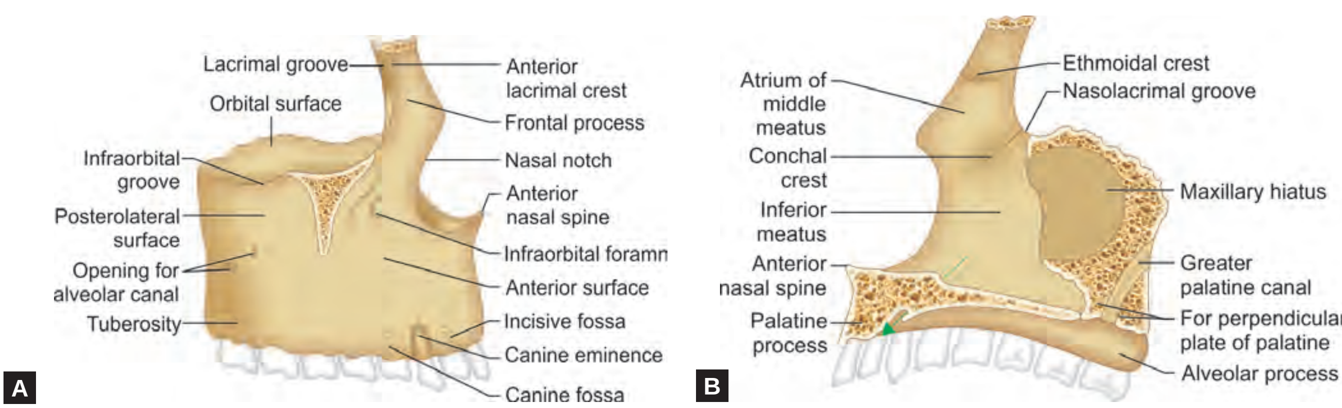


Fig. 31: Diagram showing various cranial spaces and types of hydrocephalus & haemorrhages.

Individual Skull Bones



Figs. 32A and B: Sphenoid bone: (A) Superior aspect. (B) Posterior aspect



Figs. 33A and B: Right maxilla: (A) Lateral aspect. (B) Medial aspect

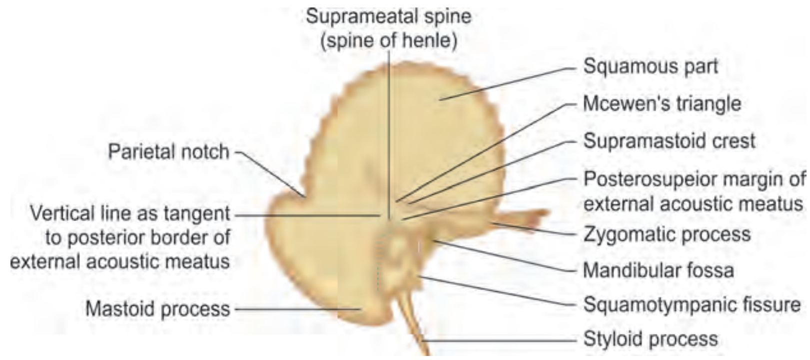
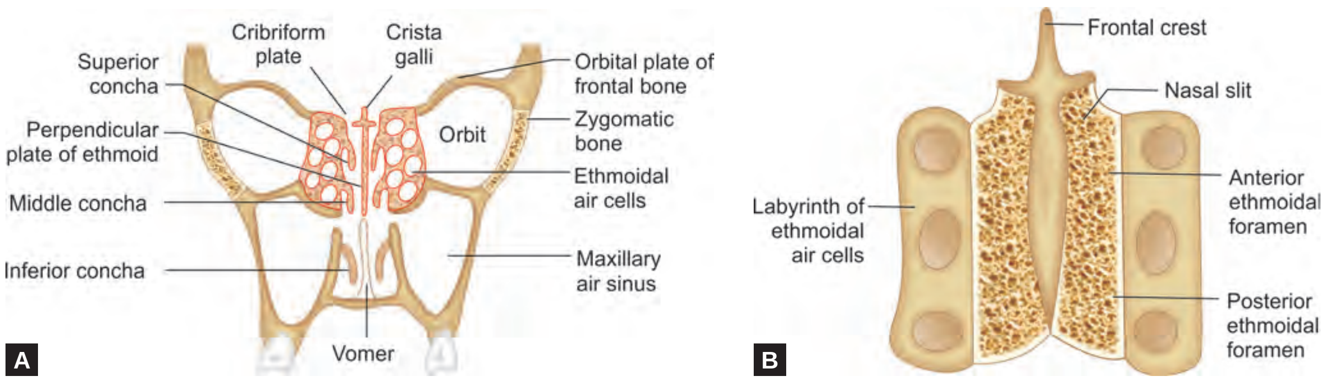


Fig. 34: Right temporal bone: External aspect



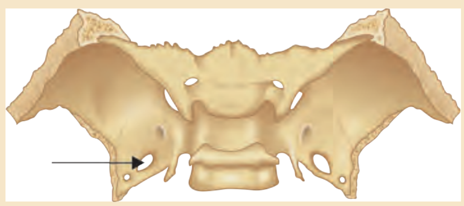
Figs. 35A and B: Ethmoid bone: (A) Location of ethmoid in relation to nasal cavity, orbits, and maxillary sinuses. (B) Superior view of ethmoid bone.

ASSESSMENT QUESTIONS

1 Maxilla doesn't articulate with: *(AIIMS 2015)*
  a. Lacrimal bone
  b. Plate of sphenoid bone
  c. Frontal bone
  d. Ethmoid bone

3. Turkish saddle is related to which structure: *(AIIMS 2014)*
  a. Hypothalamus
  b. Hypophysis
  c. Uncus
  d. Amygdaloid body

2. Which of the following structures do not pass through the marked foramen in the diagram. *(AIIMS 2014)*



  a. Maxillary nerve
  b. Sensory branch of mandibular nerve
  c. Lesser petrosal nerve
  d. Motor root of trigeminal nerve

ANSWERS WITH EXPLANATIONS

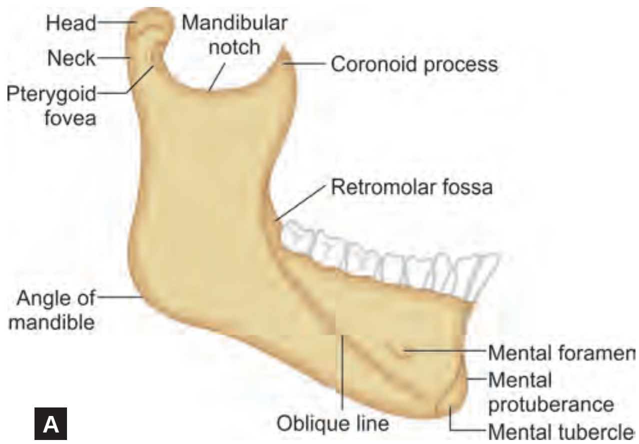
1. b. Plate of sphenoid bone
- **Maxilla** bone generally do not articulate with **plate (pterygoid) of sphenoid bone,** though sometimes it may form an articulation with the orbital surface or lateral pterygoid plate of the sphenoid bone.
- Maxilla articulates with nine bones: **Frontal**, **ethmoid**, nasal, **lacrimal**, zygomatic, inferior nasal concha, vomer, palatine, and the other maxilla.

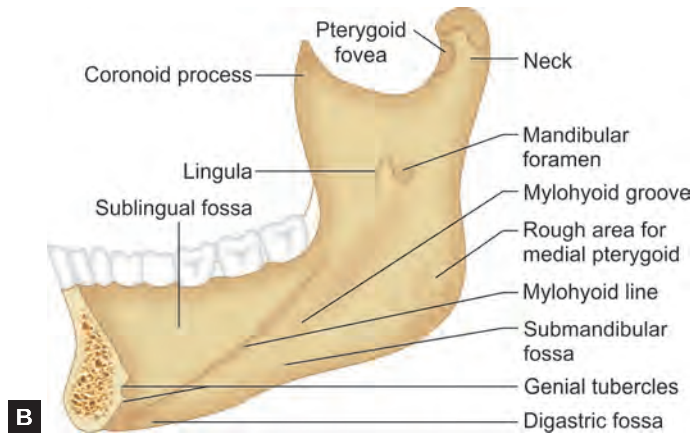
2. a. Maxillary nerve
- Maxillary nerve passes through foramen rotundum (not foramen ovale).
- The marked foramen in diagram is foramen ovale and structures passing through it are: Mandibular division of trigeminal nerve, Accessory meningeal artery, Lesser petrosal nerve, Emissary vein. (Mnemonic: MALE).

3. b. Hypophysis
- Turkish saddle (sella turcica) is a saddle-shaped depression in the body of the sphenoid bone.
- The deepest part of the sella turcica known as the hypophyseal fossa, holds the pituitary gland (hypophysis).

Mandible

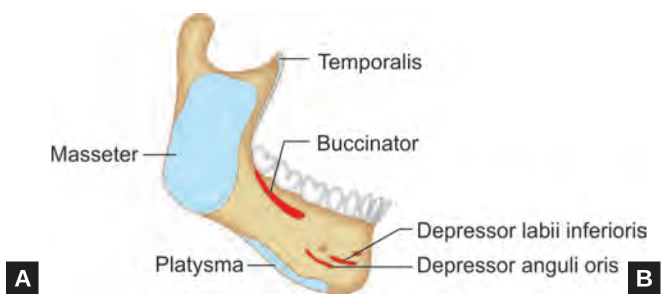
- **Mandible** is a U-shaped bone with an **alveolar process** that lodges the mandibular teeth.
- It consists of a horizontal part, the body, and a vertical part, the ramus.
- Inferior to the second premolar teeth are the **mental foramina** for the mental nerves and vessels.
- The **mental protuberance**, forming the prominence of the chin, is a triangular bony elevation inferior to the mandibular symphysis, the osseous union where the halves of the infantile mandible fuse.
- The inner aspect of symphysis menti possesses four tubercles called **genial tubercles** (mental spines) arranged into two pairs: upper and lower. Inferior border (base) of the mandible presents a small depression (**digastric fossa**) on either side near the median plane.
- **Mylohyoid line** on inner surface is a prominent oblique ridge that runs obliquely downwards and forwards from behind the 3rd molar tooth (about 1 cm below the alveolar border) to the symphysis menti below the genial tubercles.
- Ramus has two processes: **Condylar and coronoid process**. Condylar process has an expanded upper end (head) and the constricted part below (neck) which presents a depression on its anterior surface called pterygoid fovea.

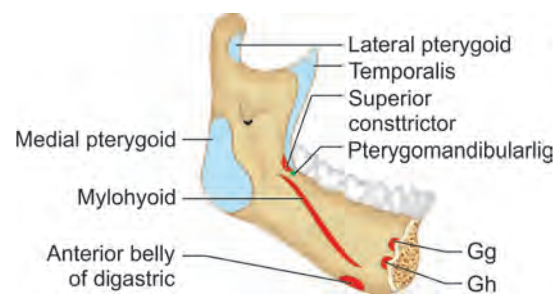




Figs. 36A and B: Right half of the mandible: (A) External aspect. (B) Internal aspect.

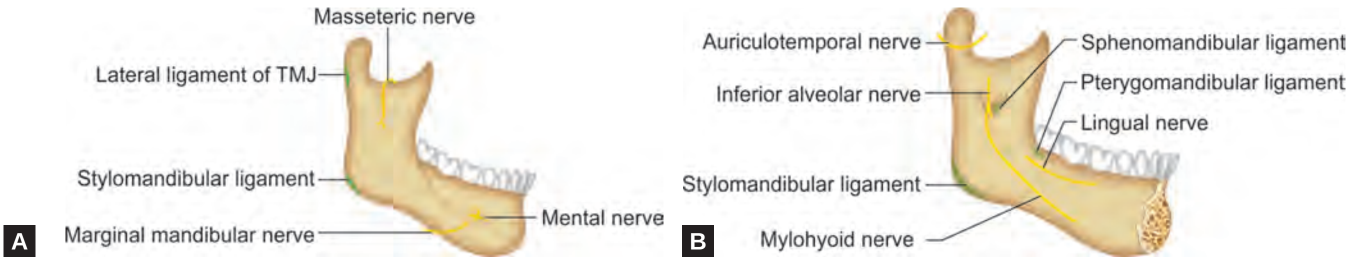
- Muscle attachments: **Buccinator** arises from oblique line below the three molar teeth; **mylohyoid** from mylohyoid line; **genioglossus** from superior genital tubercle and **geniohyoid**: arises from inferior genital tubercle; **anterior belly of digastric** from digastric fossa; **superior constrictor** arises from the area above the posterior end of the mylohyoid line; **platysma** is inserted into the base.
- **Masseter** is inserted into the outer surface of the ramus; **temporalis** is inserted into the coronoid process on this tip, anterior border, and inner surface; **lateral pterygoid** is inserted into the pterygoid fovea present in front of the neck of the mandible; **medial pterygoid** is inserted into the inner surface of the ramus above the angle of the mandible.





Figs. 37A and B: Muscle attached to the mandible: (A) Lateral surface of the right half of the mandible. (B) Inner surface of left half of the mandible (GG = genioglossus, GH= geniohyoid)

- Nerves related to mandible: **Lingual nerve** runs on the inner surface of the body close to the medial side of the root of the 3rd molar tooth; **inferior alveolar nerve** enters the mandibular foramen, and passes through the mandibular canal; **mylohyoid nerve** runs in the mylohyoid groove; **mental nerve** comes out of the mental foramen; **masseteric nerve** runs through the mandibular notch; **auriculotemporal nerve** runs to the medial side of the neck; **marginal mandibular nerve** across the lower border of the mandible.



Figs. 38A and B: Attachment of ligaments and nerves related to the mandible: (A) Lateral surface of the right half of the mandible. (B) Medial surface of the left half of the mandible.

Distinguishing features of mandible in different age groups			
Features	**In children**	**In adult**	**In old age**
Mental foramen	Present close to the inferior border of the body	Present midway between the upper and lower borders of the body	Present close to the upper border
Angle of mandible	140°	110°	140°
Relationship between condylar and coronoid processes	Coronoid process above the level of condylar process	Condylar process projects above the level of coronoid process	Coronoid process projects above the level of condylar process
Mandibular canal	Runs near the lower border	Runs parallel with the mylohyoid line	Runs close to the upper border

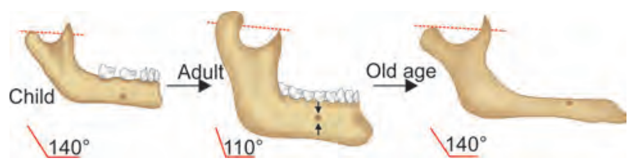


Fig. 39: Age-related changes in the mandible

Clinical Correlations

- Lingual nerve enters the submandibular region by passing just behind and inferior to the third molar tooth between medial surface of the mandible and the mucus membrane of the gum.
- In this position, it is accessible to local anesthetics and liable to be injured by the clumsy extraction of the adjacent tooth.
- **Ossification**: Mandible is formed in relation to first pharyngeal arch (**Meckel's**) cartilage by both **intramembranous** and **endochondral** ossification.
- It is the second bone to ossify in the body.
- The centre in the mesenchymal sheath of Meckel's cartilage appears during the 7th week of intrauterine life, other centres appear during 10th week.
- At birth, mandible consists of two halves connected at the symphysis menti by cartilaginous joint.
- The bony union starts from below upwards during the 1st year of the age and completed at the end of the 2nd year.
- Coronoid and condylar processes ossify from secondary cartilages not related to Meckel's cartilage.

ASSESSMENT QUESTIONS

1. **Mental foramen is located near:** *(AIIMS 2002)*
   a. First premolar of mandible
   b. Second molar of mandible
   c. Canine of mandible
   d. Canine of maxilla

2. **Which nerve is in close relation with root of the lower third molar:** *(NEET pattern 2014)*
   a. Inferior alveolar nerve
   b. Chorda tympani nerve
   c. Lingual nerve
   d. Mylohyoid nerve

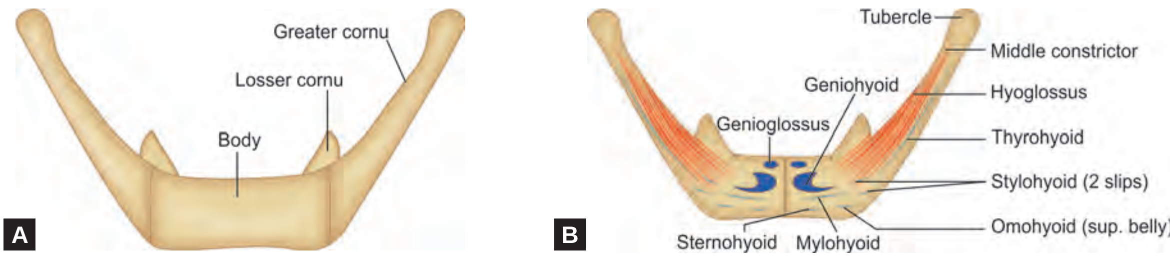
ANSWERS WITH EXPLANATIONS

1. **a. First premolar of mandible**
   - The most frequent position (63%) of the mental foramen is in line with the longitudinal axis of the 2nd premolar tooth (not given in the choice).
   - On the medial surface of mandible is the mandibular foramen for inferior alveolar nerve and vessels.
   - The foramen leads into mandibular canal which opens on lateral surface of mandible at mental foramen, situated below the second premolar tooth.

2. **c. Lingual nerve**
   - Lingual nerve moves in a groove on the medial aspect of socket for lower third molar.

Hyoid Bone

- **Hyoid Bone** is a U-shaped bone consisting of a body, paired lesser horns (cornua) laterally, and greater horns (cornua) posteriorly.
- The body has attachments for the geniohyoid, mylohyoid, omohyoid, and sternohyoid muscles.
- Greater Horn provides attachments for the middle constrictor, hyoglossus, digastric (anterior and posterior) bellies, stylohyoid, and thyrohyoid muscles.
- Lesser Horn gives attachment for the stylohyoid ligament, which runs from the styloid process to the lesser horn of the hyoid bone.



Figs. 40A and B: Hyoid bone (anterior view): (A) parts of hyoid bone; (B) muscle attachments

Radiology

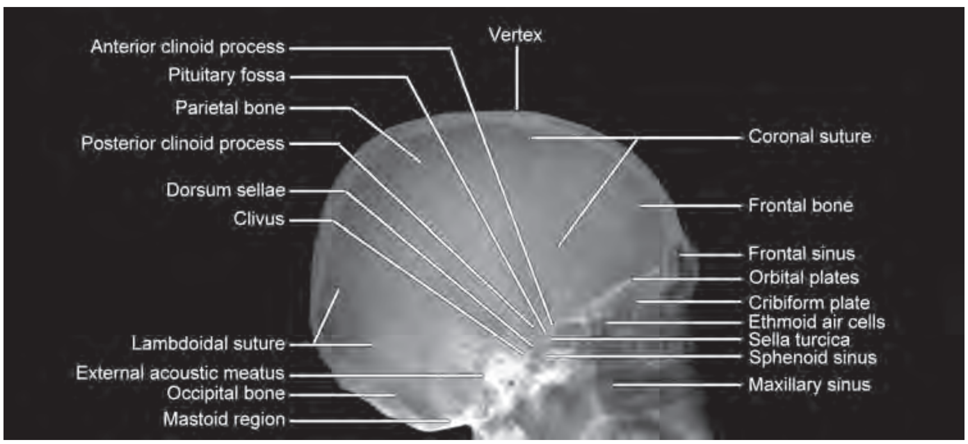


Fig. 41: Lateral view of skull X-ray.

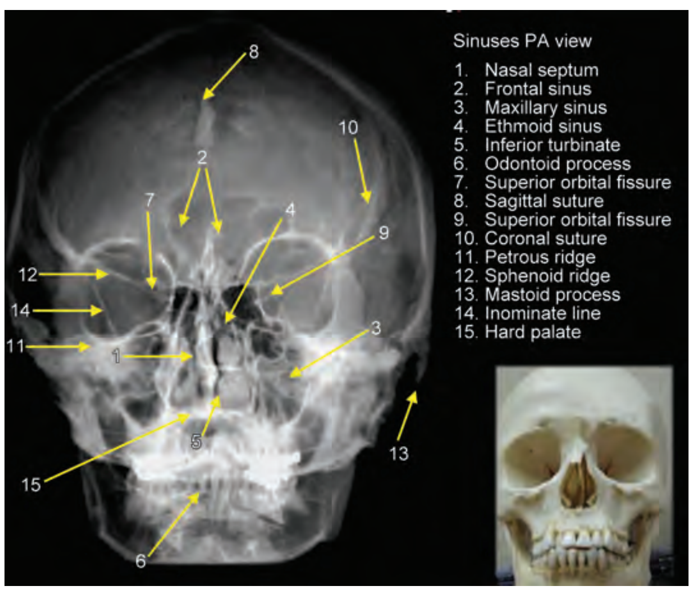


Fig. 42: Coronal view of skuul X-ray.

ASSESSMENT QUESTIONS

1. Mobile bone of skull: *(NEET Pattern 2015)*
a. Maxilla
b. Mandible
c. Ethmoid
d. Sphenoid

2. NOT a relation of sphenoid sinus: *(NEET Pattern 2015)*
a. Optic nerve
b. Mandibular nerve
c. Maxillary nerve
d. Vidian nerve

3. Chassaignac tubercle is: *(NEET Pattern 2014)*
a. Erb's point
b. Carotid tubercle on C6 vertebra
c. Found on first rib
d. Medial condyle of humerus

4. Which is NOT true about mandible: *(NEET Pattern 2015)*
a. From second pharyngeal arch
b. Body and ramus are its two parts
c. Strongest bone of skull
d. Has 16 sockets for teeth

ANSWERS WITH EXPLANATIONS

1. b. Mandible
- Temporomandibular joint is a synovial joint allowing free movements of mandible.

2. b. Mandibular nerve
- Structures related to sphenoid sinus are foramen rotundum (maxillary nerve), optic canal (optic nerve and ophthalmic artery), vidian canal (with nerve), internal carotid artery.
- Mandibular nerve is not related to sphenoid sinus.

3. b. Carotid tubercle on C6 vertebra
- The anterior tubercle of the sixth cervical transverse process (tubercle of Chassaignac). can be palpated medial to the sternocleidomastoid muscle, and against it the common carotid artery can be compressed.
- It separates the carotid artery from the vertebral artery and is used as a landmark for anaesthesia of the brachial plexus and cervical plexus.

4. a. From second pharyngeal arch
- Mandible bone develops in first pharyngeal arch.

Nerve Supply

Cranial nerves: There are 12 pairs of cranial nerves.
- The olfactory nerve (nerve of telencephalon) is the only sensory cranial nerve that projects directly to the cerebral cortex rather than indirectly via the thalamus.
- The optic nerve (nerve of diencephalon) terminates in the thalamus.
- The lower ten pairs of cranial nerves are attached to the brainstem or, in the case of the accessory nerve, to the upper cervical spinal cord; their component fibres arise from or terminate in named cranial nerve nuclei.
- The cranial nerves pass through named foramina in the skull, often with named vessels.
- Cranial nerves are confined to the head and neck except vagus, which travels through the neck and thorax, and enters the abdominal cavity by passing through the diaphragm with the oesophagus.

Spinal nerves: There are eight pairs of cervical spinal nerves.
- Cutaneous branches of the dorsal rami of the second, third, fourth and fifth cervical nerves innervate the scalp and the skin over the back of the neck, and motor branches of all of the cervical dorsal rami supply cervical postvertebral muscles.
- All of the cervical ventral rami supply anterior and lateral groups of prevertebral muscles.
- The upper four cervical ventral rami form the cervical plexus, whose branches collectively innervate the infrahyoid strap muscles and the diaphragm, and the skin covering the lateral and anterior parts of the neck, and the angle of the mandible.
- The lower four cervical ventral rami, together with most of the first thoracic ventral ramus, form the brachial plexus.
- In the head and neck, the parasympathetic system include four parasympathetic ganglia: Ciliary, pterygopalatine, otic and submandibular, which innervates the salivary and lacrimal glands, the muscus glands of the oral and nasal cavities and paranasal sinuses, and the sphincter pupillae and ciliary muscles in the eyeball.
- Fibres carried by vagus nerve are destined for pulmonary, cardiac, oesophageal, gastric and intestinal targets; they synapse in minute ganglia in the walls of the viscera and do not innervate structures in the head and neck.

Cranial Nerves

1. Olfactory nerve is described in the nose region.
2. Optic nerve is described in the eyeball region.
3. Oculomotor, Trochlear nerve and Abducent nerves are described in the eyeball region.
4. Vestibulo-cochlear nerve is described in ear region.

Trigeminal Nerve

Trigeminal nerve develops in association with the first branchial arch and supplies motor fibers (SVE) to the muscles of mastication.

- It is a major sensory nerve carrying general somatic afferent (GSA) fibres supplying fibers to the head and neck region.
- It has one motor and three sensory nuclei.
- The motor nucleus is located in pons and send the motor fibres by mandibular nerve (branch of trigeminal) to control the eight muscles developing in the first pharyngeal arch, which include muscles of mastication.
- The main sensory nucleus is present in the pons, whereas midbrain has the mesencephalic sensory nucleus of trigeminal (for proprioception) and the spinal sensory nucleus of trigeminal has neurone bodies extending into the spinal cord (carry pain and temperature).

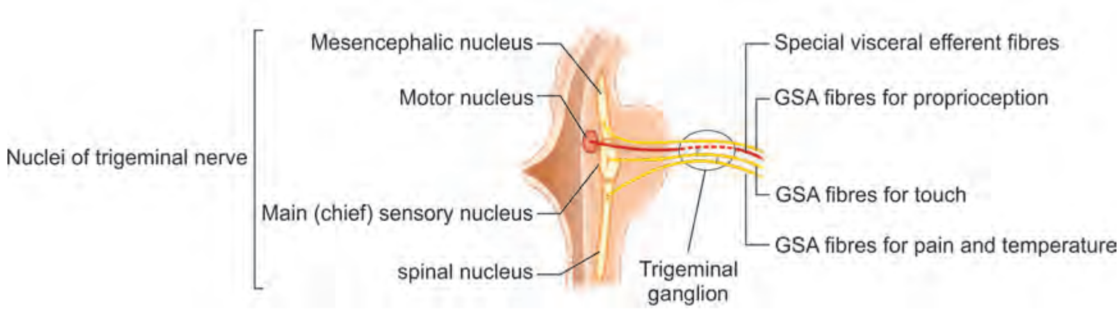


Fig. 43: Four nuclei and functional components of the trigeminal nerve.

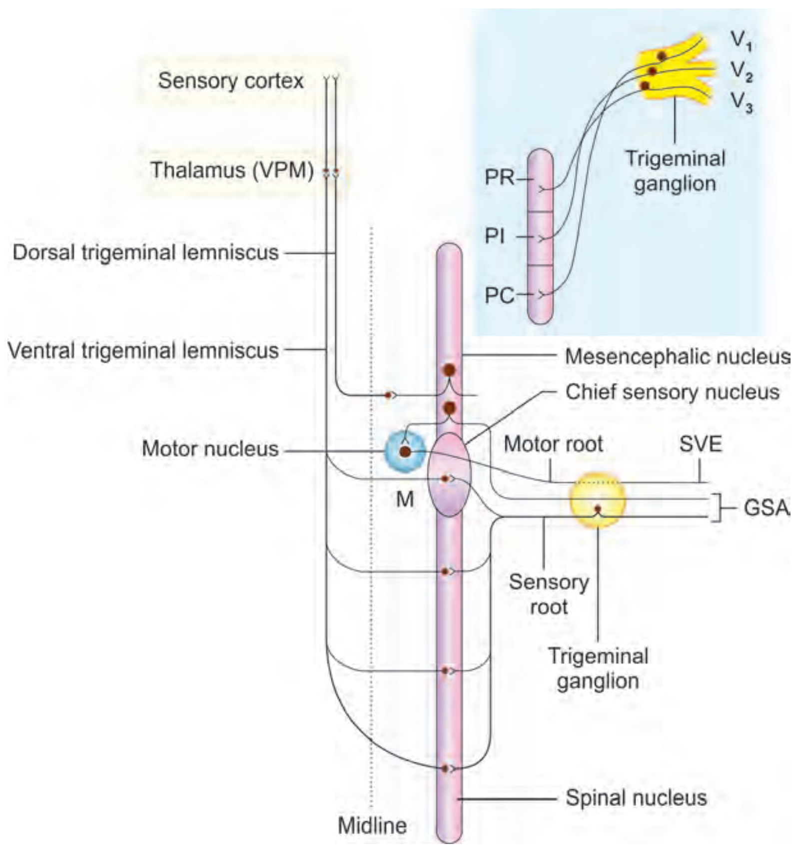


Fig. 44: Connections of trigeminal nerve nuclei. (M = motor nucleus. PR = pars rostralis, PI = pars inter-Polaris, PC = pars caudalis, VI = ophthalmic nerve, V2 = maxillary nerve, V3 = mandibular nerve, M = motor nucleus, SVE = special visceral efferent, GSA = general somatic afferent.)

Sensations carried by trigeminal nerve fibres reach the corresponding nuclei in brainstem and synapse, Second order neurone cross the midline as trigeminal lemniscus and synapse in VPM (Ventero - postero medial) nucleus of thalamus.

- Third order neurones in thalamus send fibres through the genu if internal capsule to the postcentral gyrus (parietal sensory cortex).
- Trigeminal (semilunar) ganglion consists of cell bodies of sensory fibers that distribute along three divisions: Ophthalmic (V1), maxillary (V2) and mandibular (V3).
- It creates an impression at the apex of the petrous portion of the temporal bone in the middle cranial fossa and is located in a pouch webbed with arachnoid between two layers of dura (Meckel cave).
- The cave is a recess of the dura mater formed by the evagination of the meningeal layer of the dura mater by two roots of the trigeminal nerve, below the superior petrosal sinus, in relation to the attached outer margin of the tentorium cerebelli.

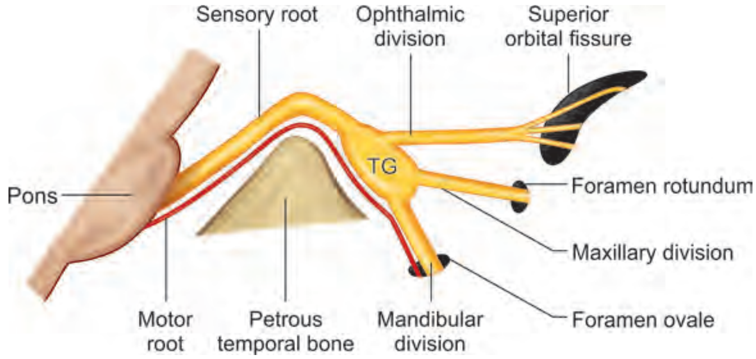
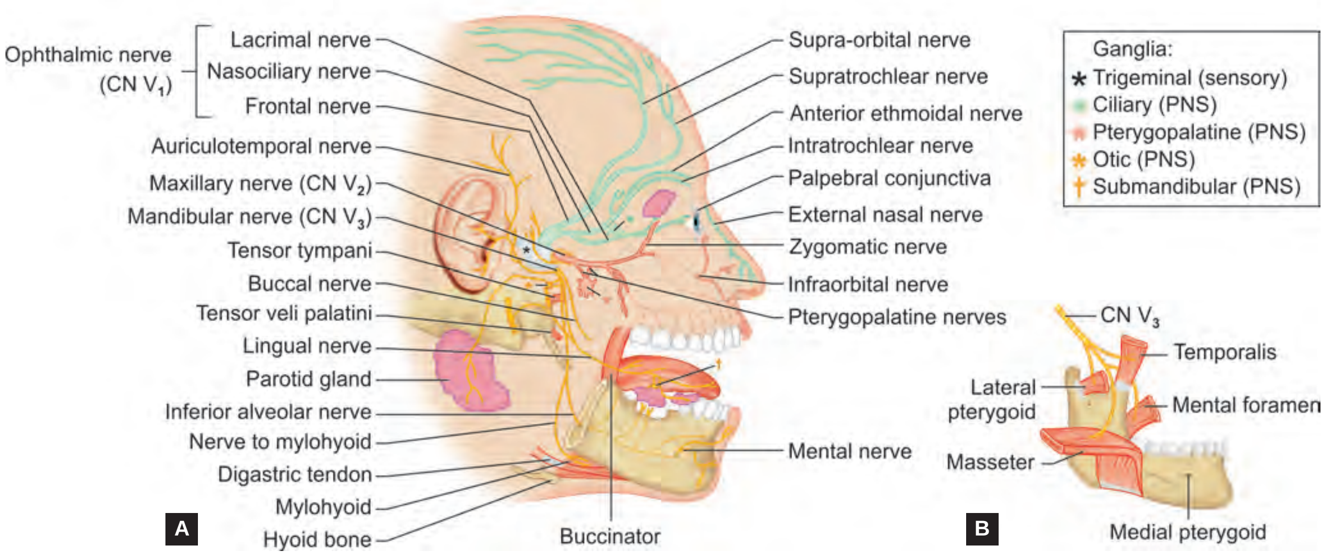


Fig. 45: Roots and divisions of the trigeminal nerve (TG = trigeminal ganglion).

- Ophthalmic Division innervates the area above the upper eyelid and dorsum of the nose.
- It gives the supraorbital, supratrochlear, infratrochlear, external nasal, and lacrimal nerves.
- Maxillary Division innervates the face below the level of the eyes and above the upper lip.
- It gives the zygomaticofacial, zygomaticotemporal, and infraorbital nerves.
- Mandibular Division innervates the face below the level of the lower lip.
- It gives the auriculotemporal, buccal, and mental nerves.



Figs. 46A and B: Distribution of trigeminal nerve (CN V) (A) The three divisions of CN V arise from the trigeminal ganglion. In addition to the trigeminal ganglion, a sensory ganglion (similar to the sensory or dorsal root ganglia of spinal nerves) and four parasympathetic ganglion (three of which are shown here) are associated with the branches of the trigeminal nerve. (B) Branches of the mandibular nerve (CN V_3) pass to the muscles of mastication.

- Dermatomes of the face arise mainly from cutaneous branches of the three major divisions of the trigeminal nerve.
- The skin covering the front and sides of the neck, and over the angle of the mandible, and over the lateral scalp and posterior aspect of the pinna is supplied by branches of the cervical plexus (C2–C4).
- The skin over the back of the head is supplied by the greater occipital nerve (C2, posterior primary ramus).

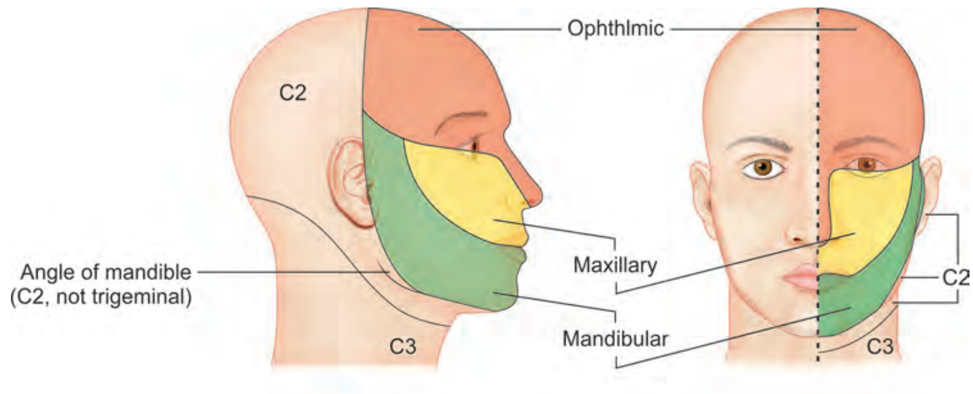


Fig. 47: Dermatomes on face: Distribution of trigeminal branches and cervical plexus contribution.

Summary of divisions of trigeminal nerve (CN V)

Division/Distributions	**Branches**
Ophthalmic nerve (CN V_1) • Sensory only • Passes through superior orbital fissure into orbit • Supplies cornea; superior conjunctiva; mucosa of anterosuperior nasal cavity; frontal, ethmoidal, and sphenoidal sinuses; anterior and supratentorial dura mater; skin of dorsum of external nose; superior eyelid; forehead; and anterior scalp	Tentorial nerve (a meningeal branch) Lacrimal nerve • Communicating branch from zygomatic nerve Frontal nerve • Supraoribital nerve • Supratrochlear nerve • Nasocillary nerve • Sensory root of ciliary ganglion • Short ciliary nerves • Long ciliary nerves • Anterior and posterior ethmoidal nerves • Infratrochlear nerves
Maxillary nerve (CN V_2) • Sensory only • Passes through foramen rotundum to enter pterygopalatine fossa • Supplies dura mater of anterior part of middle cranial fossa; conjunctiva of inferior eyelid; mucosa of postero-inferior nasal cavity, maxillary sinus, palate and anterior part of superior oral vestibule; maxillary teeth; and skin of lateral external nose, inferior eyelid, anterior cheek, and upper lip	Meningeal branch Zygomatic nerve • Zygomaticofacial branch • Zygomaticotemporal branch • Communicating branch to lacrimal nerve Ganglionic branches to (sensory root of) pterygopalatine ganglion Posterior superior alveolar branches Infra-orbital nerve Anterior and middle superior alveolar branches • Superior labial branches • Inferior palpebral branches • External nasal branches Greater palatine nerves • Posterior inferior lateral nasal nerves Lesser palatine nerves Posterior superior lateral nasal branches Nasopalatine nerve Pharyngeal nerve
Mandibular nerve (CN V_2) • Sensory and motor • Passes through foramen ovale into infratemporal fossa • Supplies sensory innervation to mucosa of anterior two-thirds of tongue, floor of mouth, and posterior and inferior oral vestibule; mandibular teeth; and skin of lower lip, buccal, parotid, and temporal regions of face; and external ear (auricle, upper external acoustic meatus, and tympanic membrane)	Somatic (general) sensory branches • Meningeal branch (nervus spinosum) • Buccal nerve • Auriculotemporal nerve • Lingual nerve • Inferior alveolar nerve • Inferior dental plexus • Mental nerve
• Supplies motor innervation to 4 muscles of mastication, mylohyoid, anterior belly of digastric, tensor veli palatini, and tensor tympani	Somatic (branchial) motor branches • Masseteric nerve • Deep temporal nerves • Nerves to medial and lateral pterygoid • Nerve to mylohyoid (and anterior belly of diagastric) • Nerve to tensor veli palatini • Nerve to tensor tympani

Clinical Correlations

- Lesion of the **trigeminal** nerve causes sensory loss on the face and weakness of the muscles of mastication that manifests as a deviation of the mandible toward the side of the lesion.
- Lesion of the **lingual** nerve near the neck of the third molar causes loss of general sensation and taste to the anterior two-thirds of the tongue as well as salivary secretion from submandibular and sublingual glands (due to loss of preganglionic parasympathetic fibers from the chorda tympani branch of CN VII).
- Lesion of the **ophthalmic** division cannot mediate the afferent limb of the corneal reflex by way of the nasociliary branch (the facial nerve mediates the efferent limb).
- Lesion of the **maxillary** division cannot mediate the afferent limb of the sneeze reflex (vagus nerve mediates the efferent limb).
- Lesion of the **mandibular** division would be associated with loss of both the afferent and the efferent limbs of the jaw jerk reflex.
- **Trigeminal neuralgia** (tic douloureux) is marked by paroxysmal pain along the course of the trigeminal nerve, especially radiating to the maxillary or mandibular area.
- The common causes of this disorder are aberrant blood vessels, aneurysms, chronic meningeal inflammation, brain tumors compressing on the trigeminal nerve at the base of the brain, and other lesions such as multiple sclerosis.
- If medical treatments are not effective, the neuralgia may be alleviated by sectioning the sensory root of the trigeminal nerve in the trigeminal (Meckel) cave in the middle cranial fossa.
- Abscess or infection of the maxillary teeth irritates the **maxillary** nerve, causing upper toothache.
- It may result in symptoms of sinusitis, with pain referred to the distribution of the maxillary nerve.
- Abscess or infection of the mandibular teeth might spread through the lower jaw to emerge on the face or in the floor of the mouth.
- It irritates the **mandibular** nerve, causing pain that may be referred to the ear because this nerve also innervates a part of the ear.

Ophthalmic Nerve

Maxillary Nerve

- Maxillary Division (V2) of trigeminal nerve is constituted by axons given by cell bodies in the trigeminal ganglion, pass through the lateral wall of the cavernous sinus in the middle cranial fossa and next the foramen rotundum to enter the pterygopalatine fossa (at the back of the orbit).
- It carries general somatic afferent (GSA) neural column, sensory fibers from the face (below the eyes and to the upper lip), palate, paranasal sinuses, and maxillary teeth.
- It mediates the afferent limb of the sneeze reflex (irritation of the nasal mucosa), vagus nerve being the efferent limb.
- Branches: **Meningeal** branch innervates the dura mater of the middle cranial fossa; **pterygopalatine nerve** connects sensory fibers that pass through the pterygopalatine ganglion and join branches off the ganglion; **posterior superior alveolar nerve** leaves the pterygopalatine fossa to innervate the cheeks, gums, molar teeth and the maxillary sinus; **zygomatic** nerve passes through the zygomatic bone in the maxillary sinus and divides into the zygomaticofacial and zygomaticotemporal nerves (this nerve carries postganglionic parasympathetic fibers to the lacrimal nerve for lacrimal secretion); **infraorbital nerve** is the anterior continuation of the maxillary nerve, enters the orbit through the inferior orbital fissure and runs through the infraorbital groove and canal and gives rise to the **middle** and **anterior** superior alveolar nerves that supply the maxillary sinus, teeth, and gums. It then emerges through the infraorbital foramen and divides in the face into the inferior **palpebral**, lateral **nasal**, and superior **labial** branches.
- Maxillary nerve branches which pass through the pterygopalatine ganglion without synapse carrying its own GSA fibers and also the general visceral afferent and efferent (GVA and GVE) fibers from the facial nerve to the nasal mucosa and the palate. The branches are discussed with pterygopalatine ganglion (refer).

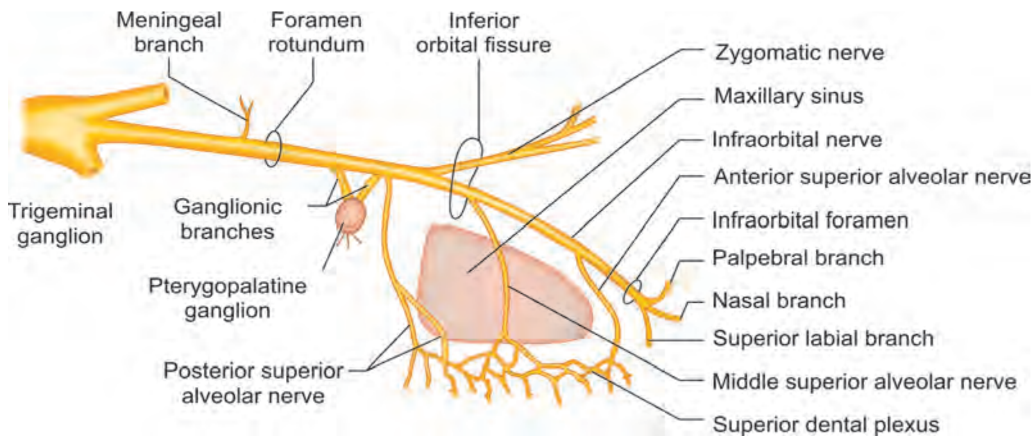


Fig. 48: Origin, course, and branches of the maxillary nerve.

Summary of branches of the maxillary nerve	
Region	**Branches**
In the middle cranial fossa	Meningeal branch
In the pterygopalatine fossa	• Ganglionic branches • Posterior superior alveolar nerves • Zygomatic nerve
In the infraorabital canal	• Middle superior alveolar nerve • Anterior superior alveolar nerve
On the face	• Palpebral branch • Nasal branch • Labial branch

Mandibular Nerve

- **Mandibular nerve** is given at trigeminal ganglion at the floor of the middle cranial fossa and passes through the foramen ovale to enter the infratemporal region.
- It supplies 8 muscles developing in first pharyngeal arch: 2 tensors (tensor tympani and tensor palati), 3 elevators of mandible (MTM: Masseter, Temporalis, Medial pterygoid) and 3 depressors of mandible (Lateral pterygoid, mylohyoid and anterior belly of digastric).
- It Provides sensory innervation to the lower teeth and gum and to the lower part of the face below the lower lip and the mouth.
- Branches: **Meningeal Branch** accompanies the middle meningeal artery, enters the cranium through the foramen spinosum, and supplies the meninges of the middle cranial fossa; **muscular Branches** include masseteric, deep temporal, medial, and lateral pterygoid nerves.
- B**uccal Nerve** descends between the two heads of the lateral pterygoid muscle and innervates skin and fascia on the buccinator muscle and penetrates this muscle to supply the mucous membrane of the cheek and gums.
- **Auriculotemporal Nerve** arises from two roots that encircle the middle meningeal artery.
- It carries postganglionic parasympathetic and sympathetic general visceral efferent (GVE) fibers to the parotid gland and sensory general somatic afferent (GSA) fibers to the temporomandibular joint and the skin of the auricle and the scalp.
- **Lingual Nerve** descends deep to the lateral pterygoid muscle, where it is joined by the chorda tympani.
- It lies anterior to the inferior alveolar nerve on the medial pterygoid muscle, deep to the ramus of the mandible.
- It crosses lateral to the styloglossus and hyoglossus muscles, passes deep to the mylohyoid muscle, and descends lateral to and loops under the submandibular duct.
- It carries general sensation from the anterior two-thirds of the tongue.
- It also carries the postganglionic fibres from the submandibular ganglion to supply the submandibular and sublingual salivary gland. The preganglionic fibres are brought by the chorda tympani nerve.
- **Inferior Alveolar Nerve** passes deep to the lateral pterygoid muscle and then between the sphenomandibular ligament and the ramus of the mandible.
- It enters the mandibular canal through the mandibular foramen and supplies the tissues of the chin and lower teeth and gum.
- It gives rise to the following branches: Mylohyoid nerve, which innervates the mylohyoid and the anterior belly of the digastric muscle; inferior dental branch, which innervates lower teeth; mental nerve, which innervates the skin over the chin; incisive branch, which innervates the canine and incisor teeth.

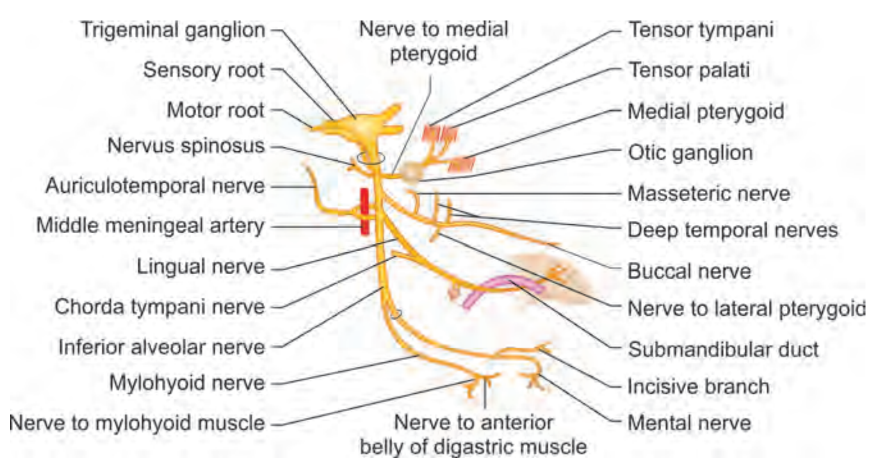


Fig. 49: Course and distribution of the mandibular nerve.

Branches of the mandibular nerve		
From main trunk	**From anterior division**	**From posterior division**
Nerve spinosus (meningeal branch)	Masseteric nerve	Auriculotemporal nerve
Nerve to medial pterygoid	Deep temporal nerves	Lingual nerve
	Nerve to lateral pterygoid	Inferior alveolar nerve
	Nerve to lateral pterygoid	Inferior alveolar nerve
	Buccal nerve	
N.B. all the branches of posterior division of the mandibular nerve are sensory except nerve to mylohyoid, which is motor		

Mnemonic

Posterior division of mandibular nerve gives ALI branches: A - Auriculotemporal nerve, L - Lingual nerve and I - Inferior alveolar nerve.

ASSESSMENT QUESTIONS

1. **Nervus spinosus is a branch of which of the following:** *(NEET Pattern 2013)*
   a. Maxillary nerve
   b. Mandibular nerve
   c. Facial nerve
   d. Nerve of pterygoid canal

2. **Post superior alveolar nerve is a branch of:** *(AIPG 2009)*
   a. Mandibular
   b. Facial
   c. Lingual
   d. Maxillary

3. **Middle superior alveolar nerve is:** *(AIIMS 2010)*
   a. Palatal branch of maxillary nerve
   b. Nasal branch of maxillary nerve
   c. Branch of mandibular nerve
   d. Branch of inferior alveolar nerve

4. **Finding of trigeminal nerve injury include:** *(PGIC 2013)*
   a. Pupillary dilation
   b. Loss of blinking reflex of eye
   c. Loss of jaw reflex
   d. Ptosis
   e. Weakness of muscle of mastication

5. **Middle superior alveolar nerve is a branch of:** *(AIIMS 2010)*
   a. Mandibular division of trigeminal nerve
   b. Palatine division of maxillary nerve
   c. Anterior nasal division of maxillary nerve
   d. Infraorbital branch of maxillary nerve

6. **All are true for trigeminal nerve EXCEPT:** *(NEET Pattern 2014)*
   a. Carries sensation from face
   b. Three sensory nuclei
   c. Two motor nuclei
   d. Maxillary nerve is a branch

7. **Skin over angle of mandible is supplied by:**
   a. Posterior primary rami of C-2,3
   b. Greater auricular nerve
   c. Maxillary nerve
   d. Mandibular nerve

8. **Meckel's cave is related to:** *(NEET Pattern 2015)*
   a. Submandibular ganglion
   b. Trigeminal ganglion
   c. Otic ganglion
   d. Pterygopalatine ganglion

9. **Branch of anterior division of mandibular nerve:** *(NEET Pattern 2012)*
   a. Meningeal
   b. Masseteric
   c. Auriculotemporal
   d. Lingual

10. **Which of the following is NOT supplied by the anterior division of mandibular nerve:** *(AIPG)*
    a. Temporalis
    b. Medial pterygoid
    c. Lateral pterygoid
    d. Masseter

ANSWERS WITH EXPLANATIONS

1. **b. Mandibular nerve**
   - Meningeal branch (nervus spinosus) arise from the main trunk of mandibular nerve.

2. **d. Maxillary**
   - Posterior superior alveolar nerve is a branch of maxillary nerve.
   - Upper (Maxillary) teeth are supplied by the superior alveolar nerves which are three in number. They are named as—posterior, anterior and middle. All are branches of maxillary nerve—the nerve of upper jaw.
   - Posterior superior alveolar nerve supplies mainly the molar teeth. It also supplies the maxillary sinus, gingiva and inner cheek region.
   - Middle superior alveolar nerve supplies the premolars.
   - Anterior superior alveolar innervates the canine and incisors.
   - Posterior superior alveolar artery is a branch of maxillary artery.
   - Upper jaw is supplied by the maxillary artery in a similar fashion as the nerve.
   - There are 3 superior alveolar arteries by the names—anterior, posterior and middle, all given by the maxillary artery.

3. a. Palatal branch of maxillary nerve

- This question doesn't have a proper answer and the most suitable option has been chosen.
- Middle superior alveolar nerve supplies the palatal teeth on the maxilla and hence can be stated as the palatal branch of maxillary nerve.
- It supplies teeth number 4, 5 (premolars) and 6 (first molar).
- It also supplies the lining of maxillary air sinus.
- It is given by the infra-orbital nerve, while running in the infra-orbital groove.
- Superior alveolar nerves (branch of maxillary nerve supply the upper (maxillary) teeth, whereas lower (mandibular) teeth are supplied by the inferior alveolar nerve (branch of mandibular nerve).
- Superior alveolar nerves are three in number and make superior dental plexus to supply the upper teeth: Posterior, middle and anterior.
- Posterior superior alveolar nerve is a branch of maxillary nerve , whereas middle and anterior are given by the infra-orbital nerve (branch of maxillary nerve).
- Middle superior alveolar block is given while operating upon upper premolars.

4. b. Loss of blinking reflex of eye; c. Loss of jaw reflex; e. Weakness of muscle of mastication

- Trigeminal nerve has 3 branches: ophthalmic, maxillary and mandibular, the lesions results in sensory loss on face.
- Injury to ophthalmic nerve injury leads to loss of corneal (blink) reflex; maxillary nerve injury results in loss of sneeze reflex and in mandibular nerve injury, there is loss of jaw jerk.
- Muscles of mastication are paralysed in mandibular nerve injury.
- Partial deafness to low pitched sound due to paralysis of tensor tympani muscle is also observed.
- Mydriasis and ptosis are not clinical features of trigeminal nerve injury.

5. d. Infraorbital branch of the maxillary nerve

- Maxillary nerve enters the inferior orbital fissure to continue as **infraorbital nerve**, which runs at the floor of orbit.
- It gives **middle** (and anterior) **superior alveolar nerve** to supply upper teeth.
- Posterior superior alveolar nerve is a direct branch of maxillary nerve given in the pterygopalatine fossa to supply the upper molar teeth.

6. c. Two motor nuclei

- Trigeminal nerve has one motor nucleus and three sensory nuclei (total 4).
- It carries sensation from the face by three branches, one of them being the maxillary nerve.

7. b. Greater auricular nerve

- Skin on the mandible (except the angle) is supplied by the mandibular division of trigeminal nerve.
- Skin on the angle of mandible is supplied by greater auricular nerve.

8. b. Trigeminal ganglion

- Meckel's cave is a recess of the dura mater present in relation to the attached outer margin of the tentorium cerebelli.
- It is formed by the evagination of the meningeal layer of the dura mater by two roots of the trigeminal nerve, below the superior petrosal sinus, over the trigeminal impression on the anterior surface of the petrous temporal bone near its apex.

9. b. Masseteric

- Anterior division of mandibular nerve gives masseteric nerve.
- Posterior division gives ALI branches: A - Auriculotemporal nerve, L - Lingual nerve and I - Inferior alveolar nerve.
- Meningeal branch (nervus spinosus) arise from the main trunk of mandibular nerve.

10. b. Medial pterygoid

- Anterior division of mandibular nerve do not supply medial pterygoid muscle.
- It is supplied by a branch of main trunk, which also supplies the two tensors (tensor tympani and tensor palati).

High Yield Point

- Artery supply to trigeminal ganglion is by **cavernous** part of internal carotid artery.

Facial Nerve

- Facial nerve has two parts: motor to facial expression muscles and nervus intermedius.
- The motor part carries SVE component, while nervus intermedius carries GSA, SVA, and GVE fibers.
- SVE (Special visceral Efferent): Facial nerve supplies the muscles of facial expression (second pharyngeal arch).
- The fibres arise from the motor nucleus of facial nerve (pons), loop around the abducent nucleus (internal genu), raising facial colliculus (at floor of fourth ventricle), exit the brainstem at the ponto-medullary junction.
- Next the fibres enter the internal auditory meatus, pass through the facial canal in the middle ear cavity, give a branch to stapedius muscle, exit the skull through the stylomastoid foramen.

- The fibres innervate the stylohyoid muscle, the posterior belly of the digastric muscle, and enter parotid salivary gland and next send branches to innervate the muscles of facial expression.
- **Nervus intermedius** (nerve of Wrisberg) is the part of the facial nerve located between the motor component of the facial nerve and the vestibulocochlear nerve (cranial nerve VIII).
- Upon reaching the facial canal, it joins with the motor root of the facial nerve at the geniculate ganglion.
- It carries fibres for taste, salivation, lacrimation, and general sensation (from the external ear).
- The first-order sensory neurons are found in the geniculate ganglion within the temporal bone.
- **Superior salivatory nucleus** contains the cell bodies of parasympathetic axons within the nervus intermedius.
  - These secretomotor fibres reach the geniculate ganglion, pass through it without synapse and reach pterygopalatine ganglion to synapse, which further pass on the fibres to lacrimal, nasal and palatine glands.
  - The sensory component of the nervus intermedius carries input about sensation from the skin of the external auditory meatus, mucous membranes of the nasopharynx and nose, and taste from the anterior two-thirds of the tongue, floor of the mouth, and the palate.
- The sensory information form the mucous membranes of the nasopharynx and palate is carried along the greater petrosal nerve, while the chorda tympani nerve (and lingual nerve) carries taste input from the anterior two thirds of the tongue, floor of mouth, and palate.

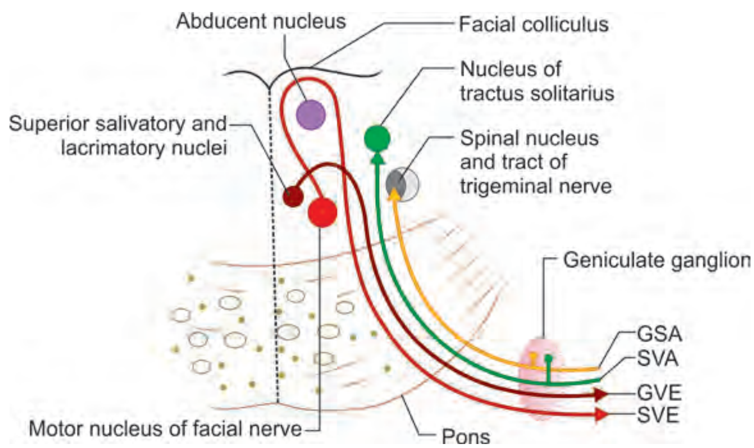


Fig. 50: Functional components and nuclei of the facial nerve.

- GSA (General Somatic Afferent) component brings general sensations from the posterior surface of the external ear through the posterior auricular branch.
- GVA (General Visceral Afferent) fibers carry fibres from the soft palate and the adjacent pharyngeal wall.
- SVA (Special Visceral Afferent) component carries taste has from palate and the anterior two-thirds of the tongue to the nucleus tractus solitarius.
- GVE (General Visceral Efferent) component begins in the superior salivatory nucleus in the lower pons, carry preganglionic parasympathetic secretomotor fibres to glands by two pathways:
  a. Lacrimal pathway—Secretomotor fibres pass through the nervus intermedius and greater petrosal nerves to the pterygopalatine (spheno-palatine. ganglion to supply LNP (lacrimal, nasal, palatine) glands.
  b. Submandibular pathway—Secretomotor fibres pass through the nervus intermedius and chorda tympani to the submandibular ganglion to innervate the submandibular and sublingual salivary glands.
- **Greater petrosal nerve** is a branch of the facial nerve that arises distal to the geniculate ganglion, inside the facial canal, in middle ear cavity.
- It enters the middle cranial fossa through the hiatus for the greater (superficial) petrosal nerve (on the anterior surface of the petrous temporal bone).
- It proceeds towards the foramen lacerum, where it joins the deep petrosal nerve (sympathetic) to form the vidian nerve of the pterygoid canal, which passes through the pterygoid canal to reach the pterygopalatine ganglion.
- The greater (superficial) petrosal nerve carries gustatory (taste) and parasympathetic fibres.
- Postganglionic parasympathetic fibres from pterygopalatine ganglion supply lacrimal gland and the mucosal glands of the nose, palate, and pharynx.
- The gustatory fibres of palate carried by this nerve, reach the geniculate ganglion and next run in facial nerve to reach eventually the nucleus tractus solitarius in medulla oblongata.
- **Vidian nerve**: Sympathetic fibres around the internal carotid artery form the deep petrosal nerve, which joins the greater petrosal nerve (parasympathetic fibres) to form the vidian nerve of pterygoid canal.

- This nerve is formed at the floor of foramen lacerum and runs anteriorly in pterygoid canal to reach the pterygopalatine ganglion.

A

Greater petrosal nerve arises from CN VII at the geniculate ganglion and emerges from the superior surface of the petrous part of the temporal bone to enter the middle cranial fossa

↓

Greater petrosal nerve joins the deep petrosal nerve (sympathetic) at the foramen lacerum to form the nerve of the pterygoid canal

↓

Nerve of pterygoid canal travels through the pterygoid canal and enters the pterygopalatine fossa

↓

Parasympathetic fibers from the nerve of pterygoid canal in the pterygopalatine fossa synapse in the pterygopalatine ganglion

↓

Postsynaptic parasympathetic fibers from this ganglion innervate the lacrimal gland via the zygomatic branch of CN V_2 and the lacrimal nerve (branch of CN V_1)

B

The chorda tympani branch arises from CN VII just superior to stylomastoid foramen

↓

The chorda tympani crosses the tympanic cavity medial to the handle of malleus

↓

The chorda tympani passes through the p etrotympanic fissure between the tympanic and the petrous parts of the temporal bone to join the lingual nerve (CN V_3) in the infratemporal fossa

↓

Parasympathetic fibers of the chorda tympani synapse in the submandibular ganglion; postsynaptic fibers follow arteries to glands

Figs. 51A and B: Parasympathetic innervation involving CN VII. (A) Innervation of the lacrimal gland. (B) Innervation of the submandibular and sublingual glands.

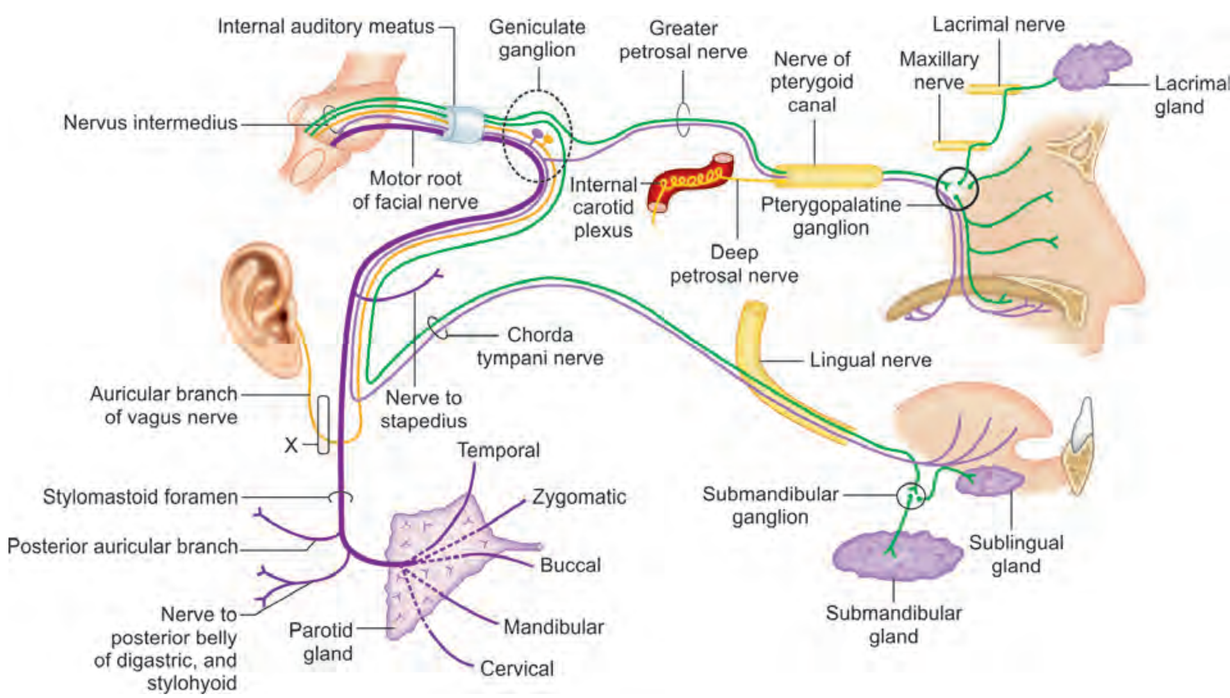


Fig. 52: Facial nerve: Origin, course and barnches.

- Facial nerve comes out through the stylomastoid foramen and appears posterior to the parotid gland, enters the parotid gland to give rise to five terminal branches—the temporal, zygomatic, buccal, mandibular, and cervical branches that radiate forward in the face.
- The fibres innervate the muscles of facial expression and send the posterior auricular branch to the muscles of the auricle and the occipitalis muscle.
- They also innervate the digastric posterior belly and stylohyoid muscles.
- **Chorda tympani nerve** is given in the middle ear cavity, runs medial to the tympanic membrane and malleus.
- It contains the SVA and GVE (parasympathetic) fibers.
- It carries pre-ganglionic fibres and is joined by lingual nerve (a branch of mandibular nerve), which carries post-ganglionic parasympathetic fibres to reach the submandibular and sublingual salivary glands.

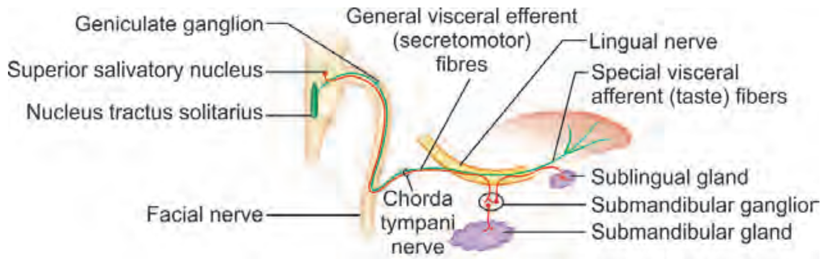


Fig. 53: Functional components of the chorda tympani nerve

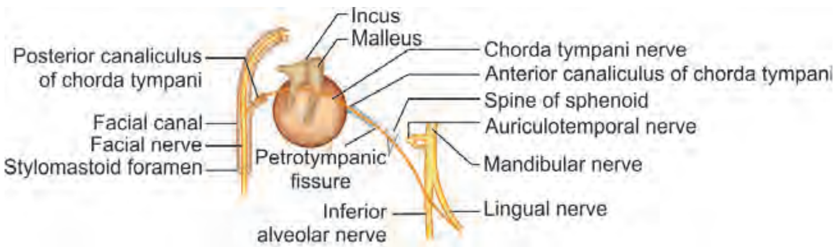


Fig. 54: Origin, course, and relations of the chorda tympani nerve

Clinical Correlations

- Facial paralysis may be caused by a lesion of the facial nerve, a stroke, or a brain tumor.
- Lesion of the facial nerve causes **Bell's palsy**, which is marked by flaccid paralysis of the ipsilateral muscles of facial expression, typical distortion of the face such as no wrinkles on the forehead, drooping of the eyebrow, inability to close or blink the eye, sagging corner of the mouth, and inability to smile, whistle, or blow.
- The palsy also causes loss of taste in the anterior two-thirds of the tongue, decreased salivary secretion and lacrimation, painful sensitivity to sounds, and deviation of the lower jaw.
- MRI studies indicate that it may be caused by viral neuronitis either in the bony first part of the facial canal (labyrinthine segment) at the apex of the internal auditory canal, or in the adjacent brainstem.
- Depending upon the level of lesion the clinical features may differ.

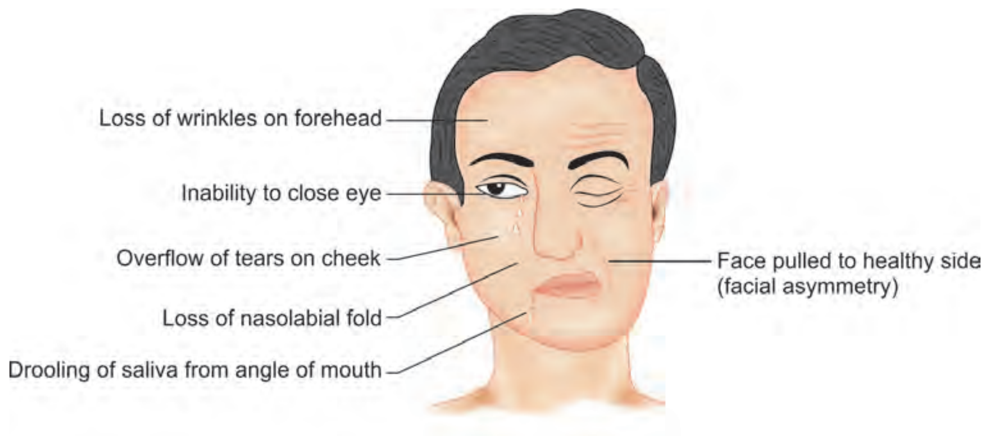
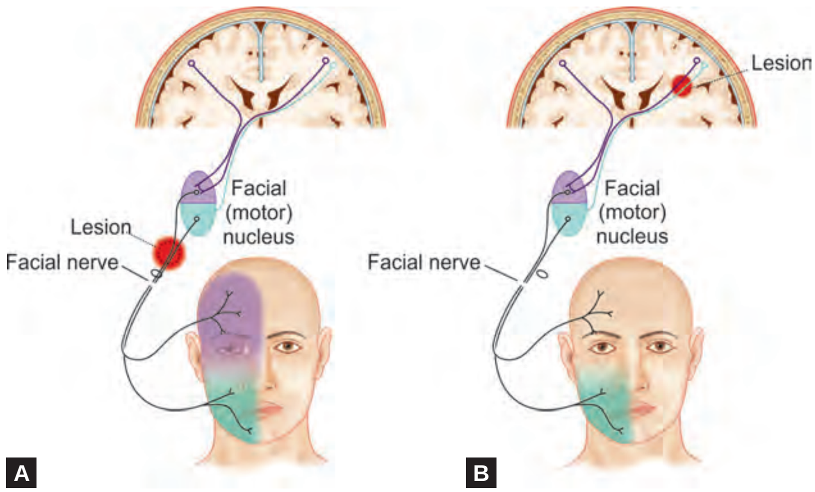


Fig. 55: Lower moor neurone palsy (Bell's palsy) on the right side.

Level of injury	Clinical features
Stylomastoid foramen	Paralysis of muscles of facial expression
Proximal to chorda tympani branch	• Paralysis of muscles of facial expression • Decreased salivation and loss of taste sensation on anterior 2/3 tongue
Proximal to nerve to stapedius	• Paralysis of muscles of facial expression • Decreased salivation and loss of taste sensation on anterior 2/3 tongue • Hyperacusis (loss of stapedial reflex)
Proximal to geniculate ganglion	• Paralysis of muscles of facial expression • Decreased salivation and loss of taste sensation on anterior 2/3 tongue • Hyperacusis (loss of stapedial reflex) • Loss of lacrimation (later may present with crocodile syndrome)

- A central lesion of the facial nerve (**UMN palsy**) results in paralysis of muscles in the lower face on the contralateral (opposite) side; consequently, forehead wrinkle is not impaired.
- Therefore, the patient with peripheral facial palsy shows no wrinkles on the affected side, but the patient with a stroke or a brain tumor shows wrinkles on both sides.
- Left sided upper motor neuron lesion (as might occur in Weber syndrome), will result in contralateral (right sided)facial palsy, where only lower face is involved, since the upper face has bilateral innervation.
- Lower face muscles like orbicularis oris have only contralateral innervation, as the left cortico-bulbar tract is lesioned, they get paralysed.
- Upper face muscles like orbicularis oculi are functional, as they are additionally innervated by right cortico-bulbar tract.
- Comparatively, in Bell's palsy (lower motor neuron lesion of facial nerve), both the upper face and lower face muscles are paralysed on the same side (ipsilateral) of the lesion.



Figs. 56A and B: Central connections of the facial motor nucleus. Cortical (upper motor neuron) or brainstem (lower motor neruron) lesions have different clinical presentation.

- **Crocodile tears syndrome** (Bogorad syndrome) is spontaneous lacrimation during eating caused by a lesion of the facial nerve proximal to the geniculate ganglion.
- It follows facial paralysis and is due to misdirection of regenerating parasympathetic fibers, which formerly innervated the salivary (submandibular and sublingual) glands, to the lacrimal glands.

ASSESSMENT QUESTIONS

1. **Facial nerve has all the following neural columns EXCEPT:**
   a. GVE
   b. SVE
   c. SVA
   d. SSA

2. **All is true about facial colliculus EXCEPT:**
   a. Raised by axons of facial nerve internal genu
   b. Abducent nucleus lies deep to it
   c. Located at the floor of fourth ventricle
   d. Present on the dorsal aspect of upper pons

3. **Lacrimation is lost in lesion of:** *(AIIMS May 2013)*
   a. Nasociliary nerve
   b. Greater petrosal nerve
   c. Anterior ethmoidal nerve
   d. Supraorbital nerve

4. **Following statements concerning chorda tympani nerve are true EXCEPT:** *(AIPG 2005)*
   a. Is a branch of facial nerve
   b. Carries secretomotor fibres to submandibular gland
   c. Joins lingual nerve in the infratemporal fossa
   d. Carries post-ganglionic parasympathetic fibres

5. **A patient with crocodile tears syndrome has spontaneous lacrimation during eating due to misdirection of regenerating autonomic nerve fibers. The lesion is located at:**
   a. Facial nerve proximal to the geniculate ganglion
   b. Chorda tympani in the infratemporal fossa
   c. Facial nerve at the stylomastoid foramen
   d. Lacrimal nerve

6. **Vidian nerve passes through**
   a. Inferior orbital fissure
   b. Foramen lacerum
   c. Tympano-mastoid fissure
   d. Pterygoid canal

7. **In the fracture of middle cranial fossa, lacrimation is affected in injury of**
   a. Nasociliary nerve
   b. Greater petrosal nerve
   c. Lesser petrosal nerve
   d. Auriculotemporal nerve

8. **Schirmer's test evaluates the function of:**
   a. Greater petrosal nerve
   b. Lesser petrosal nerve
   c. Chorda tympani nerve
   d. Auriculotemporal nerve

9. Nerve to pterygoid canal is formed from: *(NEET Pattern 2012)*
a. Deep petrosal nerve + greater petrosal nerve
b. Facial nerve
c. Lesser superficial petrosal nerve
d. Lesser petrosal nerve

10. Left sided upper motor neuron lesion of facial nerve paralyzes
a. Right half of the face
b. Left half of the face
c. Right upper half of the face
d. Right lower half of the face

11. Branch of facial nerve in facial canal: *(PGIC 2015)*
a. Greater petrosal nerve
b. Lesser petrosal
c. Chorda tympani
d. Nerve to stapedius
e. Stylohyoid nerve

12. All the following muscles are innervated by the facial nerve EXCEPT: *(AIIMS 2003)*
a. Occipitofrontalis
b. Anterior belly of digastric
c. Risorius
d. Procerus

13. Facial nerve supplies: *(PGIC 2015)*
a. Risorius
b. Anterior belly of digastric
c. Lateral pterygoid
d. Zygomaticus
e. Auricular muscles

14. A patient presents with hyperacusis, loss of lacrimation and loss of taste sensation in the anterior 2/3rd of the tongue. Inflammation extends up to which level of facial nerve
a. Vertical part
b. Vertical part proximal to nerve to stapedius
c. Vertical part and beyond nerve to stapedius
d. Proximal to geniculate ganglion

15. Which of the following is NOT supplied by secretomotor fibre of facial nerve: *(AIIMS 2014)*
a. Lacrimal gland
b. Parotid gland
c. Submandibular gland
d. Nasal gland

16. Facial nerve stimulation during testing of nerve indicated by contraction of muscle: *(AIIMS 2007)*
a. Temporalis
b. Masseter
c. Sternocleidomastoid
d. Orbicularis oris

17. Sensory fibres from the taste buds in the hard and soft palate travel along: *(AIIMS 2005)*
a. Trigeminal nerve
b. Facial nerve
c. Glossopharyngeal nerve
d. Vagus nerve

18. Nerve of Wrisberg contain: *(PGIC 2013)*
a. Motor fibers
b. Sensory fibers
c. Secretory fibers
d. Parasympathetic fibers
e. Sympathetic fibers

19. Arterial supply of facial nerve is/are: *(PGI 2015)*
a. Ascending pharyngeal artery
b. Middle meningeal artery
c. Greater palatine artery
d. Stylomastoid branch of occipital artery
e. Labyrinthine branch of ethmoidal artery

ANSWERS WITH EXPLANATIONS

1. d. SSA
- SSA (Special somatic afferent) neural column carries special peripheral sensations like smell, vison, hearing and balance, by cranial nerves 1,2 & 8.

2. d. Present on the dorsal aspect of upper pons
- Facial colliculus is present on the dorsal aspect of lower (not upper) pons.

3. a. Greater petrosal nerve
- Greater petrosal nerve carries pre-ganglionic parasympathetic secretomotor (GVE) fibres to supply the lacrimal, nasal and palatine glands.
- Injury to the nerve leads to dryness in the eye, nose and palate.

4. d. Carries post-ganglionic parasympathetic fibres
- Chorda tympani carries pre-ganglionic (and **not post-ganglionic**) para-sympathetic fibres.
- Chorda tympani nerve is **a branch of facial nerve** given in the facial canal (middle ear cavity) and carries **secretomotor fibres** to supply the sub-lingual and **sub-mandibular** salivary glands.
- It is **joined by lingual nerve** (branch of mandibular, trigeminal) in the infra-temporal fossa.
- Lingual nerve carries the post-ganglionic fibres towards the salivary glands.

5. a. Facial nerve proximal to the geniculate ganglion

- Crocodile tears syndrome (Bogorad syndrome) is spontaneous lacrimation during eating caused by a lesion of the facial nerve proximal to the geniculate ganglion.
- It follows facial paralysis and is due to misdirection of regenerating parasympathetic fibers, which formerly innervated the salivary (submandibular and sublingual) glands, to the lacrimal glands.

6. d. Pterygoid canal

- Vidian nerve is formed at the floor of foramen lacerum and runs anteriorly in pterygoid canal to reach the pterygopalatine ganglion.
- It carries both the sympathetic (deep petrosal nerve) and parasympathetic (greater petrosal nerve) fibres.

7. b. Greater petrosal nerve

- Greater petrosal nerve carries the pre-ganglionic para-sympathetic fibres to the pterygo-palatine ganglion, which relays them to the lacrimal, nasal and palatine glands.
- Injury of greater petrosal nerve causes dryness in the eyes, nose and palate ipsilaterally.

8. a. Greater petrosal nerve

- Schirmer's test evaluates the secretion of tears (function of lacrimal gland), which receives fibres through the greater petrosal nerve.

9. a. Deep petrosal nerve + greater petrosal nerve

- Vidian nerve of pterygoid canal is formed by the union of greater petrosal nerve (parasympathetic fibres) and deep petrosal nerve (sympathetic fibres).
- The nerve is formed at the floor of foramen lacerum and runs anteriorly in pterygoid canal to reach the pterygopalatine ganglion.

10. d. Right lower half of the face

- Left sided upper motor neuron lesion (as might occur in Weber syndrome), will result in contralateral (right sided) Facial palsy, where only lower face is involved, since the upper face has bilateral innervation.
- Lower face muscles like orbicularis oris have only contralateral innervation, as the left cortico-bulbar tract is lesioned, they get paralysed.
- Upper face muscles like orbicularis oculi are functional, as they are additionally innervated by right cortico-bulbar tract.
- In Bell's palsy (lower motor neuron lesion of facial nerve), both the upper face and lower face muscles are paralysed on the same side (ipsilateral) of the lesion.

11. a. Greater petrosal nerve, c. Chorda tympani, d. Nerve to stapedius

- Facial nerve gives three branches in the facial canal.

12. b. Anterior belly of digastric

- Facial nerve supplies muscles of facial expression.
- Anterior belly of digastric develops in first pharyngeal arch and supplied by mandibular nerve (branch of trigeminal).

13. a. Risorius, d. Zygomaticus, e. Auricular muscles

- Facial nerve supplies muscles of facial expression.
- Anterior belly of digastric and lateral pterygoid are supplied by mandibular nerve (branch of trigeminal).

14. d. Proximal to geniculate ganglion

- If facial nerve inflammation extends proximal to geniculate ganglion, the clinical features are: Loss of lacrimation (later may present with crocodile syndrome); hyperacusis (loss of stapedial reflex); decreased salivation and loss of taste sensation on anterior 2/3 tongue; paralysis of muscles of facial expression.

15. b. Parotid gland

- Superior salivatory nucleus sends secretomotor (GVE) fibres in facial nerve to supply two ganglia.
- The branch greater petrosal nerve preganglionic fibres continue to the pterygopalatine ganglion, which further supply the glands like lacrimal, nasal and palatine glands.
- The other branch chorda tympani carries secretomotor fibres to the submandibular ganglion, which further supply the minor salivary glands (submandibular and sublingual).
- Glossopharyngeal nerve carries the secretomotor fibres to parotid gland.

16. d. Orbicularis oris

- Facial nerve supplies the muscles of the facial expression like orbicularis oculi.
- Muscles of mastication like masseter and temporalis are supplied by the mandibular nerve, a branch of trigeminal.
- Spinal accessory nerve supplies sternocleidomastoid and the trapezius.

17. b. Facial nerve
- Taste buds in the hard and soft palate are innervated by the greater petrosal nerve—a branch of facial nerve.
- Facial nerve also carries the taste fibres from the anterior 2/3 of tongue, whereas, glossopharyngeal nerve innervates the posterior 1/3.
- Vagus nerve carries taste fibres from the posterior-most region of tongue as well as epiglottis and posterior pharyngeal wall.
- Trigeminal nerve carries general sensations from the anterior 2/3 of tongue.

18. b. Sensory fibers; c. Secretory fibers; d. Parasympathetic fibers
- Facial nerve has two parts: motor to facial expression muscles and nervus intermedius.
- The motor part carries SVE component, while nervus intermedius carries GSA, SVA, and GVE fibers.
- Nervus intermedius (nerve of Wrisberg) carries fibres for taste, salivation, lacrimation, and general sensation (from the external ear).
- The first-order sensory neurons are found in the geniculate ganglion within the temporal bone.

19. a. Ascending pharyngeal artery; b. Middle meningeal artery; d. Stylomastoid branch of occipital artery
- Facial nerve in facial canal is supplied by: Superficial petrosal branch of middle meningeal artery, stylomastoid branch of posterior auricular or occipital arteries.
- in extracranially course it is supplied by: stylomastoid branches of posterior auricular or occipital arteries, superficial temporal, transverse facial and tympanic branch of ascending pharyngeal artery.

Glossopharyngeal Nerve

- **Glossopharyngeal nerve** belongs to the **third branchial arch** and carries the fibres for neural columns SVE (pharyngeal arch muscles), SVA (taste), GVE (secretomotor), GVA (visceral sensations), and GSA (somatic sensations) fibers.
- Its nuclei are located in medulla oblongata and axons leave it at the postolivary sulcus to exit the cranial cavity through the jugular foramen.

It gives the following branches:
- **Tympanic Nerve** contributes to the tympanic plexus on the medial wall of the middle ear with sympathetic fibers from the internal carotid plexus (caroticotympanic nerves) and a branch from the geniculate ganglion of the facial nerve.
  - It carries visceral sensory fibers from the tympanic cavity, the mastoid antrum and air cells, and the auditory tube.
  - Its secretomotor axons continue beyond the tympanic plexus as the **lesser petrosal nerve** in the floor of the middle cranial fossa, which leaves through the foramen ovale to bring preganglionic parasympathetic fibers to the otic ganglion.
  - Postganglionic parasympathetic fibers leave the otic ganglion to innervate the parotid gland.
- **Communicating branch** to join the auricular branch of the vagus nerve and provides general sensation and pain fibers to the ear.
- **Pharyngeal branch** to carry visceral sensory fibers to the posterior tongue and pharyngeal wall, including the tonsillar bed.
  - It joins with the pharyngeal branch of the vagus nerve and branches from the sympathetic trunk to form the pharyngeal plexus on the middle constrictor muscle.
  - The sensory fibers mediate the afferent limb of the gag reflex (vagus nerve carry efferent limb).
- **Carotid sinus branch** to supply baroreceptive and chomoreceptive fibers (GVA) to the carotid sinus and the carotid body.
  - It mediates the afferent limbs of the carotid sinus and body reflexes that can cause a drop in heart rate and blood pressure with carotid massage (vagus nerve carry efferent limb).
- **Tonsillar branches** carry sensory fibers to the palatine tonsil and the soft palate.
- **Motor branch** carry motor fibers (SVE) to the stylopharyngeus.
- **Lingual branch** carry taste and visceral afferent fibers to the posterior one-third of the tongue and the circumvallate papillae.

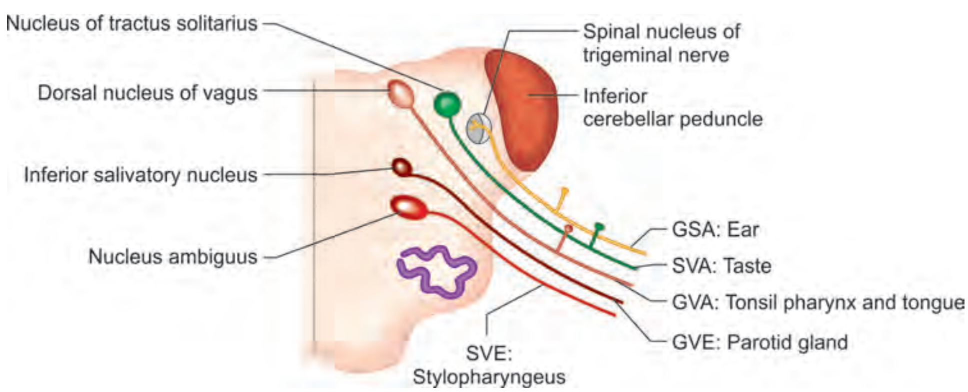


Fig. 57: Functional components and nuclei of the glossopharyngeal nerve.

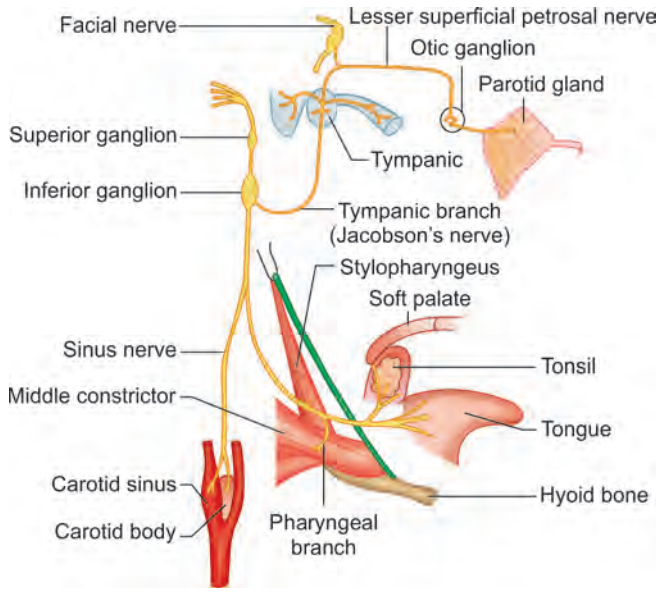


Fig. 58: Course and distribution of the glossopharyngeal nerve.

Parasympathetic (visceral motor)

Tympanic nerve arises from CN IX and emerges with it from the jugular foramen

↓

Tympanic nerve enters the middle ear via the tympanic canaliculus in the petrous part of the temporal bone

↓

Tympanic nerve forms the tympanic plexus on the promontory of the middle ear

↓

The lesser petrosal nerve arises as a branch of the tympanic plexus

↓

Lesser petrosal nerve penetrates roof of tympanic cavity (tegmen tympani) to enter middle cranial fossa

↓

Lesser petrosal nerve leaves cranium through the foramen ovale

↓

Parasympathetic fibers synapse in the otic ganglion

↓

Parasympathetic fibers pass to parotid gland via branches of auriculotemporal nerve (CN V_2)

Fig. 59: Parasympathetic innervation involving the glossopharyngeal nerve (CN IX). CN IX sends presynaptic parasympathetic (secretomotor) fibers to the otic ganglion via a convoluted route; postsynaptic fibers pass from the ganglion to the parotid gland via the auriculotemporal nerve.

Vagus Nerve

- **Vagus** Nerve is given by the medulla oblongata, comes out of the postolivary sulcus to exit the posterior cranial fossa through the jugular foramen.
- It contributes to vagus accessory complex and carries motor innervation (**SVE**) to all muscles of the larynx, pharynx (except stylopharyngeus), and palate (except tensor palati).
- It also carries parasympathetic preganglionic innervation (**GVE**) to smooth muscles and glands of the pharynx, esophagus, and gastrointestinal track (from the stomach to the transverse colon) as well as for the cardiac muscle of the heart.
- The visceral afferent fibers (**GVA**) are carried from all mucous membranes in the lower pharynx, larynx, trachea, bronchus, esophagus, and thoracic and abdominal visceral organs (except for the descending colon, sigmoid colon, rectum, and other pelvic organs).
- It mediates the afferent and efferent limbs of the cough reflex and the efferent limbs of the gag and sneeze reflex.

Vagus nerve gives numerous branches:

- **Meningeal** branch arises from the superior ganglion and supplies the dura mater of the posterior cranial fossa.
- **Auricular** branch is joined by a branch from the glossopharyngeal nerve and the facial nerve and supplies general sensory fibers to the external acoustic meatus.
- **Pharyngeal** branch supplies motor fibers to all the skeletal muscles of the pharynx, except the stylopharyngeus, by way of the pharyngeal plexus and all muscles of the palate except the tensor veli palatini.
- **Nerve to the carotid body**, which carry sensations from carotid body and the carotid sinus; superior, middle, and inferior cardiac branches which carry parasympathetic supply toward, and visceral afferent fibers back from, the cardiac plexuses.
- **Superior laryngeal nerve** which divides into internal and external branches.
- **Recurrent laryngeal nerve** which hooks around the subclavian artery on the right and around the arch of the aorta lateral to the ligamentum arteriosum on the left to ascends in the groove between the trachea and the esophagus.
  - It provides general sensory fibers to the larynx below the vocal cord and motor fibers to all muscles of the larynx except the cricothyroid muscle and becomes the **inferior laryngeal nerve** at the lower border of the cricoid cartilage.
- Right Vagus Nerve forms the **posterior vagal trunk** (or gastric nerves) and left vagus Nerve forms the **anterior vagal trunk** at the lower part of the esophagus and both enter the abdomen through the esophageal hiatus.

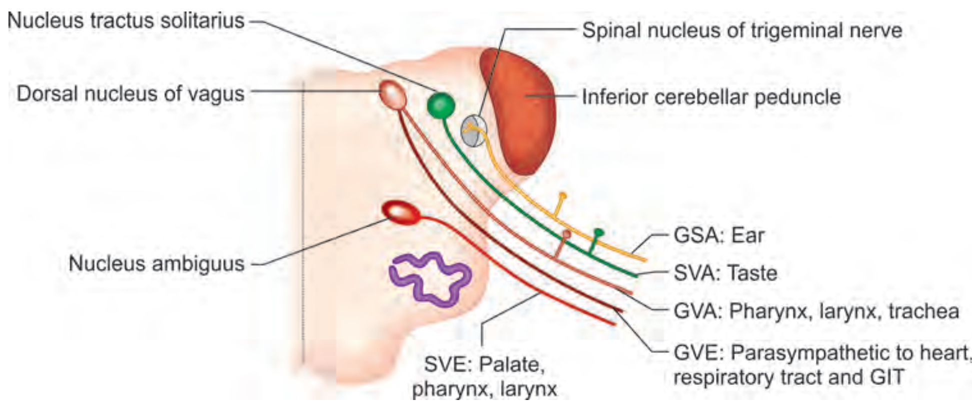
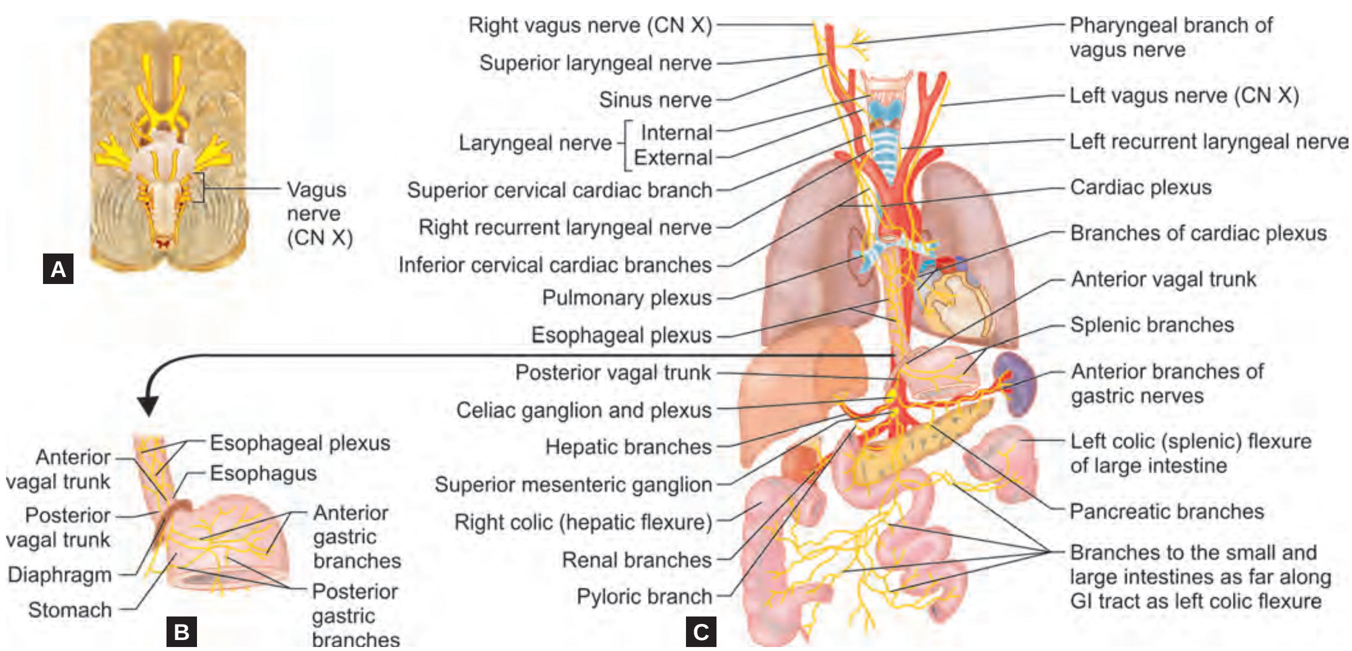


Fig. 60: Functional components and nuclei of the vagus



Figs. 61A to C: Vagus Nerve (CN X): (A) Origin of vagus nerve from medulla. (B) Anterior and posterior vogal trunks. (C) Couse in neck, thorax and abdomen.

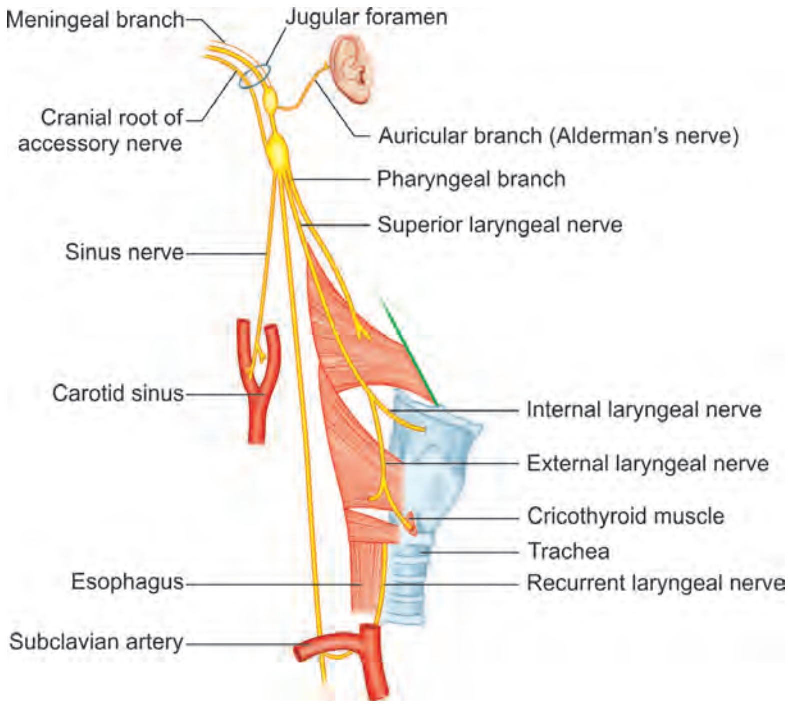


Fig. 62: Course and distribution of the vagus nerve (right) in the head and neck.

Summary of vagus nerve (CN X)

Divisions (parts)	Branches
Cranial Vagi arise by a series of rootlets from medulla (includes traditional cranial root of CN XI)	Meningeal branch to dura mater (sensory; actually fibers of C2 spinal ganglion neurons that hitch a ride with vagus nerve Auricular branch)
Cervical Exit cranium/enter neck through jugular foramen; right and left vagus nerves enter carotid sheaths and continue to root of neck	Pharyngeal branches to pharyngeal plexus (motor) Cervical cardiac branches (parasympathetic, visceral afferent) Superior laryngeal nerve (mixed) internal (sensory) and external (motor) branches Right recurrent laryngeal nerve (mixed)
Thoracic Vagi enter thorax through superior thoracic aperture; left vagus contributes to anterior esophageal plexus; right vagus to posterior plexus; form anterior and posterior vagal trunks	Left recurrent laryngeal nerve (mixed; all distal branches convey parasympathetic and visceral afferent fibers for reflex stimuli) Thoracic cardiac branches Pulmonary branches Esophageal plexus
Abdominal Anterior and posterior vagal trunks enter abdomen through esophageal hiatus in diaphragm; distribute asymmetrically	Esophageal brances Gastric branches Hepatic branches Celiac branches (from posterior vagal trunk) Pyloric branch (from anterior vagal trunk) Renal branches Intestinal branches (to left colic flexure)

Clinical Correlations

- Lesion of the vagus nerve causes dysphagia (difficulty in swallowing) resulting from lesion of pharyngeal branches; numbness of the upper part of the larynx and paralysis of cricothyroid muscle resulting from lesion of the superior laryngeal nerve; and hoarseness, dysphonia (difficulty in speaking), aphonia (loss of voice), and numbness of the lower part of the larynx resulting from lesion of the recurrent laryngeal nerve.
- Injury to vagus nerve leads to loss of palate elevation and the uvula deviates toward the intact side (away from the side of the lesion) during phonation.
- Lesion cannot mediate the afferent and efferent limbs of the cough reflex and the efferent limbs of the gag (pharyngeal) reflex and sneeze reflex.
- In addition, lesion causes loss of motor fibers to muscles of the larynx, pharynx (except the stylopharyngeus), and palate (except the tensor veli palatini); loss of taste on the epiglottis; and loss of parasympathetic supply to the thorax and abdomen as well as some visceral afferents.

ASSESSMENT QUESTIONS

1. **Galen's anastomosis is between:** *(NEET Pattern 2013)*
   a. Recurrent laryngeal nerve and external laryngeal nerve
   b. Recurrent laryngeal nerve and internal laryngeal nerve
   c. Internal laryngeal nerve and external laryngeal nerve
   d. None of the above

2. **All of the following statements about the vagus nerve are true EXCEPT:** *(AIIMS 2005)*
   a. Supplies heart and lung
   b. Carries postganglionic parasympathetic fibers
   c. Innervates right two third of transverse colon
   d. Stimulates peristalsis and relaxes sphincters

ANSWERS WITH EXPLANATIONS

1. **b. Recurrent laryngeal nerve and internal laryngeal nerve**
   - Galen's anastomosis is the connecting branch between the inferior laryngeal nerve (a branch of the recurrent laryngeal nerve) and the internal laryngeal nerve (a branch of the superior laryngeal nerve).

2. **b. Carries postganglionic parasympathetic fibers**
   - Cranial nerve 3, 7, 9 and 10 (vagus) carry the preganglionic (and not post-ganglionic) parasympathetic fibres.
   - It supplies the parasympathetic fibres to lungs and heart, and the GI system till the mid-gut.
   - The right 2/3 of the transverse colon belongs to mid-gut and is supplied by the vagus nerve.
   - Para-sympathetic system is generally evacuatory in nature and stimulates peristalsis and relaxes the sphincters, e.g. stomach empties into duodenum under vagal activity.

Accessory Nerve

- **Accessory nerve** has two parts: **cranial** and **spinal**.
- Cranial roots arise from the medulla oblongata below the roots of the vagus, whereas spinal roots arise from spinal cord C1-5, form a trunk that ascends in the vertebral canal, enter foramen magnum and join the cranial part.
- Both pass through the jugular foramen, cranial accessory fibres join the vagus nerve (vagus accessory complex) to innervate the muscles of palate, pharyngeal and larynx.
- The spinal accessory nerve supplies sternocleidomastoid muscle, lies on levator scapulae in the posterior cervical triangle, then reach and supply trapezius.

Clinical Correlations

- Spinal accessory nerve may be damaged within the posterior (occipital) triangle due to surgery or a penetrating wound leading to paralysis of the trapezius muscle (resulting in drooping of shoulder and compromised overhead abduction).

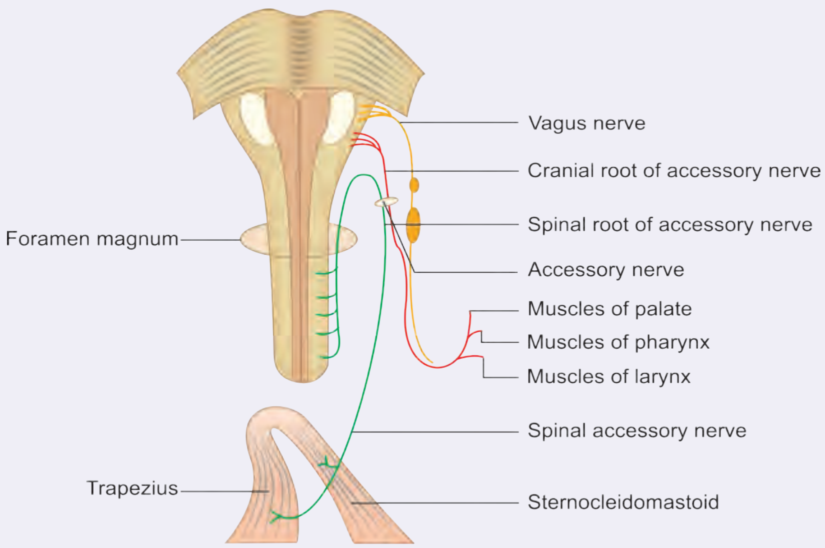


Fig. 63: Distribution of the cranial and spinal roots of the accessory nerve

- In conventional teaching, the accessory nerve has been described as having two roots: a cranial root and spinal root.
- In recent years, this description has been challenged: the cranial root has been redesignated as anatomically and functionally part of the vagus nerve, and the spinal root has become, de facto, the accessory nerve.

Vagus Accessory Complex

- Nucleus ambiguus (in medulla oblongata) gives axons to form cranial part of accessory nerve which are carried by the vagus nerve (vagus accessory complex) to innervate the muscles of palate, pharyngeal and larynx.
- Vagus nerve gives pharyngeal branches to pharyngeal plexus (which carry axons of cranial accessory nerve and the plexus itself sends these axons to muscles of palate and pharynx.

- All the muscles of palate and pharynx are supplied by the vagus accessory complex and pharyngeal plexus, with few exceptions: Tensor palati (first pharyngeal arch muscle) is supplied by mandibular nerve (trigeminal) and stylopharyngeus (third pharyngeal arch muscle) is supplied by glossopharyngeal nerve (neuron bodies in nucleus ambiguus).
- Spinal accessory nerve roots arise from spinal cord C1-5, form a trunk that ascends in the vertebral canal, enter foramen magnum and join the cranial part.
- Both pass through the jugular foramen, cranial accessory fibres join the vagus nerve (vagus accessory complex) whereas, the spinal accessory nerve supplies sternocleidomastoid muscle and trapezius.

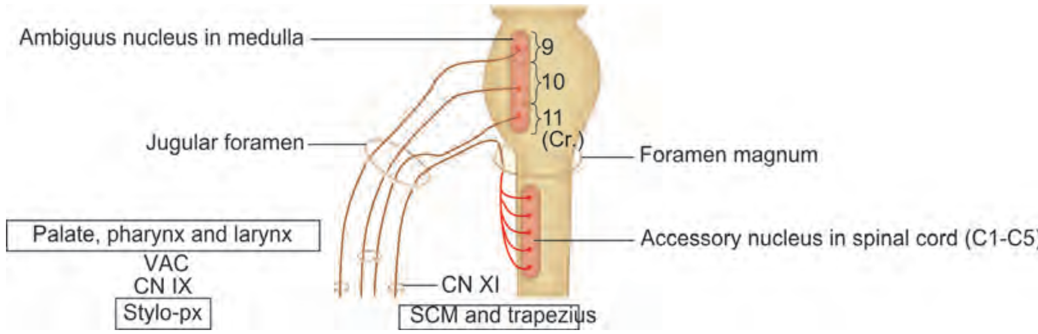


Fig. 64: Vagus accessory complex. Cranial accessory nerve (neuron bodies in nucleus ambigus) fibres are carried by vagal branches to supply muscles of palate, pharynx and larynx. Stylopharyngeus muscle is supplied by the glossopharyngeal nerve, fibres arising from nucleus ambigus.

ASSESSMENT QUESTIONS

1. **NOT supplied by cranial part of accessory nerve:** *(AIIMS 2012)*
   a. Stylopharyngeus
   b. Palatopharyngeus
   c. Cricopharyngeus
   d. Salpingopharyngeus

2. **Choose the INCORRECT statement concerning pharyngeal plexus:**
   a. Receives contributions from vagus nerve carrying cranial accessory nerve component
   b. Supplies all pharyngeal muscles except stylopharyngeus
   c. Supplies tensor tympani
   d. Supply palatoglossus

3. **Muscles spared by complete transection of cranial part of accessory nerve:** *(AIIMS 2012)*
   a. Cricopharyngeus
   b. Palatopharyngeus
   c. Stylopharyngeus
   d. Salpingopharyngeus

4. **Cranial part accessory nerve supplies all palatal muscles EXCEPT:** *(NEET Pattern 2014)*
   a. Palatoglossus
   b. Palatopharyngeus
   c. Tensor veli palati
   d. Levator palati

ANSWERS WITH EXPLANATIONS

1. **a. Stylopharyngeus**
   - Stylopharyngeus is innervated by the glossopharyngeal nerve and not the accessory nerve.
   - All the other muscles are supplied by the vago-accessory complex / pharyngeal plexus.
   - The pharyngeal branch of the vagus supplies all the muscles of the pharynx (excluding stylopharyngeus, which is supplied by the glossopharyngeal nerve) and of the soft palate (excluding tensor veli palatini, which is supplied by the mandibular division of the trigeminal via the nerve to medial pterygoid).
   - It emerges from the upper part of the inferior vagal ganglion and consists mainly of filaments derived from the cranial accessory nerve: almost all the neuronal cell bodies are in the nucleus ambiguus.
   - Stylopharyngeus muscle is the only muscle developing in the third pharyngeal arch and the only muscle to be supplied by the glossopharyngeal nerve.
   - Most of the muscles of the palate and pharynx develop in the fourth pharyngeal arch and are supplied by the cranial part of accessory nerve, whose axons are carried by the vagus nerve through the pharyngeal plexus to the muscles. (vago – accessory complex).

2. **c. Supplies tensor tympani**
   - Tensor tympani muscle develops in first pharyngeal arch and is supplied by the mandibular nerve (trigeminal).
   - Vagus nerve carry axons of cranial accessory nerve (vagus accessory complex) and gives pharyngeal branches to pharyngeal plexus and the plexus itself sends these axons to muscles of palate and pharynx.
   - All the muscles of palate and pharynx are supplied by the vagus accessory complex and pharyngeal plexus, with few exceptions like stylopharyngeus (CN IX) and tensor tympani (CN V).
   - Palatoglossus is a tongue muscle supplied by CN XI (cranial accessory nerve) and not by CN XII (hypoglossal nerve).

3. **c. Stylopharyngeus**
   - Cranial part of accessory nerve supplies most of the pharyngeal muscles with few exceptions.
   - Stylopharyngeus develops in third pharyngeal arch and supplied by glossopharyngeal nerve.

4. **c. Tensor veli palati**
   - Most of the muscle of palate are supplied by cranial accessory nerve (via vagus accessory complex) except few exceptions.
   - Tensor veli palate develops in first pharyngeal arch and supplied by mandibular branch of trigeminal nerve.

Hypoglossal nerve

- **Hypoglossal Nerve** is given by the medulla oblongata ventrally in the preolivary sulcus and passes through the **hypoglossal canal** to exit the cranial cavity.
- It loops around the occipital artery and the carotid bifurcation (in **carotid triangle**) to pass between the carotids and internal jugular vessels.
- It runs deep to the digastric posterior belly and stylohyoid muscles to enter the **submandibular triangle**.
- It enters the mouth by passing above the greater horn of the hyoid bone between the middle pharyngeal constrictor and the mylohyoid muscle.
- After crossing the loop of the lingual artery a little above the tip of the greater cornu of the hyoid, it inclines upwards and forwards on hyoglossus, passing deep to stylohyoid, the tendon of digastric and the posterior border of mylohyoid.
- Between mylohyoid and hyoglossus, the hypoglossal nerve lies below the deep part of the submandibular gland, the submandibular duct and the lingual nerve, with which it communicates.
- It then passes on to the lateral aspect of genioglossus, continuing forwards in its substance as far as the tip of the tongue.
- It supplies motor fibers to all of the intrinsic and extrinsic muscles of the tongue **except** the palatoglossus (which is supplied by the vagus accessory complex).
- It carries sensory fibers from C1 to supply the cranial dura mater through the meningeal branch to supply the upper root of the ansa cervicalis and the nerve to both the **thyrohyoid** and **geniohyoid** muscles.

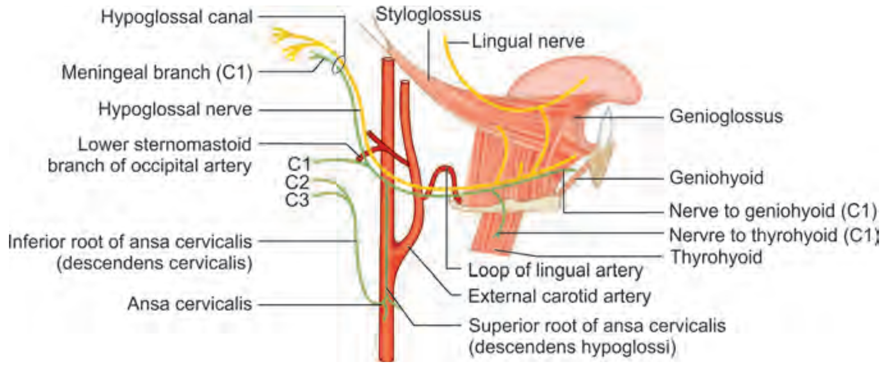
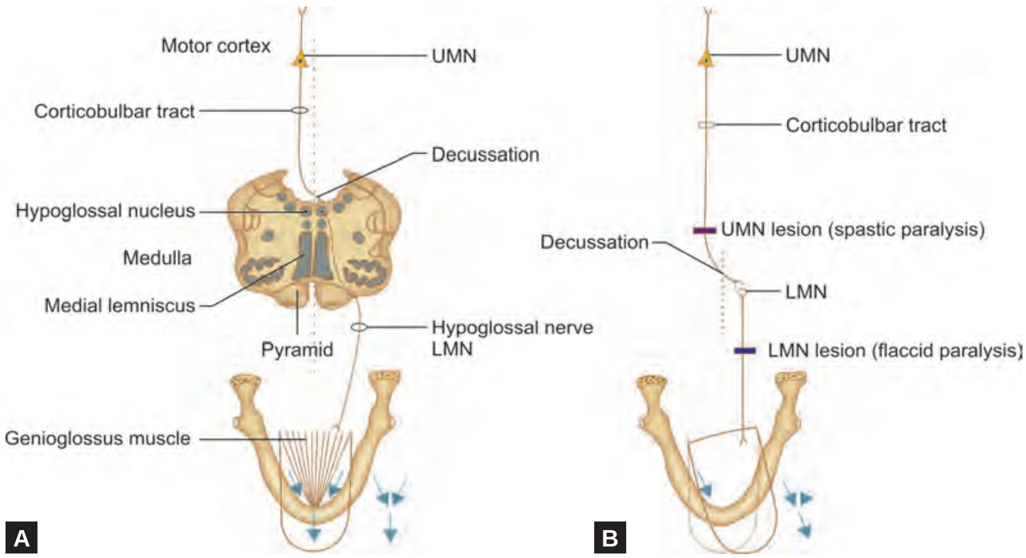


Fig. 65: Course and distribution of the hypoglossal nerve



Figs. 66A and B: Motor innervation of the tongue. Corticobulbar fibers project predominantly to the contralateral hypoglossal nucleus. An upper motor neuron (UMN) lesion causes deviation of the protruded tongue to the weak (contralateral) side. A lower motor neuron (LMN) lesion causes deviation of the protruded tongue to the weak (ipsilateral) side. (A) Normal tongue. (B) Tongue with UMN and LMN lesions.

Clinical Correlations

- Lesion of the hypoglossal nerve may be occur during neck dissection.
- Complete hypoglossal division causes unilateral lingual paralysis and eventual hemiatrophy.
- The protruded tongue deviates to the paralysed side.
- The larynx may deviate towards the active side in swallowing.
- Articulation is slow and swallowing very difficult, taste and tactile sensibility remain un-affected.
- Protruded tongue deviates to the paralyzed side: Genioglossus muscle moves the tongue anterior, inferior and medial (AIM).

- Since muscle on the affected side is paralyzed, the normal (unaffected) muscle becomes unopposed and pushes the tongue further across the midline, and tongue deviates to the side of the lesion.

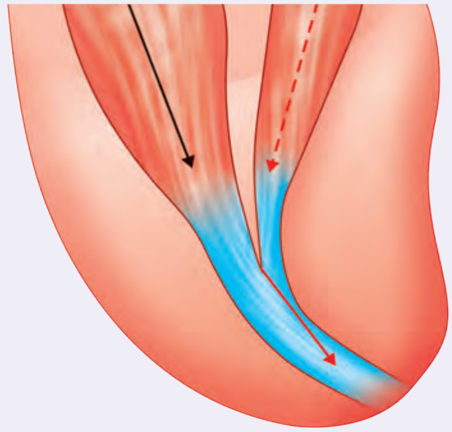


Fig. 67: Paralysis of left genioglossus, leads to unopposed activity of normal (right) genioglossus leading to deviation of tongue, towards the side of lesion

- The larynx may deviate towards the active side in swallowing: Due to unilateral paralysis of the hyoid muscles (genio-hyoid and thyrohyoid associated with loss of the first cervical spinal nerve which is carried by the hypoglossal nerve (Gray's anatomy).

ASSESSMENT QUESTIONS

1. **Palsy of right genioglossus causes**
   a. Deviation of tongue to right
   b. Deviation of tongue to left
   c. Deviation of soft palate to right
   d. Deviation of soft palate to left

2. **In complete unilateral damage to Hypoglossal nerve, all are true EXCEPT:** *(AIIMS 2012)*
   a. Tongue atrophy on affected side
   b. Deviation of tongue towards the site of lesion
   c. Deviation of Larynx to the contralateral side during swallowing
   d. Loss of tactile sensation on affected side

ANSWERS WITH EXPLANATIONS

1. **a. Deviation of tongue to right**
   - Genioglossus muscle moves the tongue anterior, inferior and medial (AIM).
   - Bilateral contraction of genioglossus help in protrusion and depression of tongue in midline, since the vector of medial pull is balanced and cancelled.
   - Palsy of right genioglossus muscle deviates the tongue to the right side, due to unopposed medial pull of the left genioglossus.

2. **d. Loss of tactile sensation on affected side**
   - Tactile sensation of tongue is not carried by the hypoglossal nerve, hence there will be no loss of tactile sensation on the tongue.
   - Hypoglossal nerve is a pure motor nerve and supplies the tongue muscles.
   - It also carries the C-1 fibres to supply the two muscles of hyoid bone: Geniohyoid and thyrohyoid.
   - Lesion of the hypoglossal nerve causes unilateral lingual paralysis and eventual hemiatrophy.
   - The protruded tongue deviates to the paralysed side and the larynx may deviate towards the active side during swallowing.

Cranial Nerve Lesions

Table of important clinical aspects of the cranial nerves

Cranial Nerve	Clinical Aspects
I Olfactory	Mediates the sense of smell (olfaction)
II Optic	Mediates the sense of sight (vision)
III Oculomotor	CN III lesion (e.g., **transtentorial [uncal] herniation**) results in droopy upper eyelid as a result of paralysis of levator palpebrae muscle; eye "looks down and out" as a result of paralysis of superior rectus muscle, medial rectus muscle, inferior rectus muscle, and inferior oblique muscle and the unopposed action of the superior oblique muscle (CN IV) and lateral rectus muscle (CN VI); double vision (diplopia) when patient looks in direction of paretic muscle; fixed and dilated pupil as a result of paralysis of sphincter pupillae muscle; lack of accommodation (cycloplegia) as a result of paralysis of the ciliary muscle; CN III lesions are associated with diabetes; an aneurysm of the posterior cerebral artery or superior cerebellar artery may exert pressure on CN III as it passes between these vessels.
IV trochlear	Innervates the superior oblique muscle CN IV lesion results in extortion of the eye, vertical diplopia that increases when looking down (e.g., reading a book), head tilting to compensate for extortion

Cranial Nerve	Clinical Aspects
V Trigeminal	Provides sensory innervation to the face and motor innervation to the muscles of mastication CN V lesion results in hemianesthesia of the face, loss of afferent limb of corneal reflex, loss of afferent limb of oculocardiac reflex, paralysis of muscle of mastrication, deviation of jaw to the injured side, hypoacusis as a result of paralysis of tensor tympani muscle, and tic douloureux (recurrent, stabbing pain)
VI Abducens	Innervation the lateral rectus muscle CN VI lesion results in convergent strabismus, inability to abduct the eye, horizontal diplopia when patient looks toward paretic muscle; an aneurysm of the labyrinthine artery or anterior inferior cerebellar artery may exert pressure on CN VI as it passes between these vessels.
VII Facial	Provides motor innervation to the muscles of facial expression, mediates taste, salivation, and lacrimation CN VII lesion results in paralysis of muscle of facial expression (upper and lower face; called Bell palsy), loss of efferent limb of corneal reflex, hyperacusis as a result of paralysis of stapedius muscle, and **crocodile tears syndrome** (tearing during eating) as a result of aberrant regeneration after trauma
VIII Vestibulocochlear	Mediates equilibrium and balance (vestibular) and hearing (cochlear) CN VIII (vestibular) lesion results in disequilibrium, vertigo, and nystagmus CN VIII (cochlear) lesion (e.g., **acoustic neuroma**) results in hearing loss and tinnitus
IX Glossopharyngeal	Mediates taste, salivation, swallowing, and input from the carotid sinus and carotid body CN IX lesion results in loss of afferent limb of gag reflex, loss of taste from posterior one third of tongue, loss of sensation from pharynx, tonsils, fauces, and back of tongue
X Vagus	Mediates speech and swallowing; innervates viscera in thorax and abdomen CN X lesion results in paralysis of pharynx and larynx, uvula deviates to **opposite side** of injured nerve, loss of efferent limb of gag reflex, and loss of efferent limb of oculocardiac reflex
XI Spinal Accessory	Innervates the sternocleidomastoid and trapezius muscle CN XI lesion results in inability to turn head to **opposite side** of injured nerve, inability to shrug shoulder
XII Hypoglossal	Innervates intrinsic and extrinsic muscles of the tongue CN XII lesion results in tongue deviation to the **same side** of injured nerve

Cervical Sympathetic Trunk

- Cervical part of sympathetic trunk lies on either side of cervical vertebral column in front of the transverse processes of cervical vertebrae and neck of the 1st rib behind the carotid sheaths.
- It is covered by the prevertebral fascia (the prevertebral fascia splits to enclose it), runs in front of the longus colli and longus capitis muscles.
- It contains preganglionic and postganglionic sympathetic fibers, cell bodies of the postganglionic sympathetic fibers, and visceral afferent fibers with cell bodies in the upper thoracic dorsal root ganglia.
- Each trunk receives preganglionic fibres from lateral horn cells of T1–T4 spinal segments.
- Sympathetic chain gives gray rami communicantes but receives **no white rami communicantes** in the cervical region.
- Cervical sympathetic chain has 3 cervical ganglia: **Superior**, **middle**, and **inferior**. They are formed by the fusion of eight primitive ganglia, corresponding to eight cervical nerves.
- **Superior Cervical Ganglion** (the largest) lies in front of the transverse processes of vertebrae C1 to C2, posterior to the internal carotid artery and anterior to the longus capitis.
  - It is formed by the fusion of four primitive cervical ganglia and contains cell bodies of postganglionic sympathetic fibers that pass to the visceral structures of the head and neck.
  - It gives the internal carotid nerve to form the internal carotid plexus (and supply **superior tarsal muscle** and dilator **pupillae** muscles).
  - It also gives the external carotid nerve to form the external carotid plexus; the pharyngeal branches to the pharyngeal plexus; and the superior cervical cardiac nerve to the heart.
- **Middle Cervical Ganglion** lies at the level of the cricoid cartilage (vertebra C6), just above the inferior thyroid artery.
  - It is formed by the fusion of the 5th and 6th primitive cervical ganglia and gives middle cervical cardiac nerve, which is the largest of the three cervical sympathetic cardiac nerves.
- **Inferior Cervical Ganglion** is formed by the fusion of the 7th and 8th primitive cervical ganglia.
  - It gets fused with the first thoracic ganglion to become the cervicothoracic (**stellate**) ganglion.
  - It lies in front of the neck of the first rib and the transverse process of vertebra C7 and behind the dome of the pleura and the vertebral artery.
  - It gives the inferior cervical cardiac nerve.
- **Ansa Subclavia** connects the middle and inferior cervical sympathetic ganglia, forming a loop around the first part of the subclavian artery.

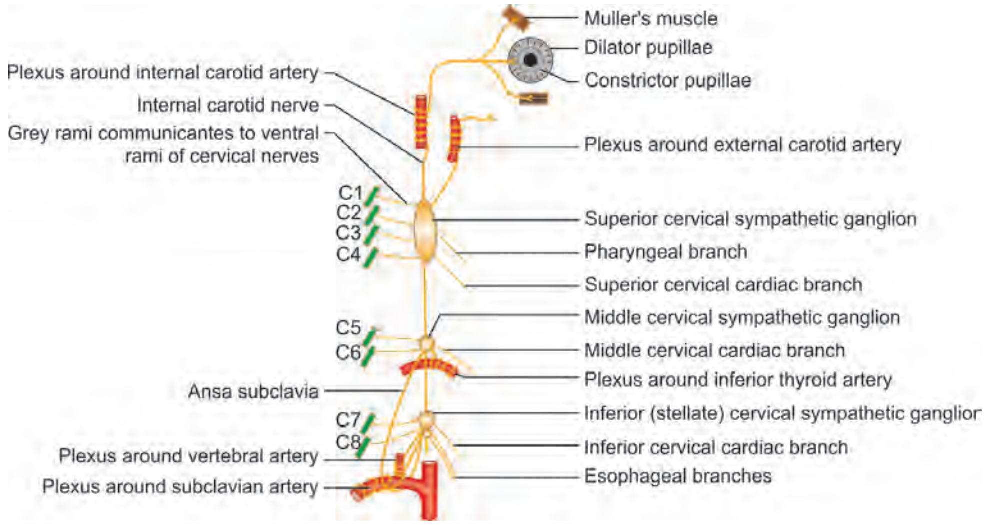


Fig. 68: Cervical sympathetic trunk and its branches

Cervical Sympathetic Ganglia

Characteristic features	Superior cervical ganglion	Middle cervical ganglion	Inferior cervical ganglion
Location	In front of the transverse processes of vertebrae C1,2	At the level of the cricoid cartilage (vertebra C6)	In front of the neck of the first rib and the transverse process of vertebra C7
Formed by the fusion of primitive cervical ganglia	1-4	5,6	7,8
Grey rami communicantes to ventral rami of cervical nerves	C1-4	C5,6	C7,8
Perivascular sympathetic plexus along	• Internal carotid artery • External carotid artery	Inferior thyroid artery	Vertebral artery Subclavian artery
Branches along cranial nerves	Along cranial nerves IX,X,XI and XII		
Visceral branches	• Superior cervical cardiac nerve • Pharyngeal plexus	• Middle cervical cardiac nerve • Thyroid • Tracheo-esophageal	Inferior cervical cardiac nerve

Cervical Plexus

- **Cervical Plexus** is contributed by the ventral primary rami of C1 to C5.
- It gives unnamed branches to longus capitis and colli, sternocleidomastoid, trapezius, levator scapulae, and scalene muscles.
- Named branches are cutaneous and motor.

Cutaneous Branches:
- **Lesser occipital nerve** (C2) ascends along the posterior border of the sternocleidomastoid to the scalp behind the auricle
- **Great auricular nerve** (C2–C3) ascends on the sternocleidomastoid to innervate the skin on auricle, behind the auricle and on the parotid gland.
- **Transverse cervical nerve** (C2–C3) innervates the skin of the anterior triangle of neck.
- **Supraclavicular nerve** (C3–C4) divides into anterior, middle, and lateral branches to supply the skin over the clavicle and the shoulder.

Motor Branches:

- **Ansa cervicalis** is a nerve loop formed by the union of the superior root (C1 or C1 and C2; descendens hypoglossi) and the inferior root (C2 and C3; descendens cervicalis).
- It is embedded on the anterior wall of carotid sheath in the anterior triangle of neck.

- It innervates the strap muscles, such as the omohyoid, sternohyoid, and sternothyroid muscles (except thyrohyoid & geniohyoid muscles, which are supplied by C1 fibres, carried by hypoglossal nerve).
- **Phrenic nerve** takes origin from the C3-5 (chiefly C4) carries motor, sensory, and sympathetic fibers.
- **Accessory phrenic nerve** (C5) may occasionally be found, descends lateral to the phrenic nerve, enters the thorax by passing posterior to the subclavian vein, and joins the phrenic nerve below the first rib to supply the diaphragm.

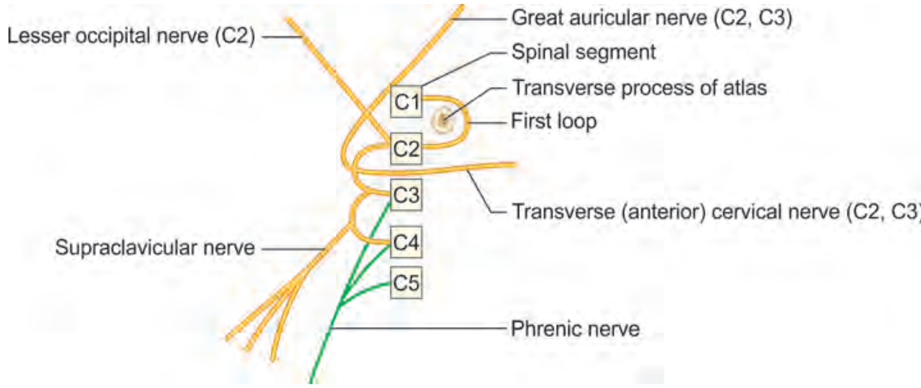


Fig. 69: Cervical plexus with loops and its cutaneous branches

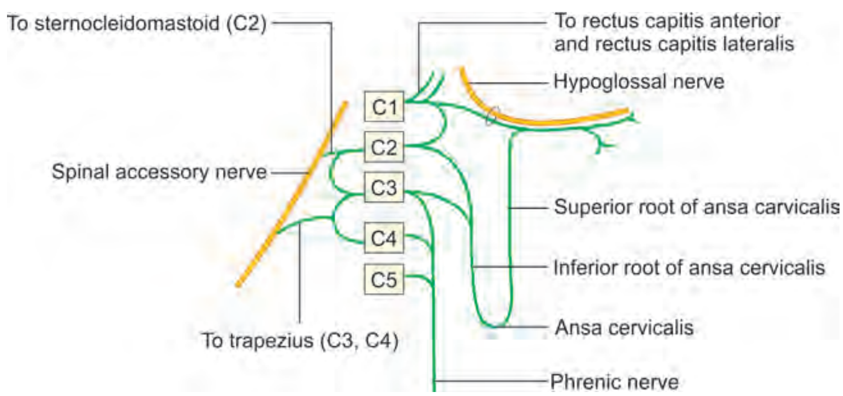


Fig. 70: Cervical plexus with its communicating branches

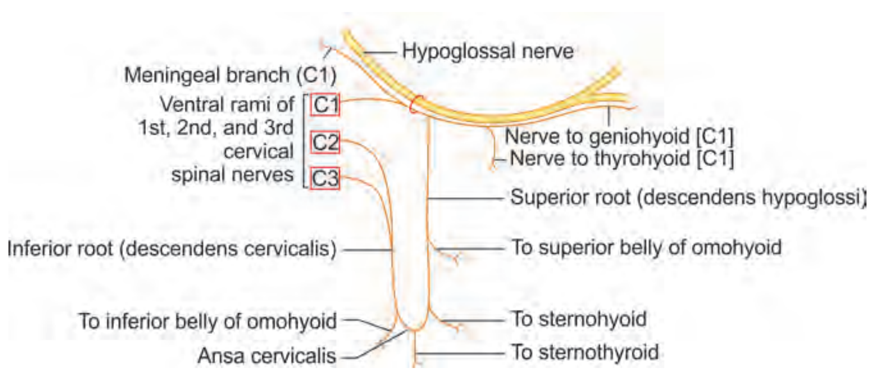


Fig. 71: Formation and distribution of the ansa cervicalis

ASSESSMENT QUESTIONS

1. **All are supplied by ansa cervicalis EXCEPT:** *(AIIMS)*
   a. Thyrohyoid
   b. Sternothyroid
   c. Sternohyoid
   d. Inferior belly of omohyoid

2. **Ansa cervicalis supplies:** *(JIPMER 2010)*
   a. Sternohyoid
   b. Mylohyoid
   c. Cricothyroid
   d. Stylohyoid

3. **Superior cervical ganglia gives gray rami communicates to:** *(NEET Pattern 2012)*
   a. C1-C4
   b. C5-C6
   c. C7-C8
   d. None

ANSWERS WITH EXPLANATIONS

1. a. Thyrohyoid

- Ansa cervicalis supplies numerous anterior neck muscles but thyrohyoid and geniohyoid are supplied by C1 fibres of spinal cord carried by the hypoglossal nerve.

2. a. Sternohyoid

- Ansa cervicalis supplies anterior neck muscles including sternohyoid.
- Mylohyoid develops in first pharyngeal arch and is supplied by the inferior alveolar nerve (mandibular nerve; trigeminal);
- Cricothyroid develops in fourth pharyngeal arch and is supplied by external laryngeal nerve branch of superior laryngeal nerve (vagus).
- Stylohyoid muscle develops in second pharyngeal arch and is supplied by the facial nerve.

3. a. C1-C4

- Superior cervical ganglia gives gray rami communicates to C1-4 spinal nerves.
- Middle cervical ganglia to C5,6 and inferior to C7,8 spinal nerves.

Ganglia

Cranial parasympathetic ganglia: Location, parasympathetic and sympathetic roots, and main distribution

Ganglion	Location	Parasympathetic root	Sympathetic root	Main distribution
Ciliary	Between optic nerve and lateral rectus, close to apex of orbit	Inferior branch of oculomotor nerve (CN III)	Branches from internal carotid plexus in cavernous sinus	Parasympathetic postsynaptic fibers from ciliary ganglion pass to ciliary muscle and sphincter pupillae of iris; sympathetic postsynaptic fibers from superior cervical ganglion pass to dilator pupillae and blood vessels of eye
Pterygopalatine	In pterygopalatine fossa, where it is suspended by ganglionic branches of maxillary nerve (sensory roots of pterygopalatine ganglion); just anterior to opening of pterygoid canal and inferior to CN V_2	Greater petrosal nerve from facial nerve (CN VII) via nerve of pterygoid canal	Deep petrosal nerve, a branch of internal carotid plexus that is a continuation of postsynaptic fibers of cervical sympathetic trunk; fibers from superior cervical ganglion pass through pterygopalatine ganglion and enter branches of CN V_2	Parasympathetic postganglionic (secretomotor) fibers from pterygopalatine ganglion innervate lacrimal gland via zygomatic branch of CN V_2; sympathetic postsynaptic fibers from superior cervical ganglion accompany branches of pterygopalatine nerve that are distributed to blood vessels of nasal cavity, palate, and superior parts of pharynx
Otic	Between tensor veli palatini and mandibular nerve (CN V_3); lies inferior to foramen ovale of sphenoid bone	Tympanic nerve from glossopharyngeal nerve (CN IX); continues from tympanic plexus as lesser petrosal nerve	Fibers from superior cervical ganglion come from plexus on middle meningeal artery	Parasympathetic postsynaptic fibers from otic ganglion are distributed to parotid gland via auriculotemporal nerve (branch of CN V_3); sympathetic postsynaptic fibers from superior cervical ganglion pass to parotid gland and supply its blood vessels
Submandibular	Suspended from lingual nerve by two ganglionic branches (sensory roots); lies on surface of hyoglossus muscle inferior to submandibular duct	Parasympathetic fibers join facial nerve (CN VII) and leave it in its chorda tympani branch, which unites with lingual nerve	Sympathetic fibers from superior cervical ganglion via plexus on facial artery chorda tympani	Parasympathetic postsynaptic (secretomotor) fibers from submandibular ganglion are distributed to sublingual and submandibular glands; sympathetic fibers from superior cervical ganglion supply sublingual and submandibular glands

Ganglion	Functional relation*	Topographically (anatomical) relation
Ciliary	Oculomotor nerve	Nasociliary nerve (branch of ophthalmic nerve; Trigeminal)
Pterygopalatine	Facial nerve	Maxillary nerve (branch of Trigeminal)
Submandibular	Facial nerve	Lingual nerve (branch of mandibular nerve; Trigeminal)
Otic	Glossopharyngeal (IX) nerve	Mandibular nerve (branch of Trigeminal)

*Functionally related nerves carry preganglionic fibres to the respective ganglion. Postganglionic fibres are carried by the topographically related nerve (mostly trigeminal nerve branches).

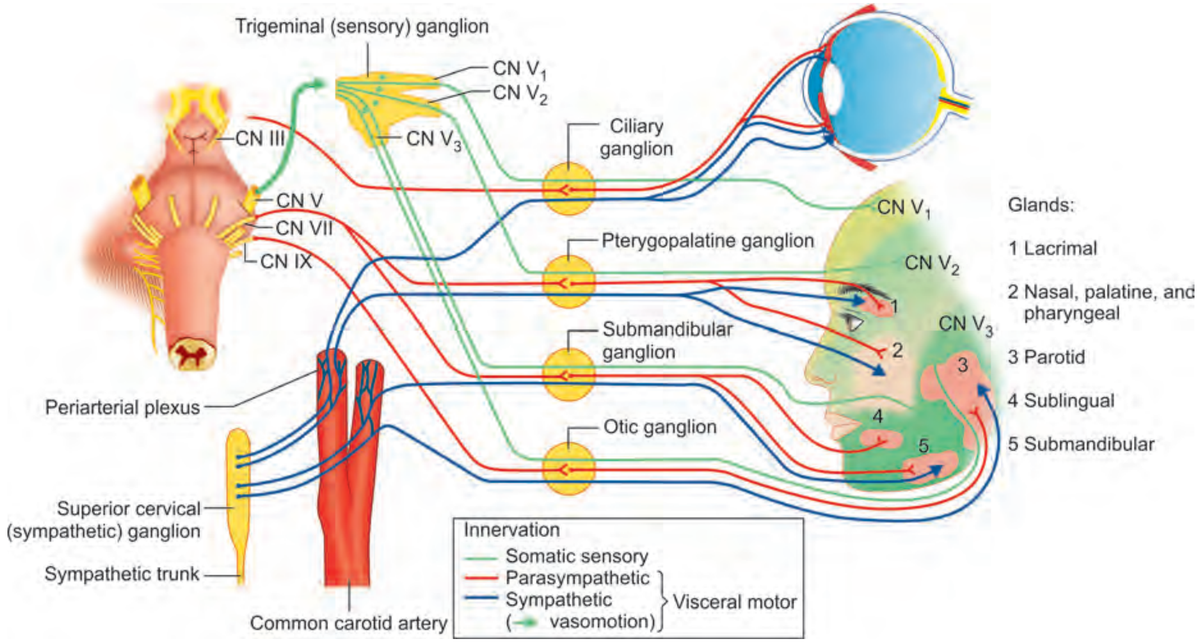


Fig. 72: Summary of autonomic innervation of head

- The cervical **sympathetic trunk** ganglia receive preganglionic fibres from neurons whose cell bodies that lie in the intermediolateral column of the upper thoracic (T1-4) spinal cord; there is no preganglionic output from the cervical spinal cord.
- Postganglionic fibres reach their target tissues in the head and neck via the **cervical spinal nerves** and **perivascular nerve plexuses** distributed along the carotid and vertebral arteries.
- **Internal carotid plexus**: Postganglionic sympathetic fibres ascend from the superior cervical ganglion, along the walls of the internal carotid artery, to enter the internal carotid plexus.
- These fibres then distribute to deep structures, which include the **superior tarsal muscle** and dilator **pupillae** muscles.
- They also contribute to the formation of **deep petrosal nerve**.
- The internal carotid plexus communicates with the trigeminal ganglion, the abducens nerve, and the pterygopalatine ganglion, tympanic branch of the glossopharyngeal nerve, etc.

ASSESSMENT QUESTIONS

1. Parasympathetic fibres to eye come via: *(NEET Pattern 2015)*
   a. Ciliary ganglion
   b. Geniculate ganglion
   c. Sphenopalatine ganglion
   d. Superior cervical ganglion

2. The nerve supplying submandibular gland is: *(NEET Pattern 2014)*
   a. V
   b. IX
   c. VII
   d. XII

3. Pterygopalatine ganglion supplies: *(NEET Pattern 2012)*
   a. Parotid gland
   b. Submandibular gland
   c. Lacrimal gland
   d. Sublingual

4. Greater petrosal nerve is formed from: *(NEET Pattern 2015)*
   a. Geniculate ganglion
   b. Plexus around ICA
   c. Plexus around middle meningeal artery
   d. None of the above

5. Deep petrosal nerve is formed from: *(NEET Pattern 2012)*
   a. Sympathetic plexus around carotid artery
   b. Facial nerve
   c. Glossopharyngeal
   d. Internal carotid plexus

6. Otic ganglion is anatomically related to: *(NEET Pattern 2012)*
   a. Glossopharyngeal nerve
   b. Mandibular nerve
   c. Vagus nerve
   d. Trochlear nerve

7. Sympathetic root of otic ganglion: *(NEET Pattern 2012)*
   a. Plexus around internal carotid artery
   b. Plexus around facial artery
   c. Plexus around ophthalmic artery
   d. Plexus around middle meningeal artery

8. Lesser petrosal nerve derives preganglionic fibers from: *(NEET Pattern 2014)*
   a. Tympanic nerve
   b. Cochlear nerve
   c. Nervus intermedius
   d. Chorda tympani

9. Lacrimal gland supplied by: *(AIIMS 2013)*
   a. Greater petrosal nerve
   b. Lesser petrosal nerve
   c. Nasociliary nerve
   d. Supraorbital nerve

ANSWERS WITH EXPLANATIONS

1. a. Ciliary ganglion
- Parasympathetic supply to eye is meant to control the smooth muscles sphincter pupillae and ciliaris.
- Edinger-Westphal nucleus sends pre-ganglionic fibres through oculomotor nerve to reach ciliary ganglion.

2. c. VII
- Submandibular gland is controlled by the superior salivatory nucleus, sending pre-ganglionic fibres by facial nerve branch (chorda tympani nerve) to reach the sub-mandibular ganglion.

3. c. Lacrimal gland
- Superior salivatory nucleus sends preganglionic fibres by facial nerve branch (greater petrosal nerve) to reach pterygopalatine ganglion and supply lacrimal, nasal, palatine glands.

4. a. Geniculate ganglion
- Greater petrosal nerve is a branch of facial nerve, given at geniculate ganglion, carry variety of axons.
- Geniculate ganglion has sensory neurons, whose axons travel by greater petrosal nerve.
- Deep petrosal nerve is formed from the T1 sympathetic plexus around the internal carotid artery.

5. d. Internal carotid plexus
- Deep petrosal nerve is contributed by sympathetic fibres around the internal carotid artery, known as internal carotid plexus.

6. b. Mandibular nerve
- Otic ganglion is functionally related to the glossopharyngeal nerve, which carries the pre-ganglionic fibres to the ganglion.
- It is anatomically (topographically) related to the mandibular nerve (branch of trigeminal), which carries post ganglionic fibres to parotid salivary gland.

7. d. Plexus around middle meningeal artery
- Fibres from the superior cervical ganglion form plexus on middle meningeal artery to reach the otic ganglion.

8. a. Tympanic nerve
- Lesser petrosal nerve carries the preganglionic parasympathetic fibres of tympanic branch of glossopharyngeal nerve.
- It runs from the tympanic plexus to the otic ganglion.

9. a. Greater petrosal nerve
- Greater petrosal nerve (branch of facial nerve) carries the preganglionic para-sympathetic fibres to the pterygopalatine ganglion, which relays them to the lacrimal, nasal and palatine glands.
- Injury of greater petrosal nerve causes dryness in the eyes, nose and palate ipsilaterally.

Reflexes

- Reflexes involving structures in the head and neck are mediated by sensory and motor branches of the cranial nerves, coordinated via respective brainstem nuclei.
- They include swallowing, gagging, sneezing and coughing; lacrimation; jaw jerk; visual reflexes (pupillary light reflex and accommodation); corneal (blink) reflex and the stapedial reflex.
- Reflexes like sneezing and coughing, also involve the recruitment of cervical and thoracic spinal neurons to mediate the coordinated contraction of intercostal and abdominal wall muscles.

Important cranial nerve reflexes

Reflex	Afferent limb	Efferent limb
Croneal reflex	Ophthalmic nerve	Facial nerve
Conjunctival reflex	Ophthalmic nerve	Facial nerve
Lacrimation (tearing) reflex	Ophthalmic nerve	Facial nerve
Oculocardiac reflex	Ophthalmic nerve	Vagus nerve
Gag reflex	Glossopharyngeal nerve	Vagus nerve
Carotid sinus reflex	Glossopharyngeal nerve	Vagus nerve
Sneezing reflex	Ophthalmic/maxillary nerve	Vagus nerve
Jaw-jerk (masseteric) reflexes*	Mandibular nerve	Mandibular nerve
Pupillary reflexes • Light reflex • Accommodation reflex		

***Jaw-jerk reflex** is the only **monosynaptic reflex** mediated by the cranial nerves.

- **Corneal blink reflex** is closure of the eyelids in response to blowing on the cornea or touching it with a wisp of cotton.
- Its afferent limb is the nasociliary nerve (branch of the ophthalmic division trigeminal nerve) and efferent limb is the facial nerve (reflex arc).
- It leads to bilateral contraction of the orbicularis oculi muscles and a momentary closure of the eyelids.
- **Masseter reflex (jaw jerk)** is elicited by hitting the mentum (mandible) down with the help of a knee hammer.
- It is a proprioceptive reflex carried by the mandibular (trigeminal) nerve towards the mesencephalic sensory nucleus of trigeminal, the fibres then reaching the motor nucleus of trigeminal in the pons.
- Motor fibres carried by the trigeminal mandibular nerve activates the masseter muscle in turn, which leads to elevation of the mandible.
- It is the only monosynaptic reflex are present in the brain.
- **Gag reflex (pharyngeal reflex)** is the a brisk and brief elevation of the soft palate and bilateral contraction of pharyngeal muscles evoked by touching the posterior pharyngeal wall.
- It helps prevent objects from entering the throat except as part of normal swallowing and helps prevent choking.
- Sensory limb is mediated predominantly by CN IX (glossopharyngeal nerve) and the motor limb by CN X (vagus nerve).

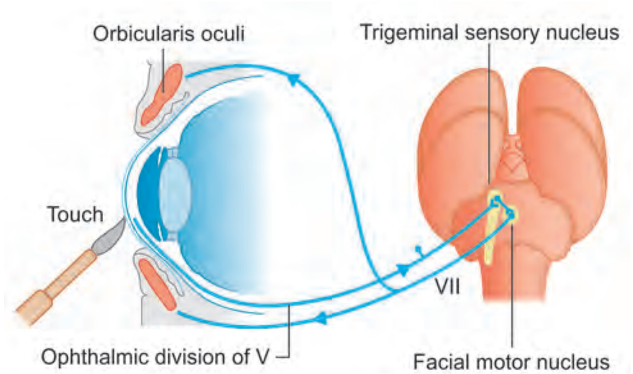


Fig. 73: Corneal reflex.

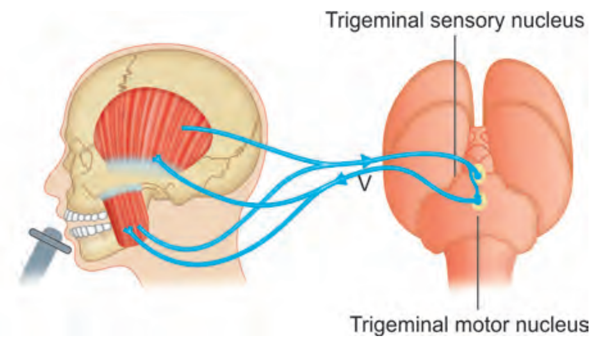


Fig. 74: Jaw-jerk reflex.

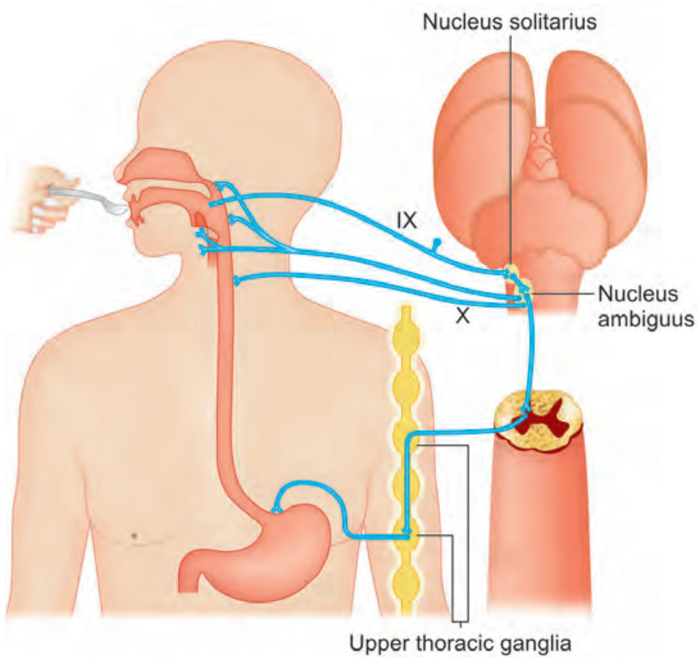


Fig. 75: Swallowing and gag reflexes.

- **Stapedius reflex (acoustic reflex)** is the contraction of stapedius muscle on exposure to high-intensity sound stimulus.
- The stapedius stiffens the ossicular chain by pulling the stapes of the middle ear away from the oval window of the cochlea, which decreases the transmission of vibrational energy to the cochlea and prevent inner ear injury.
- The afferent nerve is CN VIII (cochlear nerve. and the efferent is facial nerve.

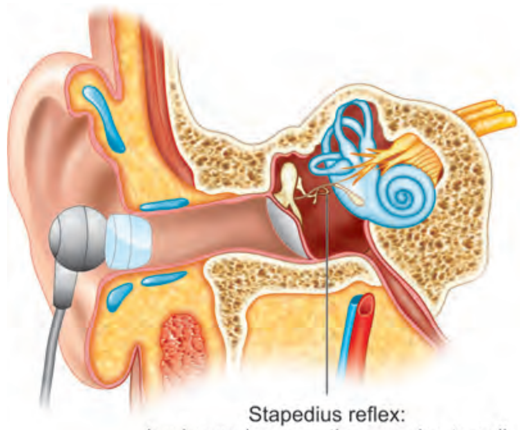


Fig. 76: Stapedial reflex.

ASSESSMENT QUESTIONS

1. Proprioceptive impulses for masseter reflex are carried to which nucleus of trigeminal nerve:
a. Mesencephalic
b. Sensory
c. Motor
d. Spinal

2. Which of the following reflexes test the integrity of nucleus ambiguus:
a. Jaw jerk
b. Stapedial reflex
c. Gag reflex
d. Corneal reflex

3. Afferent component in corneal reflex is mediated by:
a. Optic nerve *(NEET Pattern 2010, 12)*
b. Ophthalmic nerve
c. Facial nerve
d. Oculomotor nerve

4. Which is the nucleus of masseteric reflex? *(AIPG 2008)*
a. Superior sensory nucleus of trigeminal nerve
b. Spinal nucleus of trigeminal nerve
c. Mesencephalic nucleus of trigeminal nerve
d. Dorsal nucleus of vagus nerve

5. Centre for Stapedial reflex: *(AIIMS 2016)*
a. Superior olivary complex
b. Lateral lemniscus
c. Inferior colliculus
d. Medial geniculate body

ANSWERS WITH EXPLANATIONS

1. a. Mesencephalic
- Mesencephalic nucleus of trigeminal nerve receives the proprioceptive information of masseter reflex and integrates with the motor nucleus to produce contraction of jaw elevators.
- Masseter reflex is a mono-synaptic reflex where hitting on the mentum produces rapid stretching of the muscles like masseter and the jaw gets closed.
- Main sensory nucleus of trigeminal is chiefly concerned with the tactile reception, whereas, spinal nucleus receives the sensations of pain & temperature.

2. c. Gag reflex
- Gag reflex: Contraction of the constrictor muscle of the pharynx elicited by touching the back of the pharynx.
- Stapedial reflex: Contraction of the stapedius muscle in response to loud/intense sound.
- Corneal reflex: Irritation of the cornea results in reflex closure of the lids.

3. b. Ophthalmic nerve
- Corneal (blink) reflex is closure of the eyelids in response to touching it with a wisp of cotton.
- Its afferent limb is the nasociliary nerve of the ophthalmic division of the trigeminal nerve and efferent limb is the facial nerve (reflex arc).
- It leads to bilateral contraction of the orbicularis oculi muscles and a momentary closure of the eyelids.

4. c. Mesencephalic nucleus of trigeminal nerve
- Masseter reflex is a proprioceptive reflex carried by the mandibular (trigeminal) nerve towards the mesencephalic sensory nucleus of trigeminal, the fibres then reaching the motor nucleus of trigeminal in the pons.
- Motor fibres carried by the trigeminal mandibular nerve activates the masseter muscle in turn, which leads to elevation of the mandible.

5. a. Superior olivary complex
- Acoustic (stapedial) reflex: In response to loud sound contraction of the stapedius muscle stiffens the middle ear ossicles and tilts the stapes in the oval window of the cochlea; this effectively decreases the vibrational energy transmitted to the cochlea.
- Due to ease of administration and information yielded, the acoustic reflex is considered one of the most powerful differential diagnostic audiological procedures.
- The best known reflex mediated through the superior olive is the stapedius reflex.

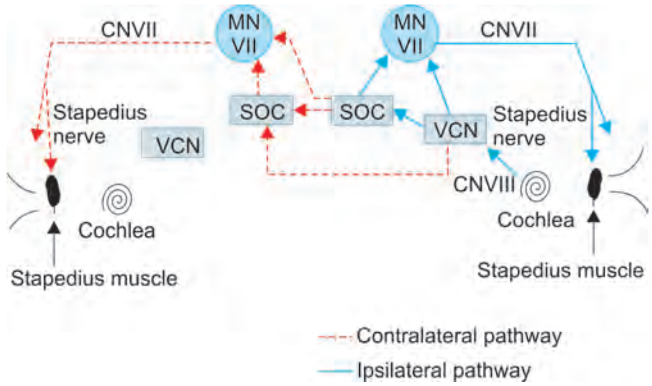


Fig. 77: Schematic of the acoustic reflex neural pathways. CNVII (facial/seventh cranial nerve); CN VIII (auditory/eighth cranial nerve); MNVII (motor nucleus of seventh cranial nerve); SOC (superior olivary complex); VCN (ventral cochlear nucleus). Dashed lines represent the contralateral pathway and solid lines represent ipsilateral pathway of acoustic reflex

- Once a high intensity auditory stimulus is initiated and reaches the cochleae, neural impulses from the auditory nerves (CN VIII) ascend from both cochleae to each ipsilateral ventral cochlear nucleus (VCN).
- From VCN the reflex has two main neural pathways: one passes from the VCN directly to the ipsilateral facial motor nucleus (CN VII) that directly innervates the stapedius muscle via the facial nerve and its stapedius branch; the other passes from the VCN to the superior olivary complex (SOC) before the impulses cross at the brainstem to innervate both ipsilateral and contralateral facial motor nuclei.

ASSESSMENT QUESTIONS

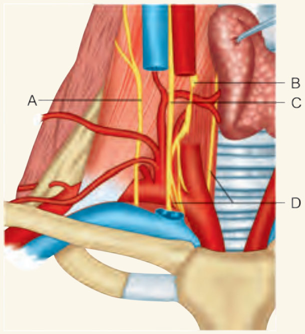
1. Lacrimation is affected in injury of: *(AIIMS 2010)*
   a. Nasociliary nerve
   b. Greater petrosal nerve
   c. Lesser petrosal nerve
   d. Auriculotemporal nerve

2. Which nerve is responsible for referred pain in ear: *(NEET pattern 2012)*
   a. Trochlear
   b. Olfactory
   c. Glossopharyngeal
   d. Abducent

3. A 50-year-old diabetic male presents with fever, headache and right eyelid pain. Examination reveals vesicles in upper eye lid, forehead and nose on the right side of face consistent with herpes zoster. Which of the following nerves is likely involved: *(JIPMER 2016)*
   a. Supraorbital nerve
   b. Supratrochlear nerve
   c. Lacrimal nerve
   d. Ophthalmic nerve

4. Which of the following clinical finding is not seen in lesions of structures passing through jugular foramen: *(JIPMER 2016)*
   a. Palatal paralysis
   b. Difficulty in shrugging of shoulder
   c. Loss of sensation from the floor of mouth
   d. Loss of taste sensation in posterior 1/3rd of tongue

5. Injury to which of the following nerve in the diagram, may affect respiratory movements: *(AIIMS 2016)*
   a. A
   b. B
   c. C
   d. D



ANSWERS WITH EXPLANATIONS

1. b. Greater petrosal nerve
- Greater petrosal nerve carries the preganglionic parasympathetic fibres to the pterygopalatine ganglion, which relays them to the lacrimal, nasal and palatine glands.
- Injury of greater petrosal nerve causes dryness in the eyes, nose and palate ipsilaterally.
- Nasociliary nerve carries sensory fibres like corneal sensations.
- Lesser petrosal nerve carries the pre-ganglionic parasympathetic fibres to the otic ganglion, which relays them to the parotid gland.
- Auriculotemporal nerve carries the post-ganglionic parasympathetic fibres from otic ganglion, to the parotid gland.

2. c. Glossopharyngeal
- Glossopharyngeal nerve supplies the ear region and oral cavity region as well.
- Any pathology of the oral region may present with referred pain to the ear region.

3. d. Ophthalmic nerve
- Ophthalmic nerve (trigeminal nerve) aupplies the forehead region, upper eyelid and nose and the presentation is consistent with the herpes spread along the course of the nerve.

4. c. Loss of sensation from the floor of mouth
- Sensations from the floor of mouth is carried by branches of trigeminal nerve, which is not involved in this lesion.
- Jugular foramen lets pass the cranial nerves 9, 10 and 11.
- These nerve supply the muscles of **palate**, pharynx and larynx, along with trapezius and sternocleidomastoid muscles.
- **Difficulty in shrugging** the shoulder is due to paralysis of trapezius muscles supplied by spinal accessory nerve.
- **Loss of taste sensation** in posterior 1/3rd of tongue is due to injury of glossopharyngeal nerve.

5. a. A
- Injury to phrenic nerve (marker 'A') compromises diaphragm (and respiratory movements).
- Phrenic nerve ('A') is identified running anterior to scalenus anterior muscle.
- Key: B - Sympathetic chain; C - Vagus nerve; D - Recurrent laryngeal nerve.
- In this diagram, sternocleidomastoid muscle has been removed to expose contents of carotid sheath.
- Carotid sheath contains vagus nerve lying between (and posterior) to two vessels: internal jugular vein (lateral) and common carotid artery (medial).
- Sympathetic chain ('B') is identified lying posteromedial to carotid sheath (and the common carotid artery).
- Vagus nerve ('C') is identified between the two vessels (internal jugular vein and common carotid artery) lying posteriorly.
- Recurrent laryngeal nerve ('D') is a branch of vagus nerve, loops under the right subclavian artery and ascends superiorly, lying in tracheo-esophageal groove.
- A transverse section at neck region is given in figure, for the orientation.

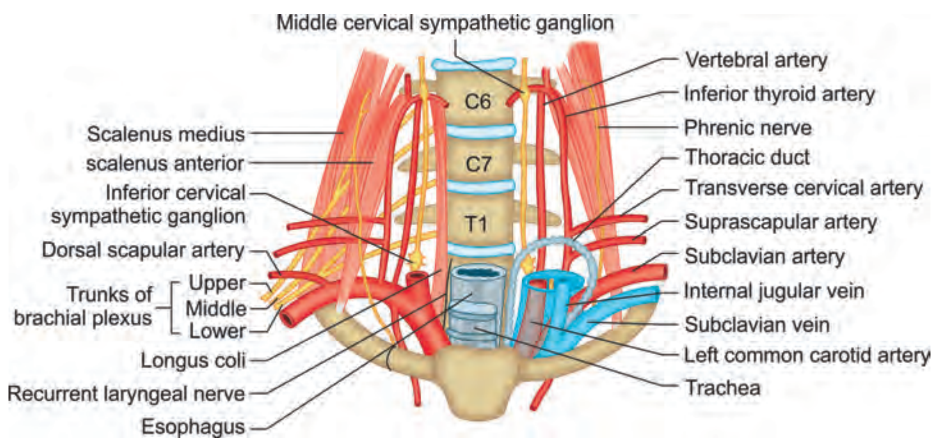


Fig. 78: Deep structures at the root of the neck

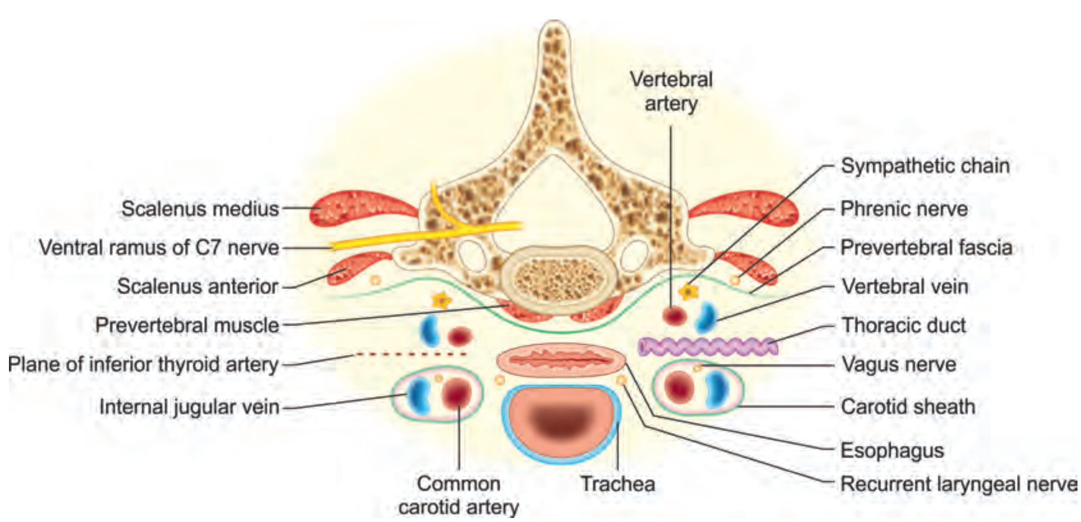


Fig. 79: Transverse section of the root of neck showing relationship of various structures in this region

ASSESSMENT QUESTION

1. Skin at the angle of jaw is supplied by: *(AIIMS 2016)*
a. Mandibular branch of trigeminal
b. Maxillary branch of trigeminal
c. Lesser occipital
d. Greater auricular

ANSWER WITH EXPLANATION

1. d. Greater auricular
- Skin at the angle of jaw is supplied by the greater auricular nerve.
- Mandibular nerve (branch of trigeminal) supply skin on the mandible (except the angle).
- Maxillary branch of trigeminal nerve supplies the skin on the cheek.
- Lesser occipital nerve supplies the skin in the lateral area of the head posterior to the ear.

Muscles in the Neck Region

Cutaneous and superficial muscles of neck

Muscle	Superior attachment	Inferior attachment	Innervation	Main action(s)
Platysma	Inferior border of mandible, skin, and subcutaneous tissues of lower face	Fascia covering superior parts of pectoralis major and deltoid muscles	Cervical branch of facial nerve (CN VII)	Draws corners of mouth inferiorly and widens it as in expressions of sadness and fright; draws skin of neck superiorly when teeth are clenched
Sternocleidomastoid (SCM)	Lateral surface of mastoid process of temporal bone and lateral half of superior nuchal line	*Sternal head:* anterior surface of manubrium of sternum *Clavicular head:* superior surface of medial third of clavicle	Spinal accessory nerve (CN X1, motor); C2 and C3 nerves (pain and proprioception)	*Unilateral contraction:* tilts head to same side (i.e., laterally flexes neck) and rotates it so face is turned superiorly toward opposite side *Bilateral contraction:* (1) extends neck at atianto-occipital joints, (2) flexes cervical vertebrae so that chin approaches manubrium, or (3) extends superior cervical vertebrae while flexing inferior vertebrae so chin is thrust forward with head kept level With cervical vertebrae fixed, may elevate manubrium and medial ends of clavicles, assisting pump-handle action of deep respiration
Trapezius	Medial third of superior nuchal line, external occipital protuberance, nuchal ligament, spinous processes of C7–T12 vertebrae, and lumbar and sacral spinous processes	Lateral third of clavicle, acromion, and spine of scapula	Spinal accessory nerve (CN XI; motor) C2 and C3 nerves (pain and proprioception)	Elevates, retracts, and rotates scapulae superiorly *Descending (superior) fibers:* elveate scapulae/shoulders, maintain level of shoulders against gravity or resistance *Transverse (middle) fibers:* retract scapulae *Ascending (inferior) fibers:* depress scapulae/shoulders *Descending and ascending fibers together:* rotate spinous process of scapulae superiorly With shoulders fixed, bilateral contraction extends neck; unilateral contraction produces lateral flexion to same side

Prevertebral Muscles

Muscle	Superior attachment	Inferior attachment	Innervation	Main action(s)
Anterior vertebral muscles				
Longus colli	Anterior tubercle of C1 vertebra (atlas); bodies of C1–C3 and transverse processes of C3–C6 vertebrae	Bodies of C5–T3 vertebrae; transverse processes of C3–C5 vertebrae	Anterior rami of C2–C6 spinal nerves	Flexes neck with rotation (torsion) to opposite side if acting unilaterally[a]

Muscle	Superior attachment	Inferior attachment	Innervation	Main action(s)
Longus capitis	Basilar part of occipital bone	Anterior tubercles of C3–C6 transverse process	Anterior rami of C1–C3 spinal nerves	
Rectus capitis anterior	Base of cranium, just anterior to occipital condyle	Anterior surface of lateral mass of atlas (C1 vertebra)	Branches from loop between C1 and C2 spinal nerves	Flex head[b]
Anterior scalene	Transverse processes of C3–C6	1st rib	Cervical spinal nerves C4–C6	
Lateral vertebral muscles				
Rectus capitis lateralis	Jugular process of occipital bone	Transverse process of atlas (C1 vertebra)	Branches from loop between C1 and C2 spinal nerves	Flexes head and helps stabilize it[b]
Splenius capitis	Inferior half of nuchal ligament and spinous processes of superior six thoracic vertebrae	Lateral aspect of mastoid process and lateral third of superior nuchal line	Posterior rami of middle cervical spinal nerves	Laterally flexes and rotates head and neck to same side; acting bilaterlly, extends head and neck[c]
Levator scapulae	Posterior tubercles of transverse processes C2–C6 vertebrae	Superior part of medial border of scapula	Dorsal scapular nerve C5 and cervical spinal nerves C3 and C4	Downward rotation of scapula and tilts its glenoid cavity inferiorly by rotating scapula
Middle scalene		Superior surface of 1st rib; posterior to groove for subclavian artery	Anterior rami of cervical spinal nerves	Flexes neck laterally; elevates 1st rib during forced inspiration[a]
Posterior scalene	Posterior tubercles of transverse processes of C5–C7 vertebrae	External border of 2nd rib	Anterior rami of cervical spinal nerves C7 and C8	Flexes neck laterally; elevates 2nd rib during forced inspiration[a]

[a]Flexion of neck = anterior (or lateral) bending of cervical vertebrae C2–C7
[b]Flexion of head = anterior (or lateral) bending of the head relative to the vertebral column at the atlanto-occipital joints
[c]Rotation of the head occurs at the atlanto-axial joints.

- Scalene muscles have an important relationship to other structures in the neck.
- The brachial plexus and subclavian artery pass between the anterior and middle scalene muscles.
- Relations of scalenus anterior muscle:
  - Anterior—Phrenic nerve, Subclavian vein, Carotid sheath, Transverse cervical artery and suprascapular artery, Prevertebral fascia, Clavicle;
  - Posterior—Subclavian artery, Pleura, Roots of brachial plexus;
  - Lateral—Brachial plexus.
- The subclavian vein and phrenic nerve pass anteriorly to the anterior scalene as the muscle crosses over the first rib. The phrenic nerve is oriented vertically as it passes in front of the anterior scalene, while the subclavian vein is oriented horizontally as it passes in front of the anterior scalene muscle.

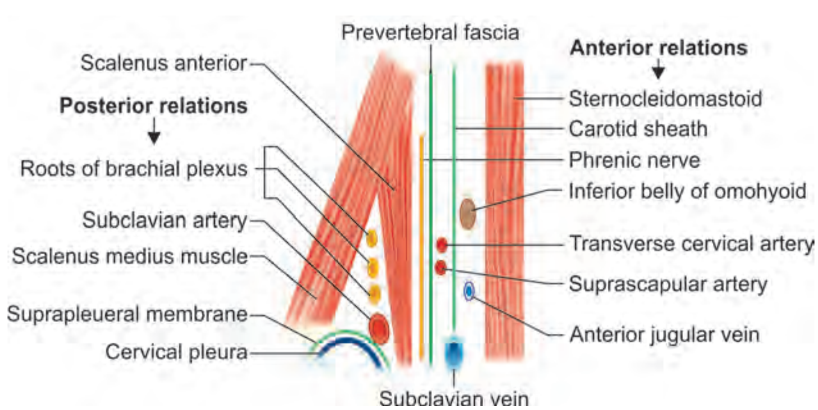


Fig. 80: Schematic sagittal section to show the anterior and posterior relations of the scalenus anterior muscle

- The interscalene triangle is present between the scalenus anterior muscle, the scalenus medius muscle and the first rib.
- The subclavian artery and the brachial plexus pass through this gap (subclavian vein runs anterior to scalenus anterior muscle and lies outside the triangle).
- A narrow interscalene triangle compresses the brachial plexus and subclavian artery (scalene syndrome) causing paresthesia, more rarely circulatory disturbances (e.g. edema, ischemia) and pain.
- Typically the ulnar side and the Little finger are affected.

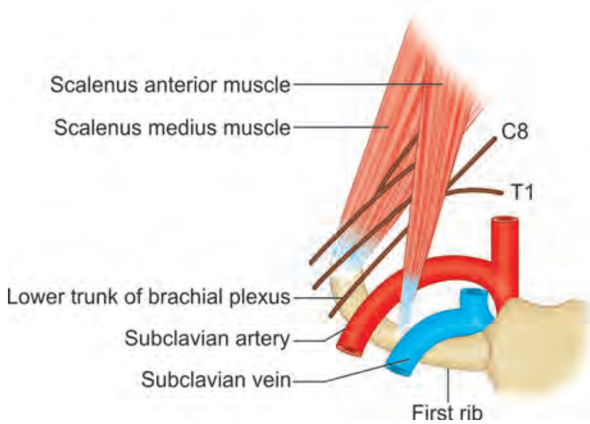


Fig. 81: Scalene triangle

- Styloid apparatus is found within the parapharyngeal space, refers to the structures derived from the 2nd branchial arch along with associated ligaments and muscles: styloid process of the temporal bone, lesser horn of the hyoid bone, stylohyoid ligament, stylomandibular ligament and stylohyoid, styloglossus and stylopharyngeus muscles.

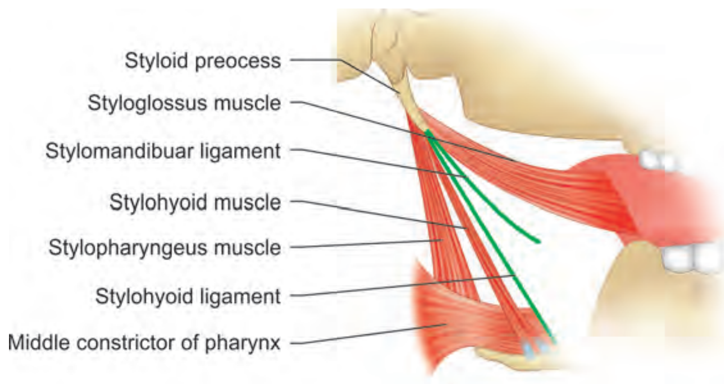


Fig. 82: Styloid apparatus

Muscles of anterior cervical region (Extrinsic muscles of larynx)				
Muscle	**Origin**	**Insertion**	**Innervation**	**Main action(s)**
Suprahyoid muscles				
Mylohyoid	Mylohyoid line of mandible	Mylohyoid raphe and body of hyoid	Nerve to mylohyoid, a branch of inferior alveolar nerve (from mandibular nerve, CN V_3)	Elevates hyoid, floor of mouth, and tongue during swallowing and speaking
Geniohyoid	Inferior mental spine of mandible	Body of hyoid	C1 via hypoglossal nerve (CN XII)	Pulls hyoid anterosuperiorly; shortens floor of mouth; widens pharynx
Stylohyoid	Styloid process of temporal bone		Stylohyoid (preparotid) branch of facial nerve (CN VII)	Elevates and retracts hyoid, thus elongating floor of mouth
Digastric	*Anterior belly:* digastric fossa of mandible	Intermediate tendon to body and greater horn of hyoid	Nerve to mylohyoid, a branch of inferior alveolar nerve	Working with infrahyoid muscles, depresses mandible against resistance; elevates and steadies hyoid during swallowing and speaking
	Posterior belly: mastoid notch of temporal bone		Digastric (preparotid) branch of facial nerve (CN VIII)	

Muscle	Origin	Insertion	Innervation	Main action(s)
Infrahyoid muscles				
Sternohyoid	Manubrium of sternum and medial end of clavicle	Body of hyoid	C1–C3 by branch of ansa cervicalis	Depresses hyoid after elevation during swallowing
Omohyoid	Superior border of scapula near suprascapular notch	Inferior border of hyoid		Depresses, retracts, and steadies hyoid
Sternothyroid	Posterior surface of manubrium of sternum	Oblique line of thyroid cartilage	C2 and C3 by a branch of ansa cervicalis	Depresses hyoid and larynx
Thyrohyoid	Oblique line of thyroid cartilage	Inferior border of body and greater horn of hyoid	C1 via hypoglossal nerve (CN XII)	Depresses hyoid and elevates larynx

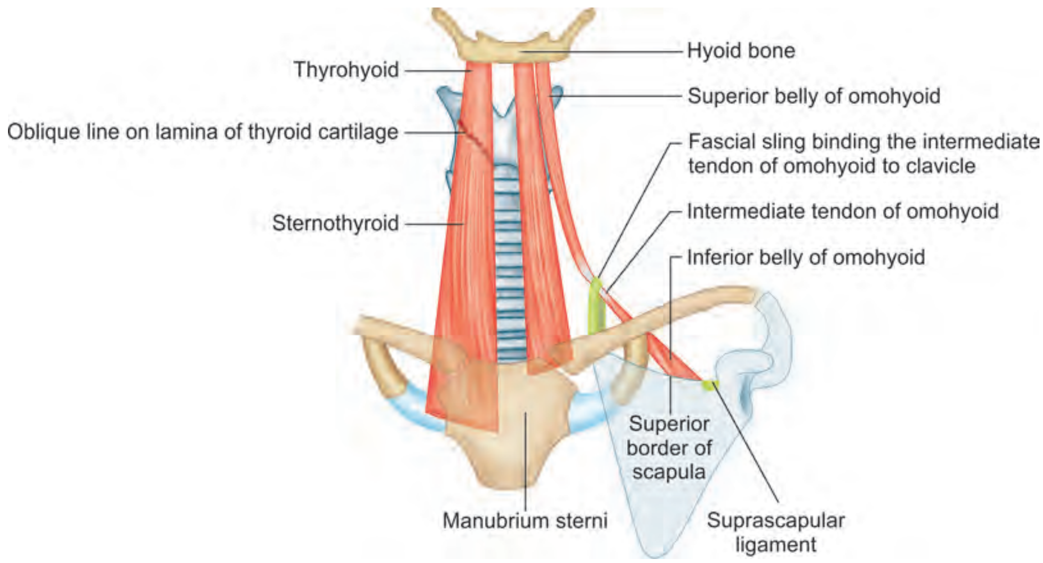


Fig. 83: Origin and insertion of the infrahyoid muscles

ASSESSMENT QUESTIONS

1. Deep injury of neck always involves: *(NEET Pattern 2015)*
a. Platysma
b. Trapezius
c. Sternocleidomastoid
d. Longus colli

2. FALSE about scalenus anterior muscle: *(NEET Pattern 2015)*
a. Covered by prevertebral fascia
b. Related anteriorly to phrenic nerve
c. Inserts in inner part of 1st rib
d. Forms floor of posterior triangle

3. True statement is:
a. Buccinator is a muscle of mastication
b. Digastric is an elevator of mandible
c. Omohyoid is a suprahyoid muscle
d. Oral diaphragm is formed by mylohyoid muscle

4. Which of the following is NOT supplied by the anterior division of mandibular nerve: *(AIPG 2011)*
a. Temporalis
b. Masseter
c. Lateral pterygoid
d. Medial pterygoid

5. Which suprahyoid muscle is supplied by both facial nerve and mandibular nerve: *(NEET Pattern 2012)*
a. Stylohyoid
b. Thyrohyoid
c. Digastric
d. Stylohyoid

6. False about sternocleidomastoid: *(NEET Pattern 2015)*
a. Arises from sternum and clavicle
b. Inserts on mastoid process
c. Motor supply by spinal accessory nerve
d. Tilt the head to opposite side

7. To give inferior alveolar nerve block the nerve is approached lateral to petrygomandibular raphe between the buccinator and: *(AIIMS 2002)*
a. Temporalis
b. Superior constrictor
c. Middle constrictor
d. Medial pterygoid

ANSWERS WITH EXPLANATIONS

1. a. Platysma
- Neck wounds that extend deep to the platysma are considered penetrating injuries.

2. d. Forms floor of posterior triangle
- Phrenic nerve runs on the anterior surface of scalenus anterior muscle, covered by prevertebral fascia.
- Scalenus anterior inserts on the first rib, but is not at the floor of posterior triangle of neck.
- Muscles at the floor are: Scalenus medius, levator scapulae, splenius capitis, semispinalis capitis.

3. d. Oral diaphragm is formed by mylohyoid muscle
- Buccinator is a muscle of facial expression (IInd pharyngeal arch; facial nerve).
- Digastric muscle pulls the mandible down on hyoid bone (depressor of mandible. to open the mouth.
- Omohyoid takes origin from scapula and insert into hyoid bone is an infrahyoid muscle.
- Oral diaphragm is the floor of the oral cavity formed by mylohyoid muscle.

4. d. Medial pterygoid
- Muscles of mastication are supplied by anterior division of mandibular nerve (except medial pterygoid being supplied by main trunk).

5. c. Digastric
- Mandibular nerve supplies anterior belly of digastric (Ist arch) and facial nerve supplies posterior belly of digastric (IInd arch).

6. d. Tilt the head to opposite side
- Sternocleidomastoid muscle takes its origin from sternum & clavicle, inserts into the mastoid process & superior nuchal line.
- It is supplied by the spinal accessory nerve, tilts the head to the same side, and turns it to the opposite side.

7. b. Superior constrictor
- The coronoid notch is palpated with index finger and the needle is introduced 1 cm above the surface of last molar medial to finger (coronoid notch) but lateral to petrygomandibular raphe between the buccinator and superior constrictor muscle.

Arteries

Carotid Arteries

- Right common carotid artery begins at the bifurcation of the brachiocephalic artery, and the left common carotid artery, arises from the aortic arch.
- Common carotid artery ascend within the carotid sheath and divide at the level of the upper border of the thyroid cartilage into the external and internal carotid arteries.
- Bifurcations almost always sit above the upper border of the thyroid cartilage lamina by an average of 1.6 cm (Mirjalili et al 2012b).
- Carotid pulse: The common carotid artery pulsations may be readily felt beneath the anterior border of sternocleidomastoid.
- It is compressed against the anterior tubercle of transverse process of the 6th cervical vertebrae called carotid tubercle (Chassaignac tubercle. by pressing medially and posteriorly with the thumb.
- It is about 4 cm above the sternoclavicular joint at the level of cricoid cartilage.
- Carotid Body Is a chemoreceptor lying at the bifurcation of the common carotid artery.
- It is stimulated by chemical changes (e.g., lack of oxygen, excess of carbon dioxide, and increased hydrogen ion concentration) in the circulating blood that help control respiration.
- It is innervated by the nerve to the carotid body, which arises from the pharyngeal branch of the vagus nerve, and by the carotid sinus branch of the glossopharyngeal nerve.
- Carotid Sinus is a pressoreceptor (baroreceptor) presenting as a dilatation located at the origin of the internal carotid artery, to detect the blood pressure and can bring about a slowing of the heart rate, vasodilation and decrease in blood pressure.
- It is innervated primarily by the carotid sinus branch of the glossopharyngeal nerve (and vagus nerve).
- Internal Carotid artery has no branches in the neck, ascends within the carotid sheath in company with the internal jugular vein and vagus nerve, enters the cranium through the carotid canal in the petrous part of the temporal bone.
- It supplies most of the ipsilateral cerebral hemisphere, eye and accessory organs, the forehead and, in part, the external nose, nasal cavity and paranasal sinuses (refer).
- External Carotid Artery extends from the level of the upper border of the thyroid cartilage to the neck of the mandible, where it ends in the parotid gland into two terminal branches the maxillary and superficial temporal arteries.
- It has as eight named branches, few anastomose with branches of the internal carotid arteries on the scalp, forehead and face, in the orbit, nasopharynx and nasal cavity, and with branches of the subclavian artery in the pharynx, larynx and thyroid glands.
- Superior Thyroid artery is the first branch of external carotid artery, given below the level of the greater horn of the hyoid bone, descends obliquely in the carotid triangle and passes deep to the infrahyoid muscles to reach the superior pole of the thyroid gland.
- Lingual artery originates at the level of the tip of the greater horn of the hyoid bone and passes deep to the hyoglossus to reach the tongue. It gives branches like dorsal lingual, sublingual, and deep lingual arteries.
- Facial artery : Refer

- Ascending Pharyngeal artery is a medial branch from the deep surface of the external carotid artery in the carotid triangle, ascends between the internal carotid artery and the wall of the pharynx. It gives branches to pharynx, palate, tonsils and eustachian tube.
- Occipital artery is a posterior branch given just above the level of the hyoid bone, passes deep to the digastric posterior belly, occupies the groove on the mastoid process, and appears on the skin above the occipital triangle.
- Posterior Auricular artery is also a posterior branch, ascends superficial to the styloid process and deep to the parotid gland and ends between the mastoid process and the external acoustic meatus.
- Maxillary artery: Refer
- Superficial Temporal Artery arises behind the neck of the mandible as the smaller terminal branch of the external carotid artery and ascends anterior to the external acoustic meatus into the scalp.
  - Its pulse can be taken immediately anterior to the tragus of the pinna.
  - It is accompanied by the auriculotemporal nerve along its anterior surface.
  - It gives the transverse facial artery, which passes forward across the masseter between the zygomatic arch above and the parotid duct below.
  - The other branches are: Zygomatico-orbital, middle temporal, anterior auricular.
  - It divides into frontal and parietal branches approximately 2.5 cm above the zygomatic arch.

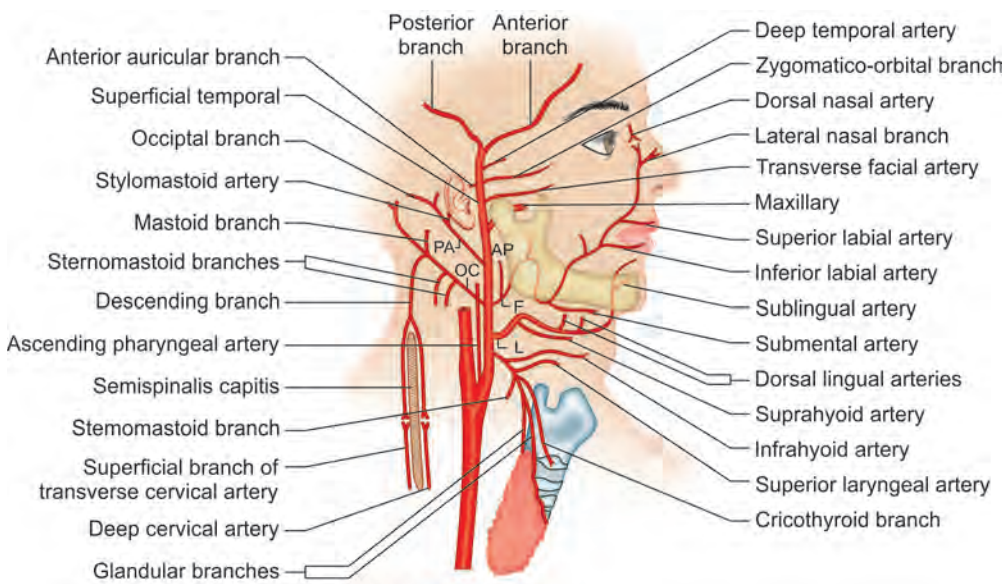


Fig. 84: Distribution of the branches of the external carotid artery shown in dark red color (F = facial artery, L = lingual artery, AP = ascending palatine artery, OC = occipital artery, PA = posterior auricular artery)

Subclavian and Vertebral Arteries

- Subclavian artery is a branch of the brachiocephalic trunk on the right but arises directly from the arch of the aorta on the left.
- It is divided into three parts that are successively anterior, deep and lateral to scalenus anterior, third part passes from the lateral margin of the muscle to the outer border of the first rib.
- Branches:
- First part gives three branches (VIT): V - Vertebral, I - Inferior thyroid artery, T - Thyrocervical trunk.
- Second part - costocervical trunk
- Third part - dorsal scapular artery

Branches of subclavian artery	Subsequent branches
Vertebral Artery • First (cervical) part • Second (vertebral) part • Third (suboccipital) part • Fourth (intracranial) part	Muscular branches Meningeal branches Posterior spinal artery Posterior inferior cerebellar artery Medullary branches
Internal thoracic artery	Anterior intercostal arteries Superior epigastric artery Musculophrenic artery

Branches of subclavian artery	Subsequent branches
Thyrocervical trunk (SIT) • Suprascapular artery • Inferior thyroid artery • Transverse cervical artery	Glandular branches Ascending cervical artery Inferior laryngeal artery Tracheal, pharyngeal, and esophageal branches Superficial branch Deep branch (dorsal scapular artery)
Costocervical trunk	Deep cervical artery Highest intercostal artery
Dorsal scapular artery	

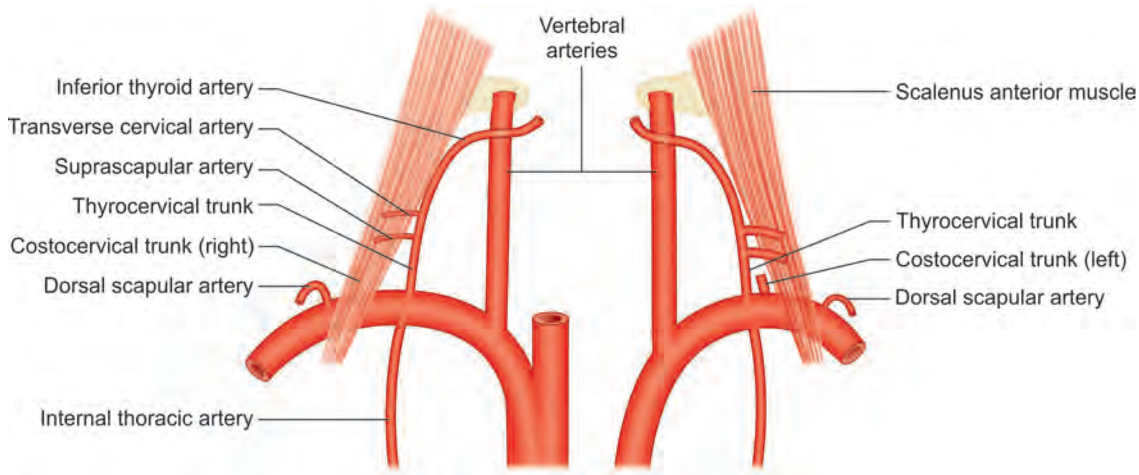


Fig. 85: Branches of the right and left subclavian arteries

Branches

- **Vertebral Artery** arises from the first part, ascends between the scalene anterior and longus colli muscles.
- It passes upwards through the foramina transversaria of the upper 6 cervical vertebrae (C1 to C6), winds around the superior articular process of the atlas, lies in suboccipital triangle.
- It passes through the posterior atlantooccipital membrane, vertebral canal, pierce dura mater and arachnoid mater to enter the subarachnoid space and passes through foramen magnum to enter the cranial cavity. Refer

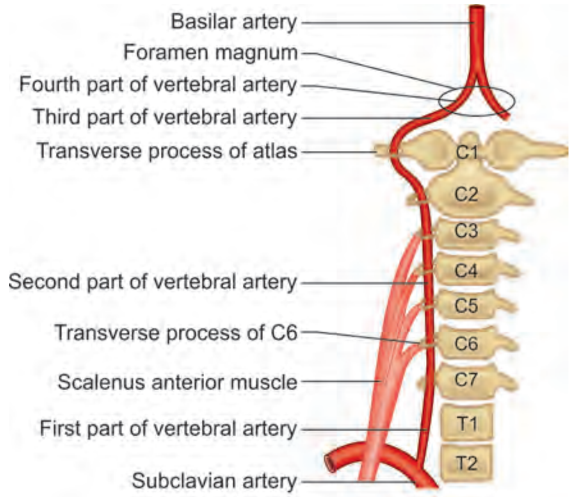


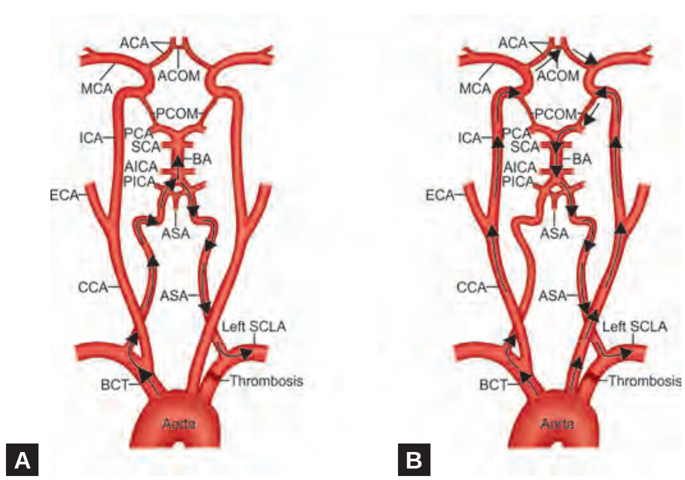
Fig. 86: Course and parts of the vertebral artery

- Thyrocervical trunk is a branch from the first part of subclavian artery. It gives three branches SIT: S – Supra-scapular artery; I – Inferior thyroid artery and T – Transverse cervical artery.
- Suprascapular artery passes in front of the scalene anterior muscle and the brachial plexus parallel to but below the transverse cervical artery. Then it passes superior to the superior transverse scapular ligament, whereas the suprascapular nerve passes inferior to this ligament.

- Inferior thyroid artery ascends in front of the scalene anterior muscle, turns medially behind the carotid sheath but in front of the vertebral vessels, and then arches downward to the lower pole of the thyroid gland. It gives ascending cervical artery, which ascends on the anterior scalene muscle medial to the phrenic nerve.
- Transverse cervical artery runs laterally across the anterior scalene muscle, phrenic nerve, and trunks of the brachial plexus, passing deep to the trapezius. It divides into a superficial branch and a deep branch, which occasionally takes the place of the dorsal (descending) scapular artery.
- Internal Thoracic artery arises from the first part of the subclavian artery, descends through the thorax behind the upper six costal cartilages, and ends at the sixth intercostal space by dividing into the superior epigastric and musculophrenic arteries.
- Costocervical Trunk arises from the posterior aspect of the second part of the subclavian artery behind the scalene anterior muscle and divides into the following arteries:
- Deep Cervical artery passes between the transverse process of vertebra C7 and neck of the first rib, ascends between the semispinalis capitis and semispinalis cervicis muscles, to anastomose with the deep branch of the descending branch of the occipital artery.
- Superior Intercostal artery descends posterior to the cervical pleura anterior to the necks of the first two ribs and gives the first two posterior intercostal arteries.
- Dorsal (Descending) Scapular artery is ‘usually’ given by the third part of the subclavian artery. Occasionally it may be replaced by the deep (descending) branch of the transverse cervical artery.

Subclavian Steal Syndrome

- Subclavian stenosis proximal to the origin of the vertebral artery, results in a reversal of the blood flow in the ipsilateral vertebral artery. Heavy manual exercise of the ipsilateral arm may increase demand on vertebral flow, producing posterior circulation TIAs (subclavian steal syndrome).
- The most common cause for a subclavian steal syndrome is atherosclerosis, occurs more commonly on the left side probably due to a more acute origin of the subclavian artery, which results in increased turbulence and accelerated atherosclerosis.
- It is a cerebral and brainstem ischemia caused by reversal of blood flow from the basilar artery through the vertebral artery into the subclavian artery in the presence of occlusive disease of the subclavian artery proximal to the origin of the vertebral artery.
- In case of decreased blood flow through the vertebral artery, it may steal blood flow from the carotid, circle of Willis, and basilar circulation and divert it through the vertebral artery into the subclavian artery and into the arm, causing vertebrobasilar insufficiency and thus brain stem ischemia and stroke.
- Symptoms are dizziness, ataxia, vertigo, visual disturbance, motor deficit, confusion, aphasia, headache, syncope, arm weakness, and arm claudication with exercise.
- It can be treated by a carotid–subclavian bypass.



Figs. 87A and B: Subclavian steal syndrome. Thrombosis of the proximal part of the subclavian artery (left results in retrograde blood flow through the ipsilateral vertebral artery and into the left subclavian artery. Blood can be shunted from the right vertebral artery and dowr the left vertebral artery (A). Blood may also reach the left vertebral artery through the carotid circulation (B). ACA, anterior cerebellar artery: ACOM, anterior communicating artery; A/CA, anterior inferior cerebellar artery; ASA, anterior spinal artery; BA, basilar artery; BCT, brachiocephalic trunk; CCA. common carotid artery; ECA, external carotid artery; ICA, internal carotid artery; CA, middle cerebral artery; PCA, posterior cerebral artery; PCOM, posterior communicating artery; PICA, posterior inferior cerebellar artery; SCA, superior communicating artery; SCLA. subclavian artery; VA, vertebral artery.

Maxillary Artery

- **Maxillary artery** is the larger terminal branch of external carotid artery given at the posterior border of the ramus of the mandible, runs deep to the neck of the mandible and enters the infratemporal fossa.
- It is divided into three parts:
  - **Mandibular Part** runs anteriorly between the neck of the mandible and the sphenomandibular ligament and gives numerous branches
  - **Pterygoid Part** runs anteriorly deep to the temporalis and superficial or deep to the lateral pterygoid muscle. Branches supply chiefly the muscles of mastication.
  - **Pterygopalatine Part** runs between the two heads of the lateral pterygoid muscle and then through the pterygomaxillary fissure into the pterygopalatine fossa, branches are given in table.

Parts and branches of maxillary artery

Part	Course	Branches	Distribution
First (mandibular)	Proximal (posterior) to lateral pterygoid muscle; runs horizontally, deep (medial) to neck of condylar process of mandible and lateral to stylomandibular ligament	Deep auricular artery	Supplies external acoustic meatus, external tympanic membrane, and temporomandibular joint
		Anterior tympanic artery	Supplies internal aspect of tympanic membrane
		Middle meningeal artery	Enters cranial cavity via foramen spinosum to supply periosteum, bone, red bone marrow, dura mater of lateral wall and calvaria of neurocranium, trigeminal ganglion, facial nerve and geniculate ganglion, tympanic cavity, and tensor tympani muscle
		Accessory meningeal artery	Enters cranial cavity via foramen ovale; its distribution is mainly extracranial to muscles of infratemporal fossa, sphenoid bone, mandibular nerve, and otic ganglion
		Inferior alveolar artery	Descends to enter mandibular canal of mandible via mandibular foramen; supplies mandible, mandibular teeth, chin, mylohyoid muscle
Second (pterygoid)	Adjacent (superficial or deep) to lateral pterygoid muscle; ascends obliquely anterosuperiorly, medial to temporalis muscle	Masseteric artery	Traverses mandibular notch, supplying temporomandibular joint and masseter muscle
		Deep temporal arteries	Anterior and posterior arteries ascend between temporalis muscle and bone of temporal fossa, supplying mainly muscle
		Pterygoid branches	Irregular in number and origin; supply pterygoid muscle
		Buccal artery	Runs antero-inferiorly with buccal nerve to supply buccal fat-pad, buccinator, and buccal oral mucosa
Third (pterygoid palatine)	Distal (anteromedial) to lateral pterygoid muscle; passes between heads of lateral pterygoid and through pterygomaxillary fissure into pterygopalatine fossa	Posterior superior alveolar artery	Descends on maxilla's infratemporal surface with branches traversing alveolar canals to supply maxillary molar and premolar teeth, adjacent gingiva, and mucous membrane of maxillary sinus
		Infra-orbital artery	Traverses inferior orbital fissure, infra-orbital groove, canal, and foramen; supplies inferior oblique and rectus muscles, lacrimal sa, maxillary canines and incisors teeth, mucous membrane of maxillary sinus, and skin of infra-orbital region of face
		Artery of pterygoid canal	Passes posteriorly through pterygoid canal; supplies mucossa of upper pharynx, pharyngotympanic tube, and tympanic cavity
		Pharyngeal branch	Passes through palatovaginal canal to supply mucosa of nasal roof, nasopharynx, sphenoidal air sinus, and pharyngotympanic tube
		Descending palatine artery	Descends through palatine canal, dividing into greater and lesser palatine arteries to mucosa and glands of hard and soft palate
		Sphenopalatine artery	Terminal branch of maxillary artery, traverses sphenopalatine foramen to supply walls and septum of nasal cavity; frontal, ethmoidal, sphenoid, and maxillary sinuses; and anteriormost palate

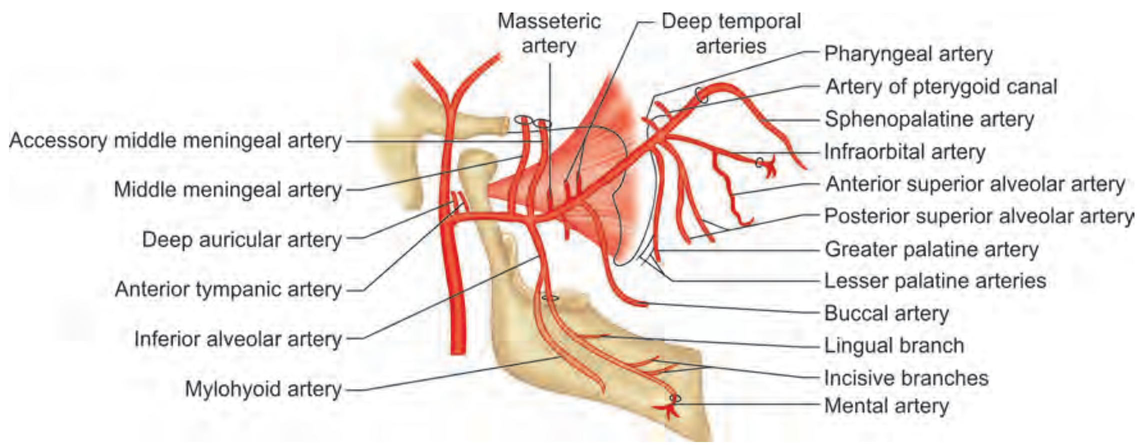


Fig. 88: Branches of the maxillary artery

High Yield Point

- Middle meningeal artery is a branch of 1st part of maxillary artery, passes through foramen spinosum, may ve damaged in skull fracture at pterion, leading to extra (epi) dural hematoma.

ASSESSMENT QUESTIONS

1. **Thyrocervical trunk is branch of which part of subclavian artery:** *(NEET Pattern 2012)*
   a. 1st
   b. 2nd
   c. 3rd
   d. None

2. **Vertebral artery passes through foramen of transverse processes of:** *(NEET Pattern 2012)*
   a. All cervical vertebrae
   b. 2nd to 5th cervical vertebrae
   c. All except 1st cervical vertebra
   d. All except 7th cervical vertebra

3. **Vertebral artery traverses all of the following EXCEPT:** *(AIIMS 2005)*
   a. Foramen magnum
   b. Subarachnoid space
   c. Intervertebral foramen
   d. Foramen transversarium

4. **Wrong statement about branches of external carotid artery is:**
   a. Anterior ethmoidal artery is a branch
   b. Maxillary artery is a terminal branch
   c. Ascending pharyngeal artery is a medial branch
   d. Superior thyroid artery is the first branch

5. **Inferior thyroid artery arises from which of these vessels:** *(NEET Pattern 2012))*
   a. Thyrocervical trunk
   b. Brachiocephalic trunk
   c. Internal carotid artery
   d. External carotid artery

6. **Exposure of left subclavian artery by supraclavicular approach does not require cutting of:** *(AIIMS 2007)*
   a. Sternocleidomastoid
   b. Scalenus anterior
   c. Scalenus medius
   d. Omohyoid

7. **Which of the following is NOT a branch of first part of maxillary artery:** *(NEET Pattern 2012)*
   a. Greater palatine artery
   b. Middle meningeal artery
   c. Deep auricular artery
   d. Inferior alveolar artery

8. **Posterior superior alveolar artery is a branch of:** *(NEET Pattern 2014)*
   a. Nasal branch of maxillary artery
   b. Palatal branch of maxillary artery
   c. Mandibular artery
   d. Inferior alveolar artery

9. **In subclavian steal syndrome there is reversal of blood flow in:**
   a. Ipsilateral vertebral artery
   b. Contralateral vertebral artery
   c. Ipsilateral subclavian artery
   d. Contralateral subclavian artery

10. **First branch of external carotid artery:** *(NEET Pattern - 2016)*
    a. Superior thyroid artery
    b. Inferior thyroid artery
    c. Ascending pharyngeal artery
    d. Thyroid ima artery

11. **Common carotid artery divides at the level of:** *(AIIMS 2007)*
    a. Hyoid bone
    b. Cricoid cartilage
    c. Superior border of thyroid cartilage
    d. Inferior border of thyroid cartilage

12. **Middle meningeal artery is direct branch of:** *(AIPG 2006)*
    a. External carotid artery
    b. Internal maxillary artery
    c. Superficial temporal artery
    d. Middle cerebral artery

13. Most common site of subclavian artery stenosis is in part: *(AIPG 2009)*
a. 1st
b. 2nd
c. 3rd
d. Terminal

14. Sternocleidomastoid is NOT supplied by the artery: *(AIIMS 2008)*
a. Superior thyroid
b. Thyrocervical trunk
c. Occipital
d. Posterior auricular artery

15. Which structure can be felt at the lower part of the medial border of sternocleidomastoid: *(NEET Pattern 2014)*
a. Subclavian artery
b. Common carotid artery
c. Internal mammary artery
d. Maxillary artery

16. All of the following are branches of the external carotid artery EXCEPT: *(AIIMS 2015)*
a. Superior thyroid artery
b. Transverse cervical artery
c. Lingual artery
d. Ascending pharyngeal artery

ANSWERS WITH EXPLANATIONS

1. a. 1st
- First part of subclavian artery gives three branches (VIT): V - Vertebral, I - Inferior thyroid artery, T - Thyrocervical trunk.
- Thyrocervical trunk itself gives three branches (SIT): S - Suprascapular artery, I - Inferior thyroid artery, T - Transverse cervical artery.

2. d. All except 7th cervical vertebra
- Vertebral artery passes through foramina transversaria of the upper 6 cervical vertebrae.

3. c. Intervertebral foramen
- Vertebral artery passes through foramina transversaria of the upper 6 cervical vertebrae, suboccipital triangle, posterior atlantooccipital membrane, vertebral canal, pierce duramater and arachnoid mater to enter the subarachnoid space and passes through foramen magnum to enter the cranial cavity.
- Spinal nerves and the radicular vessels pass through the intervertebral foramen (not the vertebral artery).

4. a. Anterior ethmoidal artery is a branch
- Ophthalmic artery gives anterior ethmoidal artery which enters the anterior ethmoid foramen in the medial wall of the orbit and supplies the ethmoidal air sinuses, medial and lateral wall of nasal cavity, and dura mater.
- External carotid artery gives 8 branches: Anterior (3): Superior thyroid artery, lingual artery, facial artery; Posterior (2): Occipital artery, posterior auricular; Medial (1): Ascending pharyngeal and Terminal (2): Maxillary, superficial temporal.

5. a. Thyrocervical trunk
- Inferior thyroid artery is a branch of thyrocervical trunk (given by first part of subclavian artery).

6. c. Scalenus medius
- Scalenus medius muscle lies postero-inferior to subclavian artery and is not required to be cut.

7. a. Greater palatine artery
- The third part of maxillary artery give descending palatine artery, which itself divides into greater & lesser palatine arteries.

8. b. Palatal branch of maxillary artery
- Posterior superior alveolar artery arises from third part of maxillary artery just before it enters the pterygomaxillary fissure.
- It supplies the molar and premolar teeth and mucus membrane of maxillary air sinus.
- There is no proper option available, palatal branch appears to be most suitable for palatal (upper) teeth.

9. a. Ipsilateral vertebral artery
- In subclavian steal syndrome there is retrograde flow in the vertebral artery due to an ipsilateral subclavian artery stenosis.
- The stenosis results in lower pressure in the distal subclavian artery and upper limb ischaemia.
- As a result, blood flows from the contralateral vertebral artery to the basilar artery and then in a retrograde direction down the ipsilateral vertebral artery away from the brainstem.

10. a. Superior thyroid artery > c. Ascending pharyngeal artery
- The first branch of external carotid artery is usually the superior thyroid artery, though sometime it could be ascending pharyngeal artery.
- **Ascending pharyngeal artery**
- It is usually the second branch of the external carotid artery, though it may be the first.
- It has a variable origin. It arises from the medial (or posterior) surface of the external carotid artery, often close to the origin and to that of the lingual artery, below the occipital artery.
- Variations are, however, numerous and frequent; it may arise :
  - External carotid artery or bifurcation of the common carotid artery (~65-80%)
  - Occipital artery (20 to 14%)
  - Common carotid artery (9 to 7%).

11. c. Superior border of thyroid cartilage
- Common carotid artery bifurcates at the level of superior border of thyroid cartilage.
- It lies at the level of C3/4 vertebra.
- Cricoid cartilage lies at the level of C-6 vertebra, and this the level where larynx becomes trachea and pharynx, the oesophagus.

12. b. Internal maxillary artery
- Middle meningeal artery is a direct branch of maxillary artery and it passes through the foramen spinosum to reach the cranial cavity.
- External carotid artery has two direct terminal branches – maxillary artery and the superficial temporal artery.
- Middle cerebral artery is a direct branch of internal carotid artery and also gives meningeal branches.

13. a. 1st
- Subclavian artery is most commonly obstructed in the proximal portion -1st part proximal to the origin of vertebral and internal thoracic artery.
- This stenosis is focal and is usually an extension of atherosclerotic narrowing from the aortic arch into the artery.
- The stenosis is more common on left side - Left subclavian is involved 3 times more frequently involved than the right.
- Subclavian artery stenosis proximal to the vertebral artery leads to subclavian steal syndrome.
- Subclavian artery may be obstructed in the 3rd part occasionally, where it lies in the interscalene triangle. Thoracic inlet syndrome (which may be due to reasons like – cervical rib. leads to subclavian artery compression in costo-clavicular region just medial to scalene triangle or in the scalene triangle itself.

14. d. Posterior auricular artery
- It's a **wrong** question, since all the four arteries mentioned supply the muscle sternocleidomastoid.
- **Posterior auricular artery** has been taken as the best answer as per the latest Journals published. The quotes text:
- The upper third of the SCM muscle was constantly supplied by branches of the **occipital artery**. The middle third of the SCM muscle received its blood supply from a branch of the **superior thyroid artery** (53%), the external carotid artery (27%), or branches of both (20%). The lower third of the muscle was supplied by a branch arising from the suprascapular artery (73%), the transverse cervical artery (7%), the **thyrocervical trunk** (13%), or the superficial cervical artery (7%).
- Applied anatomy: A superiorly based flap can be raised on sternocleidomastoid to reconstruct the lip, floor of mouth and inner cheeks. In the procedure we need to preserve most of the arterial supply of SCM while mobilizing it.
- Our answer **contradicts** Gray's Anatomy (Ed 41), but since numerous standard textbooks and Journals never mention **posterior auricular artery**, that appears to be a better option as answer.

15. b. Common carotid artery
- The common carotid artery may be compressed against the prominent transverse process of the sixth cervical vertebra (Chassaignac's or carotid tubercle), which sits lateral to the cricoid cartilage.
- Above this level, the artery is superficial and its pulsation may be readily felt beneath the anterior border of sternocleidomastoid.
- The subclavian pulsations may be detected behind the clavicle at the lateral border of sternocleidomastoid or where it crosses the first rib.

16. b. Transverse cervical artery
- Transverse cervical artery is a branch of thyrocervical trunk, which itself is a branch of subclavian artery.
- Superior thyroid artery and lingual arteries are anterior branches of external carotid artery.
- The only medial branch of external carotid artery is named as the ascending pharyngeal artery.

Meninges

- There are three concentric membranes (meninges) that envelop the brain and spinal cord.
- The outermost layer is dura mater (pachymeninx) and inner are arachnoid and pia mater (leptomeninges).
- The cranial dura mater is a two-layered membrane consisting of the external periosteal layer (i.e., the endosteum of the neurocranium) and the internal meningeal layer, which is continuous with the dura of the vertebral canal and forms dural infoldings (or reflections) that divide the cranial cavity into compartments and accommodates the dural venous sinuses.
- The arachnoid mater is a filmy, transparent spidery layer that is connected to the pia mater by web like **arachnoid trabeculae**.
- It is separated from the pia mater by the **subarachnoid space,** which contains cerebrospinal fluid (CSF) and enlarges at several locations to form **subarachnoid cisterns**.
- The arachnoid projects **arachnoid villi** (collections of which are called **arachnoid granulations**) into the cranial venous sinuses, which serve as sites where CSF reabsorption into the venous blood.
- Arachnoid Granulations are tuft like collections of highly folded arachnoid (aggregations of arachnoid villi) that project into the superior sagittal sinus and the lateral lacunae, which are lateral extensions of the superior sagittal sinus.
- Pia mater is a shiny, delicate layer that is closely applied to the brain and follows all the contours of the brain and dips into fissures and sulci.

- The cerebral arteries that run in the subarachnoid space penetrate the pia mater as they enter the brain, whereby the pia mater is reflected onto the surface of the cerebral artery continuous with the tunica adventitia.
- Vasculature of the Dura
- The arterial supply of the dura mater is by the middle meningeal artery (branch of maxillary artery), which divides into an anterior branch and a posterior branch.
- The venous drainage of the dura mater is by middle meningeal veins, which drain into the pterygoid venous plexus.
- Innervation of dura mater is derived mainly from three sources:
  1. Three divisions of trigeminal nerve
  2. C2 and 3 spinal nerves
  3. Cervical sympathetic trunk
- The supratentorial dura is supplied by the meningeal branches from the three divisions of the trigeminal nerve.

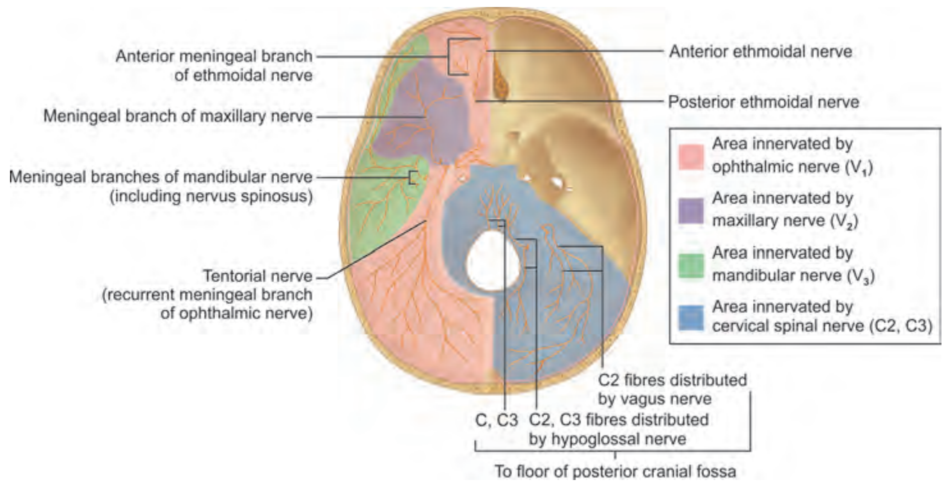


Fig. 89: Innervation of duramater in cranial cavity.

- The infratentorial dura is supplied by ascending meningeal branches of C2 and 3 spinal nerves.
  1. Anterior cranial fossa: Meningeal branches of the anterior and posterior ethmoidal nerves (ophthalmic division of trigeminal nerve. and few additional branches of maxillary division of trigeminal nerve.
  2. Middle cranial fossa: Meningeal branch of the maxillary nerve (in the anterior part) and the mandibular nerve (nervus spinosus) in the posterior part.
  3. Posterior cranial fossa: Meningeal branches of the vagus and hypoglossal nerves, carrying the C1 and C2 fibres to supply the dura.
- Vagus and hypoglossal nerves, and possibly the facial and glossopharyngeal nerves may also supply duramater (less established).
- Sensory nerve endings are restricted to the dura mater and cerebral blood vessels, and are not found in either the brain itself, or in the arachnoid or pia mater.

Dural Folds

- Falx cerebri is a sickle (crescent) shaped double fold of duramater that lies between the two cerebral hemispheres in the longitudinal fissure.
- Anteriorly the falx is fixed to the crista galli, and posteriorly it blends with the tentorium cerebelli; the straight sinus runs along this line of attachment to the tentorium.
- Its convex upper margin is attached to the internal cranial surface on each side of the midline, as far back as the internal occipital protuberance.
- The superior sagittal sinus runs in upper attached margin, lower edge is free and concave, and contains the inferior sagittal sinus.
- Tentorium cerebelli is a tent-shaped fold of the dura mater forming the roof of the posterior cranial fossa.
- It supports the occipital lobes of the cerebral hemispheres and covers the cerebellum.
- It has two margins and two surfaces. Inner free margin is U-shaped and encloses the tentorial notch for the passage of the midbrain.
- The anterior ends of the concave free margin are attached to the anterior clinoid processes.
- Outer attached margin is convex and attached on each side (in antero-posterior order) to the posterior clinoid process, the posteroinferior angle of the parietal bone, and the lips of transverse sulci on the occipital bone.
- The free and attached margins cross each other near the apex of the petrous temporal bone to enclose a triangular area anteriorly which is pierced by the oculomotor nerve.

- The convex superior surface slopes to either side from the median plane. It provides attachment to falx cerebri in the midline.
- The concave inferior surface provides attachment to falx cerebelli in its posterior part.
- Venous sinuses enclosed in the tentorium cerebelli
  - Transverse sinus, within the posterior part of the attached margin.
  - Superior petrosal sinus, within the anterolateral part of the attached margin.
  - Straight sinus, along the line of attachment between the falx cerebri and the tentorium cerebelli.
- Falx cerebelli is a small sickle-shaped dural fold in the sagittal plane projecting forward into the posterior cerebellar notch between the cerebellar hemispheres.
- It extends from the internal occipital protuberance along the internal occipital crest to the posterior margin of the foramen magnum.
- It has a free concave anterior margin and a convex-attached posterior border.
- Occipital sinus run along with its posterior attached part.
- Diaphragma sellae is a small circular horizontal fold of the inner (meningeal) layer of the dura mater forming the roof of the hypophyseal fossa covering the pituitary gland.
- It is attached anteriorly to the tuberculum sellae and posteriorly to the dorsum sellae and becomes continuous on each side with the dura mater of the middle cranial fossa.
- It has a central aperture which provides passage to the pituitary stalk or infundibulum.

Dural infoldings and the enclosed sinuses

Dural fold	Shape	Dural venous sinus enclosed
Falx cerebri	Sickle shaped, separates right and left cerebral hemisphere	Superior sagittal , inferior sagittal , straight sinuses
Tentorium cerebelli	Tent shaped (semilunar), separates occipital lobes of cerebrum from cerebellum	Transverse and superior petrosal sinuses
Falx cerebelli	Sickle shaped, extends between cerebellar hemispheres	Occipital sinus
Diaphragma sellae	Horizontal fold forms the roof of the sella turcica covering the hypophysis	Anterior & posterior Intercavernous sinuses

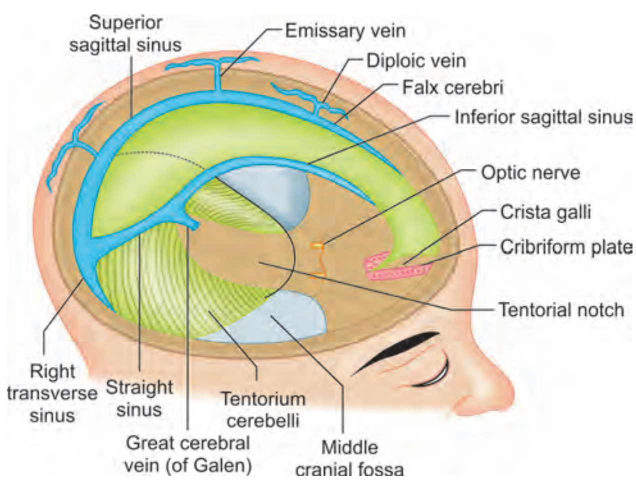


Fig. 90: Dural septa and dural venous sinuses viewed from superolateral aspect

ASSESSMENT QUESTIONS

1. Dura is supplied by all cranial nerves EXCEPT: *(AIIMS 2009)*
   a. 12
   b. 10
   c. 5
   d. 4

2. Middle cranial fossa is supplied by: *(PGIC)*
   a. Maxillary nerve
   b. Mandibular nerve
   c. Ophthalmic nerve
   d. Anterior ethmoidal nerve
   e. Posterior ethmoidal nerve

3. True about Falx cerebri: *(NEET pattern 2015)*
   a. Separates cerebellum from occipital lobe
   b. Contains straight sinus
   c. Separates two cerebellar hemisphere
   d. Contains occipital sinus

ANSWERS WITH EXPLANATIONS

1. d. 4
- CN 4 (trochlear nerve) is a pure motor nerve to supply superior oblique muscle.
- Innervation of dura mater is derived mainly from three sources: 1) Three divisions of trigeminal nerve, 2) C2 & 3 spinal nerves and 3) Cervical sympathetic trunk.
- Vagus and hypoglossal nerves, and possibly the facial and glossopharyngeal nerves may also supply duramater (less established).

2. a. Maxillary nerve; b. Mandibular nerve
- Middle cranial fossa is supplied by meningeal branch of the maxillary nerve (in the anterior part) and the mandibular nerve (nervus spinosus) in the posterior part.

3. b. Contains straight sinus
- **Falx cerebri** is a sickle shaped dural fold which separates right and left cerebral hemisphere and contains superior sagittal, inferior sagittal and straight sinuses in it.
- **Tentorium cerebelli** separates cerebellum from occipital lobes of cerebrum.
- **Falx cerebelli** is a sickle shaped dural fold that extends between and separate two cerebellar hemispheres and contains occipital sinus in its posterior attached part.

Venous Drainage of Cranial Cavity

Venous Drainage of Brain:

- There are deep (internal) cerebral veins and superficial (external) cerebral veins in the brain.
- Deeper circulation:
  - Paired internal cerebral veins (deep cerebral veins) drain the deep parts of the hemisphere.
  - They are formed near the Interventricular foramen by the union of the thalamostriate vein and choroid veins.
  - They run backward parallel with one another, between the layers of the tela chorioidea of the third ventricle, and beneath the splenium of the corpus callosum.
  - They unite to form the great cerebral vein of Galen; just before their union each receives the corresponding basal vein.
  - Most of the blood in the deep cerebral veins collects into the great cerebral vein, which empties into the straight sinus located in the midline of the tentorium.
- Superficial circulation:
  - The superficial veins at the dorsal parts of the hemispheres run upward and medially and empty into the large superior sagittal sinus in the upper margin of the falx cerebri.
  - **Superior cerebral veins** (eight to twelve) drain the superior, lateral, and medial surfaces of the hemispheres into the superior sagittal sinus.
  - **Inferior cerebral veins** are veins drain the undersurface of the cerebral hemispheres and empty into the cavernous and transverse sinuses. Those on the temporal lobe anastomose with the middle cerebral and basal veins, and join the cavernous, sphenoparietal, and superior petrosal sinuses.
  - Superior sagittal sinus divides into two parts called the transverse sinuses where the falx cerebri meets the tentorium cerebelli.
  - Sigmoid sinus, which continues the transverse sinus, empties into the internal jugular vein at the jugular foramen.
  - Cavernous sinus receives superficial veins and drain into the superior & inferior petrosal sinus, and pterygoid venous plexus which eventually reach the internal jugular vein.
- **Dural venous sinuses** are intradural spaces present between the external (periosteal layer) and the internal (meningeal layer) of the dura mater, or between duplications of the meningeal layers, containing venous blood drained from the cranial cavity.

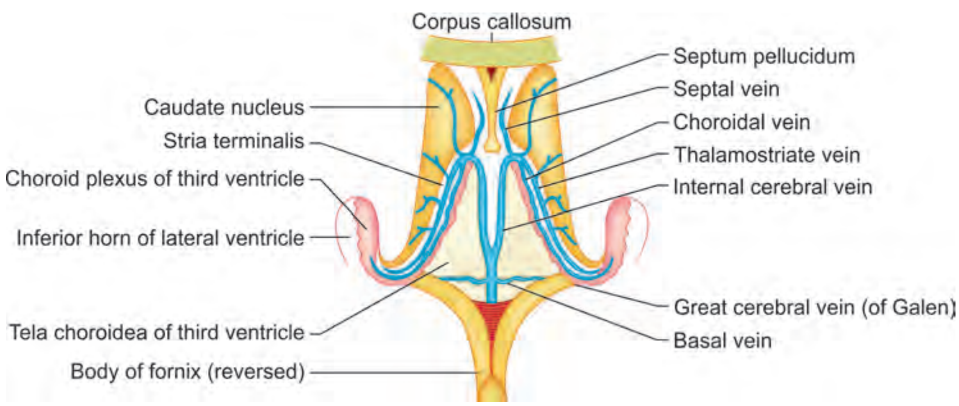


Fig. 91: Formation course, and tributaries of the internal cerebral veins and the great cerebral vein of Galen.

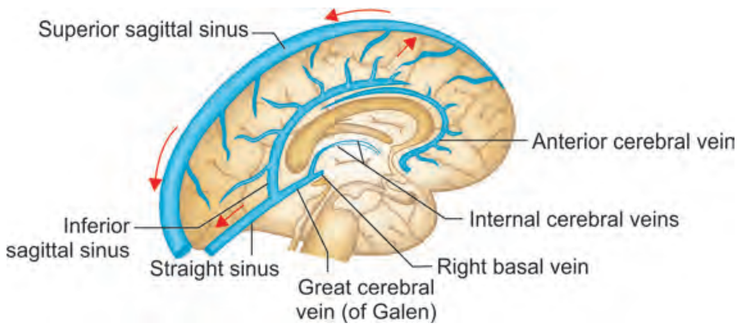


Fig. 92: Veins on the medial surface of the cerebral hemisphere.

- They may be paired or unpaired:
- Superior sagittal sinus is located along the superior aspect of the falx cerebri. Arachnoid granulations drain CSF from the subarachnoid space into the dural venous sinuses, protrude into its wall.
- Inferior sagittal sinus is located along the inferior free edge of the falx cerebri.
- Straight sinus (deeper venous drainage of brain) is formed by the meeting of the great cerebral vein of Galen with inferior sagittal sinus.
- Occipital sinus is present in the attached border of the tentorium cerebelli.
- Confluence of sinuses receive three incoming channels (tributaries) SOS: Straight sinus, Occipital sinus and Superior sagittal sinus.
- Transverse sinus drains venous blood from the confluence of sinuses to the sigmoid sinus. It also receives incoming channel (tributary) from superior petrosal sinus.
- Sigmoid Sinus drains into the internal jugular vein.
- Inferior petrosal sinus is the first tributary to internal jugular vein.

Classification of the dural venous sinuses (seven paired and seven unpaired)	
Unpaired sinuses	Paired sinuses
1. Superior sagittal	1. Cavernous
2. Inferior sagittal	2. Superior petrosal
3. Straight	3. Inferior petrosal
4. Occipital	4. Transverse
5. Anterior intercavernous	5. Sigmoid
6. Posterior intercavernous	6. Sphenoparietal
7. Basilar venous plexus	7. Petrosquamous

- **Superior sagittal sinus** begins near the crista galli (behind foramen caecum), runs in superior aspect of the falx cerebri, at posterior end, enters the confluence of the sinuses (torcula), which is situated to one side (usually the right) of the internal occipital protuberance.
  - It usually deviates to become continuous with the right transverse sinus, but it also usually connects with the occipital and contralateral transverse sinuses.
  - Diploic, meningeal veins and cortical veins drain into it.
  - The largest cortical vein that connects the superficial Sylvian (middle cerebral) vein and the superior sagittal sinus is the superior anastomotic vein (vein of Trolard); Arachnoid granulations, which transmit CSF from the subarachnoid space to the dural venous sinuses, protrude into its wall.

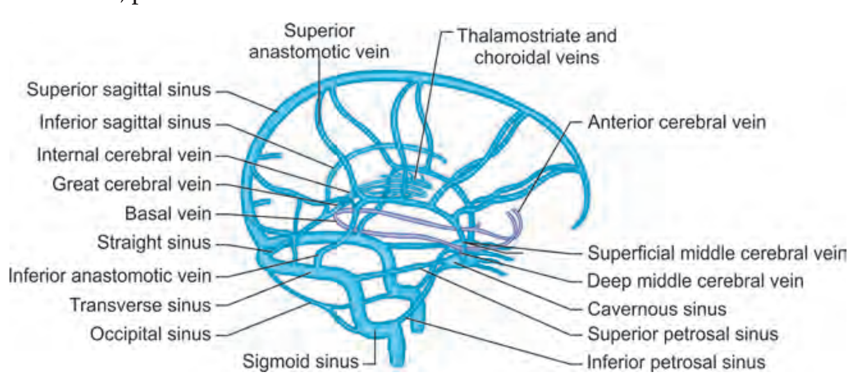


Fig. 93: The cerebral venous system showing the principal superficial and deep veins of the brain and their relationship to the dural venous sinuses, viewed from the left side.

- **Inferior sagittal sinus** is located in the posterior half or two-thirds of the free margin of the falx cerebri.
  - It receives veins from the falx and sometimes from the medial surfaces of the cerebral hemispheres (anterior pericallosal veins).
  - It is joined by the great cerebral vein of Galen and drains into the straight sinus.
- **Straight sinus** runs along the line of attachment of the falx cerebri to the tentorium cerebelli.
  - It runs posteroinferiorly as a continuation of the inferior sagittal sinus and drains into the transverse sinus, most commonly into the left one.
  - Its tributaries include the great cerebral vein (vein of Galen), which is formed by the convergence of the internal cerebral and basal veins, and some superior cerebellar veins.
- **Transverse sinus** begin at the **confluence of sinuses** and attach to the internal occipital protuberance.
  - Usually the right, is directly continuous with the superior sagittal sinus, and the left with the straight sinus.
  - The larger right transverse sinus drains blood from the superficial parts of the brain, while the small left transverse sinus mainly drains blood from the deep parts of the brain.
  - On either side, the sinuses run in the attached margin of the tentorium cerebelli, first on the squama of the occipital bone, then on the mastoid angle of the parietal bone.
  - Each follows an anterolateral curve to reach the posterolateral part of the petrous temporal bone and turn down as a sigmoid sinus, which ultimately becomes continuous with the internal jugular vein.
  - The transverse sinuses receive tributaries from the temporal and occipital lobes.
  - The inferior anastomotic vein (vein of Labbe) is the largest vein connecting the veins of the Sylvian fissure with the transverse sinus.
  - The superior petrosal sinuses drain into the transition between the transverse and sigmoid sinuses on either side.
- **Superior petrosal sinus** drain the cavernous sinus into the transverse sinus on either side.
  - It leaves the posterosuperior part of the cavernous sinus and runs posterolaterally in the attached margin of the tentorium cerebelli, crosses above the trigeminal nerve to lie in a groove on the superior border of the petrous part of the temporal bone and ends by joining the transverse sinus at the point where this curves down to become the sigmoid sinus.
- **Inferior petrosal sinus** drain the cavernous sinus into the internal jugular veins on each side.
  - It begins at the posteroinferior aspect of the cavernous sinus and run posteriorly a groove between the petrous temporal and basilar occipital bones.
  - Next it passes through the anteromedial part of the jugular foramen to drain into the superior jugular bulb.
  - The venous spaces in the sphenopetroclival area, which are filled anteriorly by blood from the cavernous sinus, medially by blood from the basilar plexus, and laterally by blood from the superior petrosal sinus, drain into the inferior petrosal sinuses
- **Sigmoid sinus** is continuations of the transverse sinus, beginning where it leave the tentorium cerebelli.
  - Each sigmoid arches downward and medially in an S-shaped groove on the mastoid part of the temporal bone and turns forwards to the superior jugular bulb, lying posterior in the jugular foramen and continues as internal jugular vein.
  - Anteriorly, a thin plate of bone separates its upper part from the mastoid antrum and air cells.
- **Sphenoparietal sinus** lies along the posterior edge of the lesser wing of the sphenoid bone and drains into the cavernous sinus.
- **Occipital sinus** lies in the falx cerebelli and drains into the confluence of sinuses.
- **Basilar plexus** consists of interconnecting venous channels on the basilar part of the occipital bone and connects the two inferior petrosal sinuses. It communicates with the internal vertebral venous plexus.
- **Diploic veins** lie in the diploe of the skull and are connected with the cranial dura sinuses by the emissary veins.
- **Emissary veins** are the small veins connecting the venous sinuses of the dura with the diploic veins and the veins on the outside of the skull.

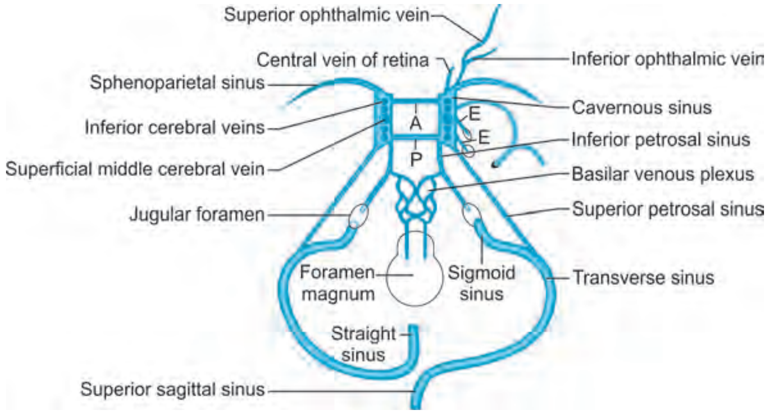


Fig. 94: Tributaries and communications of cavernous sinus (superior view) (A = anterior intercavernous sinus, P = posterior intercavernous sinus, E = emissary vein)

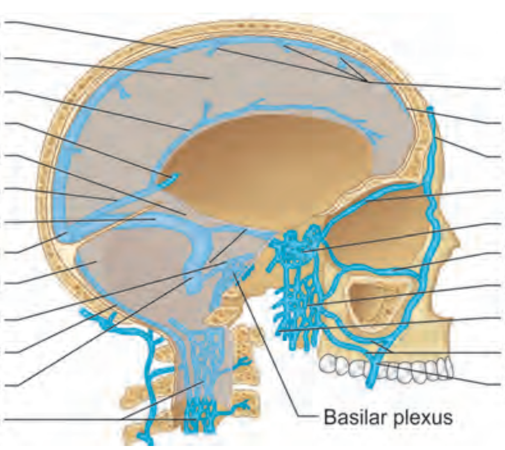


Fig. 95: Venous drainage of cranial cavity.

Cavernous Sinus

- Cavernous sinus is a dural venous sinus that lie on either side of the body of the sphenoid bone, in the middle cranial fossa, extending from the superior orbital fissure to the apex of the petrous temporal bone, with an average length of 2 cm and width of 1 cm.
- The cavity of the cavernous sinus is formed when the two layers of dura.
- The floor of the sinus is formed by the endosteal layer, while the lateral wall, roof, and medial wall by the meningeal layer.
- Medially, the roof is continuous with the diaphragm sellae.

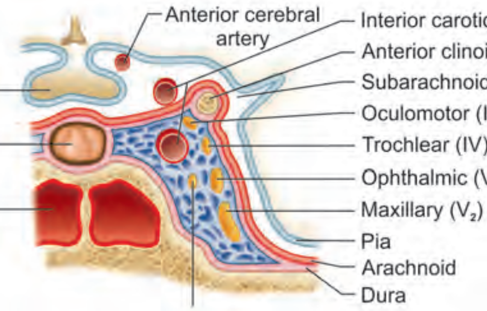


Fig. 96: Contents of cavernous sinus.

Contents

- Cavernous sinus contains the cavernous segment of the internal carotid artery, associated with a perivascular T1 sympathetic plexus.
- The cranial nerves that run forwards through the cavernous sinus to enter the orbit via the superior orbital fissure are (above downwards) oculomotor, trochlear and the ophthalmic nerve, maxillary nerve (all lie in the lateral wall of the sinus).
- The abducens nerve enters the cavernous sinus by passing within a dural tunnel (Dorello's canal) and then runs on the inferolateral side of the horizontal portion of the cavernous carotid artery, just medial to the ophthalmic nerve.
  Cavernous sinus receives blood from brain, meninges, orbit.

Tributaries (incoming channels)	Draining channels (outgoing channels/communications)
• Brain – Superficial middle cerebral vein – Inferior cerebral vein • Meninges – Sphenoparietal sinus – Anterior (frontal) trunk of middle meningeal vein • Orbit – Superior ophthalmic vein – Inferior ophthalmic vein – Central vein of retina (occasionally)	• Transverse sinus (via superior petrosal sinus) • Internal jugular vein (via inferior petrosal sinus) • Pterygoid plexus of veins (through emissary veins) • Superior ophthalmic vein • Facial vein (through pterygoid plexus & superior ophthalmic vein) • Maxillary vein (through pterygoid venous plexus) • Intercavernous sinuses • Basilar plexus of veins

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Unlike the ophthalmic nerve, the maxillary nerve does not run through the cavernous sinus or its lateral wall, but courses beneath the dura of the middle cranial fossa below the level of the cavernous sinus.

Clinical Correlations

- Cavernous sinus pathology may lead to ptosis (paralysed levator palpebrae superior), proptosis (protrusion of eyeball due to venous congestion), chemosis (swelling of the conjunctivae), periorbital oedema, and extraocular dysmotility causing diplopia secondary to a combination of third, fourth and sixth cranial nerve palsies.
- Sensory disturbances in the territory of ophthalmic & maxillary divisions of the trigeminal nerve are observed and a decreased corneal reflex may also be detected, sluggish pupillary responses (due to damage of sympathetic and parasympathetic nerves).
- There may be evidence of dilated, tortuous retinal veins and papilloedema.
- Any spreading infection involving the dangerous area of face, may lead to septic thrombosis of the cavernous sinuses; infected thrombus (usually *Staphylococcus*) pass from the facial vein or pterygoid venous complex into the sinus via either ophthalmic veins or emissary veins that enter the cranial cavity through the foramen ovale.

ASSESSMENT QUESTIONS

1. All are paired venous sinuses EXCEPT: *(NEET 2012)*
a. Superior petrosal
b. Inferior petrosal
c. Superior sagittal
d. Transverse

2. Which of the following are draining channels of cavernous sinus: *(PGIC 2002)*
a. Inferior petrosal sinus
b. Inferior ophthalmic vein
c. Sphenoparietal sinus
d. Middle cerebral vein
e. Superior ophthalmic vein

3. Tributaries of cavernous sinus are all EXCEPT: *(NEET Pattern 2015)*
a. Inferior cerebral vein
b. Central vein of retina
c. Sphenoparietal sinus
d. Superior cerebral vein

4. Which of the following is NOT a tributary of the cavernous sinus: *(AIPG 2008)*
a. Superficial middle cerebral vein
b. Superior petrosal sinus
c. Inferior petrosal sinus
d. Deep middle cerebral vein

5. Paralysis of 3rd, 4th, 6th nerves with involvement of ophthalmic division of 5th nerve, localizes the lesion to: *(AIPG 2005)*
a. Cavernous sinus
b. Apex of orbit
c. Brainstem
d. Base of skull

6. Two internal cerebral veins unite to form: *(NEET Pattern 2012)*
a. Middle cerebral vein
b. Anterior cerebral vein
c. Great cerebral vein
d. Inferior cerebral vein

7. Vein of Galen drains into: *(NEET Pattern 2015)*
a. Internal jugular vein
b. External jugular vein
c. Straight sinus
d. Superior sagittal sinus

8. Deep venous system of brain consists of: *(PGIC 2014)*
a. Internal cerebral vein
b. Great cerebral vein
c. Basal veins
d. Cavernous sinus
e. Straight sinus

9. Superior cerebral veins drains into: *(NEET pattern 2014)*
a. Great cerebral vein
b. Vein of Galen
c. Superior sagittal sinus
d. Inferior sagittal sinus

10. Falx cerebri contains: *(NEET Pattern 2014)*
a. Occipital sinus
b. Straight sinus
c. Superior petrosal sinus
d. Transverse sinus

11. All are true about diploic veins EXCEPT:
a. Lined by single layer endothelium supported by elastic tissue
b. Present in cranial bones
c. Valveless
d. Develop by 8th week of IUL

12. All of the following statements are true regarding cavernous sinus thrombosis EXCEPT: *(AIIMS 2014)*
a. Loss of jaw jerk
b. Inferior ophthalmic vein can spread infection from dangerous area of face
c. Ethmoidal sinusitis is the most common cause
d. Loss of sensation around the eye

13. Which is NOT true about cranial duramater: *(AIIMS 2014)*
a. It has periosteal an meningeal layers
b. It is supplied by 5th cranial nerve
c. It is the outermost meningeal layer
d. Dural venous sinuses are present inner to the meningeal layer

14. All of the following are true about diploic vein EXCEPT: *(AIPG 2008)*
a. Lined by single layer of endothelium supported by elastic tissue
b. Present in cranial bones
c. Valveless and thin walled
d. Develop by 8th week of IUL

15. Among the following, content of cavernous sinus is: *(AIIMS 2014)*
a. Maxillary division of trigeminal nerve
b. Ophthalmic division of trigeminal nerve
c. Trochlear nerve
d. Internal carotid artery

16. Which of the following is a direct content of cavernous sinus:
a. Occulomotor nerve
b. Trochlear nerve
c. Maxillary branch of trigeminal
d. Abducent nerve

17. All are features of cavernous sinus thrombosis EXCEPT:
a. Papilloedema
b. Proptosis
c. Sensory deficit on face due to involvement of three branches of trigeminal nerve
d. External ophthalmoplegia due to compression of three motor nerves to eyeball muscles

18. Which of these is NOT a tributary of cavernous sinus: *(NEET Pattern 2014)*
a. Sphenoparietal sinus
b. Superior petrosal sinus
c. Superficial middle cerebral vein
d. Inferior ophthalmic vein

19. Following are tributaries of cavernous sinus EXCEPT:
a. Superior ophthalmic vein
b. Central vein of retina
c. Great cerebral vein
d. Inferior ophthalmic vein

20. Which of the following is a tributary as well as drainage channel to cavernous sinus
a. Superior ophthalmic vein
b. Inferior ophthalmic vein
c. Spheno-parietal sinus
d. Superficial middle meningeal vein

ANSWERS WITH EXPLANATIONS

1. c. Superior sagittal
- Superior sagittal sinus lies in the midline structure called falx cerebri and is unpaired.

2. a. Inferior petrosal sinus > e. Superior ophthalmic vein
- Cavernous sinus drains by various outgoing channels including inferior petrosal sinus.
- Superior ophthalmic vein has bidirectional flow and is a tributary and a draining channel as well.

3. d. Superior cerebral vein
- **Superior cerebral veins** (eight to twelve) drain the superior, lateral, and medial surfaces of the hemispheres into the superior sagittal sinus.

4. d. Deep middle cerebral vein
- Deep middle cerebral vein doesn't get connected to the cavernous sinus directly.
- Superficial middle cerebral vein drains into the cavernous sinus at its anterior aspect.
- Superior and inferior petrosal sinuses are actually drainage channels for cavernous sinus but just for the sake of handling this peculiar question, we may consider them as tributaries of cavernous sinus (when the intracranial pressure increases in the posterior cranial fossa and the venous drainage is reversed).
- The dural venous sinuses are valveless and the blood can flow in either direction.

5. a. Cavernous sinus
- Cranial nerves 3, 4, 6 and the ophthalmic division of trigeminal pass through the cavernous sinus together and hence any pathology in the sinus can involve all of them.
- The other location where these nerves are together is the superior orbital fissure.
- Tolosa hunt syndrome can damage these nerves together at this location.
- Optic canal lies at the apex of orbit and cranial nerve 2 (optic) lies there.
- Brainstem has the nerve nuclei of last 10 cranial nerves and its lesion will produce more elaborate damage.
- Base of skull has many nerves in its relation and any lesion here damage the mandibular division of trigeminal also.
- Mandibular nerve escapes the lesions of cavernous sinus, since it does not pass through it.

6. c. Great cerebral vein
- Two internal cerebral veins unite to form the great cerebral vein of Galen.

7. c. Straight sinus
- Great cerebral vein of Galen is joined by the inferior sagittal sinus to drain into the straight sinus.

8. a. Internal cerebral vein; b. Great cerebral vein; c. Basal veins; e. Straight sinus
- Cavernous sinus comes under superficial circulation.

9. c. Superior sagittal sinus
- **Superior cerebral veins** (eight to twelve) drain the superior, lateral, and medial surfaces of the hemispheres into the superior sagittal sinus.

10. b. Straight sinus
- Falx cerebri is a double fold of peritoneum containing superior and inferior sagittal sinus.
- It also contains **straight sinus** at the base.
- **Occipital sinus** runs in the falx cerebelli, **superior petrosal sinus** & **transverse sinus** run in the attached margin of tentorium cerebelli.

11. d. Develop by 8th week of IUL
- Diploic veins start developing in the cranial bones at about 2 years of age and are fully developed at the age of 35 years.
- These are lined by a single layer endothelium supported by elastic tissue and are valveless.

12. a. Loss of jaw jerk
- Cavernous sinus thrombosis do not involve the mandibular nerve of trigeminal, hence jaw jerk is intact.

13. d. Dural venous sinuses are present inner to the meningeal layer
- **Dural venous sinuses** are intradural spaces present between the external (periosteal layer) and the internal (meningeal layer) of the dura mater, or between duplications of the meningeal layers, containing venous blood drained from the cranial cavity.
- Dural venous sinuses are outer to meningeal layer and inner to endosteal layer.
- Inner to the meningeal layer of duramater is subdural space.

14. d. Develop by 8th week of IUL
- The skull is unilamellar at birth and doesn't have diploe. Diploic veins are absent at birth, appear around 2–4 years of age and are maximally differentiated by 35th year.
- The major diploic veins are: Frontal, occipital, anterior and posterior temporal.
- Diploic veins have a very thin wall consisting of endothelium supported by some elastic tissue and are valveless.

15. d. Internal carotid artery
- Cavernous sinus contains the cavernous segment of the internal carotid artery, associated with a perivascular T1 sympathetic plexus.
- The cranial nerves that run forwards through the cavernous sinus to enter the orbit via the superior orbital fissure.
- In this question all the options are answers, though the first choice remains internal carotid artery.

16. d. Abducent nerve
- The abducens nerve enters the cavernous sinus by passing within a dural tunnel (Dorello's canal) and then runs on the inferolateral side of the horizontal portion of the cavernous carotid artery, just medial to the ophthalmic nerve.
- Occulomotor nerve, trochlear nerve and maxillary branch of trigeminal lie in the lateral wall of cavernous sinus.

17. c. Sensory deficit on face due to involvement of three branches of trigeminal nerve
- Sensory deficit on face due to involvement of first two branches of trigeminal nerve (third branch, mandibular nerve is spared, as it is not a content of cavernous sinus and doesn't get involved).

18. b. Superior petrosal sinus
- Superior petrosal sinus is a draining channel for cavernous sinus.

19. c. Great cerebral vein
- Great cerebral vein is a tributary to the straight sinus.

20. a. Superior ophthalmic vein
- Superior ophthalmic vein has bidirectional blood flow and is a tributary to the cavernous sinus and a draining channel as well.
- It drains venous blood of orbit into the cavernous sinus and vice versa.

Venous Drainage of Scalp and Face

- Facial vein provides the major venous drainage of the face and drains into the internal jugular vein.
  - It begins as an angular vein by the confluence of the supraorbital and supratrochlear veins. The angular vein is continued at the lower margin of the orbital margin into the facial vein.
  - Facial vein receives tributaries corresponding to the branches of the facial artery and also receives the infraorbital and deep facial veins.
  - It drains either directly into the internal jugular vein or by joining the anterior branch of the retromandibular vein to form the common facial vein, which then enters the internal jugular vein.
  - It makes clinically important connections with the cavernous sinus via the superior ophthalmic vein, inferior ophthalmic vein, and pterygoid plexus of veins.
  - This connection with the cavernous sinus provides a potential route of infection from the superficial face (danger zone of the face) to the dural venous sinuses within the cranium.

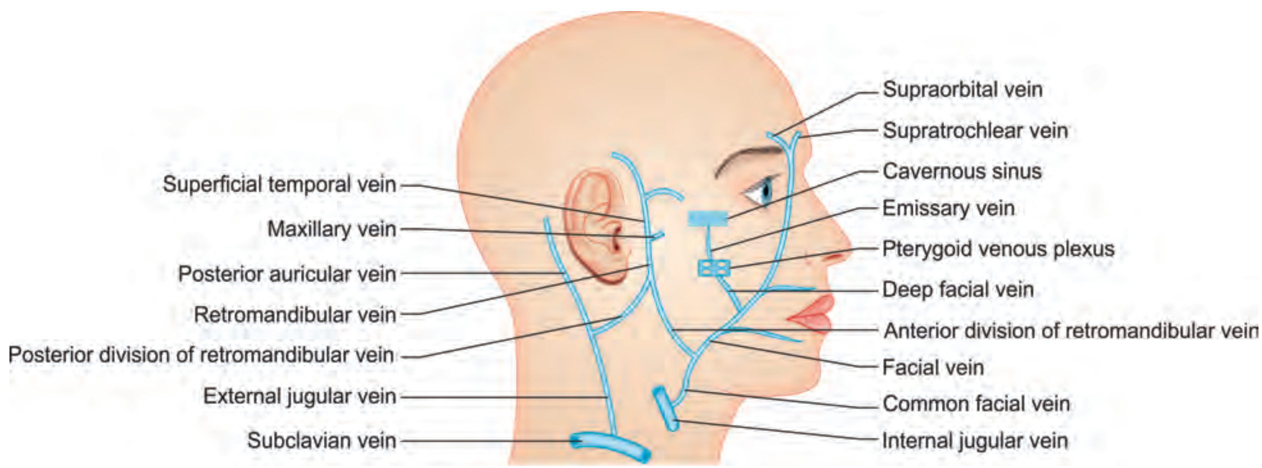


Fig. 97: Venous drainage of the face.

- **Retromandibular vein** is formed by the union of the superficial temporal and maxillary veins behind the mandible.
  - It divides into an anterior branch, which joins the facial vein to form the common facial vein, and a posterior branch, which joins the posterior auricular vein to form the external jugular vein.
- **Pterygoid venous plexus** lies on the lateral surface of the medial pterygoid muscle, receives veins corresponding to the branches of the maxillary artery, and drains into the maxillary vein.
  - It communicates with the cavernous sinus by emissary veins (which pass through the foramen ovale), the inferior ophthalmic vein by a vein (which runs through the infraorbital fissure), and the facial vein by the deep facial vein.

Vein	Origin	Course	Termination	Area drained
Supratrochlear	Begins from venous plexus on forehead and scalp, through which it communicates with frontal branch of superficial temporal vein, its contralateral partner, and supraorbital vein	Descends near midline of forehead to root of nose, where it joins supraorbital vein	Angular vein at root of nose	Anterior part of scalp and forehead
Supraorbital	Begins in forehead by anastomosing with frontal tributary of superficial temporal vein	Passes medially superior to orbit; joints supratrochlear vein; a branch passes through suprarobirtal notch and joints with superior ophthalmic vein		
Angular	Begins at root of nose by union of supratrochlear and supraorbital veins	Descends obliquely along root and side of nose to interior orbital margin	Becomes facial vein at interior margin of orbit	Anterior part of scalp and forehead; superior and interior eyelids and conjunctiva; may receive drainage from cavernous sinus
Facial	Continuation of angular vein past inferior margin of orbit	Descends along lateral border of nose, receiving external nasal and interior plapebral veins; then passes obliquely across face to cross inferior border of mandible; receives communication from retromandibular vein (after which, it is sometimes called common facial vein)	Internal jugular vein opposite or interior to level of hyoid bone	Anterior scalp and forehead; eyelids; external nose; anterior cheek; lips; chin; and submandibular gland
Deep facial	Pterygoid venous plexus	Runs anteriorly on maxilla superior to buccinator and deep to masseter, emerging medial to anterior border of masseter onto face	Enters posterior aspect of facial vein	Infratemporal fossa (most areas supplied by maxilary artery)
Superficial temporal	Begins from widespread plexus of veins on side of scalp and along zygomatic arch	Frontal and parietal tributaries untie anterior to the auricle; crosses temporal root of zygomatic arch to pass from temporal region and enter substance of the parotid gland	Joins maxillary vein posterior to neck of mandible to form retromandibular vein	Side of scalp; superficial aspect of temporal muscle and external ear
Retromandibular	Formed anterior to ear by union of superficial temporal and maxillary veins	Runs posterior and deep to ramus of mandible through substance of parotid gland; communicates at inferiror end with facial vein	Unites with posterior auricular vein to form external jugular vein	Parotid gland and masseter muscle

- **External jugular vein** is formed by the union of the posterior auricular vein and the posterior branch of the retromandibular vein.
    - It crosses the sternomastoid obliquely under the platysma and ends in the subclavian (or occasionally in the internal jugular) vein.
    - It receives the suprascapular, transverse cervical, and anterior jugular veins.

Fig. 98: Dangerous area of face.

- Dangerous area of the face includes upper nasal cavities, paranasal sinuses, cheek (especially near the medial canthus), upper lip, anterior nares, or even an upper incisor or canine tooth.
- Venous communication between the facial vein and the cavernous sinus (via the ophthalmic veins & deep facial vein) may lead to retrograde spread of infections into the cranial cavity causing cavernous sinus thrombosis, meningitis or brain abscess.

Venous Drainage of Neck

- The veins of the neck lie superficial or deep to the deep investing fascia.
- Superficial veins ultimately drain into either the external, anterior or posterior external jugular veins; they drain a much smaller volume of tissue than the deep veins.
- Deep veins tend to drain into either the internal jugular vein or the subclavian vein.
- The internal jugular vein drains blood from the skull, brain, superficial face and much of the neck.
  - It begins in the jugular foramen as a continuation of the sigmoid sinus, descends in the carotid sheath, and ends in the brachiocephalic vein.
  - It has the superior bulb at its beginning and the inferior bulb just above its termination, receives multiple veins like the facial, lingual, and superior and middle thyroid veins.
  - It descends in the neck within the carotid sheath and unites with the subclavian vein behind the sternal end of the clavicle to form the brachiocephalic vein.
  - At its junction with the internal jugular vein, the left venous angle usually receives the thoracic duct, and the right venous angle receives the right lymphatic duct.
- The left brachiocephalic vein is longer, more oblique and crosses the midline to unite with right counterpart and form SVC.

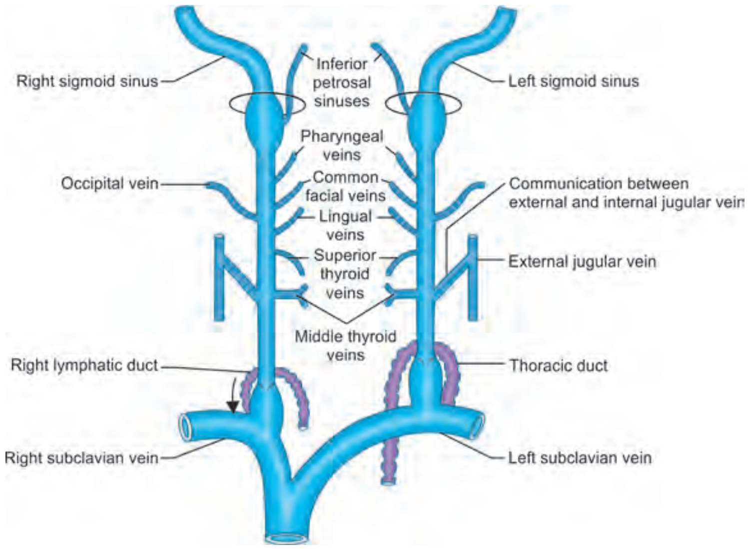


Fig. 99: Beginning and termination of the internal jugular veins along with their tributaries

Differences between right and left brachiocephalic veins

	Right brachiocephalic vein	Left brachiocephalic vein
Length	Short (2.5 cm)	Long (6 cm)
Course	Vertical (runs vertically downwards from right sternoclavicular joint to the lower margin of the right 1st costal cartilage)	Oblique (runs obliquely across the superior mediastinum from left sternoclavicular joint to the lower margin of the right 1st costal cartilage)
Tributaries	Right vertebral vein Right internal thoracic vein Right inferior thyroid vein First right posterior intercostal vein	Left vertebral vein Left internal thoracic vein Left inferior thyroid vein First left posterior intercostal vein Left superior intercostal vein

ASSESSMENT QUESTIONS

1. **Angular vein communicates with:** *(NEET Pattern 2012)*
   a. Cavernous sinus
   b. Superior sagittal sinus
   c. Inferior sagittal sinus
   d. Central sinus

2. **NOT true about facial vein is:** *(NEET Pattern 2013)*
   a. Drains in external jugular vein
   b. Largest vein of face
   c. Formed from angular vein
   d. Has no valves

3. **Septic emboli in facial vein can cause cavernous sinus thrombosis because facial vein makes clinically important connections with the cavernous sinus. The most commonly involved communicating vein is:**
   a. Superior ophthalmic
   b. Deep facial
   c. Inferior ophthalmic
   d. Pterygoid plexus of veins

4. **True regarding surface anatomy of internal jugular vein:** *(NEET Pattern 2012)*
   a. Line passing from ear lobule to midpoint of clavicle
   b. Line passing from ear lobule to medial end of clavicle
   c. Line joining ear lobule to lateral end of clavicle
   d. Line joining mastoid process to midpoint of clavicle

ANSWERS WITH EXPLANATIONS

1. **a. Cavernous sinus**
   - Angular vein is the upper most segment of the facial vein, formed by the union of the supratrochlear vein and supraorbital vein.
   - It runs obliquely downward by the side of the nose, is linked with the cavernous sinus by the superior and inferior ophthalmic veins which are devoid of valves.
2. **a. Drains in external jugular vein**
   - Facial vein is the largest vein of face with no valves.
   - It begins as angular vein, joins anterior division of retromandibular vein to form common facial vein, which in turn drains into internal jugular vein.
3. **a. Superior ophthalmic**
   - Cavernous sinuses receive blood from the facial vein via the tributaries superior and inferior ophthalmic veins.
   - Bacteria in the facial veins enter the cavernous sinus via these veins.
   - Danger area of the face is the area of the face near the nose drained by the facial veins. Pustules (pimples) or boils or other skin infections, particularly on the side of the nose and upper lip, may spread to the cavernous venous sinus via the facial vein, pterygoid venous plexus, and ophthalmic veins.
   - Bacteria in the sphenoid and ethmoid sinuses can spread to the cavernous sinuses via the small emissary veins and are the most common sites of primary infection resulting in septic cavernous sinus thrombosis.
4. **b. Line passing from ear lobule to medial end of clavicle**
   - Surface marking for internal jugular vein is drawn as a line joining a point on the neck, medial to the ear lobule to a point at the medial end of the clavicle.

Lymphatic Drainage

- Lymph nodes in the head and neck are arranged in two horizontal rings and two vertical chains on either side.
  - The outer(superficial) ring consists of the occipital, preauricular (parotid), submandibular and submental nodes.
  - The inner (deep) ring is contributed by MALT (mucosa-associated lymphoid tissue) located primarily in the nasopharynx and oropharynx (Waldeyer's ring).
  - The vertical chain consists of superior and inferior groups of nodes related to the carotid sheath.
- All lymph vessels of the head and neck drain into the deep cervical nodes, either directly from the tissues or indirectly via nodes in outlying groups.
- Lymph reaches the systemic venous circulation via either the right lymphatic duct or the thoracic duct.
- Superficial lymph nodes of the head
  - Lymphatics from the face, scalp, and ear drain into the occipital, retroauricular, parotid, buccal, submandibular, submental, and superficial cervical nodes, which themselves drain into the deep cervical nodes (including the jugulodigastric and juguloomohyoid nodes).
- Deep lymph nodes of the head
  - Nasal cavity & paranasal sinuses drain into the submandibular, retropharyngeal, and upper deep cervical.
  - Middle ear drains into the retropharyngeal & upper deep cervical nodes.
  - Tongue drains into the submental, submandibular, and upper and lower cervical.
  - Larynx drains into the upper and lower deep cervical; Pharynx drains into the retropharyngeal and upper and lower deep cervical.
  - Thyroid gland drains into the lower deep cervical, prelaryngeal, pretracheal, and paratracheal nodes.
- Superficial cervical lymph nodes lie along the external jugular vein in the posterior triangle and along the anterior jugular vein in the anterior triangle. They drain into the deep cervical nodes.
- Deep cervical lymph nodes are divided into two groups: Superior and inferior.
- **Superior** deep cervical nodes lie along the internal jugular vein in the carotid triangle of the neck.
  - They receive afferent lymphatics from the back of the head and neck, tongue, palate, nasal cavity, larynx, pharynx, trachea, thyroid gland, and esophagus.
  - The efferent vessels join those of the inferior deep cervical nodes to form the jugular trunk, which empties into the thoracic duct on the left and into the junction of the internal jugular and subclavian veins on the right.
- **Inferior** deep cervical nodes lie on the internal jugular vein near the subclavian vein.
  - They receive afferent lymphatics from the anterior jugular, transverse cervical, and apical axillary nodes.

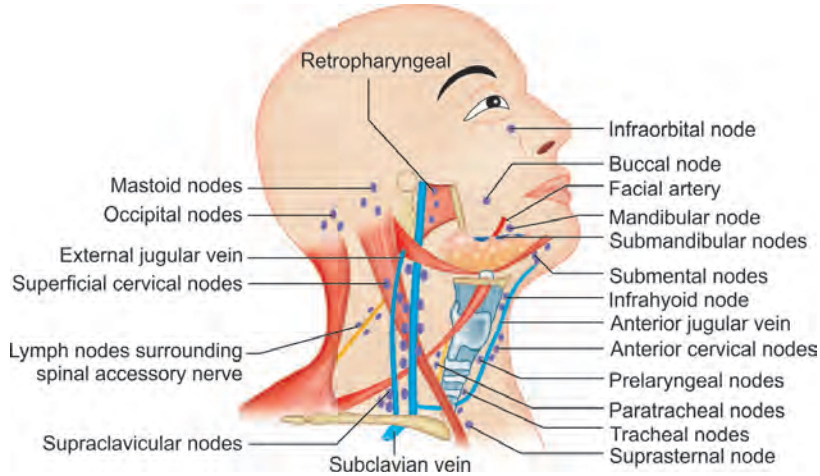


Fig. 100: Lymph nodes of the head and neck.

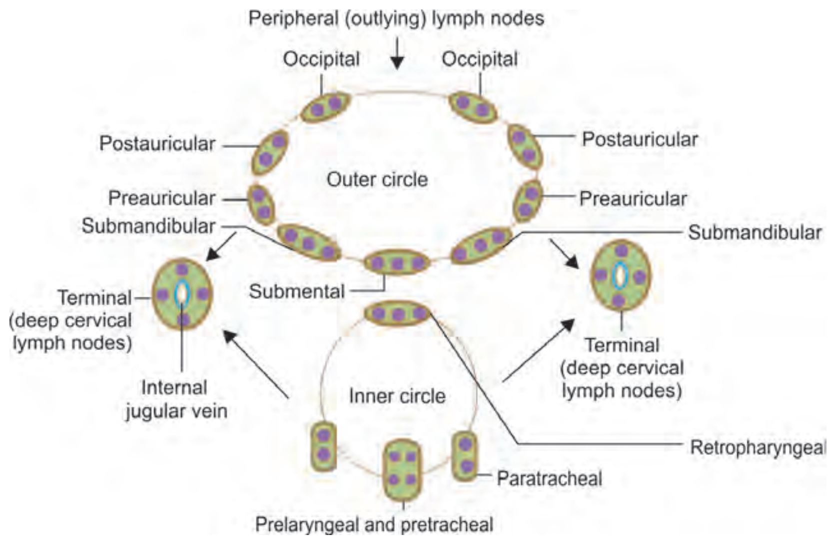


Fig. 101: General plan of location of the lymph node groups in the region of the head and neck

- **Waldeyer's ring** is an aggregation of lymphoid tissue (tonsils) underneath the epithelial lining of pharyngeal wall, surrounding the air and food pathway.
- It includes: Nasopharyngeal tonsil (posterosuperiorly), lingual tonsil (anteriorly), tubal and palatine tonsils (laterally).

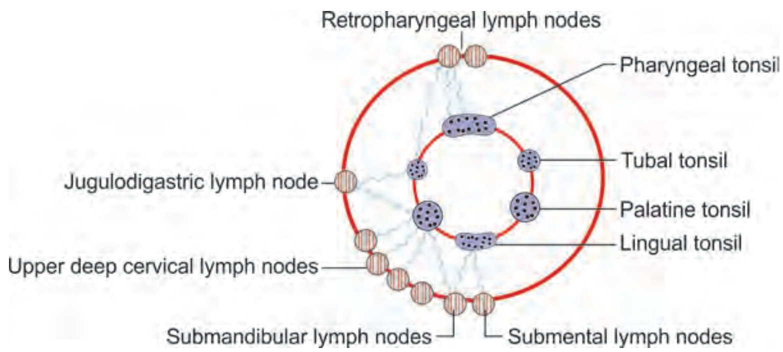


Fig. 102: Waldeyer's internal and external rings

ASSESSMENT QUESTIONS

1. **Submental lymph node of drainage by all EXCEPT:** *(NEET Pattern 2014; 15)*
   a. Anterior palate
   b. Tip of tongue
   c. Floor of mouth
   d. Lower lip

2. **Lymphatic drainage of anterior part of nose is to which lymph node:** *(NEET Pattern 2015)*
   a. Submandibular LN
   b. Parotid
   c. Pretracheal LN
   d. Retropharyngeal LN

3. NOT true about deep cervical lymph nodes: *(NEET Pattern 2013)*
a. Lie along external jugular vein
b. Tonsil is drained by jugulodigastric nodes
c. Lie deep to sternocleidomastoid
d. Tongue drains into juguloomohyoid nodes

4. Waldeyer's ring consists of all of the following EXCEPT: *(NEET Pattern 2012)*
a. Palatine tonsils
b. Pharyngeal tonsils
c. Tubal tonsils
d. Postauricular nodes

ANSWERS WITH EXPLANATIONS

1. a. Anterior palate
- Submental (suprahyoid) lymph node are situated between the anterior bellies of the digastric muscle.
- They drain the central portions of the lower lip and floor of the mouth and the tip of the tongue.
- Their efferents pass to the submandibular lymph nodes and partly to a gland of the deep cervical group.

2. a. Submandibular LN
- Anterior half of nasal cavity (including anterior part of nasal septum) drains into submandibular nodes.

3. a. Lie along external jugular vein
- Deep cervical nodes lie along internal jugular vein (not external jugular vein).

4. d. Postauricular nodes
- Waldeyer's ring includes nasopharyngeal tonsil (posterosuperiorly), lingual tonsil (anteriorly), tubal and palatine tonsils (laterally).

Development of Face, Palate and Nose

- Face is formed by three swellings: the frontonasal prominence, maxillary prominence (pharyngeal arch 1), and mandibular prominence (pharyngeal arch 1).
- Nasal placodes are the bilateral ectodermal thickenings which develop on the ventrolateral aspects of the frontonasal prominence.
- Nasal placodes invaginate into the underlying mesoderm to form the nasal pits, thereby producing a ridge of tissue that forms the medial nasal prominence and lateral nasal prominence.
- Nasolacrimal groove forms between the maxillary prominence and the lateral nasal prominence and eventually forms the nasolacrimal duct and lacrimal sac.

Structures contributing to formation of the Face

Prominence	Structures formed
Frontonasal[a]	Forehead, bridge of nose, and medial and lateral nasal prominences
Maxillary	Cheeks, lateral portion of upper lip
Medial nasal	Philtrum of upper lip, crest, and tip of nose
Lateral nasal	Alae of nose
Mandibular	Lower lip

[a]The frontonasal prominence is a single unpaired structure; the other prominences are paired.

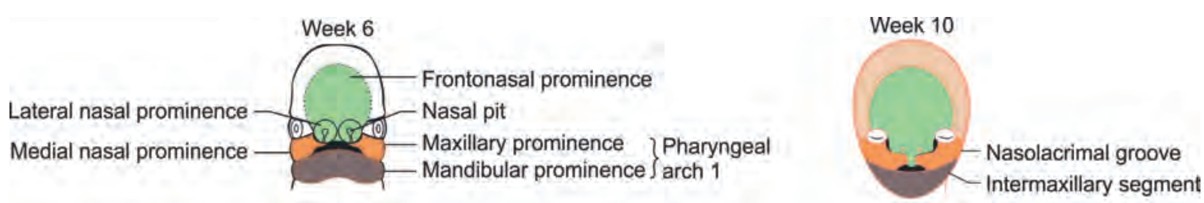


Fig. 103: Development of the face at weeks 6 and 10. Frontonasal prominence = green lateral nasal prominences = green, medial nasal prominences = green, maxillary prominences of pharyngeal arch 1 = orange, mandibular prominences of pharyngeal arch 1 = brown

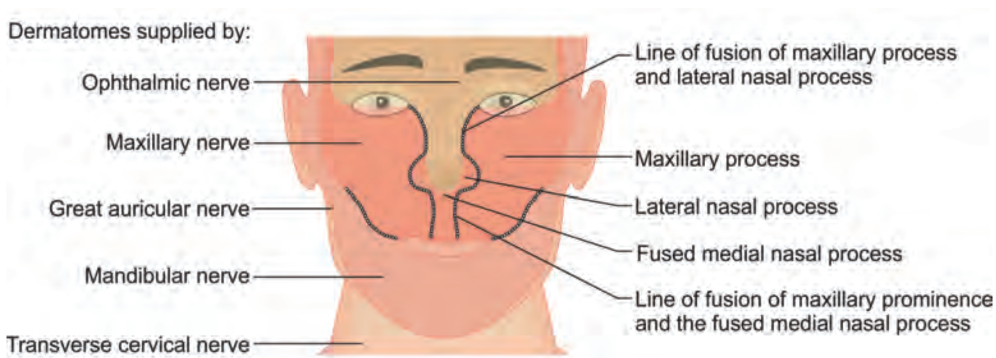


Fig. 104: The parts of the adult face derived from the ophthalmic (frontonasal), maxillary and mandibular divisions of the skin of the face, showing the lines of fusion and definitive innervation

Correlation of nerve supply of various components of face and their source of development		
Component of face	**Develops from**	**Nerve**
Forehead	Frontonasal process	Ophthalmic division of Vth nerve (V_1)
Nose	Frontonasal process	Ophthalmic division of Vth nerve (V_1)
Cheek a. Upper part b. Lower part	Maxillary process Mandibular process	Maxillary division of Vth nerve (V_2) Mandibular division of Vth nerve (V_3)
Upper lip	Fusion of maxillary processes of two sides with the frontonasal process*	Maxillary division of Vth nerve (V_2)
Lower lip	Fusion of mandibular processes of two sides	Mandibular division of Vth nerve (V_3)

*The skin of the philtrum of the upper lip is derived from skin overlying the maxillary acrocess; hence it is supplied by the maxillary nerve.

Age	Events
4th week (28th day)	• Buccopharyngeal membrane breaks down, stomodaeum communicates with foregut • Frontonasal, maxillary and mandibular processes are distinct • Lens and nasal placodes are distinguished
5th week (31 to 35 days)	• Nasal placodes invaginate, nasal pits are formed • Lateral and medial nasal prominences are evident
6th week	• Tubercles (for pinna) appear • Palatal process appear from the maxillary process
7th week	• Eyelids established • Maxillary process fused with medial nasal process
8th week	• Eyes shifted from a lateral to a frontal location
10th week	• Palatal processes and nasal septum fused with each other

- Primary palate is formed by the medial nasal prominences at the midline.
- Posterior to the primary palate, the maxillary process on each side sends a horizontal plate (palatal process); these plates fuse to form the secondary palate and also unite with the primary palate and the developing nasal septum.
- Secondary palate is formed by fusion of the lateral palatine processes (palatal shelves) that develop from the maxillary prominences.
- Definitive palate is formed by fusion of the primary and secondary palates at the incisive foramen.

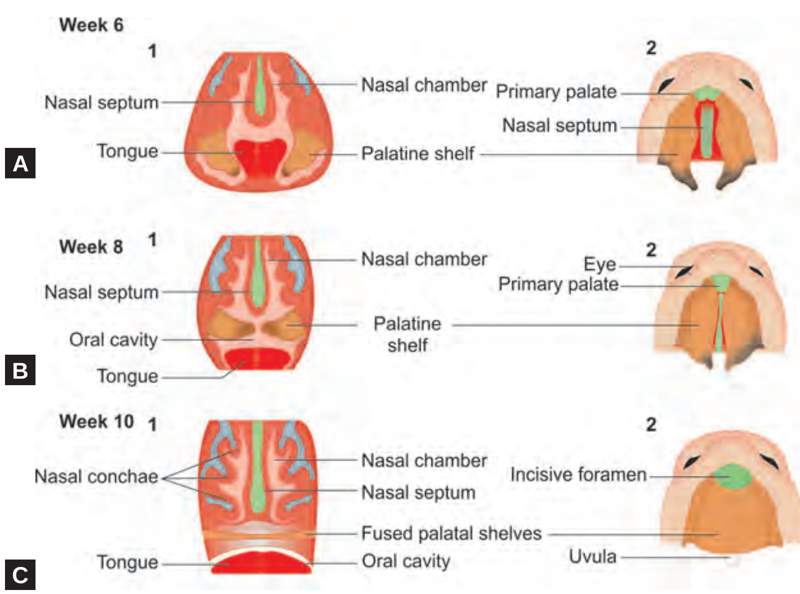
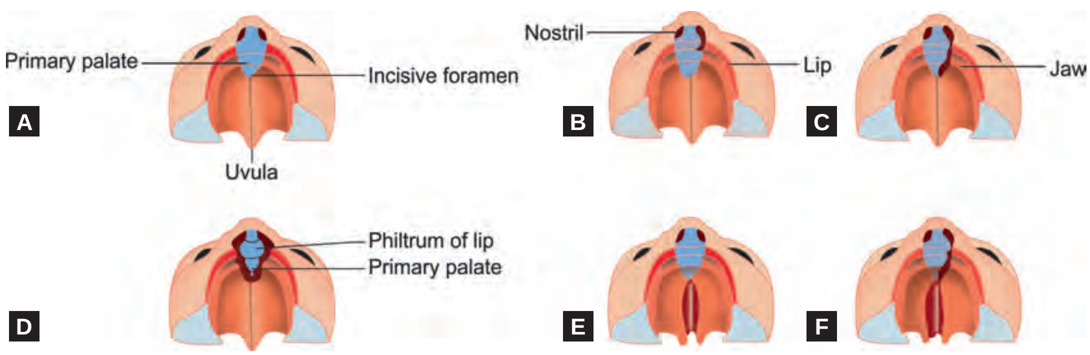


Fig. 105A to C: Development of the palate at weeks 6, 8, and 10. (1) Horizontal sections. (2) Roof of the mouth. Palatine shelves from maxillary prominence of pharyngeal arch 1 = orange, nasal septum from the medial nasal prominences = green, primary palate from the medial nasal prominences = green

Development of various components of the adult palate	
Component	**Source of development (i.e., develops from)**
1. Hard palate a. In front of incisive fossa (premaxilla) carrying four incisor teeth b. Behind the incisive fossa	Fused medial nasal processes of frontonasal process Fusion of palatine shelves (palatal process) of maxillary processes of two sides
2. Soft palate	Unossified part of fused palatine shelves (palatal processes) of two maxillary processes, which extend posteriorly beyond the nasal septum

Clinical Correlations

- Cleft palate is classified as anterior or posterior. The anatomical landmark that separates anterior from posterior cleft palate defects is the incisive foramen.
  - Anterior cleft palate occurs when the palatine shelves fail to fuse with the primary palate.
  - Posterior cleft palate occurs when the palatine shelves fail to fuse with each other and with the nasal septum.
  - Anteroposterior cleft palate occurs when there is a combination of both defects.
- Cleft lip may occur unilaterally or bilaterally.
  - Unilateral cleft lip is the most common congenital malformation of the head and neck.
  - It results from the following:
    - The maxillary prominence fails to fuse with the medial nasal prominence.
    - Midline cleft lip (hare lip) is due to non-fusion of the two medial nasal processes in the midline.



Figs. 106A to F: Ventral vie of the palate, gum, lip, and nose. (A) Normal. (B) Unilateral cleft lip extending into the nose. (C) Unilateral cleft involving the lip and jaw and extending to the incisive foramen. (D) Bilateral cleft involving the lip and jaw. (E) Isolated cleft palate. (F) Cleft palate combined with unilateral anterior cleft lip.

Development of Nasal Cavity

- **Nasal pits** are ectoderm lined depressions that result from proliferation of mesenchyme in lateral and medial nasal swellings.
- The nasal pits deepen, form blind sacs, and rupture to form the nostrils.
- **Oronasal membrane** initially separates nasal cavities from the oral cavity, but its rupture allows communication between nasal and oral cavities through the primitive choanae.
- **Nasal septum** forms as a downgrowth from the medial nasal process.
- **Lateral wall** is formed as the superior, middle, and inferior conchae.
- **Floor** of the nasal cavity is formed by fusion of the medial nasal process (nasal septum) with the palatine processes of the maxilla.
- **Roof** of the nose is formed from the lateral nasal processes.
- **Paranasal sinuses** develop as diverticula of the lateral nasal wall and extend into the maxilla, ethmoid, frontal, and sphenoid bones.

ASSESSMENT QUESTIONS

1. **A midline cleft lip is due to the failure of fusion between:** *(AIIMS 2006)*
   a. Maxillary processes
   b. Medial nasal processes
   c. Medial and lateral nasal process
   d. Medial nasal and maxillary process.

2. **Facial development takes place between:** *(PGIC 2015)*
   a. 4–8 week
   b. 8–10 week
   c. 12–14 week
   d. 18–20 week
   e. 6–10 week

ANSWERS WITH EXPLANATIONS

1. b. Medial nasal processes

- Midline cleft lip (hare lip) is due to non-fusion of the two medial nasal processes in the midline.
- Failure of fusion between medial nasal and maxillary process leads to unilateral cleft lip.
- Non-fusion of medial and lateral nasal process is not seen clinically.

2. a. 4-8 week

- Facial development begins at week 4 and the final stages of facial development occur in the period from 7–8th week.

Scalp and Face

- The scalp is composed of five layers, which can be remembered using the mnemonic SCALP: (1) Skin, (2) Connective tissue, (3) Aponeurosis, (4) Loose areolar tissue, and (5) Pericranium. The first three layers constitute the scalp proper, which moves as a unit.
- Skin has abundant hair and numerous sebaceous glands.
- Connective tissue forms a thick, vascularized subcutaneous layer which is dense, contains numerous blood vessels and nerves, sweat glands, and hair follicles. The arteries anastomose freely and are held by the dense connective tissue around them, and thus, they tend to remain open when cut, causing profuse bleeding.
- Aponeurosis (galea aponeurotica) is a tendinous sheet that covers the vault of the skull and continues as the frontal muscle anteriorly and the occipital muscle posteriorly. Laterally, the galea aponeurotica is continuous with the temporoparietal fascia.
- Loose areolar connective tissue is known as 'dangerous layer of scalp' because blood and pus freely tend to collect in this layer. If pus collects in this layer, the 'infection' may travel readily along emissary veins into the intracranial dural venous sinuses leading to their 'thrombosis', which may be fatal.
- Pericranium forms the periosteum of the neurocranium (skull).
- Arterial supply: Scalp is supplied by the supratrochlear and supraorbital branches of the internal carotid and by the superficial temporal, posterior auricular, and occipital branches of the external carotid arteries.
- Nerve supply: Scalp is innervated by the supratrochlear, supraorbital, zygomaticotemporal, auriculotemporal, lesser occipital, greater occipital, and third occipital nerves.

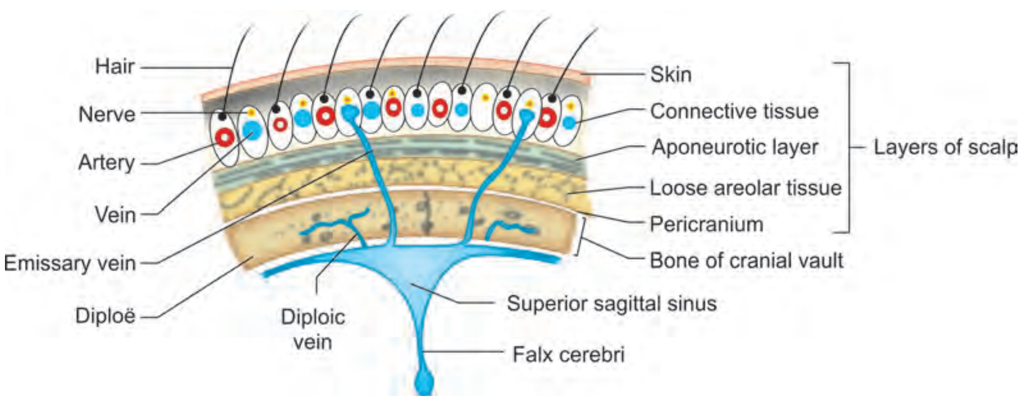


Fig. 107: Layers of scalp.

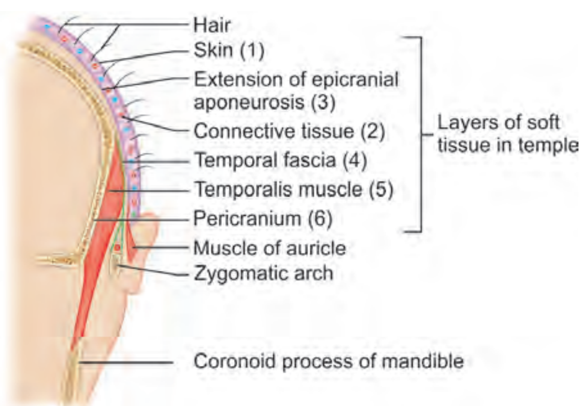


Fig. 108: Layers of the soft tissue in the temple

Muscles

Muscles of scalp and face			
Muscle[a]	**Origin**	**Insertion**	**Main action(s)**
Occipitofrontalis			
Front belly[2]	Epicranial aponeurosis	Skin and subcutaneous tissue of eyebrows and forehead	Elevates eyebrows and wrinkles skin of forehead; protracts scalp (indicating surprise or curiosity)
Occipital belly[1]	Lateral two thirds of superior nuchal line	Epicranial aponeurosis	Retracts scalp; increasing effectiveness of frontal belly
Orbicularis oculi (orbital sphincter)[2,3]	Medial orbital margin; medial palpebral ligament; lacrimal bone	Skin around margin of orbit; superior and inferior tarsal plates	Closes eyelids; palpebral part does so gently; orbital part tightly (winking)
Corrugator supercilii[2]	Medial end of superciliary arch	Skin superior to middle of supraorbital margin and superciliary arch	Draws eyebrows medially and inferiorly, creating vertical wrinkles above nose (demonstrating concern or worry)
Procerus plus transverse part of nasalis[4]	Fascia aponeurosis covering nasal bone and lateral nasal cartilage	Skin of inferior forehead, between eyebrows	Depresses medial end of eyebrow; wrinkles skin over dorsum of nose (conveying disdain or dislike)
Alar part of nasalis plus levator labii superioris alaeque nasii[4]	Frontal process of maxilla (inferomedial margin of orbit)	Major alar cartilage	Depresses ala laterally, dilating anterior nasal aperture (i.e., flaring nostrilis, as during anger or exertion)
Orbicularis oris (oral sphincter)[4]	Medial maxilla and mandible; deep surface of peri-oral skin; angle of mouth (modiolus)	Mucous membrane of lips	Tonus closes oral fissure; phasic contraction compresses and protrudes lips (kissing) or resists distension (when blowing)
Levator labii superioris[4]	Infra-orbital margin (maxilla)	Skin of upper lip	Part of dilators of mouth; retract (elevate) and/or evert upper lip; deepen nasolabial sulcus (showing sadness)
Zygomaticus minor[4]	Anterior aspect, zygomatic bone		
Buccinator (cheek muscle)[4]	Mandible, alveolar processes of maxilla and mandible, pterygoman-dibular raphe	Angle of mouth (modiolus); orbicularis oris	Presses cheek against molar teeth; works with tongue to keep food between occlusal surfaces and out of oral vestibule; resists distension (when blowing)
Zygomaricus major[4]	Lateral aspect of zygomatic bone	Angle of mouth (modiolus)	Part of dilators of mouth; elevate labial commissure—bilaterally to smile (happiness); unilaterally to sneer (disdain)
Levator anguli oris[4]	Infra-orbital maxilla (canine fossa)		Part of dilators of mouth; widens oral fissure, as when grinning or grimacing
Risorius[4]	Parotid fascia and buccal skin (highly variable)		Part of dilators of mouth; depresses labial commissure bilaterally to frown (sadness)
Depressor anguli oris[5]	Anterolateral base of mandible		
Depressor labii inferioris[5]	Platysma and anterolateral body of mandible	Skin of lower lip	Part of dilators of mouth; retracts (depresses) and/or everts lower lip (pouting, sadness)
Mentalis[5]	Body of mandible anterior to roots of inferior incisors	Skin of chin (mentolabial sulcus)	Elevates and protrudes lower lip; elevates skin of chin (showing doubt)
Platysma[6]	Subcutaneous tissue of infraclavicular and supraclavicular regions	Base of mandible; skin of cheek and lower lip; angle of mouth (modiolus); orbicularis oris	Depresses mandible (against resistance); tenses skin of inferior face and neck (conveying tension and stress)

[a]All facial muscles are innervated by the facial nerve (CN VII) via its posterior auricular branch (1) or via the temporal (2), zygomatic (3), buccal (4), marginal mandibular (5), or cervical (6) branches of the parotid plexus.

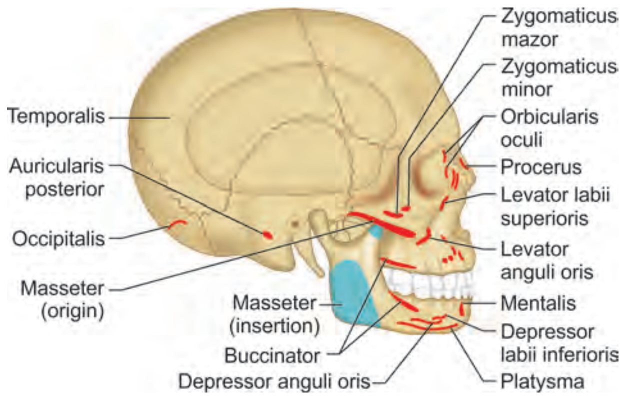


Fig. 109: Muscles of facial expression (Origin).

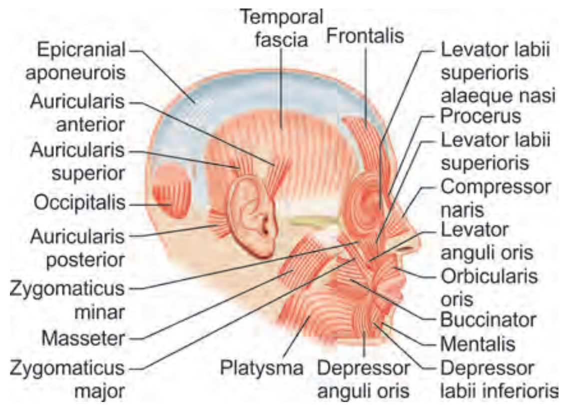


Fig. 110: Muscles of facial expression.

High Yield Points

- Risorius is a muscle of facial expression, to produce a smile, albeit an insincere-looking one that does not involve the skin around the eyes. *(NEET Pattern 2012)*.
- Palpebral part orbicularis oculi closes eyelids as in blinking or winking. *(NEET Pattern 2013)*.

Arteries

- Facial artery arises from the external carotid artery just superior to the lingual artery (above the upper border of the hyoid bone).
  - It ascends forward, deep to the posterior belly of the digastric and stylohyoid muscles, passes deep to the mandible, winds around the lower border of the mandible, reaches the anterior margin of the masseter and runs upward and forward on the face.
  - It gives the ascending palatine, tonsillar, glandular, and submental branches in the neck and the inferior labial, superior labial, and lateral nasal branches in the face.
  - Facial artery terminates as an angular artery that anastomoses with the palpebral and dorsal nasal branches of the ophthalmic artery to establish communication between the external and internal carotid arteries.
- Pulse: Facial artery can be palpated as it crosses the lower mandibular border immediately anterior to masseter border and on the face approximately 1 cm lateral to the angle of the mouth.

Superficial arteries of face and scalp

Artery	Origin	Course	Distribution
Facial	External carotid artery	Ascends deep to submandibular gland; winds around inferior border of mandible and enter face	Muscles of facial expression and face
Inferior labial	Facial artery near angle of mouth	Runs medially in lower lip	Lower lip
Superior labial		Runs medially in upper lip	Upper lip and ala (side) and septum of nose
Lateral nasal	Facial artery as it ascends along side nose	Passes to ala of nose	Skin on ala and dorsum of nose
Angular	Terminal branch of facial artery	Passes to medial angle (canthus) of eye	Superior part of cheek and inferior eyelid
Occipital	External carotid artery	Passes medial to posterior belly of digastric and mastoid process; accompanies occipital nerve in occipital region	Scalp of back of head, as far as vertex
Posterior auricular	External carotid artery	Passes posteriorly, deep to parotid gland, along styloid process between mastoid process and ear	Auricle of ear and scalp posterior to auricle
Superficial temporal	Smaller terminal branch of external carotid artery	Ascends anterior to ear to region and ends in scalp	Facial muscles and skin of temporal frontal and temporal regions
Artery	**Origin**	**Course**	**Distribution**
Transverse facial	Superficial temporal artery within parotid gland	Crosses face superficial to masseter and inferior to zygomatic arch	Parotid gland and duct, muscles and skin of face
Mental	Terminal branch of inferior alveolar artery	Emerges from mental foramen and passes to chin	Facial muscles and skin of chin
Supra-orbital[a]	Terminal branch of ophthalmic artery	Passes superiorly from supraorbial foramen	Muscles and skin of forehead and scalp and superior conjunctiva
Supratrochlear[a]		Passes superiorly from supratrochlear notch	

[a]Source is internal carotid artery.

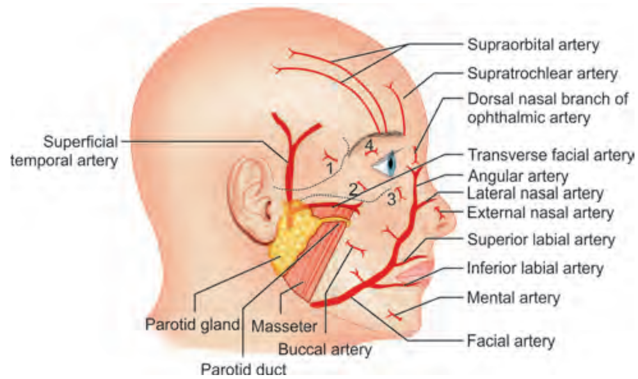


Fig. 111: Arterial supply of the face (1 = zygomaticotemporal, 2 = zygomaticofacial, 3 = infraorbital, 4 = palpebral branch of lacrimal artery)

Veins

Lymphatic Drainage

- Face has three lymphatic territories:
- **Upper** territory includes greater part of the forehead, lateral halves of the eyelids including conjunctiva, parotid area, and adjoining part of the cheek and drain into preauricular (superficial parotid) lymph nodes.
- **Middle** territory includes central part of the forehead, medial halves of the eyelids, external nose, upper lip, lateral part of lower lip, medial part of cheek, and greater part of the lower jaw and drain into submandibular lymph nodes.
- **Lower** territory includes central part of the lower lip and chin and drain into submental lymph nodes.

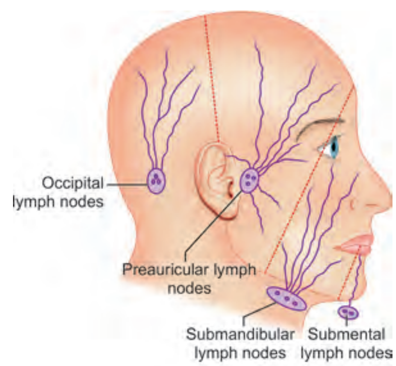


Fig. 112: Lymphatic drainage of the scalp and face

Nerves

- Dermatomes of the face arise mainly from cutaneous branches of the three major divisions of the trigeminal nerve.
- The skin covering the front and sides of the neck, and over the angle of the mandible, and over the lateral scalp and posterior aspect of the pinna is supplied by branches of the cervical plexus (C2–C4), and the skin over the back of the head is supplied by the greater occipital nerve (C2, posterior primary ramus).

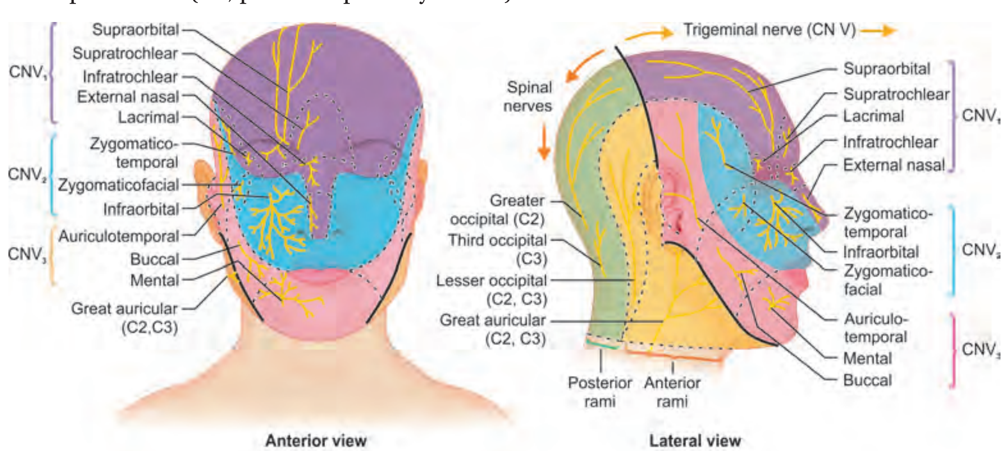


Fig. 113: Cutaneous nerve of face and scalp

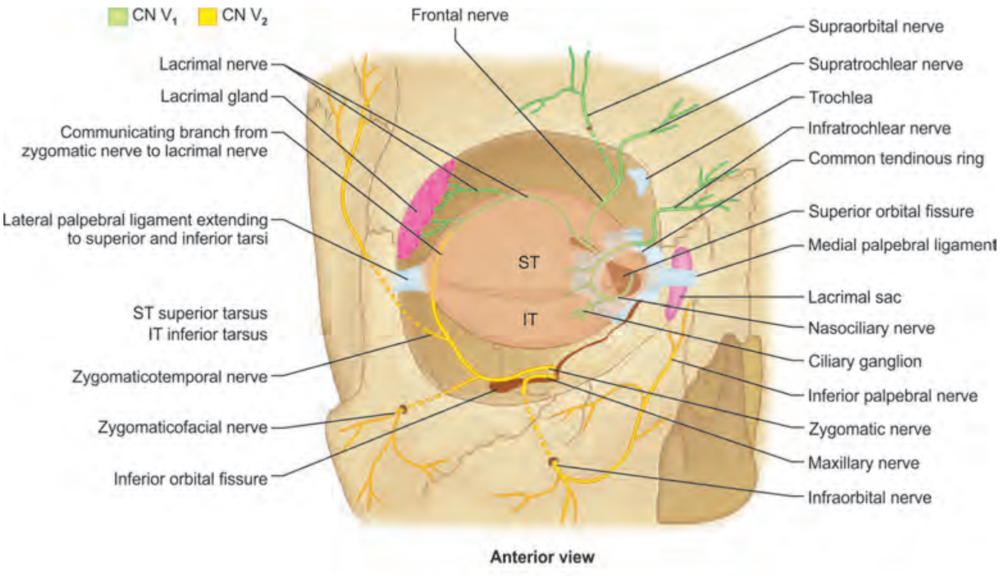


Fig. 114: Cutaneous nerves of orbital/peri-orbital region. Cutaneous nerves are shown in relation to the orbital walls and rim and the fibrous skeleton of the eyelids. The skin of the superior eyelid is supplied by branches of the ophthalmic nerve (CN V_1), whereas the inferior eyelid is supplied mainly by branches of the maxillary nerve (CN V_2).

Cutaneous nerves of face and scalp

Nerve	Origin	Course	Distribution
Zygomaticotemporal	Larger terminal branch (with zygomaticofacial nerve) of zygomatic nerve	Sends communicating branch to lacrimal nerve in orbit; then passes to temporal fossa via zygomaticotemporal canal in zygomatic bone	Hairless skin anterior part of temporal fossa
Cutaneous nerves derived from mandibular nerve (CN V_3)			
Auriculotemporal	In infratemporal fossa via two roots from posterior trunk of CN V_3 that encricle middle meningeal artery	Passes posteriorly deep to ramus of mandible and superior deep part of parotid gland, emerging posterior to temporomandibular joint	Skin anterior to auricle and posterior two thirds of temporal region; skin of tragus and adjacent helix of auricle; skin of roof of external acoustic meatus; and skin of superior tympanic membrane
Buccal	In infratemporal fossa as sensory branch of anterior trunk of CN V_3	Passes between two parts of lateral pterygoid muscle, emerging anteriorly from cover of ramus of mandible and masseter, uniting with buccal branches of facial nerve	Skin and oral mucosa of cheek (overlying and deep to anterior part of buccinator); buccal gingivae (gums) adjacent to second and third molars
Mental	Terminal branch of inferior alveolar nerve (CN V_3)	Emerges from mandibular canal via mental foramen in anterolateral aspect of body of mandible	Skin of chin and skin; oral mucosa of inferior lip
Cutaneous nerves derived from anterior rami of cervical spinal nerves			
Great auricular	Spinal nerves C2 and C3 via cervical plexus	Ascends vertically across sternocleidomastoid, posterior to external jugular vein	Skin overlying angle of mandible and inferior lobe of auricle; parotid sheath
Lesser occipital		Follows posterior border of sternocleidomastoid; then ascends posterior to auricle	Scalp posterior to aruicle
Cutaneous nerves derived from posterior rami of cervical spinal nerves			
Greater occipital nerve	As medial branch of posterior ramus of spinal nerve C2	Emerges between axis and obliquus capitis inferior; then pierces trapezius	Scalp of occipital region
Third occipital nerve	As lateral branch of posterior ramus of spinal nerve C3	Pierces trapezius	Scalp of lower occipital and suboccipital regions

ASSESSMENT QUESTIONS

1. **Which of the following is NOT a branch of facial artery:** *(NEET Pattern 2014)*
   a. Superior labial
   b. Inferior labial
   c. Lateral nasal
   d. Sublingual

2. **Which artery is palpated at the anterior border of masseter?** *(NEET Pattern 2012)*
   a. Superficial temporal
   b. Occipital
   c. Facial
   d. External carotid

3. **A patient has loss of sensation at angle of jaw and parotid area. Which of the following nerve is most likely to be injured?**
   a. Mandibular nerve
   b. Auriculotemporal nerve
   c. Lesser occipital nerve
   d. Greater auricular nerve

4. **Nerve supply of tip of nose:** *(NEET Pattern 2013)*
   a. External nasal branch of ophthalmic nerve
   b. Inferior orbital nerve
   c. Buccal branch of mandibular nerve
   d. Orbital branch of maxillary nerve

5. **All the muscles of the face are supplied by facial nerve EXCEPT:** *(JIPMER)*
   a. Levator anguli oris
   b. Corrugator supercilli
   c. Levator palpebrae superioris
   d. Risorius

6. **Tissue expander in scalp is placed between:** *(NEET Pattern 2016)*
   a. Skin and galea aponeurotica
   b. Subcutaneous tissue and loose areolar connective tissue
   c. Aponeurosis and periosteum
   d. Areolar tissue and bone

7. **Nerve supply to platysma is**
   a. Ansa cervicalis
   b. Cervical branch of facial nerve
   c. Marginal mandibular branch of facial nerve
   d. Mandibular nerve

8. **Nerve supply of scalp:** *(PGIC)*
   a. Auriculotemporal nerve
   b. Zygomatic nerve
   c. Occipital nerve
   d. Supratrochlear nerve
   e. Infratrochlear nerve

9. **The lymphatic drainage in central part of the lip is:**
   a. Sub mandibular
   b. Sub mental nodes
   c. Deep cervical nodes
   d. Jugulodigastric nodes

ANSWERS WITH EXPLANATIONS

1. **d. Sublingual**
   - Sublingual artery is a branch of lingual artery.

2. **c. Facial**
   - The pulsations of facial artery can be felt at two sites, at the base of the mandible close to anteroinferior angle of the masseter; about 1.25 cm lateral to the angle of the mouth.

3. **d. Greater auricular nerve**
   - The skin at the angle of mandible and parotid area is innervated by the greater auricular nerve.

4. **a. External nasal branch of ophthalmic nerve**
   - Tip of the nose is under the ophthalmic nerve territory, supplied by the external nasal branch.

5. **c. Levator palpebrae superioris**
   - Facial nerve supplies muscles of facial expression, levator palpebrae superioris is for elevation of upper eyelid having dual nerve supply: Major (skeletal) part supplied by occulomotor nerve and the smooth muscle part is supplied by the T1 sympathetic fibres.

6. **c. Aponeurosis and periosteum**
   - The plane of dissection/insertion is usually the natural relatively avascular plane beneath the subcutaneous tissue (and over the muscle fascia. in most parts of the body).
   - However, in the scalp and forehead, the tissue expander is placed in the subgaleal plane to minimize bleeding.
   - Tissue expansion has been used on the scalp for treating scalp scarring, in lieu of hair transplantation when there is insufficient donor hair to transplant on the scar or the scar tissue is not vascularized to support hair growth.
   - For example, in a patient who had melanomas removed from the scalp resulting in hair loss, tissue expansion can be used to allow for the removal of scars and complete hair coverage.

   Note: The layer of loose areolar connective tissue beneath the aponeurotic layer accounts for the free mobility of the scalp proper on the underlying bone. It also provides an easy plane of cleavage.

7. b. Cervical branch of facial nerve
- Platysma develops in second pharyngeal arch and is supplied by facial nerve (cervical branch).

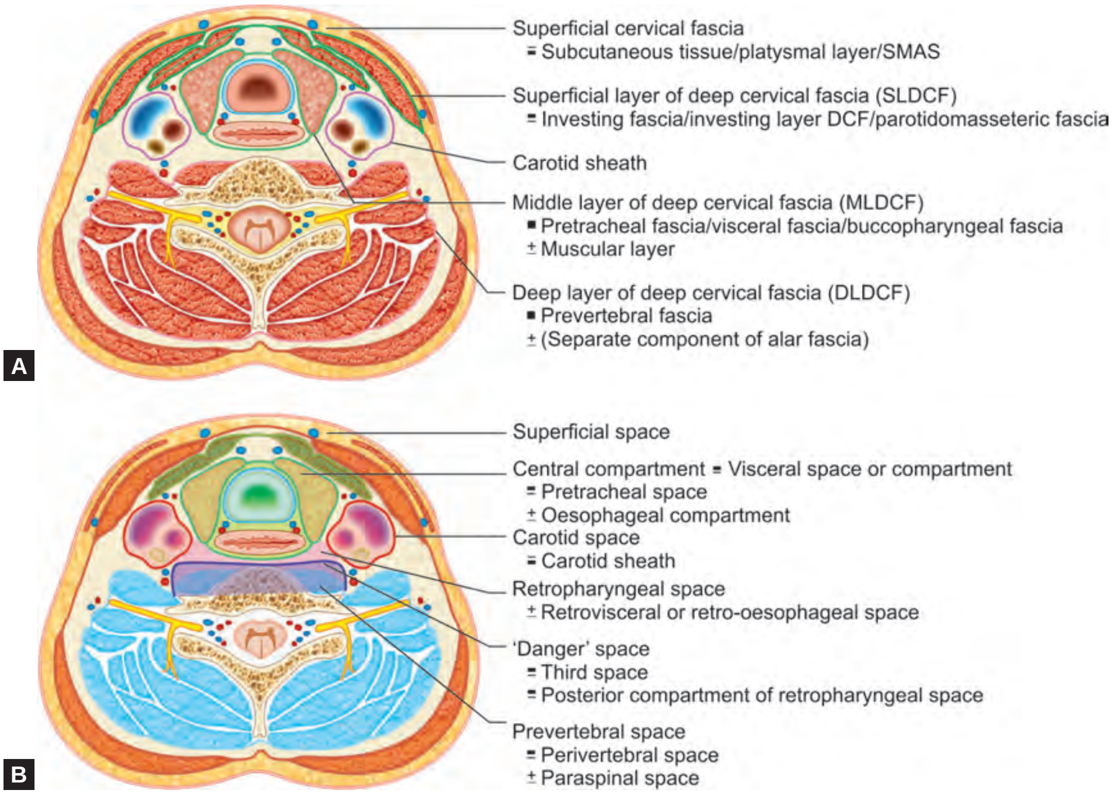
8. a. Auriculotemporal nerve; b. Zygomatic nerve; c. Occipital nerve; d. Supratrochlear nerve
- Infratrochlear nerve do not supply the region of scalp.

9. b. Sub mental nodes
- Central part of the lower lip and chin and drain into submental lymph nodes.

Neck Fascia and Spaces

Deep Cervical Fascia

- Deep cervical fascia formxs a. Investing layer, b. Pretracheal layer and c. Prevertebral layer.
- Superficial (Investing) Layer of Deep Cervical Fascia encircles the neck and splits to enclose the sternocleidomastoid and trapezius muscles and is at the roof of posterior triangle.
  - It is attached superiorly along the mandible, mastoid process, external occipital protuberance, and superior nuchal line of the occipital bone.
  - Inferiorly it is attached along the acromion and spine of the scapula, clavicle, and manubrium sterni.
- Pretracheal Layer of Deep Cervical Fascia invests the larynx and trachea, encloses the thyroid gland, is continuous with the buccopharyngeal facia, and contributes to the formation of the carotid sheath.
  - It attaches superiorly to the thyroid and cricoid cartilages and inferiorly to the pericardium.
  - A thyroid mass usually moves with swallowing because the thyroid gland is enclosed by pretracheal fascia.
- Prevertebral Layer of Deep Cervical Fascia is cylindrical and encloses the vertebral column and its associated muscles.
  - It is attached to the external occipital protuberance and the basilar part of the occipital bone and becomes continuous with the endothoracic fascia and the anterior longitudinal ligament of the bodies of the vertebrae in the thorax.
  - It lies behind the pharynx and esophagus, envelops the phrenic nerve, scalene muscles, cervical primary rami, cervical sympathetic chain, and subclavian and vertebral arteries.
  - It lies at the floor of posterior triangle and extends laterally over the first rib into the axilla to form axillary sheath enveloping the divisions and cords of the brachial plexus with the axillary artery.
  - Subclavian/Axillary veins lie outside the axillary sheath and therefore can distend freely.



Figs. 115A and B: (A) The layers of cervical fascia. Abbreviation: SMAS, superficial musculo-aponeurotic system. (B) The deep 'spaces' in the neck. (A and B) Infrahyoid transverse section of the neck.

Source: Adapted from McMinn RMH, Last's Anatomy. Redrawn with permission from Guidera AK, Dawes PJD, Stringer MD 2012 Cervical fascia: a terminological pain in the neck. ANZ Surg 82:786-791)

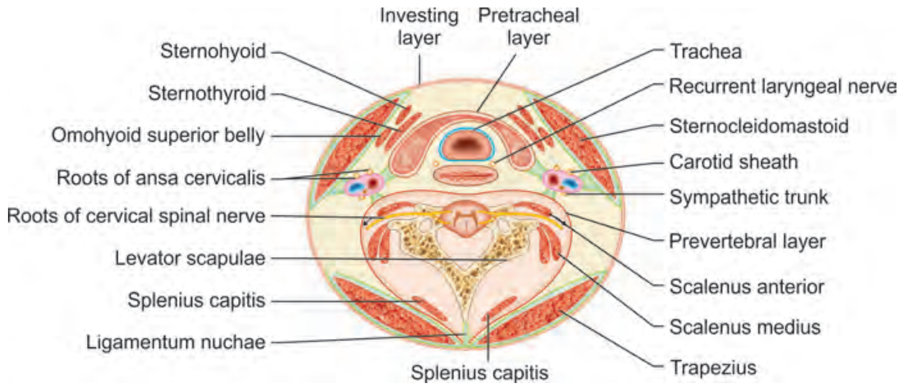
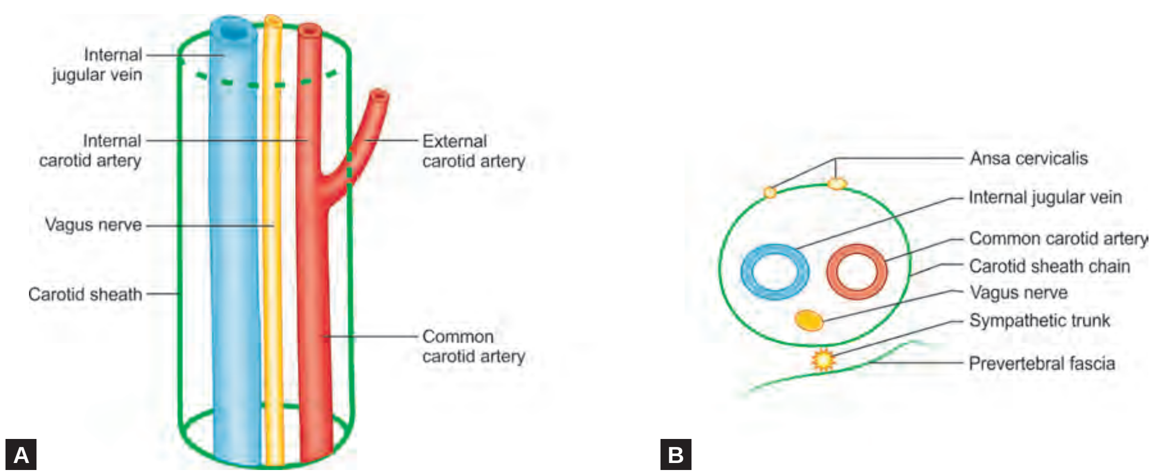


Fig. 116: Diagrammatic transverse section through neck at the level of the 6th cervical vertebra to show the horizontal disposition of the three layers of deep cervical fascia

- It is said to have two layers: Alar fascia (anterior part) and Proper prevertebral fascia (posterior part). Danger space is a potential space lying between the two.
- Carotid Sheath has contributions from all three layers of deep cervical fascia: Prevertebral, pretracheal, and investing layers and is attached to the base of the skull superiorly.
- The four major structures contained in the carotid sheath are: Common carotid artery (as well as the internal carotid artery more superiorly), internal jugular vein, vagus nerve (CN X) and the deep cervical lymph nodes.
  - The carotid artery lies medial to the internal jugular vein, and the vagus nerve is situated posteriorly between the two vessels.
  - In the upper part, the carotid sheath also contains the glossopharyngeal nerve (IX), the accessory nerve (XI), and the hypoglossal nerve (XII), which pierce the fascia of the carotid sheath.
- The ansa cervicalis is embedded in the anterior wall of sheath. It is formed by "descendens hypoglossi" (C1) and "descendens cervicalis" (C2-C3).
- Sympathetic trunk lies posterior to it.



Figs. 117A and B: Carotid sheath: (A) Surface view (B) Sectional view

- Alar Fascia is present between buccopharyngeal and prevertebral fasciae, the two separated by a narrow space, the so-called 'danger space'.
- It forms a sheet across the midline between the transverse processes of the cervical vertebrae and extends outwards to fuse with the carotid sheath.
- In the midline the alar layer is attached to the buccopharyngeal fascia thus dividing the retropharyngeal space into two compartments.
- Above, the alar fascia is attached to the skull base, while inferiorly, usually about the level of C7 vertebra (some authors mention T2 vertebra), it fuses with the visceral fascia.
- It is the posterior border of the retropharyngeal space and separates the retropharyngeal space from the 'danger space.
- Buccopharyngeal Fascia covers the buccinator muscles and the pharynx and blends with the pretracheal fascia.

- It is attached to the pharyngeal tubercle and the pertygomandibular raphe.
- Pharyngobasilar Fascia is the fibrous coat in the wall of the pharynx and is situated between the mucous membrane and the pharyngeal constrictor muscles.

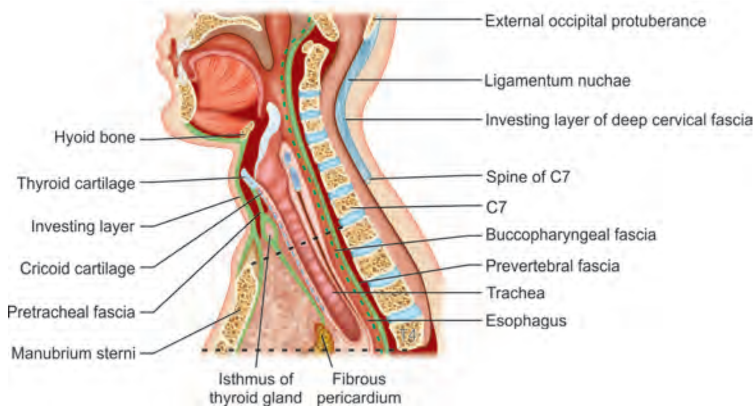


Fig. 118: Vertical extent (disposition) of the three layers of the deep cervical fascia, Buccopharyngeal fascia is also shown. Note the continuity of fascial spaces of the neck into the mediastinum

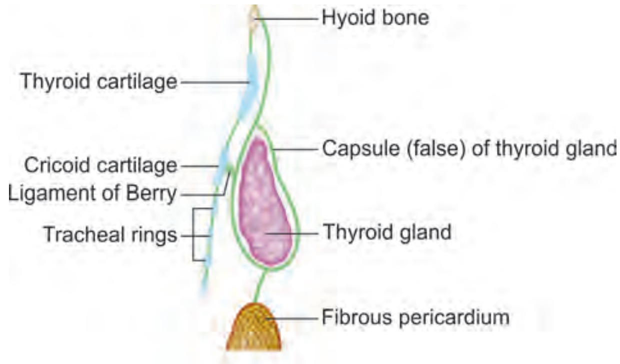


Fig. 119: Vertical disposition of pretracheal fascia enclosing thyroid gland.

Spaces

- Posterior visceral space lies posterior to the pharynx and cervical oesophagus.
- It extends from the skull base down to the superior mediastinum, its caudal limit being the level of fusion between the alar and visceral layers of fascia.
- The posterior visceral space is often referred to as the retropharyngeal space in the upper neck.
  - Retropharyngeal Space is present between the buccopharyngeal fascia (anterior) and prevertebral fascia (posterior), extending from the base of the skull into the posterior mediastinum.
  - Neck infections in front of PVF in the retropharyngeal space forms acute retropharyngeal abscess which bulges forward in the paramedian position. This is due to firm midline attachment between the buccopharyngeal fascia and the prevertebral (alar) fascia divides the space into two segments.
  - Laterally the space is sealed by the attachments of both these fascial layers to the carotid sheath.
  - Retropharyngeal abscess or infection may spread from the neck into the posterior mediastinum through the retropharyngeal space.
- Prevertebral space is the potential space lying behind the prevertebral fascia and in front of the vertebral column.
  - It extends from the skull base to the coccyx, and encloses the prevertebral muscles.
  - Almost all of the pathology that affects the prevertebral space arises from either the adjacent vertebrae or their intervertebral discs, or the spinal cord and associated nerve roots and spinal nerves.
- Tuberculosis of the spine may breach the space and form a Pott's abscess.
  - Danger space lies between the anterior (alar part) and posterior layers of prevertebral fascia.
  - It extends from the skull base down to the posterior mediastinum, where the alar, visceral and prevertebral layers of deep cervical fascia fuse.
  - The potential space so created is closed superiorly, inferiorly and laterally; infections can only enter by penetrating its walls.

- ➢ The danger space is so called because its loose areolar tissue offers a potential route for the rapid downward spread of infection, primarily from the retropharyngeal, para-pharyngeal or prevertebral spaces, to the posterior mediastinum.
- Carotid space is a layer of loose connective tissue demarcated by adjacent portions of the investing layer of deep cervical fascia, the pretracheal fascia and the prevertebral fascia.
  - ➢ A potential cavity exists within the carotid sheath that permits the spread of infections from the upper neck down into the lower neck and mediastinum.
  - ➢ Infections around the carotid sheath may be restricted because, superiorly (near the hyoid bone) and inferiorly (near the root of the neck), the connective tissues adhere to the vessels.

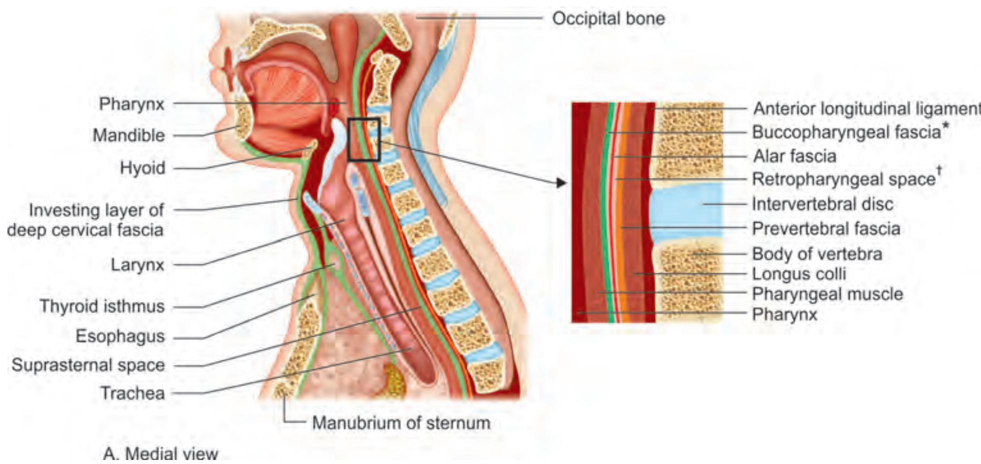


Fig. 120: Retropharyngeal space

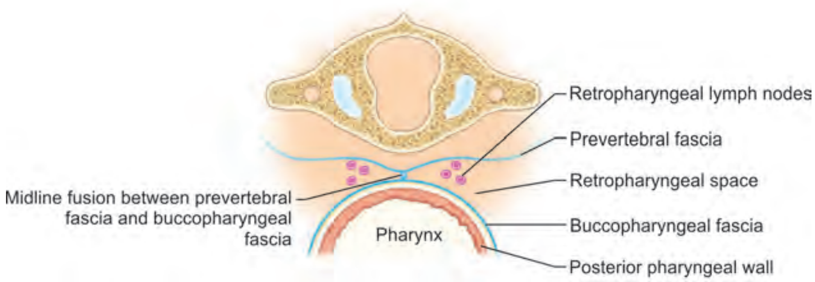


Fig. 121: Retropharyngeal space

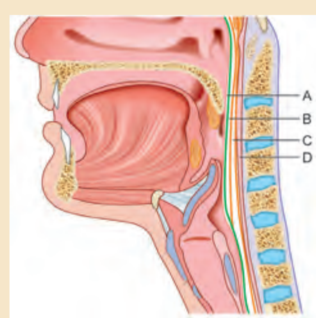
ASSESSMENT QUESTIONS

1. Structure NOT enclosed by carotid sheath: *(JIPMER 2010)*
   a. Internal carotid artery
   b. Vagus
   c. Cervical sympathetic chain
   d. Internal jugular vein

2. Fascia around nerve bundle of brachial plexus is derived from: *(AIIMS 2008; 2011)*
   a. Prevertebral fascia
   b. Deep cervical fascia
   c. Clavipectoral fascia
   d. Pectoral fascia

3. All is true about cervical fascia EXCEPT:
   a. Ligament of Berry fixes thyroid gland to cricoid cartilage
   b. Prevertebral fascia forms the roof of posterior triangle
   c. Ansa cervicalis is embedded in the anterior wall of carotid sheath
   d. Carotid sheath is formed by pretracheal and prevertebral fascia

4. In the given diagram identify the dangerous space: *(AIIMS 2016)*
   a. A
   b. B
   c. C
   d. D



ANSWERS WITH EXPLANATIONS

1. c. Cervical sympathetic chain
- Carotid sheath encloses internal carotid and common carotid artery.
- The cervical sympathetic chain is closely related to posterior wall of the sheath, lying on the prevertebral fascia.

2. a . Prevertebral fascia
- Fascia around the brachial plexus is called as axillary sheath and is a derivative of **pre-vertebral fascia**.
- Prevertebral fascia (PVF) covers the anterior vertebral muscles and lies on the anterior aspect of scalenus muscles, forming the floor of posterior triangle of neck.
- Brachial plexus emerge between scalenus and medius in the neck and pass behind the clavicle along with subclavian artery to reach the axilla.
- In the process they carry an extension of PVF over them as a cover (the axillary sheath) towards the axilla.
- Subclavian/Axillary veins lie outside the axillary sheath and therefore can distend freely.
- Neck infections behind the PVF are usually due to tuberculosis of cervical vertebra and may form **chronic retropharyngeal abscess** – a bulging in the posterior wall of pharynx.
- The pus may track into the axilla via the axillary sheath and point in the posterior/lateral wall of axilla.

3. b. Prevertebral fascia forms the roof of posterior triangle
- Prevertebral fascia forms the floor of posterior triangle, the roof is formed by the investing layer of deep cervical fascia.

4. c. C
- Danger space (marker 'C') is the potential space that lies between the anterior (alar part) and posterior layers of prevertebral fascia (both shown in brown colour).
- This diagram shows the sagittal section of head & neck region, layers of cervical fascia and spaces.
- Prevertebral fascia (shown in brown colour) has two parts: Alar fascia (anterior part) and Proper prevertebral fascia (posterior part). Danger space is a potential space lying between the two.
- Buccopharyngeal (visceral) fascia (shown in green colour) lies behind the pharynx.
- Key: A - Un-named space; B - Retropharyngeal space; C - Danger space; D - Prevertebral space.
- Retropharyngeal Space (marker 'B') is present between the buccopharyngeal fascia (anterior) and prevertebral fascia (posterior).
- Prevertebral space (marker 'D') is the potential space lying behind the prevertebral fascia and in front of the vertebral column.

Neck Triangles

- A quadrilateral area is evident in the neck, limited superiorly by the inferior border of the mandible and a line continued from the angle of the mandible to the mastoid process, inferiorly by the upper border of the clavicle, anteriorly by the anterior median line, and posteriorly by the anterior border of trapezius.
- It is further divided into anterior and posterior triangles by sternocleidomastoid, which passes obliquely from the sternum and clavicle to the mastoid process and occipital bone.
- **Anterior triangle** is further subdivided into the carotid triangle, submandibular triangle, submental triangle, and muscular triangle. The posterior triangle is further subdivided into the occipital triangle and subclavian triangle.

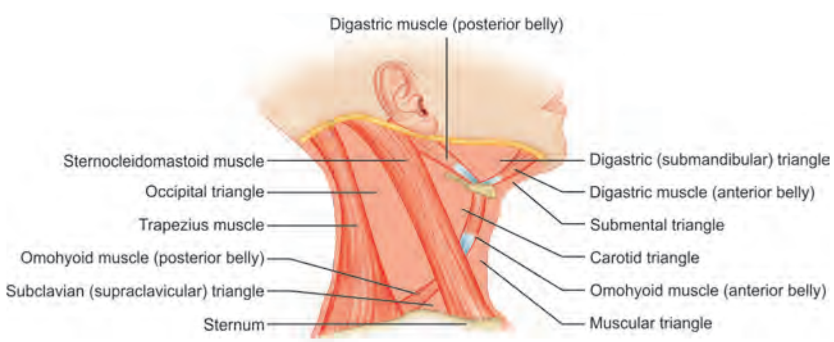


Fig. 122: Triangles of neck (Anterior and Posterior).

- **Posterior Triangle** is bounded by the posterior border of the sternocleidomastoid (SCM) muscle, the anterior border of the trapezius muscle, and the superior border of the clavicle (middle third).
  - Platysma and the investing layer of the deep cervical fascia lies at the roof.
  - The floor formed by prevertebral fascia overlying anterior and lateral groups of prevertebral muscles.
  - It is crossed, approximately 2.5 cm above the clavicle, by the inferior belly of omohyoid, which subdivides it into occipital and supraclavicular triangles.
- **Occipital triangle** is bounded by SCM, trapezius and inferior belly of omohyoid.
  - Its floor, from above down, is formed by semispinalis capitis (occasionally), splenius capitis, levator scapulae, and scaleni medius and posterior.
  - The roof has skin, superficial fascia, platysma and deep fascia.
  - Contents–
- **Subclavian** (supraclavicular, omoclavicular) triangle is bounded by SCM, clavicle and inferior belly of omohyoid.
  - It corresponds to supraclavicular fossa.
  - Its floor contains the first rib, scalenus medius and the first slip of serratus anterior.

- It is covered by skin, superficial and deep fasciae, and platysma, and crossed by the supraclavicular nerves.

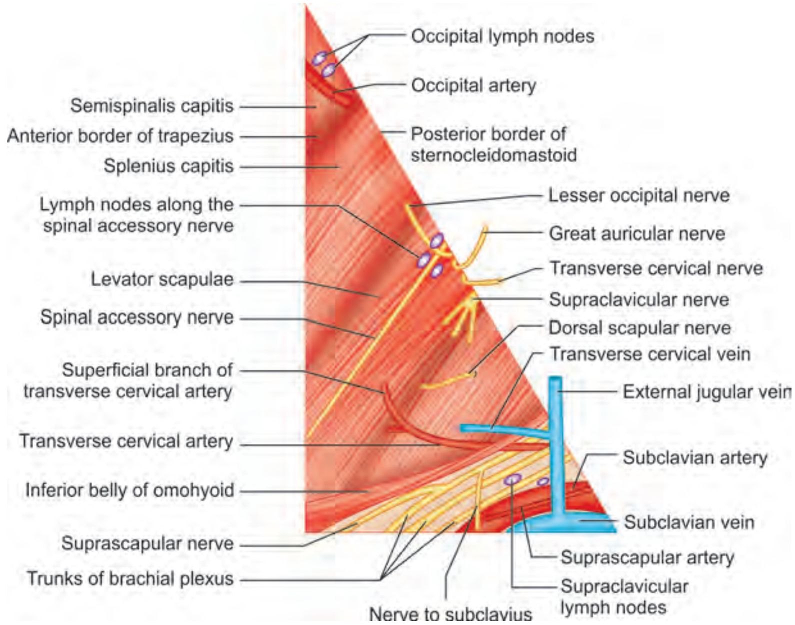
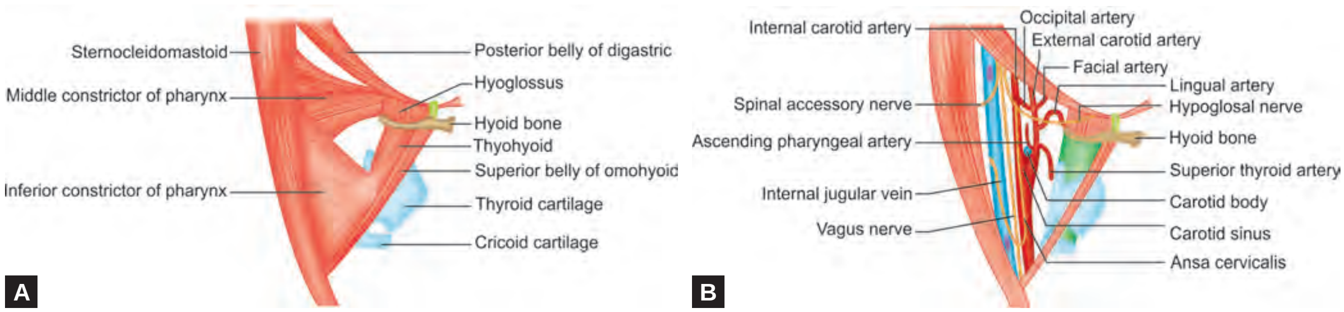


Fig. 123: Schematic diagram showing the floor and contents of the right posterior triangle

Triangle	Main contents and the underlying structures
A. Posterior triangle	
1. Occipital triangle	• Spinal accessory nerve • Dorsal scapular nerve • Cervical plexus (branches) e.g., supraclavicular nerves • Brachial plexus (uppermost part/trunks) • Superficial transverse cervical artery • Occipital artery • External jugular vein (part)
2. Supraclavicular (omoclavicular or subclavian) triangle	• Subclavian artery (3rd part)* • Subclavian vein (occasionally) • Brachial plexus (trunks)** • Nerve to subclavius • Superficial transverse cervical, suprascapular, and dorsal scapular vessels • External jugular vein (terminal part)
B. Anterior triangle	
1. Carotid triangle	• Common carotid artery bifurcation and two branches • Carotid sinus & body (at bifurcation) • Five first branches of external carotid and the corresponding veins • Last three cranial nerves (X, XI, XII) • Internal and external laryngeal nerves (vagus branches) • Carotid sheath (containing common and internal carotid artery, internal jugular vein and vagus nerve) • Ansa cervicalis (embedded on carotid sheath anteriorly) • Cervical sympathetic trunk (posterior to carotid sheath)
2. Submandibular (digastric. Triangle)	• Anterior part • Submandibular salivary gland and lymph nodes • Facial artery (superficial) and vein (deep) to submandibular gland • Hypoglossal nerve • Submental and mylohyoid vessels and nerves (lie on mylohyoid) • Posterior part • External carotid artery • Carotid sheath and its contents • Structures passing between the external and internal carotid arteries*** • Parotid gland (lower part)
3. Submental triangle	• Submental lymph nodes • Small veins that unite to form the anterior jugular vein
4. Muscular triangle	• Strap (ribbon) muscles: sternothyroid, sternohyoid, thyrohyoid • Thyroid gland, trachea, and esophagus (deep level)

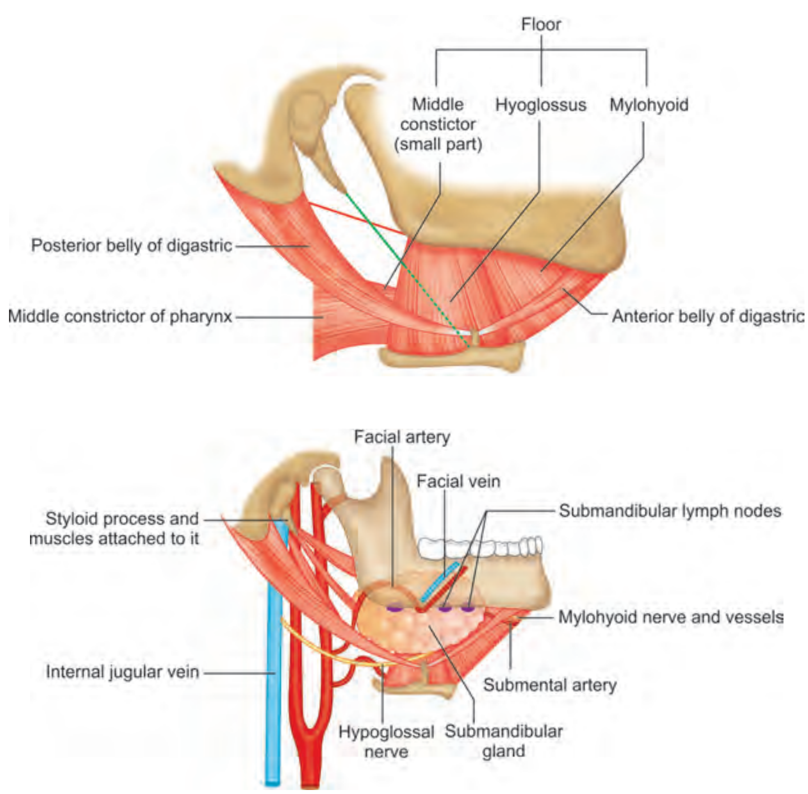
Triangle	Main contents and the underlying structures
*Subclavian artery (3rd part) can be blocked on first rib in supraclavicular triangle. **Brachial plexus can be blocked in the scalene triangle between scalenus anterior and medius. ***Internal carotid artery, internal jugular vein and vagus nerve lie deeper and are separated from the external carotid artery by styloglossus, stylopharyngeus and the glossopharyngeal nerve.	

- **Anterior triangle** is bounded anteriorly by the median line of the neck and posteriorly by the anterior margin of sternocleidomastoid.
  - At the base is the inferior border of the mandible and its projection to the mastoid process, and its apex is at the manubrium sterni.
  - It is subdivided by the anterior and posterior bellies of digastric anterior and anterior (superior) belly of the omohyoid into the submandibular, carotid, muscular, and submental triangles.
- **Carotid triangle** is bounded posteriorly by sternocleidomastoid, anteroinferiorly by the superior belly of omohyoid and superiorly by stylohyoid and the posterior belly of digastric.
  - At floor are seen parts of thyrohyoid, hyoglossus and inferior and middle pharyngeal constrictor muscles.



Figs. 124A and B: Carotid triangle: (A) Boundaries and floor; (B) boundaries and contents

- **Digastric triangle** is bordered superiorly by the lower border of the mandible and its projection to the mastoid process, posteroinferiorly by the posterior belly of digastric and by stylohyoid, and anteroinferiorly by the anterior belly of digastric.
  - It is covered by the skin, superficial fascia, platysma and deep fascia, which contain branches of the facial and transverse cutaneous cervical nerves.
  - Its floor is formed by mylohyoid and hyoglossus.



Figs. 125A and B: Digastric (submandibular) triangle: (A) Boundaries and floor; (B) boundaries and contents

- **Submental triangle** is single, demarcated by the anterior bellies of both digastric muscles.
  - Its apex is at the chin, its base is the body of the hyoid bone.
  - The floor is formed by both mylohyoid muscles.
- **Muscular triangle** is limited anteriorly by the midline of neck from the hyoid bone to the sternum, posteroinferiorly by anterior margin of sternocleidomastoid and posterosuperiorly by the superior belly of omohyoid.

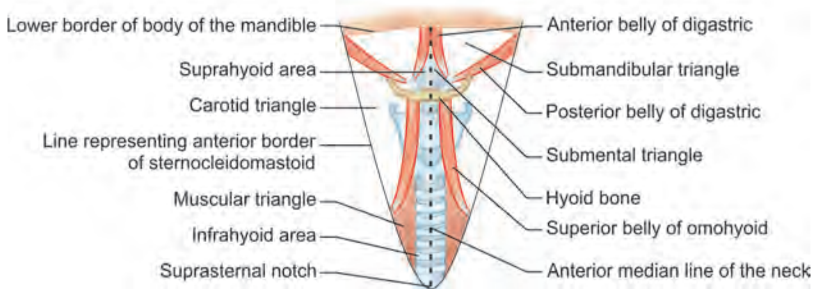


Fig. 126: Schematic diagram of anterior median region of the neck showing suprahyoid and infrahyoid area

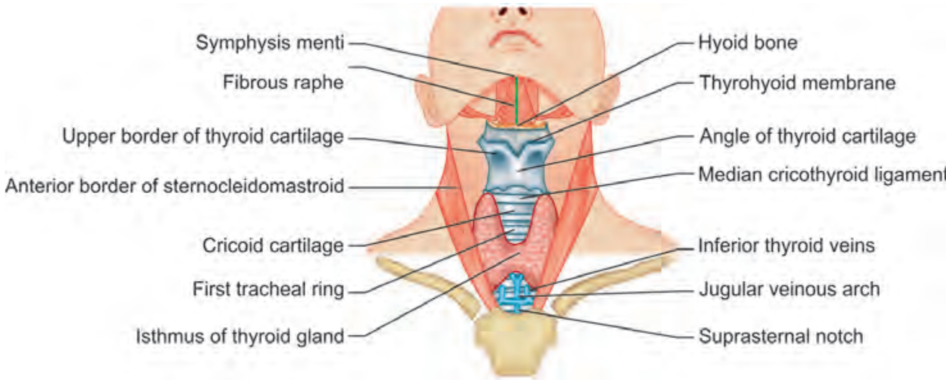


Fig. 127: Structures in the anterior median line of the neck

Clinical Correlations

- **Internal jugular vein catheterization**. The most commonly used approach is on the right side, above the level of the thyroid cartilage (C5) (high approach) and medial to the sternocleidomastoid muscle within the carotid triangle.
- **Brachial plexus nerve block**. The needle is inserted at vertebral level C6 into the interscalene groove (between the anterior and middle scalene muscles) using the cricoid cartilage (C6) and sternocleidomastoid muscle as landmarks.
- **Stellate ganglion block** is performed under fluoroscopy by inserting the needle at the level of the C6 vertebra to avoid piercing the pleura, although the ganglion lies at the level of the C7 vertebra.
  - The needle of the anesthetic syringe is inserted between the trachea medially and the sternocleidomastoid muscle and the common carotid artery laterally using the cricoid cartilage (C6) and the transverse process of C6 vertebra (Chassaignac or carotid tubercle) as landmark.
  - It produces a temporary interruption of sympathetic function such as in a patient with excess vasoconstriction in the upper limb.
  - Features similar to Horner syndrome appear post-procedure.

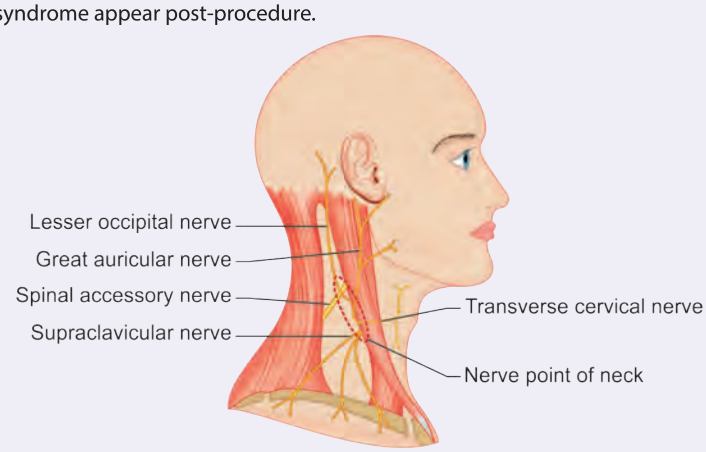


Fig. 128: Cutaneous branches of the cervical plexus. Note the location of 'nerve point of the neck' (dotted red circle)

- In case of haemorrhage, subclavian artery can be blocked against the first rib by applying downward and posterior pressure.
- The artery enter the posterior (occipital) triangle in an area bounded anteriorly by the scalene anterior muscle, posteriorly by the scalene medius, and inferiorly by the first rib.

- **Cervical plexus nerve block**: The needle is inserted at vertebral level C3 along a landmark line connecting the mastoid process to the transverse process of C6 and anesthetic is injected to spread up and down.
- A cervical plexus nerve block is used in superficial surgery on the neck or thyroid gland and for pain management.
- Suboccipital triangle is present on the back of the neck bounded by the following three muscles:
  - Rectus capitis posterior major - above and medially
  - Obliquus capitis superior - above and laterally
  - Obliquus capitis inferior - below and laterally
- Note: Rectus capitis posterior minor is also in this region but does not form part of the triangle.
- The triangle is covered by a layer of dense fibro-fatty tissue, situated beneath the semispinalis capitis.
- The floor of the triangle is formed by the posterior atlanto-occipital membrane, and the posterior arch of the atlas.
- Contents of the suboccipital triangle:
  - Third part of vertebral artery
  - Dorsal ramus of nerve C1- suboccipital nerve
  - Suboccipital venous plexus
- Vertebral artery and the suboccipital nerve lie in the deep groove on the upper surface of the posterior arch of the atlas.

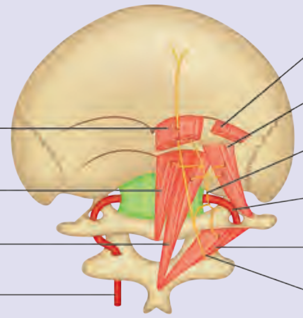


Fig. 129: Boundaries and contents of the suboccipital triangle

ASSESSMENT QUESTIONS

1. All are contents of occipital triangle EXCEPT: *(NEET Pattern 2013)*
   a. Great auricular nerve
   b. Suprascapular nerve
   c. Lesser occipital nerve
   d. Occipital artery

2. On both sides submental triangle is bounded by:
   a. Hyoid bone
   b. Anterior digastric
   c. Posterior digastric
   d. Mylohyoid

3. Structure superficial to mylohyoid in anterior digastric triangle are all EXCEPT:
   a. Deep part of submandibular gland
   b. Hypoglossal nerve
   c. Part of parotid gland
   d. Mylohyoid artery and nerve

4. All of the following are in the anterior triangle of neck EXCEPT: *(PGIC 2010)*
   a. Digastric
   b. Subclavian
   c. Muscular
   d. Submental
   e. Carotid

5. All is true about digastric triangle EXCEPT:
   a. On either side is anterior belly of digastric muscle
   b. Floor is formed by mylohyoid muscle
   c. Floor is formed by hyoglossus muscle
   d. Contains mylohyoid nerve and vessels

6. All the following are contents of sub occipital triangle EXCEPT:
   a. Vertebral artery
   b. Dorsal ramus of CI nerve
   c. Sub occipital plexus of vein
   d. Occipital artery

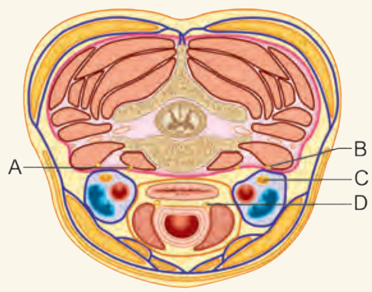
7. If there is a superficial cut in the region of middle part of posterior triangle of neck, patient will experience problem in:
   a. Adduction of arm
   b. Protraction of scapula
   c. Shrugging of shoulder
   d. Overhead abduction of arm

8. A 43-year-old woman came with a large abscess in the middle of the right posterior triangle of the neck. The physician incised and drained the abscess. Five days later the patient noticed that she could not extend her right hand above her head to brush her hair. Which of the following are the signs and symptoms of additional harm *(AIPG 2006)*
   a. Damage to scalenus medius
   b. Injury to suprascapular nerve
   c. Cut to spinal part of accessory nerve
   d. Spread of infection to shoulder joint

9. After surgery on right side of neck, a person could not raise his arm above head and also could not shrug the shoulder. What is the possible cause? *(PGIC 2013)*
a. Damage to spinal accessory nerve
b. Paralysis of trapezius muscle
c. Injury to axillary nerve
d. Paralysis of latissimus dorsi
e. Paralysis of deltoid muscle

10. Chassaignac tubercle lies at level of:
a. Erb's point
b. Stellate ganglion
c. Atlas
d. Odontoid process

11. Identify the vagus nerve in the transverse section of neck: *(AIIMS 2015)*



a. A
b. B
c. C
d. D

12. All of the following are true about Scalenus anterior muscle EXCEPT: *(AIIMS 2010)*
a. It is attached to the scalene tubercle of second rib
b. It is anterior to the transverse cervical artery
c. It is pierced by the phrenic nerve
d. It separates the subclavian vein from the subclavian artery

ANSWERS WITH EXPLANATIONS

1. b. Suprascapular nerve
- Cervical plexus gives branches into the posterior (occipital part) triangle, including supraclavicular nerves.
- Suprascapular nerve is a branch from the upper trunk of brachial plexus and a content of subclavian part of posterior triangle.

2. b. Anterior digastric
- Submental triangle is bounded by anterior belly of digastric (laterally), midline of the neck between the mandible and the hyoid bone (medially) and base of hyoid bone.
- Mylohyoid muscle is at the floor and submental lymph nodes are the content.

3. d. Mylohyoid artery and nerve
- Deep part of submandibular gland and hypoglossal nerve are deep to mylohyoid muscle.
- Structures passing superficial to mylohyoid in anterior part of digastric triangle are submandibular gland (superficial part), facial vein, facial artery, mylohyoid nerve and vessels, hypoglossal nerve and submandibular nodes.

4. b. Subclavian
- Posterior triangle of neck has two parts: Occipital & subclavian.
- Subclavian triangle is also called as supraclavicular or omoclavicular triangle.

5. a. On either side is anterior belly of digastric muscle
- Digastric triangle is bounded by anterior belly of digastric anteriorly and posterior belly posteriorly.
- Mylohyoid and hyoglossus muscles are at the floor.
- Digastric triangle contains mylohyoid nerve and vessels, submandibular gland, facial artery and vein, hypoglossal nerve and submandibular lymph nodes.

6. d. Occipital artery
- Contents of suboccipital triangle are vertebral artery (3rd part), suboccipital nerve (dorsal ramus of C1) and suboccipital venous plexus.
- Occipital artery lies in occipital triangle.

7. c. Shrugging of shoulder > d. Overhead abduction of arm
- Spinal accessory nerve runs superficial in the posterior triangle of neck and prone to iatrogenic injury for e.g., incision and drainage of an abscess.
- The nerve lesion causes paralysis of trapezius muscle leading to difficulty in shrugging the shoulder and overhead abduction.
- Overhead abduction is carried out by serratus anterior and trapezius muscle together.

8. c. Cut to spinal part of accessory nerve
- The physician has damaged the spinal accessory nerve, while performing incision and drainage in the posterior triangle of neck, thus leading to paralysis of trapezius muscle and inability to do overhead abduction at the shoulder joint.
- Injury to suprascapular nerve leads to paralysis of supraspinatus and infraspinatus, resulting in weakness of abduction and lateral rotation at the shoulder joint.
- Scalenus medius also lies in the posterior triangle but is not involved in raising hand over head.
- Spread of infection to shoulder joint might produce difficulty in abduction but the history of the patient is not suggestive of such an etiology here.

9. a. Damage to spinal accessory nerve; b. Paralysis of trapezius muscle
- Spinal accessory nerve is prone to iatrogenic injury in posterior triangle of neck, which leads to paralysis of trapezius muscle and difficulty in shrugging the shoulder.
- There is also weakness of overhead abduction (carried out by serratus anterior and trapezius).

10. a. Erb's point
- Chassaignac or carotid tubercle is a large anterior tubercle of the transverse process of the sixth cervical vertebra. The common carotid artery may be compressed against the tubercle, which sits lateral to the cricoid cartilage. Above this level, the artery is superficial and its pulsation may be readily felt beneath the anterior border of sternocleidomastoid.
- Erb's point is 2 to 3 cm above the clavicle and beyond the posterior border of the sternomastoid, at the level of the transverse process of the sixth cervical vertebra; stimulation here contracts various arm muscles.
- Stellate ganglion is not at the level of Chassaignac tubercle.
- Although the ganglion lies at the level of the C7 vertebra, stellate ganglion block is performed under fluoroscopy by inserting the needle at the level of the C6 vertebra to avoid piercing the pleura. The needle of the anesthetic syringe is inserted between the trachea medially and the sternocleidomastoid muscle and the common carotid artery laterally using the cricoid cartilage (C6) and the transverse process of C6 vertebra (Chassaignac or carotid tubercle) as landmark.

11. c. C
- Vagus nerve (C) lies inside the carotid sheath sandwiched between common carotid artery medially and internal jugular vein laterally.
- A - Sympathetic trunk lies postero-medial to the carotid sheath in the carotid triangle of neck. Stellate ganglion block is done here.
- B - Phrenic nerve, lies anterior to scalenus anterior muscle, covered by pre-vertebral fascia, in the posterior triangle of neck.
- D - Recurrent laryngeal nerve, branch of vagus running in the tracheo-oesophageal groove.

12. a. It is attached to the scalene tubercle of second rib
- Scalenus anterior (and scalenus medius) both attach to first rib (and 'not' second).
- Phrenic descends anterior of the muscle from the lateral to the medial side (but nerve fibres may pierce the muscle occasionally).
- Scalenus anterior muscle is sandwiched between subclavian artery from subclavian vein, and separates the two vessels. (But as a variation, the muscle may be present posterior to the artery sometime).
- Transverse cervical artery passes anterior to the scalenus anterior muscle (may be found running posterior as a variation). Scalenus anterior muscle is considered to be an important surgical landmark in the neck region.
- Relations: Anterior – Phrenic nerve, Subclavian vein, Carotid sheath, Transverse cervical artery and suprascapular artery, Pre-vertebral fascia, Clavicle; Posterior – Subclavian artery, Pleura, Roots of brachial plexus; Lateral – Brachial plexus

High Yield Points

- The posterior belly of the digastric and stylohyoid muscles are innervated by the facial nerve, whereas the anterior belly of the digastric and mylohyoid muscles are innervated by the trigeminal nerve.
- The geniohyoid and thyrohyoid muscles are innervated by C1 through the hypoglossal nerve.

Oral Cavity

- Oral cavity has two parts: Oral vestibule and the oral cavity proper.
- **Oral Vestibule** is bounded by lips and cheeks externally and teeth and gums internally and receives opening of parotid duct at the parotid papilla opposite second maxillary molar.
- **Oral Cavity Proper** is bounded anteriorly and laterally by teeth and gums; its roof is formed by the palate, and its floor is formed by the tongue and the mucosa, supported by the geniohyoid and mylohyoid muscles.
- It communicates posteriorly with the oropharynx.

Tongue

- Tongue is attached by muscles to the hyoid bone, mandible, styloid process, palate, and pharynx.
- It has a V-shaped sulcus terminalis which divides it into anterior two-thirds and a posterior one-third, which differ developmentally, hence structurally, and innervation-wise.
- **Foramen cecum** is located at the apex of the V and indicates the embryologic site of origin of the embryonic thyroglossal duct.
- **Lingual Papillae** are small, nipple-shaped projections on the anterior two-thirds of the dorsum of the tongue. They are divided into the circumvallate, fungiform, filiform, and foliate papillae.
- **Circumvallate Papillae** are arranged in the form of a V in front of the sulcus terminalis, are studded with numerous taste buds and are innervated by the glossopharyngeal nerve.
- **Fungiform Papillae** are mushroom-shaped projections with red heads and are scattered on the sides and the apex of the tongue.
- Filiform Papillae are numerous, slender, conical projections that are arranged in rows parallel to the sulcus terminalis.
- Foliate Papillae are rudimentary in humans.
- Lingual Tonsil is the collection of nodular masses of lymphoid follicles on the posterior one-third of the dorsum of the tongue.

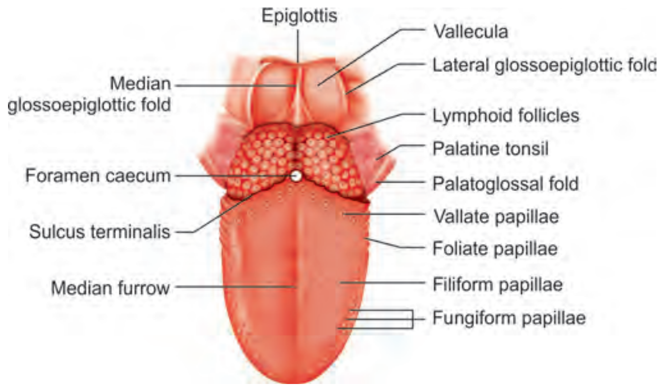
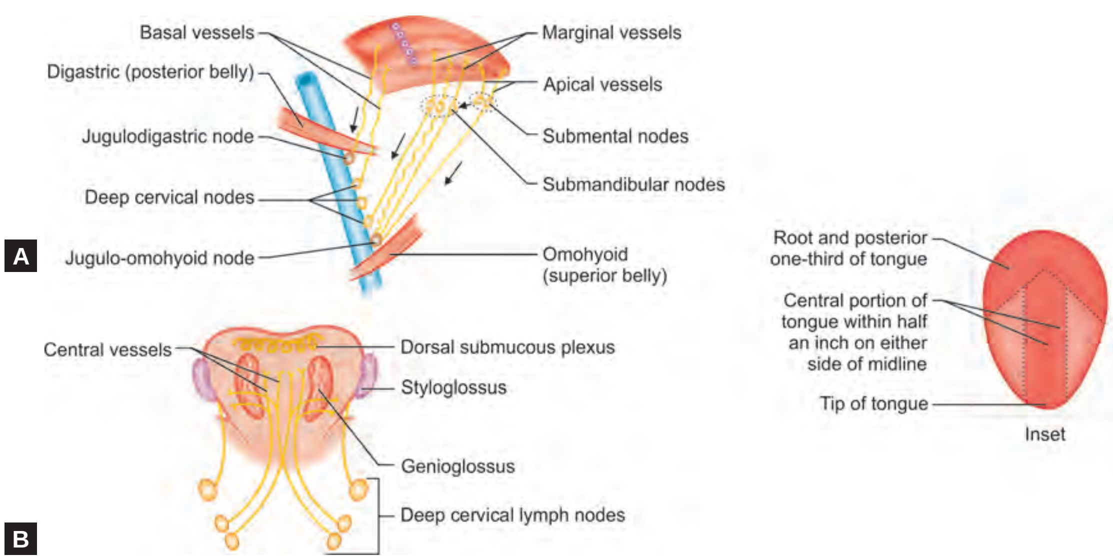


Fig. 130: Features on the dorsal surface of the tongue

- **Arterial supply**: Lingual Artery is an anterior branch of external carotid artery at the level of the tip of the greater horn of the hyoid bone in the carotid triangle.
  - It passes deep to the hyoglossus and lies on the middle pharyngeal constrictor muscle.
  - It gives suprahyoid, dorsal lingual, and sublingual arteries and terminates as the deep lingual artery, which ascends between the genioglossus and inferior longitudinal muscles.
- **Venous Drainage**: **Deep lingual vein** is the principal vein of the tongue, visible on the inferior surface of the tongue near the median plane.
  - **Venae comitantes** accompanying the lingual artery and are joined by dorsal lingual veins and **venae comitantes** accompanying the hypoglossal nerve.
  - These veins unite at the posterior border of the hyoglossus to form the lingual vein, which drains into either common facial vein or internal jugular vein.
- **Lymphatic Drainage**: The lymphatics of tongue are grouped into four groups:
  - **Apical** vessels drain the tip and inferior surface of the tongue into submental lymph nodes after piercing the mylohyoid muscle. Their efferents go to the submandibular nodes mainly, some cross the hyoid bone to reach the jugulo-omohyoid nodes.
  - **Marginal** vessels drain the marginal portions of the anterior two-third of the tongue unilaterally into submandibular lymph nodes and then to the lower deep cervical lymph nodes, including jugulo-omohyoid.
  - **Central** vessels drain the central portion of the anterior two-third of the tongue (i.e., area within 0.5 inch on either side of midline). They pass vertically downwards in the midline of the tongue between the genioglossus muscles and then drain bilaterally into the deep cervical lymph nodes.
  - **Basal** vessels drain the root of the tongue and posterior one-third of the tongue bilaterally into upper deep cervical lymph nodes, including jugulodigastric.



Figs. 131A and B: Lymphatic drainage of the tongue: (A) showing course and direction of apical, marginal, and based lymph vessels; (B) showing course and direction of central lymph vessels. Figure in the inset shows areas (in red) having bilateral lymphatic drainage

- **Nerve supply**; Motor nerve supply to the muscles (extrinsic and intrinsic) of the tongue is hypoglossal nerve (except palatoglossus, which is supplied via the pharyngeal plexus, innervated by the cranial accessory nerve fibres carried by vagal branches).
- Proprioception is carried by the lingual, glossopharyngeal or hypoglossal nerves, and the cervical spinal nerves.
- Sensory supply reflects its embryological development: Anterior two-thirds (presulcal part) is derived from first arch mesenchyme and the posterior third (postsulcal part) from third arch mesenchyme.
- General sensations from the anterior two-thirds of the tongue are carried by the lingual nerve (mandibular, trigeminal) and taste sensation by the chorda tympani (facial nerve).
- Both general sensation and taste sensation from the posterior one-third are carried by glossopharyngeal nerve.
- Posterior most tongue (including valleculae. and the epiglottis receive both general and taste innervation from the internal laryngeal branch of the vagus nerve.

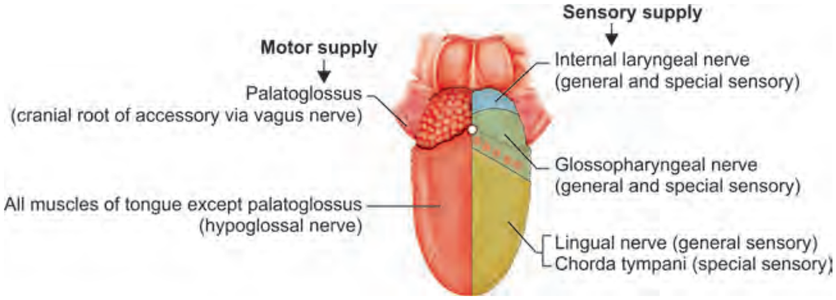


Fig. 132: Neve supply of the tongue. Right half of the figure shows motor supply and left half shows sensory supply

Muscles of tongue

Muscle	Shape and Position	Proximal Attachment	Distal Attachment	Main Action (s)
Extrinsic muscle of tongue[a]				
Genioglossus	Fan-shaped muscle; constitutes bulk of tongue	Via a short tendon from superior part of mental spine of mandible	Entire dorsum of tongue; inferiormost and posteriormost fibers attach to body of hyoid bone	Bilateral activity depresses tongue, especially central part, creating a longitudinal furrow; posterior part pulls tongue anteriorly for protrusion;[a] most anterior part retracts apex of protruded tongue; unilateral contraction deviates ("Wags") tongue to contralateral side
Hyoglossus	Thin, quadrilateral muscle	Body and greater horn of hyoid bone	Inferior aspects of lateral part of tongue	Depresses tongue, especially pulling its sides inferiorly; helps shorten (retrude) tongue
Styloglossus	Small, short triangular muscle	Anterior border of distal styloid process; stylohyoid ligament	Sides of tongue posteriorly, interdigitating with hyoglossus	Retrudes tongue and curls (elevates) its sides, working with genioglossus to form a central trough during swallowing
Palatoglossus[b]	Narrow crescent-shaped palatine muscle; forms posterior column of isthmus of fauces	Palatine aponeurosis of soft palate	Enters posterolateral tongue transversely, blending with intrinsic transverse muscles	Capable of elevating posterior tongue or depressing soft palate; most commonly acts to constrict isthmus of fauces
Intrinsic muscles of tongue[a]				
Superior longitudinal	Thin layer deep to mucous membrane of dorsum	Submucosal fibrous layer and median fibrous septum	Margins of tongue and mucous membrane	Curls tongue longitudinally upward elevating apex and sides of tongue; shortens (retrudes) tongue
Inferior longitudinal	Narrow band close to inferior surface	Root of tongue and body of hyoid bone	Apex of tongue	Curls tongue longitudinally downward, depressing apex; shortens (retrudes) tongue
Transverse	Deep to superior longitudinal muscle	Median fibrous septum	Fibrous tissue at lateral lingual margins	Narrows and elongates (protrudes) tongue[c]
Vertical	Fibers intersect transverse muscle	Submucosal fibrous layer of dorsum of tongue	Inferior surface of borders of tongue	Flattens and broadens tongue[c]

[a]Except for palatoglossus, the muscles of the tongue are innervated by the hypoglossal nerve (CN XII)
[b]Actually a palatine muscle, the palatoglossus is innervated by the vagus nerve (CN X)
[c]Act simultaneously to protrude tongue.

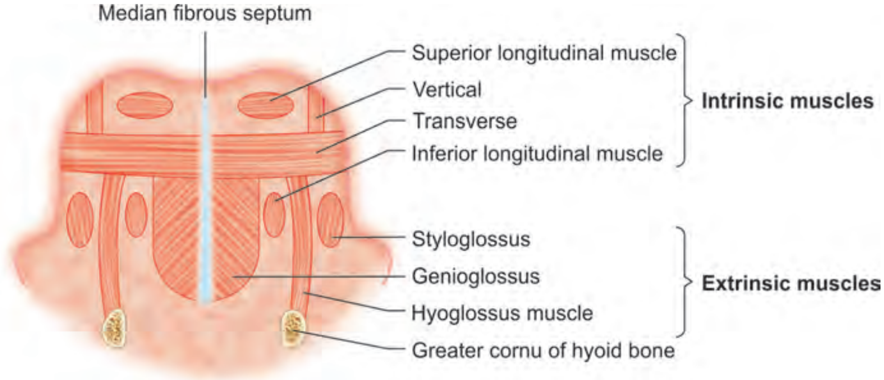


Fig. 133: Coronal section of the tongue showing arrangement of intrinsic and extrinsic muscles of the tongue

Taste Pathway

- NTS (Nucleus Tractus Solitarius) in the medulla receives taste sensation from three nerves: 1. The anterior two-thirds of the tongue via the chorda tympani nerve of the facial nerve (CN VII) 2. The posterior third of the tongue via the glossopharyngeal nerve (CN IX) 3. The posteriormost tongue (and epiglottic region of the pharynx) via the vagus nerve (CN X).
- Cranial nerves (taste) → **nucleus tractus solitarius** → medial lemniscus → VPM thalamus → Genu of internal capsule → Parietal lobe (gustatory cortex - area 43).

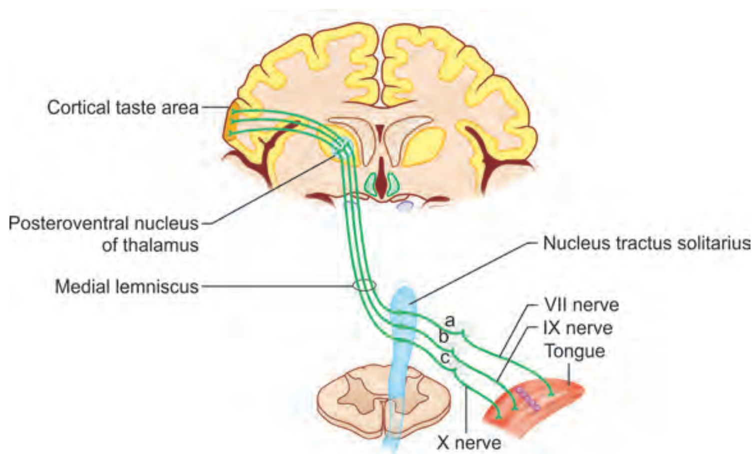


Fig. 134: Taste pathways; a = geniculate ganglion of facial nerve, b = superior ganglion of glossopharyngeal nerve, c = inferior ganglion (ganglion nodosum) of vagus nerve. The taste area is located in the inferior part of the postcentral gyrus (primary sensory cortex). According to Barr and Kiemann the taste (gustatory) area is located in the inferior part of the parietal lobe, posterior to the general sensory area for the mouth in the post-central gyrus

ASSESSMENT QUESTIONS

1. **The taste pathway from circumvallate papillae of the tongue goes through:**
   a. Chorda tympani branch of Facial nerve
   b. Greater petrosal nerve branch of Facial nerve
   c. Superior laryngeal branch of Vagus nerve
   d. Lingual branch of Glossopharyngeal nerve

2. **Protrusion of tongue NOT possible in damage of:** *(NEET Pattern 2015)*
   a. Styloglossus
   b. Hyoglossus
   c. Palatoglossus
   d. Genioglossus

3. **Taste sensations from anterior 2/3rd of tongue are carried by:** *(NEET Pattern 2012)*
   a. Glossopharyngeal
   b. Chorda tympani
   c. Trigeminal
   d. Greater auricular

4. **Tip of tongue drains lymphatics into:** *(JIPMER)*
   a. Occipital lymph node
   b. Submental lymph node
   c. Deep cervical lymph nodes
   d. Tonsiliar lymph nodes

5. **Anterior 2/3rd of the tongue is demarcated by:** *(AIIMS 2016)*
   a. Passavant ridge
   b. Circumvallate papillae
   c. Sulcus terminalis
   d. Filiform papillae

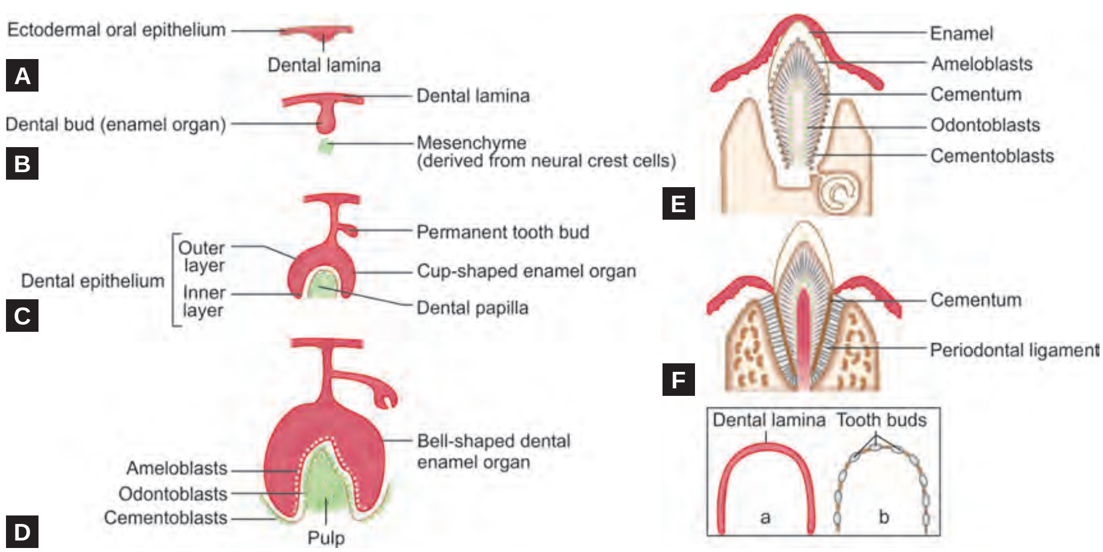
ANSWERS WITH EXPLANATIONS

1. **d. Lingual branch of Glossopharyngeal nerve**
   - SVA (special visceral afferent) fibers for taste sensation from anterior two-thirds of the tongue run in the chorda tympani of the facial nerve, from posterior one-third of the tongue run in the glossopharyngeal nerve, palate is supplied by the facial nerve through its greater petrosal branch which sends fibers into the palatine nerves.
   - Taste sensation from the epiglottis is carried by the internal laryngeal branch of the superior laryngeal nerve (branch of the vagus).
2. **d. Genioglossus**
   - Posterior part of genioglossus pulls tongue anteriorly for protrusion.
   - It is also called safety muscle of tongue as it prevents backward fall of tongue into the oral cavity, especially if the patient is unconscious.
3. **b. Chorda tympani**
   - Taste sensation from anterior 2/3rd of tongue is carried by chorda tympani (branch of facial nerve), towards the facial nerve and geniculate ganglion.
4. **b. Submental lymph node**
   - **Apical** vessels drain the tip and inferior surface of the tongue into **submental lymph nodes** after piercing the mylohyoid muscle.
   - Their efferents go to the submandibular nodes mainly, some cross the hyoid bone to reach the jugulo-omohyoid nodes.
5. **c. Sulcus terminalis**
   - Sulcus terminalis V shape structure which divides the tongue into anterior two-thirds (oral part) and posterior one-third (pharyngeal part).
   - The two parts differ in their developmental origin and accordingly mucosa, innervation and lymphatic drainage as well.

Teeth

Development

- Teeth are derived from neural crest cells and the surface ectoderm.
- Neural crest cells form the odontoblast which forms the dentin of teeth, whereas the surface ectoderm give ameloblasts, which forms the enamel.
- A **dental lamina** develops in the oral epithelium (ectoderm origin) as a downgrowth into the underlying mesenchyme (neural crest origin), and gives rise to the **dental buds**, which develop into a cup-shaped **enamel organ**.
- The **enamel organs** are derived from ectoderm and develop first for the deciduous teeth, next the permanent teeth, and gives rise to the ameloblasts, which form enamel.
- The **dental papillae** are formed by a condensation of neural crest mesenchyme that underlie the enamel organs, and give rise to the odontoblasts (which form dentin) and dental pulp.
- The **dental sacs** are formed by a condensation of neural crest mesenchyme surrounding the dental papillae, and give rise to **cementoblasts** (which form cementum) and the periodontal ligaments.



Figs. 135A to F: Stages in the development of teeth: A, formation of dental lamina; B, development of tooth bud (enamel organ); C, cap-stage; D, bell-stage; E, early tooth eruption; F, fully erupted deciduous tooth. The figures in the inset show formation of dental lamina (a) and tooth buds of all deciduous teeth (b)

- Deciduous (primary) teeth are twenty in number: Two incisors, one canine, and two molars in each quadrant.
- Permanent teeth are thirty two in number: Two incisors, one canine, two premolars, and three molars in each quadrant.

Deciduous teeth

Deciduous teeth	Central incisor	Lateral incisor	Canine	1st Molar	2nd Molar
Eruption (months)[a]	6–8	8–10	16–20	12–16	20–24
Shedding (years)	6–7	7–8	10–12	9–11	10–12

[a]In some normal infants, the first teeth (medial incisors) may not erupt until 12–13 months of age.

Permanent teeth

Permanent teeth	Central incisor	Lateral incisor	Canine	1st Premolar	2nd Premolar	1st Molar	2nd Molar	3rd Molar
Eruption (years)	7–8	8–9	10–12	10–11	11–12	6–7	12	13–25

- Structure: Enamel is the hardest substance (in our body) that covers the crown.
  - Dentin is a hard substance that is nurtured through the fine dental tubules of odontoblasts lining the central pulp space.
  - The pulp fills the central cavity, which is continuous with the root canal. It contains numerous blood vessels, nerves, and lymphatics, which enter the pulp through an apical foramen at the apex of the root.
- Parts of the Teeth: The **Crown** projects above the gingival surface and is covered by enamel, **neck** is the constricted area at the junction of the crown and root, **root**, embedded in the alveolar part of the maxilla or mandible, is covered with cement, which is connected to the bone of the alveolus by a layer of modified periosteum, the periodontal ligament.
- Each maxillary molar generally has three roots, and each mandibular molar has two roots.
- Types of Teeth:
  - Incisors are chisel-shaped teeth used for cutting or biting, have a single root.
  - Canines, have a single prominent cone and a single root, used for tearing.
  - Premolars are used for grinding, have two cusps. The upper first premolar tooth may be bifid, and all others each have a single root.
  - Molars, which usually have three (sometimes three to five) cusps, are used for grinding. The upper molar teeth have three roots, and the lower one has two roots.
- Nerve supply of Teeth and Gums
  - Maxillary Teeth are innervated by the anterior, middle, and posterior, superior alveolar branches of the maxillary nerve. Mandibular Teeth are supplied by the inferior alveolar branch of the mandibular nerve.
  - In maxillary Gingiva the outer (buccal) surface is innervated by posterior, middle, and anterior superior alveolar and infraorbital nerves.
    - Lingual surface is innervated by greater palatine and nasopalatine nerves.
  - In mandibular Gingiva the buccal surface is innervated by buccal and mental nerves.
    - Inner (lingual) surface is innervated by lingual nerves.

Innervation of the teeth and gingivae

Maxilla	Nasopalatine nerve	Greater palatine nerve		Palatal gingivae
	Anterior superior alveolar nerve	Middle superior alveolar nerve	Posterior superior alveolar nerve	Teeth
	Infraorbital nerve	Posterior superior alveolar nerve and buccal nerve		Buccal gingivae
	1 2 3 4	5 6	7 8	Tooth position
	Mental nerve	Buccal nerve and perforating branches of inferior alveolar nerve		Buccal gingivae
Mandible	Incisive nerve	Inferior alveolar nerve		Teeth
	Lingual nerve and perforating branches of inferior alveolar nerve			Lingual gingivae

With permission from Berkovitz BKB, Holland GR, Moxham BJ. 2009. Oral Anatomy, Embryology and Histology, 4th ed. Edinburgh: Mosby.

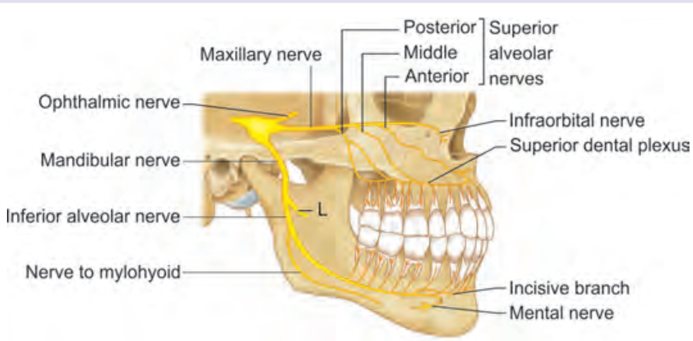


Fig. 136: Nerve supply of the teeth (L = lingual nerve)

ASSESSMENT QUESTIONS

1. Dental papilla give rise in: *(NEET Pattern 2015)*
a. Enamel
b. Dental cuticle
c. Tooth pulp
d. None

2. Neural crest cells give rise to all the dental structures EXCEPT: *(NEET Pattern 2015)*
a. Odontoblasts
b. Dentine
c. Enamel
d. Tooth pulp

3. Middle superior alveolar nerve is a branch of: *(AIPG 2009)*
a. Mandibular nerve
b. Maxillary nerve
c. Lingual nerve
d. Facial nerve

ANSWERS WITH EXPLANATIONS

1. c. Tooth pulp
- The **dental papillae** are formed by a condensation of neural crest mesenchyme that underlie the enamel organs, and give rise to the odontoblasts (which form dentin) and dental pulp.

2. c. Enamel
- Enamel is formed by ameloblast cells developing in surface ectoderm of oral cavity.
- The **dental papillae** are formed by a condensation of neural crest mesenchyme that underlie the enamel organs, and give rise to the odontoblasts (which form dentin) and dental pulp.

3. b. Maxillary nerve
- Middle superior alveolar nerve is a branch of the infraorbital nerve (branch of maxillary nerve), to supply the upper premolars.

Salivary Glands

Development
- Salivary glands develop in the oral epithelium.
- Parotid glands are derived from surface ectoderm lining the oral cavity.
- Submandibular and sublingual glands also develop from surface ectoderm lining the oral cavity, though some authors believe these two glands develop both from ectoderm and endoderm.

Parotid Gland

Parotid gland is the largest of the three salivary glands and occupies the retromandibular space between the ramus of the mandible in front and the mastoid process and the sternocleidomastoid muscle behind.

- It is invested with a dense fibrous capsule, the parotid sheath, derived from the investing layer of the deep cervical fascia.
- It is separated from the submandibular gland by a facial extension and the stylomandibular ligament, which extends from the styloid process to the angle of the mandible. (Therefore, pus does not readily exchange between these two glands.)

- **Bed of parotid gland** is related to three bony structures:
  - **Ramus of the mandible** covered by two muscles (masseter laterally and medial pterygoid medially).
  - **Mastoid process** covered by two muscles (sternocleidomastoid laterally and posterior belly of digastric muscle medially).
  - **Styloid process** covered by three muscles (styloglossus, stylopharyngeus, and stylohyoid).
- **Relations** of parotid gland
  - **Anteromedial Surface** is deeply grooved by the posterior border of the ramus of the mandible with covering muscles and lateral aspect of the temporomandibular joint.
  - **Postero medial surface** is moulded onto the mastoid and styloid processes and their covering muscles. The styloid process separate the gland from internal carotid artery, internal jugular vein, and last four cranial nerves.
  - **Superficial Surface** covered from superficial to deep by skin, superficial fascia containing anterior branches of greater auricular nerve, superficial parotid (preauricular) lymph nodes, platysma, parotid fascia and deeper parotid lymph nodes.

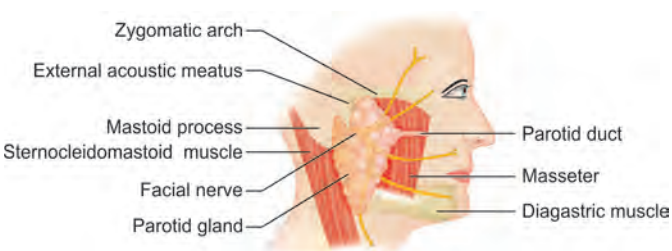


Fig. 137: Main features of the parotid region

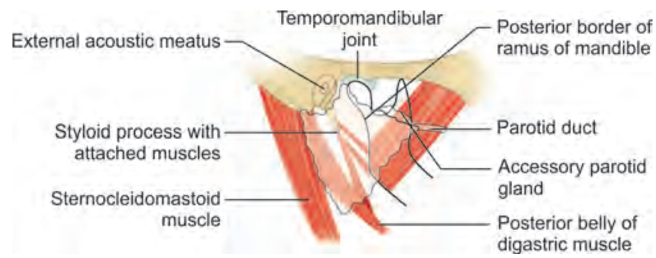


Fig. 138: Parotid bed and location of the parotid gland

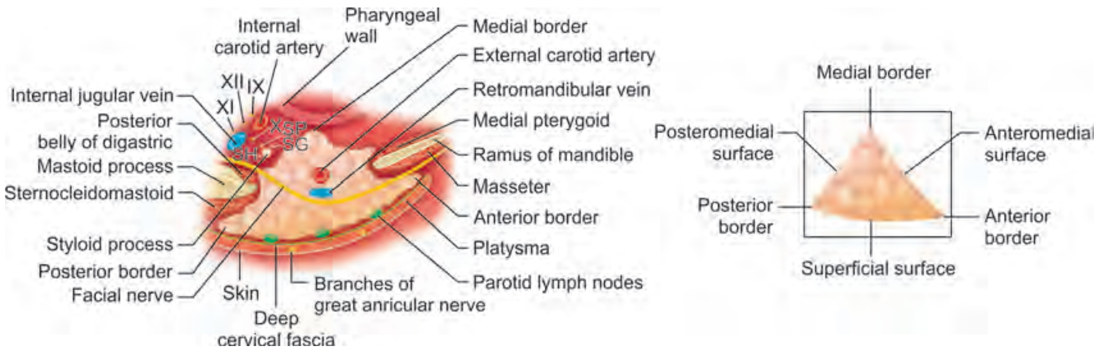


Fig. 139: Horizontal section through parotid gland showing its relations and the structures passing through it. The inset figure shows borders and surfaces of the parotid gland (SG: Styloglossus muscle, SH: Stylohyoid muscle, SP: Stylopharyngeus muscle)

- Stensen's parotid duct crosses the masseter, pierces the buccinator muscle, and opens into the vestibule of the oral cavity opposite the upper second molar tooth.
- Parotid duct can be palpated at tense anterior margin of masseter muscle.

Fig. 140: Sites of origin and termination of the parotid duct

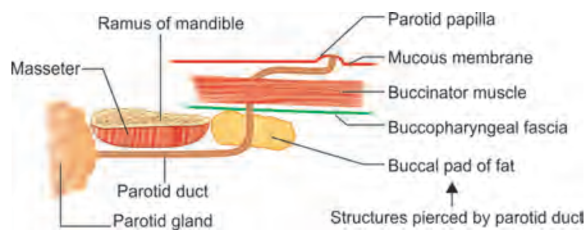


Fig. 141: Course of the parotid duct. Also note the structures pierced by it during its course from the parotid gland to the vestibule of the mouth

- Parotid gland secretes copious watery (serous) saliva by parasympathetic stimulation and produces a small amount of viscous saliva by sympathetic stimulation.
- The parasympathetic (secretomotor) innervation pathway is: Inferior salivatory nucleus → glossopharyngeal nerve → tympanic branch→ tympanic plexus (middle ear cavity) → lesser petrosal nerve→ foramen ovale→ otic ganglion→ auriculotemporal nerve (trigeminal, mandibular)→ parotid gland.
- Otic Ganglion lies in the infratemporal fossa, just below the foramen ovale between the mandibular nerve and the tensor veli palatini (muscle is deeper and medial).
  - Preganglionic axons originate in the inferior salivatory nucleus and travel in the glossopharyngeal nerve and its tympanic branch.

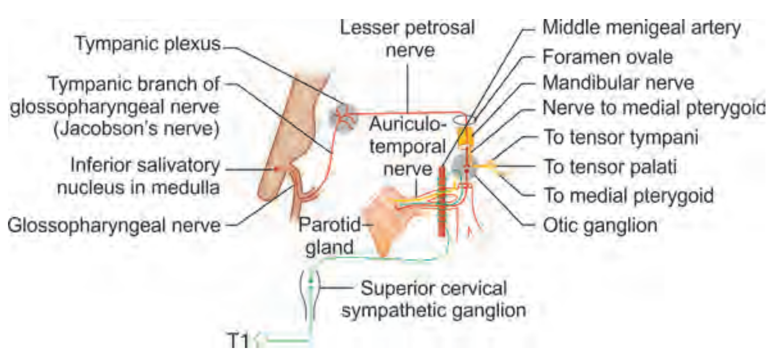


Fig. 142: Otic ganglion and its connections

  - They traverse the tympanic plexus and lesser petrosal nerve, and pass through the foramen ovale to reach the otic ganglion, where they synapse.
  - Postganglionic fibres pass by communicating branches to the auriculotemporal nerve, which conveys them to the parotid gland.
  - Stimulation of the lesser petrosal nerve produces vasodilator and secretomotor effects.

Clinical Correlations

- Frey's syndrome (auriculotemporal nerve syndrome): Patient presents with flushing and beads of perspiration (gustatory sweating) and hyperaesthesia in and around parotid region, instead of salivation in response to taste of food after injury of the auriculotemporal nerve.
  - Penetrating wounds of the parotid gland may damage auriculotemporal and great auricular nerves.

- The auriculotemporal nerve contains parasympathetic cholinergic (secretomotor), sensory, and sympathetic fibres.
- The great auricular nerve contains sensory and sudomotor (sympathetic cholinergic) fibres.
- When these nerves are cut, during regeneration the secretomotor fibres grow into endoneurial sheaths of fibres supplying cutaneous receptors for pain, touch and temperature, and sympathetic fibres supplying sweat glands and blood vessels.
- A stimulus intended for salivation evokes cutaneous hyperesthesia, sweating, and flushing.
- It can occur after parotid surgery and may be treated by cutting the tympanic plexus in the middle ear.
- Denervation by tympanic neurectomy or auriculotemporal nerve avulsion may be advocated, but are often not curative.
- The symptoms can be managed by the subcutaneous infiltration of purified botulinum toxin into the affected area, and use of antiperspirant.

ASSESSMENT QUESTIONS

1. Lesser petrosal nerve derives preganglionic fibers from: *(NEET Pattern 2014)*
a. Tympanic nerve
b. Cochlear nerve
c. Nervus intermedius
d. Chorda tympani

2. Parasympathetic secretomotor fibers to parotid come from all EXCEPT: *(AIPG 2009)*
a. Otic ganglion
b. Greater petrosal nerve
c. Auriculotemporal nerve
d. Tympanic plexus

3. Incorrect regarding location of otic ganglion is: *(AIIMS 2015)*
a. Anterior to middle meningeal artery
b. Lateral to tensor veli palatini
c. Lateral to mandibular nerve
d. Inferior to foramen ovale

4. After removal of the parotid gland, patient is having sweating on cheeks while eating. Auriculotemporal nerve which contains parasympathetic secretomotor fibers to parotid gland have reinnervated which nerve? ***(AIIMS 2012)***
a. Facial
b. Glossopharyngeal
c. Buccal
d. Greater auricular

5. Parotid duct opens: *(NEET Pattern 2012)*
a. Opposite 1st molar
b. Opposite 2nd molar
c. Into the papilla
d. Opposite incisor

6. True about parotid gland: *(PGIC 2015)*
a. Enclosed by deep cervical fascia of neck
b. Related to retromandibular vein
c. Related to facial nerve
d. External carotid artery enters the gland through anteromedial surface
e. Parotid lymph node lies behind the gland

7. True regarding parotid gland is all EXCEPT: *(PGIC)*
a. Accessory parotid glands is above parotid duct
b. Mandible ramus grooves anteromedial surface
c. Styloid and mastoid muscles are posteromedially
d. Auriculo temporal nerve superiorly and great auricular nerve laterally
e. Pharynx examination is unnecessary

ANSWERS WITH EXPLANATIONS

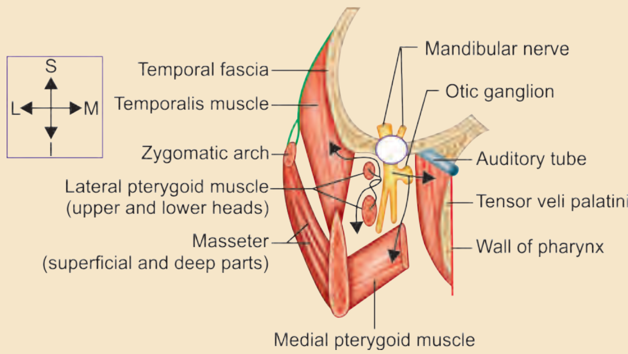
1. a. Tympanic nerve
- Inferior salivatory nucleus sends preganglionic parasympathetic fibres through tympanic branch of glossopharyngeal nerve, which forms tympanic plexus in the middle ear cavity, and sends fibres through lesser petrosal nerve to reach the otic ganglion.

2. b. Greater petrosal nerve
- Parasympathetic secretomotor fibres to the parotid gland are carried by the lesser petrosal and not the greater petrosal nerve.
- Greater petrosal nerve carries secretomotor fibres to the pterygopalatine ganglion and supplies the lacrimal, nasal and palatine glands.
- Secretory fibres to the parotid gland start in the inferior salivatory nucleus (brainstem) → glossopharyngeal nerve → tympanic branch → tympanic plexus → lesser petrosal nerve → otic ganglion → auriculotemporal nerve → parotid gland.
- Tympanic plexus is present in the middle ear and receives the preganglionic fibres from the glossopharyngeal nerve.
- Otic ganglion lies just inferior to the foramen ovale, through which the lesser petrosal nerve passes and carries the preganglionic fibres to the ganglion.
- Auriculotemporal nerve is a branch of mandibular nerve, which carries the postganglionic fibres from the otic ganglion to the parotid gland.

3. c. Lateral to mandibular nerve
- Otic ganglion is medial (not lateral) to **mandibular nerve.**
- **Relations of otic ganglion:**
  - Otic ganglion lies inferior to foramen ovale.
  - Mandibular nerve lies lateral to the ganglion and tensor veli palati muscles is medial (deeper).
  - Anteriorly located is medial pterygoid muscle and posterior is middle meningeal artery.

4. c. Buccal

- This is a case of post-parotidectomy gustatory sweating, leading to sweating on the cheek (buccal nerve territory).
- The symptoms of gustatory sweating (Frey's syndrome) are redness and sweating on the cheek area adjacent to the ear. They can appear when the affected person eats, sees, dreams, thinks about or talks about certain kinds of food which produce strong salivation.
- If the sweating was mentioned in the pre-auricular area, the answer would have been great auricular nerve.
- The etiology in most cases is damage to the auriculotemporal nerve which supply sensory fibres to the preauricular and temporal areas, carries parasympathetic fibres to the parotid gland and sympathetic vasoconstrictor and sudomotor fibres to the skin of the same area.
- Injury to the auriculotemporal nerve denervates the sweat glands and the vessels of the skin over its distribution, in addition to producing the sensory disturbance.
- Both the parasympathetic and sympathetic nerves of the face are cholinergic, hence compatible, and in the process of regeneration, parasympathetic fibres become misdirected and grow along sympathetic pathways. Thus, a gustatory stimulus produce sweating and flushing.
- Gustatory sweating is mainly observed in the region of previous parotid lobe removal, but can also be found in other areas deriving their sensory supply from the buccal, greater auricular and lesser occipital nerves.



5. b. Opposite 2nd molar

- Stensen's parotid duct crosses the masseter, pierces the buccinator muscle, and opens into the vestibule of the oral cavity opposite the upper second molar tooth.

6. a. Enclosed by deep cervical fascia of neck; b. Related to retromandibular vein; c. Related to facial nerve

- Parotid gland is enclosed in a capsule formed by investing layer of deep cervical fascia.
- Retromandibular vein and facial nerve run through the substance of parotid gland.
- External carotid artery enters the gland through posteromedial surface.
- Parotid lymph nodes lie partly in the superficial fascia and partly deep to deep fascia over the parotid gland.

7. e. Pharynx examination is unnecessary

- In pathological enlargement of parotid gland, pharynx examination is necessary since, medial border of gland is related to the lateral wall of oropharynx (dig).

Submandibular and Sublingual Glands

- **Submandibular gland** is present in the submandibular triangle covered by the investing layer of the deep cervical fascia.
  - It wraps around the posterior border of mylohyoid, has a large part superficial to the muscle and a small part which lies deep to the muscle.
  - The deep portion is located between the hyoglossus and styloglossus muscles medially and the mylohyoid muscle laterally and between the lingual nerve above and the hypoglossal nerve below.
  - **Wharton's duct** arises from the deep portion and runs forward between the mylohyoid and the hyoglossus, where it runs medial to and then superior to the lingual nerve (lingual nerve loop under submandibular duct).
    - Next it runs between the sublingual gland and the genioglossus and drains at the summit of the sublingual papilla (caruncle) at the side of the frenulum of the tongue.

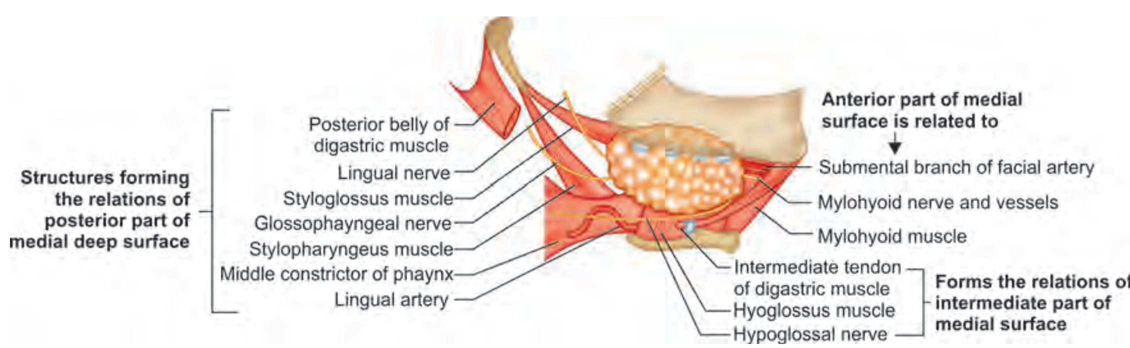


Fig. 143: Relations of the medial (deep) surface of the submandibular gland

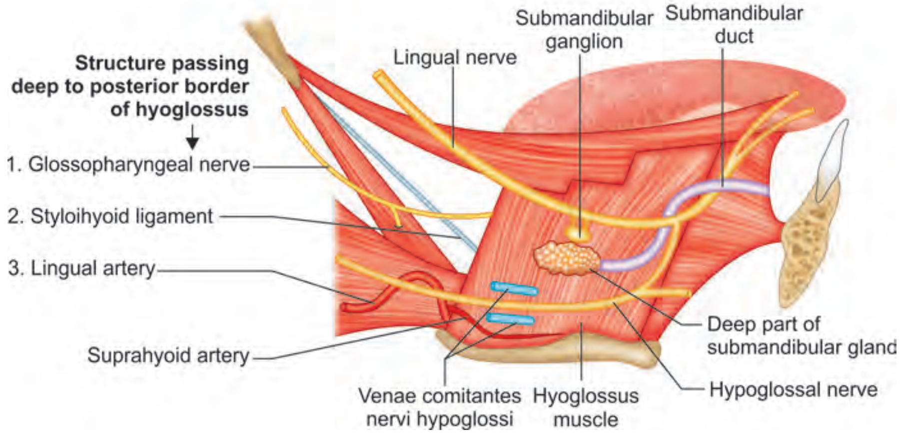


Fig. 144: Superficial relations of the hyoglossus muscle

Submandibular ganglion: The preganglionic axons originate in the superior salivatory nucleus in the pons.
- They emerge from the brainstem in the nervus intermedius and leave the main facial nerve trunk in the middle ear to join the chorda tympani, which subsequently joins the lingual nerve.
- These fibres eventually reach the submandibular ganglion, where they synapse.
- Postganglionic fibres innervate the submandibular, sublingual and lingual salivary glands; some axons re-enter the lingual nerve to access the lingual glands, while others pass directly along blood vessels to enter the submandibular and sublingual glands.
- Stimulation of the chorda tympani has a direct secretomotor effect and also dilates the arterioles in both the glands.

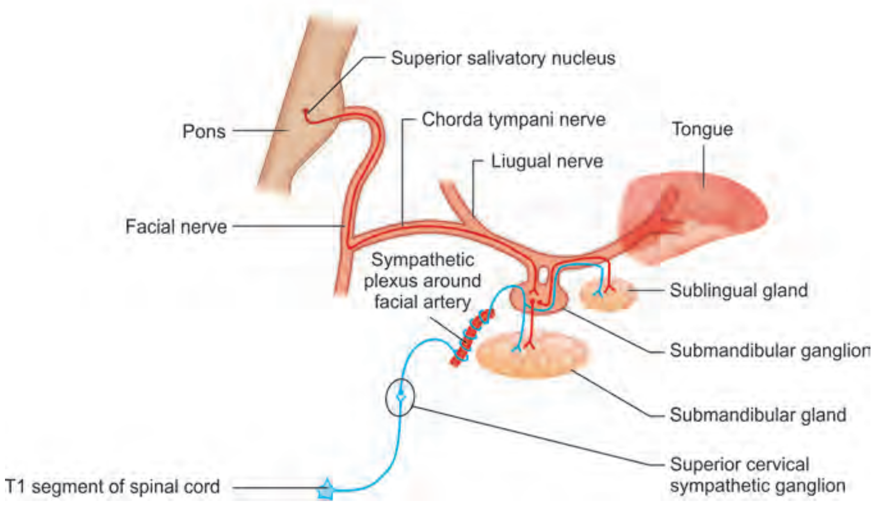


Fig. 145: Submandibular ganglion and its connections

- **Sublingual gland** is located in the floor of the mouth between the mucous membrane above and the mylohyoid muscle below and surrounds the terminal portion of the submandibular duct.
  - It empties into the floor of the mouth along the sublingual fold by 12 short ducts, few of those enter the submandibular duct.
  - Like submandibular salivary gland it is served by the same neural pathway.
    - Superior salivatory nucleus sends the parasympathetic preganglionic secretomotor fibres by facial nerve → chorda tympani nerve → submandibular ganglion.
    - The post ganglionic fibres are carried by the lingual nerve (branch of mandibular, trigeminal).

ASSESSMENT QUESTIONS

1. **Otic ganglion supplies:** *(NEET Pattern 2012)*
   a. Submandibular gland
   b. Lingual gland
   c. Parotid gland
   d. All three

2. **Preganglionic fibres to the submandibular ganglion arise from:** *(NEET pattern 2012)*
   a. Superior salivatory nucleus
   b. Inferior salivatory nucleus
   c. Nucleus of tractus solitarius
   d. Nucleus ambiguous

3. Lobes of submandibular gland are divided by which muscle? *(NEET pattern 2015)*
a. Mylohyoid
b. Genioglossus
c. Stylohyoid
d. Styloglossus

4. Nerve which loops around submandibular duct? *(NEET pattern 2015)*
a. Mandibular nerve
b. Lingual nerve
c. Hypoglossal nerve
d. Recurrent laryngeal nerve

5. Structures NOT injured in submandibular gland excision: *(NEET Pattern 2015)*
a. Inferior alveolar nerve
b. Lingual nerve
c. Hypoglossal nerve
d. Marginal mandibular branch of facial nerve

6. Which one of the following is the CORRECT statement during operation on the submandibular gland? *(AIIMS 2006)*
a. The submandibular gland is seen to wrap around the posterior border of mylohyoid.
b. The facial artery and vein are divided as they course through the deep part of the gland.
c. The hypoglossal nerve is seen to loop under the submandibular duct
d. Damage to the lingual nerve will cause loss of sensation to the posterior third of the tongue

ANSWERS WITH EXPLANATIONS

1. c. Parotid gland
- Otic ganglion supplies parotid salivary gland. Submandibular ganglion supplies submandibular and sublingual salivary glands.

2. a. Superior salivatory nucleus
- Superior salivatory nucleus sends the parasympathetic preganglionic secretomotor fibres by facial nerve → chorda tympani nerve → submandibular ganglion. The post ganglionic fibres are carried by the lingual nerve (branch of mandibular, Trigeminal).

3. a. Mylohyoid
- Submandibular gland wraps around the posterior border of mylohyoid.
- Thus, the gland has a large part superficial to the muscle and a small part which lies deep to the muscle.

4. b. Lingual nerve
- Submandibular duct runs medial to and then superior to the lingual nerve (lingual nerve loop under submandibular duct).

5. a. Inferior alveolar nerve
- Submandibular duct runs anteriorly between the lingual nerve and hypoglossal nerve, which are prone to be injured in dissection in the region.
- Marginal mandibular branch of facial nerve passes posterior inferior to angle of jaw, and is prone to injury in the excision.

6. a. The submandibular gland is seen to wrap around the posterior border of mylohyoid
- Submandibular gland wraps around the posterior border of mylohyoid. Thus, the gland has a large part superficial to the muscle and a small part which lies deep to the muscle.
- It is the lingual nerve and not the hypoglossal which loops under the submandibular duct.
- Hypoglossal nerve keeps running inferior to the submandibular duct.
- Damage to the lingual nerve causes loss of sensation to the anterior 2/3 of the tongue.
- Posterior 1/3 of tongue is supplied by the glossopharyngeal nerve.
- Facial artery and vein are related to superficial (not deep) part of the gland.

Tonsils

- Tonsils are aggregations of lymphoid tissue located in the posterior wall of the pharynx, which trap bacteria and viruses entering through the pharynx, and mount immune response to protect from infection.
- **Waldeyer Tonsillar Ring** is collection of lymphoid tissue at the oropharyngeal isthmus, formed by the **pharyngeal, palatine, tubal** and **lingual** tonsils encircling the back of the throat (refer).
  - **Pharyngeal Tonsil** is present in the posterior wall and roof of the nasopharynx and is (called adenoid if enlarged).
  - **Tubal** (Eustachian) Tonsil is a collection of lymphoid nodules near the pharyngeal opening of the auditory tube.
  - **Lingual** Tonsil is a collection of lymphoid follicles on the posterior portion of the dorsum of the tongue.
- **Palatine Tonsil** is present on each side of the oropharynx in an interval between the **palatoglossal** and **palatopharyngeal** folds.
  - Lower pole of the tonsil is attached to the tongue.
  - A triangular fold (**plica triangularis**) of mucous membrane extends from anterior pillar to the anteroinferior part of tonsil and encloses a space called anterior tonsillar space.
  - Upper pole of the tonsil extends into soft palate.
  - Its medial surface is covered by a semilunar mucosal fold (**Plica semilunaris**), extending between anterior and posterior pillars and enclosing a potential space called supratonsillar fossa.
  - The **tonsillar bed** is formed (from within outwards) by: Pharyngobasilar fascia, superior constrictor muscle and buccopharyngeal fascia.

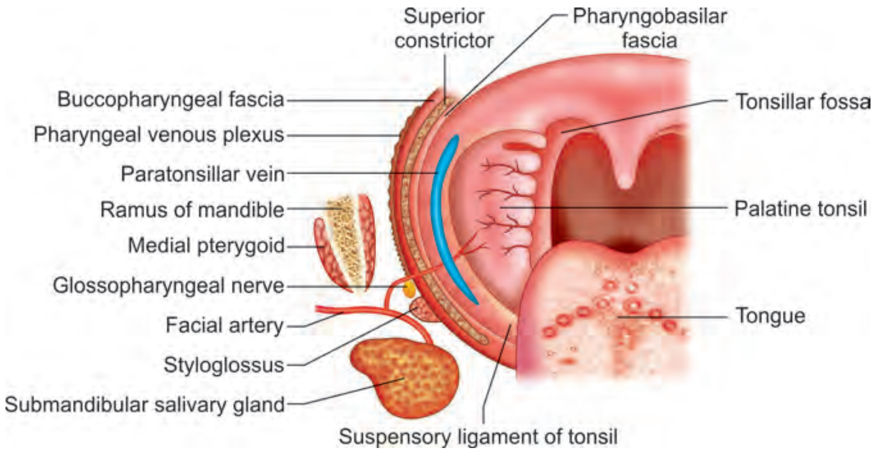


Fig. 146: Horizontal section through right palatine tonsil showing structures deep to its lateral surface

Artery supply of palatine tonsil:

- Tonsil is mainly supplied by the tonsillar branches of **facial artery**.
- **Lingual artery** is a branch of external carotid artery which gives **dorsal lingual** branches to the tonsil.
- **Ascending palatine artery** is a branch of facial artery, which also supplies the tonsil.
- The upper pole of the tonsil also receives branches from the **ascending pharyngeal artery** (branch of external carotid artery), which enter the tonsil posteriorly, and from the **descending palatine artery** (branch of maxillary artery) and its branches, the **greater and lesser palatine arteries**.

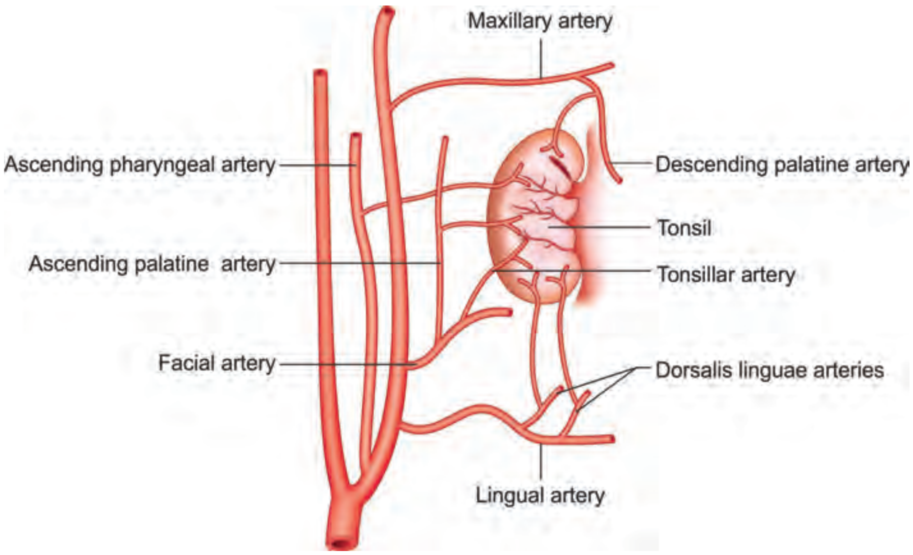


Fig. 147: Arteries supplying the tonsil

- **Nerve supply (palatine tonsil)**: It receives branches of the glossopharyngeal nerve and the lesser palatine branch of the maxillary nerve.
  - Since the glossopharyngeal nerve also supplies ear region, any pathology of the tonsil and tonsillar fossa may be accompanied by pain referred to the ear.
- **Lymphatic drainage (palatine tonsil)**: Tonsillar lymphatics drain to the upper deep cervical lymph nodes directly (especially the **jugulodigastric** nodes) or indirectly through the retropharyngeal lymph nodes.
  - The jugulodigastric nodes are enlarged in tonsillitis, and are palpable superficially 1–2 cm below the angle of the mandible.
- **Adenoids** (nasopharyngeal tonsil) is a subepithelial collection of lymphoid tissue at the junction of roof and posterior wall of nasopharynx.
  - Unlike palatine tonsils adenoids have no crypts and no capsule.
  - Adenoid are present at birth, shows physiological enlargement up to the age of six years and then tends to atrophy at puberty and almost completely disappears by the age of 20.
  - The arterial supply is by ascending palatine branch of facial , ascending pharyngeal branch of external carotid artery, pharyngeal branch of the third part of maxillary artery, ascending cervical branch of inferior thyroid artery of thyrocervical trunk.

ASSESSMENT QUESTIONS

1. **All are true about palatine tonsil EXCEPT:** *(PGIC 2014)*
   a. Develop from 2nd pharyngeal pouch
   b. Irritation cause referred pain in ear via auricular branch of vagus
   c. Mainly supplied by facial artery
   d. Situated in the lateral wall of the oropharynx
   e. Lymphatics pass to jugulo omohyoid node

2. **The palatine tonsil receives its arterial supply from all of the following EXCEPT:** *(AIIMS 2005)*
   a. Facial
   b. Ascending palatine
   c. Sphenopalatine
   d. Dorsal lingual

3. **All are true about adenoids EXCEPT:** *(NEET Pattern 2012)*
   a. Physiological growth up to 6 years
   b. Crypta magna present
   c. Present in nasopharynx
   d. Supplied by facial artery

4. **Plica triangularis is present in:** *(NEET pattern 2012)*
   a. Antero inferior part of tonsil
   b. Dorsum of tongue
   c. Inlet of larynx
   d. None

5. **Bed of tonsil is formed by:** *(NEET Pattern 2012)*
   a. Superior constrictor
   b. Middle constrictor
   c. Inferior constrictor
   d. Platysma

6. **Sensory supply to tonsil is by which nerve?** *(NEET Pattern 2012)*
   a. Greater palatine nerve
   b. Lesser palatine nerve
   c. Vagus
   d. Glossopharyngeal nerve

ANSWERS WITH EXPLANATIONS

1. **b. Irritation cause referred pain in ear via auricular branch of vagus; e. Lymphatics pass to jugulo omohyoid node**
   - Tonsil develops in the region of **pharyngeal pouch two**, whose endoderm forms the tonsillar epithelium.
   - It is present on each side of the **oropharynx** in an interval between the palatoglossal and palatopharyngeal folds and mainly supplied by **facial artery** branches.
   - It receives branches of the glossopharyngeal nerve and the lesser palatine branch of the maxillary nerve.
   - Since the **glossopharyngeal** nerve also supplies ear region, any pathology of the tonsil and tonsillar fossa may be accompanied by pain referred to the ear.
   - Lymphatics drain to the upper deep cervical lymph nodes directly (especially the **jugulodigastric** nodes).

2. **c. Sphenopalatine**
   - Sphenopalatine artery is a branch of maxillary artery and does not give branches to the tonsil. It supplies the nasal septum, lateral wall of nose and the paranasal sinuses.
   - Tonsil is mainly supplied by the tonsillar branches of facial artery.
   - Lingual artery is a branch of external carotid artery which gives dorsal lingual branches to the tonsil.
   - Ascending palatine artery is a branch of facial artery, which also supplies the tonsil.
   - The upper pole of the tonsil also receives branches from the ascending pharyngeal artery, which enter the tonsil posteriorly, and from the descending palatine artery and its branches, the greater and lesser palatine arteries.

3. **b. Crypta magna present**
   - Adenoids (nasopharyngeal tonsil) is a subepithelial collection of lymphoid tissue at the junction of roof and posterior wall of nasopharynx.
   - Unlike palatine tonsils adenoids have no crypts and no capsule.
   - Adenoid are present at birth, shows physiological enlargement up to the age of six years and then tends to atrophy at puberty and almost completely disappears by the age of 20.
   - Ascending palatine branch of facial artery contributes to blood supply of adenoids.

4. **a. Antero inferior part of tonsil**
   - **Palatine Tonsil** is present on each side of the oropharynx in an interval between the palatoglossal and palatopharyngeal folds.
   - Lower pole of the tonsil is attached to the tongue.
   - A triangular fold (**plica triangularis**) of mucous membrane extends from anterior pillar to the anteroinferior part of tonsil and encloses a space called anterior tonsillar space.

5. **a. Superior constrictor**
   - The **tonsillar bed** is formed (from within outwards) by: Pharyngobasilar fascia, superior constrictor muscle and buccopharyngeal fascia.

6. **d. Glossopharyngeal nerve**
   - Tonsil is supplied by the branches of the glossopharyngeal nerve and the lesser palatine branch of the maxillary nerve.

Palate

- Palate forms the roof of the mouth and the floor of the nasal cavity and is of two types; Hard and soft.
- **Hard Palate** is the anterior four-fifths of the palate and forms a bony framework covered with a mucous membrane between the nasal and oral cavities.
  - It consists of the palatine processes of the maxillae and horizontal plates of the palatine bones.
  - It contains the incisive foramen in its median plane anteriorly and the greater and lesser palatine foramina posteriorly.
  - It receives sensory innervation through the greater palatine and nasopalatine nerves and blood from the greater palatine artery.

- **Soft Palate** is a fibromuscular fold extending from the posterior border of the hard palate and makes up one fifth of the palate.
  - It moves posteriorly against the pharyngeal wall to close the oropharyngeal (faucial) isthmus while swallowing or speaking.
  - It is continuous with the palatoglossal and palatopharyngeal folds.
- **Arterial supply**: Greater and lesser palatine arteries of the descending palatine artery (branch of maxillary artery), the ascending palatine artery (branch of facial artery), and the palatine branch of the ascending pharyngeal artery.
- **Venous Drainage** is into pharyngeal venous plexus and pterygoid venous plexus.
- **Lymphatic Drainage** is into retropharyngeal and upper deep cervical lymph nodes.
- **Nerve supply**: Most of the palate muscles are supplied by the cranial accessory nerve, fibres carried by the vagal branches (vagus accessory complex; pharyngeal plexus), except tensor palati (which is supplied by the mandibular nerve, trigeminal).
- General sensations are carried by the lesser palatine nerves (branches of maxillary nerve; trigeminal) through pterygopalatine ganglion and glossopharyngeal nerve.
- Taste sensations are contained in lesser palatine nerves, travel through greater petrosal nerve to geniculate ganglion of facial nerve and eventually reach the nucleus tractus solitarius.

Clinical Correlation

- Lesion of the vagus nerve causes deviation of the uvula toward the opposite side of the lesion on phonation because of paralysis of the musculus uvulae (elevator of uvula).

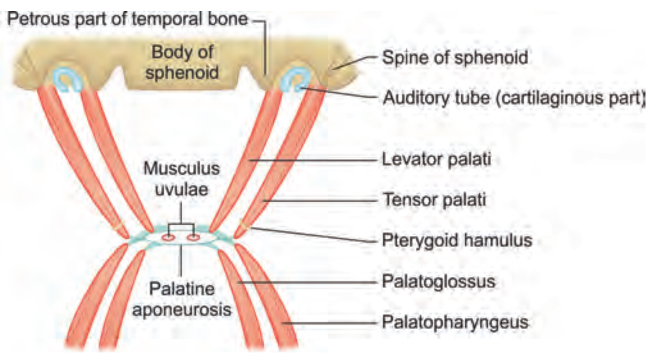


Fig. 148: Muscles of the soft palate

Muscles of soft palate

Muscle	Superior attachment	Inferior attachment	Innervation	Main action
Tensor veli palatini	Scaphoid fossa of medial pterygoid plate, spine of sphenoid bone, and cartilage of pharyngotympanic tube	Palatine aponeurosis	Medial pterygoid nerve (a branch of mandibular nerve, CN V_3) via otic ganglion	Tenses soft palate and opens mouth of pharyngotympanic tube during swallowing and yawning
Levator veli palatini	Cartilage of pharyngotympanic tube and petrous part of temporal bone		Pharyngeal branch of vagus nerve (CN X) via pharyngeal plexus	Elevates soft palate during swallowing and yawning
Palatoglossus	Palatine aponeurosis	Side of tongue		Elevates posterior part of tongue and draws soft palate onto tongue
Palatopharyngeus	Hard palate and palatine aponeurosis	Lateral wall of pharynx		Tenses soft palate and pulls walls of pharynx superiorly, anteriorly, and medially during swallowing
Musculus uvulae	Posterior nasal spine and palatine aponeurosis	Mucosa of uvula		Shortens uvula and pulls it superiorly

ASSESSMENT QUESTIONS

1. **The sensory supply of the palate is through all of the following EXCEPT:** *(AIPG 2002)*
   a. Facial nerve
   b. Hypoglossal nerve
   c. Glossopharyngeal nerve
   d. Vagus nerve
2. **Sensory fibers from the taste buds in the hard and soft palate travel along:** *(AIIMS 2005)*
   a. Trigeminal nerve
   b. Facial nerve
   c. Glossopharyngeal nerve
   d. Vagus nerve
3. **Soft palate is supplied by:** *(NEET Pattern 2012)*
   a. Cranial accessory
   b. Trigeminal
   c. Abducent
   d. None
4. **Which of the following does NOT supply the palate?**
   a. Tonsillar branch of facial artery
   b. Ascending palatine artery
   c. Descending palatine artery
   d. Ascending pharyngeal artery

ANSWERS WITH EXPLANATIONS

1. b. Hypoglossal nerve

- Hypoglossal nerve is a pure motor nerve to supply the tongue muscles.
- General sensations of palate are carried by the lesser palatine nerves (branches of maxillary nerve; trigeminal) and glossopharyngeal nerve.
- Taste sensations are contained in lesser palatine nerves, travel through greater petrosal nerve (branch of facial nerve).

2. b. Facial nerve

- Taste sensations are carried by lesser palatine nerves, next travel through greater petrosal nerve to reach geniculate ganglion of facial nerve and eventually reach the nucleus tractus solitarius.

3. a. Cranial accessory

- Most of the palate muscles are supplied by the cranial accessory nerve, fibres carried by the vagal branches (vagus accessory complex; pharyngeal plexus), except tensor palati (which is supplied by the mandibular nerve, trigeminal).

4. a. Tonsillar branch of facial artery

- Palate is supplied by greater and lesser palatine arteries of the descending palatine artery (branch of maxillary artery), the ascending palatine artery (branch of facial artery), and the palatine branch of the ascending pharyngeal artery.

Pharynx

- Pharynx, the upper portion of gut tube, is funnel-shaped fibromuscular tube that extends from the base of the skull to the inferior border of the cricoid cartilage.
- It conducts food to the esophagus and air to the larynx. It has three parts; **Nasopharynx**, **oropharynx** and **laryngopharynx**.

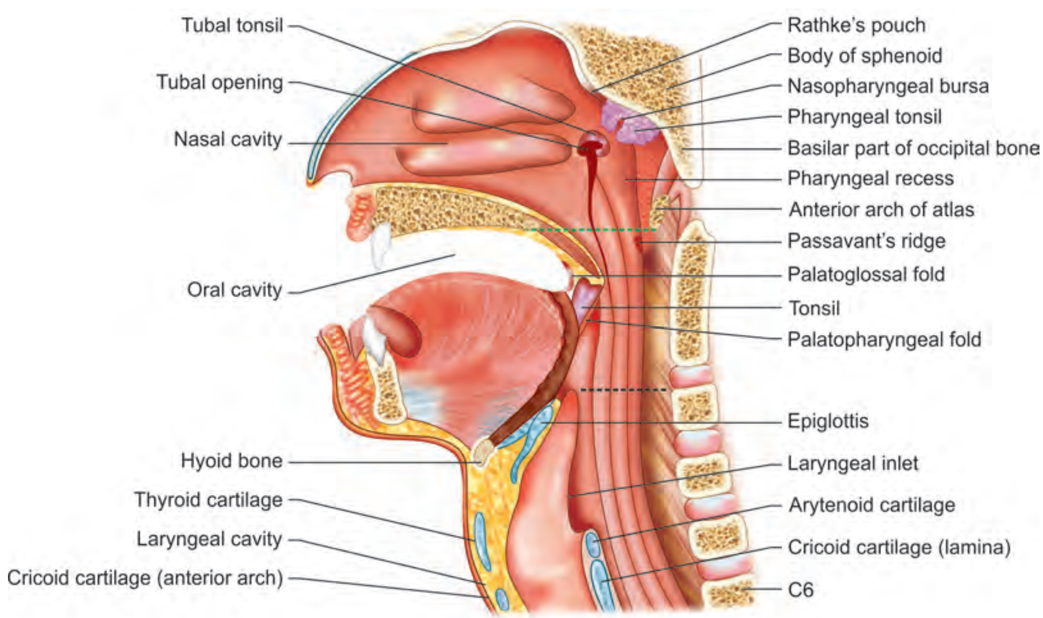


Fig. 149: The sagittal section through the nose, mouth, pharynx, and larynx

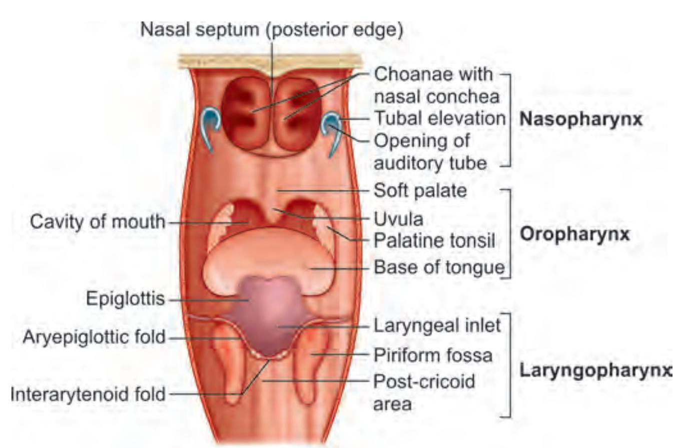


Fig. 150: Coronal view of pharynx.

- **Nasopharynx** is present behind the nasal cavity above the soft palate and communicates with the nasal cavities through the nasal choanae.
- Pharyngeal tonsils are present in its postero-superior wall.
- It is connected with the tympanic cavity through the auditory (Eustachian) tube, which equalizes air pressure on both sides of the tympanic membrane.
- **Oropharynx** extends between the soft palate above and the superior border of the epiglottis below and communicates with the mouth through the oropharyngeal isthmus.
    - Palatine tonsils are located here, lodged in the tonsillar fossae and are bounded by the palatoglossal and palatopharyngeal folds.
- **Laryngopharynx** is also called hypopharynx and extends from the upper border of the epiglottis to the lower border of the cricoid cartilage.
    - It contains the piriform recesses, one on each side of the opening of the larynx, in which swallowed foreign bodies may be lodged.

	Nasopharynx	Oropharynx	Laryngopharynx (hypopharynx)
Situation	**Behind nasal cavity**	**Behind oral cavity**	**Behind larynx**
Extent	Base of skull (body of sphenoid) to soft palate	Soft palate to upper border of epiglottis	Upper border of epiglottis to lower border of cricoid cartilage
Communications	Anteriorly with nasal cavity	• Anteriorly with oral cavity • Superiorly with nasopharynx • Inferiorly with laryngopharynx	• Superiorly with oropharynx • Inferiorly continues as esophagus
Nerve supply	Pharyngeal branches of pterygopalatine ganglion	• Glossopharyngeal nerve • Vagus nerve	• Glossopharyngeal nerve • Vagus nerve
Relations Anterior	Posterior nasal aperture	Oral cavity	• Inlet of larynx • Posterior surface of cricoid • Arytenoid cartilage
Posterior	Body of sphenoid bone, pharyngeal tonsils	C2,3 vertebrae	C4,5 vertebrae
Lateral	Opening of auditory tube	Palatine tonsils (in tonsillar fossa)	Piriform fossa
Lining epithelium	Ciliated columnar	Stratified squamous (non-keratinized)	Stratified squamous (non-keratinized)
Function	Respiratory pathway	Respiratory and food pathway	Food pathway

Muscles

Muscles of Pharynx				
Muscle	**Origin**	**Insertion**	**Innervation**	**Main Action(s)**
External layer				
Superior pharyngeal constrictor	Pterygoid hamulus, pterygomandibular raphe, posterior end of mylohyoid line of mandible, and side of tongue	Pharyngeal tubercle on basilar part of occipital bone	Pharyngeal branch of vagus (CN X) and pharyngeal plexus	Constrict walls of pharynx during swallowing
Middle pharyngeal constrictor	Stylohyoid ligament and greater and lesser horns of hyoid	Pharyngeal raphe	Pharyngeal branch of vagus (CN X) and pharyngeal plexus, plus branches of external and recurrent laryngeal nerves of vagus	
Inferior pharyngeal constrictor	Oblique line of thyroid cartilage and side of cricoid cartilage	Cricopharyngeal part encircles pharyngo-esophageal junction without forming a raphe		
Internal layer				
Palatopharyngeus	Hard palate and palatine aponeurosis	Posterior border of lamina of thyroid cartilage and side of pharynx and esophagus	Pharyngeal branch of vagus (CN X) and pharyngeal plexus	Elevate (shorten and widen) pharynx and larynx during swallowing and speaking
Salpingopharyngeus	Cartilaginous part of pharyngotympanic tube	Blends with palatopharyngeus		
Stylopharyngeus	Styloid process of temporal bone	Posterior and superior borders of thyroid cartilage with palatopharyngeus	Glossopharyngeal nerve (CN IX)	

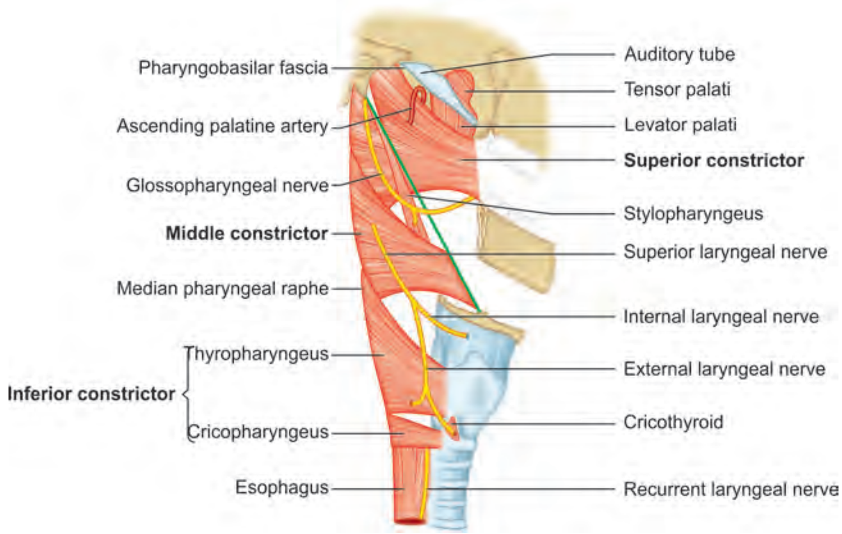


Fig. 151: Origin and insertion of the constrictors of the pharynx

- **Arterial supply**: Ascending pharyngeal artery, ascending palatine branch of the facial artery, descending palatine arteries, pharyngeal branches of the maxillary artery, and branches of the superior and inferior thyroid arteries.
- **Nerve supply**: The **pharyngeal plexus** is present on the middle pharyngeal constrictor.
  - It is contributed by the pharyngeal branches of the **glossopharyngeal** and **vagus** nerves (vagus accessory complex).
  - It also receives the **sympathetic** branches from the superior cervical ganglion.
  - Its glossopharyngeal component supplies sensory fibers to the pharyngeal mucosa.
- **Vagus accessory complex**: Cranial accessory nerve fibres (from nucleus ambigus) are carried by the vagal branches to supply most of the muscles of palate, pharynx and larynx.
  - Cranial accessory nerve fibres (carried by the vagal branches) supply most of the muscles of palate, except stylopharyngeus, which is supplied by the glossopharyngeal nerve.

Clinical Correlations

- Pharyngeal lesions may irritate the glossopharyngeal and vagus nerves and the pain is referred to the ear because these nerves contribute sensory innervation to the external ear as well.
- The gaps in the pharyngeal wall has some structures passing through them.

The gaps in the pharyngeal wall and structures passing through them

Gap	Structures passing through them
Between the base of skull and the upper concave border of superior constrictor (sinus of Morgagni)	• Auditory tube • Levator palati muscle • Ascending palatine artery • Palatine branch of the ascending pharyngeal artery
Between the superior and middle constrictors	• Stylopharyngeus muscle • Glossopharyngeal nerve
Between the middle and inferior constrictors	• Internal laryngeal nerve • Superior laryngeal vessels
Between the lower border of inferior constrictor and the esophagus (in the tracheoesophageal groove)	• Recurrent laryngeal nerve • Inferior laryngeal vessels

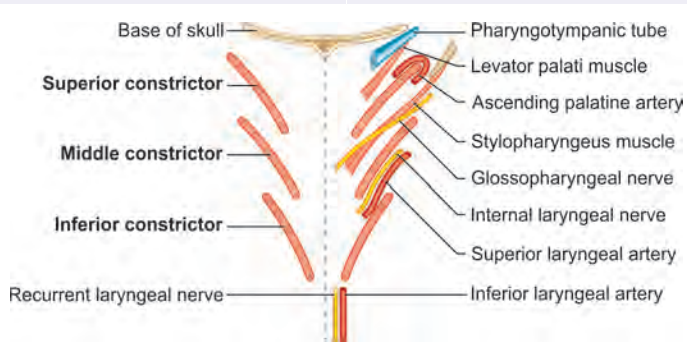


Fig. 152: Structures passing through the gaps in the pharyngeal wall

- Nasopharyngeal Isthmus: Some fibres of the **palatopharyngeus** muscle (arising from palatine aponeurosis) sweep horizontally backwards and join the upper fibres of the **superior constrictor** muscle to form a U-shaped muscle-loop in the posterior pharyngeal wall underneath the mucosa, which is pulled forward during swallowing to form the **Passavant ridge**.
  - During swallowing the pharyngeal isthmus (the opening between the free edges of soft palate and posterior wall) is closed by the elevation of the soft palate and pulling forward of posterior pharyngeal wall (Passavant ridge).
  - This U-shaped muscle loop thus acts as a palatopharyngeal sphincter.
- **Piriform fossa** is a deep recess broad above and narrow below in the anterior part of lateral wall of the laryngopharynx, on each side of the laryngeal inlet.
  - These recesses are produced due to bulging of larynx into laryngopharynx.
  - Superiorly it is separated from epiglottic vallecula by lateral glossoepiglottic fold.
- **Swallowing** is the act of transferring a food bolus from the mouth through the pharynx and esophagus into the stomach. It has three phases: **Oral**, **pharyngeal** and **oesophageal**.
  - In **Oral Phase** the food bolus is pushed backward by elevating the tongue by the styloglossus and palatoglossus through the fauces into the oropharynx.
  - During **Pharyngeal Phase** tensor veli palatini and levator veli palatini muscles elevate the soft palate and uvula to close the entrance into the nasopharynx.
    - The walls of the pharynx are raised by the three longitudinal pharyngeal muscles (palatopharyngeus, stylopharyngeus, and salpingopharyngeus) to receive the bolus of food.
    - The suprahyoid muscles elevate the hyoid bone and the larynx to close the opening into the larynx, thus passing the bolus over the epiglottis and preventing the food from entering the respiratory passageways.
  - In **Esophageal Phase** there is sequential contraction of the three pharyngeal constrictor muscles (superior, middle, and inferior pharyngeal constrictors) that moves the bolus down into the esophagus, where it is propelled further by peristalsis into the stomach.

Clinical Correlations

- Inferior constrictor muscle has two parts: Upper thyropharyngeus made up of oblique fibres and lower cricopharyngeus made up of transverse fibres.
  - There is a potential gap posteriorly between the two parts called as pharyngeal dimple or **Killian's dehiscence**.
  - The propulsive thyropharyngeus is supplied by the pharyngeal plexus and the sphincteric cricopharyngeus is supplied by the recurrent laryngeal nerve.
  - In a case of neuromuscular incoordination the cricopharyngeus may fail to relax while the thyropharyngeus contracts, the bolus of food may get pushed backwards and tend to produce a diverticulum.
  - Through this weak area the mucosa and submucosa of the pharynx bulge to form a pharyngeal pouch or **Zenker's diverticulum**.

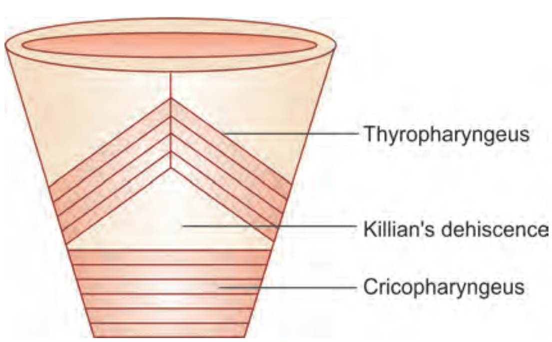


Fig. 153: Killian's dehiscence

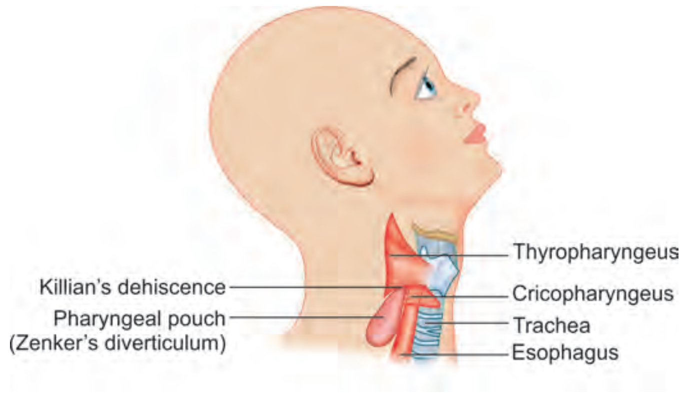


Fig. 154: Pharyngeal diverticulum

- Fascia and spaces related to pharynx: The two named layers of fascia in the pharynx are the Pharyngobasilar and buccopharyngeal fascia.
  - **Pharyngobasilar Fascia** forms the submucosa of the pharynx.
    - It blends with the periosteum of the base of the skull attaching to the basilar part of the occipital bone and the petrous part of the temporal bone medial to the pharyngotympanic tube, and to the posterior border of the medial pterygoid plate and the pterygomandibular raphe.
    - It lies internal to the muscular coat of the pharynx.

- **Buccopharyngeal fascia** covers the muscular wall of pharynx externally, and basically is the thinner external part of the epimysium.
  - It covers the superior constrictor and passes forwards over the pterygomandibular raphe to cover buccinator.
  - Above the upper border of the superior constrictor, it blends with the pharyngobasilar fascia.

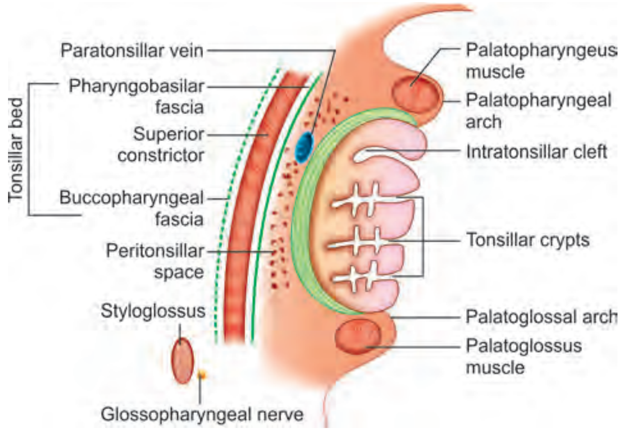


Fig. 155: Relations of tolsis (Tonsilar bed).

- **Retropharyngeal Space** is a potential space between the buccopharyngeal fascia and the prevertebral fascia, extending from the base of the skull to the superior mediastinum.
- It permits movement of the pharynx, larynx, trachea, and esophagus during swallowing.

ASSESSMENT QUESTIONS

1. **Lower border of pharynx is the level of:** *(NEET Pattern 2015)*
   a. C2
   b. C3
   c. C4
   d. C6

2. **Which of the following structures is seen in oropharynx?** *(NEET Pattern 2014)*
   a. Pharyngotympanic tube
   b. Fossa of Rosenmuller
   c. Palatine tonsil
   d. Piriform fossa

3. **Which of the following part is NOT included in hypopharynx?**
   a. Pyriform sinus
   b. Post cricoid region
   c. Anterior pharyngeal wall
   d. Posterior pharyngeal wall

4. **Killian dehiscence is in:** *(NEET Pattern 2012)*
   a. Superior constrictor
   b. Inferior constrictor
   c. Middle constrictor
   d. None

5. **Location of pyriformis fossa:** *(NEET Pattern 2012)*
   a. Nasopharynx
   b. Oropharynx
   c. Laryngeal part of pharynx
   d. None

6. **Passavant ridge is formed by:** *(NEET Pattern 2012)*
   a. Tensor veli palati and superior constrictor
   b. Palatopharyngeus and superior constrictor
   c. Palatopharyngeus and inferior constrictor
   d. Palatoglossus and superior constrictor

7. **Sinus of Morgagni is between:** *(NEET pattern 2014)*
   a. Middle constrictor and inferior constrictor
   b. Middle constrictor and superior constrictor
   c. Superior constrictor and skull
   d. None of the above

8. **Eustachian tube passes between:** *(NEET Pattern 2012)*
   a. Superior and middle constrictors
   b. Above superior constrictor
   c. Middle and inferior constrictor
   d. Below inferior constrictor

9. **Which of the following passes between base of the skull and superior constrictor muscle?** *(AIIMS)*
   a. Eustachian tube, levator palatini muscle, ascending palatine artery
   b. Maxillary nerve and levator palatine muscle
   c. Eustachian tube and stylopharyngeus muscle
   d. Ascending palatine artery and glossopharyngeal nerve

10. **Rouviere's nodes are situated in:** *(NEET Pattern 2012)*
    a. Nasopharynx
    b. Oral cavity
    c. Retropharynx
    d. Clavicular nodes

11. **Eustachian tube opens:** *(NEET Pattern 2012)*
    a. Above superior turbinate
    b. Behind posterior end of inferior turbinate
    c. Anterior to inferior turbinate
    d. Between superior and middle turbinate

12. **Gerlach tonsil is:** *(NEET Pattern 2013)*
    a. Palatine tonsil
    b. Lingual tonsil
    c. Tubal tonsil
    d. Nasopharyngeal tonsil

13. **What is present in the retropharyngeal space of Gillette?** *(NEET Pattern 2012)*
    a. Platysma
    b. Loose areolar tissue and lymph nodes
    c. Vertebrae
    d. Hypoglossal nerve

ANSWERS WITH EXPLANATIONS

1. d. C6
- Pharynx, the upper portion of gut tube, is funnel-shaped fibromuscular tube that extends from the base of the skull to the inferior border of the cricoid cartilage at the level of C6 vertebra.
- It continues inferiorly as the esophagus.

2. c. Palatine tonsil
- Palatine tonsils are present in tonsillar fossa in the oropharynx.
- Pharyngeal recess (fossa of Rosenmüller) is a deep depression behind the tubal elevation (opening of pharyngotympanic tube) in nasopharynx.
- Piriform fossa is a deep recess broad above and narrow below in the anterior part of lateral wall of the laryngopharynx, on each side of the laryngeal inlet.

3. c. Anterior pharyngeal wall
- Hypopharynx (laryngopharynx) has no description of anterior pharyngeal wall.
- The anterior relations are: Inlet of larynx, posterior surface of cricoid and arytenoid cartilage.

4. b. Inferior constrictor
- Inferior constrictor muscle has two parts: Upper thyropharyngeus made up of oblique fibres and lower cricopharyngeus made up of transverse fibres.
- There is a potential gap posteriorly between the two parts called as pharyngeal dimple or **Killian's dehiscence**.

5. c. Laryngeal part of pharynx
- Piriform fossa is a deep recess broad above and narrow below in the anterior part of lateral wall of the laryngopharynx, on each side of the laryngeal inlet.

6. b. Palatopharyngeus and superior constrictor
- Some fibres of the **palatopharyngeus** muscle (arising from palatine aponeurosis) sweep horizontally backwards and join the upper fibres of the **superior constrictor** muscle to form a U-shaped muscle-loop in the posterior pharyngeal wall underneath the mucosa, which is pulled forward during swallowing to form the **Passavant ridge**.

7. c. Superior constrictor and skull
- Sinus of Morgagni is a gap between the base of skull and the upper concave border of superior constrictor muscle.
- Structures passing through that are: Auditory tube, levator palati muscle, ascending palatine artery and palatine branch of the ascending pharyngeal artery.

8. b. Above superior constrictor
- Eustachian tube passes through sinus of Morgagni, which is a gap between the base of skull and the upper concave border of superior constrictor muscle.

9. a. Eustachian tube, levator palatini muscle, ascending palatine artery
- Between base of the skull and superior constrictor muscle lies the Morgagni sinus, through which passes the auditory tube, levator palati muscle, ascending palatine artery and palatine branch of the ascending pharyngeal artery.

10. c. Retropharynx
- Rouviere's node is the most superior of the lateral group of the retropharyngeal lymph nodes found at the base of the skull.

11. b. Behind posterior end of inferior turbinate
- Eustachian tube opens into the nasopharynx, 1.25 cm behind the posterior end of inferior turbinate.

12. c. Tubal tonsil
- Gerlach tonsil is the lymphoid collection at the pharyngeal opening of auditory tube (tubal tonsils).

13. b. Loose areolar tissue and lymph nodes
- **Retropharyngeal Space** is a potential space between the buccopharyngeal fascia and the prevertebral fascia, extending from the base of the skull to the superior mediastinum.
- It permits movement of the pharynx, larynx, trachea, and esophagus during swallowing.

Esophagus

Esophagus is a muscular tube (approximately 25 cm long), begins at the lower border of the pharynx at the level of the cricoid cartilage (C6), descends behind the trachea, passes through superior and posterior mediastinum and ends in the stomach at T11.

Constrictions:

Site of constriction	Vertebral level	Distance from upper incisor
Beginning (pharyngo-oesophagus junction)	C6	15 cm
Aortic arch	T4	23 cm
Left principal bronchus	T6	28 cm
Esophageal hiatus in diaphragm	T10	40 cm

- Radiology books mention an additional constriction at the level of left atrium (Not mentioned in Gray's Anatomy 41Ed)
- Esophagus is the second narrowest part of the alimentary tract, the narrowest being the vermiform appendix.

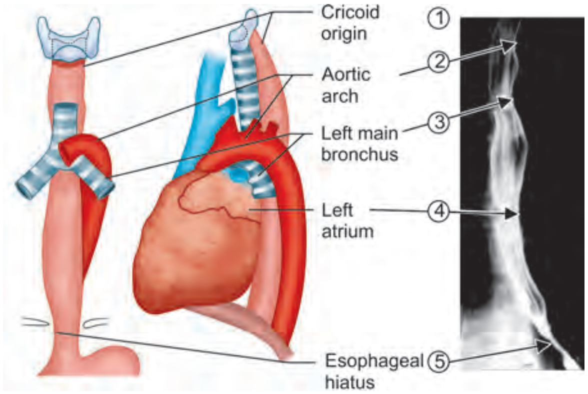


Fig. 156: The normal esophageal constrictions

- Upper third of the esophagus, the muscularis externa is formed by skeletal muscle; in the middle third, smooth muscle fascicles intermingle with striated muscle; and this increases distally such that the lower third contains only smooth muscle (Gray's Anatomy; Ed41).
- Upper 5% of the esophagus consists of skeletal muscle only. The middle 45% of the esophagus consists of both skeletal muscle and smooth muscle interwoven together. The distal 50% has smooth muscle only (Another view)

Region	Arterial supply	Venous drainage*	Lymphatic drainage	Nerve supply
Cervical	Inferior thyroid arteries (subclavian artery → thyrocervical trunk → inferior thyroid artery)	Inferior thyroid veins → brachiocephalic veins → superior vena cava	Paratracheal (into deep cervical lymph nodes)	• Vagus (Recurrent laryngeal nerves) • Sympathetic trunk
Thoracic	Descending thoracic aorta branches • Oesophageal • Bronchial arteries	• Azygous vein • Hemiazygos veins • Intercostal veins • Bronchial veins	Posterior mediastinal nodes	• Vagus • T1-4 (sympathetic)
Abdominal	• Left gastric artery • Inferior phrenic artery (Left) • Short gastric artery • Posterior gastric artery	• Left gastric vein** • Short gastric	• Left gastric lymph nodes • Thoracic duct (directly)	• Vagus • T5-12 (sympathetic)

*Venous drainage: Blood from the esophagus drains into a submucous plexus and thence into a peri-esophageal venous plexus, from which the esophageal veins arise.
** Left gastric vein → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava.

- **Vagal parasympathetic fibres** are motor to the distal esophagus and both stimulatory and inhibitory to the lower esophageal sphincter, maintaining basal tone and coordinating distal esophageal peristalsis with relaxation of the sphincter during swallowing (the latter being mediated by intrinsic nitrergic inhibitory neurons under vagal control).
- **Sympathetic supply** of the distal esophagus originates from T5-12 spinal nerves mainly via the greater and lesser splanchnic nerves and the coeliac plexus.
- Nociceptive signals are conveyed by afferent nerves accompanying sympathetic nerves and by vagal afferents, which are also involved in mechanosensory signalling.

Relations

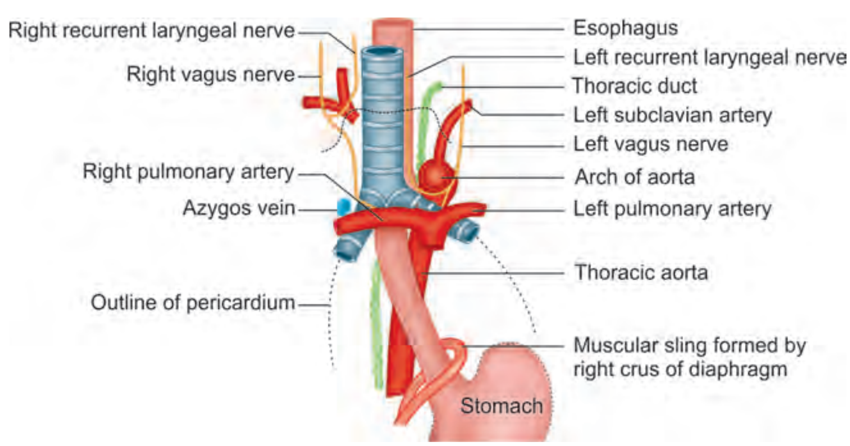


Fig. 157: Anterior and lateral relations of esophagus.

Clinical Correlations

- **Achalasia of esophagus** is failure of relaxation of the inferior esophageal sphincter (LES), resulting from degeneration of myenteric (Auerbach) plexus in the esophagus.
- It leads to dysphagia for solids and liquids. Barium swallow shows dilated esophagus above the LES and distal stenosis (bird beak appearance).
- Esophageal varices (varicosities) may occur in cases of portal hypertension, leading to massive bleeding (haematemesis and melena).
- Dilated subepithelial and submucosal venous plexuses are observed in esophagus as high pressure blood is shunted from portal into systemic circulation [Portal vein →left gastric (coronary) vein → esophageal veins →azygos vein→ vena cava].
- Barrett esophagus presents with the replacement of esophageal stratified squamous epithelium (whitish mucosa. with 'intestinal metaplasia' - simple columnar epithelium (with Goblet cells).
- It is a predisposing factor for esophageal adenocarcinoma.

ASSESSMENT QUESTIONS

1. What is the arterial supply of the thoracic esophagus? *(NEET Pattern 2012)*
a. Inferior thyroid artery
b. Inferior phrenic artery
c. Bronchial artery
d. Left gastric artery

2. Venous drainage of esophagus: *(AIIMS 2014)*
a. Azygos vein, inferior thyroid vein, right gastric vein
b. Azygos vein, inferior thyroid vein, left gastric vein
c. Azygos vein, right gastric vein, left gastric vein
d. Superior thyroid vein, inferior thyroid vein, azygos vein, hemiazygos vein

3. Extent of esophagus is: *(NEET Pattern 2015)*
a. C3- C6
b. C6-T11
c. T10-T12
d. None

4. Second constriction in esophagus is seen at the following site: *(NEET Pattern 2015)*
a. Where it crosses left main bronchus
b. Crossing of aorta
c. At pharyngoesophageal junction
d. Where it pierces the diaphragm

5. Distance of the lower esophageal sphincter from the upper incisors is: *(NEET Pattern 2012)*
a. 15 cm
b. 22.5 cm
c. 27.5 cm
d. 37.5 cm

ANSWERS WITH EXPLANATIONS

1. c. Bronchial artery
- Thoracic esophagus is supplied by the branches of descending thoracic aorta like bronchial arteries.
- Inferior thyroid artery supply cervical esophagus.
- Inferior phrenic artery and left gastric artery supply the abdominal esophagus.

2. b. Azygous vein, inferior thyroid vein, left gastric vein
- Cervical esophagus drains into inferior thyroid vein, thoracic into azygous venous system and abdominal oesophagus into the left gastric vein.

3. b. C6-T11
- Oesophagus begins at the lower border of cricoid cartilage (C6 vertebral level) and opens into stomach at T11 vertebral level.

4. b. Crossing of aorta
- Second constriction of esophagus lies at the level of crossing of arch of aorta (23 cm from upper incisors).

5. d. 37.5 cm
- Lower esophageal sphincter lies at a distance of 40 cm (some authors mention 37.5 cm) from the upper incisors.

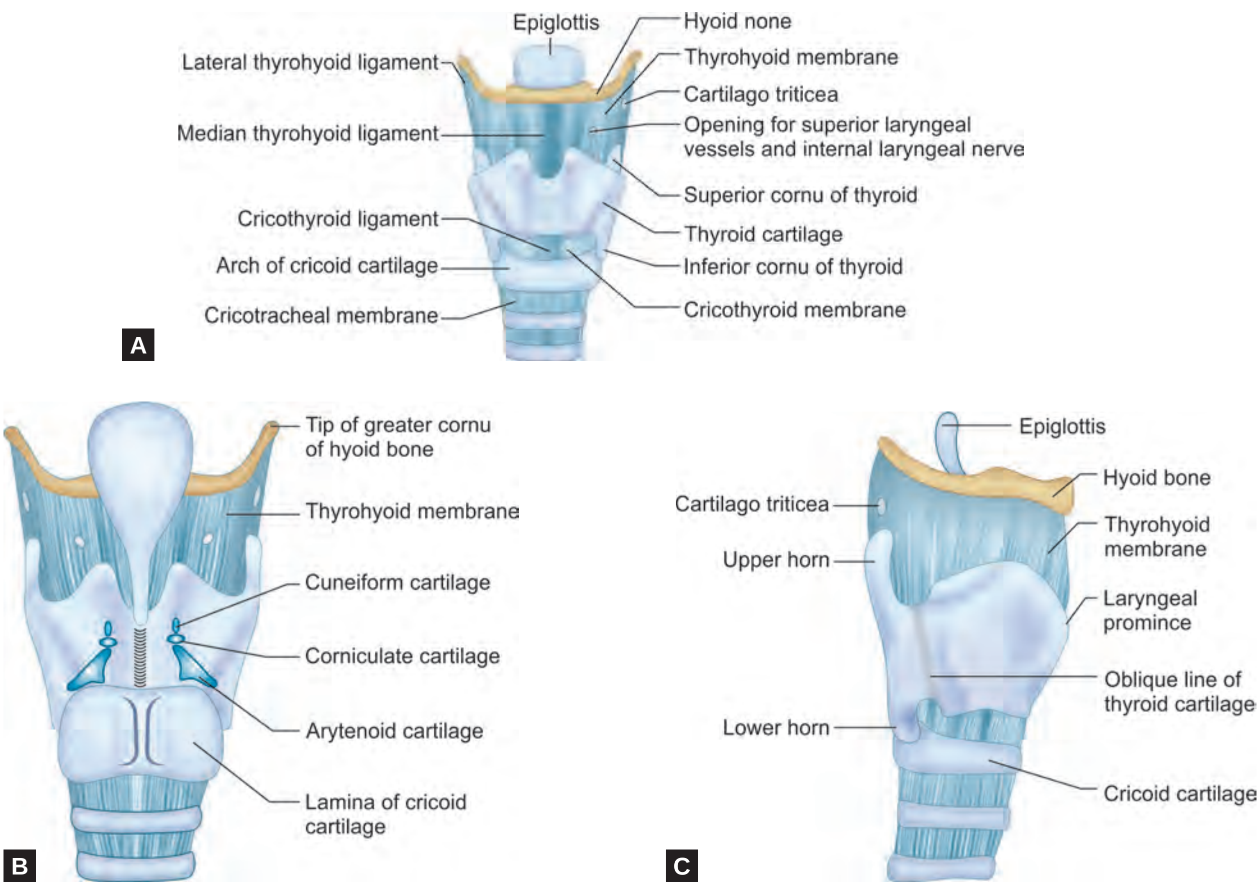
High Yield Point

- The cricopharyngeus muscle, the sphincter of the upper esophageal opening, remains closed except during deglutition (swallowing) and emesis (vomiting).

Larynx

- Larynx is a component of respiratory tube working as a conduit of air, protects the airway (sphincter action), is involved in phonation (speech) and help in deglutition.
- It is situated in front of laryngopharynx, extends from the root of the tongue to the trachea and lies in front of the C3, 4, 5 vertebrae (higher level in females and still higher in children).
- It has total 9 cartilages (3 paired and three unpaired). The unpaired cartilages are large and in the midline: **Thyroid, cricoid** and **epiglottis**. The paired cartilages are small and include: **Arytenoid, corniculate** and **cuneiform.**
- Some authors include a pair of **tritiate** cartilage under larynx skeleton.
- **Thyroid cartilage** is the largest cartilage of larynx and made up of hyaline variety.
- It has two quadrilateral laminae, which meet in front at an angle called thyroid angle forming a laryngeal prominence known as the Adam's apple (apparent in males).
- It is acute (90°) in males and obtuse (120°).

- Thyroid cartilage has a superior horn that is joined to the tip of the greater horn of the hyoid bone by the lateral thyroid ligament and an inferior horn that articulates with the cricoid cartilage.
- It has an oblique line on the lateral surface of its lamina that gives attachment for the inferior pharyngeal constrictor, sternothyroid, and thyrohyoid muscles.
- **Cricoid cartilage** is hyaline variety and forms a complete ring (signet), lies at the level of C6 vertebra and articulates with the thyroid cartilage.
- Its lower border marks the end of the pharynx and larynx.
- **Epiglottis** is made up of elastic cartilage and is a spoon-shaped plate that lies behind the root of the tongue and forms the superior part of the anterior wall of the larynx.
- The lower end attaches to the back of the thyroid cartilage.
- **Arytenoid** cartilages are paired hyaline cartilages (partly elastic).
- They are pyramid shaped, with bases that articulate with and rotate on the cricoid cartilage.
- The have vocal processes, which give attachment to the vocal ligament and vocalis muscle, and muscular processes, which give attachment to the thyroarytenoid muscle and the lateral and posterior cricoarytenoid muscles.
- It sits on the top of the cricoid cartilage and rotates to change the opening of the vocal folds (rima glottidis).
- **Corniculate** cartilages are paired elastic cartilages that lie on the apices of the arytenoid cartilages, enclosed within the aryepiglottic folds of mucous membrane.
- **Cuneiform** cartilages are also paired elastic cartilages that lie in the aryepiglottic folds anterior to the corniculate cartilages.



Figs. 158A to C: Skeleton of the larynx: (A) Anterior view; (B) posterior view; (C) lateral view

Unpaired	Paired
Thyroid	Arytenoid
Cricoid	Corniculate
Epiglottis	Cuneiform

Hyaline Cartilage	Elastic cartilage
Thyroid	Epiglottis
Cricoid	Corniculate
Basal part of arytenoid cartilage	Cuneiform
	Process of arytenoids

- The ligaments of the larynx are two types: **Extrinsic** membrane or ligament attaches to the structures outside the larynx, i.e. to the hyoid bone or trachea, whereas **intrinsic** membranes join structures within the larynx but not extending to hyoid bone or trachea.
- **Extrinsic** ligaments connect the thyroid cartilage and epiglottis with the hyoid bone, and the cricoid cartilage with the trachea:
  - **Thyrohyoid** membrane connects thyroid cartilage to hyoid bone and is pierced by superior laryngeal vessels and internal laryngeal nerve
  - **Cricotracheal** membrane connects cricoid cartilage to the first tracheal ring
  - **Hyoepiglottic** ligament attaches epiglottis to hyoid bone.
- **Intrinsic** ligaments connect the several cartilages of the larynx to each other.
  - Beneath the mucous membrane of the larynx is a broad sheet of fibrous tissue containing many elastic fibers, and termed the **elastic membrane** of the larynx. It is subdivided on either side by the interval between the ventricular and vocal ligaments.
  - The upper portion extends between the arytenoid cartilage and the epiglottis and is often poorly defined (**Quadrangular membrane**). The lower part is a well-marked membrane forming, with its fellow of the opposite side, the **conus elasticus** which connects the thyroid, cricoid, and arytenoid cartilages to one another.
  - **Conus Elasticus** (Cricovocal Ligament) is the paired lateral portion of the fibroelastic membrane that extends between the superior border of the entire arch of the cricoid cartilage and the vocal ligaments. It is formed by the cricothyroid, median cricothyroid, and vocal ligaments.

Extrinsic and intrinsic membranes and ligaments of the larynx		
	Extrinsic	**Intrinsic**
Membranes	• Thyrohyoid	• Cricovocal (conus elasticus)
	• Cricotracheal	• Quadrate/Quadrangular
Ligaments	• Median and lateral thyroid	• Vocal
	• Cricotracheal	• Vestibular • Cricothyroid

- **Vocal Ligament** extends from the posterior surface of the thyroid cartilage to the vocal process of the arytenoid cartilage, and is considered the upper border of the conus elasticus.
- **Vestibular** (Ventricular) Ligament extends from the thyroid cartilage to the anterior lateral surface of the arytenoid cartilage.
- **Thyrohyoid Membrane** extends from the thyroid cartilage to the medial surface of the hyoid bone. The middle thicker region is called the middle thyrohyoid ligament, the lateral portion gets pierced by the internal laryngeal nerve and the superior laryngeal vessels.
- **Cricothyroid Ligament** extends from the arch of the cricoid cartilage to the thyroid cartilage and the vocal processes of the arytenoid cartilages.

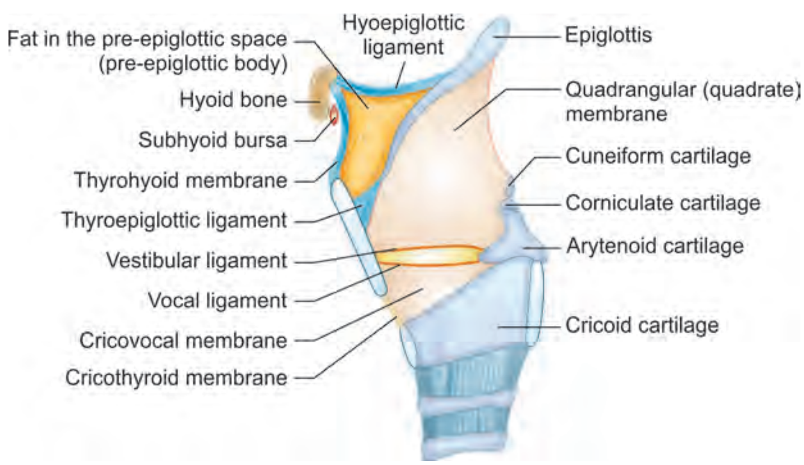


Fig. 159: Sagittal section of the larynx showing ligaments and membranes. Note the location of quadrangular and cricovocal membranes

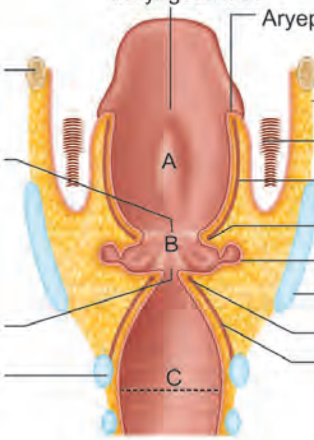


Fig. 160: Coronal section of the laryngeal cavity showing its subdivisions. A = vestibule, B = ventricle of the larynx, C = infraglottic compartment

Clinical Correlations

- Laryngotomy may be required in case of severe edema or an impacted foreign body calls for rapid admission of air into the larynx and trachea.
- It can be performed through the cricothyroid membrane (cricothyrotomy), through the thyroid cartilage (thyrotomy), or through the thyrohyoid membrane (superior laryngotomy).
- The cavity of larynx is divided into three parts by the vestibular and vocal folds: **Vestibule**, **ventricle**, and **infraglottic compartment**.
- **Vestibule** extends from the laryngeal inlet to the vestibular (ventricular) folds.
- **Ventricle** of larynx extend between the vestibular fold and the vocal fold.
- **Infraglottic compartment** extends from the rima glottidis to the lower border of the cricoid cartilage.
- **Rima Glottidis** is the space between the vocal folds and arytenoid cartilages and is the narrowest anteroposterior cleft of the laryngeal cavity. The anteroposterior diameter of glottis is 24 mm in adult males and 16 mm in adult females.
- **Vestibular Folds** (False Vocal Cords) extend from the thyroid cartilage above the vocal ligament to the arytenoid cartilage.
- **Vocal Folds** (True Vocal Cords) extend from the angle of the thyroid cartilage to the vocal processes of the arytenoid cartilages.
  - They contain the vocal ligament near their free margin and the vocalis muscle.
  - Vocal folds alter the shape and size of the rima glottidis by movement of the arytenoids and control the stream of air passing through the rima glottidis to facilitate respiration and phonation.
  - Rima glottidis becomes wide during inspiration and narrow and wedge-shaped during expiration and sound production.

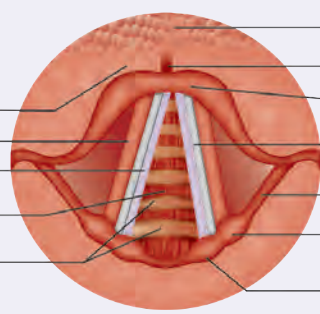


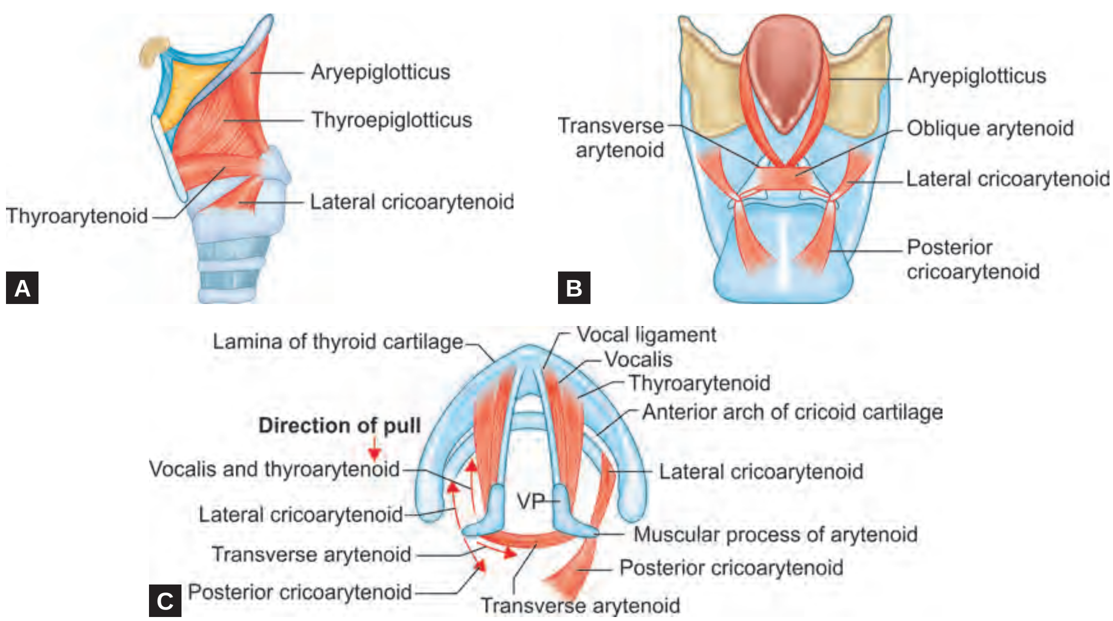
Fig. 161: The sagittal section through the nose, mouth, pharynx, and larynx

- Muscles of larynx are two types: Intrinsic and extrinsic
- Intrinsic muscles: Most of the muscles in the larynx are **adductors** of vocal cord (closure of glottis), the only **abductor** muscle is **posterior cricoarytenoid**, which is called the safety muscle of larynx. It abducts the vocal cords to let pass the air through laryngeal sphincter for breathing.
- **Cricothyroid** muscle is a tensor of vocal cord and raises the pitch of voice, whereas posterior part of **thyroarytenoid** muscle is a relaxor of vocal cords while maintaining (or increasing) tension in the anterior part.
- Primary elevators of larynx are attached to the thyroid cartilage and pull it up: Stylopharyngeus, salpingopharyngeus, palatopharyngeus and thyrohyoid.
- Secondary elevators act indirectly as they are attached to the hyoid bone: Mylohyoid, digastric, stylohyoid, geniohyoid.
- Depressors of larynx are: Sternohyoid, sternothyroid and omohyoid.

Muscles of Larynx				
Muscle	**Origin**	**Insertion**	**Innervation**	**Main Action(s)**
Cricothyroid	Anterolateral part of cricoid cartilage	Inferior margin and inferior horn of thyroid cartilage	External laryngeal nerve (from CN X)	Stretches and tenses vocal ligament
Thyro-arytenoid[a]	Lower half of posterior aspect of angle of thyroid laminae and cricothyroid ligament	Anterolateral arytenoid surface		Relaxes vocal ligament
Posterior crico-arytenoid	Posterior surface of lamina of cricoid cartilage	Vocal process of arytenoid cartilage	Inferior laryngeal nerve (terminal part of recurrent laryngeal nerve, from CN X	Abducts vocal folds
Lateral cricoarytenoid	Arch of cricoid cartilage			Adducts vocal folds (interligamentous portion)
Transverse and oblique arytenoids[b]	One arytenoid cartilage	Contralateral arytenoid cartilage		Adduct arytenoid cartilages (adducting intercartilaginous portion of vocal folds, closing posterior rima glottidis)
Vocalis[c]	Lateral surface of vocal process of arytenoid cartilage	Ipsilateral vocal ligament		Releaxes posterior vocal ligament while maintaining (or increasing) tension of anterior part

[a]Superior fibers of the thyro-arytenoid muscles pass into the ary-epiglottic fold, and some of them reach the epiglottic cartilage. These fibers constitute the thyro-epiglottic muscle, which widens the laryngeal inlet.
[b]Some fibers of the oblique arytenoid muscles continue as ary-epiglottic muscles
[c]This slender muscle slip lies medial to and is composed of fibers finer than those of the thyro-arytenoid muscle.

Cricothyroid	Stretches and tenses vocal ligament	Posterior cricoarytenoid	Abducts vocal folds
Thyro-arytenoid Vocalis	Relaxes vocal ligament Relaxes posterior vocal ligament while maintaining (or increasing) tension of anterior part	Lateral cricoarytenoid	Adducts vocal folds (ligamen-tous portion)
		Transverse and oblique arytenoids	Adduct arytenoid cartilages



Figs. 162A to C: Intrinsic muscles of the larynx: (A) lateral view; (B) posterior view; (C) direction of pull of some intrinsic muscles (VP = vocal process of arytenoid)

Extrinsic Muscles of Larynx

- **Arterial** supply: Above the vocal fold by superior laryngeal artery (branch of superior thyroid artery); below the vocal fold by inferior laryngeal artery (branch of inferior thyroid artery). Rima glottidis has dual blood supply.
- **Venous** drainage: Superior laryngeal vein (drains into the superior thyroid vein) and inferior laryngeal vein (drains into the inferior thyroid vein).
- **Lymphatic drainage**: Lymphatics above the vocal cords pierce the thyrohyoid membrane, run along superior thyroid vessels and drain into upper deep cervical lymph nodes (anterosuperior group) and below the vocal cords pierce the cricothyroid membrane, reach prelaryngeal and pretracheal nodes, and drain into lower deep cervical lymph nodes (posteroinferior group).
- **Nerve supply**: Vagus nerve gives two branches to supply larynx: **Superior laryngeal** nerve and **recurrent laryngeal** nerve.
- **Superior laryngeal nerve** arises from the inferior ganglion of the vagus, runs downwards and forwards on the superior constrictor, deep to the internal carotid artery, and reaches the middle constrictor where it divides into the external and internal laryngeal nerve.
- **External laryngeal nerve** accompanies the superior thyroid artery, pierces the inferior constrictor and supplies the cricothyroid muscle. It also gives branches to the inferior constrictor and to the pharyngeal plexus.
- **Internal laryngeal nerve** passes downwards and forwards, pierces the thyrohyoid membrane and enters the larynx. It supplies the mucous membrane of the larynx up to the level of the vocal folds.
  - **Right recurrent laryngeal nerve** is a branch of vagus given in front of the right subclavian artery, winds backwards under the artery, and they runs upwards and medially behind the subclavian and common carotid arteries to reach the tracheoesophageal groove. In the upper part of the groove it is related to the inferior thyroid artery.
- **Left recurrent laryngeal nerve** arises from the vagus in the mediastinum at the level of arch of aorta, loops around it and then ascends into the neck in the tracheoesophageal groove. Left nerve has a longer course than the right, passes through thoracic aperture twice and is more prone to injury statistically.
- All the muscles of larynx develop in sixth arch and are supplied by recurrent laryngeal nerve except the cricothyroid muscle (develops in fourth arch and supplied by external Laryngeal nerve).
- Sensory supply to laryngeal mucosa above vocal cords is by internal laryngeal nerve and below the vocal cords by recurrent Laryngeal nerve.

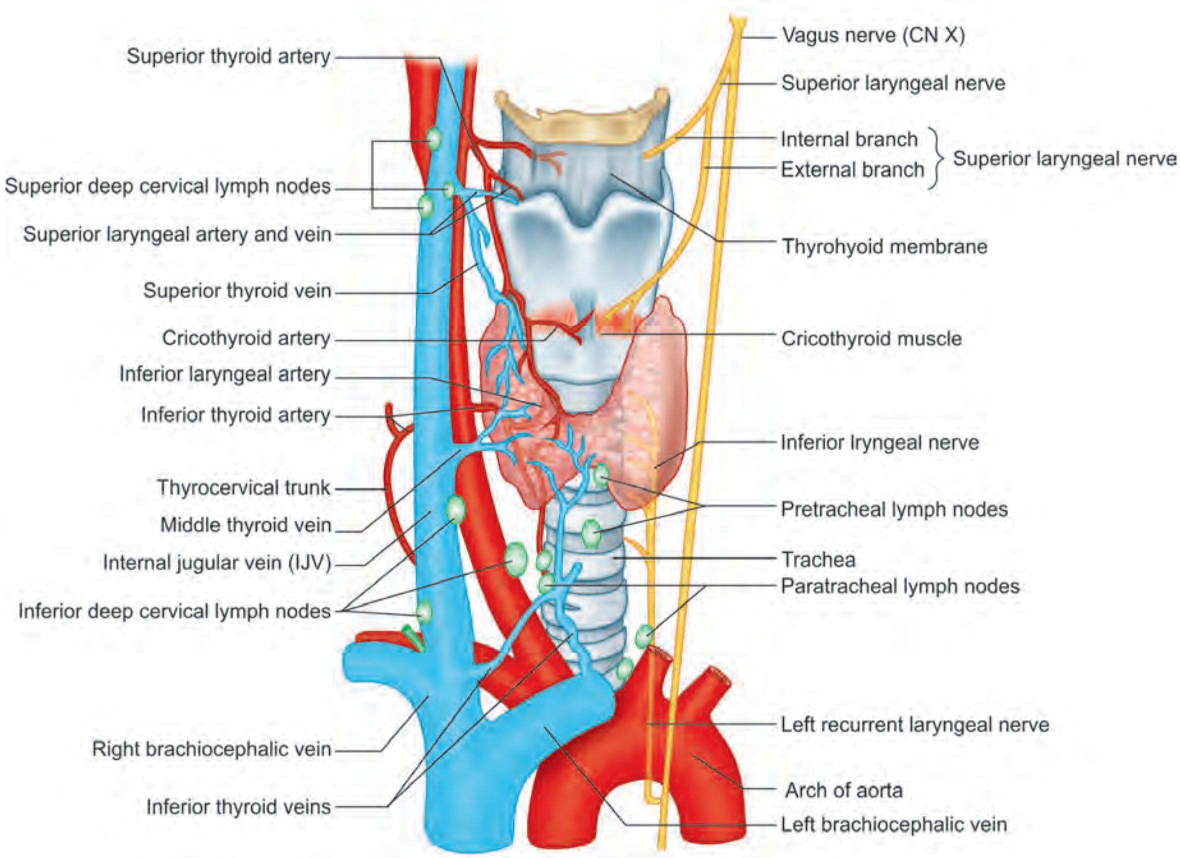


Fig. 163: Vessels, nerves, and lymph nodes of larynx. The superior and inferior thyroid arteries give rise to the superior and inferior laryngeal arteries, respectively, they anastomose with each other. The laryngeal nerves are derived from the vagus (CN X) through the internal and external branches of the superior laryngeal nerve and the inferior laryngeal nerve from the recurrent laryngeal nerve. The left recurrent laryngeal nerve passes inferior to the arch of the aorta

Clinical Correlations

- Damage to the external laryngeal (branch of superior laryngeal) nerve can result when ligating the superior thyroid artery during thyroidectomy.
- It can be avoided by ligating the superior thyroid artery at its entrance into the thyroid gland.
- Injury to the nerve result in a weak voice with loss of projection, and the vocal cord on the affected side appears flaccid.
- Unilateral damage to the recurrent laryngeal nerve can occur while ligating inferior thyroid artery during thyroidectomy.
- It results in loss of sensation below the vocal cord and a hoarse voice, inability to speak for long periods, and movement of the vocal fold on the affected side toward the midline.
- Bilateral injury to the recurrent laryngeal nerve results in acute breathlessness (dyspnea) since both vocal folds move toward the midline and close off the air passage (and tracheostomy might be required).
- **Cricothyrotomy** is an incision through the skin and cricothyroid membrane and insertion of a tracheotomy tube into the trachea for relief of acute respiratory obstruction.
- When making a skin incision, care must be taken not to injure the anterior jugular veins, which lie near the midline of the neck.
- It is preferable for non-surgeons to perform a tracheostomy for emergency respiratory obstructions.

ASSESSMENT QUESTIONS

1. Larynx extends from: *(NEET Pattern 2015)*
a. C2-C7
b. C1-C4
c. C5-C6
d. C3-C6

2. Function of larynx: *(NEET pattern 2015)*
a. Speech
b. Protection of airway
c. Conduit of air
d. All

3. Anterior posterior diameter of vocal cords in both males and females is: *(NEET pattern 2013)*
a. 24 and 36 mm
b. 36 and 48 mm
c. 23 and 17 mm
d. 48 and 36 mm

4. Paired laryngeal cartilage(s) is/are: *(PGIC 2014)*
a. Thyroid
b. Arytenoid
c. Corniculate
d. Cricoid
e. Cuneiform

5. Which of the following forms complete ring? *(AIIMS 2013)*
a. Thyroid cartilage
b. Cricoid
c. Cuneiform cartilage
d. Epiglottis

6. Which laryngeal cartilage is NOT elastic? *(NEET Pattern 2012)*
a. Epiglottis
b. Corniculate
c. Cuneiform
d. Thyroid

7. All of the following ligaments are components of external laryngeal membrane EXCEPT: *(AIIMS 2010)*
a. Cricothyroid
b. Thyrohyoid
c. Cricotracheal
d. Hyoepiglottic

8. False about larynx:
a. 9 cartilages: 3 paired and 3 unpaired cartilages
b. Extends from C3 to C6 vertebrae
c. External laryngeal nerve supply all larynx muscles except cricothyroid
d. Cricothyroid is a tensor of vocal cord

9. Nerve supply of larynx above level of vocal cord: *(NEET Pattern 2015)*
a. Superior laryngeal
b. Recurrent laryngeal
c. Glossopharyngeal
d. External laryngeal

10. Damage to the external laryngeal nerve during thyroid surgery could result in the inability to:
a. Relax the vocal cords
b. Tense the vocal cords
c. Widen the rima glottidis
d. Abduct the vocal cords

11. Wrong pair of matching regarding the muscles working on vocal cords: *(NEET Pattern 2012)*
a. Thyroarytenoid: Relaxor
b. Lateral cricoarytenoid: Adductor
c. Posterior cricoarytenoid: Abductor
d. Cricothyroid: Tensor

12. Which of the following doesn't elevate the larynx? *(NEET 2012)*
a. Sternohyoid
b. Thyrohyoid
c. Mylohyoid
d. None

13. Internal laryngeal nerve runs along which border of pharyngeal muscle: *(NEET Pattern 2013)*
a. Medial
b. Lateral
c. Superior
d. Inferior

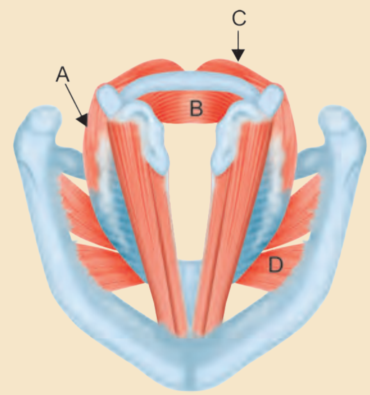
14. Injury of which of these nerve cause vocal cord paralysis? *(AIIMS)*
a. Recurrent laryngeal
b. External laryngeal
c. Internal laryngeal
d. Superior laryngeal

15. The recurrent laryngeal nerve supplies: *(PGIC)*
  a. Vocalis muscle
  b. Posterior cricoarytenoid
  c. Cricothyroid
  d. Stylopharyngeus
  e. Omohyoid

16. During a thyroid operation, a nerve coursing along with the superior thyroid artery is injured. What can be the possible consequence(s)? *(PGIC 2013)*
  a. Loss of sensation above vocal cord
  b. Loss of sensation below vocal cord
  c. Paralysis of lateral cricoarytenoid muscle
  d. Paralysis of cricothyroid muscle
  e. Loss of sensation in pyriform fossa

17. All of the following are true about the larynx EXCEPT: *(NEET Pattern 2012)*
  a. All intrinsic muscles are supplied by the recurrent laryngeal nerve
  b. Cricothyroid is supplied by the external laryngeal nerve
  c. Posterior cricoarytenoid abduct the vocal cords
  d. Lymphatic drainage of the larynx is to the deep cervical nodes

18. Which muscle is responsible for abduction of vocal cord, in the given diagram? *(AIIMS 2016).*
  a. A
  b. B
  c. C
  d. D



ANSWERS WITH EXPLANATIONS

1. d. C3-C6
- It is situated in front of laryngopharynx, extends from the root of the tongue to the trachea and lies in front of the C3, 4, 5 vertebrae in a normal adult male.

2. d. All
- Larynx is a component of respiratory tube working as a conduit of air, protects the airway (sphincter action), is involved in phonation (speech) and help in deglutition.

3. c. 23 and 17 mm
- Rima Glottidis is the space between the vocal folds and arytenoid cartilages and is the narrowest anteroposterior cleft of the laryngeal cavity.
- The anteroposterior diameter of glottis is 24 mm in adult males and 16 mm in adult females.

4. b. Arytenoid; c. Corniculate; e. Cuneiform
- Unpaired cartilages of larynx are in the midline: Epiglottis, thyroid and cricoid and paired cartilage are: Arytenoid, corniculate and cuneiform.

5. b. Cricoid
- Larynx has nine cartilages out of which only the cricoid makes a complete ring (signet shape).

6. d. Thyroid
- Larynx is made up of hyaline cartilage and partly elastic cartilage.
- Thyroid cartilage has hyaline variety.

7. a. Cricothyroid
- Cricothyroid membrane lies deep (under laryngeal mucosa) and belongs to internal laryngeal membrane.
- Cricothyroid ligament is present between cricoid and thyroid cartilage of the larynx.
- The median cricothyroid ligament is a flat band of white tissue joining the cricoid and thyroid cartilages.
- The lateral cricothyroid ligament is also known as the cricothyroid membrane (also called conus elasticus). This ligaments keep the two connected cartilages together preventing them from travelling far from each other.
- The upper margin of the membrane forms the true vocal cords.
- The ligament is cut during emergency cricothyrotomy.

8. c. External laryngeal nerve supply all larynx muscles except cricothyroid
- All larynx muscles are supplied by the recurrent laryngeal nerve except the cricothyroid muscle (supplied by the external laryngeal nerve).

9. a. Superior laryngeal
- Laryngeal mucosa up to the level of the vocal folds is innervated by the internal laryngeal nerve (branch of superior laryngeal nerve).
- Recurrent laryngeal nerve supplies it below the vocal cords.

10. b. Tense the vocal cords
- Injury to external laryngeal nerve leads to paralysis of cricothyroid muscle and inability to tense the vocal cords resulting in weakness of voice.

11. a. Thyroarytenoid: Relaxor
- The most appropriate answer is thyroarytenoid, though there is no perfect answer available.
- The posterior part of thyroarytenoid muscle is a relaxor of vocal cords while maintaining (or increasing) tension in the anterior part.
- Most of the muscles in the larynx (including **lateral cricoarytenoid**) are adductors of vocal cord.
- **Posterior cricoarytenoid** is the safety muscle of larynx, it abducts the vocal cords to let pass the air through laryngeal sphincter for breathing.
- **Cricothyroid** muscle is a tensor of vocal cord and raises the pitch of voice.

12. a. Sternohyoid
- Primary elevators of larynx are attached to the thyroid cartilage and pull it up: Stylopharyngeus, salpingopharyngeus, palatopharyngeus and thyrohyoid.
- Secondary elevators act indirectly as they are attached to the hyoid bone: Mylohyoid, digastric, stylohyoid, geniohyoid.
- Depressors of larynx are: Sternohyoid, sternothyroid and omohyoid.

13. c. Superior
- Internal laryngeal nerve (internal branch of superior laryngeal nerve) runs along the superior border of the inferior pharyngeal constrictor muscle and pierces the thyrohyoid membrane along with superior laryngeal vessels and enters the larynx.

14. a. Recurrent laryngeal
- Vocal cord movements depends upon the larynx muscles, most of which are supplied by the recurrent laryngeal nerve.
- Superior laryngeal nerve gives external laryngeal nerve which supplies only one muscle of larynx (cricothyroid).
- Internal laryngeal branch of superior laryngeal nerve is sensory.

15. a. Vocalis muscle, b. Posterior cricoarytenoid
- Recurrent laryngeal nerve supplies most of the larynx muscles (except cricothyroid).

16. d. Paralysis of cricothyroid muscle
- The nerve coursing along with the superior thyroid artery is external laryngeal nerve (branch of superior laryngeal nerve, vagus) which supplies cricothyroid muscle.
- All the muscles of larynx are supplied by recurrent laryngeal nerve except the cricothyroid muscle.
- Sensory supply to laryngeal mucosa above vocal cords is by internal laryngeal nerve and below the vocal cords by recurrent laryngeal nerve.

17. a. All intrinsic muscles are supplied by the recurrent laryngeal nerve
- All intrinsic muscles of larynx are supplied by the recurrent laryngeal nerve except cricothyroid which is supplied by the external laryngeal nerve.

18. c. C
- This is a question about posterior cricoarytenoid muscle, which is the only abductor of vocal cords in larynx.
- The diagram shows a transverse view of larynx, with muscles attached to various cartilages and named accordingly.
- Marker 'C' is the posteriormost muscle called posterior cricoarytenoid, attaching to cricoid and arytenoid cartilages.
- Marker 'A' is lateral cricoarytenoid muscle lying between cricoid and arytenoid cartilages. It is an adductor of vocal cords.
- Marker 'B' is the transverse arytenoid muscle, which is also an adductor of vocal cords.
- The muscle at marker 'D' is connecting thyroid cartilage with the cricoid cartilage and is called as cricothyroid muscle - a tensor of vocal cord.

Trachea

- Trachea is a part of respiratory tube, beginning below the larynx (level with the sixth cervical vertebra), and ends at the carina (at the level of the disc between T4-5 vertebra, opposite the sternal angle).
- Trachea begins at the inferior border of the cricoid cartilage (C6 vertebra) as a continuation of the larynx and terminates by bifurcating into right and left primary bronchi at upper border of 5th thoracic vertebra (Gray's anatomy; Ed40).

Gray's Anatomy (Ed 41)
Trachea descends from the larynx at the level of the C6 vertebra and divides into right and left principal bronchi typically inferior to the sternal plane, level with the upper half of the T6 vertebra (Mirjalili; 2012).

- The extent of trachea varies as follows:
- C6 to T4 in cadaver placed in supine position.
- C6 to T6 in living individuals in standing position (latest).
- C6 to T3 in newborn.

Note: Trachea lies in the midline but point of bifurcation is usually to the right side.

- Dimensions:
- Length: 10–11 cm (within a range of 8-16 cm).
- External diameter: 2 cm in males and 1.5 cm in females.
- Internal diameter: 12 mm in adult, 1-4 mm in newborn.
- Structure: A long tube formed of cartilage and fibromuscular wall, and lined internally by respiratory mucosa.
- The anterolateral portion of the trachea consists of 16–20 U-shaped superimposed incomplete rings of hyaline cartilage and posteriorly lies the trachealis muscle.
- The last tracheal ring merges into the incomplete rings at the origin of each principal bronchus; the bifurcation is marked by a cartilaginous spur, the **carina**, which can be observed by bronchoscopy as a raised ridge of tissue in the sagittal plane.
  - It is located about 25 cm from the incisor teeth and 30 cm from the nostrils.
- Arteries: Branches of the inferior thyroid arteries and their anastomosis with bronchial arteries.
- Veins: Inferior thyroid venous plexus.
- Lymphatics: Pretracheal and paratracheal lymph nodes.
- Nerves: branches of the vagus, recurrent laryngeal nerves and sympathetic trunks

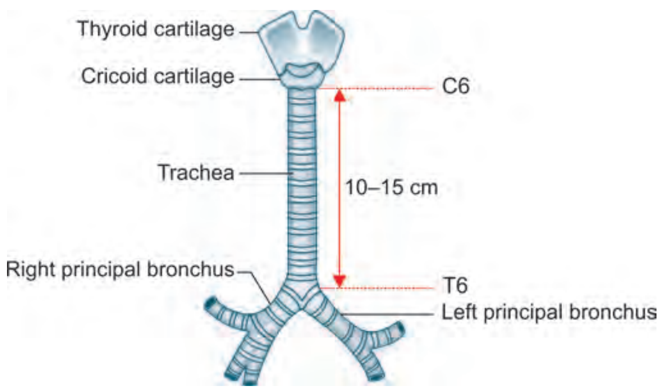


Fig. 164: Trachea-location and dimensions

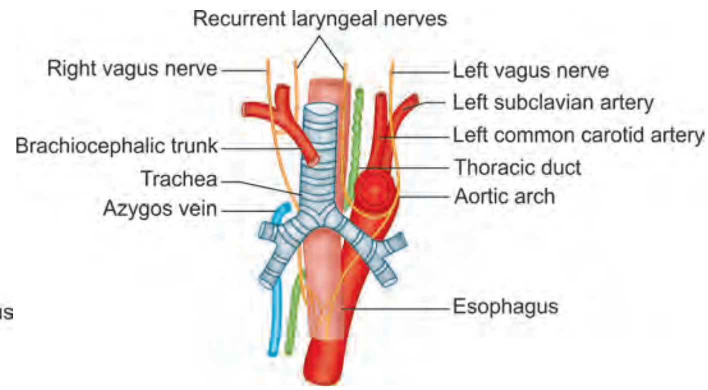


Fig. 165: Posterior and lateral relations of the trachea

ASSESSMENT QUESTIONS

1. Length of trachea is: *(NEET Pattern 2012)*
   a. 8-10 cm
   b. 10-12 cm
   c. 12-15 cm
   d. 15 cm

2. Tracheal bifurcation is at:
   a. Upper border of T4
   b. Lower border of T4
   c. Upper border of T5
   d. Lower border of T5

3. At what level does the trachea bifurcates? *(NEET Pattern 2012)*
   a. Upper border of T4
   b. Lower border of T4
   c. 27.5 cm from the incisors
   d. Lower border of T5

4. In emergency tracheostomy the following structures are damaged EXCEPT: *(AIIMS 2007)*
   a. Isthmus of the thyroid
   b. Inferior thyroid artery
   c. Thyroidea ima artery
   d. Inferior thyroid vein

ANSWERS WITH EXPLANATIONS

1. b. 10-12 cm
- Trachea has a length of about 8 to 16 cm (10-11 cm is mentioned in Gray's Anatomy Ed41).
- It commences at the lower border of the larynx, level with the sixth cervical vertebra.
- Inside the trachea at the level of the fifth thoracic vertebra (T5) there is a cartilaginous ridge known as the carina of trachea which runs across from the front to the back of the trachea and marks the point of bifurcation into the right and left primary bronchi.
- The carina is opposite the sternal angle and can be positioned up to two vertebrae lower or higher, depending on breathing.

2. c. Upper border of T5
- Trachea bifurcates into right and left primary bronchi at upper border of 5th thoracic vertebra (Gray's Anatomy Ed40).
- The answer depends upon the statements mentioned in the standard textbooks and it is advisable not to use personal logic and imagination.

3. b. Lower border of T4
- The most appropriate option has been taken as the answer.
- Trachea bifurcates into bronchi at the level of the disc between T4-5 vertebra, opposite the sternal angle.
- Trachea bifurcates into right and left primary bronchi at upper border of 5th thoracic vertebra (Gray's Anatomy Ed40).
- Trachea divides into right and left principal bronchi typically inferior to the sternal plane, level with the upper half of the T6 vertebra (Gray's Anatomy Ed41).
- Carina (at tracheal bifurcation) is located about 25 cm from the incisor teeth and 30 cm from the nostrils.

4. b. Inferior thyroid artery
- In **emergency tracheostomy** structures located in the midline may be damaged: Isthmus of thyroid gland, Inferior thyroid veins, thyroid ima artery, left brachiocephalic vein, thymus and pleura (especially infants).
- Inferior thyroid artery is not damaged in this procedure.

Ear

Ear is divided into three parts—the outer ear, middle ear and the inner ear.
- Outer ear consists of the pinna and the external ear canal.
- Middle ear includes the tympanic cavity and the three ossicles. It communicates with nasopharynx via the eustachian tube.
- Inner ear sits in the bony labyrinth, has the semicircular canals (for balance and eye tracking in motion); the utricle and saccule (for balance when stationary) and the cochlea (for hearing).

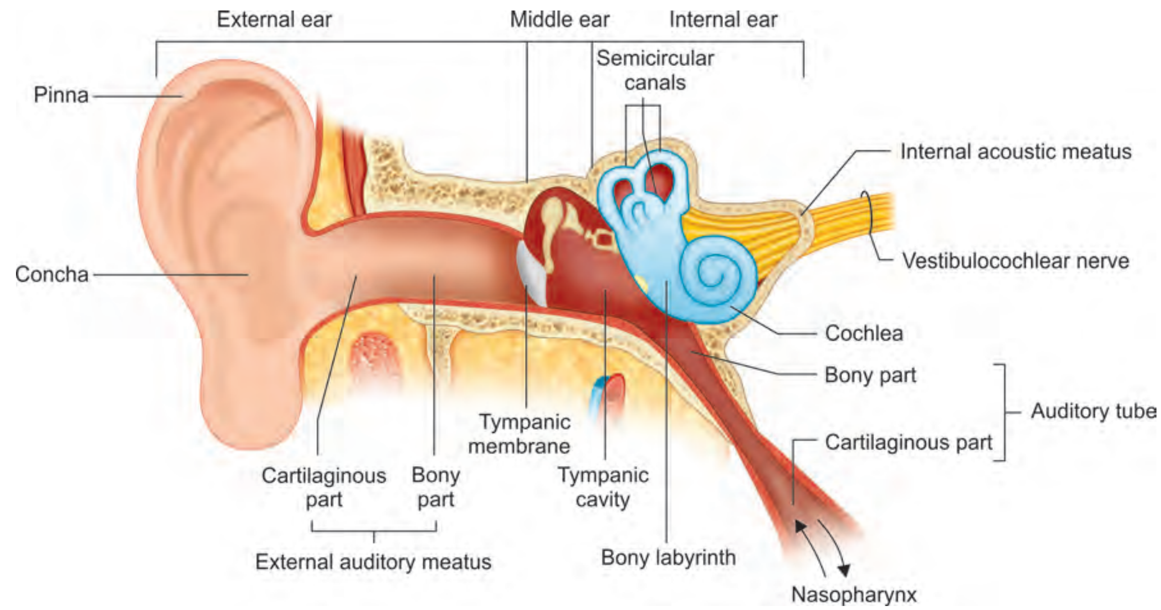
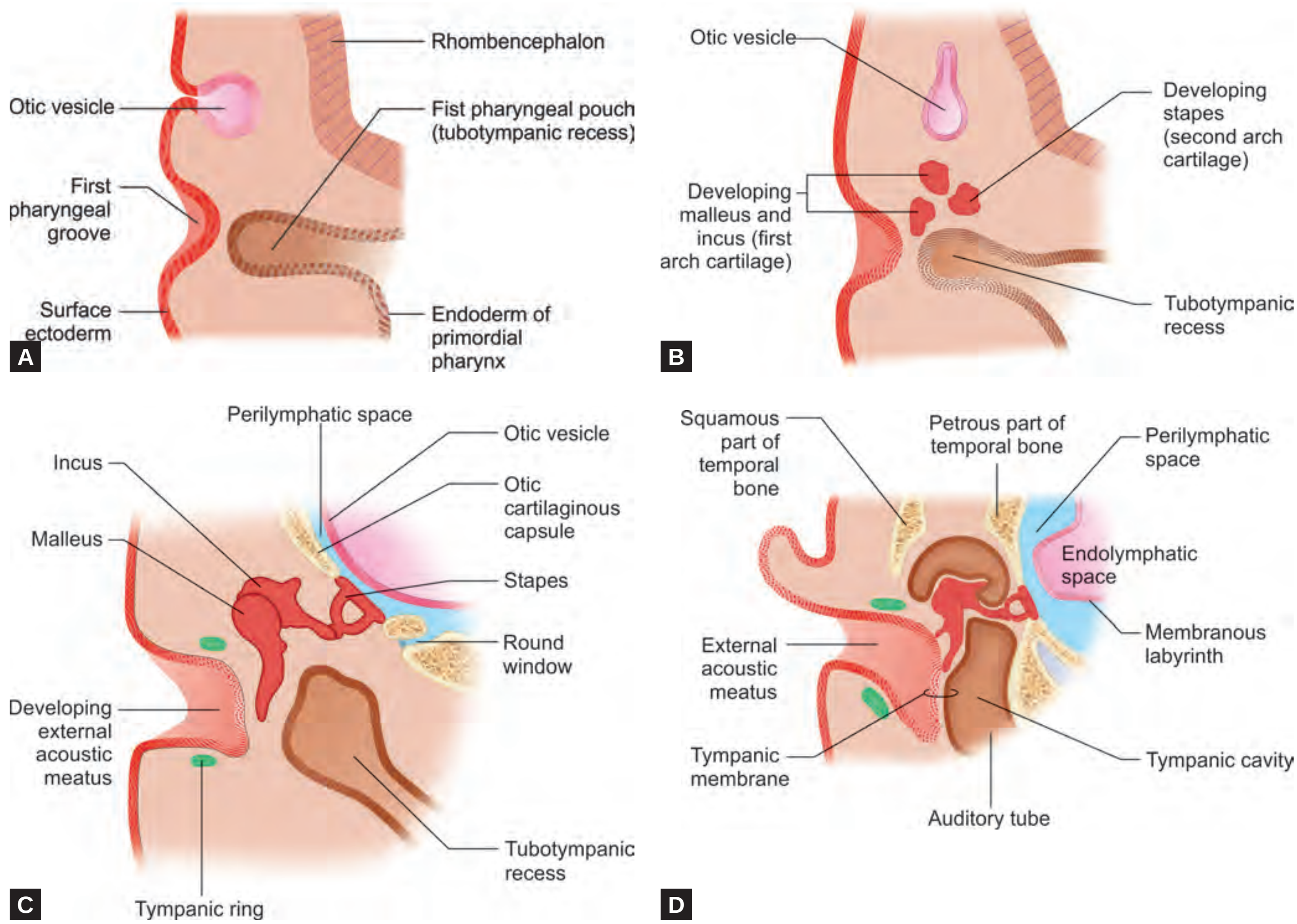


Fig. 166: The ear and its subdivisions (external, middle, and internal ear)

Ear - Development
- Internal ear develops from the **otic vesicle**, which is a derivative of the **otic placode** (surface ectoderm thickening), in the fourth week of development.
- This vesicle divides into a ventral component, which gives rise to the saccule and cochlear duct and a dorsal component, which gives rise to the utricle, semicircular canals, and endolymphatic duct.
- The epithelial structures thus formed are known collectively as the membranous labyrinth.
- Except for the cochlear duct, which forms the organ of Corti, all structures derived from the membranous labyrinth are involved with equilibrium.
- **Utricular** portion forms the utricle, semicircular ducts, and vestibular ganglion of CN VIII.
- **Saccular** portion forms the saccule, cochlear duct, and spiral ganglion of CN VIII.
- **Vestibular** pouch forms the semicircular canals, the utricle, and endolymphatic duct.
- **Cochlear** pouch gives rise to the saccule, which forms a diverticulum that, in turn, forms the cochlear duct.
- **Otic capsule** develops from the mesenchyme around the otocyst and forms the perilymphatic space, which develops into the scala tympani and scala vestibule.
- The **cartilaginous** otic capsule ossifies to form the **bony** labyrinth.

- The middle ear, consisting of the **tympanic cavity** and **auditory tube**, is lined with epithelium of endodermal origin and is derived from the first pharyngeal pouch.
- The ossicles are derived from the first (**malleus and incus**) and second (**stapes**) pharyngeal arches.
- The **external auditory meatus** develops from the first pharyngeal cleft and is separated from the tympanic cavity by the tympanic membrane.
- **Tympanic membrane** is derived from all the three germ layers: an ectodermal epithelial lining, an intermediate layer of mesenchyme, and an endodermal lining from the first pharyngeal pouch.



Figs. 167A to D: Schematic drawings showing development of the ear. (A) This drawing shows the relationship of te surface ectoderm derived otic vesicle to the first pharyngeal arch during the fourth week of development. (B) The otic vesicle sinks deep into the mesenchymal tissue and develops into the membranous labyrinth. Note the development of the tubotympanic recess lined by endoderm into the future middle-ear cavity and auditory tube. In addition, accumulation of mesenchyme from the first and second pharyngeal arches gives rise to the auditory ossicles. (C) At this later stage of development, the first pharyngeal groove grows toward the developing tubotympanic recess. The auditory ossicles assume a location inside the tympanic cavity. (D) This final stage of development shows how the tympanic membrane develops from all three germ layers; surface ectoderm, mesoderm, and endoderm. Note that the wall of the otic vesicle develops into the membranous labyrinth

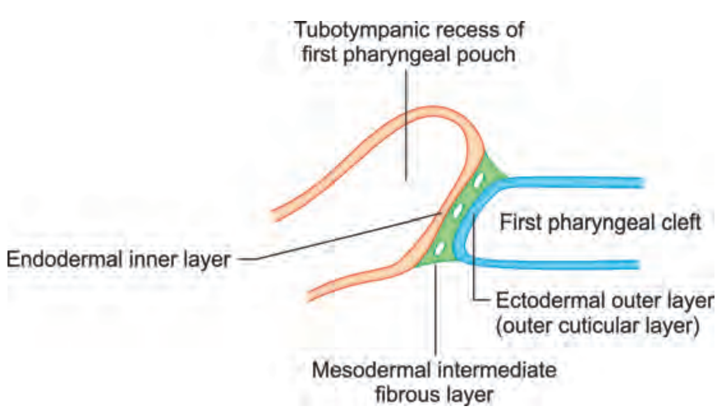
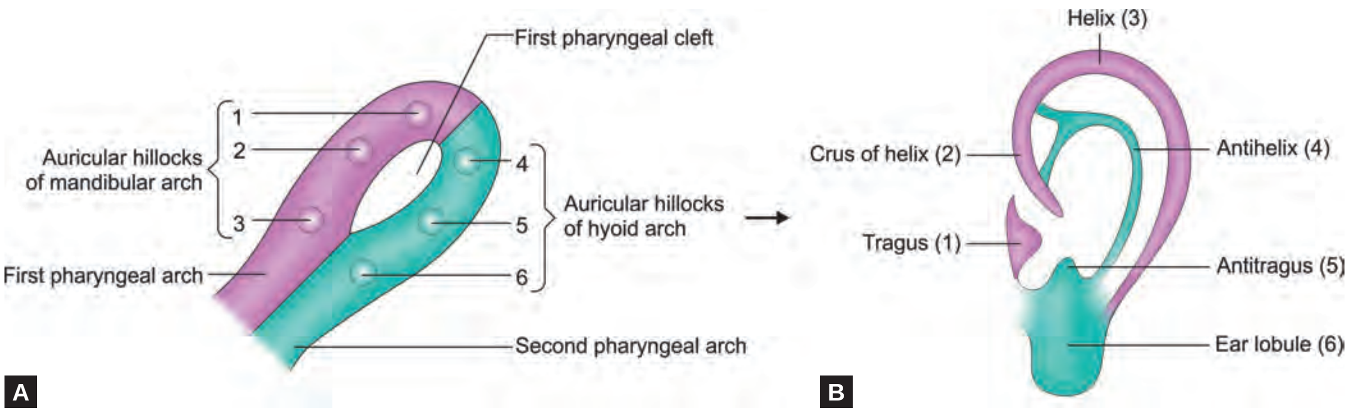


Fig. 168: Development of tympanic membrane

- Auricle develops from six tissue elevations (**auricular hillocks**), which form around the margins of the dorsal portion of the first pharyngeal cleft (external auditory meatus).
- First three develop on the caudal edge of the first pharyngeal (mandibular) arch and next three on the cranial edge of the second pharyngeal (hyoid) arch.
- The tragus develops from the first arch the area of skin supplied by the mandibular nerve (trigeminal) extends little above the tragus. Helical root, and helical crus also develop in first arch.
- Second branchial arch forms major portion of the auricle which includes antihelix, antitragus, and lower helix and ear lobule.
- Faulty fusion between the first and the 2nd arch tubercles causes preauricular sinus or cyst.



Figs. 169A and B: Development of auricle or pinna

- Ear ossicles: Malleus, incus and stapes develop from the neural crest cell derived secondary mesenchyme.
- Stapes bone has of dual origin, with the stapedial footplate being composed of cells of both neural crest (Reichert's cartilage) and mesodermal (otic capsule) origin.
  - If the neural crest part of the stapes fails to form the mesodermal part does not develop, indicating that the two parts are interdependent. If Reichert's cartilage fails to form, the otic capsule part does not develop.
  - The head and crus of the stapes is of neural crest origin, along with the central part of the stapedial footplate; however, the outer ring of the stapedial footplate is of mesoderm origin. This is the part of the stapes that connects to the mesodermal annular ligament. Part of the stapes is, therefore, derived from the otic capsule.
- At birth, the auditory ossicles have achieved their full adult size.

Embryonic Structure	Adult Derivative
Internal ear	
Otic Vesicle	
Utricular portion (Ectoderm)	Utricle, semicircular ducts, vestibular ganglion of CN VIII, endolymphatic duct and sac
Saccular portion (Ectoderm)	Saccule, cochlear duct (organ of Corti), spiral ganglion of CN VIII
Middle ear	
Pharyngeal arch 1	Malleus (Mackel cartilage; neural crest cells) Incus (Meckel cartilage; neural crest cells)
	Tensor tympani muscle (mesoderm)
Pharyngeal arch 2	Stapes (Reichert cartilage; neural crest cells) Stapedius muscle (mesoderm)
Pharyngeal pouch 1	Epithelial lining of the auditory tube (endoderm) Epithelial lining of the middle ear cavity (endoderm)
Pharyngeal membrane 1	Tympanic membrane (ectoderm, mesoderm and neural crest cells, and endoderm)
External ear	
Pharyngeal groove 1	Epithelial lining of the external auditory meatus (ectoderm)
Auricular hillocks	Auricle

ASSESSMENT QUESTIONS

1. **Auricular hillocks develop from pharyngeal arch:**
   a. 1
   b. 2
   c. 1 and 2
   d. 2 and 3

2. **Foot plate of stapes derived from:**
   a. Meckel's cartilage
   b. Otic capsule
   c. Reichert's cartilage
   d. Hyoid arch

3. **Which of the following part of ear is derived from all three germ layers:** *(NEET Pattern 2012)*
   a. External auditory canal
   b. Ear ossicles
   c. Tympanic membrane
   d. Ear muscles

ANSWERS WITH EXPLANATIONS

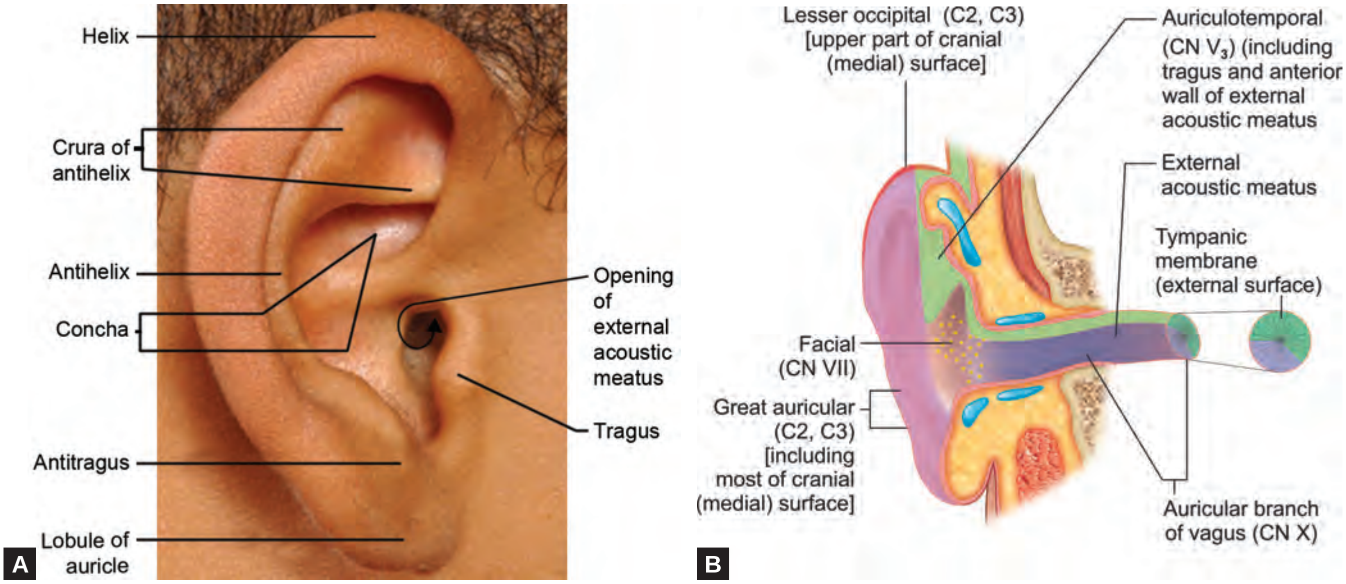
1. **c. 1 and 2**
   - Auricle develops from six tissue elevations (**auricular hillocks**), First three develop on the caudal edge of the first pharyngeal (mandibular) arch and next three on the cranial edge of the second pharyngeal (hyoid) arch.

2. **c. Reichert's cartilage > b. Otic capsule.**
   - Footplate of stapes has **dual origin** from the Reichert's cartilage and otic capsule.
   - If Reichert's cartilage fails to form, the otic capsule part does not develop.
   - **Reichert's cartilage** is the second arch cartilage (derived from the neural crest cells) and form bones like stapes, styloid process, lesser cornu and upper body of hyoid.

3. **c. Tympanic membrane**
   - **Tympanic membrane** is derived from all the three germ layers: an ectodermal epithelial lining (from the first pharyngeal cleft), an intermediate layer of mesenchyme, and an endodermal lining (from the first pharyngeal pouch).
   - External auditory canal develops from the ectoderm of pharyngeal cleft.
   - Ear ossicles develop from the neural crest cell derived secondary mesenchyme.
   - Ear muscles develop in second pharyngeal arch mesoderm.

External Ear and Tympanic Membrane

- External ear consists of an **auricle** and an **external auditory meatus** and separated from the middle ear by the **tympanic membrane**.
- **Auricle** consists of cartilage connected to the skull by ligaments and muscles and is covered by skin.
  - It receives sound waves and channel them into the external auditory meatus.
  - **Helix** is the slightly curved outer rim of the auricle and **antihelix** is the broader curved eminence internal to the helix, which divides the auricle into an outer scaphoid fossa and the deeper concha.
  - **Concha** is the deep cavity in front of the antihelix and anterior to it lies a small projection called **tragus**.
  - **Lobule** is the lower portion of auricle made up of areolar tissue and fat but no cartilage.
- **Arterial supply** is from the superficial temporal and posterior auricular arteries.
- **Nerve supply:**
  - **Great auricular nerve** (C2,3), is the **major** nerve supply to auricle and supplies ear lobule and most of the cranial surface and the posterior part of the lateral surface (helix, antihelix).
  - **Lesser occipital nerve** supplies upper and cranial (posterior) part of the auricle (especially the helix).
  - **Auriculotemporal nerve** supplies the tragus, crus of the helix and the adjacent part of the helix.
  - **Auricular branch of the vagus** (Arnold's nerve) sends the axons along the **facial nerve** branches and supply small areas on both aspects of the auricle, in the depression of the concha and over its eminence.
    - These areas may show vesicles in facial nerve involvement in Ramsay Hunt syndrome (Herpes zoster).
  - **Facial nerve** itself has minimal supply in the auricle (scattered area on the depression of the concha and over its eminence).
- **External auditory meatus** is approximately 2.5 cm long, extending from the concha to the tympanic membrane.
- Its external one-third is formed by cartilage, and the internal two-thirds is formed by bone.
- The cartilaginous portion is wider than the bony portion and has numerous ceruminous glands that produce wax.



Figs. 170A and B: (A) External featurer of Auricle. (B) Nerve supply to Auricle, extended canal and tympanic membrane.

- It receives blood from the superficial temporal, posterior auricular, and maxillary arteries (deep auricular branch).
- The innervation is by the **auriculotemporal** branch of the trigeminal nerve and the **auricular branch of the vagus nerve**, which is joined by a branch of the **facial nerve** and the **glossopharyngeal nerve**.
- Anterior wall and roof is supplied by auriculotemporal nerve. Posterior wall and floor is innervated by auricular branch of vagus.
- Posterior wall (not floor) also receives sensory fibres from facial nerve.
- **Tympanic Membrane** lies placed obliquely making an angle of about 55° with the floor of the external acoustic meatus and faces downwards, forwards, and laterally sloping medially from posterosuperiorly to anteroinferiorly; thus, the anteroinferior wall is longer than the posterosuperior wall.
- It consists of three layers: an outer (cutaneous), an intermediate (fibrous), and an inner (mucous) layer.
- It has a thickened fibrocartilaginous ring at the greater part of its circumference, which is fixed in the tympanic sulcus at the inner end of the meatus.
- The membrane has a small triangular portion between the anterior and posterior malleolar folds called the pars flaccida. The remainder of the membrane is called the pars tensa.
- The cone of light is a triangular reflection of light seen in the anteroinferior quadrant. The most depressed center point of the concavity is called the umbo (knob).
- The external (lateral) concave surface is covered by skin and is innervated by the auriculotemporal branch of the trigeminal nerve and the auricular branch of the vagus nerve. The auricular branch is joined by branches of the glossopharyngeal and facial nerves.
  - This surface is supplied by the deep auricular artery of the maxillary artery.

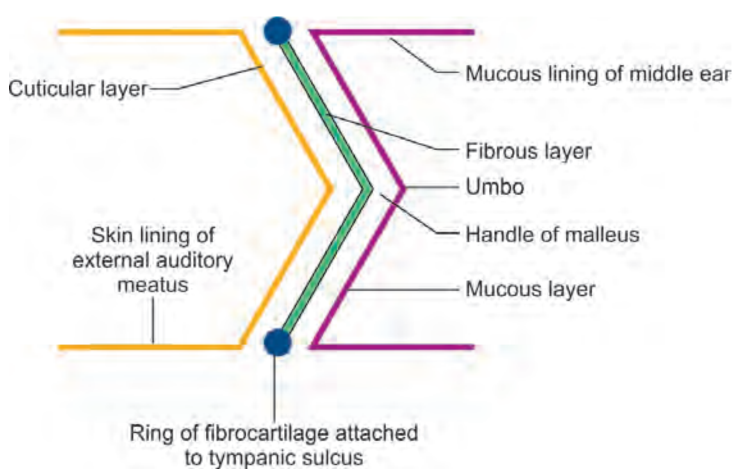
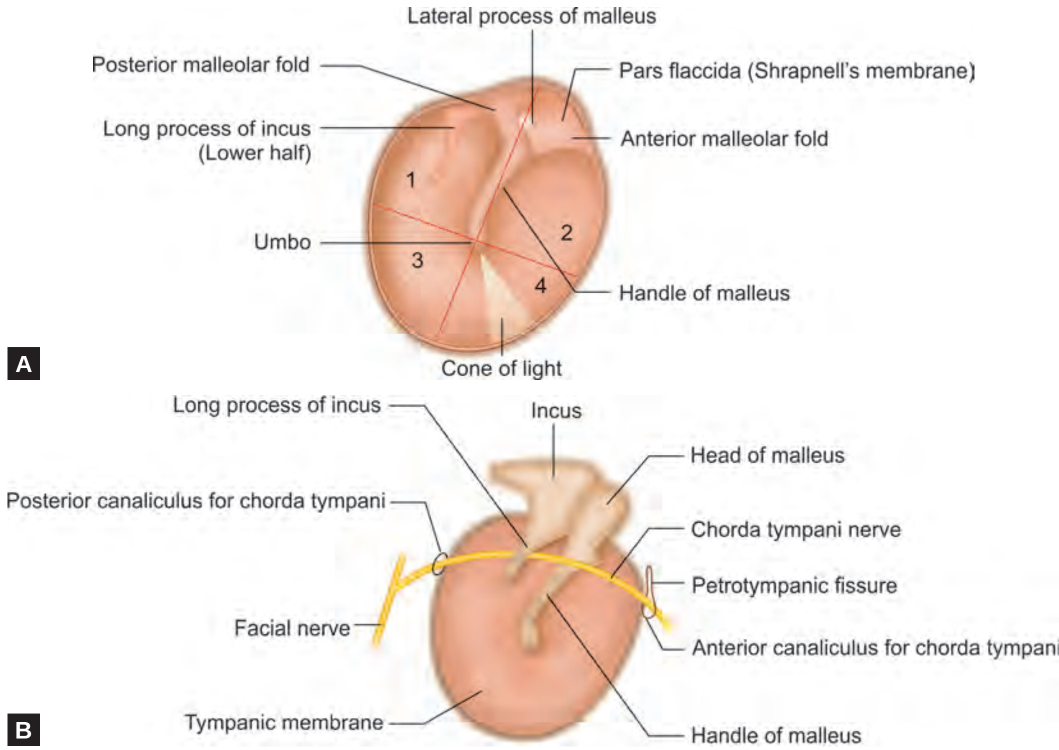


Fig. 171: Layers of the tympanic membrane.

- The internal (medial) surface is covered by mucous membrane, is innervated by the tympanic branch of the glossopharyngeal nerve, and serves as an attachment for the handle of the malleus.

➤ This surface receives blood from the auricular branch of the occipital artery and the anterior tympanic artery.



Figs. 172A and B: Tympanic membrane (schematic diagram): (A) External surface of tympanic membrane as seen through otoscope: 1 = posterosuperior quadrant, 2 = anterosuperior quadrant, 3 = posteroinferior quadrant, 4 = anteroinferior quadrant; (B) Medial surface of tympanic membrane snowing the course of the chorda tympani nerve.

ASSESSMENT QUESTIONS

1. Lobule of ear supplied is by: *(AIIMS 2015)*
   a. Greater auricular nerve
   b. Auriculotemporal nerve
   c. Lesser occipital nerve
   d. Auricular branch of vagus

2. Cartilagenous part of external auditory canal is
   a. Medial *(NEET Pattern 2014)*
   b. Lateral 1/3
   c. Medial 2/3
   d. Lateral 2/3

3. Greater part of the auricle is supplied by:
   a. Auriculotemporal nerve
   b. Lesser occipital nerve
   c. Greater auricular nerve
   d. Auricular branch of vagus

4. The angle that tympanic membrane makes with the horizontal plane is: *(NEET Pattern 2013)*
   a. 15°
   b. 25°
   c. 45°
   d. 55°

ANSWERS WITH EXPLANATIONS

1. a. Greater auricular nerve
- **Greater auricular nerve** supplies the **lobule of ear** on medial (cranial) as well as lateral (outer) surface.

2. b. Lateral 1/3
- The cartilaginous part forms the outer one-third (8 mm) of the meatus and the bony part forms the inner two-third (16 mm).

3. c. Greater auricular nerve
- Greater part of auricle is supplied by **greater auricular nerve** (branch of the cervical plexus).

4. d. 55°
- Tympanic membrane is placed obliquely making an angle of about 55° with the floor of the external acoustic meatus.

Middle Ear

- Middle ear is located within the petrous portion of the temporal bone and consists of the tympanic cavity with its ossicles.
- It communicates anteriorly with the nasopharynx via the auditory (Eustachian) tube and posteriorly with the mastoid air cells and the mastoid antrum through the aditus ad antrum and is traversed by the chorda tympani and lesser petrosal nerve.
- The tympanic cavity is divided into three parts:
  ➤ **Epitympanum** (attic), a part above the pars tensa of tympanic membrane containing head of malleus, body, and short process of incus.

- **Mesotympanum**, a part opposite to tympanic membrane containing handle of malleus, long process of incus, and stapes. It is the narrowest part of the middle ear.
- **Hypotympanum**, a part below the tympanic membrane.

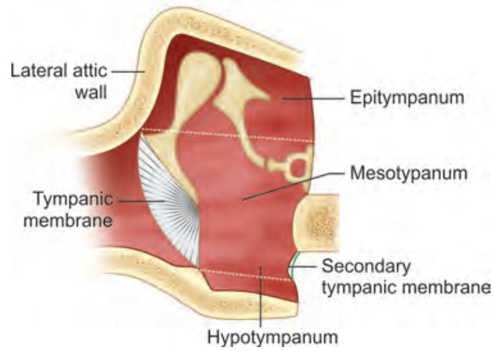


Fig. 173: Subdivisions of the middle ear.

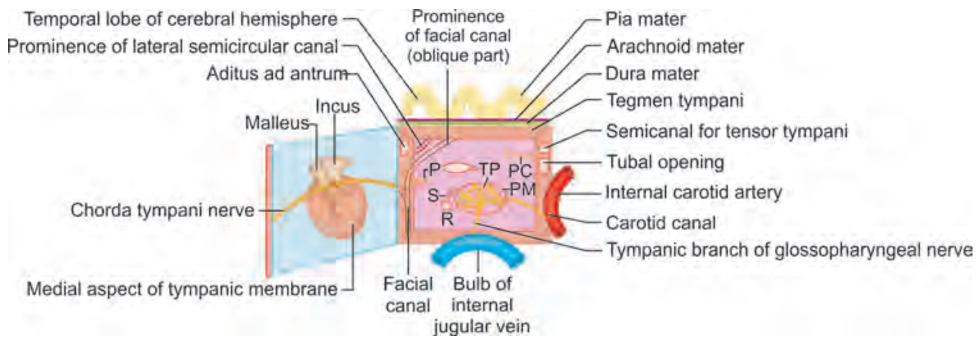


Fig. 174: Schematic diagram to show the boundaries (and their relations) of the middle ear. The middle ear is likened to a six-sided box and its lateral side is opened out (O = Oval window, P = Pyramid, PC = Processus cochleariformis, PM = Promontory, R = Round window, S = Sinus tympani, TP = Tympanic plexus).

Relations:

- Middle ear cavity has a roof made up of tegmen tympani, which separates it from the middle cranial fossa.
- The floor separates it from the superior bulb of the internal jugular vein.
- The anterior wall inferior separates the middle ear from the internal carotid artery. Anterior wall shows two openings for tensor tympani and auditory tube.
- Posterior wall has an opening superiorly (aditus) through which epitympanic process communicates with the mastoid antrum.
- The lateral wall of middle ear cavity has the tympanic membrane, which separates it from the external ear canal.
- Medial wall separates it from the internal ear and present the promontory formed by the basal turn of the cochlea, the fenestra vestibuli (oval window), the fenestra cochlea (round window), and the prominence of the facial canal.
- Oval window is pushed back and forth by the footplate of the stapes and transmits the sound vibrations of the ossicles into the perilymph of the scala vestibuli in the inner ear.
- Round window is closed by the secondary tympanic (mucous) membrane of the middle ear and accommodates the pressure waves transmitted to the perilymph of the scala tympani.

Wall of middle ear	Structure/Relation
Roof (Trigeminal wall)	• Tegmen tympani • Middle cranial fossa • Temporal lobe of cerebrum
Floor (Jugular wall)	• Superior bulb of internal jugular vein
Anterior wall (Carotid wall)	• Internal carotid artery
Posterior wall (Mastoid wall)	• Aditus • Mastoid antrum
Lateral wall (Membranous wall)	• Tympanic membrane • External acoustic meatus
Medial wall (Labyrinthine wall)	• Internal ear

- Contents of middle ear cavity are: Chorda tympani (branch of facial nerve), ear ossicles, two muscles.
- Facial nerve runs in the bony canal along the medial and posterior walls of tympanic cavity and gives rise to three branches: Greater petrosal nerve, nerve to stapedius muscle and chorda tympani nerve.

- Ear ossicles are miniature bones namely malleus, incus, and stapes.
- Sound waves created vibrations in the tympanic membrane makes ossicular chain push the footplate of the stapes into the oval window, creating a traveling wave in the perilymph-filled scala vestibuli.
- At birth, the auditory ossicles have achieved their full adult size. They increase in density during the first years of life as marrow cavities are replaced with endosteal bone.
- Malleus consists of a head, neck, handle (manubrium), and anterior and lateral processes. Its rounded head articulates with the incus in the epitympanic recess and handle is fused to the medial surface of the tympanic membrane and serves as an attachment for the tensor tympani muscle.
- Incus has a body and two processes (crura). Its long process descends vertically, parallel to the handle of the malleus, and articulates with the stapes and short process extends horizontally backward to the fossa of the incus and provides the attachment for the posterior ligament of the incus.
- Stapes has a head and neck, two processes (crura), and a base (footplate). Its neck provides insertion of the stapedius muscle. The base (footplate) is attached by the annular ligament to the margin of the oval window.

Features of the three ear ossicles

	Malleus	Incus	Stapes
Resemblance	Hammer	Anvil or premolar tooth	Strirrup
Development	First pharyngeal arch cartilage	First pharyngeal arch cartilage	Second pharyngeal arch cartilage
Muscle attached	Tensor tympani	None	Stapedius
Joint/Joints	Incudomalleolar (saddle type of synovial joint)	Incudomalleolar and incudostapedial	Incudostapedial (ball and socket type of synovial joint)

- Muscles in the middle ear cavity are tensor tympani and stapedius.
- **Stapedius** muscle is the smallest of the skeletal muscles in the human body.
  - It pulls the head of the stapes posteriorly, thereby tilting the base of the stapes and prevents (or reduces) excessive oscillation of the stapes and thus protects the inner ear from injury from a loud noise, and its paralysis results in hyperacusis.
- **Tensor tympani** draws the tympanic membrane medially and tightens it (in response to loud noises), thereby increasing the tension and reducing the vibration of the tympanic membrane.
  - Origin: It arises from the cartilaginous portion of the auditory tube and the adjoining part of the great wing of the sphenoid, as well as from the osseous canal in which it is contained.
  - Course: Passing backward through the canal, it ends in a slender tendon which enters the tympanic cavity, makes a sharp bend around the extremity of the septum, known as the processus cochleariformis.
  - Insertion: It is inserted into the handle (manubrium) of the malleus, near its root.
  - Innervation of the tensor tympani is from the tensor tympani nerve, a branch of the mandibular division of the trigeminal nerve (V). As the tensor tympani is innervated by motor fibres of the trigeminal nerve, it does not receive fibres from the trigeminal ganglion, which has sensory fibres only.
  - Function: When tensed, the action of the muscle is to pull the malleus medially, tensing the tympanic membrane, damping vibration in the ear ossicles and thereby reducing the amplitude of sounds.
  - This muscle is contracted primarily to dampen the noise produced by chewing. (Compared to the more general dampening function of the stapedius muscle.)

Muscles of the middle ear

Muscle	Origin	Insertion	Nerve Supply	Action
Tensor tympani	Wall of auditory tube and wall of its own canal	Handle of malleus	Mandibular division of trigeminal nerve	Dampens down vibrations of tympanic membrane
Stapedius	Pyramid (bony projection on posterior wall of middle ear)	Neck of stapes	Facial nerve	Dampens down vibrations of stapes

- **Arterial Supply**: Anterior tympanic (branch of maxillary artery), stylomastoid (branch of posterior auricular artery), petrosal and superior tympanic (middle meningeal artery branches), a branch from the artery of pterygoid canal and tympanic branch of the internal carotid artery.
- **Venous Drainage** is into pterygoid venous plexus and superior petrosal sinus.
- **Lymphatics** drain towards retropharyngeal, parotid and upper deep cervical lymph nodes.
- **Nerve Supply**: Tympanic Plexus is present on the promontory in the medial wall of the middle ear. It is contributed by:
- Tympanic branch of the glossopharyngeal nerve (Jacobson's nerve), superior and inferior caroticotympanic nerves derived from sympathetic plexus around the internal carotid artery, and a branch from geniculate ganglion.
- Tympanic branch of glossopharyngeal nerve enters the middle ear through a canaliculus in the floor of the tympanic cavity and contributes to the formation of tympanic plexus.
  - It supplies the lining of middle ear, mastoid antrum, and auditory tube.
  - It also carry the preganglionic parasympathetic secretomotor fibres to the tympanic plexus, which further sends the fibres along the lesser petrosal nerve to supply the parotid gland via otic ganglion.

- Mastoid antrum is an air space in the petrous portion of the temporal bone, communicating posteriorly with the mastoid cells and anteriorly with the epitympanic recess of the middle ear (via the aditus to mastoid antrum).
- Its roof is formed by tegmen tympani, which separates the antrum from middle cranial fossa.
- The floor of antrum receives the openings of mastoid air cells, posterior wall is related to sigmoid sinus and medial wall presents bulging of the lateral semicircular canal.
- The lateral wall of the antrum is formed by a plate of bone 1.5 cm thick in the adult (2 mm thick in a newborn). Its surface marking is suprameatal triangle of McEwen's.
- The mastoid air cells are innervated by a meningeal branch of the mandibular division of the trigeminal nerve.

ASSESSMENT QUESTIONS

1. Which of the following is a WRONG statement regarding middle ear cavity:
a. Narrowest part is mesotympanum
b. Footplate of stapes lies in epitympanum
c. Chorda tympani is a content of epitympanum
d. Toynbee's muscle is a content

2. Muscle entering middle ear from pyramid apex is: *(NEET pattern 2012)*
a. Stapedius
b. Tensor tympani
c. Tensor palatine
d. Auricularis

3. Superior wall of middle ear is formed by: *(NEET Pattern 2015)*
a. Tympanic membrane
b. Jugular bulb
c. Tegmen tympani
d. None

4. Prussak's space is related to: *(NEET Pattern 2015)*
a. Mesotymapnum
b. Epitympanum
c. Hypotympanum
d. Inner ear

5. Scutum is present in middle ear: *(NEET Pattern 2015)*
a. Roof
b. Lateral wall
c. Medial wall
d. Floor

6. Opening of Eustachian tube in middle ear: *(NEET Pattern 2013)*
a. Medial wall
b. Lateral wall
c. Anterior wall
d. Posterior wall

7. Which of the following is related to floor of middle ear: *(NEET pattern 2012)*
a. Round window
b. Internal carotid artery
c. Internal jugular vein
d. Tegmen tympani

8. All of the following are true about the middle ear cavity EXCEPT: *(NEET pattern 2012)*
a. Roof is formed by tegmen tympani
b. Anterior wall has opening of two canals
c. Medial wall is formed by tympanic membrane
d. Floor has bulb of internal jugular vein

9. Promontory seen in the middle ear is:
a. Jugular bulge
b. Basal turn of cochlea
c. Semicircular canal
d. Head of incus

10. Stapes foot plate covers: *(AIIMS 2003)*
a. Round window
b. Oval window
c. Inferior sinus tympani
d. Pyramid

11. The distance between tympanic membrane an medial wall of middle ear at the level of center is:
a. 3 mm
b. 4 mm
c. 6 mm
d. 2 mm

12. Distance of tympanic membrane from promontory is:
a. 2 mm
b. 5 mm
c. 6 mm
d. 7 mm

13. Tympanic branch of the middle ear is derived from: *(NEET pattern 2012)*
a. Facial nerve
b. Glossopharyngeal nerve
c. Nerve to stapedius
d. Chorda tympani

14. Mastoid antrum is present in which part of temporal bone: *(NEET Pattern 2015)*
a. Tympanic
b. Petrous
c. Squamous
d. Mastoid

15. Lateral wall of mastoid antrum is related to: *(NEET pattern 2015)*
a. Superficial temporal artery
b. External auditory canal
c. Emissary vein
d. Meningeal artery

16. Which of the following is the type of joints between ear ossicles *(AIPG 2008)*
a. Primary cartilaginous
b. Secondary cartilaginous
c. Synovial
d. Fibrous

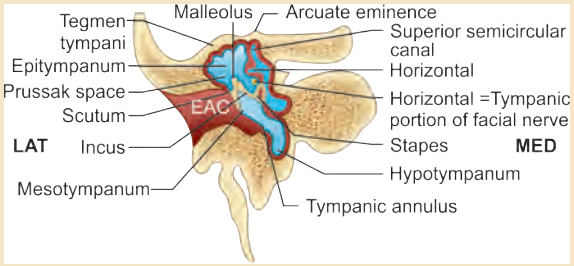
ANSWERS WITH EXPLANATIONS

1. b. Footplate of stapes lies in epitympanum
- Epitympanum contains head of malleus, body, and short process of incus, along with the chorda tympani nerve.
- Stapes bone is present in mesotympanum, which is the narrowest part of middle ear cavity.
- There are two muscles in the middle ear cavity: Stapedius and tensor tympani (Toynbee's muscle).

2. a. Stapedius
- Pyramid is a conical bony projection below the aditus containing stapedius muscle whose tendon appears through its summit, passes forwards to be attached to the neck of the stapes.

3. c. Tegmen tympani
- Superior wall (roof) of middle ear is formed by a thin plate of bone called tegmen tympani, which separates the tympanic cavity from the middle cranial fossa.

4. b. Epitympanum
- Prussak's space lies medial to pars flaccida, lateral to the neck of malleus and above the lateral process of malleus.
- Anteriorly, posteriorly and superiorly, it is bounded by lateral malleal ligament.
- Posteriorly, it also has a gap through which the space communicates with epitympanum.
- It is a site for pars flaccida acquired cholesteatoma formation.



5. b. Lateral wall
- The scutum (shield) is a sharp bony spur that is formed by the superior wall of the external auditory canal and the lateral wall of the tympanic cavity.
- It forms the lateral margin of Prussak's space. It is usually the first bony structure to be eroded by the enlarging cholesteatoma.

6. c. Anterior wall
- The tympanic end of the tube is situated in the anterior wall of the middle ear.

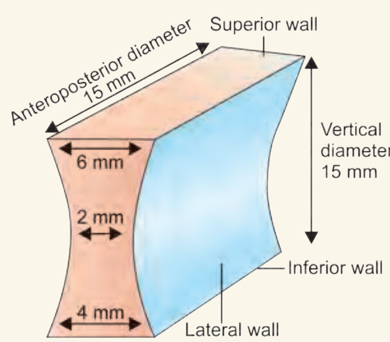
7. c. Internal jugular vein
- The floor of middle ear cavity is formed by a thin plate of bone, which separates the tympanic cavity from the jugular bulb.

8. c. Medial wall is formed by tympanic membrane
- Tympanic membrane is present on the lateral wall of middle ear cavity.

9. b. Basal turn of cochlea
- The medial wall of middle ear cavity shows promontory, a rounded prominence in the centre produced by first (basal) turn of the cochlea.
- The tympanic branch of the glossopharyngeal nerve ramifies on it to form the tympanic plexus.

10. b. Oval window
- The footplate of stapes closes the oval window and is attached to its margin by annular ligament.
- Round window is covered by secondary tympanic membrane.

11. d. 2 mm
- Middle ear cavity is shaped like a cube, compressed from side to side.
- In coronal section it resembles a biconcave disc.
- The vertical and anteroposterior diameters are 15 mm each, and transverse diameters are: 6 mm (at roof), 2 mm (at floor) and 2 mm (in the centre).



The shape and dimensions of the middle ear cavity.

12. a. 2 mm
- Distance between tympanic membrane (lateral wall) and promontory (medial wall) of middle ear cavity is 2 mm.

13. b. Glossopharyngeal nerve
- Tympanic branch of the middle ear contributes to tympanic plexus and is derived from glossopharyngeal nerve.

14. b. Petrous

- Mastoid antrum is an air space in the petrous portion of the temporal bone, at the upper part of mastoid process.

15. b. External auditory canal

- The lateral wall of mastoid antrum corresponds to the suprameatal triangle of MacEwen's on the outer surface of the skull, which is related to posterosuperior margin of the external auditory meatus.

16. c. Synovial

- Ear ossicles have multiaxial synovial articulations between them, which are freely mobile joints.
- Malleus and incus form the saddle variety and incus and stapes has the ball and socket variety of synovial joint.

Eustachian Tube

- **Eustachian (pharyngo-tympanic) tube** connects the middle ear to the nasopharynx and maintains the equilibrium of air pressure on either side of the tympanic membrane for its proper vibration and sound conduction.
- It has a length of **36 mm** and communicates the middle ear cavity with the nasopharynx.
- Lateral 1/3 (12 mm) is bony and begins at the *anterior* wall of middle ear cavity.
- Medial 2/3 (24 mm) is made up of **elastic** cartilage and opens in the nasopharynx, behind the **inferior turbinate** of nasal cavity.
- From its tympanic end it runs anterior, inferior and medial at an angle of 45° with the sagittal plane and 30° with the horizontal.
- The cartilaginous part lies in the groove between the petrous part of the temporal bone and the posterior border of the greater wing of the sphenoid bone.
- The pharyngeal end is relatively large and slit-like (vertically).
- It is situated in the lateral wall of the pharynx, about 1.25 cm behind the posterior end of inferior nasal concha.
- Eustachian tube is opened during movements like swallowing by dilator tubae (tensor veli palatini) and aided by salpingopharyngeus.
- The fibres of origin of tensor palati muscles are attached to lateral wall of the tube and its contraction during swallowing, yawning and sneezing opens the tube and helps in maintaining equality of air pressure on both sides of tympanic membrane.
- Contraction of levator palati muscles which runs below the floor of cartilaginous part also helps in opening the tube.
- The diameter of the tube is greatest at the pharyngeal orifice, least at the junction of the two parts (the isthmus), and widens again towards the tympanic cavity.
- **Arterial supply**: The osseous part of the auditory tube is supplied by the tubal artery (branch of the accessory meningeal artery) and the caroticotympanic (branches of the internal carotid artery).
- The cartilaginous part of the tube is supplied by the deep auricular and pharyngeal branches of the maxillary artery, the ascending palatine artery (usually a branch of the facial artery, occasionally given directly by the external carotid artery) and the ascending pharyngeal branch of the external carotid artery.
- Some authors also mention the artery of the pterygoid canal and the middle meningeal artery as the source of arterial supply.
- **Venous drainage**: The veins of the pharyngotympanic tube usually drain to the **pterygoid venous plexus**.
- **Nerve supply** is by tympanic plexus and from the pharyngeal branch of the pterygopalatine ganglion.

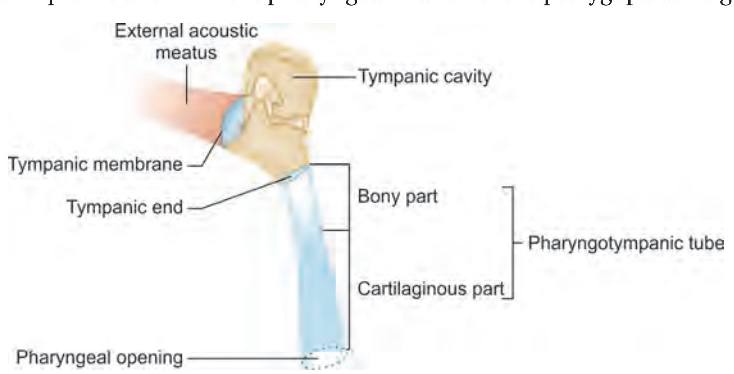


Fig. 175: Pharyngotympanic tube.

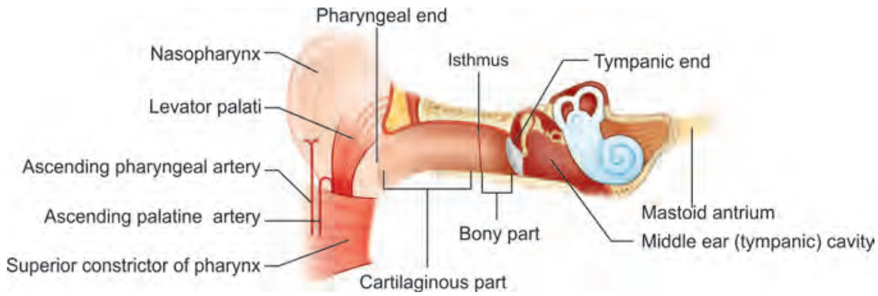


Fig. 176: Bony and cartilaginous parts, isthmus, tympanic, and pharyngeal ends of the pharyngotympanic tube.

Differences between the eustachian tube of an infant and an adult

	Infant	Adult
Length	18 mm	36 mm
Direction	More or less horizontal (makes an angle of 10° with the horizontal plane)	Oblique, directed downwards, forwards and medially (makes an angle of 45° with the horizontal plane)
Angulation of isthmus	No angulation	Angulation present

ASSESSMENT QUESTIONS

1. **TRUE about pharyngotympanic tube is/are:** *(PGIC 2015)*
   a. 36 mm in length
   b. 1/3 cartilaginous and 2/3 bony
   c. Runs anteromedially making an angle of 30°with the sagittal plane
   d. Tensor veli palati opens it
   e. Narrowest diameter is at the isthmus

2. **Blood supply of the Eustachian tube is by all EXCEPT:** *(NEET 2012)*
   a. Ascending pharyngeal artery
   b. Middle meningeal artery
   c. Artery of pterygoid canal
   d. Facial artery

3. **Eustachian tube is supplied by:** *(PGIC 2005)*
   a. Tympanic plexus
   b. Caroticotympanic nerve
   c. Glossopharyngeal nerve
   d. Pterygopalatine ganglion
   e. All

4. **TRUE about anatomy of eustachian tube:** *(PGIC 2014)*
   a. Aerate middle ear
   b. Open during swallowing
   c. Lager and wider in adult than children
   d. More horizontal in infant and children
   e. Open in oropharynx

ANSWERS WITH EXPLANATIONS

1. **a. 36 mm in length; d. Tensor veli palati opens it; e. Narrowest lumen is at the isthmus.**
   - **Eustachian (pharyngo-tympanic) tube** has a length of **36 mm**.
   - It communicates the middle ear cavity with the nasopharynx.
   - Lateral 1/3 (12 mm) is bony and begins at the *anterior* wall of middle ear cavity.
   - Medial 2/3 (24 mm) is made up of **elastic** cartilage and opens in the nasopharynx, behind the **inferior turbinate** of nasal cavity.
   - It runs anterior, inferior and medial at an angle of 45°with the sagittal plane and 30°with the horizontal.
   - It is opened by dilator tubae (**tensor veli palatini**) and aided by **salpingopharyngeus**.
   - **Levator veli palatini** *might* allow passive opening.
   - The diameter of the tube is greatest at the pharyngeal orifice, **least** at the junction of the two parts (the **isthmus**), and widens again towards the tympanic cavity.

2. **d. Facial artery**
   - Arteries to the pharyngotympanic tube arise from the ascending palatine artery, the pharyngeal branch of the maxillary artery, **ascending pharyngeal artery**, **middle meningeal artery** and the **artery of the pterygoid canal**.
   - Ascending palatine artery is usually a branch of the facial artery but occasionally given directly by the external carotid artery.

3. **e. All**
   - Eustachean tube is supplied by tympanic plexus and from the pharyngeal branch of the pterygopalatine ganglion.
   - Tympanic plexus itself is contributed by tympanic branch of the glossopharyngeal nerve, superior and inferior caroticotympanic nerves derived from sympathetic plexus around the internal carotid artery, and a branch from geniculate ganglion.

4. **a. Aerate middle ear; b. Open during swallowing; d. More horizontal in infant and children**
   - Eustachian tube communicates the nasopharynx with the middle ear cavity and aerates it.
   - In infants the tube is shorter, relatively wider and more horizontal than adult.
   - It opens during movements like swallowing, yawning and sneezing.

Inner Ear

- Inner ear consists of the **cochlea** housing the cochlear duct for auditory sensation, and the **vestibule** housing the utricle and saccule, and the **semicircular canals** housing the semicircular ducts for the sense of balance and position.
- The membranous labyrinth is a closed system of fluid filled intercommunicating membranous sacs and ducts filled with endolymph.
- It lies within the complex intercommunicating bony cavities and canals (**bony labyrinth**) in the petrous part of the temporal bone.
- The space between the membranous and bony labyrinth is filled with perilymph.

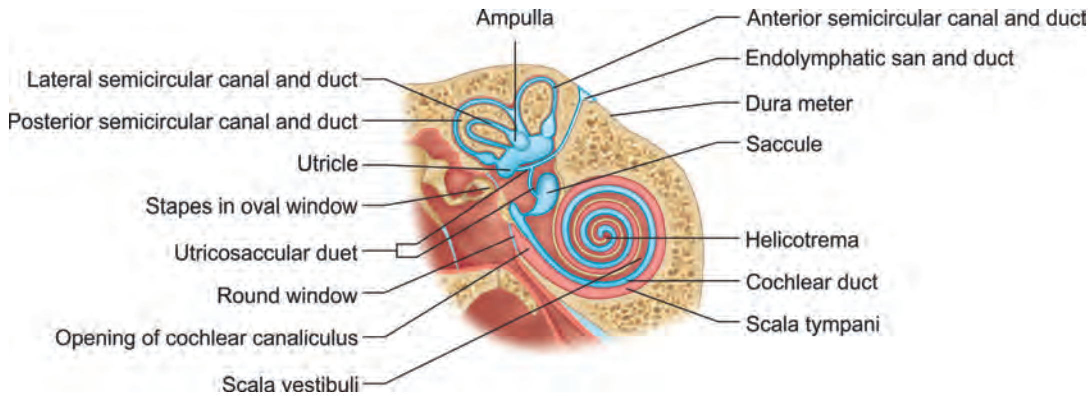


Fig. 177: Membranous labyrinth.

Structure and function of internal ear components.

Bony labyrinth component (Containing perilymph and the membranous labyrinth)	Membranous labyrinth component (Within bony labyrinth and containing endolymph)	Structures and sensory receptors	Major function
Vestibule	Utricle, saccule	Maculae	Detect linear movements and static position of the head
Semicircular canals	Semicircular ducts	Cristae ampullares	Detect rotational movements of the head
Cochlea	Cochlear duct	Spiral organ	Detect sounds

- The **bony labyrinth** has three parts: **Cochlea**, **vestibule** and **semicircular canals** (three).
- **Cochlea** consists of a central pillar called modiolus, and a bony cochlear canal.
    - The apex (cupula) is directed towards the medial wall of the tympanic cavity and the base is towards the bottom of the internal acoustic meatus.
- **Vestibule** is a central ovoid cavity of bony labyrinth between cochlea in front and three semicircular canals behind.
    - It lies medial to the middle ear cavity.

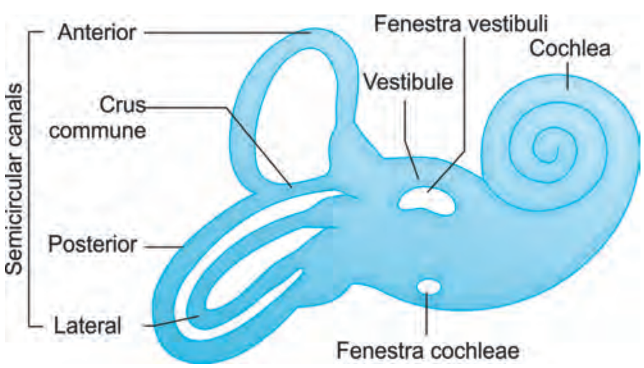
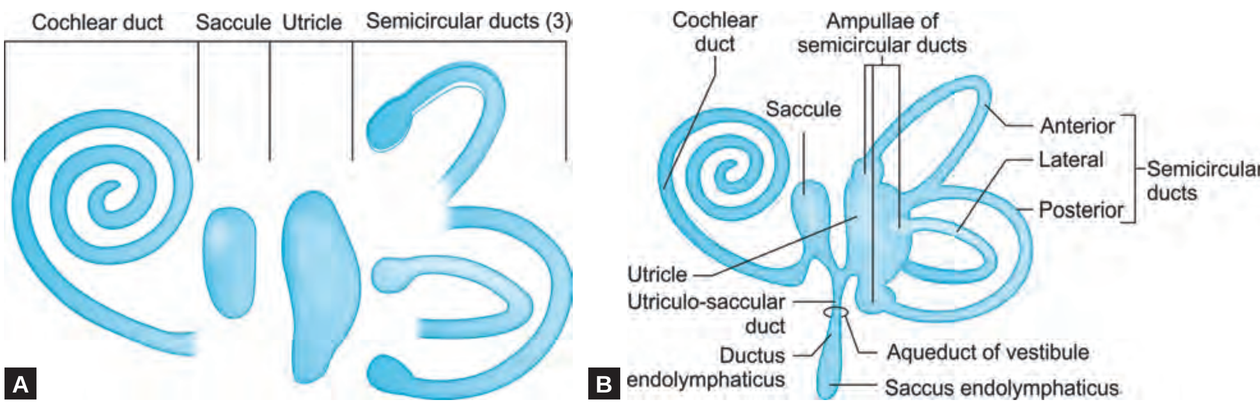


Fig. 178: Parts of the bony labyrinth.

- **Semicircular canals** (kinetic labyrinth) are three bony semicircular canals: anterior (superior), posterior, and lateral (horizontal).
- They lie in three planes at right angles to each other and open in the vestibule by five openings.
- Each canal is about two-third of a circle and is dilated at one end to form the ampulla.
  - **Anterior** semicircular canal lies in a vertical plane at right angle to the long axis of the petrous temporal bone, is convex upwards and its position is indicated on the anterior surface of the petrous temporal bone as arcuate eminence.
  - **Posterior** semicircular canal also lies in a vertical plane parallel to the long axis of petrous temporal bone.
  - **Lateral** semicircular canal lies in the horizontal plane. The lateral semicircular canals of two sides lie in the same plane.
- The anterior semicircular canal of one side lies parallel to the posterior semicircular canal of the other side.
- The anterior and posterior semicircular canals, lying across and along the long axis of the petrous temporal bone, are each at 45º with the sagittal plane.
- **Membranous labyrinth**: The **cochlear duct** lies within the bony cochlea, the saccule, and utricle lie within the bony vestibule, and three semicircular ducts lie within the three bony semicircular canals.
- The cochlear duct (basal turn) is connected to saccule by **ductus reuniens**.
- The saccule and utricle are connected to each other by Y-shaped **utriculo-saccular duct**, which expands to form ductus and saccus endolymphaticus.
- The utricle is connected to three semicircular ducts through five openings.



Figs. 179A and B: Membranous labyrinth: (A) Four parts of labyrinth. (B) Complete labyrinth.

- **Cochlear system**: The sensory receptor within **cochlear duct** is spiral organ of Corti which sends the auditory information by the cochlear nerve (CN VIII).
- Cochlear Duct (Scala Media) is a spiral anterior part of the membranous labyrinth having two and three-fourth turns.
- It lies in the middle part of the cochlear canal between scala vestibuli and scala tympani.
- The cochlear duct contains spiral organ of Corti and appears triangular in shape in cross section.
- Base is formed by the osseous spiral lamina (medially) and basilar membrane (laterally).
- Vestibular membrane (Reissner's membrane) is at the roof, which passes from upper surface of spiral lamina to the wall of cochlea.
- Laterally it is bounded by the outer wall of cochlear canal.
- The scala vestibuli and scala tympani containing perilymph lie above and below basilar membrane respectively.
- Cochlear duct (containing endolymph) is bathed above and below by the perilymph within the two scalae.
- The two scalae are continuous with each other through a narrow opening at the apex of cochlear duct called **helicotrema**.

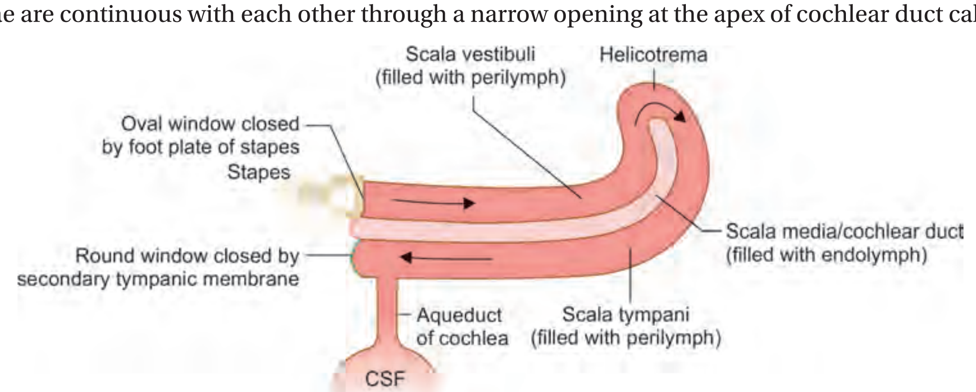


Fig. 180: Diagrammatic representation of the cochlear duct within cochlear canal. Note that cochlear duct is filled with endolymph and scala vestibuli and scala tympani are filled with perilymph (CSF = Cerebrospinal fluid).

- **Spiral Organ of Corti** has a tunnel of Corti formed by the inner and outer rod cells. It contains a fluid called corticolymph.
- The hair cells are the receptor cells of hearing located on basilar membrane and their apices possess stereocilia (hair), which are overlaid by tectorial membrane.
- The inner cells are flask shaped and arranged in a single row while outer cells are cylindrical and arranged in 3 or 4 rows.
- Sound vibrations create fluid waves in perilymph of scala vestibuli, which pass to the perilymph of scala tympani, in the process the basilar membrane bulge and the overlying hair cells are stimulated.
- The inner hair cells are richly supplied by the cochlear nerve fibres and are responsible for transmission of auditory impulses.
- The outer hair cells are innervated by efferent fibres from the olivary complex and are concerned with modulation function of inner hair cells.
- Deiter's cells are situated between the outer hair cells and provide support. The Hansen's cells lie outside the hair cells also support the hair cells.
- Membrana tectoria is made up of gelatinous substance and overlies the hair cells. Medially it is attached to osseous spiral lamina. The shearing force between the hair cells and tectorial membrane stimulate the hair cells.
- **Basilar membrane** separates the cochlear duct from the scala tympani.
- The pitch localization along its length is 20 Hz at the apex and 20,000 Hz at the base of the cochlea.
- Its vibration results in deformation of the hair cell microvilli against the tectorial membrane and the stimulus is further carried to CNS.
- Ninety percent of afferent fibres (peripheral processes of bipolar neurons of spiral ganglion) supply the inner hair cells while only 10% supply the outer hair cells.
- The spiral ganglion is located in the spiral canal within the modiolus near the base of the spiral lamina.
- The central processes of bipolar ganglion cells form the cochlear nerve (CN VIII).
- Efferent fibres to the outer hair cells come from olivocochlear bundle. Their cell bodies are located in the superior olivary complex.

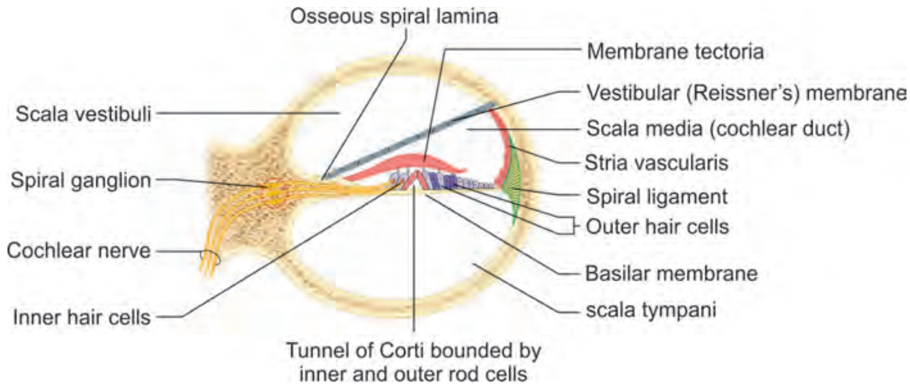


Fig. 181: Cross-section of the cochlear canal showing boundaries of the cochlear duct and organ of Corti within it.

- **Vestibular system**: The saccule is a small globular membranous sac lying in the anteroinferior part of the vestibule.
- The utricle is an oblong membranous sac, is larger than the saccule and lies in the posterosuperior part of the vestibule.
- The saccule is connected in front to the basal turn of cochlear duct by the ductus reuniens and behind with the utricle by a Y-shaped utriculo-saccular duct.
- The vertical limb of Y continues as endolymphatic duct (ductus endolymphaticus) and its dilated blind terminal end is called saccus endolymphaticus.
- The **endolymphatic duct** passes through a bony canal (aqueduct of vestibule) in the posterior part of petrous temporal bone and its dilated terminal end projects on the posterior surface of petrous temporal bone beneath the dura mater of the posterior cranial fossa.
- The endolymph is absorbed by the epithelial cells lining the saccus and drains into extradural vascular plexus.
- The utricle receives the three semicircular ducts posteriorly through five openings.
- **Semicircular Ducts** are three in number : anterior, posterior, and lateral and lie within the corresponding semicircular canals.
- They open into the utricle by five openings. Each duct has one dilated end called ampulla.
- It corresponds to the ampulla of the corresponding semicircular canal.
- The ampullary end of each duct bears a raised crest (crista ampullaris), which projects into its lumen.
- Peripheral receptors in vestibular system are: **Maculae** are located in the medial walls of saccule and utricle.
- They sense position of head in response to gravity and linear acceleration, i.e. static balance.
- **Cristae** are located in the ampullated ends of the three semicircular ducts.

- They detect angular acceleration, i.e., kinetic balance.
- The information of balance is carried by the vestibular nerve (CN VIII).
- Mechanism of hearing: Sound waves induce vibration of the tympanic membrane, which in turn, vibrate the ossicles, which amplify the intensity of the sound waves.
- The vibrations of the stapes against the oval window transmit the sound waves to the perilymph in the scala vestibule and then in the scala tympani through the helicotrema.
- Sound waves could be transmitted across the vestibular (Reissner's) membrane to the endolymph of the cochlear duct.
- Vibrations or pressure waves of the perilymph and of endolymph stimulate oscillatory movements of the basilar membrane and hence hair cells in the organ of Corti on the basilar membrane, which convert (transduce) sound waves to nerve impulses that travel via the cochlear nerve to the brain.
- For equilibrium, the three semicircular canals, the utricle and the saccule, detect sensations regarding body position and equilibrium.
- Sensory hair cells within the vestibular apparatus transmit information about the position of the head (produced by the flow of endolymph) to the brain via the vestibular nerve.

ASSESSMENT QUESTIONS

1. **Inner ear is present in which bone:** *(NEET pattern 2014)*
   a. Parietal bone
   b. Petrous part of temporal bone
   c. Occipital bone
   d. Petrous part of squamous bone

2. **NOT a part of bony labyrinth:** *(NEET Pattern 2015)*
   a. Cochlea
   b. Vestibule
   c. Utricle
   d. Semicircular canal

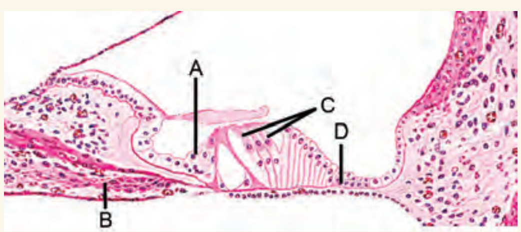
3. **Horizontal semicircular canal is:** *(AIPG)*
   a. Anterior
   b. Superior
   c. Posterior
   d. Lateral

4. **TRUE about internal ear anatomy:**
   a. Three semicircular canals here 6 opening into the vestibule
   b. The angle between anterior and posterior SCC is 180°
   c. Vestibule is the central chamber
   d. Spiral canal makes 2 turns

5. **Infection of CNS spreads in inner ear through:** *(AIIMS 2010)*
   a. Cochlear aqueduct
   b. Endolymphatic sac
   c. Vestibular aqueduct
   d. Hyrtl's fissure

6. **Endolymphatic duct drains into:**
   a. Subdural space
   b. Subarachnoid space
   c. Extradural space
   d. Epidural space

7. **Which area is innervated by the peripheral processes of the spiral ganglion:** *(AIIMS 2016)*
   a. A
   b. B
   c. C
   d. D



ANSWERS WITH EXPLANATIONS

1. **b. Petrous part of temporal bone**
   - Inner ear is present in a complex intercommunicating bony cavities and canals (bony labyrinth) in the petrous part of the temporal bone.
2. **c. Utricle**
   - Bony labyrinth components (containing perilymph and the membranous labyrinth) are vestibule, semicircular canals and cochlea.
3. **d. Lateral**
   - Horizontal semicircular canal is also called lateral semicircular canal.

4. c. Vestibule is the central chamber

- Vestibule is the central part of bony labyrinth. Semicircular canal forms 2/3rd of a circle and are at right angle to each other.
- The utricle receives the three semicircular ducts posteriorly through five openings.

5. a. Cochlear aqueduct

- Perilymph filled **cochlear aqueduct** is in direct continuation with CSF and may serve as a channel of spread of infection between inner ear and CNS.
- **Vestibular aqueduct** contains endolymphatic duct filled with endolymph, which does not communicate freely with CSF.
- The **endolymphatic duct** passes through the bony canal (**aqueduct of vestibule**) in the posterior part of petrous temporal bone and its dilated terminal end projects on the posterior surface of petrous temporal bone beneath the dura mater of the posterior cranial fossa.
- The endolymph is absorbed by the epithelial cells lining the saccus and drains into extradural vascular plexus.
- **Hyrtl's fissure** connects middle ear to subarachnoid space.

6. a. Subdural space

- Endolymphatic duct passes through vestibular aqueduct and drain into endolymphatic sac, located under the duramater (subdural space) on petrous temporal bone.
- It is a reservoir of excess endolymph.

7. a. A

- The inner hair cells (marker 'A') are innervated by the peripheral processes of the spiral ganglion.
- This is a diagram of organ of Corti in the inner ear, showing inner and outer cells, basilar membrane and spiral ganglion cells (please refer to for more details).
- The hair cells of the organ of Corti are innervated by the peripheral processes of bipolar cells of the spiral ganglion (marker 'B'). They are stimulated by vibrations of the basilar membrane (marker 'D').
- Inner hair cells (marker 'A') are the chief sensory elements; they synapse with dendrites of myelinated neurons whose axons make up 90% of the cochlear nerve.
- Outer hair cells (marker 'C') synapse with dendrites of unmyelinated neurons whose axons make up 10% of the cochlear nerve. They reduce the threshold of the Inner hair cells.

Internal Auditory Meatus

- Internal auditory meatus is a canal within the petrous part of the temporal bone of the skull between the posterior cranial fossa and the inner ear.
- The falciform (or transverse) crest separates the superior part from the inferior part.
- A vertical projection from the roof divides the superior part into two sections: Anterosuperior and posterosuperior section.
- The anterosuperior part transmits the facial nerve (along with nervus intermedius) and is separated from the posterosuperior section, which transmits the superior vestibular nerve, by Bill's bar.
- The cochlear nerve runs anteroinferiorly and the inferior vestibular nerve runs posteroinferiorly.
- Labyrinthine vessels also pass through the meatus.

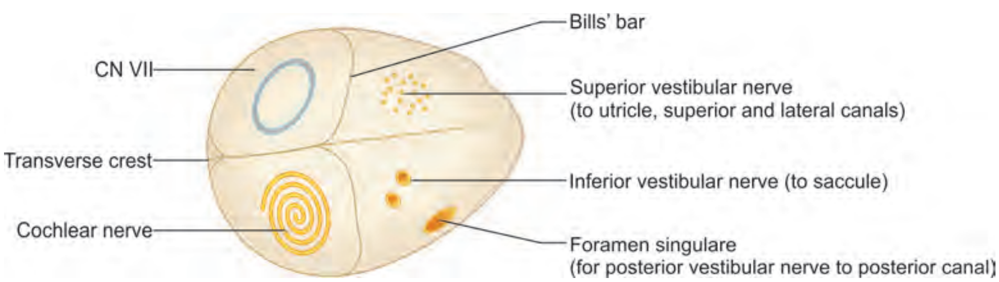
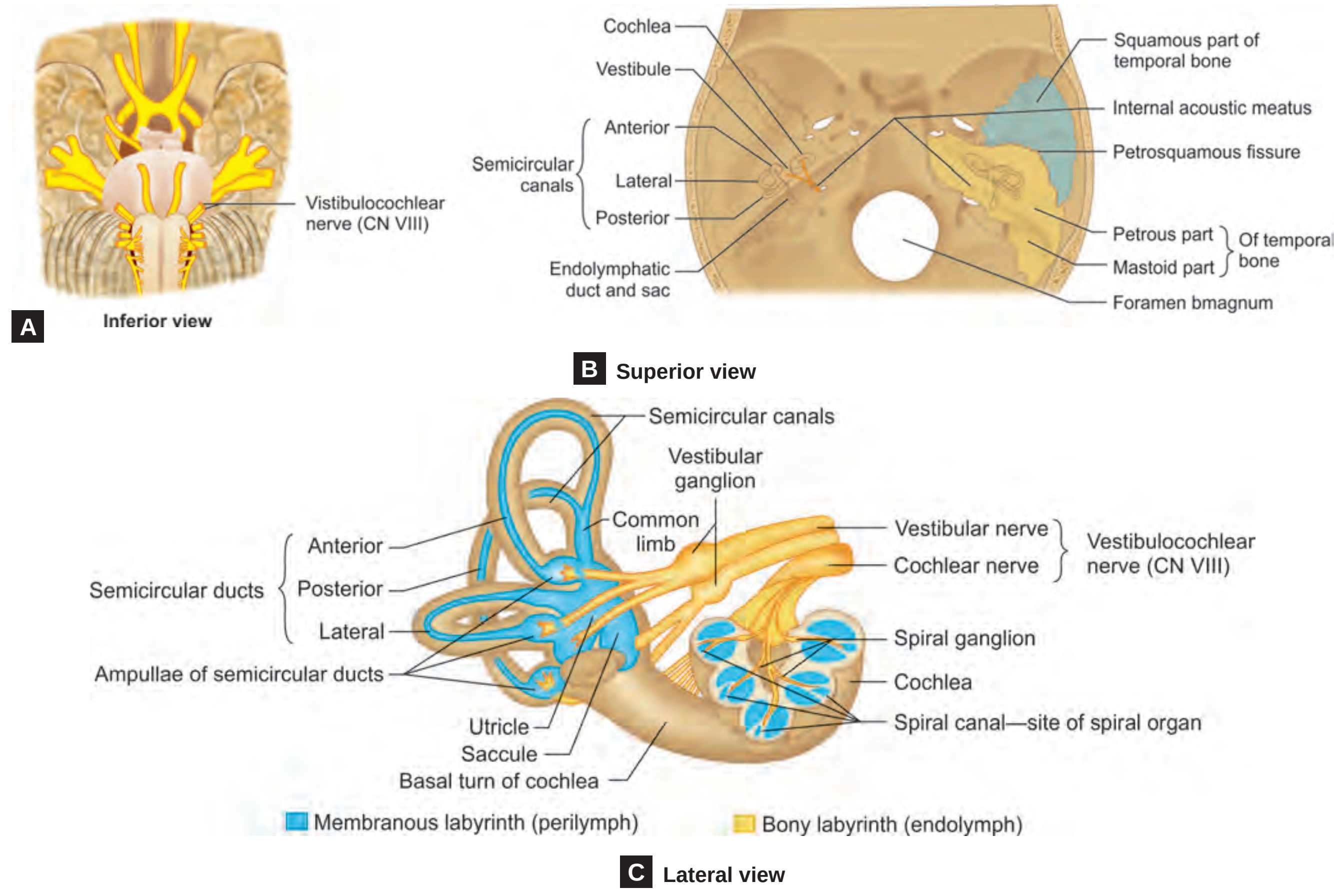


Fig. 182: Inner aspect of lateral end of internal auditory canal with structures passing through different areas.

Vestibulocochlear Nerve

- Vestibulocochlear nerve leaves the pontocerebellar angle laterally and enters the internal acoustic meatus (with the facial nerve) and remains within the temporal bone to supply sensory fibers to the sensory cells of the inner ear.
- The cochlear portion (for hearing) derives from bipolar neurons in the spiral (cochlear) ganglion that innervate the hair cells of the cochlea (organ of Corti).
- The vestibular portion (for equilibrium) arises from bipolar neurons in the vestibular ganglion that innervate sensory cells of the ampullae of the semicircular ducts as well as the utricle and saccule.



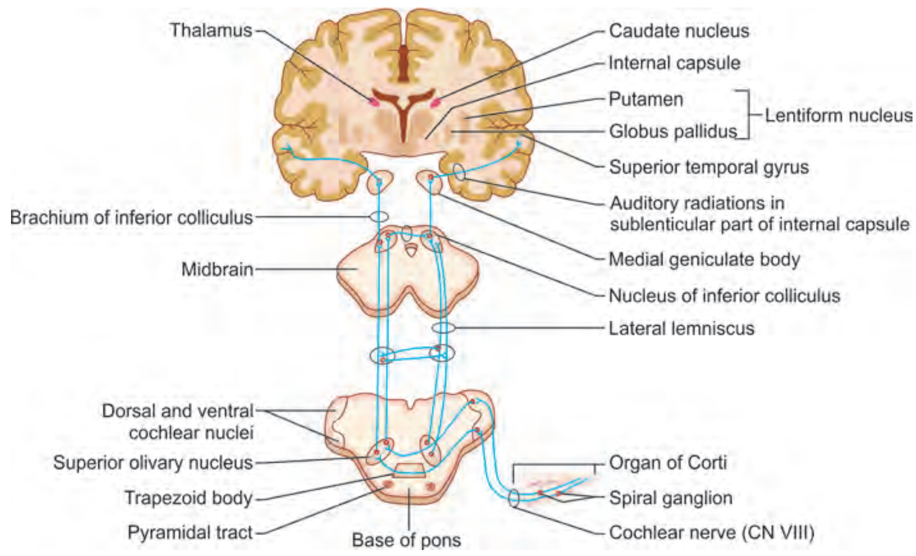
Figs. 183A and B: Vestibulocochlear nerve (CN VIII). (A) Original vestibulo-cochlar nerve from ponto-medullary junction. (B) The internal surface of the cranial base shows the location of the bony labyrinth of the internal ear within the temporal bone. (C) This view of the bony and membranous labyrinths shows (1) innervation of the cochlea by the cochlear nerve of CN VIII for the sense of hearing and (2) innervation of the vestibular apparatus by the vestibular nerve of CN VIII for equilibrium and motion.

Auditory Pathway

- Auditory information is an exteroceptive sensation, which belongs to SSA (special somatic afferent), detecting sound frequencies from 20 Hz to 20,000 Hz.
- The primary afferents of the auditory pathway arise from cell bodies in the spiral ganglion of the cochlea.
- The bipolar cells of the spiral (cochlear) ganglion project peripherally to the hair cells of the organ of Corti.
- They project centrally as the cochlear nerve to the cochlear nuclei. The cochlear nerve [cranial nerve (CN) VIII] extends from the spiral ganglion to the cerebellopontine angle, where it enters the brainstem.
- The cochlear nuclei project contralaterally to the superior olivary nucleus and lateral lemniscus.
- The superior olivary nucleus, which plays a role in sound localization, receives bilateral input from the cochlear nuclei and projects to the lateral lemniscus.
- The trapezoid body (ventral pons) contains decussating fibers from the ventral cochlear nuclei.
- The ventral cochlear nucleus projects via the trapezoid body or the intermediate acoustic stria to relay centres in either the superior olivary complex, the nuclei of the lateral lemniscus, or the inferior colliculus.
- The lateral lemniscus receives input from the contralateral cochlear nuclei and superior olivary nuclei and project to the nucleus of inferior colliculus.
- The medial geniculate body receives input from the nucleus of the inferior colliculus.
- It projects through the internal capsule (sublentiform fibres) as the auditory radiation to the primary auditory Cortex.
- The medial geniculate body is connected reciprocally to the primary auditory cortex, which lies in the posterior half of the superior temporal gyrus and also dives into the lateral sulcus as the transverse temporal gyri (Heschl's gyri).
- Connections also run from the nucleus of the lateral lemniscus to the deep part of the superior colliculus, to coordinate auditory and visual responses.

Clinical Correlations

- Presbycusis results from degenerative disease of the organ of Corti in the first few millimeters of the basal coil of the cochlea (high-frequency loss of 4,000 to 8,000 Hz).



Auditory pathway (Mnemonic: SLIM – 41,42.)

Figs. 184: Superior olivary nucleus, L: Lateral lemniscus, I: Inferior colliculus, M: Medial geniculate body, 41,42: Temporal auditory cortex. Organ of Corti (inner ear) → cochlear (spiral) ganglion and nerve → cochlear nuclei → trapezoid body → superior olivary nucleus → lateral lemniscus → inferior colliculus → medial geniculate body → sublentiform fibres of internal capsule → auditory cortex (41, 42 Brodmann area)

ASSESSMENT QUESTION

1. **The auditory pathway consists of all of the following EXCEPT:**
   a. Lateral geniculate body
   b. Superior olivary nucleus
   c. Trapezoid body
   d. Inferior colliculus

ANSWER WITH EXPLANATION

1. **a. Lateral geniculate body > c. Trapezoid body**
   - Medial (not lateral) geniculate body is related to auditory pathway.
   - Trapezoid body is present in the ventral pons and contains the crossing fibres from the cochlear nuclei towards the superior olivary nucleus.

Vestibular Pathway

- Vestibular nuclei project fibers to:
  - Flocculonodular lobe of the cerebellum
  - CN III, IV, and VI through the medial longitudinal fasciculus (MLF)
  - Spinal cord through the lateral vestibulospinal tract
  - Ventral posteroinferior and posterolateral nuclei of the thalamus, both of which project to the postcentral gyrus.

Histology

- The auricle (pinna) is made up of elastic cartilage and is covered by skin (stratified squamous epithelium).
- External auditory canal is covered by skin with sebaceous glands and ceruminous glands (modified apocrine sweat glands that produce wax).
- Tympanic membrane is lined by skin (stratified squamous epithelium) on its external surface and simple cuboidal epithelium on its inner surface.

Nose

Surface Anatomy of Nose

- **Glabella** is a small horizontal ridge, which is easily palpable between the superciliary arches.
- It is the most forward projecting point of the forehead in the midline at the level of the supraorbital ridge
- **Nasion** is the intersection of the frontal bone and two nasal bones. It is present between the eyes, just superior to the bridge of the nose and just inferior to the glabella.
- **Radix**: The junction between the frontal bone and the nasal bone (dorsum of the nose).
- **Rhinion**: It is the soft-tissue correlate of the osseocartilaginous junction of the nasal dorsum. It is the anterior tip at the end of the suture of the nasal bones.
- **Columella**: Column between the nostrils at the base of nose.

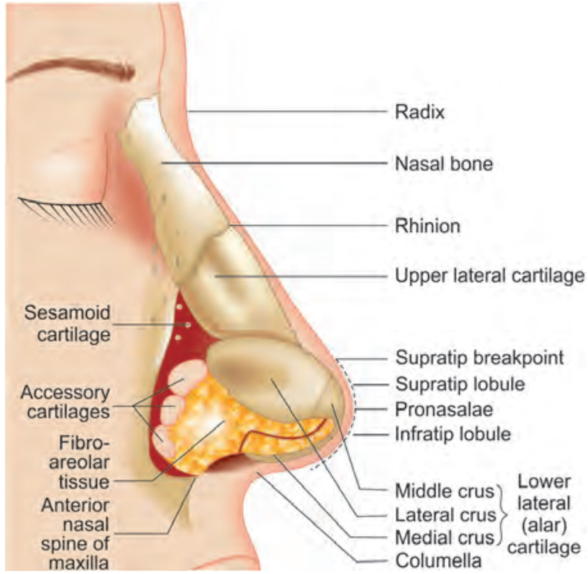


Fig. 185: External features of nose.

- Nasal cavity has the function to warm, clean, humidify, filter the inhaled air for respiration, and appreciate the special senses of smell and taste.
- It opens to the exterior on the face through the anterior nasal apertures (nostrils) and communicates posteriorly with the nasopharynx through the choanae.
- Vestibule is a slight dilatation inside the aperture of each nostril, lined with skin containing hair, sebaceous glands, and sweat glands.
- **Roof** is formed by the bones : Nasal, frontal, cribriform plate of ethmoid, and body of sphenoid.
  - The axons of olfactory nerves pass through the cribriform plate of ethmoid to reach the olfactory bulb in brain.
- **Floor** is contributed by the palatine process of the maxilla and the horizontal plate of the palatine bone.
  - It has the incisive foramen, which transmits the nasopalatine nerve and terminal branches of the sphenopalatine artery.
- **Medial wall** is the **nasal septum** formed by the perpendicular plate of the ethmoid bone, vomer, and septal cartilage.
  - It also get contributions by processes of the palatine, maxillary, frontal, sphenoid, and nasal bones.

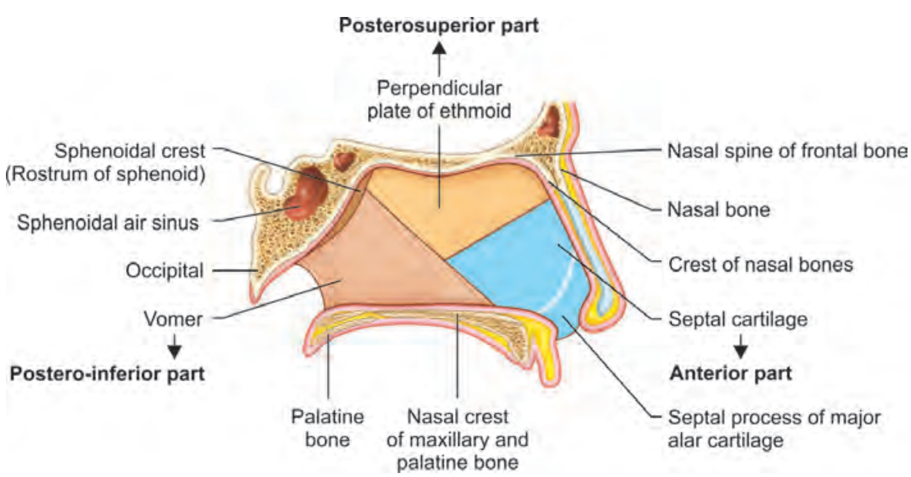


Fig. 186: Formation of the nasal septum.

- **Lateral wall of nose** is subdivided into three parts:
  - **Vestibule** is a small depressed area in the anterior part, lined by modified skin containing hair called vibrissae
  - **Atrium** of the middle meatus is the middle part.
  - The posterior part contains the **conchae** and the spaces under each called the respective **meatus**.
  - The skeleton of the lateral wall is partly bony, partly cartilaginous, and partly made up only of soft tissues.
  - The bony part is formed from before backwards by the following bones (1) Nasal, (2) frontal process of maxilla (3) Lacrimal, (4) Labyrinth of ethmoid bone with superior and middle conchae; (5) Inferior nasal concha; (6) Perpendicular plate of the palatine bone together with its orbital and sphenoidal processes, and (7) Medial pterygoid plate.
  - The cartilaginous part is formed by : (a) The superior nasal cartilage; (b. the inferior nasal cartilage; and 3 or 4 small cartilages of the ala.

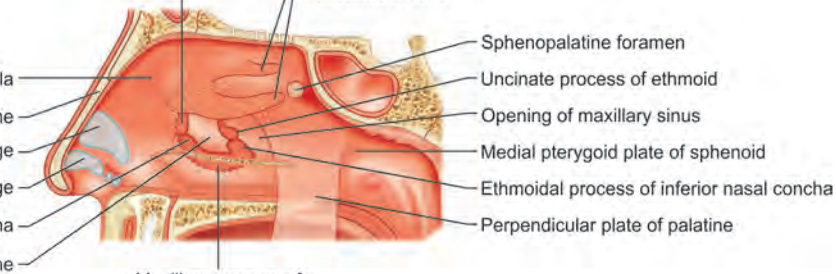


Fig. 187: Formation of the lateral wall of the nasal cavity. Red circle indicates the position of maxillary air sinus.

- **Inferior turbinate** is an independent facial bone (not a part of ethmoid), which extends horizontally along the lateral wall of the nasal cavity and articulates with bones like maxilla, palatine, lacrimal and **ethmoid**.
- It is the largest of the three turbinates.
- The inferior meatus lies underneath the inferior concha, and is the **largest** of the three meatuses.
- The **nasolacrimal duct** opens into it at the junction of its anterior one-third and posterior two-thirds.
- This opening is guarded by the lacrimal fold, or Hasner's valve.
- The middle meatus lies underneath the middle concha.
- It presents the following features: (1) The ethmoidal bulla, is a rounded elevation produced by the underlying middle ethmoidal sinuses, (2) The hiatus semilunaris, is a deep semicircular sulcus below the bulla, (3) The infundibulum is a short passage at the anterior end of the hiatus, (4) The opening of the frontal air sinus is seen in the anterior part of the hiatus semilunaris, (5) The opening of the maxillary air sinus is located in the posterior part of the hiatus semilunaris. It is often represented by two openings, (6 The opening of the middle ethmoidal air sinus is present at the upper margin of the bulla.
- The superior meatus lies below the superior concha.
- This is the shortest and shallowest of the three meatuses.
- It receives the openings of the posterior ethmoidal air sinuses.

Openings in the lateral wall of nasal cavity:

The openings in the lateral wall of the nose

Sites	Openings
Sphenoethmoidal recess	Opening of the sphenoidal air sinus
Superior meatus	Opening of the posterior ethmoidal air sinuses
Middle meatus • On bulla • In hiatus semilunaris – Anterior part – Middle part – Posterior part	 Opening of the middle ethmoidal air sinuses Opening of the frontal air sinus Opening of the anterior ethmoidal air sinuses Opening of the maxillary air sinus
Inferior meatus	Opening of the nasolacrimal duct (in the anterior part of meatus)

- Some authors mention the opening of the frontal sinus into the infundibulum.
- Sphenopalatine Foramen is the opening into the pterygopalatine fossa; transmits the sphenopalatine artery and nasopalatine nerve.

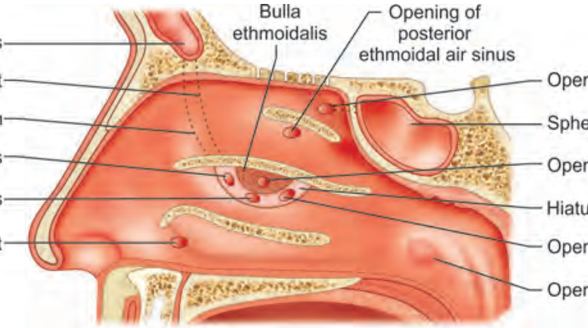
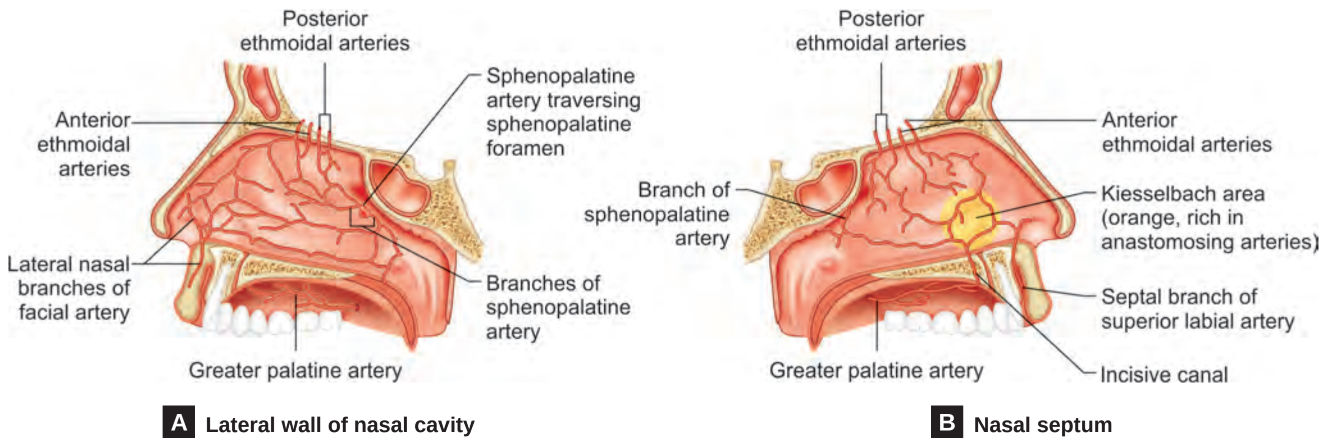


Fig. 188: Lateral wall of the nose with conchae removed showing openings of various sinuses and nasolacrimal duct.

- Mucous membrane of nose has three regions: **Vestibule**, **respiratory** region and **olfactory** region.
  - **Vestibule** is present at the entrance of nostrils, bound by the alar cartilages and lined by skin with hair.
  - **Respiratory** area occupies the lower two-thirds of the nasal cavity.
  - **Olfactory** Region is located at the roof of nasal cavity, includes the superior nasal concha and the upper one-third of the nasal septum.
    - It has neuroepithelium, whose axons constitutes olfactory nerves, which enter the cranial cavity passing through the cribriform plate of the ethmoid bone to synapse in the olfactory bulb.
- Arterial supply:
  - The **sphenopalatine** artery (branch of maxillary artery) is the most important supply to the nasal cavity, giving posterior lateral nasal and posterior septal branches.
  - ly there are other contributions: Lateral nasal branches of the anterior and posterior **ethmoidal** arteries of the ophthalmic artery; the **greater palatine** branch (its terminal branch reaches the lower part of the nasal septum through the incisive canal) of the descending palatine artery of the maxillary artery; the septal branch of the **superior labial artery** of the facial artery and the **lateral nasal** branch of the facial artery.
- **Little's area** is a highly vascular area located in the anteroinferior part of the nasal septum just above the vestibule.
- Four (or five) arteries anastomose here to form a vascular plexus called **Kiesselbach's plexus**.
- It is exposed to the drying effect of inspiratory current and to finger nail trauma and is the usual site for epistaxis.
- Participating arteries are: Septal branch of the anterior ethmoidal artery (a branch of ophthalmic artery), Septal branch of the sphenopalatine artery (a branch of maxillary artery), septal branch of the greater palatine artery (a branch of maxillary artery) and septal branch of the superior labial artery (a branch of facial artery). Occasionally septal branch of the posterior ethmoidal artery (a branch of ophthalmic artery) may also contribute to the plexus.
- **Woodruff's plexus** is a **venous** plexus just inferior to the posterior end of the inferior turbinate, is considered as a frequent source of **posterior epistaxis**.



Figs. 189A and B: Arterial supply of nasal cavity. An open-book view of the lateral and medial walls of the right side of the nasal cavity is shown. The left "page" shows the lateral wall of the nasal cavity. The sphenopalatine artery (a branch of the maxillary) and the anterior ethmoidal artery (a branch of the ophthalmic) are the most important arteries to the nasal cavity. The right "page" shows the nasal septum. An anastomosis of four to five named arteries supplying the septum occurs in the antero-inferior portion of the nasal septum (Kiesselback area, orange) an area commonly involved in chronic epistaxis (nosebleeds).

Clinical Correlations

- **Epistaxis** is a nosebleed resulting usually from rupture of the sphenopalatine artery.
- It may occur from nose picking, which tears the veins in the vestibule of the nose.
- It also occurs from the anterior inferior part of nasal septum (Kiesselbach's area or plexus), where branches of the sphenopalatine (from maxillary), greater palatine (from maxillary), anterior ethmoidal (from ophthalmic), and superior labial (from facial) arteries converge.
- The sphenopalatine artery may be ligated under endoscopic visualization as it enters the nose through the sphenopalatine foramen.
- The ethmoidal arteries are exposed within the orbit and ligated.
- The maxillary artery is exposed surgically behind the posterior wall of the maxillary sinus and ligated.
- Nerve supply:
  - Smell sensation is carried by olfactory nerve under special somatic afferent (**SSA**) neural column.
  - General sensation under general somatic afferent (**GSA**) column is carried by the **anterior ethmoida**l branch of the ophthalmic nerve; the **nasopalatine**, posterior–superior, and posterior–inferior lateral nasal branches of the maxillary nerve via the pterygopalatine ganglion; and the anterior-superior alveolar branch of the infraorbital nerve.

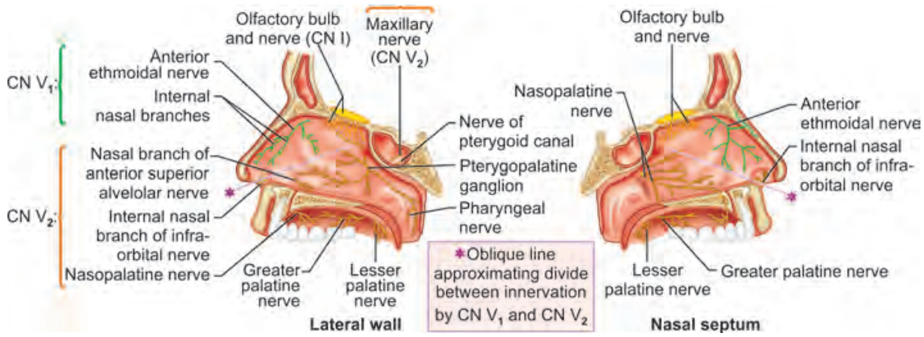


Fig. 190: Distribution of trigeminal nerve (CN V). (A) The three divisions of CN V arise from the trigeminal ganglion. In addition to the trigeminal ganglion, a sensory ganglion (similar to the sensory or dorsal root ganglia of spinal nerves) and four parasympathetic ganglia (three of which are shown here) are associated with the branches of the trigeminal nerve; (B) Branches of the mandibular nerve (CN V3) pass to the muscles of mastication. (C) This "opened book" view of the lateral wall and spetum of the right nasal cavity demonstrates superficial and deep distribution of CNV2 (and, incidentally, CN I) to the nasal and upper over the midline of the head.

ASSESSMENT QUESTIONS

1. Osseocartilaginous junction is present at: *(NEET Pattern 2012)*
a. Nasion
b. Rhinion
c. Radix
d. Columella

2. All is true about the openings in the lateral wall of nasal cavity and nasopharynx EXCEPT:
a. Nasolacrimal duct opens in the inferior meatus
b. Posterior ethmoidal sinus opens in the superior meatus
c. Inferior turbinate is a part of ethmoid bone
d. Eustachian tube opens in nasopharynx behind the inferior turbinate

3. TRUE about anatomy of lateral wall of nose: *(PGIC 2013)*
a. Superior turbinate is a separate bone
b. Ethmoid bone forms an important part of the lateral wall
c. Middle turbinate is formed by medial process of the ethmoidal labyrinth
d. Opening of inferior meatus is present
e. Inferior turbinate is a separate bone

4. The roof of the olfactory region is formed by: *(NEET Pattern 2014)*
a. Nasal bone
b. Cribriform plate of ethmoid
c. Sphenoid
d. Temporal bone

5. Olfactory region in nose is: *(NEET Pattern 2013)*
a. Below inferior turbinate
b. Above superior turbinate
c. Between middle and inferior turbinate
d. None

6. All the following bones contribute to the formation of Nasal septum EXCEPT: *(AIPG 2008)*
a. Sphenoid
b. Lacrimal
c. Palatine
d. Ethmoid

7. Bony nasal septum is formed by all EXCEPT *(NEET Pattern 2012)*
a. Vomer
b. Sphenoid
c. Ethmoid
d. Nasal spine of nasal bone

8. All are part of ethmoid bone EXCEPT: *(NEET pattern 2014)*
a. Agger nasi
b. Bulla ethmoidalis
c. Uncinate process
d. Inferior turbinate

9. Uncinate process arises from: *(NEET Pattern 2014)*
a. Ethmoid bone
b. Palatine bone
c. Nasal bone
d. Maxilla bone

10. Turbinate that articulates with ethmoid bone is: *(NEET pattern 2012)*
a. Superior
b. Middle
c. Inferior
d. All of the above

11. One of the following opens in the middle meatus of the nose: *(NEET Pattern 2015)*
a. Naso-lacrimal duct
b. Eustachian tube
c. Sphenoidal air sinus
d. Maxillary air sinus

12. Ethmoidal sinus opens into which of the following: *(NEET Pattern 2012)*
a. Hiatus
b. Middle meatus
c. Superior meatus
d. All of the above

13. Which of the following sinuses open into middle meatus: *(PGIC 2014)*
a. Frontal sinus
b. Anterior ethmoidal sinus
c. Posterior ethmoidal sinus
d. Maxillary sinus
e. Sphenoid sinus

14. Blood supply of little's area are: *(PGIC 2015)*
a. Greater palatine artery
b. Septal branch of superior artery
c. Anterior ethmoidal artery
d. Septal branch of sphenopalatine artery
e. Nasal branch of sphenopalatine artery

15. Little's area is: *(NEET Pattern 2015)*
a. Anteroinferior lateral wall
b. Anteroinferior nasal septum
c. Posteroinferior lateral wall
d. Posteroinferior nasal septum

ANSWERS WITH EXPLANATIONS

1. b. Rhinion
- Rhinion is the soft-tissue correlate of the osseocartilaginous junction of the nasal dorsum.

2. c. Inferior turbinate is a part of ethmoid bone
- **Inferior turbinate** is an independent facial bone (not a part of ethmoid), which extends horizontally along the lateral wall of the nasal cavity and articulates with bones like maxilla, palatine, lacrimal and **ethmoid**.

3. b. Ethmoid bone forms an important part of the lateral wall; c. Middle turbinate is formed by medial process of the ethmoidal labyrinth; d. Opening of inferior meatus is present; e. Inferior turbinate is a separate bone
- Ethmoid bone has major contribution in the nose formation, including lateral wall of nose.
- Superior and middle concha are formed by medial process of the ethmoidal labyrinth, whereas inferior concha is an independent bone.

4. b. Cribriform plate of ethmoid
- The roof of nasal cavity, formed by the cribriform plate of ethmoid bone, has olfactory epithelium.

5. b. Above superior turbinate
- The olfactory mucosa lines the upper one-third of nasal cavity including the roof formed by cribriform plate and the medial and lateral walls up to the level of superior turbinate.

6. b. Lacrimal
- Lacrimal bone contributes to the medial wall of the orbit and not the nasal septum.
- Nasal septum is mainly formed of vomer and the perpendicular plate of ethmoid bone.
- It receives contributions from the nasal crests of palatine bone.
- The rostrum of sphenoid bone also contributes to the nasal septum.

7. d. Nasal spine of nasal bone
- Bony nasal septum is contributed by the nasal spine of frontal bone.
- It is the crest of nasal bone which contributes to nasal septum.

8. d. Inferior turbinate
- Inferior turbinate is a separate bone and not a part of ethmoid bone.

9. a. Ethmoid bone
- In the **ethmoid** bone, a curved lamina, the **uncinate process**, projects downward and backward from the labyrinth; it forms a small part of the medial wall of the maxillary sinus, and articulates with the ethmoidal process of the inferior nasal concha.
- It can be seen in the middle meatus (lateral wall of nose).

10. c. Inferior
- **Inferior turbinate** is a facial bone which extends horizontally along the lateral wall of the nasal cavity and articulates with bones like maxilla, palatine, lacrimal and **ethmoid**.

11. d. Maxillary air sinus
- Maxillary sinus opens in the hiatus semilunaris of middle meatus near the roof of the sinus.
- Nasolacrimal duct opens into the anterior part of inferior meatus closed by a mucosal flap called Hasner's valve.
- Eustachian tube opens into the lateral wall of nasopharynx, about 1.25 cm behind the posterior end of inferior nasal concha.
- Sphenoid air sinus opens into spheno-ethmoidal recess of nasal cavity.

12. d. All of the above
- **Anterior** ethmoidal sinus opens into hiatus semilunaris (middle meatus).
- **Middle** ethmoidal sinus opens into surface of bulla ethmoidalis (middle meatus).
- **Posterior** ethmoidal sinus opens into superior meatus (posterior part).

13. a. Frontal sinus; b. Anterior ethmoidal sinus; d. Maxillary sinus
- Middle meatus has hiatus semilunaris with openings of some sinuses: Frontal sinus opens at the front of hiatus semilunaris, anterior ethmoidal sinus in the middle and maxillary sinus in the posterior part.
- Middle ethmoidal sinus opens in the middle meatus at the bulla.

14. a. Greater palatine artery, b. Septal branch of superior artery, c. Anterior ethmoidal artery, d. Septal branch of sphenopalatine artery

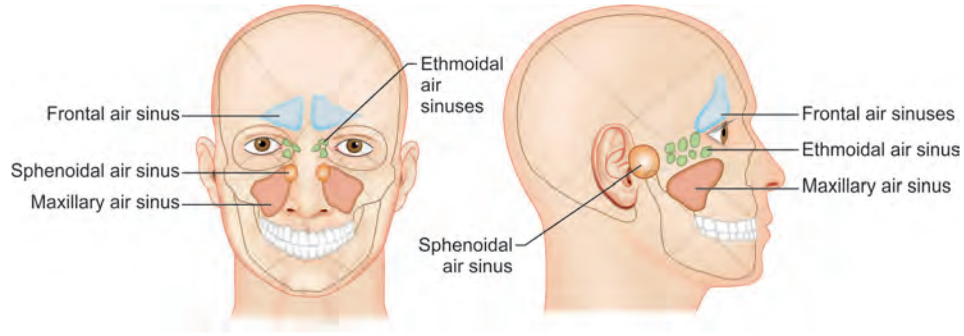
- Little's area is a highly vascular area located in the anteroinferior part of the nasal septum just above the vestibule.
- Here the septal branches of the anterior ethmoidal, sphenopalatine, greater palatine, and superior labial arteries anastomose to form a vascular plexus called Kiesselbach's plexus.

15. b. Anteroinferior nasal septum

- Little's area is situated in the anterior inferior part of nasal septum just above the vestibule.
- It is exposed to the drying effect of inspiratory current and to finger nail trauma and is the usual site for epistaxis.

Paranasal Sinuses

- Skull bones around nasal cavity develop pneumatization and spaces called paranasal sinuses, which help in reduction of weight and resonance for voice.
- At birth, both small **ethmoidal** and **maxillary** sinuses are present, but the **frontal** sinus is nothing more than an out-pouching from the nasal cavity, and there is no pneumatization of the **sphenoid** bone.
- **Ethmoidal air sinus** shows numerous ethmoidal air cells, within the ethmoidal labyrinth between the orbit and the nasal cavity.
- Sinus pathology may erode through the thin orbital plate of the ethmoid bone (lamina papyracea) and enter into the orbit.
- Three groups are identified: **Posterior** ethmoidal air cells, drain into the superior nasal meatus, **middle** ethmoidal air cells, drain into the summit of the ethmoidal bulla (middle meatus) and **anterior** ethmoidal sinus drain into the anterior aspect of the hiatus semilunaris (middle meatus).
- **Frontal air sinus** is located in the frontal bone and opens into the hiatus semilunaris of the middle nasal meatus by way of the frontonasal duct (or infundibulum). It is innervated by the supraorbital branch of the ophthalmic nerve.
- **Maxillary air sinus** is the largest of the paranasal air sinuses and is the only paranasal sinus that may be present at birth.
- It lies in the maxilla bone lateral to the lateral wall of the nasal cavity and inferior to the floor of the orbit, and drains into the posterior aspect of the hiatus semilunaris in the middle meatus.
- **Sphenoidal air sinus** is located within the body of the sphenoid bone and drains into the spheno-ethmoidal recess of the nasal cavity.
- It is innervated by branches from the maxillary nerve and by the posterior ethmoidal branch of the nasociliary nerve.
- Pituitary gland lies in the sella turcica in the body of sphenoid above this sinus and can be reached by the trans-sphenoidal approach, which follows the nasal septum through the body of the sphenoid.



Figs. 191A and B: Positions of paranasal air sinuses on the surface: (A) Front view; (B) Side view.

Sinus	Drainage
Frontal sinus	Middle meatus (through frontonasal duct) Into hiatus semilunaris (anterior part)
Maxillary sinus	Middle meatus Into hiatus semilunaris (posterior part)
Sphenoidal sinus	Spheno-ethmoidal recess
Anterior ethmoidal sinus	Middle meatus Into hiatus semilunaris
Middle ethmoidal sinus	Middle meatus Surface of bulla ethmoidalis
Posterior ethmoidal sinus	Superior meatus (posterior part)

ASSESSMENT QUESTION

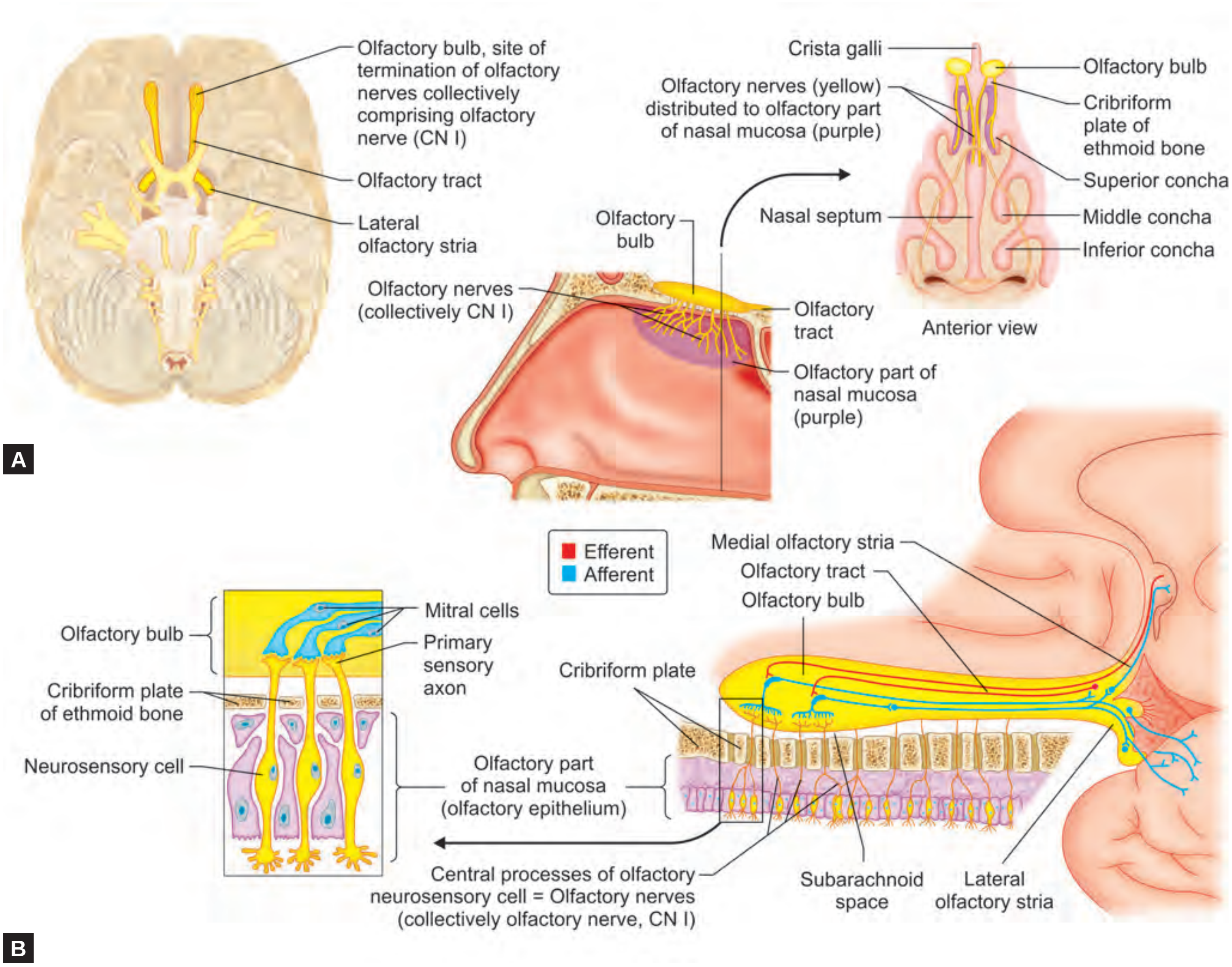
1. **Onodi cells and Haller cells of ethmoid labyrinth seen in relation to following respectively** *(AIIMS 2009)*
   a. Optic nerve and floor of orbit
   b. Optic nerve and Internal carotid artery
   c. Optic nerve and nasolacrimal duct
   d. Orbital floor and nasolacrimal duct

ANSWER WITH EXPLANATION

1. **b. Optic nerve and Internal carotid artery**
   a. Ethmoid bone is a pneumatic bone and has numerous air cells around the nose.
   b. Onodi cell is the most posterior ethmoidal cell that is present superior and lateral to the sphenoid sinus and is intimately related to the optic nerve and internal carotid artery.
   c. Optic nerve may be seriously damaged in ESS (Endoscopic sinus surgery).
   d. Haller cell represents an extension of anterior ethmoidal air cells extending into the infra-orbital margin (roof of maxillary sinus).

Olfactory Nerve

- Olfactory nerve consists of approximately 20 bundles of unmyelinated afferent fibers (special somatic afferent) that arise from neurons in the olfactory area, the upper one-third of the nasal mucosa, and carry the sense of smell (olfaction).
- The axons pass through the foramina in the cribriform plate of the ethmoid bone and synapse in the olfactory bulb.



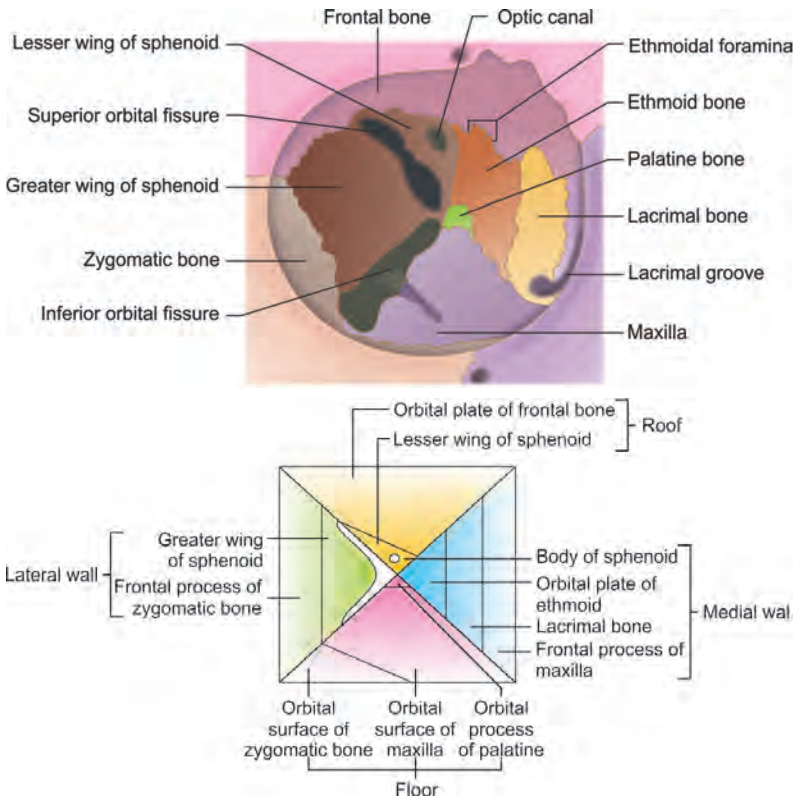
Figs. 192A and B: (A) Medial view of lateral wall of nosal cavity; (B) Medicial view of sagittal section through cribriform plate of ethnoid bone

Orbit and Eyeball

- Orbit is the socket in the skull where the eye and its appendages are present.

Bony Orbit

- Walls of orbit:
  - **Medial wall** (4 bones) is formed by maxilla, lacrimal bone, ethmoid and the sphenoid (body).
  - **Lateral wall** (2 bones) is contributed by the zygomatic bone, and sphenoid (greater wing).
  - **Roof** (2 bones) has frontal bone and sphenoid (lesser wing)
  - Floor (3 bones) is formed by maxilla, zygomatic and palatine bones.
- The thickest wall is lateral and the thinnest is medial.



Figs. 193: Bones of the orbit.

Fissures, Canals, and Foramina Related with Orbit

- **Superior orbital fissure** is present between the lateral wall and the roof of orbit.
  - It communicates with the middle cranial fossa and is bounded by the greater and lesser wings of the sphenoid.
  - It transmits the oculomotor, trochlear, abducens, three branches of ophthalmic nerve and the ophthalmic (superior and inferior) veins.
- **Inferior orbital fissure** is formed between the medial wall and the floor of orbit.
  - It is bounded by the greater wing of the sphenoid (above) and the maxillary and palatine bones (below) and bridged by the orbitalis (smooth) muscle.
  - It communicates with the infratemporal and pterygopalatine fossae and transmits the maxillary nerve and its zygomatic branch and the infraorbital vessels.
  - Maxillary nerve passes through it to run at the floor of the orbit as inferior orbital nerve.
- **Optic Canal** is formed by the two roots of the lesser wing of the sphenoid, lies in the posterior part of the roof of the orbit and connects the orbit with the middle cranial fossa.
  - It transmits the optic nerve and ophthalmic artery.
- **Infraorbital Groove** and foramen transmit the infraorbital nerve and vessels.
- **Supraorbital Notch**/Foramen transmits the supraorbital nerve and vessels.
- Anterior and posterior **ethmoidal Foramina** are present at the junction of roof and medial wall of orbit and transmit the anterior and posterior ethmoidal nerves and vessels, respectively.
- Nasolacrimal canal is formed by the maxilla, lacrimal bone, and inferior nasal concha. It transmits the nasolacrimal duct from the lacrimal sac to the inferior nasal meatus.

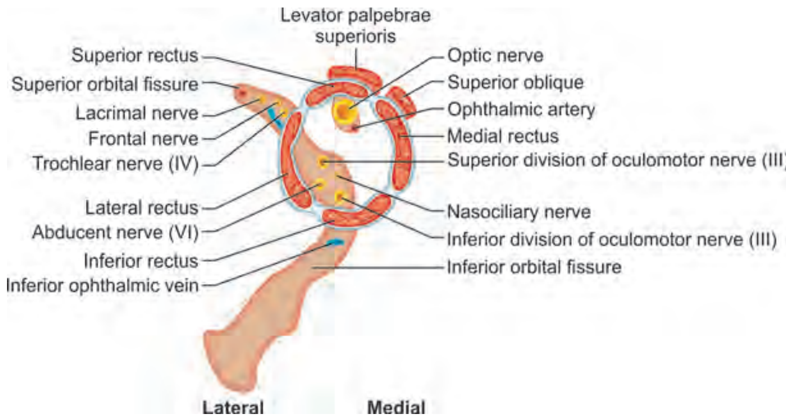


Fig. 194: Structures passing through the orbital fissures.

ASSESSMENT QUESTIONS

1. Lamina papyracea separates nose from: *(NEET pattern 2013, 15)*
  a. Sphenoid bone
  b. Orbit
  c. Frontal bone
  d. Maxillary sinus

2. All of the following bones are a part of the floor of the orbit EXCEPT: *(AIIMS 2013)*
  a. Ethmoid
  b. Maxilla
  c. Palatine
  d. Zygomatic

3. Maximum contribution to floor of orbit is by: *(NEET Pattern 2012)*
  a. Maxilla
  b. Sphenoid
  c. Palatine
  d. Zygomatic

4. Choose the WRONG statement concerning the wall of the orbit:
  a. Roof: Frontal bone
  b. Roof: Greater wing sphenoid
  c. Medial wall: Ethmoid bone
  d. Medial wall: Sphenoid bone

5. TRUE statement about orbital articulation is: *(AIPG)*
  a. Medial wall of orbit is formed by maxilla, sphenoid, ethmoid and the lacrimal bone
  b. Floor is formed by maxilla, zygomatic and ethmoid
  c. Lateral wall of orbit is formed by the frontal bone, zygomatic bone, and greater wing of sphenoid
  d. Inferior orbital fissure is formed between the medial wall and the floor of orbit

ANSWERS WITH EXPLANATIONS

1. b. Orbit
- Lamina papyracea is a smooth, oblong bone plate which forms the lateral surface of the labyrinth of the ethmoid bone.
- The plate covers in the middle and posterior ethmoidal cells and forms a large part of the medial wall of the orbit.
- It is paper-thin and fractures easily.

2. a. Ethmoid
- Ethmoid bone forms the medial wall of the orbit.
- The floor (3 bones) of the orbit is chiefly contributed by the orbital plate of the **maxilla** which articulates with the **zygomatic** bone anterolaterally and the small triangular orbital process of the **palatine** bone posteromedially.

3. a. Maxilla
- Maxilla gives maximum contribution to floor of orbit.
- Other contribution are zygomatic bone, anterolaterally and orbital process of palatine bone at the posterior angle.

4. b. Roof: Greater wing sphenoid
- Greater wing of sphenoid is present in the lateral wall (and not roof) of orbit.

5. a. Medial wall of orbit is formed by maxilla, sphenoid, ethmoid and the lacrimal bone
- Medial wall of orbit is formed by (in anterior to posterior order): Maxilla, lacrimal, ethmoid and sphenoid body.
- Floor is formed by maxilla and zygomatic bones, with small contribution from palatine bone.
- Lateral wall is contributed by the greater wing of sphenoid and zygomatic bone.
- Inferior orbital fissure is present between the lateral wall and floor of orbit.

Eyeball Development

- Development of the eye involves a series of inductive interactions between neighbouring tissues in the embryonic head.
- These are the **neurectoderm** of the forebrain (which forms the sensory retina and accessory pigmented structures), the **surface ectoderm** (which forms the lens and the anterior corneal epithelium) and the intervening **neural crest and their mesenchyme** (which contributes to the fibrous coats of the eye and to tissues of the anterior segment of the eye) and the **primary mesenchyme**.

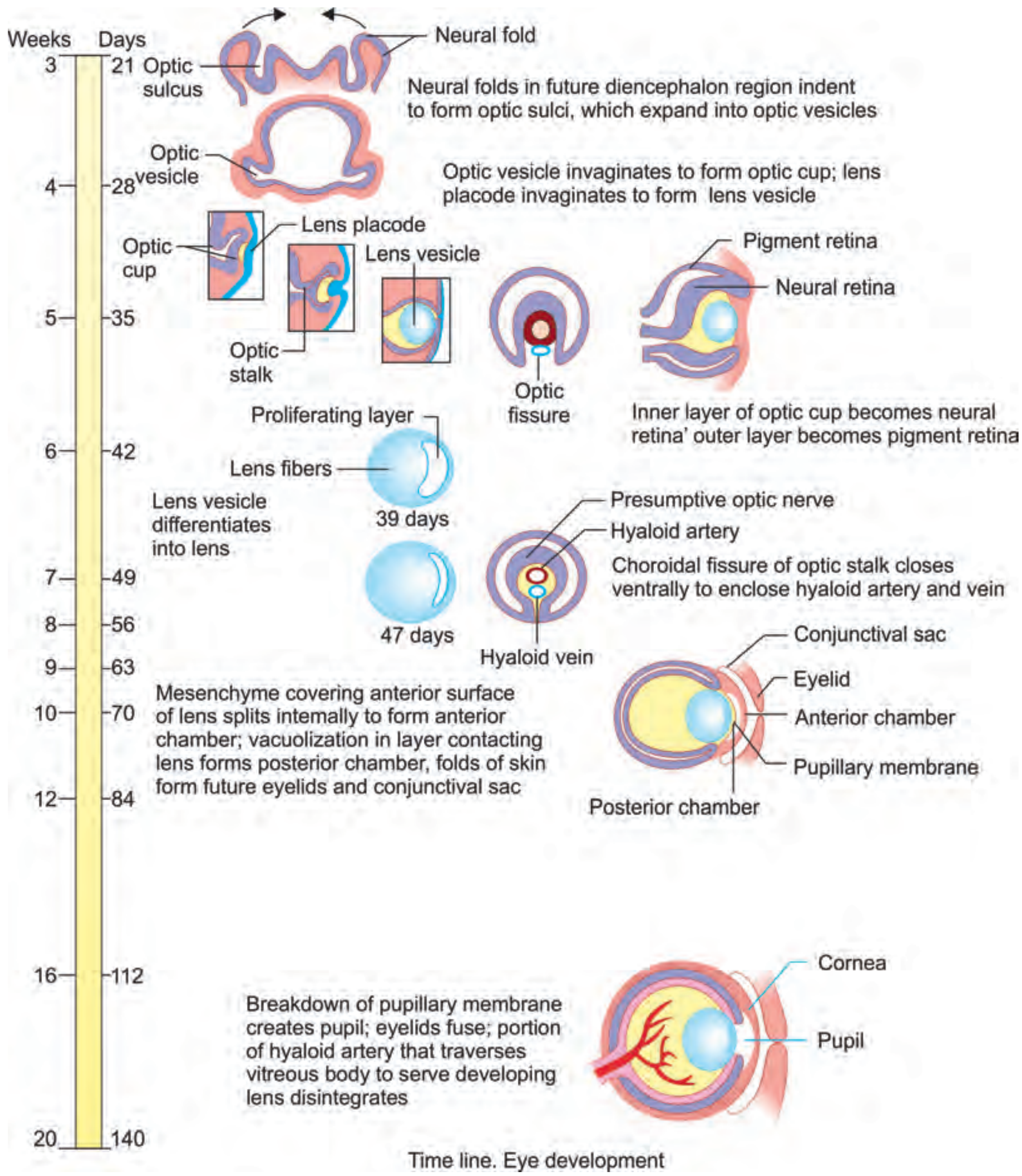


Fig. 195: Development of eyeball.

- Note: Previously it was believed that neuroectoderm give rise to **neural crest cells**, but recently it has been mentioned that they are the **fourth germ layer** (derivative of epiblast ?).
- The first morphological sign of eye development is a thickening of the diencephalic neural folds at 29 days post ovulation, when the embryo has seven to eight somites, by 32 days, the optic vesicles are formed. The development continues through the tenth week.
- PAX6 is the master gene for eye development, is expressed in the single eye field at the neural plate stage. The eye field is separated into two optic primordia by SHH (Sonic HedgeHog), which upregulates PAX2.
- **Neuroectoderm** of the diencephalon (forebrain) evaginates to form the **optic vesicle**, which in turn invaginates to form the **optic cup** and **optic stalk**.
- The inner layer of the optic cup is made of neuroepithelium (**neural retina**), while the outer layer is composed of **retinal pigment epithelium** (RPE). The middle portion of the optic cup develops into the ciliary body and iris.
- Optic cup forms: Retina, epithelium of iris and ciliary body and iris muscles (sphincter and dilator pupillae).
- Optic stalk forms the optic nerve, optic chiasma and optic tract.
- The optic vesicles contact the surface ectoderm and induce the formation of **lens placode**, which eventually separates from the ectoderm to form the **lens vesicle** (and eye lens) at the open end of the optic cup. Surface ectoderm also forms the **anterior epithelium of cornea**.
- Through a groove at the bottom of the optic vesicle known as choroid fissure the **hyaloid blood vessels** enter the eye. Hyaloid artery and vein form the **central artery and vein of the retina**.
- The extracellular mesenchyme (mostly neural crest derived secondary mesenchyme and a small portion of primary mesenchyme) forms the **sclera**, the **corneal endothelium** and **stroma**, **blood vessels**, muscles, and **vitreous**.

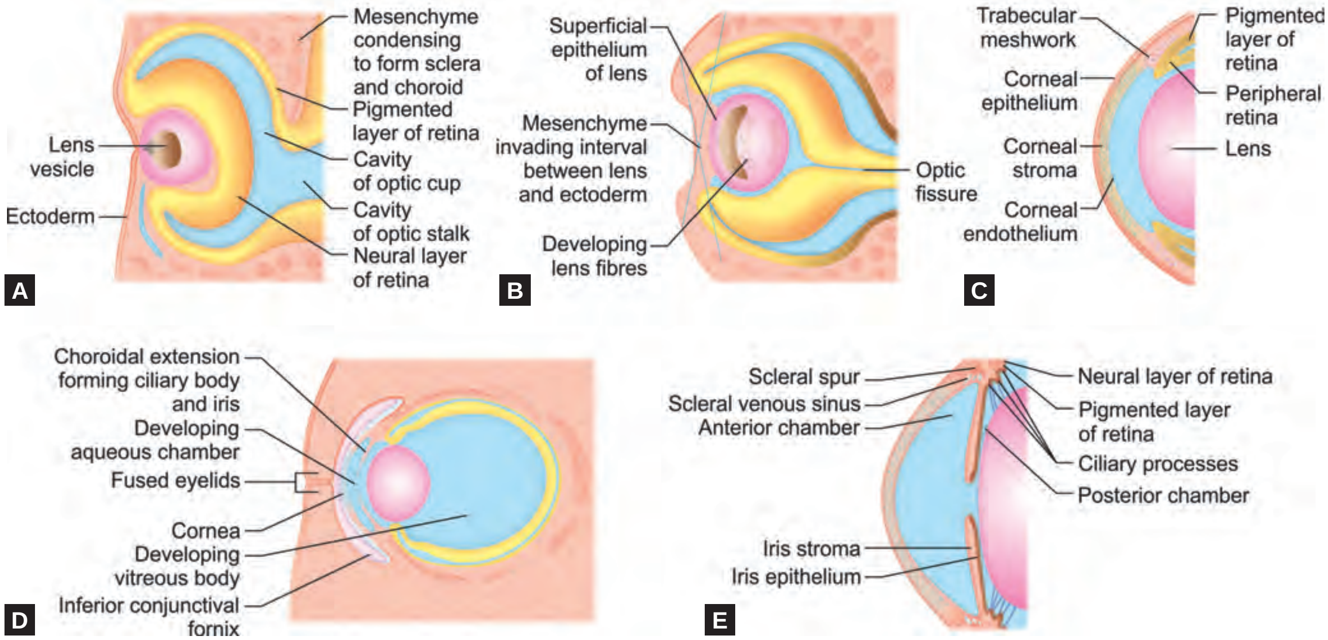


Fig. 196A to E: Development of eye. (A) Thick nervous and the thinner pigmented layers of the developing retina and the lens are evident. The two layers of the embryonic optic cup are separated by the intraretinal space. (B) The surface ectoderm anterior to the lens forms the corneal epithelium, whereas the corneal stroma and endothelium will differentiate from the invading mesenchyme (of neural crest and mesodermal origin). (C) The development of the anterior aqueous chamber is apparent with choroidal extensions and iris visible. The eyelids have developed and are fused; the extent of the conjunctival formices can be seen. (D) Anterior growth of the peripheral retina, pigmented layer of the retina and mesenchymal proliferation at the anterior part of the retina will give rise to the ciliary body and iris. The surface ectoderm anterior to the lens forms the corneal epithelium, whereas the corneal stroma and endothelium will differentiate from invading mesenchyme (of neural crest and mesodermal origin). (E) Details of the developing uveal tract. Note the development of the anterior and posterior aqueous chambers, separated by the iris, and the attachment of the lens to the ciliary body.

- Ocular Muscles: Extrinsic eye muscles are derived from mesenchymal cells near the prechordal plate.
- Three **preotic myotomes**, each supplied by its own nerve (cranial nerve Ill, IV and VI), form the extrinsic muscles of the eye.
- Conjunctiva (bulbar and palpebral) is derived from **surface ectoderm** and so are the skin of eye and glands like lacrimal gland.
- Connective tissue and bony structure of the orbit are derived from **neural crest cells**.

Precursor	Derivatives
Neural (plate) ectoderm	Retina (Including neural and pigment epithelium) Optic nerve Smooth muscle of the iris (sphincter pupillae and dilator pupillae) Epithelium of ciliary body and iris Vitreous (partly)
Surface ectoderm	First layer of cornea (surface epithelium) Eye lens Bulbar and palpebral conjunctiva Lacrimal glands Tarsal glands
Neural crest cells	Cornea: Descemet's membrane and endothelium Sclera Uveal and conjunctival melanocytes Meningeal sheaths of the optic nerve Smooth muscular layer of the ocular and orbital blood vessels Ciliary ganglion Orbital bones
Secondary mesenchyme (derived from neural crest cells)	Cornea: Bowman's membrane and stroma Choroid Iris (includes stroma, excludes epithelium) Ciliary body (includes stroma, ciliaris muscle, excludes epithelium) Vitreous (partly)
Primary mesenchyme	Endothelial lining of blood vessels of the eye Blood vessels in sclera and choroid Trabecular meshwork endothelium Vitreous (partly) Extraocular muscles (somitomeres)

Iris	
Derivatives	**Precursor**
Epithelium	Neural plate ectoderm
Stroma (connective tissue)	Neural crest cell derived mesenchyme
Muscles (sphincter pupillae and dilator pupillae	Neural plate ectoderm

Ciliary body	
Derivatives	**Precursor**
Epithelium	Neural plate ectoderm
Stroma (connective tissue)	Neural crest cell derived mesenchyme
Muscles (ciliaris)	Neural crest cell derived mesenchyme

Cornea	
Derivatives	**Precursor**
Surface epithelium (first layer of cornea)	Surface ectoderm
Bowman's membrane and stroma	Mesenchyme (mostly neural crest cell derived)
Descemet's membrane and endothelium	Neural crest cells

ASSESSMENT QUESTIONS

1. **Corneal stroma is derived from:** *(NEET Pattern 2013)*
   a. Paraxial mesoderm
   b. Intermediate mesoderm
   c. Lateral plate mesoderm
   d. Ectoderm

2. **Ciliaris muscle is derived from:**
   a. Neural crest cells
   b. Neural plate ectoderm
   c. Surface ectoderm
   d. Mesoderm

3. **Corneal endothelium develop from:**
   a. Neural crest cells
   b. Neural plate ectoderm
   c. Surface ectoderm
   d. Mesoderm

4. **Optic vesicle is derived from:** *(NEET Pattern 2016)*
   a. Surface ectoderm
   b. Neuroectoderm
   c. Mesoderm
   d. Neural crest cells

5. **Stroma of cornea develops from:** *(NEET Pattern 2013, 14, 15)*
   a. Neural ectoderm
   b. Surface ectoderm
   c. Mesoderm
   d. Neural crest

6. **All are derived from neuroectoderm EXCEPT:** *(NEET Pattern 2012)*
   a. Dilator pupillae
   b. Lens vesicle
   c. Optic nerve
   d. Posterior layers of retina

7. **All of the following are mesodermal in origin EXCEPT** *(AIPG)*
   a. Dilators of iris
   b. Iris stroma
   c. Ciliary body
   d. Choroid

8. **Stroma of cornea develops from:** *(NEET Pattern 2015)*
   a. Neural ectoderm
   b. Surface ectoderm
   c. Mesoderm
   d. Neural crest

9. **Which of the following is NOT a derivative of neural ectoderm:** *(AIIMS 2013)*
   a. Sphincter pupillae
   b. Dilator pupillae
   c. Ciliary muscle
   d. Retina

10. **Crystalline lens develops from:** *(NEET Pattern 2012)*
    a. Mesoderm
    b. Endoderm
    c. Surface ectoderm
    d. Neuroectoderm

11. **The following ocular structure is NOT derived from surface ectoderm:** *(AIIMS 2006)*
    a. Crystalline lens
    b. Sclera
    c. Corneal epithelium
    d. Epithelium of lacrimal glands

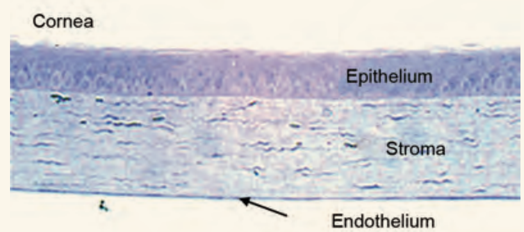
12. **Optic cup is derived from:** *(NEET Pattern 2015)*
    a. Neural ectoderm
    b. Surface ectoderm
    c. Mesoderm
    d. Neural crest

13. **Optic cup give rise to:** *(NEET Pattern 2015)*
    a. Lens
    b. Retina
    c. Cornea
    d. Sclera

14. **All are derived from neural crest EXCEPT:** *(NEET Pattern 2015)*
    a. Adrenal medulla
    b. Pigment cell in skin
    c. Corneal stroma
    d. Retinal pigmented epithelium

ANSWERS WITH EXPLANATIONS

1. **d. Ectoderm**
   - Stroma of cornea develops from neural crest cells derived (secondary) mesenchyme.
   - Note: Neural crest cells are now considered as fourth germ layer. Earlier neural crest cells were thought to arise from neuroectoderm.
2. **a. Neural crest cells > d. Mesoderm**
   - Neural crest cells form secondary mesenchyme (mesoderm) to give ciliaris muscle.
3. **a. Neural crest cells**
   - Neural crest cells form all the layers of cornea except the first layer.
   - The first layer of cornea develops from surface ectoderm.
4. **b. Neuroectoderm**
   - Optic vesicle derived from an evagination developing on either side of the forebrain (neuroectoderm) of the early embryo, from which the percipient parts of the eye are formed.
5. **d. Neural crest > c. Mesoderm**
   - Stroma of cornea develops from neural crest cells derived (secondary) mesenchyme.
   - The adult cornea has developmentally three layers: Outer epithelium layer (surface ectoderm), middle stromal layer of collagen-rich extracellular matrix between stromal keratocytes (neural crest) and inner layer of endothelial cells (neural crest).
   - Note: Eyeball is chiefly a derivative of neural crest cells (secondary mesenchyme).
   - The role of primary mesenchyme is very minimal in development of eyeball.
   - Both the type of ectoderm (neural plate ectoderm and surface ectoderm) contribute significantly to the developing eyeball.



6. **b. Lens vesicle**
   - **Lens vesicle** develops from the surface ectoderm.
   - **Neuroectoderm** evaginates to form the optic vesicle, which in turn invaginates to form the optic cup and optic stalk.
   - Optic cup forms: **Retina**, iris muscles (sphincter and **dilator pupillae**) and epithelium of iris and ciliary body.
   - Optic stalk forms the **optic nerve.**
7. **a. Dilators of iris**
   - Muscles of iris: sphincter and dilator pupillae are derived from the neural plate ectoderm.
8. **d. Neural crest > c. Mesoderm**
   - Corneal stroma is derived from the neural crest cell derived (secondary) mesenchyme.
   - The role of primary mesenchyme is minimal.
9. **c. Ciliary muscle**
   - Ciliary muscle is derived from secondary mesenchyme formed by neural crest cells.
   - Neural ectoderm forms the retina and iris muscles (sphincter and dilator pupillae).
10. **c. Surface ectoderm**
    - Surface ectoderm forms the eye lens and first layer of cornea.
11. **b. Sclera**
    - Sclera is a derivative of neural crest cells.
    - Surface ectoderm forms the eye lens, first layer of cornea and glands like lacrimal.
12. **a. Neural ectoderm**
    - **Neuroectoderm** of the diencephalon (forebrain) evaginates to form the **optic vesicle**, which in turn invaginates to form the **optic cup** and **optic stalk**.
13. **b. Retina**
    - The inner layer of the optic cup is made of neuroepithelium (**neural retina**), while the outer layer is composed of **retinal pigment epithelium** (RPE). The middle portion of the optic cup develops into the ciliary body and iris.
    - Optic cup forms: Retina, epithelium of iris and ciliary body and iris muscles (sphincter and dilator pupillae).
14. **d. Retinal pigmented epithelium**
    - Compared with neural crest-derived melanocytes, retinal pigment epithelium (RPE) cells in the back of the eye are pigment cells of a different kind. They are a part of the brain itself.
    - The neural retina and retinal pigment epithelium (RPE) originate from different portions of the optic vesicle, the more distal part developing as the neural retina and the proximal part as RPE.

Eyeball

- Eyeball has 3 coats: **Corneoscleral coat**, **vascular pigmented middle coat** and **inner nervous coat**.
- The external Coat consisting of the **sclera** and the **cornea**.
    - **Sclera** is the tough white fibrous coat enveloping the posterior five-sixths of the eye.
    - **Cornea i**s the transparent structure forming the anterior one-sixth of the external coat, responsible for the refraction of light entering the eye.
- The middle coat (uveal tract) is vascular and pigmented, contains most of the blood vessels of the eyeball and consists of the choroid, ciliary body, and iris.
    - **Choroid** has an outer pigmented (dark brown) layer and an inner highly vascular layer, which invests the posterior five-sixths of the eyeball.
        - It nourishes the retina and darkens the eye.
    - **Ciliary Body** is the thickening in the vascular tunic. It is continuous with the choroid behind and the iris in front and consists of the ciliary ring, ciliary processes, and ciliaris muscle.
        - Ciliaris is a smooth muscle innervated by parasympathetic fibers, pulls the ciliary ring and ciliary processes, relaxing the suspensory ligament of the lens and allowing it to increase its convexity.
    - **Iris** is the thin, contractile, circular, pigmented diaphragm with a central aperture, the pupil.
        - It contains circular muscle fibers (sphincter pupillae) and radial fibers (dilator pupillae).
- Deeper most is the nervous coat, which consists of the **retina**, having an outer pigmented layer and an inner nervous layer.
    - It has a posterior part that is photosensitive; its anterior part, which is not photosensitive, constitutes the inner lining of the ciliary body and the posterior part of the iris.
    - **Rods** are approximately 120 million in number and are most numerous approximately 0.5 cm from the fovea centralis. They contain rhodopsin, a visual purple pigment and are specialized for vision in dim light.
    - **Cones** are 7 million in number and are most numerous in the foveal region. They are associated with visual acuity and color vision.
    - **Optic Disk**, also called as the blind Spot, consists of optic nerve fibers formed by axons of the ganglion cells.
        - These cells are connected to the rods and cones by bipolar neurons.
        - It is located nasal (or medial) to the fovea centralis and the posterior pole of the eye, has no receptors, and is insensitive to light.
        - It has a depression in its center termed the physiologic cup.

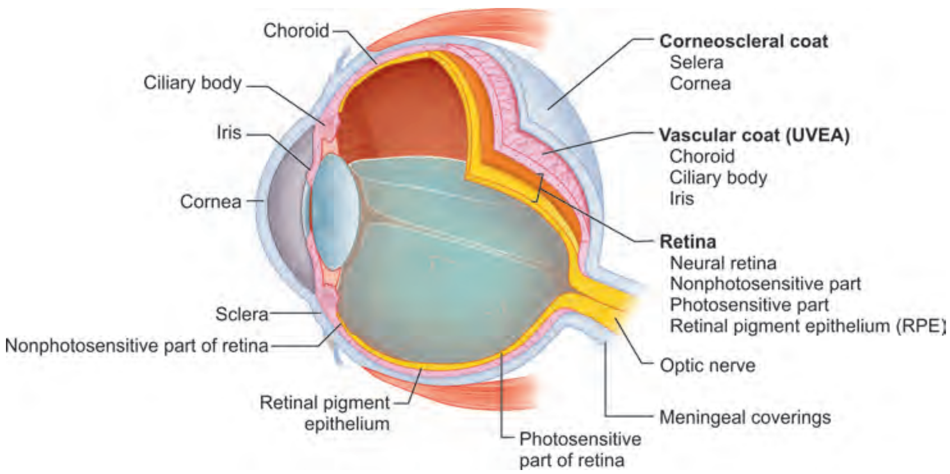


Fig. 197: Schematic diagram of the layers of the eye. The wall of the eyeball is organized in three separate cocentric layers: an outer supporting fibrous layer, the corneoscleral coat; a middle vascular coat of uvea; and an inner layer consisting of the retina. Note that the retina has two layers. Neural retina (*yellow*) and a retinal pigment epithelium (*orange*). The photosensitive and nonphotosensitive parts of the neural retina occupy different regions of the eye. The photosensitive part of the retina is found in the posterior part of the eye and terminates anteriorly along the ora serrata. The nonphotosensitive region of the retina is located anterior to the ora serrata and lines the inner aspect of the ciliary body and the posterior surface of the iris. The vitreous body (*partially removed*) occupies considerable space within the eyeball.

-
    - Macula lutea, also called as the yellow spot, is the area near the center of the retina on the temporal side of the optic disk for the most distinct vision.
        - It contains the fovea centralis, which is a central depression (foveola) in the macula.
            - Fovea centralis is avascular and is nourished by the choriocapillary lamina of the choroid.
            - Contains only cones and is the site of highest visual acuity.
            - Each cone is connected with only one ganglion cell for detailed vision.
- Corneoscleral junction lies between the sclera and cornea. The iris is attached at its periphery to the middle of the anterior surface of the ciliary body. Peripheral to this attachment the ciliary body and narrow rim of sclera form the iridocorneal angle.
- Sinus venosus sclerae (canal of Schlemm) is a circularly running canal within the sclera, lying just behind the junction.

- Posterior to the canal is a triangular projection scleral spur, which points forwards and inwards and provides attachment to the ciliary muscle.

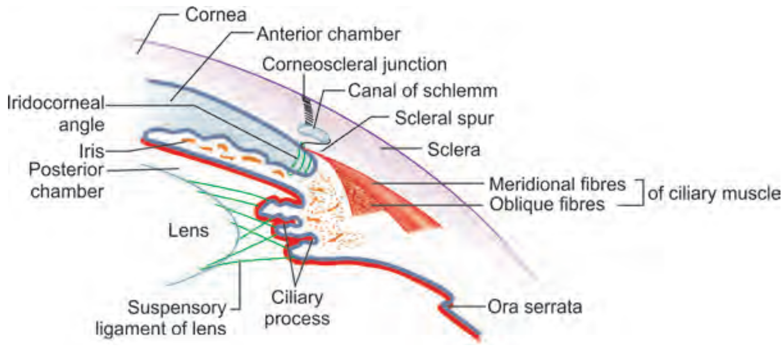
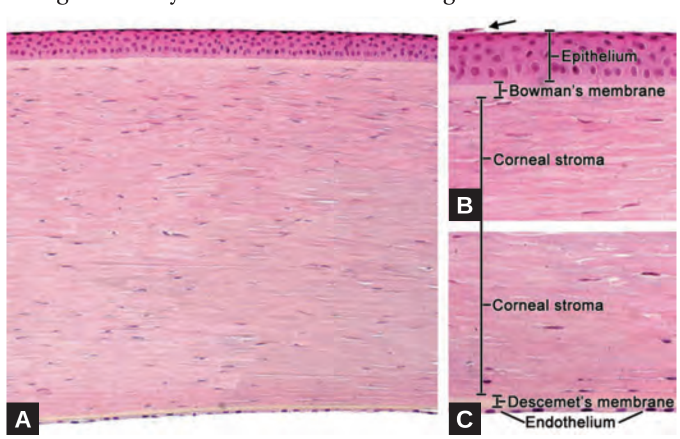


Fig. 198: Meridional section of the eyeball showing ciliary region and the iridocorneal angle.

- Refractive media of the eyeball is constituted by the cornea, aqueous humor, lens, and vitreous body.
- **Cornea** has five layers:
  - Corneal epithelium is non-keratinized stratified squamous epithelium.
    - It is continuous with the conjunctival epithelium.
  - Bowman's layer (anterior limiting membrane) is an acellular layer, composed of mainly type I collagen.
  - Corneal stroma (substantia propria) makes 90% of the corneal thickness and has regularly arranged collagen (type I) fibers along with sparsely distributed interconnected keratocytes (for repair and maintenance).
  - Descemet's membrane (posterior limiting membrane) is the thin acellular layer that serves as the modified basement membrane of the corneal endothelium, composed mainly of collagen type IV fibrils, (less rigid than collagen type I).
  - Corneal endothelium is a simple squamous or low cuboidal epithelium, responsible for regulating fluid and solute transport between the aqueous and corneal stromal compartments.
    - The cells of the endothelium do not regenerate, instead, they stretch to compensate for dead cells which reduces the overall cell density of the endothelium, which may affect fluid regulation.
- Cornea is supplied by the ophthalmic division of the trigeminal nerve by long & short ciliary nerves.
- **Aqueous humor** is formed by the ciliary processes and provides nutrients for the avascular cornea and lens.
  - It passes through the pupil from the posterior chamber (between the iris and the lens) into the anterior chamber (between the cornea and the iris) and is drained into the scleral venous plexus through the canal of Schlemm at the iridocorneal angle.
  - Impaired drainage causes an increased intraocular pressure, leading to atrophy of the retina and blindness.
- **Lens** is the transparent avascular biconvex body, 1 cm in diameter and 4 mm thick, placed between the anterior and posterior compartments of the eyeball.
  - It is enclosed in an elastic capsule, held in position by radially arranged zonular fibers (suspensory ligament of the lens), which are attached medially to the lens capsule and laterally to the ciliary processes.
  - It flattens to focus on distant objects by pulling the zonular fibers and gains more convex shape to accommodate the eye for near objects by contracting the ciliary muscle and thus relaxing zonular fibers.



Figs. 199A to C: Cornea. (A) Section through the full thickness of the cornea shows the corneal stroma and the two corneal surfaces covered by different types of epithelia. The corneal stroma does not contain blood or lymphatic vessels. (B) A higher magnification of the anterior surface of the cornea showing the corneal stroma covered by a stratified squamous corneal epithelium. The basal cells that rest on Bowman's membrane, which is a homogenous condensed layer of corneal stroma, are low columnar in contrast to the squamous surface cells. (C) A higher magnification photomicrograph of the posterior surface of the cornea covered by a thin layer of simple squamous epithelium (corneal endothelium). These cells are in direct contact with the aqueous humor of the anterior chamber of the eye. Note the very thick Descemet's membrane (basal lamina) of the corneal endothelial cells.

- **Vitreous body** is the transparent gel called vitreous humor, which fills the eyeball posterior to the lens (vitreous chamber between the lens and the retina).
  - It holds the retina in place and provides support for the lens.
- Fascia bulbi (Tenon's capsule. is a thin membrane which envelops the eyeball from the optic nerve to the limbus, separating it from the orbital fat and forming a socket in which it moves.
  - It is perforated by the tendons of the ocular muscles, and is reflected backward on each as a tubular sheath.
  - The expansions from the sheaths of the lateral rectus and medial rectus are strong, especially that from the latter muscle, and are attached to the zygomatic bone and lacrimal bone respectively.
    - They check the actions of these two Recti, hence called medial and lateral check ligaments.
  - **Suspensory ligament of Lockwood** is the thickening of the lower part of the fascia bulbi .
    - It is slung like a hammock below the eyeball, being expanded in the centre, and narrow at its extremities which are attached to the zygomatic and lacrimal bones respectively.

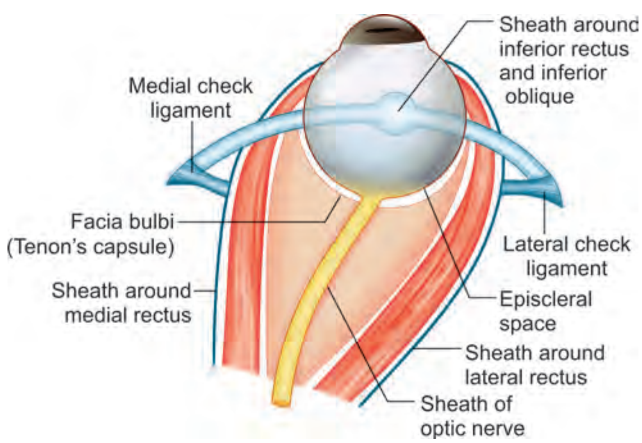


Fig. 200: Fascia bulbi (Tenon's capsule).

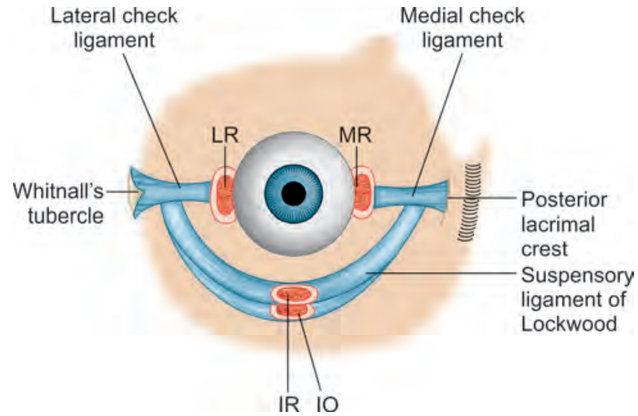


Fig. 201: Suspensory and check ligaments of the eye (IO = inferior oblique, IR = inferior rectus, LR = lateral rectus, MR = medial rectus).

- Eyelid has five layers: Skin, superficial fascia, orbicularis oculi muscle, tarsal plate & palpebral fascia and conjunctiva.
- The superficial fascia of eyelids is thin, loose and devoid of fat.
- The tarsal plates are made up of condensed fibrous tissue, and form the skeleton of the eyelids.
  - The inferior tarsal plate is a narrow strip attached to the inferior orbital margin by palpebral fascia.
  - The superior tarsal plate is much larger and diamond shaped.
  - The medial ends of tarsi are attached to lacrimal crest of maxilla in front of lacrimal sac by a strong fibrous band called medial palpebral ligament and lateral ends of tarsi to a tubercle of zygomatic bone (**Whitnall's tubercle**) by lateral palpebral ligament.
  - **Meibomian** tarsal glands are modified sebaceous glands, partly embedded on the deeper aspects of the tarsal plates.
- Levator palpebrae superioris is a skeletal muscle inserting on the skin of the upper eyelid, as well as the superior tarsal plate.
- Superior tarsal muscle is a smooth muscle, attached to the levator palpebrae superioris, also insert on the superior tarsal plate itself.
- There are two types of ciliary glands opening into the follicles of eyelashes:
  - Glands of Zeis, the modified sebaceous glands.
  - Glands of Moll, the modified sweat glands.

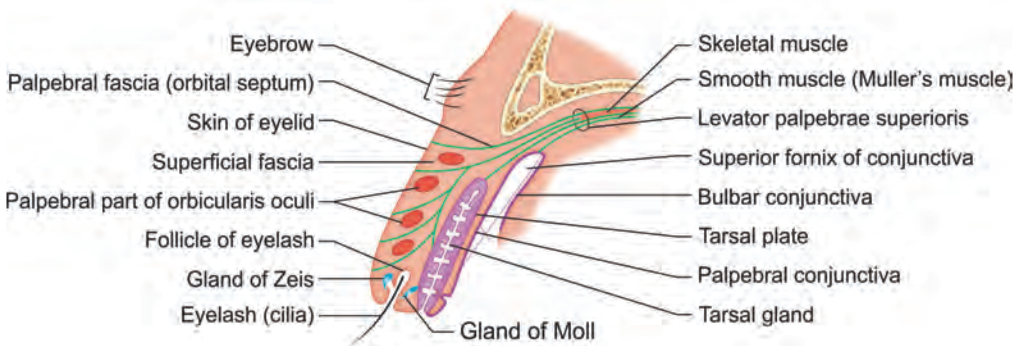


Fig. 202: Structure of the eyelid (sagittal section of upper eyelid).

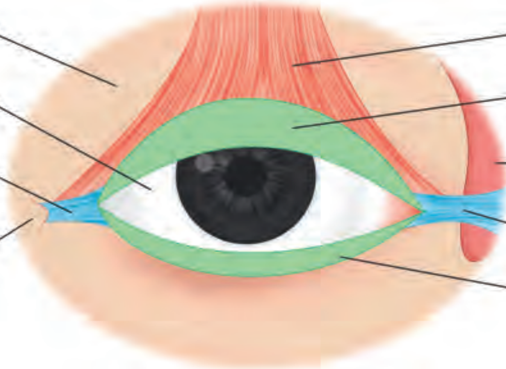


Fig. 203: Tarsal plates and palpebral fascia.

ASSESSMENT QUESTIONS

1. **Thinnest area of sclera:** *(AIIMS 2009)*
   a. Limbus
   b. Behind rectus insertion
   c. Equator
   d. In front of rectus insertion

2. **Sclera is thinnest at:** *(NEET Pattern 2012)*
   a. Limbus
   b. Equator
   c. Anterior to attachment of superior rectus
   d. Posterior to attachment of superior rectus

3. **Ligament of Lockwood is seen at:** *(NEET Pattern 2015)*
   a. Ear
   b. Palate
   c. TM joint
   d. Orbit

4. **Continuation of inner layer of choroid is:** *(NEET Pattern 2012)*
   a. Non pigmented layer of retina
   b. Sclera
   c. Pigmented layer of retina
   d. None

ANSWERS WITH EXPLANATIONS

1. **b. Behind rectus insertion**
   - Sclera is the thinnest (weakest) behind the attachment of recti muscle into the sclera.
   - It is about 300 µm under the attachment of recti muscles.
   - Sclera is the thickest posteriorly (1350 µm).
   - The thickness gradually decrease towards the attachment of recti and the again increases - The sclera at the limbus is quite thick (800 µm) again.
2. **d. Posterior to attachment of superior rectus**
   - The thinnest part of the sclera is just posterior to (and under) the attachment of the four recti muscles.
3. **d. Orbit**
   - Ligament of Lockwood's is the suspensory ligament of eyeball, which forms a hammock stretching below the eyeball between the medial and lateral check ligaments and enclosing the inferior rectus and inferior oblique muscles of the eye.
4. **c. Pigmented layer of retina**
   - Inner surface of choroid is smooth, brown and lies in contact with pigmented epithelium of the retina.
   - The outer surface is rough and lies in contact with sclera.

Lacrimatory Apparatus

- **Lacrimal gland** lies in the upper lateral region of the orbit on the lateral rectus and the levator palpebrae superioris muscles.
- It is drained by 12 lacrimal ducts, which open into the superior conjunctival fornix.
- **Lacrimal canaliculi** are two curved canals that begin as a lacrimal punctum (or pore) in the margin of the eyelid and open into the lacrimal sac.
- **Lacrimal sac** is the upper dilated end of the nasolacrimal duct, which opens into the inferior meatus of the nasal cavity.
- Tears enter the lacrimal canaliculi through their lacrimal puncta (which is on the summit of the lacrimal papilla) before draining into the lacrimal sac, nasolacrimal duct, and finally, the inferior nasal meatus.
- The nasolacrimal duct opens into the inferior meatus is partially covered by a mucosal fold (valve of Hasner).
  - Excess tears flow through nasolacrimal duct which drains into the inferior nasal meatus.
  - It is directed downward, backward and laterally.

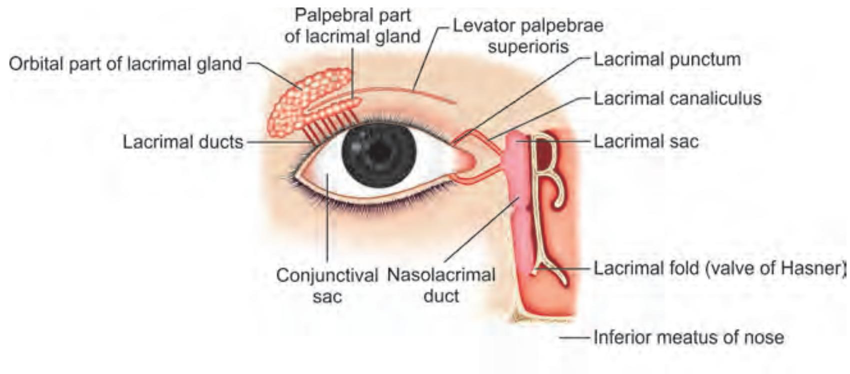


Fig. 204: Lacrimal apparatus.

ASSESSMENT QUESTION

1. Valve of Rosenmuller is located at: *(NEET Pattern 2015)*
a. Cystic duct
b. Opening of nasolacrimal duct
c. Junction of lacrimal sac and canaliculus
d. None

ANSWER WITH EXPLANATION

1. c. Junction of lacrimal sac and canaliculus
- Valve of Rosenmuller is a fold of mucous membrane at the junction between canaliculus and lacrimal sac.

Arterial Supply (Eyeball)

- Ophthalmic artery is a branch of the internal carotid artery (cerebral part), enters the orbit through the optic canal beneath the optic nerve.
  - It gives numerous ocular and orbital vessels
- **Central artery of the retina** travels in the optic nerve, divides into superior and inferior branches to the optic disk, and each of those further divides into temporal and nasal branches.
  - It is an **end artery** that does not anastomose with other arteries, and thus, its occlusion results in blindness.
- Long posterior ciliary arteries (branches of ophthalmic artery) pierce the posterior part of the sclera at some distance from the optic nerve, and run forward, between the sclera and choroid, to the ciliary muscle, where they divide into two branches.
  - They form an arterial circle, the **circulus arteriosus major** (around the circumference of the iris), from which numerous converging branches run, in the substance of the iris, to its pupillary margin, where they form a second (incomplete) arterial circle, the **circulus arteriosus minor**.
- **Haller's circle** (zinn/zonula): An (often incomplete) vascular circle within the sclera, formed by branches of the short *posterior ciliary arteries*, whose centripetal branches supply the laminar region of the optic nerve head.
  - It is associated with the fibrous extension of the ocular tendons (annulus of Zinn).

Arteries of orbit

Artery	Origin	Course and distribution
Ophthalmic	Internal carotid artery	Traverses optic foramen to reach orbital cavity
Central artery of retina	Ophthalmic artery	Pierces dural sheath of optic nerve and runs to eyeball; branches from center of optic disc; supplies optic retina (except cones and rods)
Supraorbital		Passes superiorly and posteriorly from supraorbital foramen to supply forehead and scalp
Supratrochlear		Passes from supraorbital margin to forehead and scalp.
Lacrimal		Passes along superior border of lateral rectus muscle to supply lacrimal gland, conjunctiva, and eyelids
Dorsal nasal		Courses along dorsal aspect of nose and supplies its surface
Short posterior ciliaries		Pierce sclera at periphery of optic nerve to supply choroid, which in turn supplies cones and rods of optic retina
Long posterior ciliaries		Pierce sclera to supply ciliary body and iris
Posterior ethmoidal		Passes through posterior ethmoidal foramen to posterior ethmoidal cells
Anterior ethmoidal		Passes through anterior ethmoidal foramen to anterior cranial fossa; supplies anterior and middle ethmoidal cells, frontal sinus, nasal cavity, and skin on dorsum of nose.
Anterior ciliary	Muscular (rectus) branches of ophthalmic artery	Pierces sclera at attachments of rectus muscles and forms network in iris and ciliary body
Infraorbital	Third part of maxillary artery	Passes along infraorbital groove and foramen to face

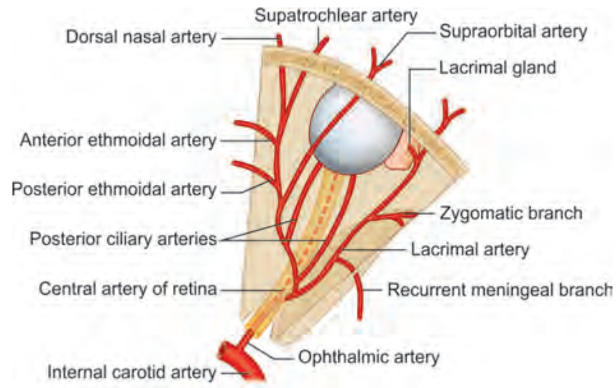


Fig. 205: Ophthalmic artery

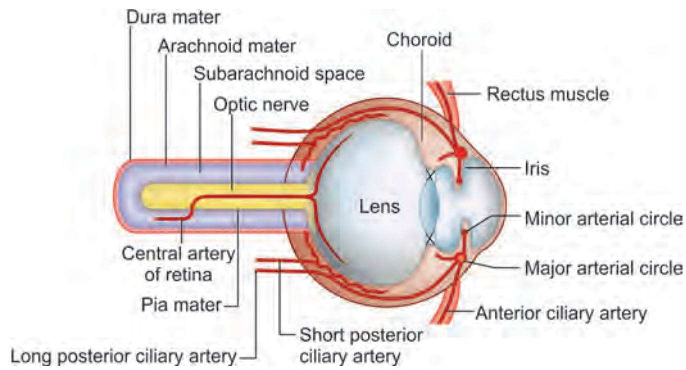


Fig. 206: Arterial supply of the eyeball

ASSESSMENT QUESTIONS

1. **NOT a branch of ophthalmic artery:** *(JIPMER 2010)*
   a. Dorsal nasal artery
   b. Superficial temporal artery
   c. Central artery of retina
   d. Supratrochlear artery

2. **Which of the following is WRONG regarding ophthalmic artery:** *(NEET Pattern 2015)*
   a. Present in dura along with optic nerve
   b. Supplies anterior ethmoidal sinus
   c. Artery to retina is end artery
   d. Leaves orbit through inferior orbital fissure

ANSWERS WITH EXPLANATIONS

1. **b. Superficial temporal artery**
   - Ophthalmic artery gives central artery of retina.
   - It also gives the supraorbital & supratrochlear arteries, along with dorsal nasal artery.
   - Superficial temporal artery is a terminal branch of external carotid artery.

2. **d. Leaves orbit through inferior orbital fissure**
   - Ophthalmic artery arises from internal carotid artery as it emerges from the roof of the cavernous sinus, enters the orbit through optic canal inferolateral to the optic nerve, both lying in a common dural sheath.
   - Gives central artery to retina (an end artery), and also supplies ethmoidal sinuses by giving ethmoidal arteries.

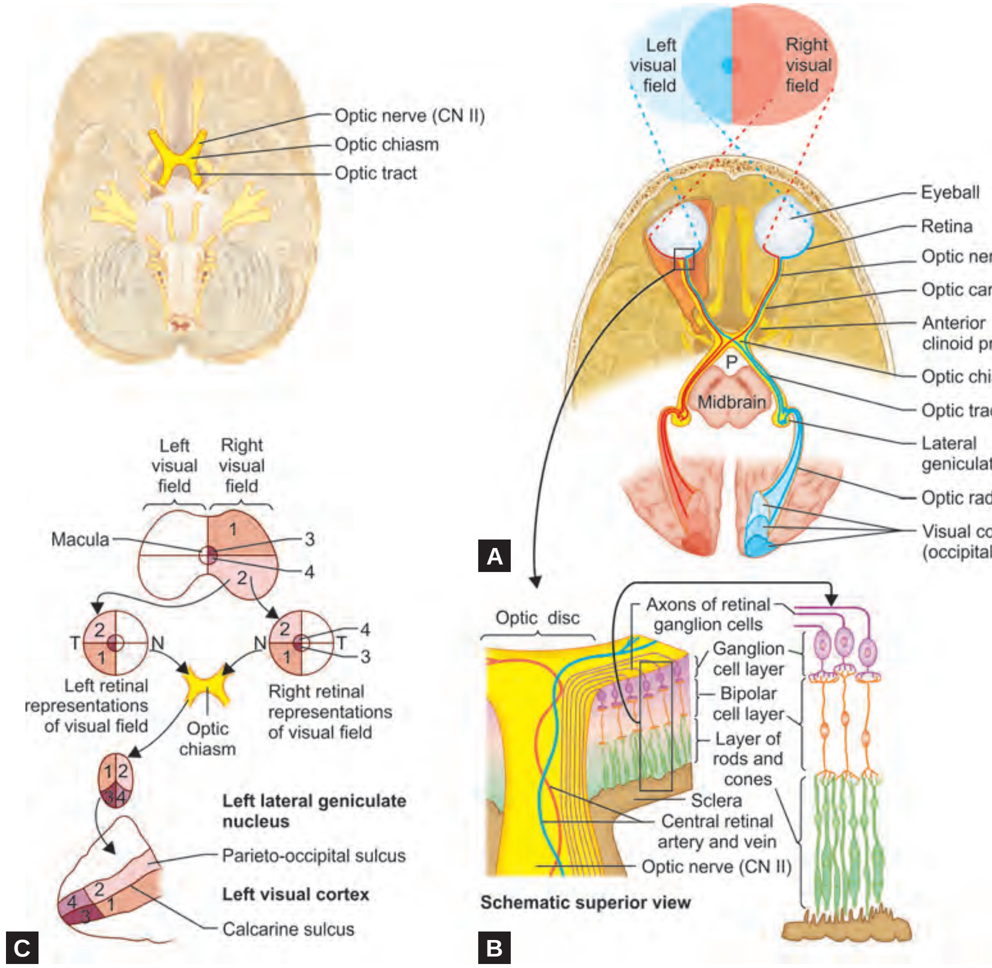
Venous Drainage (Eyeball)

Ophthalmic Veins (dig):

- **Superior ophthalmic vein** is formed by the union of the supraorbital, supratrochlear, and angular veins.
  - It receives branches corresponding to most of those of the ophthalmic artery and, in addition, receives the inferior ophthalmic vein before draining into the cavernous sinus.
- **Inferior ophthalmic vein** begins by the union of small veins in the floor of the orbit.
  - It communicates with the pterygoid venous plexus and often with the infraorbital vein and terminates directly or indirectly into the cavernous sinus.

Optic Nerve and Visual Pathway

- Optic nerve is formed by the axons of ganglion cells of the retina, which converge at the optic disk.
  - Optic nerve is not a true nerve and is actually a CNS tract, myelinated by oligodendroglia.
  - Optic nerve axons are covered by a membrane continuous with the dura and leave the orbit by passing through the optic canal.



Figs. 207A to C: Optic nerve (CN III). (A) Origin and course of visual pathway. (B) Rods and cones in retina. (C) Right visual field representation on retinae, left lateral geniculate nucleus, and left visual cortex.

- It carries SSA (special somatic afferent) fibers for vision from the retina to the brain and mediates the afferent limb of the pupillary light reflex, whereas parasympathetic fibers in the oculomotor nerve mediate the efferent limb.
- It joins the optic nerve from the corresponding eye to form the optic chiasma, which contains fibers from the nasal retina that cross over to the opposite side of the brain.
- The fibers from the temporal retina pass ipsilaterally through the chiasma.

- Retina constitute a chain of three neurons that project visual impulses via the optic nerve and the lateral geniculate body (LGB) to the visual cortex.
  - Rods and cones are the first-order receptor cells that respond directly to light stimulation.
    - Rods contain rhodopsin (visual purple) are sensitive to low-intensity light and work for night vision.
    - Cones contain the iodopsin, operate at high illumination levels, are concentrated in the fovea centralis and responsible for high visual acuity, day vision and color vision.
  - Bipolar neurons are the second-order neurons that relay stimuli from the rods and cones to the ganglion cells.
  - Ganglion cells are the third-order neurons that form the optic nerve.
    - They project directly to the hypothalamus, superior colliculus, pretectal nucleus, and lateral geniculate body.
  - Three other type of cells are present in retina: Horizontal, Amacrine and Muller cells.
    - Horizontal cells are the laterally interconnecting neurons in the inner nuclear layer of the retina. They interconnect photoreceptors and bipolar cells, inhibit neighboring photoreceptors (lateral inhibition) and play a role in the differentiation of colors.
    - Amacrine cells operate at the inner plexiform layer (IPL), receive input from bipolar cells and project inhibitory signals to ganglion cells.
    - Muller cells are the retinal glial cells, that serve as support cells for the neurons of the retina, they extend from the inner limiting layer to the outer limiting layer.

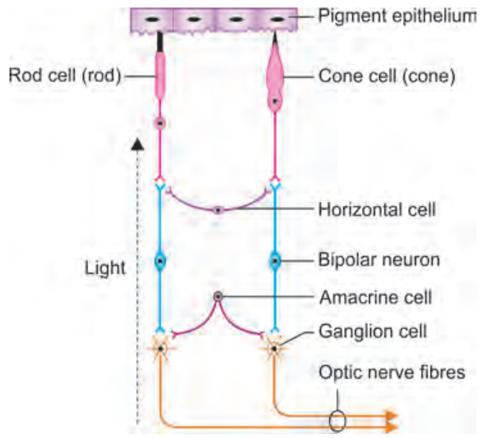


Fig. 208: Three basic layers of retina and their constituent cells. The arrow (on the left side) indicates the direction of light falling on the retina. It is important to note that several rods and cones converge on a single bipolar neuron and several bipolar neurons activate one ganglion cells. The one-to-one relationship between rods and cones, bipolar neurons and ganglion cells shown in this figure is only for the sake of simplicity.

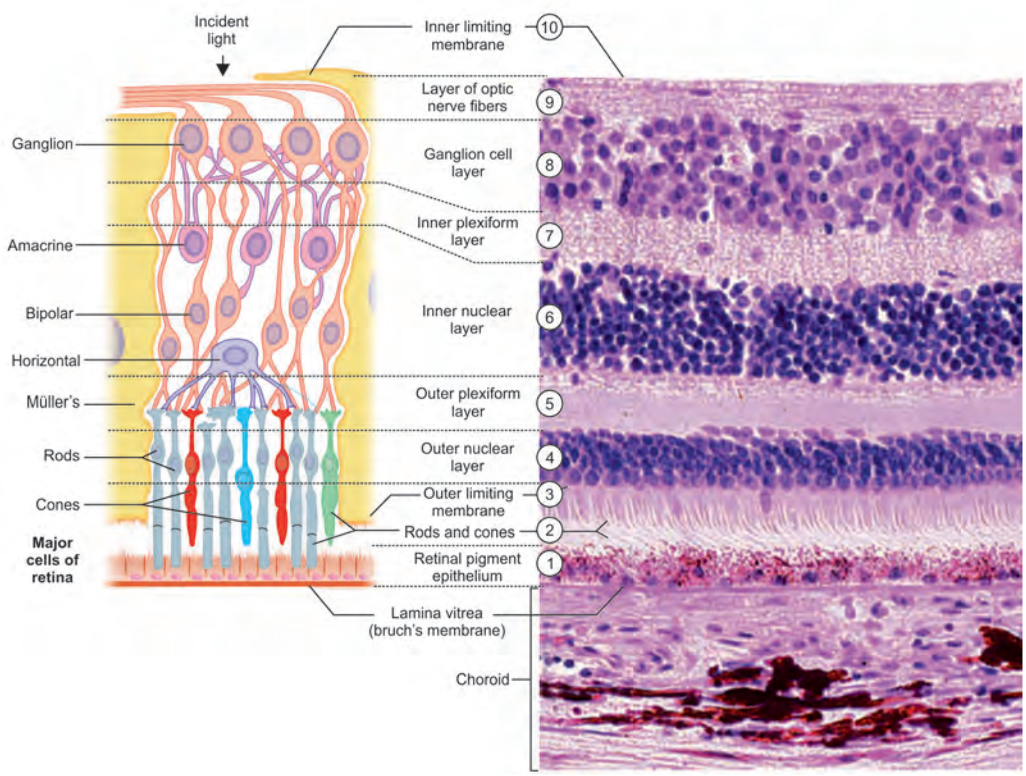


Fig. 209: Schematic drawing and photomicrograph of the layers of the retina. On the basis of histologic features that are evident in the photomicrograph *on right*, the retina can be divided into ten layers. The layers correspond to the diagram *on left*, which shows the distribution of major cells of the retina. Note that light enters the retina and passes through its inner layers before reaching the photoreceptors of the rods and cones that are closely associated with retinal pigment epithelium. Also, the interrelationship between the bipolar neurons and ganglion cells that carry electrical impulses from the retina to the brain is clearly visible. The Bruch's membrane (lamina vitrea) separates the inner layer of the vascular coat (choroid) from the retinal pigment epithelium ×440

Optic pathway

- **Optic nerve**, constituted by the axons of ganglion cells in retina, project from the nasal hemiretina to the contralateral lateral geniculate body and from the temporal hemiretina to the ipsilateral lateral geniculate body.
- O**ptic chiasma** contains decussating fibers from the two nasal hemiretinas and non-crossing fibers from the two temporal hemiretinas and projects fibers to the suprachiasmatic nucleus of the hypothalamus.
- **Optic tract** contains fibers from the ipsilateral temporal hemiretina and the contralateral nasal hemiretina. It projects to the ipsilateral lateral geniculate body, pretectal nuclei, and superior colliculus.
- **Lateral geniculate body** is a six-layered nucleus. Layers 1, 4, and 6 receive crossed fibers; layers 2, 3, and 5 receive uncrossed fibers.
  - It receives fibers from the ipsilateral temporal hemiretina and the contralateral nasal hemiretina
  - It also receives input from layer VI of the striate cortex (Brodmann's area 17).

- ➤ It projects through the optic radiation (geniculo-calcarine tract) to layer IV of the primary visual cortex (Brodmann's area 17), through two divisions.
  - Upper division projects to the upper bank of the calcarine sulcus (cuneus). It contains input from the superior retinal quadrants, which represent the inferior visual-field quadrants.
  - Lower division loops from the lateral geniculate body anteriorly (Meyer's loop), then posteriorly, to terminate in the lower bank of the calcarine sulcus (lingual gyrus). It contains input from the inferior retinal quadrants, which represent the superior visual field quadrants.
- **Visual cortex** (Brodmann's area 17) is located on the banks of the calcarine fissure.
  - ➤ Cuneus is the upper bank and lingual gyrus is the lower bank.
  - ➤ It has a retinotopic organization: The posterior area receives macular input (central vision); intermediate area receives paramacular input (peripheral input) and the anterior area receives monocular input.
- Optic pathway lesions:
  1. Optic nerve injury – leads to ipsilateral blindness, with no direct pupillary light reflex.
  2. Midline lesions (like pituitary tumor) results in bitemporal hemianopia (tunnel vision)
  3. Bilateral lateral compression causes binasal hemianopia (nasal visual field is lost). One of the etiology is calcified internal carotid artery.
  4. A lesion in the optic tract results in contralateral homonymous hemianopia. A lesion on the left side, compromises the visual field on right side i.e., right half of each eye is blind (nasal vision of left eye and temporal vision of right eye is lost).
  5. A lesion in the optic radiation (geniculo-calcarine tract) again results in contralateral homonymous hemianopia. But
     a. Transection of upper division of geniculo-calcarine tract causes a contralateral lower quadrantanopia.
     b. Transection of lower division of geniculo-calcarine tract causes a contralateral upper quadrantanopia (pie in the sky).
  6. Lesions of visual cortex leads to contralateral hemianopia with macular sparing. One case is cortical blindness due to a block in posterior cerebral artery resulting in contralateral homonymous hemianopia with macular sparing (macular area on brain has additional supply from middle cerebral artery).

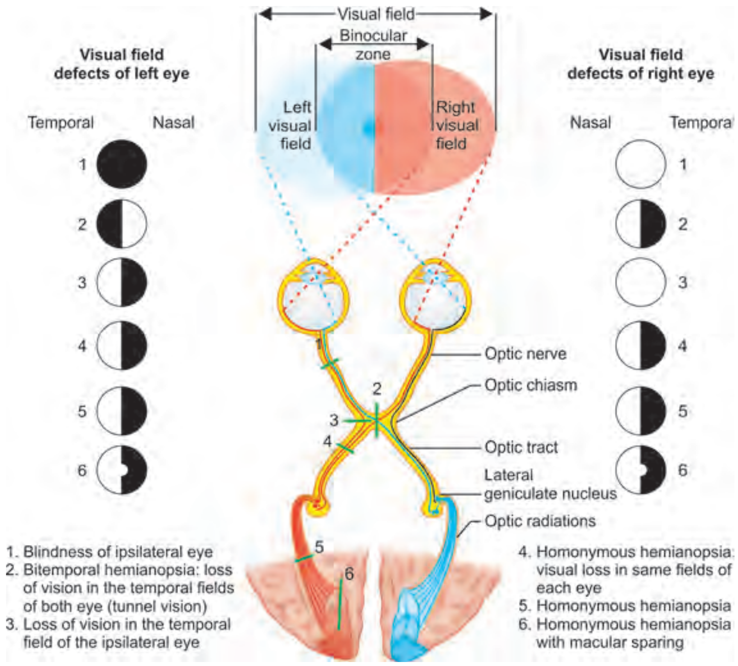


Fig. 210: Visual pathway and lesions.

ASSESSMENT QUESTIONS

1. Which order neuron is bipolar cell in the retina: *(NEET Pattern 2012)*

a. First order
b. Second order
c. Third order
d. Fourth order

2. Optic nerve is which order neuron:

a. First
b. Second
c. Third
d. Fourth

3. Cornea is lined by which epithelium: *(NEET Pattern 2012)*

a. Ciliated columnar
b. Simple columnar
c. Squamous non-keratinized
d. Pseudostratified columnar

ANSWERS WITH EXPLANATIONS

1. b. Second order

- Bipolar neuron is the second order neuron in the visual pathway.
- Rods and cones are the first-order receptor cells that respond directly to light stimulation.
- Bipolar neurons are the second-order neurons that relay stimuli from the rods and cones to the ganglion cells.
- Ganglion cells third-order neurons that form the optic nerve (CN II).

2. c. Third

- Rods and cones are the first order neurones, synapsing with the bipolar cell (second order neurone), which in turn synapse on the ganglion cell neurone (third order neurone).
- Optic nerve is collection of the axons of ganglion cell neurone ,which is third order neurone in the visual pathway.

3. c. Squamous non-keratinized

- Cornea has an outer epithelium at surface lined by non-keratinized stratified squamous epithelium.
- The innermost corneal endothelium is lined by the simple squamous epithelium.

Eyeball Muscles

Eyeball has two types of muscles—smooth and skeletal muscles:

- Smooth muscles: Iris (dilator & sphincter pupillae), Muller muscle
  - Dilator pupillae is a smooth muscle with radial arrangements of fibers in the iris.
    - It is innervated by the sympathetic system, which acts by releasing noradrenaline, which acts on α1-receptors.
    - In threatening stimuli that activates the fight-or-flight response, this innervation contracts the muscle and dilates the iris (mydriasis), thus temporarily letting more light/information reach the retina.
  - Sphincter pupillae is present in circular arrangement on the iris, is supplied by the cholinergic fibres of parasympathetic nervous system, via oculomotor nerve.
    - Its contraction leads to miosis of pupil.
  - Muller muscle in the eyeball is supplied by the T1 sympathetic pathway. One of its component is superior tarsal muscle, which elevates the upper eyelid.

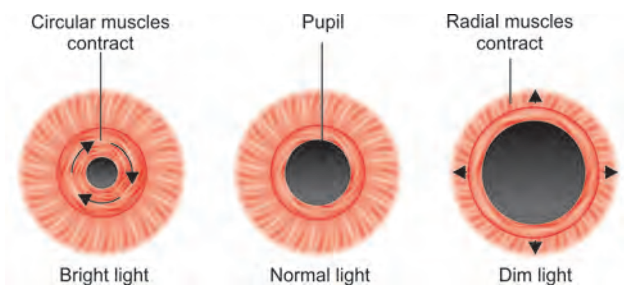


Fig. 211: Smooth muscles of iris and their functions.

- Skeletal muscles

Extra-ocular muscles of orbit.

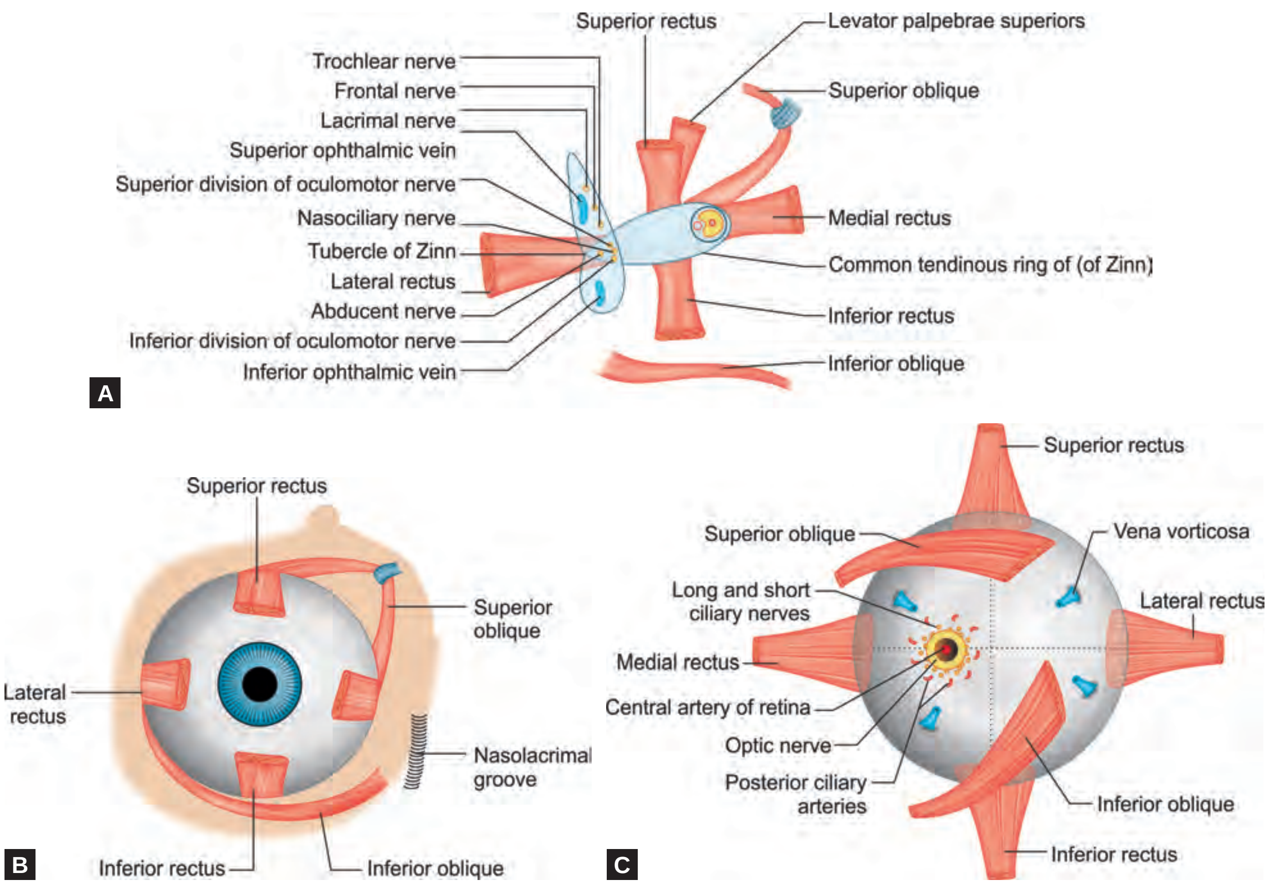
Muscle	Origin	Insertion	Innervation	Main action[a]
Levator palpebrae superioris	Lesser wing of sphenoid bone, superior and anterior to optic canal	Superior tarsus and skin of superior eyelid	Oculomotor nerve (CN III); deep layer (superior tarsal muscle) is supplied by sympathetic fibers	Elevates superior eyelid
Superior oblique (SO)	Body of sphenoid bone	Its tendon passes through a fibrous ring a trochlea, changes its direction, and inserts into sclera deep to superior rectus muscle	Trochlear nerve (CN IV)	Abducts, depresses, and medially rotates eyeball
Inferior oblique (IO)	Anterior part of floor of orbit	Sclera deep to lateral rectus muscle	Oculomotor nerve (CN III)	Abduts, elevates, and laterally rotates eyeball
Superior rectus (SR)	Common tendinous ring	Sclera just posterior to corneoscleral junction		Elevates, adducts, and rotates eyeball medially
Inferior rectus (IR)				Depresses, adducts, and rotates eyeball laterally
Medial rectus (MR)				Adducts eyeball
Lateral rectus (LR)			Abducent nerve (CN VI)	Abducts eyeball

[a]The actions described are for muscles acting alone, starting from the primary position (gaze directed anteriorly). In fact, muscles rarely act independently and almost always work together in synergistic and antagonistic groups. Clinical testing requires maneuvers to isolate muscle actions. Only the actions of the medial and lateral rectus are tested, starting from the primary position.

Muscle	Primary action	Secondary action
Superior rectus	Elevation	Adduction and intorsion
Inferior rectus	Depression	Adduction and extorsion
Medial rectus	Adduction	
Lateral rectus	Abduction	
Superior oblique*	Intorsion	Abduction and depression
Inferior oblique	Extorsion	Abduction and elevation

* The primary (main) action of the superior oblique muscle is intorsion (internal rotation), the secondary action is depression (primarily in the adducted position) and the tertiary action is abduction (lateral rotation).

- Superior oblique is inserted into the posterior part of the eyeball; when it contracts, the back of the eyeball is elevated, and the front of the eyeball is depressed (particularly in the adducted position).
- **Intorsion** is the medial (inward) rotation of the upper pole (12 o'clock position) of the cornea, carried out by the superior oblique and superior rectus muscles (Mnemonic; SIN - Superiors are intortors).
- **Extorsion** is the lateral (outward) rotation of the upper pole of the cornea, caused by the inferior oblique and inferior rectus muscles.
- Muscles of the eye movement are innervated by the oculomotor, trochlear, and abducens nerves. Formula to remember innervation of extraocular eye muscles is (LR6, SO4)3 (Superior Oblique – CN4; Lateral Rectus – CN6; All Other eye movement muscles – CN3).
- Common tendinous Ring of Zinn is a fibrous ring that surrounds the optic canal and the medial part of the superior orbital fissure.
- It is the common tendinous origin of the four rectus muscles of the eye and transmits the following structures through it : Oculomotor nerve (superior & inferior division), abducent nerves and nasociliary nerve (branch of ophthalmic division of trigeminal nerve) as they pass through the superior orbital fissure.
- It also encloses the optic nerve, ophthalmic artery, and central artery and vein of the retina, which enter the orbit through the optic canal within the tendinous ring.
- LFT nerves are left outside the tendinous ring: Lacrimal & frontal nerves (branches of ophthalmic division of trigeminal nerve) and trochlear nerve as they pass through the superior orbital fissure.
- The ophthalmic (superior & inferior) veins usually lies outside the ring while they pass the fissure.



Figs. 212A to C: Extraocular muscles: (A) Origin; (B) insertion of the recti muscles; (C) insertion of the oblique muscles.

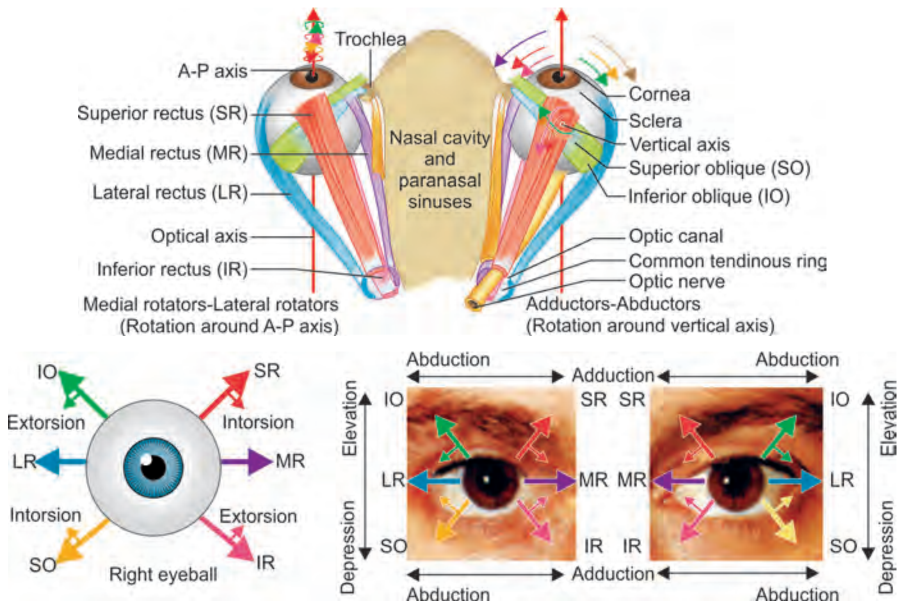


Fig. 213: Eyeball muscles and their respective movements.

- Ptosis is the drooping eyelid, may be seen in some clinical cases.
- Oculomotor ptosis due to paralysis of the levator palpebrae (e.g., transtentorial herniation).
- Oculosympathetic ptosis due to paralysis of the superior tarsal (Muller) muscle as seen in Horner syndrome. This is a very slight ptosis, or pseudoptosis (e.g., Pancoast tumor).

ASSESSMENT QUESTIONS

1. Which of the following is longest extraocular muscle? *(NEET Pattern 2012)*
 a. Superior rectus
 b. Medial rectus
 c. Superior oblique
 d. Inferior oblique

2. Which of the following muscles produce intorsion of eye ball: *(NEET Pattern 2015)*
 a. Superior rectus and superior oblique
 b. Inferior rectus and inferior oblique
 c. Inferior rectus and superior oblique
 d. Superior rectus and inferior oblique

3. Which extraocular muscle is supplied by opposite side nucleus: *(AIIMS 2014)*
 a. Lateral rectus
 b. Medial rectus
 c. Superior rectus
 d. Inferior rectus

4. A patient is unable to move eye outward beyond midline. The lesion is in: *(NEET Pattern 2012)*
 a. Trochlear nerve
 b. Occulomotor nerve
 c. Abducent nerve
 d. None

5. Ptosis is due to lesion of:
 a. Facial nerve
 b. Somatic fibres of occulomotor nerve
 c. Superior cervical ganglion
 d. Edinger Westphal nucleus

6. Primary action of superior oblique is: *(NEET Pattern 2012)*
 a. Intorsion
 b. Depression
 c. Adduction
 d. Abduction

7. Action of inferior oblique: *(NEET Pattern 2015)*
 a. Adduction
 b. Depression
 c. Extorsion
 d. Intorsion

8. Main action of superior rectus: *(NEET Pattern 2012)*
 a. Extorsion
 b. Intorsion
 c. Elevation
 d. Depression

9. Which of the following is supplied by the third cranial nerve: *(NEET Pattern 2012)*
 a. Superior oblique
 b. Inferior oblique
 c. Lateral rectus
 d. Dilator papillae

ANSWERS WITH EXPLANATIONS

1. c. Superior oblique
- Superior oblique is the longest and thinnest extraocular muscle.

2. a. Superior rectus and superior oblique
- Both the **S**uperiors are **IN**tortors (Mnemonic: SIN).
- **Superior rectus** and **superior oblique** muscles cause inward rotation (intortion) of the eyeball.

3. c. Superior rectus
- Both the superiors are supplied by the contralateral nucleus.
- Occulomotor nerve supplies contralateral superior rectus muscle and trochlear nerve supplies contralateral superior oblique muscle.
- A lesion in the brainstem at the level of left superior colliculi will damage the left sided occulomotor nuclei and causes paralysis of the right superior rectus muscle.
- A lesion at the level of left inferior colliculi compromises the trochlear nucleus and leads to paralysis of the right superior oblique muscle.

4. c. Abducent nerve
- A lesion of **abducent** nerve paralyses the lateral rectus muscle and eyeball is unable to perform **abduction**.

5. b. Somatic fibres of Occulomotor nerve > c) Superior cervical ganglion
- Ptosis occurs due to paralysis of levator palpebrae superioris, the skeletal part of whose is supplied by occulomotor nerve.
- Partial ptosis may result due to paralysis of superior tarsal muscle (part of Muller muscle), due to interruption of T1 sympathetic pathway (a feature of Horner syndrome). For e.g., superior cervical ganglion lesion.

6. a. Intorsion
- Primary action of superior oblique is inward rotation (intortion) of the eyeball.
- Secondary actions are depression and abduction.

7. c. Extorsion
- Primary action of inferior oblique is outward rotation (extortion) of the eyeball.
- Secondary actions are elevation and abduction.

8. c. Elevation
- Primary action of superior rectus is elevation of eyeball (antagonist of inferior rectus).
- Secondary actions are adduction and intorsion.

9. b. Inferior oblique
- Muscles of the eye movement are innervated by the oculomotor, trochlear, and abducens nerves.
- Formula to remember innervation of extraocular eye muscles is (LR6, SO4)3 (Superior Oblique – CN4; Lateral Rectus – CN6; All Other eye movement muscles – CN3).

Nerves of Orbit and Ciliary Ganglion

- **Ophthalmic nerve** is the first division of trigeminal nerve, provides sensory innervation to the eyeball, tip of the nose, and skin of the face above the eye and mediates the afferent limb of the corneal reflex.
- It is given by the trigeminal ganglion at the floor of the middle cranial fossa.
- It is a pure sensory nerve, passes in the lateral wall of cavernous sinus and gives three branches, which pass through the superior orbital fissure: **Lacrimal**, **frontal** and **nasociliary** nerves.
  - **Lacrimal nerve e**nters the orbit through the superior orbital fissure and reach the lacrimal gland, giving branches to the lacrimal gland, conjunctiva, and the skin of the upper eyelid.
    - Its terminal part is joined by the zygomaticotemporal nerve that carries postganglionic parasympathetic and sympathetic GVE fibers.
  - **Frontal nerve** enters the orbit through the superior orbital fissure, runs superior to the levator palpebrae superioris.
    - It divides into the **supraorbital nerve**, which passes through the supraorbital foramen (supplies the scalp, forehead, frontal sinus, and upper eyelid) and the **supratrochlear nerve**, which passes through the trochlea (supplies the scalp, forehead, and upper eyelid).

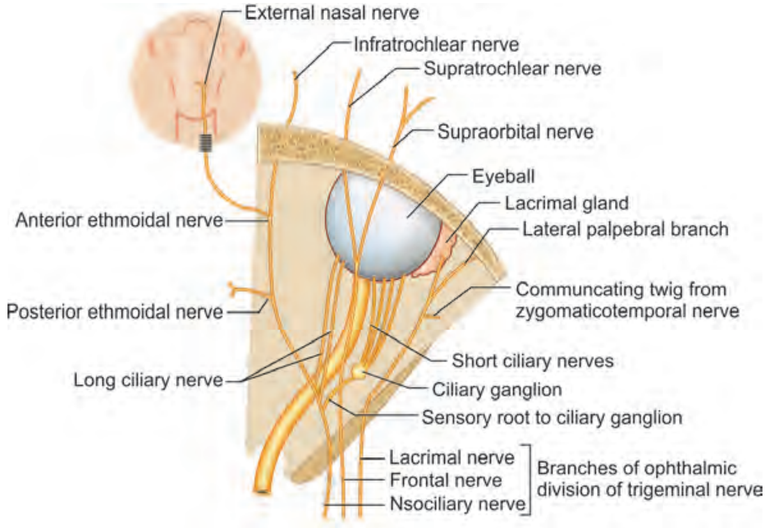


Fig. 214: Branches and distribution of the ophthalmic nerve.

- **Nasociliary nerve** enters the orbit through the superior orbital fissure, within the common tendinous ring. Branches:
  - **Anterior and posterior ethmoidal nerves**, **infratrochlear nerve, long and short ciliary nerves**, **meningeal** branch to supply dura in the anterior cranial fossa and a **communicating** branch is given to the ciliary ganglion.
  - **Anterior ethmoidal nerve** is given in the orbit, passes out of orbit into the anterior cranial fossa (through anterior ethmoidal foramen) and supplies the duramater there. It runs in proximity to the cribriform plate of ethmoid bone and supplies the ethmoidal air cells. The nerve then enters the nasal cavity (passing a foramen close to crista galli), gives external and internal nasal branches to supply internal nasal cavity, nasal septum as well as the skin on the exterior of nose.
  - **Posterior ethmoidal nerve** passes through the posterior ethmoidal foramen to the sphenoidal and posterior ethmoidal sinuses.
  - **Infratrochlear nerve** innervates the eyelids, conjunctiva, skin of the nose, and lacrimal sac.

- **Short ciliary nerves** carry both parasympathetic and sympathetic nerve fibers.
  - The parasympathetic fibres arise from the Edinger-Westphal nucleus and synapse in the ciliary ganglion via the oculomotor nerve, the postganglionic fibres leave the ciliary ganglion in the short ciliary nerve and supply the **ciliary muscle** and **sphincter pupillae**.
  - Sympathetic fibres are provided by the superior cervical ganglion and they reach the ganglion either as branches of the nasociliary nerve or directly from the extension of the plexus on the ophthalmic artery (sympathetic branch to ciliary ganglion).
- **Long ciliary nerves** provide sensory innervation to the eyeball, including the cornea (reflex).
  - In addition, they carry sympathetic fibers from the superior cervical ganglion to the **dilator pupillae** muscle.

  Note: The sympathetic fibers to the dilator pupillae muscle mainly travel in the nasociliary nerve but there are also sympathetic fibers in the short ciliary nerves that pass through the ciliary ganglion without forming synapses.
- **Ciliary ganglion** is a parasympathetic ganglion situated behind the eyeball, between the optic nerve and the lateral rectus muscle.
  - Preganglionic axons originate in the Edinger–Westphal preganglionic nucleus of the midbrain.
  - They travel via a branch of the oculomotor nerve (nerve to the inferior oblique) to the ciliary ganglion, where they synapse.

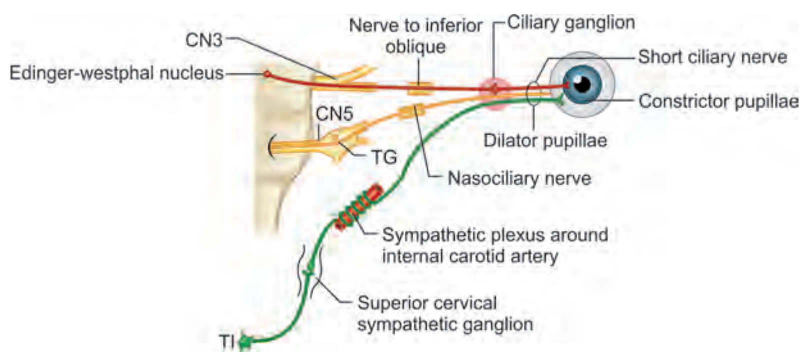


Fig. 215: Roots and distribution of the ciliary ganglion.

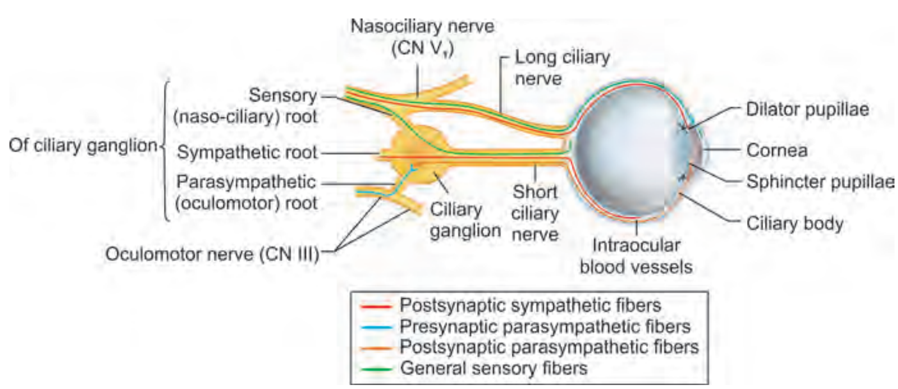


Fig. 216: Various nerve components of ciliary galnglion.

  - Postganglionic fibres travel in the short ciliary nerves, which pierce the scleral coat of the eyeball and run forwards in the perichoroidal space to enter the ciliary muscle and sphincter pupillae.
  - Their activation mediates accommodation of the eye to near objects and pupillary constriction.
- **Lacrimatory pathway:** Superior **salivatory nucleus** → facial nerve → pterygopalatine ganglion → maxillary & ophthalmic nerve (trigeminal) → **lacrimal gland.**

ASSESSMENT QUESTIONS

1. **A muscle with radially arranged fibres in iris is supplied by:** *(AIIMS 2011)*
   a. Oculomotor nerve
   b. Sympathetic supply from cervical plexus nerve from cervical sympathetic chain
   c. Parasympathetic supply
   d. None

2. **Anterior ethmoidal nerve supplies all EXCEPT:** *(AIIMS 2010)*
   a. Dura mater in anterior cranial fossa
   b. Ethmoidal air cells
   c. Internal nasal cavity
   d. Maxillary sinus lining

ANSWERS WITH EXPLANATIONS

1. **b. Sympathetic supply from cervical plexus nerve from cervical sympathetic chain**
   - **Dilator pupillae** is a smooth muscle with radial arrangements of fibres in the iris and is supplied by the T-1 sympathetic fibres, which arise from the lateral horn cells of the spinal cord.
   - These fibres ascend up in the sympathetic chain and synapse in superior cervical ganglion.
   - The post-ganglionic fibres pass through around the branches of carotid arteries to reach the eyeball muscles like dilator pupillae.

2. **d. Maxillary sinus lining**
   - Anterior ethmoidal nerve does not supply the maxillary sinus lining.
   - Anterior ethmoidal nerve is a branch of nasociliary nerve (Trigeminal – ophthalmic) given in the orbit, passes out of orbit into the anterior cranial fossa (through anterior ethmoidal foramen) and supplies the dura mater there.
   - It runs in proximity to the cribriform plate of ethmoid bone and supplies the ethmoidal air cells.
   - The nerve then enters the nasal cavity (passing a foramen close to crista galli), gives external and internal nasal branches to supply internal nasal cavity, nasal septum as well as the skin on the exterior of nose.

Nerves Supplying Eyeball Muscles

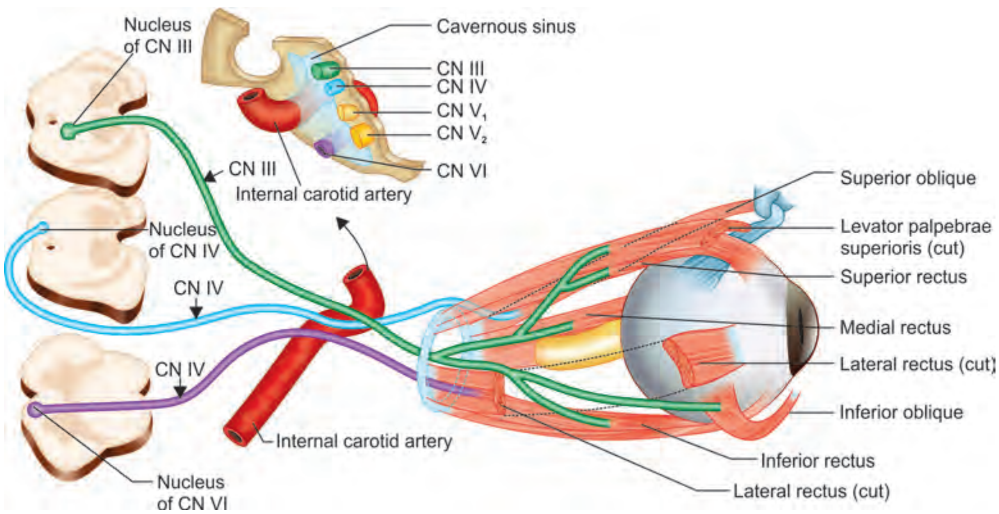
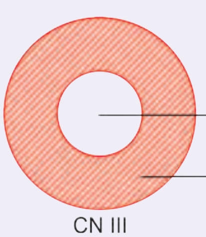


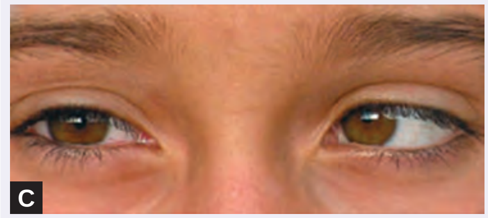
Fig. 217: Nerve supply to the eyeball muscles.

CN III, IV, VI palsies



CN III has both motor (central) and parasympathetic (peripheral) components.
Motor output to ocular muscles—affected primarily by vascular disease (e.g., diabetes mellitus: glucose → sorbitol) due to ↓ diffusion of oxygen and mutrients to the interior fibers from compromised vasculature that resides on outside of nerve. Signs: ptosis, 'down and out' gaze (A)

Parasympathetic output—fibers on the periphery are 1st affected by compression (e.g., posterior communicating artery aneurysm, uncal herniation). Signs: diminished or absent pupillary light reflex, 'blown pupil' often with 'down-and-out' gaze.

CN IV damage	Eye moves upward, particularly with contralateral gaze (B) and head tilt toward the side of the lesion (problems going down stairs, may present with compensatory head tilt in the opposite direction).	
CN VI damage	Medially directed eye that cannot abduct (C)	

Figs. 218A to C: Lesions of cranial nerve supplying eyeball.

Oculomotor Nerve

- **Oculomotor nerve** arises from the midbrain, runs in the lateral wall of cavernous sinus, enters the orbit through the superior orbital fissure and divides into a superior division, which innervates the superior rectus and levator palpebrae superioris muscles, and an inferior division, which innervates the medial rectus, inferior rectus, and inferior oblique muscles.
  - Its inferior division also carries preganglionic parasympathetic fibers (with cell bodies located in the Edinger–Westphal nucleus) to the ciliary ganglion.
- Oculomotor nuclear complex is present in the upper midbrain (at the level of superior colliculi).
- Motor nucleus (GSE, general somatic efferent) sends axons to supply all the muscles of eyeball (except superior oblique and lateral rectus).
- Edinger Westphal nucleus (GVE, general visceral efferent) is a parasympathetic nucleus, sends fibres to the smooth muscles—sphincter pupillae and ciliaris.
- **Course**: Oculomotor nerve emerges at the midbrain on the medial side of the crus of the cerebral peduncle and passes between the superior cerebellar and posterior cerebral arteries and runs forward in the interpeduncular cistern on the lateral side of the posterior communicating artery to reach cavernous sinus.
  - It enters the cavernous sinus by piercing the posterior part of the roof on the lateral side of the posterior clinoid process, descends along the lateral dural wall of the cavernous sinus, dividing into superior and inferior divisions which run beneath the trochlear and ophthalmic nerves.
- **Superior rectus** muscle is supplied contralaterally by the occulomotor nerve. Left occulomotor nucleus gives fibres, which cross the midline and join the right oculomotor nerve to supply the right superior rectus. Similarly right occulomotor nucleus supplies the left superior rectus muscle.
- **Levator palpebrae superioris** has a single central sub nucleus, which sends fibres through each oculomotor nerve to supply respective sided muscle.

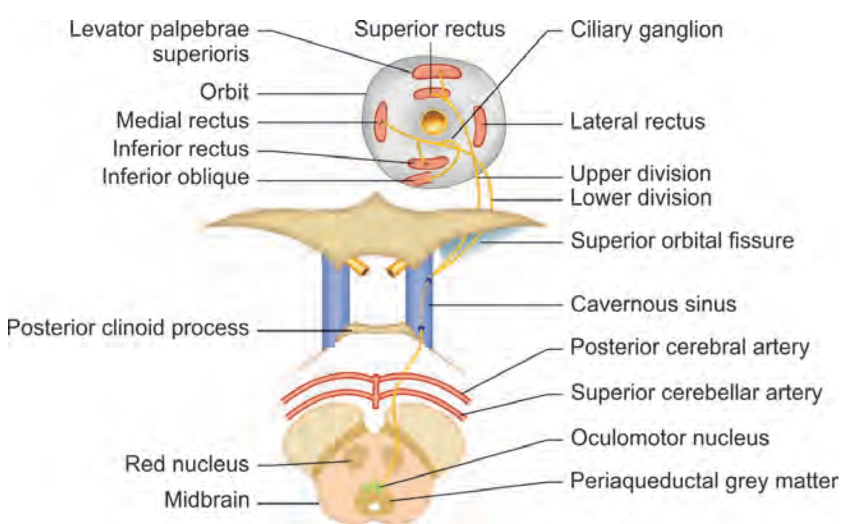
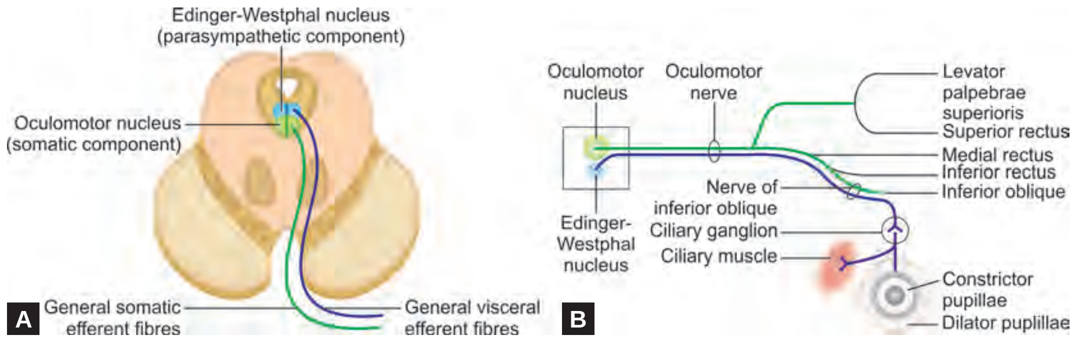


Fig. 219: Origin, course, and distribution of the oculomotor.



Figs. 220A and B: Oculomotor nerve: (A) The functional components and nuclei of the oculomotor nerve. (B) The distribution of the constitutional fibres of the oculomotor nerve.

Clinical Correlations

- Occulomotor nerve lesions leads to paralysis of the levator palpebrae superioris (ptosis) and a wrinkled brow due to the inability to raise the eyelid; fixed dilated pupil (with loss of light and accommodation reflex) due to paralysed constrictor pupillae muscle & ciliary muscles; and downward and outward position of the eye (strabismus) due to the unopposed action of the superior oblique and lateral rectus muscles.

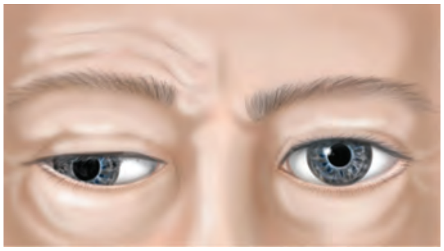


Fig. 221: Appearance of the eyes in right third nerve palsy. The right side of Werner's face illustrates: a wrinkled brow due to the inability to raise the right eyelid; ptosis of his right eye lid due to the inactivation of the levator palpebrae superioris muscle; dilation of his right pupil due to the decreased tone of the constrictor pupillae muscle; and downward and outward movement of his right eye due to the unopposed action of the right superior oblique and and lateral rectus muscles.

ASSESSMENT QUESTIONS

1. **All are characteristics of 3rd nerve EXCEPT:** *(AIIMS 2006)*
   a. Carries parasympathetic nerve
   b. Supplies inferior oblique
   c. Enters orbit through the inferior orbital fissure
   d. Causes miosis

2. **Oculomotor nerve palsy causes all of the following EXCEPT:**
   a. Ptosis
   b. Mydriasis
   c. Medial deviation of eyeball
   d. Pupillary reflex lost

3. **Which of the following statement is /are TRUE about oculomotor nerve:** *(PGIC 2014)*
   a. Arise from pons
   b. Edinger- Westphal nucleus gives rise to parasympathetic supply
   c. Arise from medulla
   d. Passes through interpeduncular fossa
   e. Related to medial wall of cavernous sinus

ANSWERS WITH EXPLANATIONS

1. **c. Enters orbit through the inferior orbital fissure**
   - Oculomotor nerve passes through superior (not inferior) orbital fissure to enter the orbit.
   - It carries preganglionic parasympathetic fibres to supply muscles like sphincter pupillae which causes miosis.
   - It also carries motor fibres to supply eyeball muscles like inferior oblique.

2. **c. Medial deviation of eyeball**
   - Oculomotor nerve palsy leads to a wrinkled brow due to the inability to raise the eyelid; ptosis of eyelid due to the weakness of the levator palpebrae superioris muscle; dilation of pupil due to the decreased tone of the constrictor pupillae muscle; and downward and outward position of eye due to the unopposed action of the superior oblique and lateral rectus muscles.

3. **b. Edinger- Westphal nucleus gives rise to parasympathetic supply; d. Passes through interpeduncular fossa**
   - Oculomotor nerve nuclei are present in the midbrain, send axons which exit ventrally from midbrain and pass through the interpeduncular fossa before they pass through lateral wall of cavernous sinus and enter orbit eventually.
   - Edinger Westphal nucleus sends parasympathetic fibres to the two smooth muscles in the eyeball: sphincter pupillae and ciliaris.

Trochlear Nerve

- **Trochlear nerve** is a motor nerve carrying general somatic efferent (GSE) fibres to supply the **superior oblique muscle**.
  - Its axons arise from the midbrain, decussates in the **superior medullary velum**, runs in the lateral wall of cavernous sinus, enters the orbit through the superior orbital fissure (outside the tendinous ring of Zinn) and innervates the superior oblique muscle.
  - Trochlear nerve innervates the **contralateral** superior oblique.
    - Left trochlear nucleus gives the axons which decussate within the brainstem (internal decussation) and become the right trochlear nerve (hypothetically it is left trochlear nerve, but for all practical purposes, it is called as left trochlear nerve).
    - Similarly left trochlear nerve arises from the neuron bodies on the right (right oculomotor nucleus). Lesion of right trochlear nucleus (left trochlear nerve) paralyses the left superior oblique muscle.
- Trochlear nerve is the only cranial nerve which **exits dorsally** from the brainstem.
  - This nerve exits dorsally/posteriorly, loops around the brainstem and turns anteriorly to move along with other cranial nerves - which all exit the brainstem anteriorly.
  - Trochlear nerve gains additional length as it goes dorsal and then comes ventral, whereas other nerves were simply exiting ventrally. Thus the nerve has the **longest intracranial course**. It is also having the longest intracranial (**subarachnoid**) course.
- Trochlear nerve is rarely paralyzed alone. Severe head injury may lead to torn trochlear nerve (due to its long intracranial course) and the patient presents with paralysed superior oblique.
  - It results in **vertical diplopia** (double vision) on looking down, and difficulty in reading/going downstairs.
  - This happens because the superior oblique normally assists the inferior rectus in pulling the eye downward, especially when the eye is in a medial (adducted) position.
  - 'Head tilt test' is a cardinal diagnostic feature - Diplopia is reduced on turning the head away from the site of lesion.
- The patient develops **contralateral** (not ipsilateral) head tilt to compensate for *extorted eye* on the side of lesion.
- Trochlear nerve has very few axons and is the **smallest**, **slimmest** and **most slender** of all cranial nerves. It is the only cranial nerve, which has **dorsal exit** from the brain. Most of its fibres undergo **internal decussation** to supply contralateral superior oblique muscle. It has **longest** intracranial (subarachnoid course).

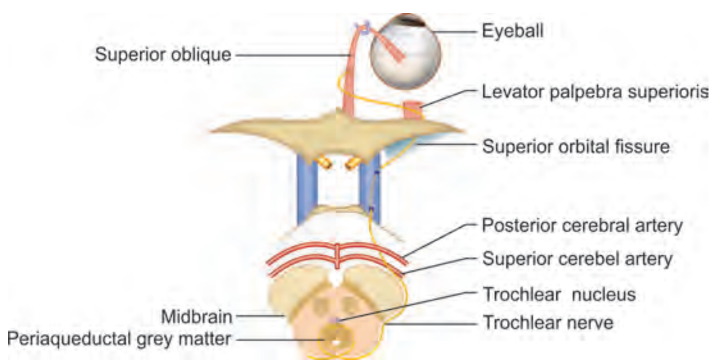


Fig. 222: Origin, course, and distribution of the trochlear nerve.

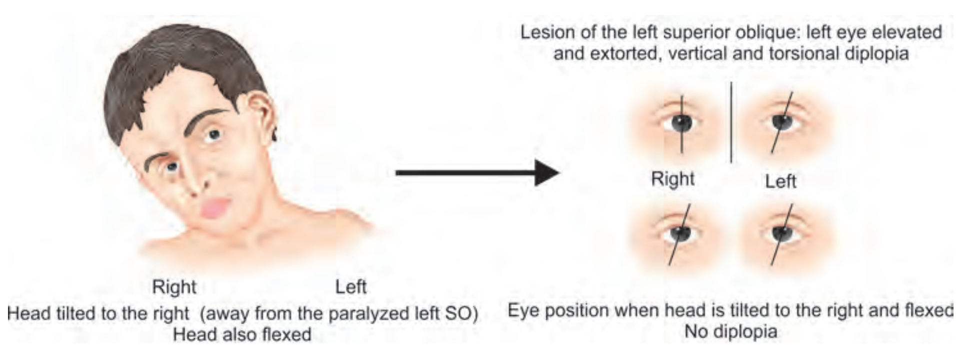


Fig. 223: Paralysis of left superior oblique muscle leads to contralateral head tilt (to right side).

ASSESSMENT QUESTIONS

1. All is true about trochlear nerve EXCEPT: *(AIPG 2009)*
a. Longest intracranial course
b. Arise from dorsal aspect
c. Supplies ipsilateral superior oblique
d. Arises from outside the common tendinous ring

2. All is true about trochlear nerve EXCEPT:
a. Innervates contralateral superior oblique
b. Causes depression of eyeball in adducted position
c. Lies outside the ring of Zinn
d. Patient attains ipsilateral head tilt, in lesion

3. Which of the following is NOT true about the trochlear nerve: *(AIIMS 2011)*
a. Has the longest intracranial course
b. Supplies the ipsilateral superior oblique muscle
c. Only cranial nerve that arises from the dorsal aspect of the brainstem
d. Enters orbit through the superior orbital fissure outside the annulus of Zinn

ANSWERS WITH EXPLANATIONS

1. c. Supplies ipsilateral superior oblique
a. Trochlear nerve innervates the contralateral (and not ipsilateral) superior oblique.
b. Left trochlear nucleus gives the axons which decussate within the brainstem (internal decussation) and become the right trochlear nerve. Similarly left trochlear nerve arises from the neuron bodies on the right (right oculomotor nucleus).
c. Lesion of right trochlear nucleus will paralyse the left superior oblique.
d. Trochlear nerve passes through the superior orbital fissure to reach the orbit and supply superior oblique muscle. It passes outside the common tendinous ring of Zinn. Occulomotor & Abducent nerves also pass through the superior orbital fissure, but they pass inside the CTR of Zinn.

2. d. Patient attains Ipsilateral head tilt, in lesion
a. Trochlear nucleus in the midbrain, send fibres to innervate the **contralateral superior oblique** muscle.
b. Superior oblique muscle causes inward rotation (**intortion**) of the eyeball. Additionally, it also causes **depression** and **abduction** of eyeball. It is the chief muscle to cause depression of the adducted eye and is assisted by inferior rectus for the movement.
c. Trochlear nerve passes through the superior orbital fissure but stays **outside the ring of Zinn**.
d. Trochlear nerve is rarely paralyzed alone. It results in **vertical diplopia** (double vision) on looking down, e.g. when going down stairs. This happens because the superior oblique normally assists the inferior rectus in pulling the eye downward, especially when the eye is in a medial (adducted) position. The patient develops **contralateral** (not ipsilateral) head tilt to compensate for *extorted eye* on the affected side.

3. b. Supplies the ipsilateral superior oblique muscle
a. Trochlear nerve has internal decussation and supplies contralateral superior oblique muscle.
b. It is the only cranial nerve with dorsal exit from the brain, has the longest intracranial course, enters orbit through the superior orbital fissure outside the annulus of Zinn.

Abducent Nerve

- **Abducent nerve** nucleus is in the pons, axons leave the brain at the pontomedullary junction anteriorly and then pierces the dura on the dorsum sellae of the sphenoid bone.
- It passes through the cavernous sinus lying inferolateral to internal carotid artery and enters the orbit through the supraorbital fissure to supply motor fibers (GSE) to the lateral rectus.
- Abducent nerve pierces dura mater relatively early in its intracranial course and has got the longest intradural course, among the cranial nerves.
- It is the earliest nerve to get involved in raised intracranial tension.
- Abducent nerve has the longest intracranial (intradural) course. Because of the long course, it is often stretched when intracranial pressure rises and causes weakness/paralysis of the lateral rectus muscle of the eye and loss of the lateral gaze. The patient will present with a medial deviation of the affected eye (internal strabismus) or diplopia on lateral eye movement.
- Lesion of the abducens nerve may result from a sepsis or thrombosis in the cavernous sinus. If the opposite side of the body is affected, there is a brainstem tumor or midline pontine stroke.

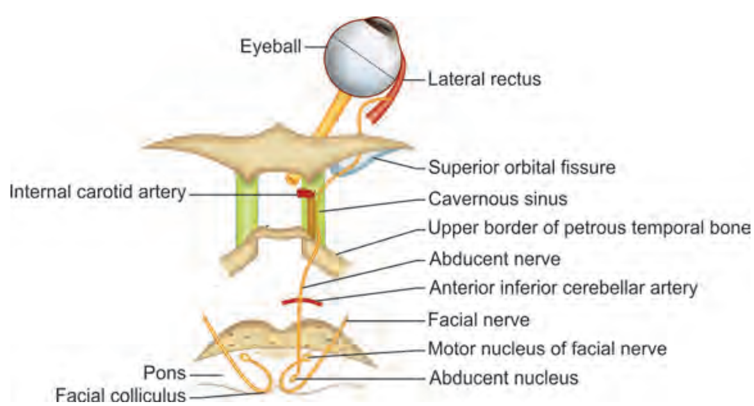


Fig. 224: Origin, course, and distribution of the abducent nerve.

ASSESSMENT QUESTIONS

1. Radially arranged muscle on the iris is supplied by:
a. Oculomotor nerve
b. Sympathetic supply from cervical plexus nerve from cervical sympathetic chain
c. Parasympathetic supply
d. Short ciliary nerve

2. Sensory supply of cornea is by: *(AIIMS 2015)*
a. Supratrochlear nerve
b. Infratrochlear nerve
c. Supraorbital nerve
d. Nasolacrimal nerve

3. Cornea is supplied by: *(NEET Pattern 2014)*
a. Frontal branch of trigeminal nerve
b. Lacrimal branch of trigeminal nerve
c. Nasociliary branch of ophthalmic nerve
d. Trochlear nerve

4. All is true about Trochlear nerve EXCEPT:
a. Slender most cranial nerve
b. Has longest intradural course
c. Innervates contralateral superior oblique
d. Shows internal decussation

ANSWERS WITH EXPLANATIONS

1. b. Sympathetic supply from cervical plexus nerve from cervical sympathetic chain
- **Dilator pupillae** has the **radially arranged fibres** on iris and is supplied by the **T-1 sympathetic fibres**, which start from the lateral horn cells of the spinal cord.
- These fibres synapse in **superior cervical ganglion** on the cervical sympathetic chain. The post-ganglionic fibres pass through around the branches of **internal carotid arteries** to reach the eyeball muscles like dilator pupillae via **long ciliary nerves**.
- It is innervated by the **sympathetic** system, which acts by releasing noradrenaline, which acts on α1-receptors.
- Threatening stimuli that activates the **fight-or-flight** response, this innervation contracts the muscle and dilates the iris, thus temporarily letting more light/information reach the retina.

2. d. Nasolacrimal nerve
- There appears to be misprint as cornea is supplied by branches of nasociliary (not nasolacrimal) nerve.
- The ophthalmic division of the trigeminal nerve gives nasociliary nerve which further sends long ciliary nerves and short ciliary nerves to supply cornea.

3. c. Nasociliary branch of ophthalmic nerve
- Cornea is supplied by long and short ciliary nerves branches of nasociliary nerve, which itself is a branch of ophthalmic division of the trigeminal nerve.

4. b. Has longest intradural course
- Abducent (not trochlear) nerve has got the longest intradural course, since it pierces dura mater relatively early in its intracranial course.

Light and Accommodation Reflex

- **Light reflex** controls the diameter of the pupil in response to the intensity of light that falls on the retina.
- Pathway: In response to light shown into the pupil, the **ganglion cells** in retina project the information bilaterally to the **pretectal nuclei**, which further sends (through the posterior commissure) crossed and uncrossed fibers to the accessory oculomotor (**Edinger-Westphal**) nucleus.
- Edinger-Westphal nucleus of oculomotor nerve gives preganglionic parasympathetic fibers, which synapse in **ciliary ganglion**.
- Ciliary ganglion gives postganglionic fibers to innervate the **sphincter pupillae** muscle of the iris.

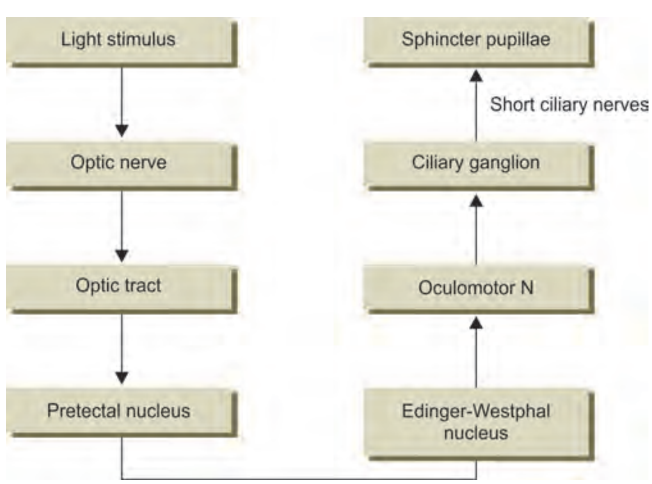


Fig. 225: Light reflex.

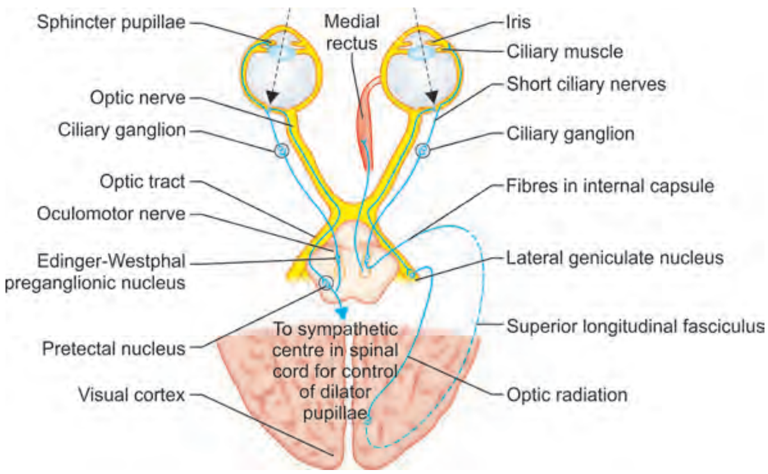
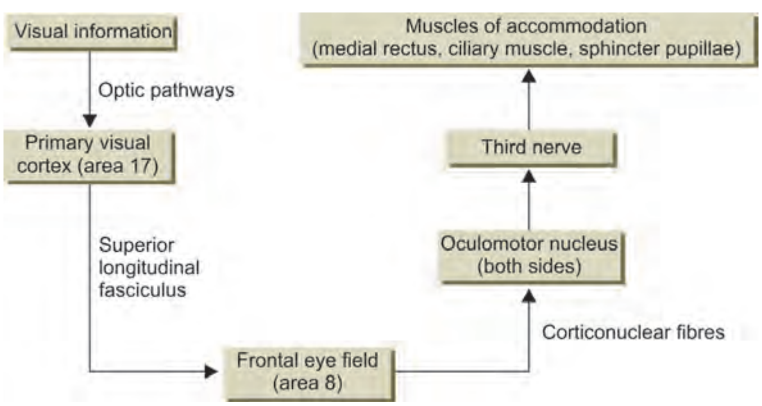


Fig. 226: The neural pathways of the pupiliary light reflex (left) and the accommodation reflex (right). (From Oxford Textbook of Functioning Anatomy, Vol 3 Head and Neck, Mackinnon P, Morris J (eds) 1990. With permission of Oxford University Press.)

- **Accommodation reflex** occurs in response to focusing on a near object, is controlled by the parasympathetic nervous system and involves three responses; pupil accommodation, lens accommodation, and convergence.
- It involves optic nerve (afferent limb of reflex), superior centers (interneuron) and oculomotor nerve (efferent limb of reflex).
- The visual information reaching primary visual cortex (Brodmann's area 17) is projected to the visual association cortex (Brodmann's area 19), which is further conveyed to the frontal eye field (area 8) through the superior longitudinal fasciculus.
- The frontal cortex sends corticotectal tract to the superior colliculus and pretectal nucleus.
- The superior colliculus and pretectal nucleus project to the oculomotor complex of the midbrain. This complex includes the following structures:
  - The rostral accessory oculomotor (Edinger-Westphal) nucleus, which mediates **pupillary constriction** through the ciliary ganglion.
  - The caudal accessory oculomotor (Edinger-Westphal) nucleus, which mediates contraction of the **ciliary muscle**. This contraction increases the convexity and refractive power of the lens.
  - The **medial rectus** subnucleus of CN III, which mediates convergence.



227: Accommodation reflex.

Ocular Motility

- Frontal eye field is located in the posterior part of the middle frontal gyrus (Brodmann's area 8).
- It regulates voluntary (saccadic) eye movements.
- Activation causes contralateral deviation of the eyes, whereas destruction causes transient ipsilateral conjugate deviation of the eyes (i.e. toward the lesion).
- Occipital visual cortex located in Brodmann's areas 17, 18 and 19 has cortical centers for involuntary (smooth) pursuit and tracking movements. Stimulation causes contralateral conjugate deviation of the eyes.
- Subcortical center for lateral conjugate gaze is located in the abducent nucleus of the pons and in the paramedian pontine reticular formation (PPRF).

- It receives input from the contralateral frontal eye field and projects to the **ipsilateral lateral rectus** muscle.
- Through the medial longitudinal fasciculus (MLF), it sends projection to the **contralateral medial rectus** subnucleus of the oculomotor complex.
- Activation of the frontal eye fields move both the eyes in contralateral direction. For example, activation of left frontal eye fields moves both (right and left eyes) towards right side.
- Subcortical center for vertical conjugate gaze is located in the midbrain at the level of the posterior commissure.
- It is called the rostral interstitial nucleus (RIN) of the MLF and is associated with Parinaud's syndrome.

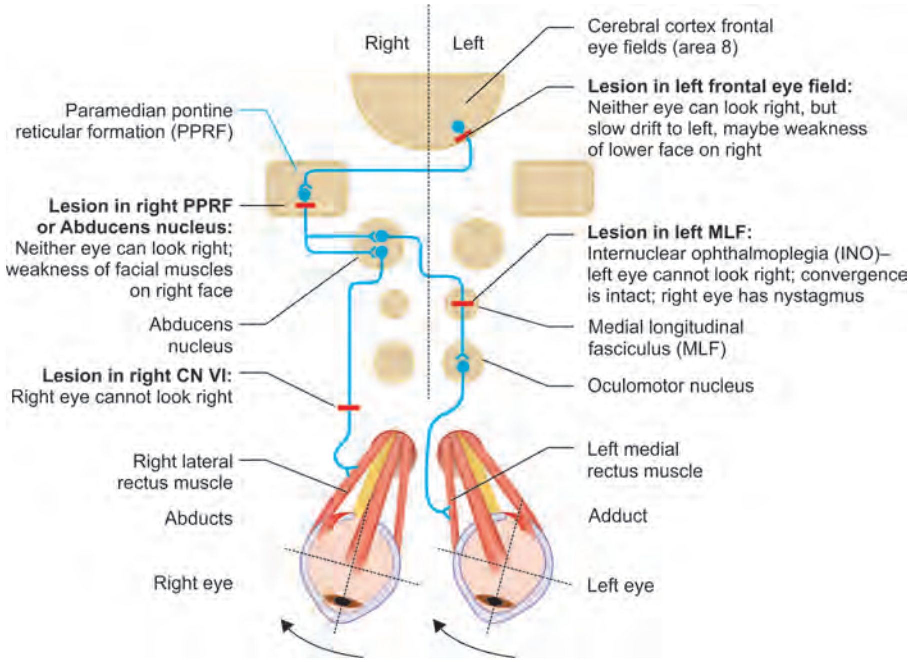
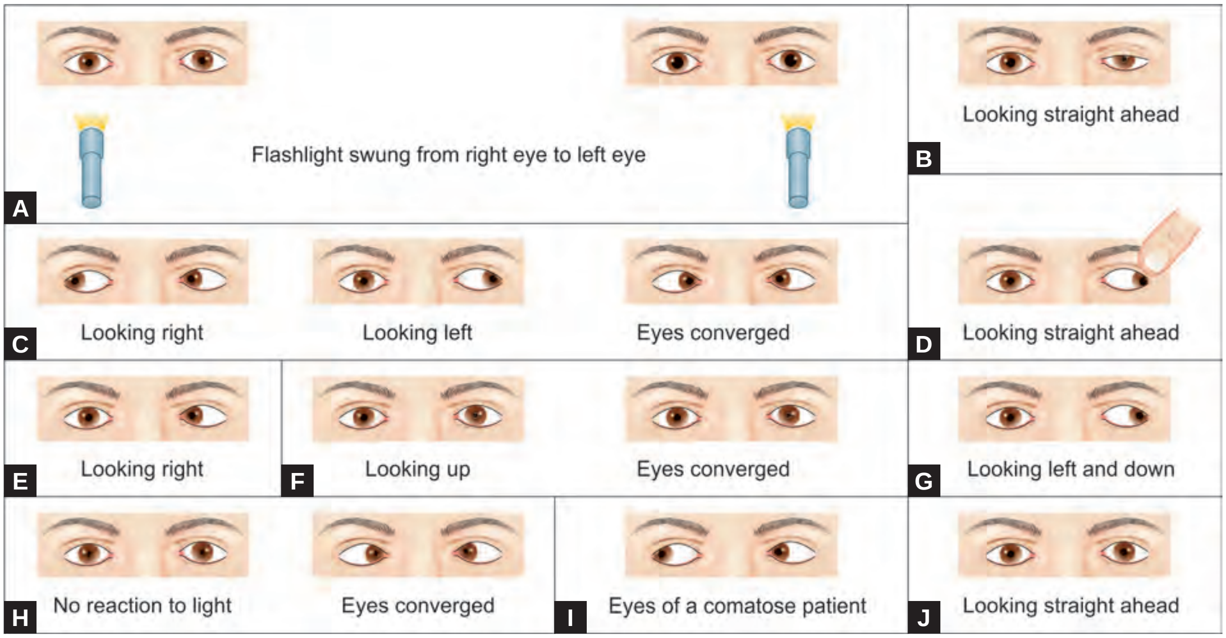


Fig. 228: Voluntary horizontal gaze circuit.

Lesions

- **Internuclear ophthalmoplegia** (MLF syndrome) may occur due to demyelination of the MLF (as in multiple sclerosis) between the abducent and oculomotor nuclei in horizontal gaze circuitry.
- It causes medial rectus palsy on attempted lateral conjugate gaze and monocular horizontal nystagmus in the abducting eye.
- Convergence remains normal.
- **One and a half syndrome** occurs due to bilateral lesions of the MLF and a unilateral lesion of the abducent nucleus.
- On attempted lateral conjugate gaze, the only muscle that functions is the intact lateral rectus.
- **Argyll Robertson pupil** is pupillary light–near dissociation, leading to absence of a miotic reaction to light, both direct and consensual, with the preservation of a miotic reaction to near stimulus (accommodation–convergence).
- It occurs in syphilis and diabetes.
- **Horner syndrome** is caused by transection of the oculo-sympathetic pathway leading to miosis, ptosis, enophthalmos and hemianhidrosis.
- Relative afferent (**Marcus Gunn**) pupil results from a lesion of the optic nerve, the afferent limb of the pupillary light reflex (e.g., retrobulbar neuritis seen in multiple sclerosis).
- The diagnosis can be made with the swinging flashlight test
- Transtentorial (uncal) herniation may occur due to a brain tumor or hematoma (subdural or epidural).
- The parahippocampal uncus is forced through the tentorial incisure and pushes the contralateral crus cerebri against the tentorial edge (Kernohan's notch) resulting in pressure on the ipsilateral oculomotor nerve and posterior cerebral artery.
- Ipsilateral hemiparesis occurs as a result of pressure on the corticospinal tract, which is located in the contralateral crus cerebri.
- Pressure on the ipsilateral oculomotor nerve leads to 'down-and-out eye' with ptosis and fixed and dilated pupil.
- Compression of the posterior cerebral artery, leads to ischaemia in visual cortex, resulting in contralateral homonymous hemianopia.
- **Papilloedema** is noninflammatory congestion of the optic disk as a result of increased intracranial pressure.
- It usually does not alter visual acuity, but may cause bilateral enlarged blind spots.
- It is often asymmetric and is greater on the side of the supratentorial lesion.
- **Adie's tonic pupil** is a large pupil that reacts slowly to light but does react to near (light–near dissociation).
- It is frequently seen in women with absent knee or ankle jerks.

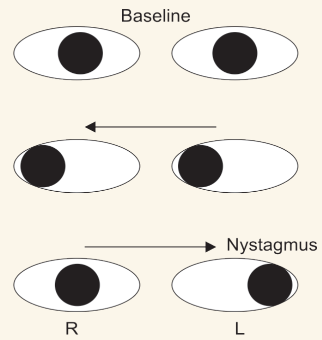


Figs. 229A to J: Ocular motor palsies and pupiliary syndromes. (A) Relative afferent (Marcus Gunn) pupil, left eye. (B) Horner syndrome, left eye. (C) Internuclear ophthalmoplegia, right eye. (D) Third nerve palsy, left eye. (E) Sixth nerve palsy, right eye. (F) Paralysis of upward gaze and convergence (Parinaud syndrome). (G) Fourth nerve palsy, right eye. (H) Argyll Robertson pupil. (I) Destructive lesion of the right frontal eye field. (J) Third nerve palsy with ptosis, right eye. (Modified from Fix JD. *High-Yield Neuroanatomy,* 3rd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2005:124)

ASSESSMENT QUESTION

1. Assess the following diagram and identify the problem: *(AIIMS 2016)*

a. Oculomotor palsy
b. Internuclear ophthalmoplegia
c. Weber syndrome
d. Duane retraction syndrome



ANSWER WITH EXPLANATION

1. b. Internuclear ophthalmoplegia

- **Internuclear ophthalmoplegia** (MLF syndrome) may occur due to demyelination of the MLF (as in multiple sclerosis) between the abducent and oculomotor nuclei in horizontal gaze circuitry.
- It causes medial rectus palsy on attempted lateral conjugate gaze and monocular horizontal nystagmus in the abducting eye. Convergence remains normal.
- When an attempt is made to gaze contralaterally (relative to the affected eye), the affected eye shows no adduction.
- The contralateral eye abducts, but with nystagmus.
- Additionally, the divergence of the eyes leads to horizontal diplopia. For example, if the right eye is affected the patient develops diplopia on looking to the left.

Infratemporal region

- Infratemporal Fossa is the irregularly shaped cavity, situated below and medial to the zygomatic arch, not fully enclosed by bone in all directions.
- Its boundaries are:
  - Anteriorly is the maxilla bone (posterior surface) and posterior is the temporal bone (styloid and mastoid processes).
  - At the medial boundary is the sphenoid bone (lateral pterygoid plate) and lateral is the mandible bone (ramus and coronoid process).
  - At the roof is greater wing of the sphenoid and infratemporal crest and the floor is open below.

- Contents: Lower portion of the temporalis muscle, the lateral and medial pterygoid muscles, the pterygoid venous plexus, maxillary artery and its branches, the mandibular nerve and its branches, the otic ganglion, and the chorda tympani nerve.

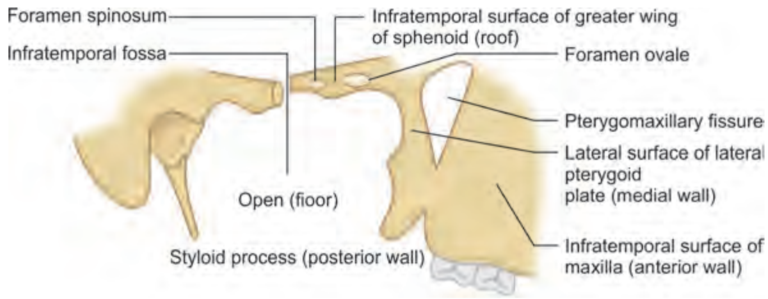


Fig. 230: Boundaries of the infratemporal fossa.

Communications:

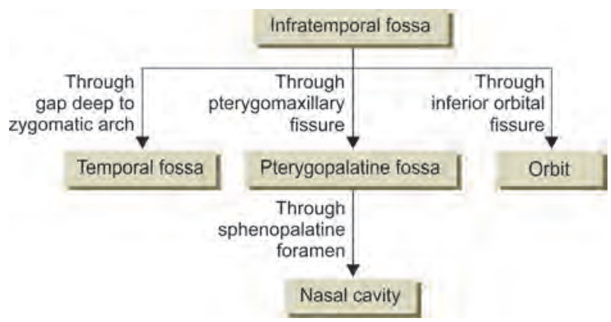
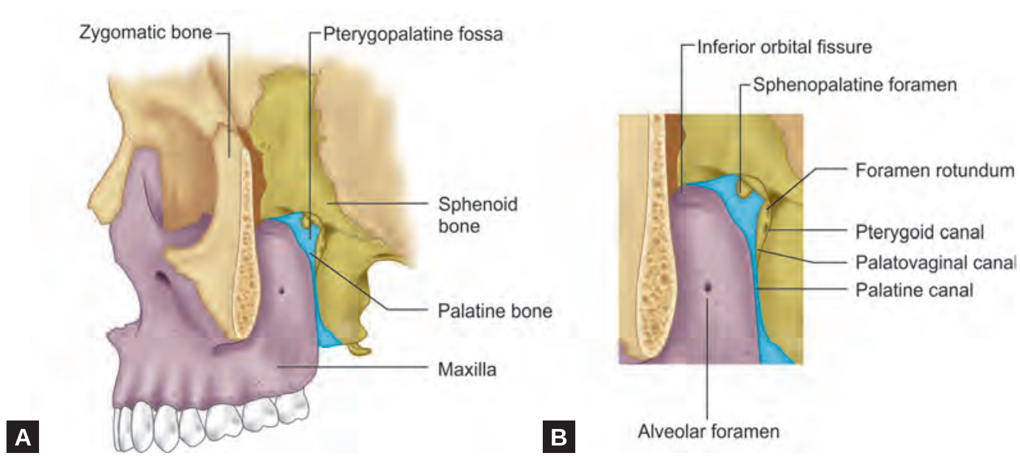


Fig. 231: Communications of the infratemporal fossa.

- Temporal fossa is the shallow depression on the side of the skull bounded by the temporal lines and terminating below the level of the zygomatic arch.
- Its boundaries are:
  - Anteriorly is the frontal bone (zygomatic process) and zygomatic bone (the frontal process).
  - Posterior & superior is the temporal line.
  - Lateral boundary is zygomatic arch and inferior is the infratemporal crest.
  - The floor is contributed by parts of the frontal, parietal, temporal, and greater wing of the sphenoid bone.
- Contents are: Temporalis muscle, the deep temporal nerves and vessels, the auriculotemporal nerve and the superficial temporal vessels.

Pterygopalatine Fossa and Ganglion

- Pterygopalatine fossa is a cone-shaped paired depression deep to the infratemporal fossa and posterior to the maxilla on each side of the skull, located between the pterygoid process and the maxillary tuberosity, close to the apex of the orbit.



Figs. 232A and B: Pterygopalatine fossa. (A) Anterolateral view. (B) Lateral view.

- The **boundaries** and relations of pterygopalatine fossa:
  - **Anterior Wall**: Posterior surface of the maxilla bone.
  - **Posterior Wall**: Pterygoid process and greater wing of the sphenoid.
    - The openings and their contents in posterior wall are: **Foramen rotundum** to middle cranial cavity (contains maxillary nerve); **pterygoid canal** to foramen lacerum (contains nerve of the pterygoid canal); **palatovaginal canal** to choana (containing pharyngeal branch of the maxillary artery and pharyngeal nerve from the pterygopalatine ganglion).
  - **Medial Wall:** Perpendicular plate of the palatine bone.
    - The opening is the sphenopalatine foramen to the nasal cavity, which transmits the sphenopalatine artery and nasopalatine nerve.
  - **Lateal Wall** is open as the pterygomaxillary fissure to the infratemporal fossa.
  - **Roof** is formed by greater wing and body of the sphenoid.
    - The opening is the inferior orbital fissure to the orbit which transmits the maxillary nerve.
  - **Floor** has fusion of the maxilla and the pterygoid process of the sphenoid.
    - The opening is the greater palatine foramen to the palate, which transmits the greater palatine nerve and vessels.

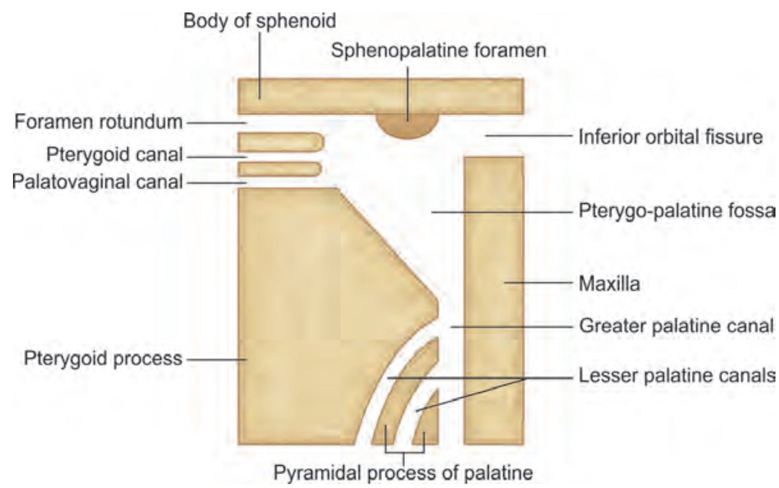
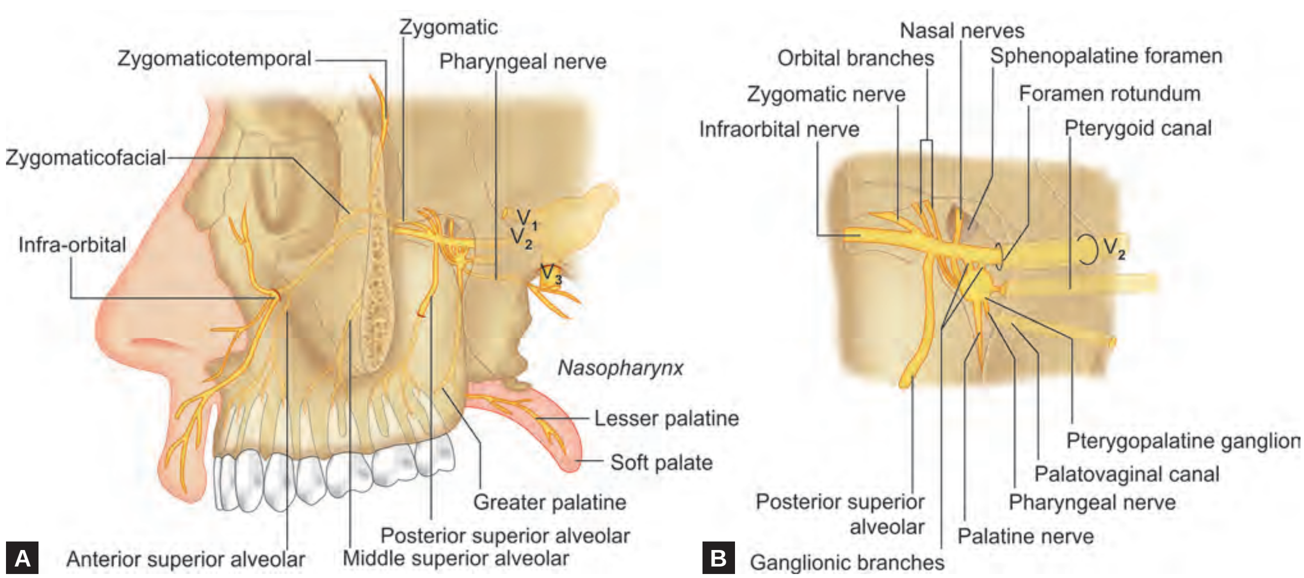


Fig. 233: Boundaries of the pterygopalatine fossa.

- Contents: Maxillary nerve passes through foramen rotundum to enter the pterygopalatine fossa, pterygopalatine ganglion, maxillary artery (third part).



Figs. 234A and B: Maxillary nerve [V_2]. (A) Terminal branches. (B) In relationship to the pterygopalatine ganglion.

- Communications of pterygopalatine fossa:

Direction	Passage	Connection
Posteriorly	Foramen rotundum	Middle cranial fossa
	Pterygoid canal (Vidian)	Middle cranial fossa, foramen lacerum
	Palatovaginal canal (pharyngeal)	Nasal cavity/nasopharynx
Anteriorly	Inferior orbital fissure	Orbit
Medially	Sphenopalatine foramen	Nasal cavity
Laterally	Pterygomaxillary fissure	infratemporal fossa
Inferiorly	Greater palatine canal (pterygopalatine)	Oral cavity
		Lesser palatine canals

- Pterygopalatine Ganglion lies in the pterygopalatine fossa just below the maxillary nerve, lateral to the sphenopalatine foramen, anterior to the pterygoid canal and behind the perpendicular plate of palatine bone.
  - It has neuron bodies of parasympathetic postganglionic GVE fibers and receives preganglionic parasympathetic fibers from the facial nerve by way of the greater petrosal nerve and the nerve of the pterygoid canal.
  - It sends postganglionic parasympathetic fibers to the nasal and palatine glands and to the lacrimal gland through the maxillary, zygomatic, and lacrimal nerves.
  - It also receives postganglionic sympathetic fibers (by the deep petrosal nerve and the nerve of the pterygoid canal), which are distributed along with the postganglionic parasympathetic fibers.
- Maxillary nerve branches which pass through the pterygopalatine ganglion without synapse carrying its own GSA fibers and also the general visceral afferent and efferent (GVA and GVE) fibers from the facial nerve to the nasal mucosa and the palate. The branches are:
  - **Orbital** (innervate orbit and posterior ethmoidal and sphenoidal sinuses); **pharyngeal** branch run in palatovaginal canal (supply the roof of the pharynx and sphenoidal sinus); posterior superior **lateral nasal** branches (supply the nasal septum, posterior ethmoidal air cells, and superior and middle conchae).
  - **Greater palatine nerve** descends through the palatine canal and emerges through the greater palatine foramen to innervate the hard palate and the inner surface of the maxillary gingiva; **lesser palatine nerve** descends through the palatine canal and emerges through the lesser palatine foramen (innervate the soft palate and the palatine tonsil), carries visceral sensory (GVA) and taste fibers (for the soft palate) that belong to the facial nerve and have their cell bodies in the geniculate ganglion.
  - It also contains postganglionic parasympathetic and sympathetic GVE fibers that come from the facial nerve via the greater petrosal and vidian nerves and supply mucus glands in the nasal cavity and the palate; **nasopalatine nerve** runs obliquely downward and forward on the septum (innervates the nasal septum, hard palate, incisors, the skin of the philtrum and the gums).

Clinical Correlates

- Vidianectomy (carried out for vasomotor rhinitis cases) lesions the nerve of the pterygoid canal and results in vasodilation; a lack of secretion of the lacrimal, nasal, and palatine glands; and a loss of general and taste sensation of the palate.

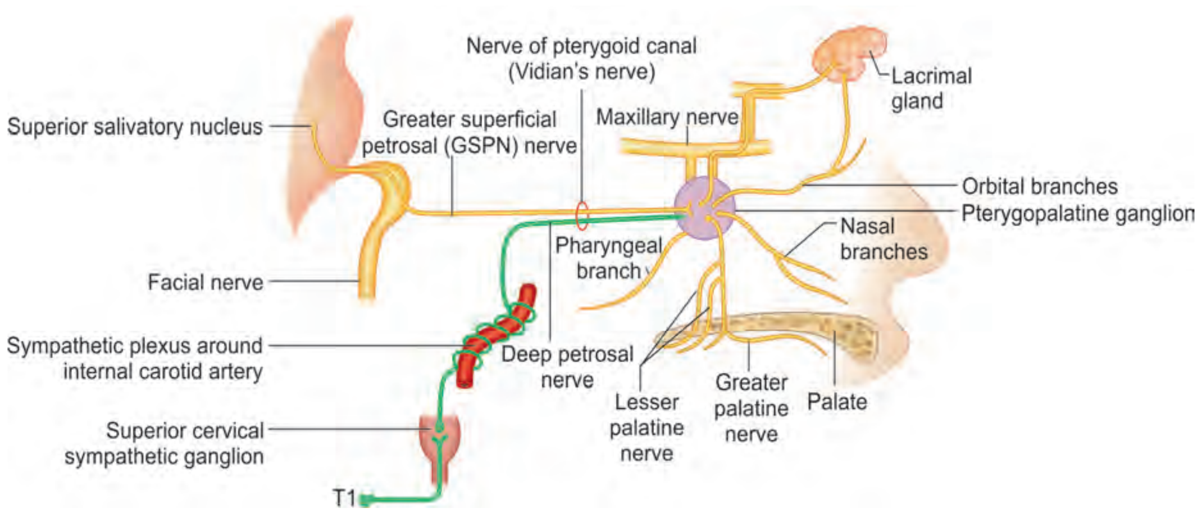
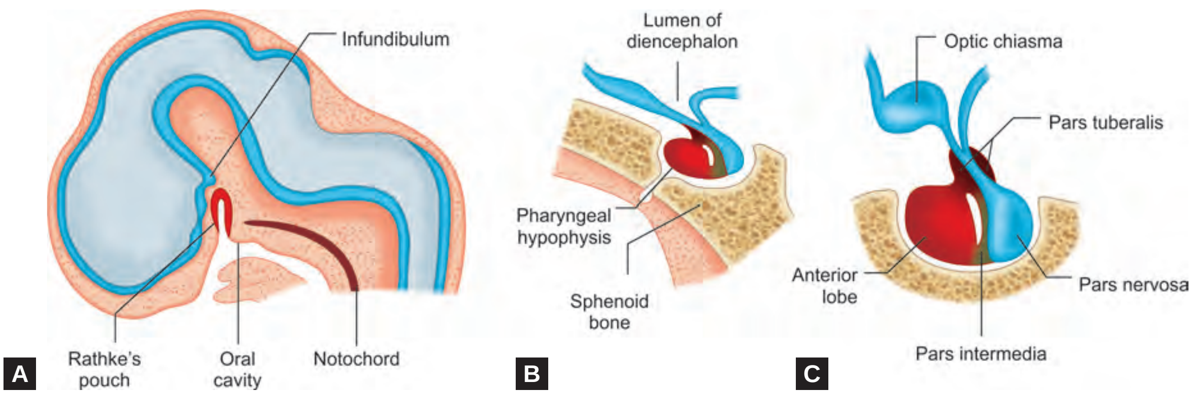


Fig. 235: Pterygopalatine ganglion, its roots and branches.

Pituitary

- Anterior pituitary (or adenohypophysis) is a lobe of the gland that regulates several physiological processes (including stress, growth, reproduction, and lactation).
  - It develops from the Rathke's pouch, an ectodermal diverticulum of the primitive oral cavity (stomodeum).
  - It includes the pars tuberalis, pars intermedia, and pars distalis.
  - Intermediate lobe synthesizes and secretes melanocyte-stimulating hormone.
- The posterior pituitary (or neurohypophysis) is a lobe of the gland that is functionally connected to the hypothalamus by the median eminence via a small tube called the pituitary stalk (also called the infundibular stalk or the infundibulum).
  - It develops from a ventral evagination of the hypothalamus.
  - It includes the median eminence, infundibular stem, and pars nervosa.



Figs. 236A to C: (A) Sagittal section through the cephalic part of a 6 week embryo showing Rathke's pouch as a dorsal outpocketing of the oral cavity and the infundibulum as a thikening in the floor of the diencephalon. (B and C) Sagittal sections through the developing hypophysis in the 11th and 16th weeks of development, respectively, Note formation of the pars tuberalis encircling the stalk of the pars nervosa.

- Pituitary gland rests upon the hypophysial fossa of the sphenoid bone in the floor of the middle cranial fossa and is surrounded by a small bony cavity (sella turcica) covered by a dural fold (diaphragma sellae).

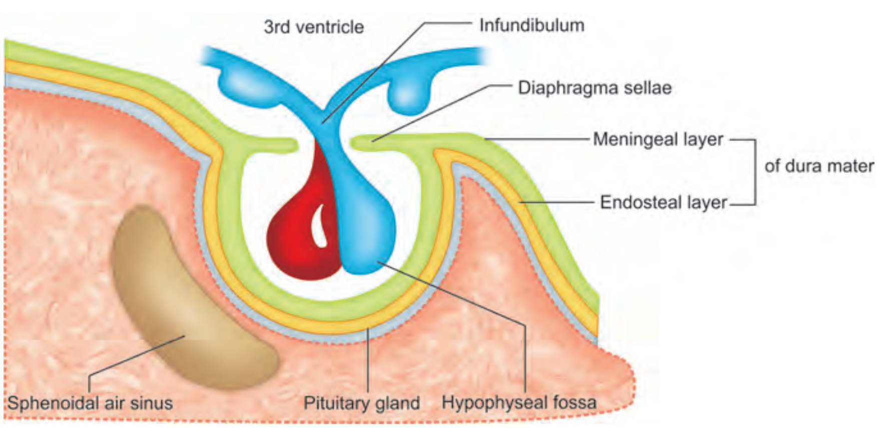


Fig. 237: Location of hypophysis cerebri (pituitary gland).

- Parts of pituitary gland

Pituitary gland derivation and terminology.

Derivation	Tissue eye	Part	Lobe
Oral ectoderm			
Hypophyseal diverticulum from the roof of the stomodeum	Adenohypophysis (glandular tissue)	Pars anterior Pars tuberalis Pars intermedia	Anterior lobe
Neuroectoderm			
Neurohypophyseal diverticulum from the floor of the diencephalon	Neurohypophysis (nervous tissue)	Pars nervosa Infundibular stem Median eminence	Posterior lobe

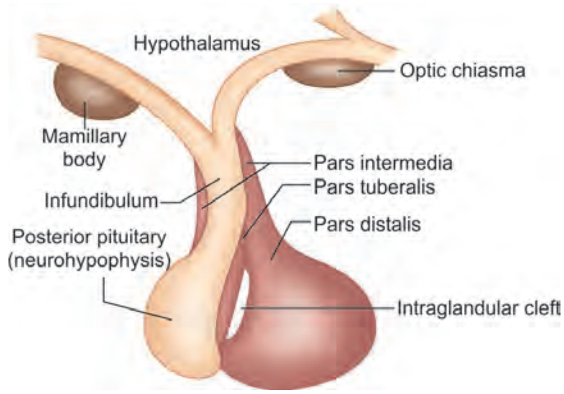


Fig. 238: Parts of hypophysis cerebri as seen in sagittal section.

- Hypothalamo-hypophysial tract consists of nerve fibres arising from the supraoptic and paraventricular nuclei of the hypothalamus and projecting into the posterior lobe of the pituitary gland.
  - The vasopressin and ADH produced in the mentioned nuclei are transported by the nerve fibres of the tract, and stored in the nerve terminals (Herring bodies) of these fibres in the posterior lobe (neurohypophysis).
- Hypothalamo-hypophysial portal system consists of two sets of capillaries: one in the hypothalamus (median eminence) and the other in the hypophysis cerebri (sinusoids of pars anterior).
  - The neurons of the hypothalamus produce hormones-releasing factors in the capillaries of the median eminence and upper part of the infundibulum.

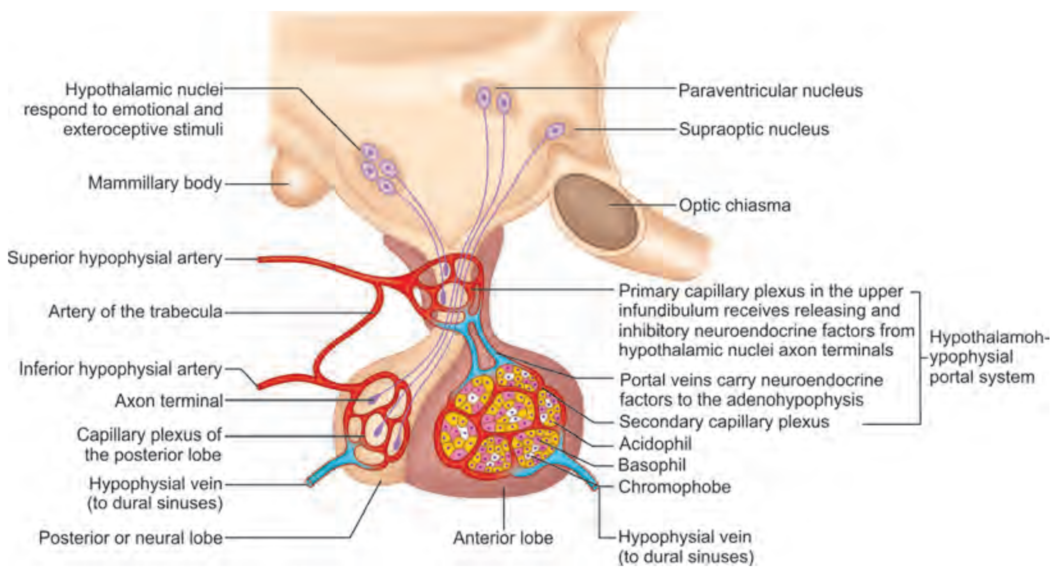


Fig. 239: The main systems controlling the endocrine secretory activities of the pituitary gland.

- These are carried by the portal system to pars anterior.
- Arterial supply: Superior and inferior hypophyseal arteries supply the pituitary gland.
- Venous Drainage: There are three routes for venous drainage of neurohypophysis: To adenohypophysis via long and short portal vessels; into dural venous sinuses via inferior hypophyseal veins and to hypothalamus via capillaries passing to median eminence. Venous blood carries the hormones to the target sites.

ASSESSMENT QUESTIONS

1. Anterior pituitary develops from: *(NEET Pattern 2013)*
a. Infundibulum
b. Neuroectoderm
c. Rathke's pouch
d. None

2. All are derivatives of Rathke's pouch EXCEPT: *(NEET Pattern 2015)*
a. Pars intermedia
b. Pars tuberalis
c. Neurohypophysis
d. Pars distalis

3. Herring bodies are seen in: *(NEET Pattern 2012)*
a. Pars tuberalis
b. Pars intermedia
c. Neurohypophysis
d. Pars terminalis

4. Venous drainage from neurohypophysis is routed through all of the following EXCEPT: *(AIIMS 2004)*
a. Portal vessels to adenohypophysis
b. Superior hypophyseal veins to ventricular tanycytes
c. Inferior hypophyseal veins to dural venous sinuses
d. Capillaries to median eminence and hypothalamus

ANSWERS WITH EXPLANATIONS

1. c. Rathke's pouch
- Anterior lobe (adenohypophysis) of pituitary develops from Rathke's pouch (ectodermal diverticulum of the primitive oral cavity).

2. c. Neurohypophysis
- Neurohypophysis (posterior lobe) develops from a ventral evagination of the hypothalamus (diencephalon).
- It includes the median eminence, infundibular stem, and pars nervosa.
- Rathke's pouch gives rise to the various components of the anterior pituitary including pars anterior, pars tuberalis, pars intermedia.

3. c. Neurohypophysis
- Herring bodies are neurosecretory structures present in the neurohypophysis (posterior pituitary).
- They represent the terminal end of the axons from the hypothalamus for temporary storage of hormones.

4. b. Superior hypophyseal veins to ventricular tanycytes
- There are no vessels by the name superior hypophyseal veins.
- There are three routes for venous drainage of neurohypophysis: To adenohypophysis via long and short portal vessels; into dural venous sinuses via inferior hypophyseal veins and to hypothalamus via capillaries passing to median eminence.

Thyroid and Parathyroid

- Thyroid gland is an endocrine gland that produces thyroxine and thyrocalcitonin, which are essential for metabolism and growth.
  - It takes iodine from food to produce thyroid hormones and is controlled by thyroid-stimulating hormone produced by the pituitary gland.
- Thyroid gland consists of right and left lobes connected by the isthmus, which crosses the second, third (and fourth) tracheal rings (most precisely third).
- A remnant of the thyroglossal duct (pyramidal lobe) may extend upward from the isthmus, usually to the left of the midline and may be anchored to the hyoid bone as a fibrous or muscular band called levator glandulae thyroideae.
- The Ligament of Berry is the superior suspensory ligament of the thyroid gland located adjacent to the cricoid cartilage on the posterior surface of the thyroid gland.

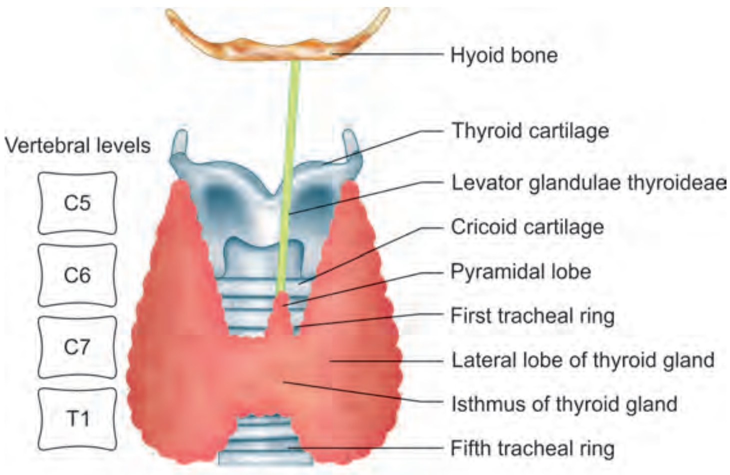


Fig. 240: Parts and extent of the thyroid gland.

Relations

- Anteriorly: Pretracheal fascia, sternohyoid muscle and the superior belly of omohyoid muscle. Inferiorly it is overlapped by the anterior border of the sternocleidomastoid muscle.
- Posteriorly: Prevertebral fascia, carotid sheath, parathyroid glands and trachea.
- Laterally: Thyroid gland is covered by the sternothyroid muscle, which is attached to the oblique line of the thyroid cartilage preventing the upper pole of the gland from extending onto the thyrohyoid muscle.
- Medially: Recurrent laryngeal nerve, trachea, larynx and oesophagus. The superior pole of the gland contacts the inferior pharyngeal constrictor and superior part of cricothyroid. The external laryngeal nerve runs medial to the superior pole to supply the cricothyroid muscle.
- The isthmus is covered by sternothyroid and is separated from it by pretracheal fascia. The superior thyroid arteries anastomose along its upper border and the inferior thyroid veins leave the thyroid gland at its lower border.

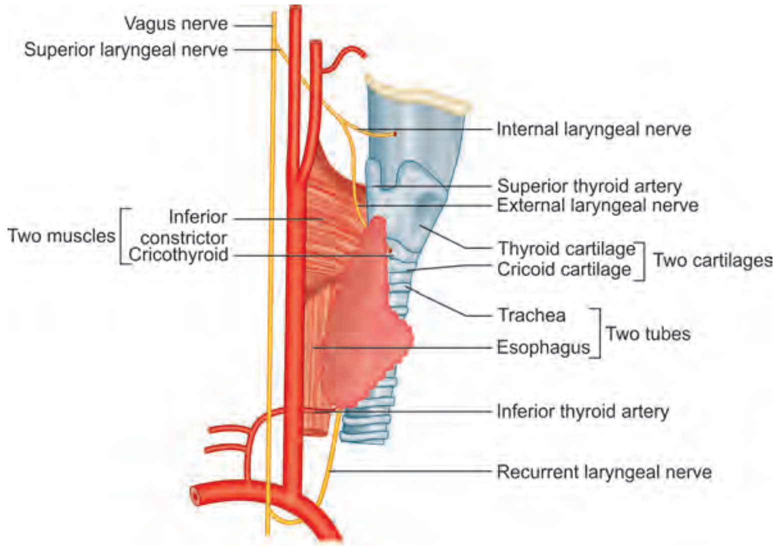


Fig. 241: Medial relations of the lateral lobe of the thyroid gland. The figure also shows intimate relationship of the external and recurrent laryngeal nerves with the superior and inferior thyroid arteries, respectively.

- Arterial supply: Superior and inferior thyroid arteries and the thyroid ima artery (in 10% of population).
  - External carotid artery via the superior thyroid artery.
  - Subclavian artery/thyrocervical trunk via the inferior thyroid artery.
  - Arch of the aorta via the thyroid ima artery.
- Note: Thyroid ima artery has variable origin and may arise from brachiocephalic trunk, common carotid artery, Subclavian artery, etc.

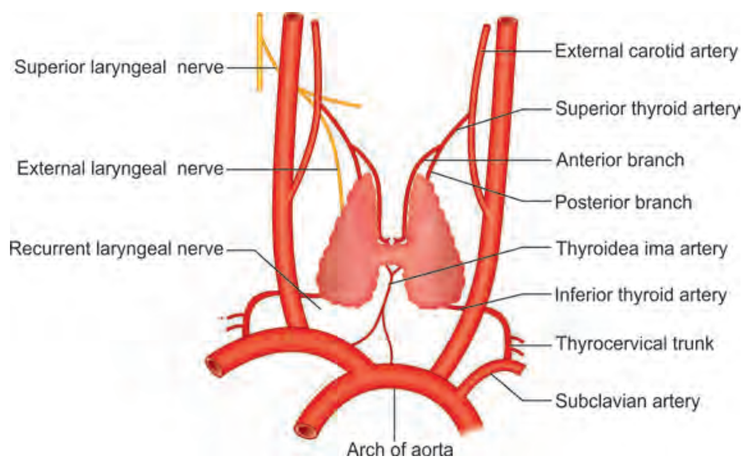


Fig. 242: Arterial supply of the thyroid gland.

- Venous drainage: Superior and middle thyroid veins drain into the internal jugular vein and the inferior thyroid vein drain into the brachiocephalic vein.

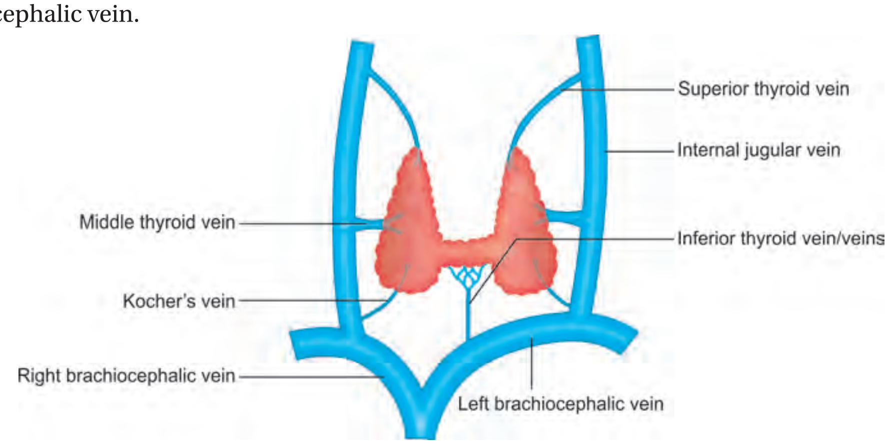


Fig. 243: Venous drainage of the thyroid gland.

- Lymphatic drainage
  - The upper group of lymphatics follow superior thyroid artery and lower lymphatics follow the inferior thyroid arteries.
    - The upper lymphatics drain into the prelaryngeal and upper deep cervical (jugulodigastric) lymph nodes.
  - The lower group drains into pretracheal and lower deep cervical lymph nodes and group of lymph nodes along the recurrent laryngeal nerves.
    - Those from lower part of isthmus drain into retrosternal or brachiocephalic nodes lying in the superior mediastinum.

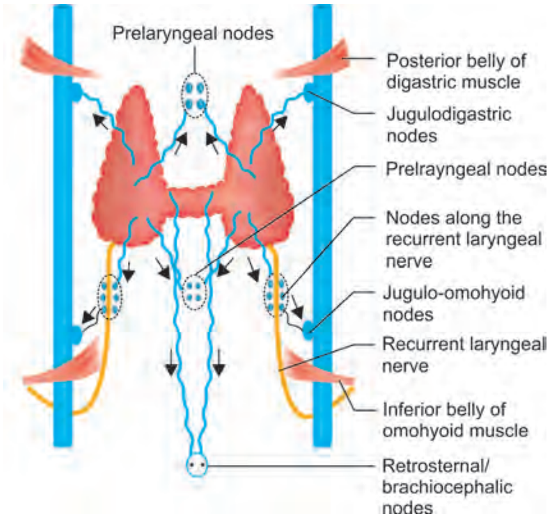
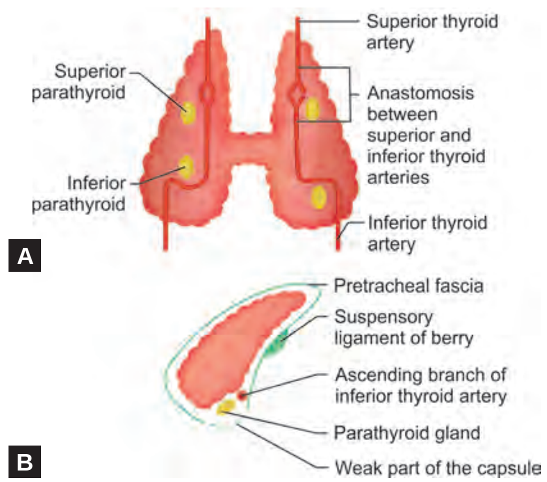


Fig. 244: Lymphatic drainage of the thyroid gland.

- **Parathyroid Glands** are endocrine glands that play a vital role in the regulation of calcium and phosphorus metabolism and are controlled by the pituitary and hypothalamus.
- Parathyroid glands are 4 small ovoid bodies that lie against the dorsum of the thyroid under its sheath but with their own capsule.
  - The superior parathyroid glands are consistently located on the posterior surface of the upper thyroid lobes near the inferior thyroid artery.
  - The inferior parathyroid glands are located on the lateral surface of the lower thyroid lobes (not constant).
- Arterial supply: Each parathyroid gland receives blood supply from inferior thyroid artery, and also from the anastomosis between superior and inferior thyroid arteries.



Figs. 245A and B: Location of the parathyroid glands: (A) Posterior aspect of the thyroid gland. (B) Section through thyroid lobe along with its capsule.

Clinical Correlations

- Thyroid surgery is a potential risk for vital nerves which include superior laryngeal nerve and recurrent laryngeal nerve.
  - Superior thyroid artery and the external laryngeal nerve diverge from each other near the apex.
    - Therefore, during operative procedure, the superior thyroid artery should be ligated as close to the apex of thyroid lobe as possible to avoid injury to the external laryngeal nerve.
  - The recurrent laryngeal nerve lies very close to the inferior thyroid artery near the base of the thyroid lobe.

- Therefore, during thyroidectomy, in olden times it was advocated that the inferior thyroid artery should be ligated as away from the base of the thyroid lobe as possible to avoid injury to the recurrent laryngeal nerve.
- But recently it has been realized inferior thyroid artery supplies recurrent laryngeal nerve and parathyroid glands as it nears the thyroid gland and the advocated method compromises blood supply to recurrent laryngeal nerve and also the parathyroid glands.
  - So, the latest approach is that ligation is being done at capsular level by identifying every small branch entering the gland (capsular ligation of inferior thyroid artery, closest to the gland), to retain the blood supply of parathyroids and the nerve as well.

ASSESSMENT QUESTIONS

1. **Isthmus of thyroid gland overlies the:** *(NEET Pattern 2015)*
   a. 1st tracheal cartilage
   b. 1st and 2nd tracheal cartilage
   c. 2nd, 3rd and 4th tracheal cartilage
   d. 3rd and 4th tracheal cartilage
2. **Isthmus of thyroid is at the level of tracheal rings:**
   a. 1st and 2nd
   b. 2nd and 3rd
   c. 3rd and 4th
   d. 5th and 6th
3. **Isthmus of thyroid gland lies at which level:** *(NEET Pattern 2015)*
   a. C2
   b. C4
   c. C5
   d. C7
4. **Inferior thyroid artery is related to:** *(NEET Pattern 2012)*
   a. Superior laryngeal nerve
   b. Recurrent laryngeal nerve
   c. Glossopharyngeal nerve
   d. XII nerve
5. **Inferior thyroid artery is a branch of:** *(NEET Pattern 2015)*
   a. Thyrocervical trunk
   b. External carotid artery
   c. Internal carotid artery
   d. None of the above
6. **NOT true is:** *(AIIMS 2009)*
   a. Superior thyroid artery is branch of external carotid
   b. Parathyroid artery is branch of post division of superior thyroid artery
   c. Inferior thyroid artery is branch of thyrocervical trunk
   d. Thyroid ima artery is invariably a branch of arch of aorta
7. **Inferior thyroid vein drains into:** *(NEET Pattern 2012)*
   a. Internal jugular vein
   b. Superior vena cava
   c. Brachiocephalic vein
   d. External jugular vein
8. **Ligament of Berry in thyroid fixes:** *(NEET Pattern 2014)*
   a. Hyoid bone
   b. Cricoid cartilage
   c. Trachea
   d. Thyroid
9. **Lymphatic drainage of thyroid gland is mainly:** *(NEET Pattern 2015)*
   a. Sublingual nodes
   b. Submandibular nodes
   c. Deep cervical nodes
   d. Submental nodes
10. **Inferior parathyroid develops from which arch:** *(NEET Pattern 2012)*
    a. 1st
    b. 2nd
    c. 3rd
    d. 4th

ANSWERS WITH EXPLANATIONS

1. **c. 2nd, 3rd and 4th tracheal cartilage**
   - Isthmus of thyroid gland overlies usually present anterior to the second, third and fourth tracheal cartilages.
2. **b. 2nd and 3rd**
   - The isthmus connects the lower parts of the two lobes, although occasionally it may be absent.
   - It measures 1.25 cm transversely and vertically, and is usually anterior to the second, third and fourth tracheal cartilages.
   - Some authors mention it as second and third ring, most precisely third ring.
3. **d. C7**
   - Isthmus of thyroid gland lies at C7 vertebral level.
4. **b. Recurrent laryngeal nerve**
   - The recurrent laryngeal nerve lies very close to the inferior thyroid artery near the base of the thyroid lobe.
5. **a. Thyrocervical trunk**
   - Thyrocervical trunk gives three branches (SIT): S - Suprascapular artery, I - Inferior thyroid artery, T - Transverse cervical artery.
6. **b. Parathyroid artery is branch of post division of superior thyroid artery**
   - Parathyroid arteries are usually branches of inferior thyroid (and not superior thyroid) artery.
   - Superior thyroid artery is a branch of external carotid artery and contributes partly towards the parathyroid blood supply.
   - Inferior thyroid artery is a branch of thyrocervical trunk and is the main source of blood supply to the parathyroids.
   - Thyroid ima artery is present in a small group of population and has a variable origin (may be a branch of arch of aorta, subclavian artery, common carotid artery).
7. **c. Brachiocephalic vein**
   - Superior and middle thyroid veins drain into the internal jugular vein and the inferior thyroid vein drain into the brachiocephalic vein.
8. **b. Cricoid cartilage**
   - The ligament of Berry is the superior suspensory ligament of the thyroid gland located adjacent to the cricoid cartilage on the posterior surface of the thyroid gland.

9. c. Deep cervical nodes

- The upper group of lymphatics follow superior thyroid artery and lower lymphatics follow the inferior thyroid arteries and ultimately drain into upper and lower deep cervical lymph nodes.

10. c. 3rd

- Superior parathyroid gland develops in 4th pharyngeal pouch and inferior in the third.

Deep Structures in the Neck

TM Joint

- **Temporomandibular joint** is a bicondylar synovial joint. Some authors consider it as a combined gliding and hinge type of the synovial joint (ginglymoid–diarthrodial compound synovial joint).
- The articular surfaces of the bones are covered by fibrocartilage (not hyaline), hence it is considered as atypical synovial joint.
- It has two (superior and inferior) synovial cavities divided by an articular disk.
  - There is an upper gliding joint between the articular tubercle and mandibular fossa above and the articular disk below where forward gliding (protrusion) and backward gliding (retraction/translation) take place.
  - The lower hinge joint is between the disk and the mandibular head (condyle) where elevation (closing) and depression (opening) of the jaw take place. During yawning, the disk and the head of the mandible glide across the articular tubercle.

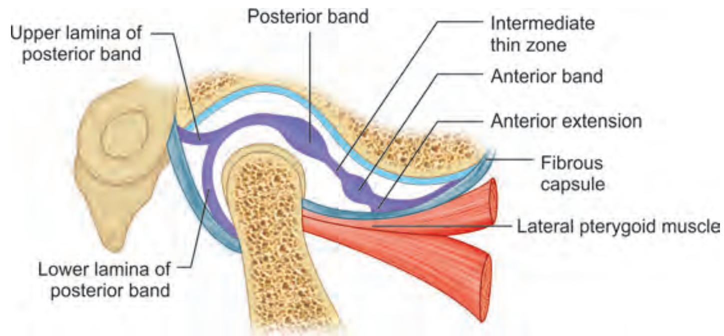
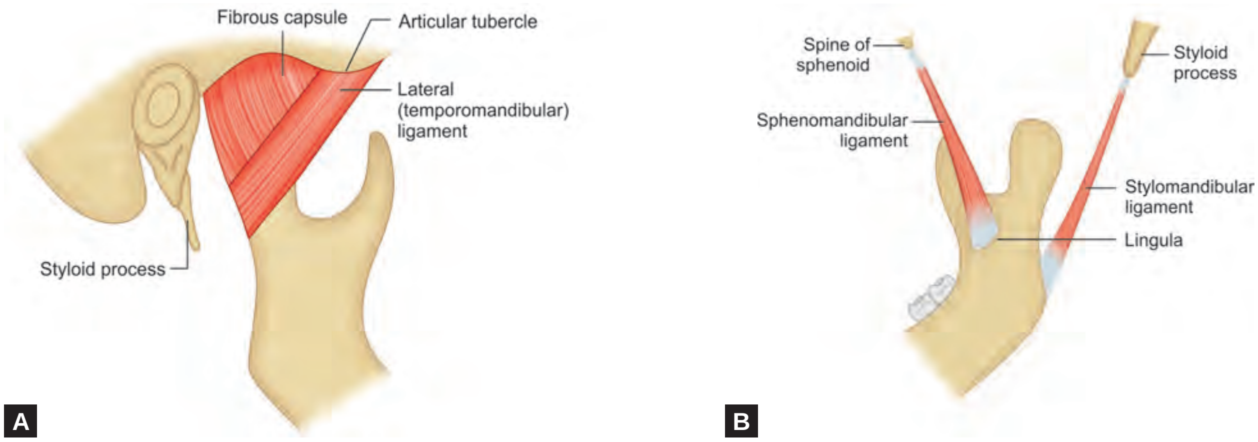


Fig. 246: Parts of the intra-articular disc.

- TM joint has an **articular capsule** that extends from the articular tubercle and the margins of the mandibular fossa to the neck of the mandible.
- It is reinforced by the **lateral (temporomandibular) ligament**, which extends from the tubercle on the zygoma to the neck of the mandible, and the **sphenomandibular ligament**, which extends from the spine of the sphenoid bone to the lingula of the mandible.
- **Stylomandibular ligament** extends from the styloid process to the posterior border of the ramus of the mandible, near the angle of the mandible, separating the parotid from the submandibular gland.
- Pterygomandibular raphe is a ligamentous band between the buccinator muscle and the superior pharyngeal constrictor, extends between the pterygoid hamulus superiorly and the posterior end of the mylohyoid line of the mandible inferiorly.



Figs. 247A and B: Ligaments of the temporomandibular joint: (A) fibrous capcule and lateral ligament; (B) accessory ligaments.

- TM joint is innervated by the auriculotemporal and masseteric branches of the mandibular nerve.
- The arterial supply is by the superficial temporal, maxillary (middle meningeal and anterior tympanic branches), and ascending pharyngeal arteries.

Movements of temporomandibular joint.	
Movements of mandible	**Muscle(s)**
Elevation (close mouth)	Temporalis, masseter, and medial pterygoid
Depression (open mouth)	Lateral pterygoid, suprahyoid, and infrahydoid muscles[a]
Protrusion (protrude chin)	Lateral pterygoid, masseter, and medial pterygoid[b]
Retrusion (retrude chin)	Temporalis (posterior oblique and near horizontal fibers) and masseter
Lateral movements (grinding and chewing)	Temporalis of same side, pterygoids of opposite side, and masseter

[a] The prime mover is normally gravity; these muscles are mainly active against resistance.
[b] The lateral pterygoid is the prime mover here, with minor secondary roles played by the masseter and medial pterygoid.

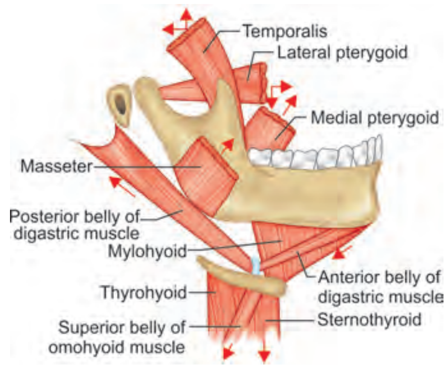


Fig. 248: Muscles of mastication producing movements of the temporomandibular joint. The arrows indicate the direction of their actions. Chief muscles of mastication are labelled in bold.

Clinical Correlations

- Dislocation of the temporomandibular joint occurs anteriorly as the mandible head glides across the articular tubercle during yawning and laughing.
- Upper fibers of lateral pterygoid muscles insert onto anterior aspect of articular disc as well as on to the head of mandible; spasms of this muscle in activities like yawning can result in dislocation of mandible by pulling the disc anterior to the articular tubercle.

Muscles Acting on TM Joint

Muscles acting on mandible/temporomandibular joint.

Muscles of mastication:

Temporalis	Triangular muscle with broad attachment to floor of temporal fossa and deep surface of temporal fascia	Narrow attachment to tip and medial surface of coronoid process and anterior border of ramus of mandible		Via deep temporal branches	Elevates mandible, closing jaws; posterior, more horizontal fibers are 1° rectractors of mandible
Masseter	Quadrate muscle attaching to inferior border and medial surface of maxillary process of zygomatic bone and the zygomatic arch	Angle and lateral surface of ramus of mandible	Anterior trunk of mandibular nerve (CN V_3)	Via masseteric nerve	Elevates mandible, closing jaws; superficial fibers make limited contribution to protrusion of mandible
Lateral pterygoid	Triangular two-headed muscle from (1) infratemporal surface and crest of greater wing of sphenoid and (2) lateral surface of lateral pterygoid plate	Superiod head attaches primarily to joint capsule and articular disc of TMJ; inferior head attaches primarily to pterygoid fovea on anteromedial aspect of neck of condyloid process of mandible		Via lateral pterygoid nerve	Acting bilaterally, protracts mandible and depresses chin; acting unilaterally, swings jaw toward contralateral side; alternate unilateral contraction produces larger lateral chewing movements

Medial pterygoid	Quadrangular two-headed muscle from (1) medial surface of lateral pterygoid plate and pyramidal process of palatine bone and (2) tuberosity of maxilla	Medial surface of ramus of mandible, inferior to mandibular foramen; in essence, a mirror image of ipsilateral masseter, two muscles flanking ramus	Anterior trunk of mandibular nerve (CN V_3)	Via medial pterygoid nerve	Acts synergistically with masseter to elevate mandible; contributes to protrusion; alternate unilateral activity produces smaller grinding movements
Suprahyoid muscles:					
Digastric	Base of cranium		Facial and mandibular nerves		Depresses mandible against resistance when infrahyoid muscles fix or depress hyoid bone
Stylohyoid	Styloid process		Facial nerve		
Mylohyoid	Medial body of mandible	Hyoid bone	Mandibular nerve		
Geniohyoid	Anterior body of mandible		Nerve to geniohyoid (C1-C2)		
Infrahyoid muscles:					
Omohyoid	Scapula	Hyoid bone	Ansa cervicalis from cervical plexus (C1-C3)		Fixes or depresses hyoid bone
Sternohyoid	Manubrium of sternum				
Sternothyroid		Thyroid cartilage			
Thyrohyoid	Thyroid cartilage	Hyoid bone	C1 (via hypoglossal n.–CN XII)		
Muscle of facial expression:					
Platysma	Subcutaneous tissue of infraclavicular and supraclavicula regions	Base of mandible, skin of cheek and lower lip, angle of mouth (modiolus), and orbicularis oris	Cervical branch of facial nerve (CN VII)		Depresses mandible against resistance

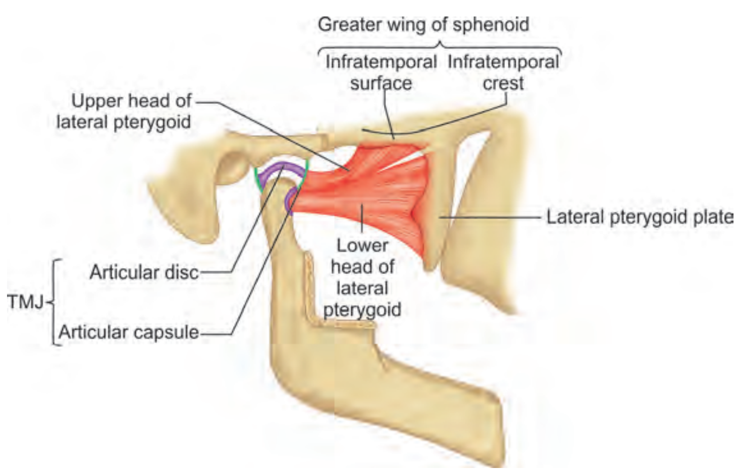


Fig. 249: Origin and insertion of the lateral pterygoid muscle.

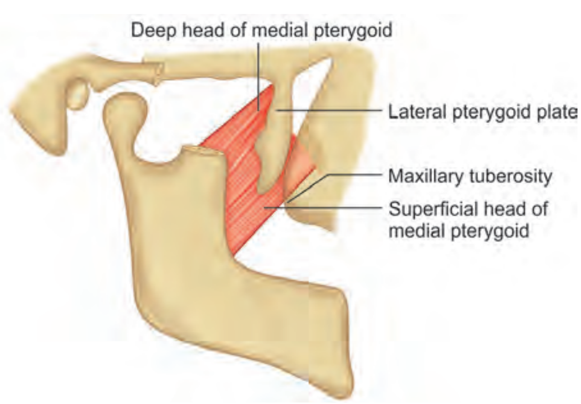


Fig. 250: Origin and insertion of the medial pterygoid muscle.

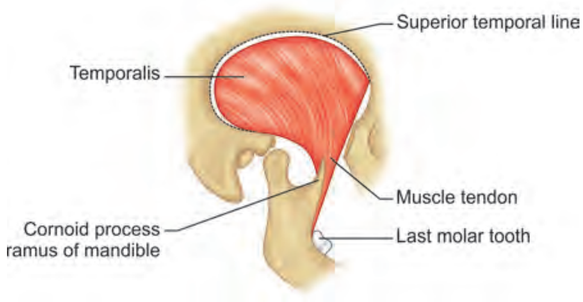


Fig. 251: Origin and insertion of the temporalis muscle.

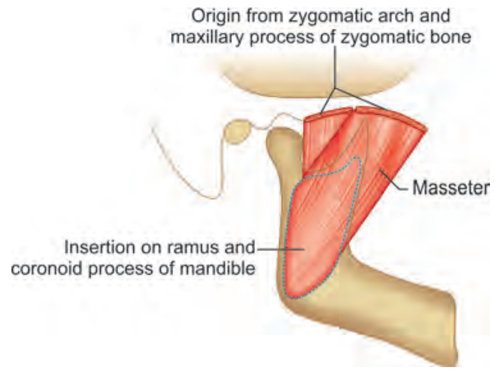


Fig. 252: Origin and insertion of the masseter muscle.

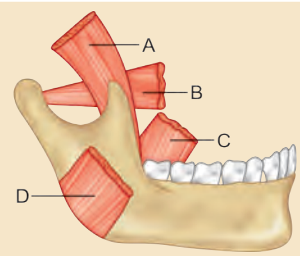
ASSESSMENT QUESTIONS

1. **A person having difficulty in opening in mouth but not in closing the mouth. Which of the following statement is correct about concerned muscle:** *(PGIC 2013)*
   a. Origin from lateral pterygoid plate
   b. Origin from medial pterygoid plate
   c. Insertion to anterior margin of articular disc
   d. Supplied by mandibular nerve
   e. Depress mandible while opening it

2. **Following are the TM Joint ligaments EXCEPT:** *(NEET Pattern 2014)*
   a. Stylomandibular
   b. Temporomandibular
   c. Tympanomandibular
   d. Sphenomandibular

3. **Muscle which opens mouth is:** *(NEET Pattern 2012, 14)*
   a. Lateral pterygoid
   b. Medial pterygoid
   c. Masseter
   d. Temporalis

4. **Identify muscle causing protrusion of mandible in the diagram:** *(AIIMS 2015)*
   a. A
   b. B
   c. C
   d. D



5. **In dislocation of the jaw, displacement of the articular disc beyond the articular tubercle of the temporomandibular joint results from spasm or excessive contraction of the following muscle:** *(AIIMS 2003)*
   a. Buccinator
   b. Lateral pterygoid
   c. Masseter
   d. Temporalis

6. **In temporomandibular joint least vascularity is seen in which of the following:** *(AIIMS 2002)*
   a. Articular cartilage
   b. Anterior part of articular disc
   c. Posterior part of articular disc
   d. Central part of articular disc

ANSWERS WITH EXPLANATIONS

1. **a. Origin from lateral pterygoid plate; c. Insertion to anterior margin of articular disc; d. Supplied by mandibular nerve; e. Depress mandible while opening it**
   - Lateral pterygoid muscle takes its origin from lateral pterygoid plate and inserts into the pterygoid fovea on the neck of mandible along with the anterior margin of articular disc.
   - Lateral pterygoid is supplied by the mandibular nerve and causes protrusion and depression of mandible, helping to open the mouth.
   - Elevation of mandible is brought about by the contraction of MTM (Masseter, Temporalis and Medial pterygoid) muscles.
   - Depression is carried out by digastric, geniohyoid and the mylohyoid muscles along with the lateral pterygoids.

2. **c. Tympanomandibular**
   - TM joint has a capsular ligament strengthened by temporomandibular, sphenomandibular, and stylomandibular ligaments.

3. **a. Lateral pterygoid**
   - MTM (Masseter, Temporalis, Medial pterygoid) are elevators of mandible, to close the mouth.
   - Lateral pterygoid is depressor of mandible to open the mouth.

4. **b. Lateral pterygoid**
   - **Lateral pterygoid muscle** causes protrusion of mandible bone.
   - **Lateral pterygoid** muscle inserts into the *pterygoid fovea* on the neck of mandible and pulls mandible forward and down (**protrusion and depression**) to help open the mouth.
   - **MTM (Masseter, temporalis and medial pterygoid)** muscles are elevators of mandible**, whereas, lateral pterygoid is a depressor.**

5. b. Lateral pterygoid
- Lateral pterygoid muscles acting bilaterally protract and depress the jaw for opening of mouth.
- Since its upper fibers insert onto anterior aspect of articular disc as well as on to the head of mandible; spasms of this muscle in activities like yawning can result in dislocation of mandible by pulling the disc anterior to the articular tubercle.

6. d. Central part of articular disc
- In sagittal section the articular disc has three distinct parts: an anterior band, a thinner intermediate zone and a posterior band.
- The central part of the disc itself is avascular and not innervated.

ASSESSMENT QUESTIONS

1. Which of the following doesn't have the same neural pathway:
a. Accommodation and ciliary nerves
b. Salivatory nucleus and lacrimation
c. Lateral geniculate body and auditory pathway
d. Greater petrosal nerve and gustatory pathway

2. Buccinator muscle is pierced by all EXCEPT: *(AIIMS 2008, 15)*
a. Buccal branch of facial nerve/artery
b. Mucus gland of buccopharyngeal fascia
c. Parotid duct
d. Buccal branch of mandibular nerve

3. The smallest cranial nerve is the: *(NEET Pattern 2014)*
a. Olfactory
b. Oculomotor
c. Trochlear
d. Accessory

4. Which of the following is a WRONG pair regarding features of cranial nerves
a. Most commonly involved in basal skull fracture: Facial nerve
b. Most commonly involved in raised intracranial tension: Abducent nerve
c. Most commonly affected in spinal anesthesia: Abducent nerve
d. Most commonly involved in intracranial aneurysm: Optic nerve

5. Choose the INCORRECT statement about cranial nerves:
a. Abducent has the longest intracranial course
b. Trochlear shows internal decussation
c. Olfactory is the shortest
d. Vagus has largest distribution

ANSWERS WITH EXPLANATIONS

1. c. Lateral geniculate body and auditory pathway
- **Lateral** geniculate body is for **Light** (visual) pathway and **Medial** geniculate body for **Music** (auditory pathway). Mnemonic: **L-L & M-M.**
- **Auditory pathway:** Organ of Corti (inner ear) → cochlear (spiral) ganglion & nerve → cochlear nuclei → trapezoid body → superior olivary nucleus → lateral lemniscus → inferior colliculus → **medial geniculate body** → sublentiform fibres of internal capsule → auditory cortex (41, 42 Brodmann area)
- **Visual pathway:** Optic nerve → optic tract → **lateral geniculate body** → optic (Geniculocalcarine) tract → occipital/striate visual cortex (17, 18, 19 Brodmann area).
- **Gustatory pathway:** Gustatory (taste) pathway from palate is carried by **greater petrosal (facial) nerve** → **geniculate ganglion** → **nucleus tractus solitarius** → medial lemniscus → VPM thalamus → Genu of internal capsule → gustatory cortex (43, Brodmann area).
- **Accommodation pathway:** Optic nerve → Lateral geniculate body → visual cortex (17 & 19) → Frontal eye field (8) → Edinger Westphal nucleus → Ciliary ganglion → short ciliary nerves → Ciliary muscle
- **Lacrimatory pathway:** Superior **salivatory nucleus** → facial nerve → pterygopalatine ganglion → maxillary & ophthalmic nerve (trigeminal) → **lacrimal gland.**

2. d. Buccal branch of facial nerve
- Buccal branch of facial nerve supplies buccinator but doesn't pierce it.
- Buccinator muscle is 'not' pierced by buccal branch of facial nerve (or artery).
- Buccal branch of mandibular nerve does pierce the buccinator muscle and supplies proprioceptive fibres to it. It passes between the two heads of lateral pterygoid and runs downwards and forwards to supply the skin and mucous membrane related to buccinator.
- Molar mucous glands of buccopharyngeal fascia pierce the buccinator muscle to reach the oral cavity.
- Parotid duct runs to the anterior border of masseter, winds round it and pierces the buccinator muscle, to enter the oral cavity. It opens into the oral vestibule opposite the upper second molar tooth.

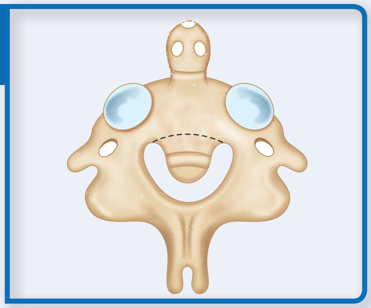
3. c. Trochlear
- The thinnest, slimmest and the smallest cranial nerve is trochlear nerve.

4. d. Most commonly involved in intracranial aneurysm: Optic nerve
- Most commonly involved in intracranial aneurysm is occulomotor nerve

5. a. Abducent has the longest intracranial course
- Trochlear nerve has the longest intracranial course.

CHAPTER 6

Back



Surface Marking

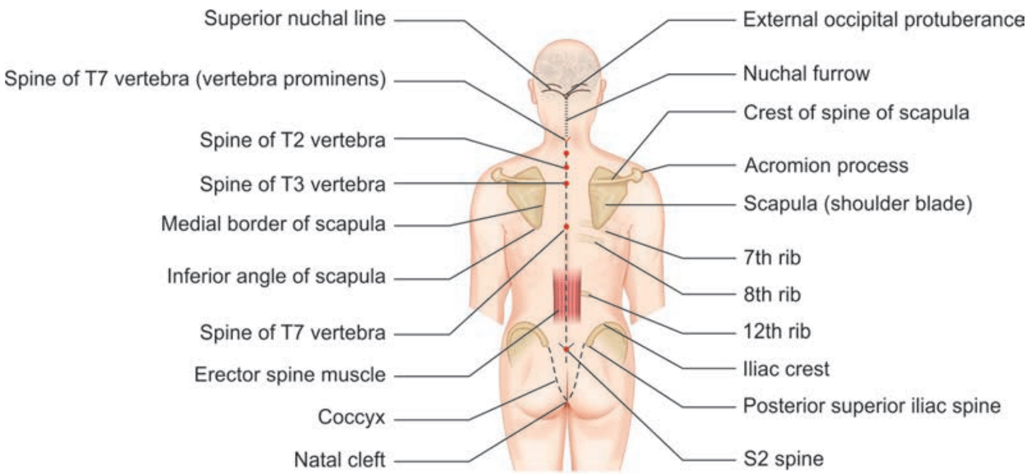
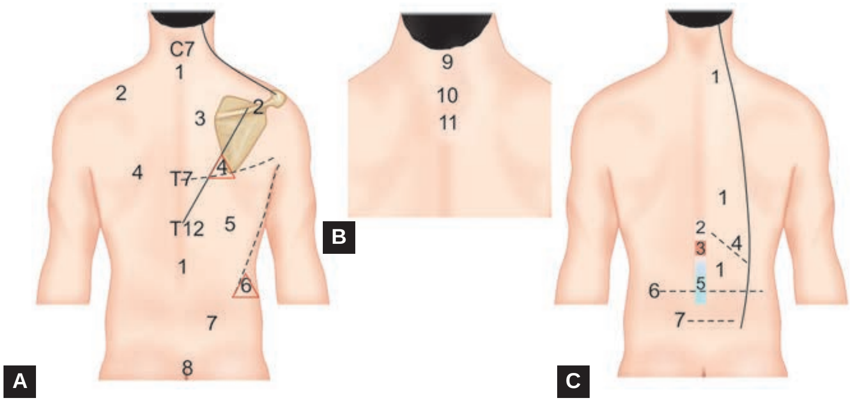


Fig. 1: Surface landmarks on the back of the body. Please correlate with Table 6.1.



Figs. 2A to C: The surface anatomy of the back. Key: A, 1, median furrow; 2, spine of scapula; 3, trapezius (between solid black lines); 4, triangle of auscultation; 5, latissimus dorsi (between dashed black lines); 6, lumbar (Petit's) triangle; 7, posterior superior iliac spine; 8, superior part of natal cleft (approximates S3). B, 9, ligamentum nuchae; 10, spinous process of C7 (vertebra prominens); 11, spinous process of T1. C, 1, erector spinae (black line represents lateral border); 2, zone of spinal cord termination (white); ranges from the middle third of T11 to the middle third of L3; 3, mean level of spinal cord termination (red): middle third of L1 vertebral body which corresponds with the lower part of the interspinous space between T12 and L1; 4, rib 12 (dashed black line); 5 zone of supracristal plane intersection with vertebral column (blue): ranges from the L2–L3 junction to the L4–L5 junction/interspinous space; 6, highest point of iliac crest and supracristal plane (Tuffier's line): almost always intersects the vertebral column from L4 to the L4/5 junction; 7, posterior superior iliac spine and interspinous plane, marked by a skin indentation (dimple of Venus). Note the overlap between zone 5 and the zone of spinal cord termination.

The **cervical** curve is convex anteriorly **(lordosis)** and extends from the first cervical to the second thoracic vertebra; the **thoracic** curvature is concave anteriorly **(kyphosis)** and extends from the second to the twelfth thoracic vertebra; and the lumbar curvature is convex anteriorly and extends from the twelfth thoracic vertebra to the lumbosacral prominence.

- **Inion** is the point situated on the external occipital protuberance in the median plane.
- The spinous process of C2 is the first palpable midline feature, located several centimeters inferior to the inion.
- The **ligamentum nuchae** terminates inferiorly at the spine of the seventh cervical vertebra (C7, vertebra prominens), which is the most superior visible projection in this region.

- The spine of the first thoracic vertebra (T1) is palpable immediately inferior to C7 and is usually more prominent than the spine of C7.
- In the thoracic regions, tips of the thoracic spines lie opposite the body of the next lower vertebra. For example, tip of the T4 thoracic spine lies at the level of T5 vertebral body.
- **Termination of spinal cord:**
  - In adults, the spinal cord terminates, on average level with the middle third of the body of L1 (ranging from the middle third of T11 to the middle third of L3).
  - In children, the cord terminates at the lower third of the body of L1 (ranging from the lower third of T12 to the middle of L2), but may terminate as low as L3 in younger children.
- **Lumbar puncture** is done at the level of a line joining the highest point of iliac crest and supracristal plane **(Tuffier's line)**, which almost always intersects the vertebral column from L4 to the L4/5 junction (Gray's Anatomy Ed41). The spinal needle may be inserted at higher or lower levels: between the lumbar vertebrae L3/L4, L4/L5 or L5/S1 (Most of the authors).
- The inferior margin of the posterior superior iliac spines (PSIS) lies at level of the second sacral spine (ranges from the L5–S1 vertebral junction to the S2 spinous process). It serves as a useful landmark for the inferior limit of the adult dural sac.
- The **triangle of auscultation** lies between the upper border of latissimus dorsi, the lower inferolateral border of trapezius and the inferomedial border of rhomboid major; although for simplicity, the medial border of the scapula is often substituted for the latter muscle.
- The **lumbar (Petit's) triangle**, one of the sites of the rare primary lumbar hernia, lies inferiorly just lateral to the highest point of the iliac crest, between the inferolateral border of latissimus dorsi, the posterior-free border of external oblique and the iliac crest.

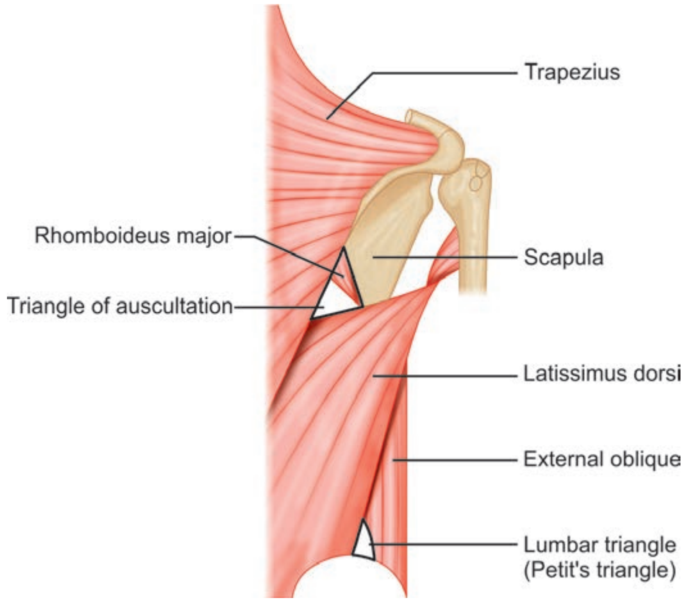


Fig. 3: Triangle of auscultation and Lumbar triangle.

Vertebral Levels

Table 6.1: Approximate levels of some spines on the back of the body

Vertebral spine	Level
T2	Superior angle of the scapula
T3	Where crest of spine of the scapula meets its medial border
T7	Inferior angle of the scapula
L4	Highest point of iliac crest
S2	Posterior-superior iliac spine

Table 6.2: Vertebral spines as landmarks for the viscera

Spine/space	Vertebral body level	Viscera
C5	C6	Cricoid cartilage; start of esophagus
C7	C7-T1	Lung apex
T3	Upper T4	Aorta reaches vertebral column, medial part of scapular spine
T3-T4 space	T4-5 disc	Sternal plane/angle of Louis
T4	Upper T5	Tracheal bifurcation; concavity of aortic arch; azygos vein—superior vena cava junction; bifurcation of pulmonary trunk; upper border of heart
T7	Upper T8	Inferior angle of scapula; lower border of heart; inferior vena cava crosses diaphragm; central tendon of diaphragm
T10	Upper T11	Lowest level of pleura; pylorus; transpyloric plane; hilum of left kidney; origin of renal arteries and superior mesenteric artery; pancrase (neck); spinal cord termination
L1-L2 space	Mid L2	Pancreas (head); duodenojejunal flexure
L2-L3 space	Mid L3	Lower border of kidney
L3-L4 space	Mid L4	Bifurcation of aorta
L4-L5 space	Mid L5	Formation of inferior vena cava

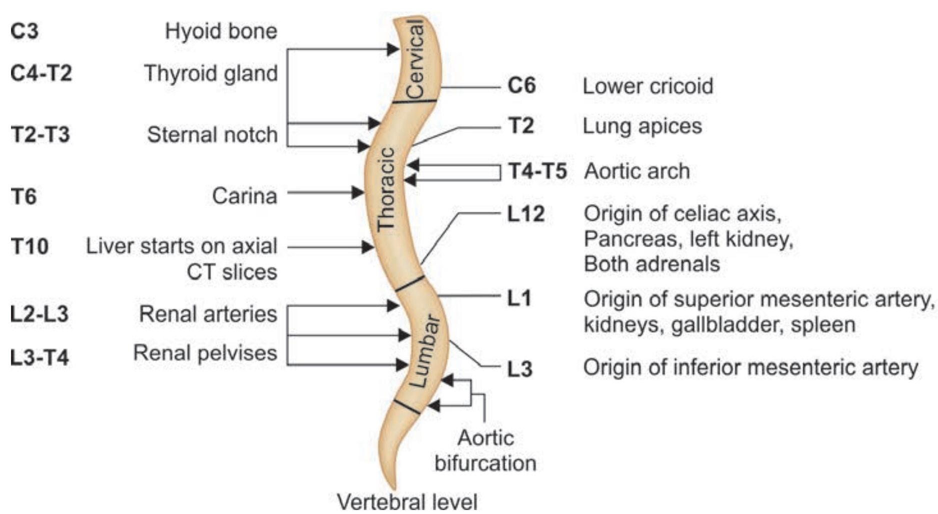


Fig. 4: Anatomical structures and the corresponding vertebral levels.

ASSESSMENT QUESTION

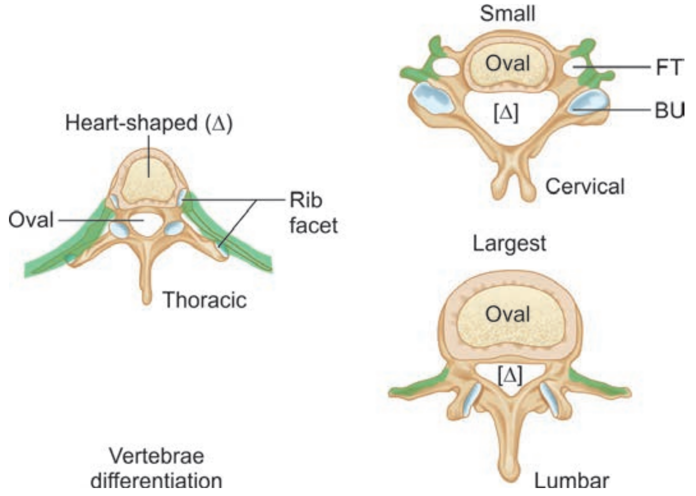
1. **All are true about vertebrae levels EXCEPT:**
   a. Heart lies at T5–8 in recumbent position
   b. Superior vena cava enters right atrium at T5
   c. Azygos vein enters SVC at T4
   d. Hemiazygos vein crosses left to right at T5

ANSWER AND EXPLANATION

1. **Hemiazygos vein crosses left to right at T5**
   - Hemiazygos vein crosses left to right at the level of T-8 vertebrae, which is also the inferior extent of heart in supine/recumbent position. IVC enters the heart at the same level after passing through the central tendon of diaphragm. Azygos vein enters the SVC at T-4 vertebra level, which then enters heart at T-5 level (superior extent of heart).

Bones

Vertebrae



Vertebrae differentiation

Table 6.3: Cervical vertebrae*	
Part	**Characteristics**
Vertebral body	Small and wider from side to side than anteroposteriorly: superior surface concave with uncus of body (uncinate process); inferior surface convex
Vertebral foramen	Large and triangular
Transverse processes	Foramina transversaria and anterior and posterior tubercles; vertebral arteries and accompanying venous and sympathetic plexuses pass through foramina transversaria of all cervical vertebrae except C7, which transmits only small accessory vertebral veins.
Articular processes	Superior facets directed superoposteriorly; inferior facets directed inferoanteriorly; obliquely placed facets are most nearly horizontal in this region
Spinous processes	Short (C3–C5) and bifid (C3–C6); process of C6 long, that of C7 is longer (thus, C7 is called 'vertebra prominens')

*The C1, C2 and C7 vertebrae are atypical.

Table 6.4: Thoracic vertebrae	
Part	**Characteristics**
Vertebral body	Heart-shaped; one or two costal facets for articulation with head of rib
Vertebral foramen	Circular and smaller than those of cervical and lumbar vertebrae (admits the distal part of a medium-sized index finger)
Transverse processes	Long and strong and extend posterolaterally; length diminishes from T1 to T12 (T1–T10 have facets for articulation with tubercle of rib)
Articular processes	Nearly vertical articular facets: superior facets directed posteriorly and slightly laterally; inferior facets directed anteriorly and slightly medially; planes of facets lie on an arc centered in the vertebral body
Spinous processes	Long; slope posteroinferiorly; tips extend to level of vertebral body below

Table 6.5: Lumbar vertebrae	
Part	**Characteristics**
Vertebral body	Massive; kidney-shaped when viewed superiorly
Vertebral foramen	Triangular; larger than in thoracic vertebrae and smaller than in cervical vertebrae
Transverse processes	Long and slender; accessory process on posterior surface of base of each process
Articular processes	Nearly vertical facets; superior facets directed posteromedially (or medially); inferior facets directed anterolaterally (or laterally); mammillary process on posterior surface of each superior articular process
Spinous processes	Short and sturdy; thick, broad, and hatchet-shaped

Table 6.6: Osteologic features of the vertebral column

	Body	Superior articular facets	Inferior articular facets	Spinous processes	Vertebral canal	Transverse processes	Comments
Atlas (C1)	None	Concave, face generally superior	Flat to slightly concave, face generally inferior	None, replaced by a small posterior tubercle	Triangular, largest of cervical region	Largest of cervical region	Two large lateral masses, joined by anterior and posterior arches
Axis (C2)	Tall with a vertical projecting dens	Flat to slightly convex, face generally superior	Flat, face anterior and inferior	Largest of cervical region, bifid	Large and triangular	Form anterior and posterior tubercles	Large superior articular processes that support the atlas and cranium
C3-C6	Wider than deep; have uncinate processes	Flat, face posterior and superior	As above	Bifid	Large and triangular	End as anterior and posterior tubercles	Considered typical cervical vertebrae
C7	Wider than deep	As above	Transition to typical thoracic vertebrae	Large and prominent, easily palpable	Triangular	Thick and prominent, may have a large anterior tubercle forming an 'extra rib'	Often called 'vertebral prominens' because of large spinous process
T2-T9	Equal width and depth Has costal demifacets for attachment of the heads of ribs 2 to 9	Flat, face mostly posterior	Flat, face mostly anterior	Long and pointed, slant inferiorly	Round, smaller than cervical	Project horizontally and slightly posterior, have costal facets for tubercles of ribs	Considered typical thoracic vertebra
T1 and T10-T12	T1 has a full costal facet for rib 1 and a partial demifacet for rib 2 T10-T12 each has a full costal facet	As above	As above	As above	As above	T10-T12 may lack costal facets	Considered 'atypical' thoracic vertebra primarily because of manner of rib attachment
L1-L5	Wider than deep, L5 is slightly wedged (i.e. higher height anteriorly than posteriorly)	Slightly concave, face medial to posterior-medial	L1-L4 slightly convex, face lateral to anterior-lateral L5: flat, faces anterior and slightly lateral	Stout and rectangular	Triangular contains cauda equina	Slender, project laterally	Superior articular processes have mammillary bodies
Sacrum	Fused Body of first sacral vertebra most evident	Flat, face posterior and slightly medial	None	None, replaced by multiple spinous tubercles	As above	None, replaced by multiple transverse tubercles	
Coccyx	Fusion of four rudimentary vertebrae	Rudimentary	Rudimentary	Rudimentary	Ends at the first coccyx	Rudimentary	

ASSESSMENT QUESTIONS

1. Difference between typical cervical & thoracic vertebra: *(AIPG 2007)*
   a. Has a triangular body
   b. Has a foramen transversarium
   c. Superior articular facet directed backwards & upwards
   d. Has a large vertebral body

2. Which of these parts of vertebral canal will show secondary curves with concavity backwards: *(AIPG 2007)*
   a. Cervical
   b. Thoracic
   c. Sacral
   d. Coccyx

3. All of the following characteristics differentiate a typical cervical vertebrae from a thoracic vertebrae EXCEPT: *(AIIMS 2007)*
   a. Has a triangular vertebral canal
   b. Has foramen transversarium
   c. Superior articular facet is directed backwards & upwards.
   d. Has a large vertebral body

ANSWERS AND EXPLANATIONS

1. b. Has a foramen transversarium
- Cervical vertebra is characterized by foramina in its transverse process—foramen transversarium.
- Cervical & lumbar vertebrae have oval bodies and are triangular in thoracic region.
- Superior articular facets are directed backwards & upwards in both the cervical as well as thoracic vertebrae.
- Cervical vertebra has a small body, the lumbar vertebra bodies are the largest.

2. a. Cervical
- Cervical curvature is a secondary curvature, with a posterior concavity.
- Secondary curvatures develop after birth-like cervical & lumbar curvatures.
- These curvatures are convex anteriorly and concave backwards.
- Primary curvatures like thoracic and sacral & coccygeal curvatures are present since birth and are concave anteriorly.

3. d. Has a large vertebral body
- Vertebral body is the smallest in the cervical region. Large vertebral body is present at the level of lumbar vertebra.
- Vertebral foramen is triangular and large in the cervical vertebra.
- The foramen is small and circular in thoracic vertebra.
- Cervical vertebrae are identified by the foramen transversarium in their transverse process.
- Superior articular facets are directed backwards & upwards in the cervical and thoracic regions.

Cervical Vertebra

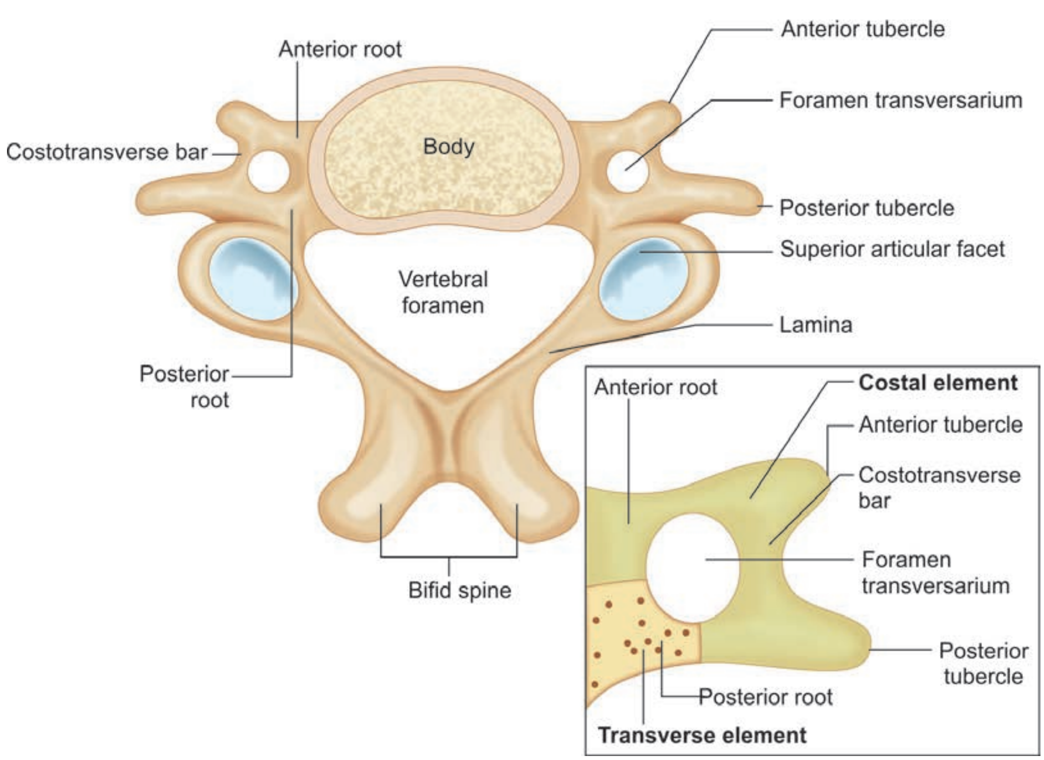
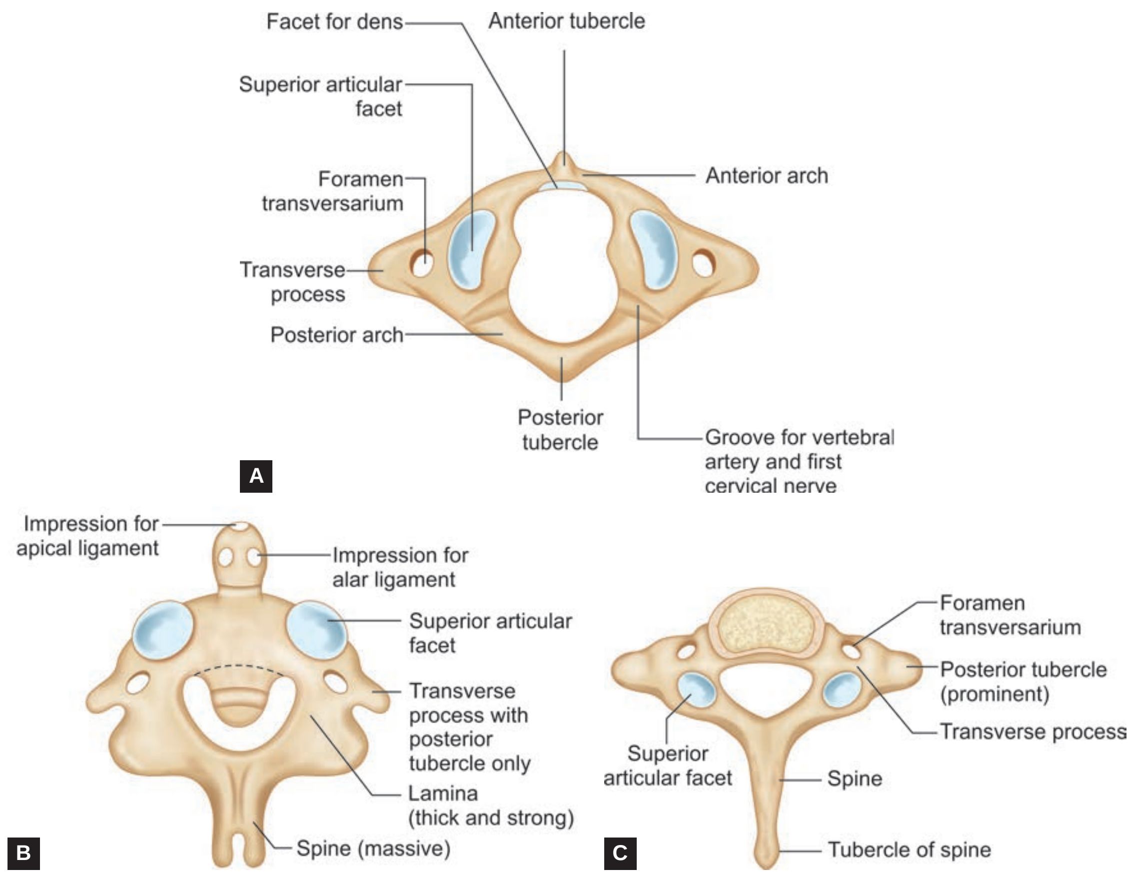
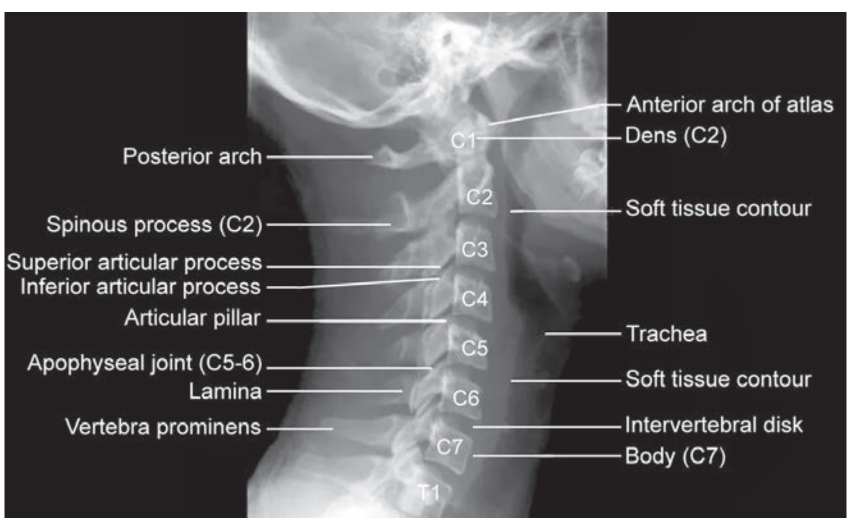


Fig. 5: Typical cervical vertebra (superior aspect); inset on the right side shows the costal and transverse elements of the transverse process.



Figs 6A to C: Atypical cervical vertebrae: (A) Atlas vertebra (superior aspect); (B) Axis vertebra (posterosuperior aspect); (C) Seventh cervical vertebra (superior aspect).

Radiology



Curvatures

The **primary curves** form during fetal development. The **secondary curves** develop after birth.

- Primary curvatures are present at birth and are due to shape of the vertebral bodies. These are thoracic and sacral and are concave forward (or convex dorsally).
- Secondary curvatures are acquired after birth consequent to changes in the posture with age and are mainly due to the shape of the intervertebral disc. These are cervical and lumbar and are convex forwards.

- The cervical curvature appears during the months of neck-holding and acquired at 4 to 5 months after birth.
- The lumbar curvature appears while the upright posture is being attained during the age of 12 to 18 months.

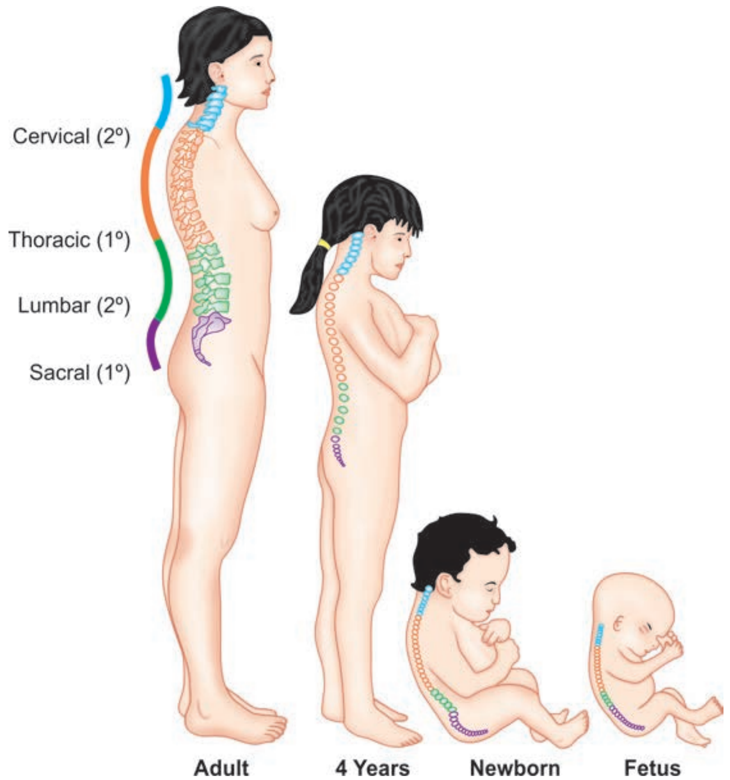


Fig. 7: Curvatures of vertebral column. The four curvatures of the adult vertebral column: cervical, thoracic, lumbar, and sacral are contrasted with the C-shaped curvature of the column during fetal life, when only the primary (1°) curvatures exist. The secondary (2°) curvatures develop during infancy and childhood.

ASSESSMENT QUESTIONS

1. **Number of vertebrae in vertebral column:** *(NEET Pattern 2013)*
   a. 25
   b. 27
   c. 29
   d. 33

2. **Which vertebral segment is numerically most constant:** *(AIIMS 2012)*
   a. Cervical
   b. Thoracic
   c. Lumbar
   d. Sacral

3. **Which of these parts of vertebral canal will show secondary curves with concavity backwards:** *(AIPG 2007)*
   a. Cervical
   b. Thoracic
   c. Sacral
   d. Coccyx

4. **Which of the following is TRUE regarding vertebral column curvature:** *(PGIC 2015)*
   a. Primary curves are concave forward
   b. Lumbar curve is primary
   c. Thoracic curve develops when infant starts walking
   d. Cervical appears when the infant starts supporting its head
   e. Lumbar curve appears when the child assumes the upright posture

5. **Typical cervical vertebrae can be differentiated from thoracic vertebra by all EXCEPT:** *(AIIMS 2012)*
   a. Triangular vertebral canal
   b. Foramen transversarium
   c. Superior articular facet directed backwards and upwards
   d. Small vertebral body

ANSWERS WITH EXPLANATIONS

1. **d. 33**
   - There are total thirty-three vertebrae, upper twenty-four are articulating and separated from each other by intervertebral discs, seven cervical vertebrae, twelve thoracic vertebrae and five lumbar vertebrae. The lower nine are fused, five in the sacrum and four in the coccyx. The number of vertebrae in a region can vary but overall the number remains the same. The number of those in the cervical region however is only rarely changed.

2. a. Cervical

- The number of vertebrae in a region can vary but overall the number remains the same. The number of those in the cervical region however is only rarely changed.

3. a. Cervical

- Secondary curvatures are acquired after birth: Cervical and lumbar, which are concave backwards.

4. a. Primary curves are concave forward; d. Cervical appears when the infant starts supporting its head

- Vertebral column has four curvatures that occur in the cervical, thoracic, lumbar, and sacral regions. The fetal thoracic and sacral kyphoses are concave anteriorly, whereas the acquired cervical and lumbar lordoses are concave posteriorly. The cervical lordosis becomes evident when an infant begins to raise (extend) the head while prone and to hold the head erect while sitting. The lumbar lordosis becomes apparent when the child learns to assume the upright posture for standing and walking.

5. c. Superior articular facet directed backwards and upwards

- Superior articular facet is directed backwards & upwards in both the cervical as well as thoracic vertebrae, and hence cannot help us to differentiate the two from each other. Thoracic vertebra is in addition directed laterally (BUL – backward/upward/lateral). The vertebral canal in cervical vertebrae is triangular, which is oval in thoracic vertebrae. Vertebral vessels (artery & vein) pass through the upper six foramina transversaria present in the cervical vertebrae. Cervical vertebrae have the smallest bodies, whereas, lumbar are the largest.

Joints

Craniovertebral Joints

Atlantooccipital Joint

- It is an ellipsoid (and condylar) synovial joint between the superior articular facets of the atlas and the occipital condyles.
- It is involved primarily in flexion, extension, and lateral flexion of the head. It helps in yes (nodding) movement.

Atlantoaxial Joints

- These are synovial joints consisting of two lateral plane joints, which are between the articular facets of the atlas and the axis, and one median pivot joint between the dens of the axis and the anterior arch of the atlas.
- They are involved in rotation of the atlas and head as a unit on the axis. This helps in 'No' movement.

Components of the Occipitoaxial Ligament (Figs 6.8 and 6.9)

- **Cruciform Ligament**
- **Transverse Ligament** runs between the lateral masses of the atlas, arching over the dens of the axis.
  - It is attached on each side to the medial surface of the lateral mass of the atlas.
  - In the median plane its fibres are prolonged: (a) upwards to the basiocciput and (b) downwards to the body of the axis, thus forming the cruciform ligament of the atlas.
  - It embraces the narrow neck of the dens and prevents its backward dislocation.
  - A synovial bursa is interposed between the transverse ligament and dens. It is said to be the large posterior part of the median atlantoaxial joint.
- **Longitudinal Ligament** extends from the dens of the axis to the anterior aspect of the foramen magnum and to the body of the axis.
- **Apical Ligament** xtends from the apex of the dens to the anterior aspect of the foramen magnum (of the occipital bone).
- **Alar Ligament** extends from the apex of the dens to the tubercle on the medial side of the occipital condyle.
  - These ligaments are very strong, called check ligaments (check excessive rotation and flexion of head).
- **Tectorial Membrane** is the upward extension of the posterior longitudinal ligament from the body of the axis to the basilar part of the occipital bone anterior to the foramen magnum.
  - It covers the posterior surface of the dens and the apical, alar, and cruciform ligaments.
  - Inferiorly, it is attached to the posterior surface of the body of the axis and superiorly to the upper surface of the basilar part of the occipital bone above the attachment of upper band of the cruciform ligament.

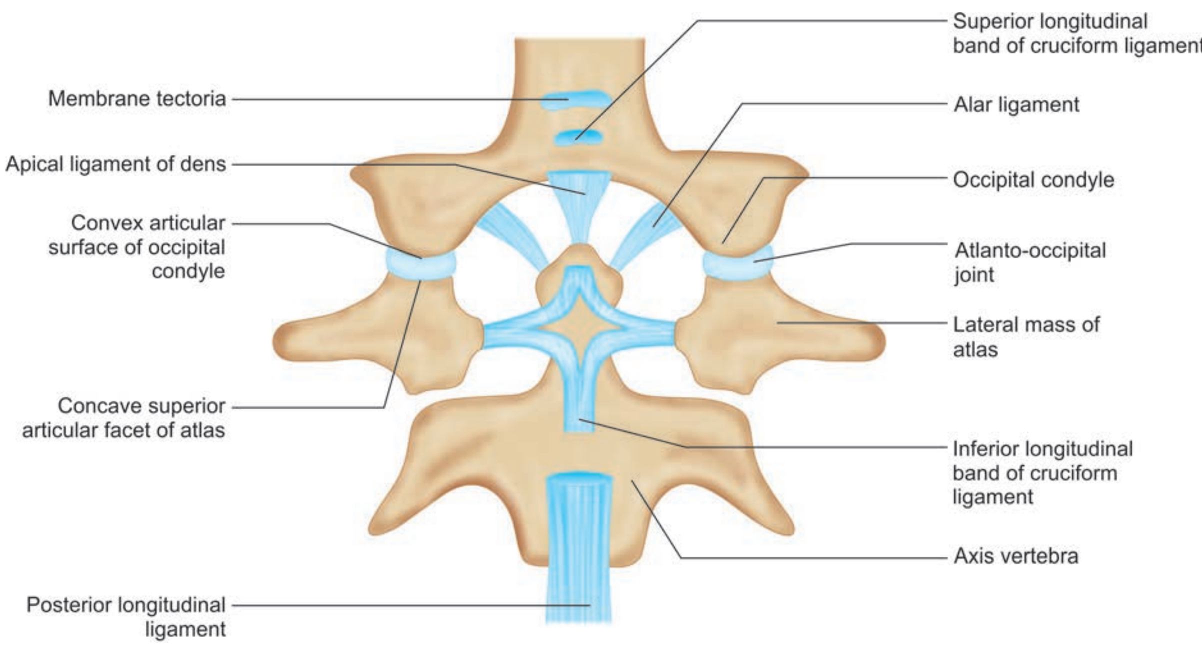


Fig. 8: Posterior view of the ligaments connecting the axis with occipital bone.

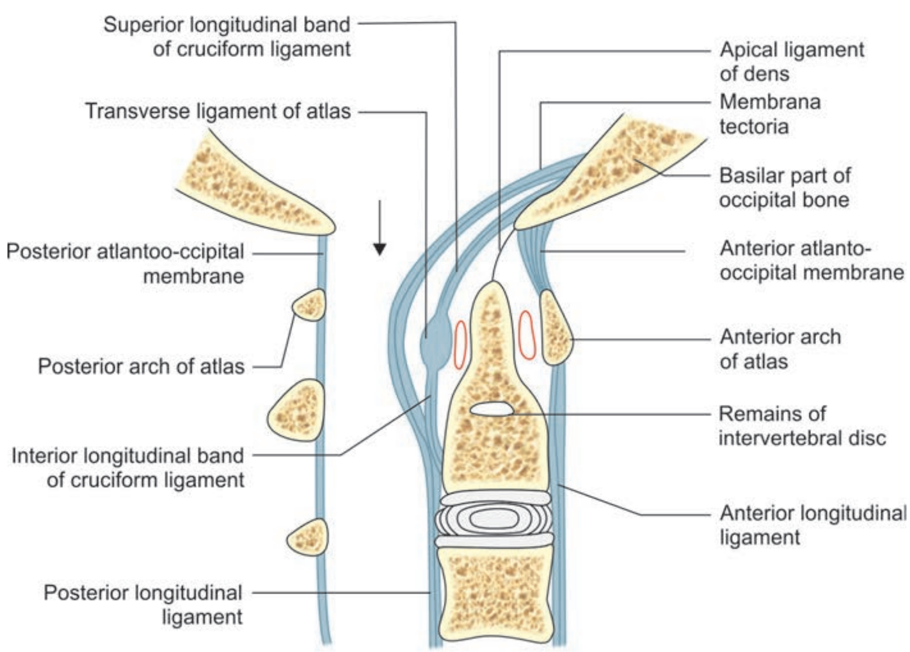


Fig. 9: Median sagittal section through the foramen magnum and 1st-3rd cervical vertebrae.

ASSESSMENT QUESTIONS

1. **The movement at the following joint permits a person to look towards the right or left:** *(AIPG 2004)*
   a. Atlanto-occipital joint
   b. Atlantoaxial joint
   c. C2-C3 joint
   d. C3-C4 joint

2. **Membrana tectoria is derived from:** *(AIIMS 2014)*
   a. Anterior atlanto-occipital membrane
   b. Posterior atlanto-occipital membrane
   c. Anterior longitudinal ligament
   d. Posterior longitudinal ligament

3. **Transverse ligament of atlas is part of:** *(AIIMS)*
   a. Cruciform ligament
   b. Ligamenta flava
   c. Anterior longitudinal ligament
   d. Posterior longitudinal ligament

4. **Cranio-vertebral joint does not include:** *(AIIMS 2015)*
   a. Atlas
   b. Axis
   c. Wings of sphenoid
   d. Basi-occiput

ANSWERS WITH EXPLANATIONS

1. **b. Atlantoaxial joint**
   - To look towards right or left ('NO' movement of head) occurs at the atlantoaxial joint. 'YES' movement occurs at the atlanto-occipital joint (B) and involves flexion & extension of head over vertebra. C2-C3 and C3-C4 joints allow mainly flexion & extension of the neck and a small degree of rotation is also possible.
2. **d. Posterior longitudinal ligament**
   - Membrana tectoria is continuation of posterior longitudinal ligament into the cranial cavity through the foramen magnum. It is attached inferiorly to the posterior surface of the body of axis and has superior attachment to the basiocciput in the cranial cavity.
3. **a. Cruciform ligament**
   - Transverse ligament forms the horizontal part of cruciform ligament.
4. **c. Wings of sphenoid**
   - Sphenoid bone has no articualtion in cranio-vertebral joints.

Movements

- Flexion, extension, lateral flexion and rotation are the movements that occur in cervical, thoracic and lumbar spine. 'Yes' (nodding) movement happens at atlanto-occipital joint and 'No' movement at atlantoaxial joint. Sacral and coccygeal spine has no movements.

Movement	Spine region
Maximum flexion	Cervical
Maximum extension	Lumbar
Maximum lateral flexion	Cervical & lumbar
Maximum rotation	Thoracic
Least rotation	Lumbar
No movements	Sacrum & coccyx

- Flexion of the vertebral column is maximum in the cervical region. Extension of the vertebral column is most marked in the lumbar region (more extensive than flexion). However, the interlocking articular processes here prevent rotation. The lumbar and cervical region intervertebral discs that are large relative to the size of the vertebral bodies, whereas thoracic region has thin intervertebral discs. Rotation is maximum in thoracic region but flexion is limited, including lateral flexion.

ASSESSMENT QUESTION

1. **The lumbar region of the vertebral column permits all the following movements EXCEPT:** *(AIPG 2003)*
   a. Flexion
   b. Extension
   c. Lateral flexion
   d. Rotation

ANSWER WITH EXPLANATION

1. **d. Rotation**
   - Lumbar region shows restricted rotation movement.

Muscles

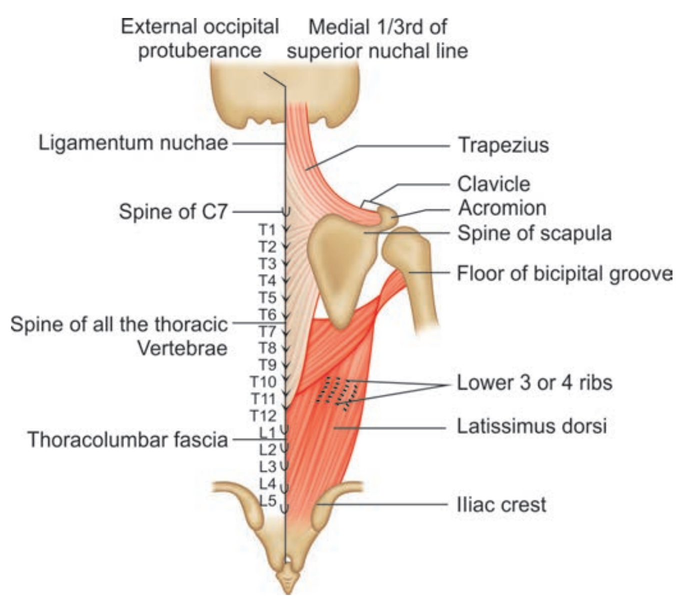


Fig. 10: Origin and insertion of the trapezius and latissimus dorsi muscles

Muscle	Proximal Attachement	Distal Attachement	Innervations	Muscle Action
superficial posterior axio-appendicular (extrinsic shoulder) muscles				
Trapezius	Medial third of superior nuchal line; external occipital protuberance; nuchal ligament; spinous processes of C7–T12 vertebrae	Lateral third of clavicle; acromion and spine of scapula	Spinal accessory nerve (CN XI) (motor fibers) and C3, C4 spinal nerves (pain and proprioceptive fibers)	Descending part elevates; ascending part depresses; and middle part (or all parts together) retracts scapula; descending and ascending parts act together to rotate glenoid cavity superiorly
Latissimus dorsi	Spinous processes of inferior 6 thoracic vertebrae, thoracolumbar fascia, iliac crest, and inferior 3 or 4 ribs	Floor of intertubercular sulcus of humerus	Thoracodorsal nerve (C6, C7, C8)	Extends, adducts, and medially rotates humerus; raises body toward arms during climbing

Table 6.7: Intermediate layer of intrinsic back muscles

Muscle	Proximal attachment	Distal attachment	Nerve supply	Main action(s)
Erector Spinae Iliocostalis Longissimus Spinalis	Arises by a broad tendon from posterior part of iliac crest, posterior surface of sacrum, sacroiliac ligaments, sacral and inferior lumbar spinous processes, and supraspinous ligament	*Iliocostalis:* Lumborum, thoracis, cervicis; fibers run superiorly to angles of low ribs and cervical transverse processes *Longissimus:* Thoracis, cervicis, capitis; fibers run superiorly to ribs between tubercles and angles to transverse processes in thoracic and cervical regions, and to mastoid process of temporal bone *Spinalis:* Thoracis, cervicis, capitis; fibers run superiorly to spinous processes in the upper thoracic region and to cranium	Posterior rami of spinal nerves	*Acting bilaterally:* Extend vertebral column and head, as back is flexed, control movement via eccentric contraction *Acting unilaterally:* Laterally flex vertebral column

Table 6.8: Suboccipital muscles and suboccipital triangle

Suboccipital Muscles

Muscle	Origin	Insertion
Rectus capitis posterior major	Spinous process of vertebra C2	Lateral part of inferior nuchal line of occipital bone
Rectus capitis posterior minor	Posterior tubercle of posterior arch of vertebra C1 (atlas)	Medial part of inferior nuchal line of occipital bone
Obliquus capitis inferior	Posterior tubercle of posterior arch of vertebra C2 (axis)	Transverse process of vertebra C1 (atlas)
Obliquus capitis superior	Transverse process of vertebra C1	Occipital bone between superior and inferior nuchal lines

Suboccipital triangle

Aspect of triangle	Structures
Superomedial boundary	Rectus capitis posterior major
Superolateral boundary	Obliquus capitis superior
Inferolateral boundary	Obliquus capitis inferior
Floor	Posterior atlanto-occipital membrane and posterior arch of vertebra C1 (atlas)
Roof	Semispinalis capitis
Contents	Vertebral artery and suboccipital nerve

Nerves

Table 6.9: Nerves of posterior cervical region, including suboccipital region/triangles

Nerve	Origin	Course	Distribution
Suboccipital	Posterior ramus of spinal nerve C1	Runs between cranium and C1 vertebra to reach suboccipital triangle	Muscles of suboccipital triangle
Greater occipital	Posterior ramus of spinal nerve C2	Emerges inferior to obliquus capitis inferior and ascends to posterior scalp	Skin over neck and occipital bone
Lesser occipital	Anterior rami of spinal nerves C2-C3	Passes directly to skin	Skin of superior posterolateral neck and scalp posterior to external ear
Posterior rami, nerves C3-C7	Posterior rami of spinal nerves C3-C7	Pass segmentally to muscles and skin	Intrinsic muscles of back and overlying skin (adjacent to vertebral column)

Table 6.10: Numbering of spinal nerves and vertebrae

Segmental level	Number of nerves	Level of exit from vertebral column
Cervical	8 (C1-C8)	Nerve C1[a] (suboccipital nerve) passes superior to arch of vertebra C1 Nerves C2-C7 pass through IV foramina superior to the corresponding vertebrae Nerve C8 passes through the IV foramen between vertebra C7 and T1
Thoracic	12 (T1-T12)	Nerves T1-L5 pass through IV foramina inferior to the corresponding vertebrae
Lumbar	5 (L1-L5)	
Sacral	5 (S1-S5)	Nerves S1-S4 branch into anterior and posterior rami within the sacrum, with the respective rami passing through the anterior and posterior sacral foramina
Coccygeal	1 (Co1)	5th sacral and coccygeal nerves pass through the sacral hiatus

[a]The first cervical nerves lack posterior roots in 50% of people, and the coccygeal nerves may be absent.
(Modified from *Barr's The Human Nervous System*).

Meningeal Spaces

Table 6.11: Spaces associated with spinal meninges

Space	Location	Contents
Epidural	Space between periosteum lining bony wall of vertebral canal and spinal dura mater	Fat (loose connective tissue); internal vertebral venous plexuses; inferior to L2 vertebra, ensheathed roots of spinal nerves
Subarachnoid (leptomeningeal)	Naturally occurring space between arachnoid mater and pia mater	CSF; radicular, segmental, medullary, and spinal arteries; veins; arachnoid trabeculae

"Although it is common to refer to a "subdural space" there is no naturally occurring space at the arachnoid-dura junction (Haines, 2006).

Filum Terminale

- The filum terminale, a filament of connective tissue, approximately 20 cm long, descends from the apex of the conus medullaris.
- Its upper 15 cm, the filum terminale internum, is continued within extensions of the dural and arachnoid meninges and reaches the caudal border of the second sacral vertebra.
- Its final 5 cm, the filum terminale externum, fuses with the investing dura mater, and then descends to the dorsum of the first coccygeal vertebral segment.
- The filum is continuous above with the spinal pia mater.
- A few strands of nerve fibers, which probably represent the roots of rudimentary second and third coccygeal spinal nerves, adhere to its upper part.
- The central canal is continued into the filum for 5–6 mm.
- A capacious part of the subarachnoid space surrounds the filum terminale internum, and is the site of election for access to the cerebrospinal fluid (CSF) via a lumbar puncture.
- The cervical enlargement, the source of the large spinal nerves that supply the upper limbs, extends from the third cervical to the second thoracic segments.
- Its maximum circumference (approximately 38 mm) is in the sixth cervical segment (a spinal cord segment provides the attachment of the rootlets of a pair of spinal nerves).

- The lumbar enlargement, the source of the large spinal nerves that supply the lower limbs, extends from the first lumbar to the third sacral segments.
- The equivalent vertebral levels are the ninth to twelfth thoracic vertebrae.
- Its greatest circumference (approximately 35 mm) is near the lower part of the body of the twelfth thoracic vertebra.

Lumbar Puncture

- A line is then taken between the highest points of the iliac crests: this line almost always intersects the vertebral column at the L4 vertebral body or L4/L5 intervertebral disc level.
- With the spines now identified, the skin is anesthetized and a needle is inserted between the spines of L3 and L4 (or L4 and L5).
- In order: subcutaneous tissue, supraspinous ligament, interspinous ligament, ligamentum flavum, epidural space containing the internal vertebral venous plexus, dura, arachnoid, and finally, the subarachnoid space.

Newborn

- The supracristal plane intersects the vertebral column slightly higher (L3–4).

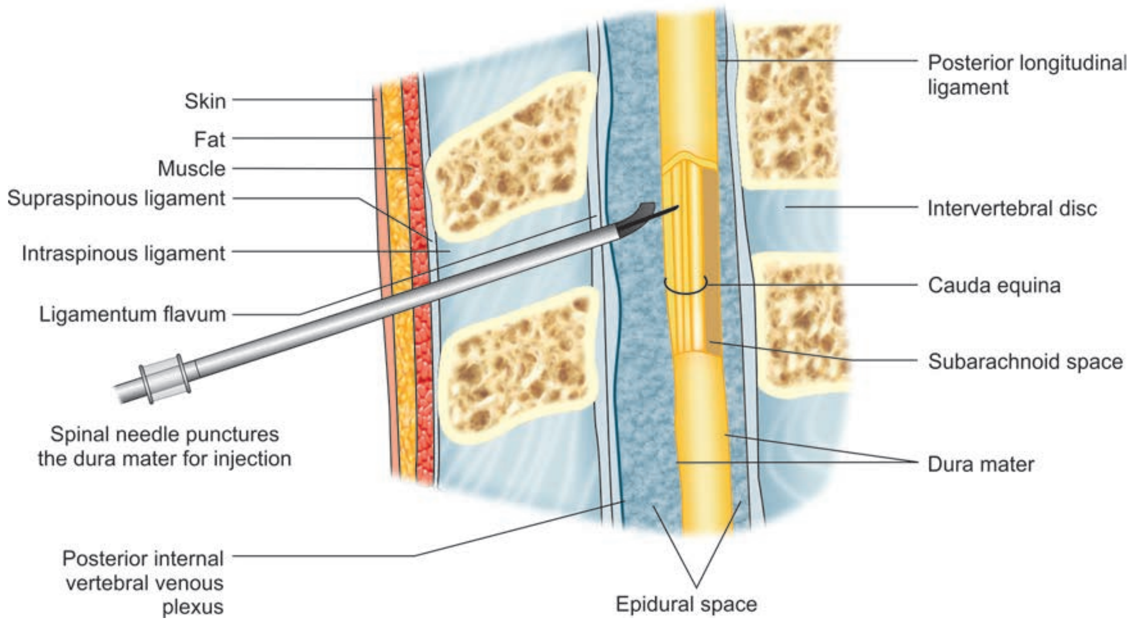


Fig. 11: Structures pierced during lumbar puncture

Structures pierced during lumbar puncture are: Skin → subcutaneous tissue → supraspinous and interspinous ligament → Ligament flavum → Dura mater → Arachnoid mater.

ASSESSMENT QUESTIONS

1. In epidural lumbar puncture, all structures are pierced EXCEPT: *(AIIMS)*
a. Posterior longitudinal ligament
b. Ligamentous flavum
c. Interspinous ligament
d. Supraspinous ligament

2. Not a boundary of Triangle of Auscultation: *(AIIMS 2008)*
a. Scapula
b. Trapezius
c. Latissimus dorsi
d. Serratus anterior

3. TRUE about boundary of triangle of auscultation is: *(NEET Pattern 2015)*
a. Lateral boundary by latissimus dorsi
b. Medial boundary by scapula
c. Lateral boundary by latissimus dorsi
d. Medial boundary by trapezius

ANSWERS WITH EXPLANATIONS

1. a. Posterior longitudinal ligament

- In lumbar puncture, posterior longitudinal ligament is not pierced

2. d. Serratus anterior

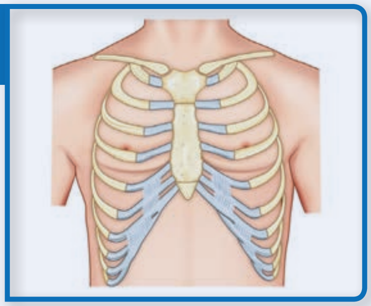
- Serratus anterior is inserted on the medial border of scapula but lies anterior to scapula. Hence, it is not in the triangle of auscultation.
- Triangle of Auscultation is bounded by 2 muscles and scapula. Superiorly – Trapezius, Inferiorly – Latissimus dorsi and Laterally – medial wall of Scapula.
- Rib 7 and Rhomboideus major lie in the floor of the triangle. Since minimal muscle fibers lie over the triangle, auscultation by stethoscope is better over this triangle, especially, the sounds of swallowed fluids. Cardiac end of the stomach lies deep to this triangle.

3. c. Lateral boundary by latissimus dorsi

- *Triangle of auscultation has trapezius (superior), latissimus dorsi (inferior) and medial wall of scapula as lateral boundary.

CHAPTER 7

Thorax



Thoracic Cavity and Apertures

- The **superior thoracic aperture** measures 5 cm anteroposteriorly and 10 cm transversely.
  - It is kidney-shaped, bounded by manubrium anteriorly, first rib laterally, and the first thoracic vertebrae posteriorly.
  - It slopes down and forwards, so that the apex of the lung extends upwards into the neck behind the anterior end of the first rib.
  - Structures that pass between the thorax and the upper limb therefore pass over the first rib and the apices of the lungs and the apical pleurae.
- **Inferior thoracic aperture** is wider in the transverse plane than in the sagittal plane and slopes obliquely inferiorly and posteriorly, so that the thoracic cavity is deeper posteriorly than anteriorly.
  - The boundaries are the xiphoid process anteriorly, twelfth thoracic vertebral body posteriorly, twelfth rib posterolaterally and anterolateral is the costal margin (distal cartilaginous ends of the seventh to tenth ribs unite and ascend to form the margin).

Table 1: Comparison of thoracic cavity as seen in transverse sections of the thorax in adult and infant

Thoracic cavity in adult	Thoracic cavity in infant
Kidney shaped	Circular
Ribs obliquely placed	Ribs horizontally placed
Transverse diameter can be increased by thoracic breathing (hence respiration is thoraco-abdominal)	Transverse diameter cannot be increased by thoracic breathing (hence respiration is purely abdominal)

Surface Marking and Landmarks

The jugular (suprasternal) notch is palpable in the midline at the superior sternal border and typically lies at the level of the junction between the 2nd (males) and 3rd (female) thoracic vertebrae.

- The horizontal sternal plane is 'traditionally' reported to pass through the intervertebral disc between the fourth and fifth thoracic vertebrae posteriorly.
- Here lies the sternal angle (of Louis), which is at the junction between manubrium and body of the sternum.
  - It indicates the level where (1) the second rib (costal cartilage) articulate with the sternum, (2) the aortic arch begins and ends, (3) the trachea bifurcates into the right and left primary bronchi, (4) bifurcation of the pulmonary trunk, (5) the site where the superior vena cava penetrates the pericardium to enter the right atrium, (6) it marks the plane of separation between the superior and inferior mediastinum (traditional concept).
- **Sternal angle** lies between the T4 (fourth thoracic vertebra) and the upper half of the T5 (fifth thoracic vertebra) in the majority of adults (Mirjalili et al 2012a).
- The trachea is a 10–11 cm long, descends from the larynx at the level of the C6 (sixth cervical vertebra) and divides into right and left principal bronchi typically inferior to the sternal plane, level with the upper half of the T6 (sixth thoracic vertebra).
- Aortic arch concavity lies at T5 vertebra (upper half); 1 cm inferior to the sternal plane.
- Bifurcation of the pulmonary trunk, level with the upper half of the sixth thoracic vertebra, approximately 3 cm inferior to the sternal angle.

Aorta

- Starting at the aortic valve, the ascending aorta curves anteriorly, superiorly and to the right, and becomes the aortic arch posterior to the right half of the manubrium at the level of the **right second costal cartilage** (T4 vertebra).
- It continues to ascend to the right side of the manubrium sterni, then arches to the left across or over the sternal plane and descends such that the aortic knuckle protrudes just to the left of the manubrium sterni around the first intercostal space and continues as descending aorta at **left second costal cartilage** (T4 vertebra).

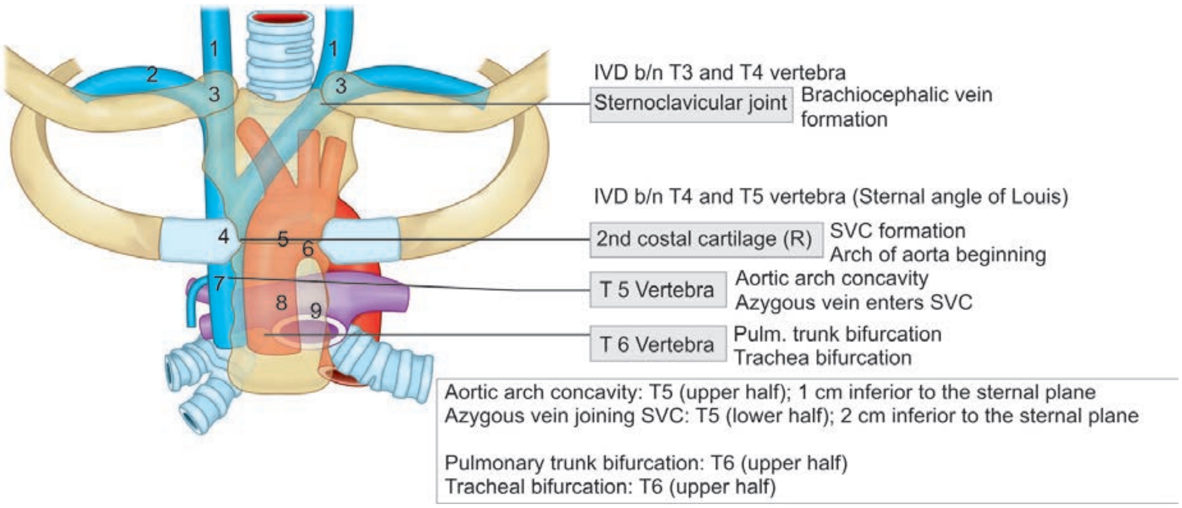


Fig. 1: Surface anatomy of the great vessels of heart and tracheobronchial tree relative to bony landmarks. Key: 1, internal jugular vein; 2, subclavian vein; 3, formation of the brachiocephalic vein posterior to the sternoclavicular joints; 4, formation of the superior vena cava; 5, manubriosternal joint, 6, concavity of the aortic arch; 7, azygos vein entering the superior vena cava; 8, tracheal bifurcation; 9, bifurcation of the pulmonary trunk.

Veins

The left and right brachiocephalic veins are formed posterior to the sternoclavicular joints; the right brachiocephalic vein descends almost vertically, whereas the left brachiocephalic vein passes obliquely posterior to the manubrium sterni.

The superior vena cava is formed at the lower border of the right 1st costal cartilage by the union of right and left brachiocephalic (innominate) veins.

It passes vertically downwards behind the right border of the sternum and pierces the pericardium at the level of the right 2nd costal cartilage, and terminates into the right atrium at the lower border of the right 3rd costal cartilage (Mnemonic: 1, 2, 3).

- Azygous vein terminate in the superior vena cava at the level of the 2nd costal cartilage (behind sternal angle).

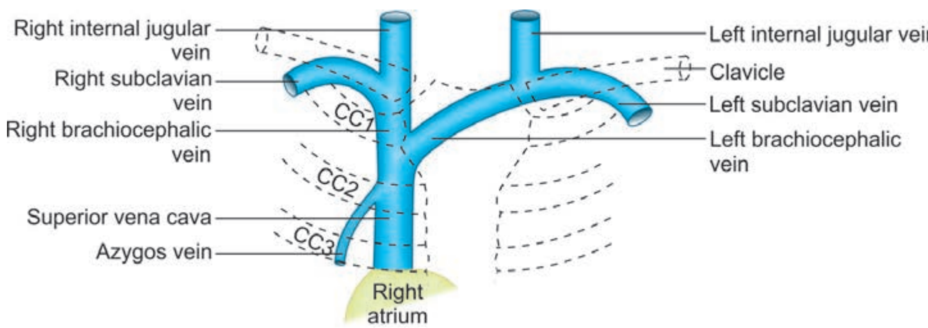


Fig. 2: Surface marking for the veins.

- CT data is different and shows that SVC forms posterior to the right second costal cartilage (or first intercostal space) and the associated part of the manubrium sterni, and joins the right atrium between the right fourth and fifth costal cartilages.
- The azygos vein enters the superior vena cava approximately 2 cm inferior to the sternal plane at the level of the lower part of the fifth thoracic vertebra.

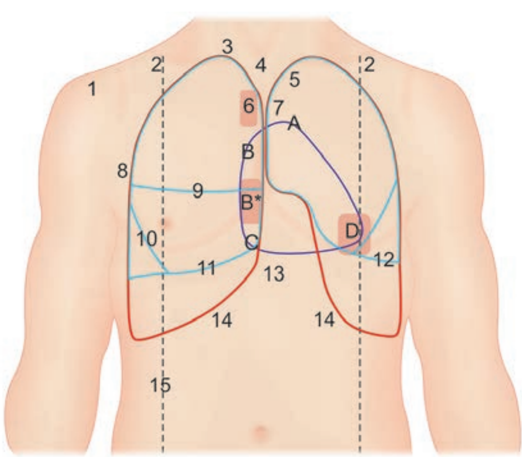


Fig. 3: Surface anatomy of the anterior thoracic region. Key: 1, right acromioclavicular joint; 2, mid-clavicular line; 3, apex of right lung, located posterior to the medial third of the clavicle; 4, sternal notch of manubrium sterni (tracheal palpation); 5, sternoclavicular joint (junction of the internal jugular and subclavian veins; formation of brachiocephalic vein); 6, zone of formation of the superior vena cava (white zone); 7, sternal angle (second costal cartilage); 8, anterior axillary fold (pectoralis major); 9, horizontal fissure; 10, right oblique fissure; 11, lower anterior border of the right lung (seventh rib in the mid-clavicular line); 12, lower anterior border of the left lung (fifth rib in the mid-clavicular line); 13, xiphisternum; 14, costal margin; 15, tenth costal cartilage, forming the lower part of the costal margin.

A–D: surface markings of the heart. A overlies the left second costal cartilage; B overlies the right third costal cartilage; B*, zone of the superior vena cava meeting the right atrium; C, right sixth costal cartilage; D, zone of location of the cardiac apex (fifth intercostal space).

The xiphisternal joint lies at the level of the T9 vertebral body, which marks the lower limit of the thoracic cavity in front, the upper surface of the liver, diaphragm, and lower border of the heart.

ASSESSMENT QUESTIONS

1. Trachea bifurcates at the vertebra level:
a. T2
b. T3
c. T4
d. T5

2. Carina is situated at which level: *(NEET Pattern 2015)*
a. T3
b. T4
c. T6
d. T9

3. Posterior to sternum is: *(NEET Pattern 2013)*
a. Left atrium
b. Left ventricle
c. Right atrium
d. Right ventricle

4. NOT true about superior vena cava: *(NEET Pattern 2015)*
a. Opens into right atrium
b. Pierces pericardium at 3rd costal cartilage
c. Enters the heart of level of 3rd costal cartilage
d. Receives azygos vein behind sternal angle

5. Arch of aorta lies at what vertebral level? *(NEET Pattern 2014)*
a. T5
b. T4
c. T6
d. T2

6. At Saint Louis angle what crosses? *(NEET Pattern 2012)*
a. Arch of aorta
b. Azygous vein
c. Common carotid artery
d. Innominate vein

ANSWERS WITH EXPLANATIONS

1. d. T5
- Trachea bifurcates at the disc between T4/5 vertebra (Most of the authors).*Trachea bifurcates at the upper border of T5 vertebra (Gray's Anatomy Ed40)
- Trachea bifurcates at the upper half of T6 vertebra (Gray's Anatomy Ed41)

2. c. T6
- **Carina** is present at the bifurcation of trachea into bronchi (T-6 vertebra level).
- The last tracheal ring merges into the incomplete rings at the origin of each principal bronchus; the bifurcation is marked by a cartilaginous spur, the carina.

3. d. Right ventricle
- The sternocostal surface of heart is majorly constituted by the **right ventricle.**

4. b. Pierces pericardium at 3rd costal cartilage
- Superior vena cava pierces pericardium at the level of right 2nd costal cartilage and enters the right atrium at 3rd costal cartilage.
- Azygous vein terminate in the superior vena cava at the level of the 2nd costal cartilage (behind sternal angle).

5. b. T4
- Arch of aorta beginning and ending is at the same level - T4 vertebra.

6. a. Arch of aorta
- At sternal angle of Louis arch of aorta begins (anteriorly) and ends (posteriorly), crosses from right to left.
- Azygous vein terminate in the superior vena cava at the same level.

Mammary Gland (Surface Marking)

Female breast extends vertically from the second or third to the sixth rib, and from the lateral sternal border medially almost to the mid-axillary line laterally.
- The tail of the breast extends towards the axilla along the inferolateral border of pectoralis major.
- In adult males, the nipple is usually sited either in the fourth intercostal space or over the fifth rib in the mid-clavicular line, approximately 20 cm from the sternal notch and mid-clavicular point.

Embryology

The lung buds are invested by **splanchnopleuric mesenchyme** derived from the medial walls of the pericardioperitoneal canals, whereas the lateral walls produce **somatopleuric mesenchyme**, which contributes to the body wall.
- In the midline, the somatopleuric mesenchyme gives rise to the **sternum** and **costal cartilages** and is penetrated by the developing **ribs**, which arise from the thoracic sclerotomes.
- The heart is formed from tissues derived from the midline **splanchnopleuric coelomic epithelium** with later contributions from **neural crest mesenchyme**.

- The splanchnopleuric **coelomic epithelium** gives rise to the myocardium, including the conduction system of the heart.
- The endocardium, including its derived cardiac mesenchymal population, which produces the valvular tissues of the heart.
- Splanchnopleuric coelomic epithelium is also the source of the epicardium, coronary arteries and interstitial fibroblasts.

Development of Heart

On approximately day 16, heart progenitor cells migrate through the primitive streak to a position cranial to the neural folds where they establish a horseshoe-shaped region in the splanchnic layer of lateral plate mesoderm called the primary heart forming regions (HFRs).

- This cardiogenic area is at the cephalic end of embryo between the septum transversum and prochordal plate.
- The intraembryonic celom lying in this area forms pericardial cavity and the splanchnopleuric mesoderm underneath the pericardial cavity forms the heart tube.

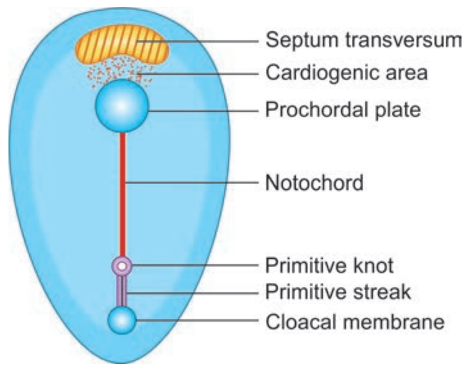
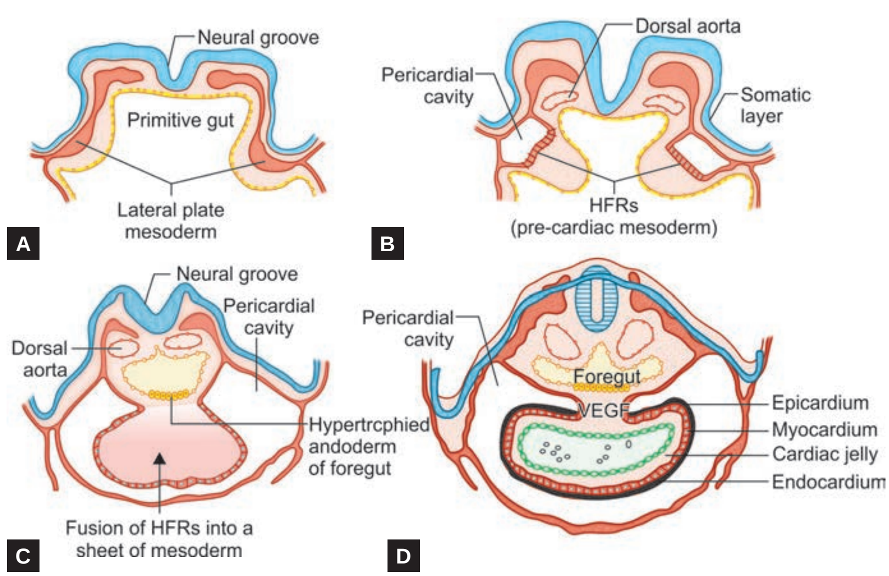


Fig. 4: Cardiogenic area.

Lateral plate mesoderm located at the cephalic area of the embryo splits into a somatic layer and splanchnic layer, thus forming the pericardial cavity.

- As lateral folding of the embryo occurs, the HFRs fuse in the midline and form a continuous sheet of mesoderm that remodel into **a single endocardial tube** (endocardium).
- Mesoderm around the endocardium forms the myocardium. The myocardial cells secrete some extracellular matrix rich in hyaluronic acid called **cardiac jelly**.
- **Cardiac jelly** a gelatinous substance secreted by cardiac myocytes, is present between the endothelium and myocardium of the embryonic heart, which transforms into the connective tissue of the endocardium.
- The extracellular matrix of the heart, historically termed **cardiac jelly**, acts as a site for the deposition of inductive factors from the myocardial cells, which, in turn, modify the differentiation of specific endocardial cells.
- It has been called a gelatinoreticulum, a myoepicardial reticulum and, more recently, the myocardial basement membrane.
- Cardiac jelly accumulates within the endocardial cushions, which are precursors cardiac valves. (**Gray's Anatomy - Ed41**)
- Mesoderm that migrates from the coelomic wall near the liver into the cardiac region forms the epicardium.



Figs. 5A to D: Schematic diagrams depict cross sections of an embryo at the level of the developing heart. (A) Formation of lateral plate mesoderm. (B) splitting of lateral plate mesoderm. (C) Fusion of heart-forming regions (HFRs) in the midline into a sheet of mesoderm. (D) Vascular endothelial growth factor (VEGF) induction of single endocardial tube. Neuroectoderm and ectoderm, blue; mesoderm, red; endoderm, yellow; epicardium, black; and endocardium, green.

Before the head fold formation, the endothelial heart tube lies in the floor of the pericardial cavity caudal to septum transversum.

- As the head fold forms, the pericardial cavity and heart tube comes to lie ventral to the foregut and cranial to the septum transversum.
- During formation of head fold, the pericardial cavity and heart tube undergoes 180° rotation and the heart tube comes to lie on the roof of the pericardial cavity.

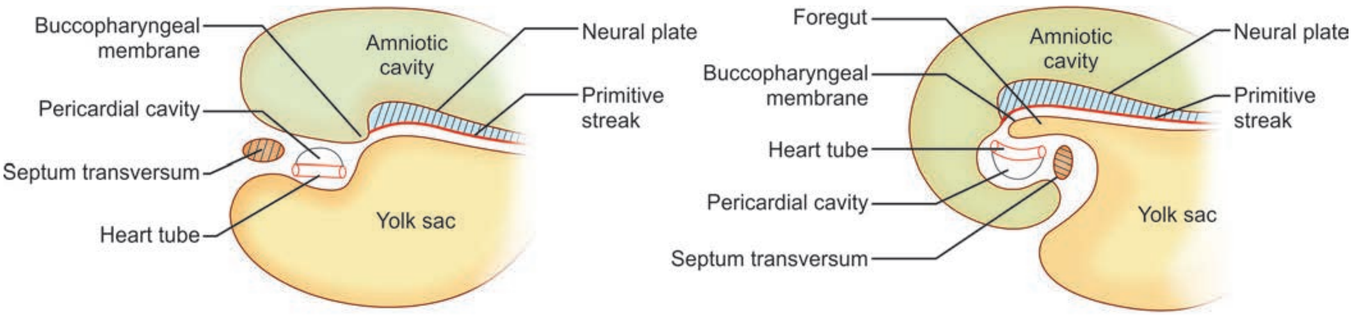
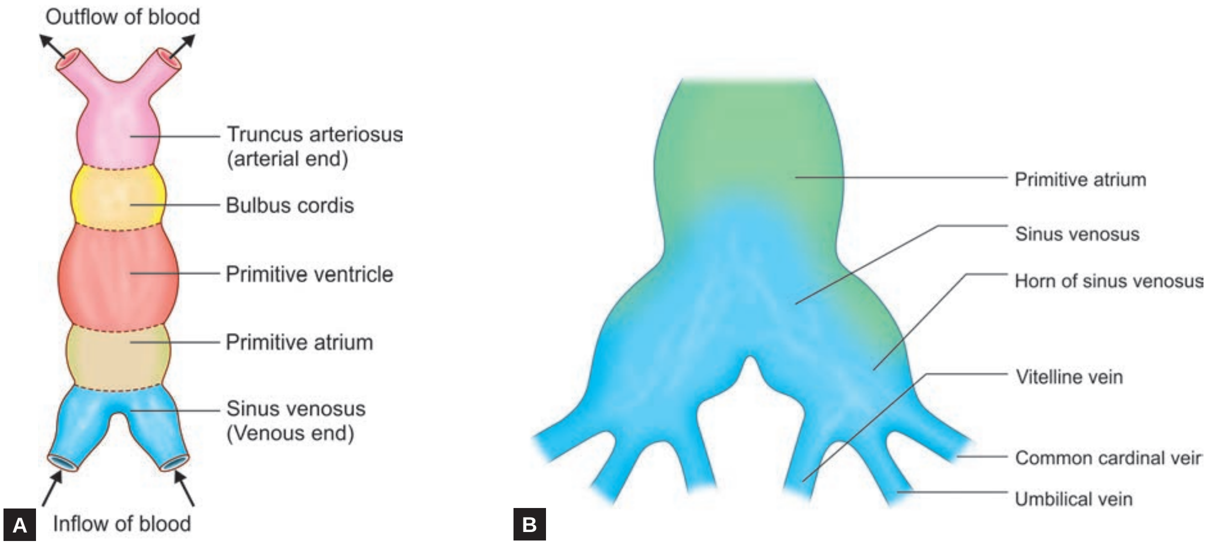


Fig. 6: Formation of head fold and inversion of pericardial cavity.

The heart beat begins at the end of the third week and beginning of fourth week of intrauterine life (day 22).

- The blood flow during the fourth week can be visualized by Doppler ultrasonography.

The heart tube develops five dilatations: sinus venosus, primitive atrium, primitive ventricle, bulbus cordis and the truncus arteriosus.



Figs. 7A and B: (A) Heart tube showing 5 subdivisions (B) Vein systems draining into sinus venosus.

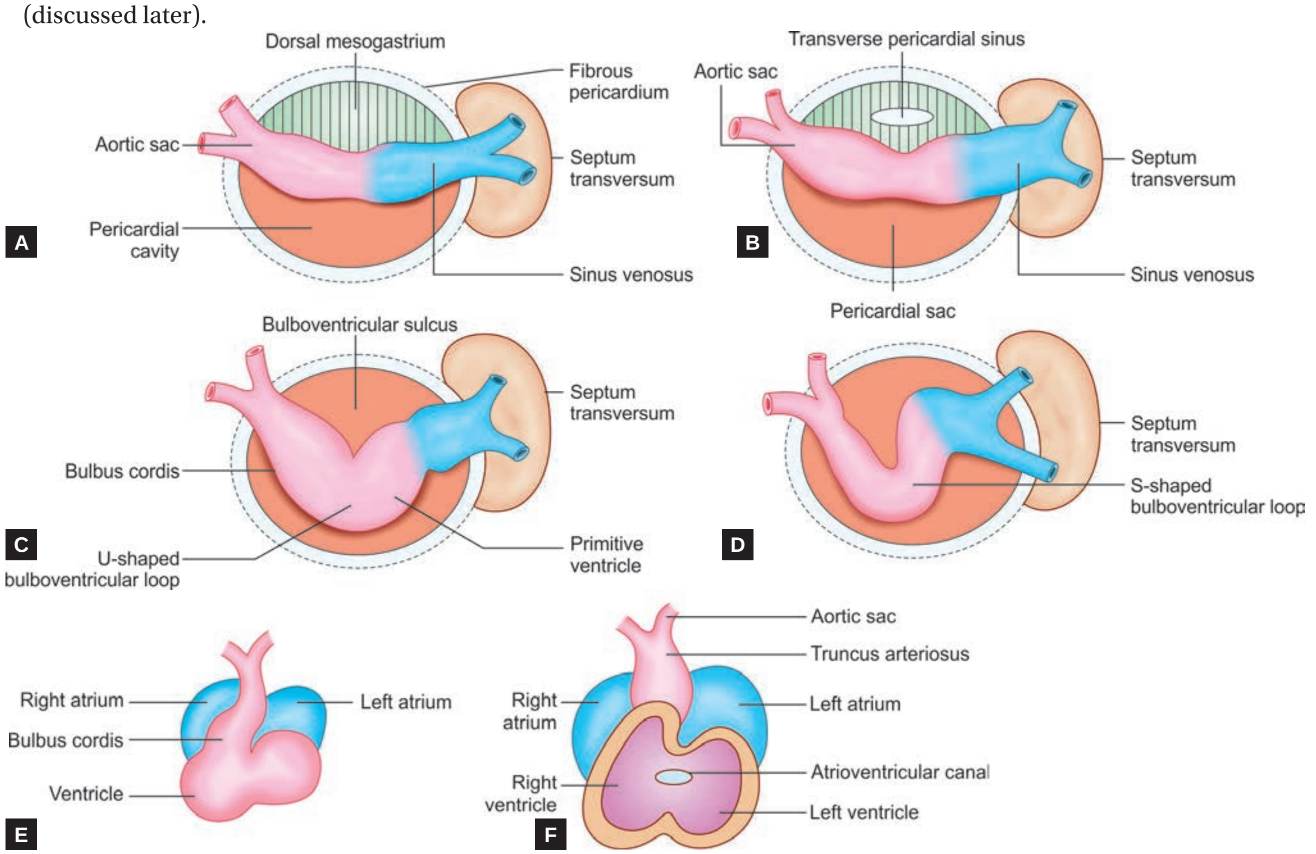
Table 2: Embryonic dilatation and their derivatives

Embryonic dilatation	Adult derivatives
1. Truncus arteriosus	Ascending aorta Pulmonary trunk
2. Bulbus cordis	Smooth upper part of the right ventricle (Conus arteriosus) Smooth upper part of the left ventricle (aortic vestibule)
3. Primitive ventricle	Trabeculated part of the right ventricle Trabeculated part of the left ventricle
4. Primitive atrium	Trabeculated part of the right atrium Trabeculated part of the left atrium
5. Sinus venosus	Smooth part of the right atrium (sinus venarum) Coronary sinus Oblique vein of the left atrium

Truncus arteriosus (ventral aorta) divides into ascending aorta and pulmonary trunk by formation of the aorticopulmonary (AP) septum.

- During the fourth week these dilations undergo dextral looping which is complete by day 28.
- The atria gradually assumes posterior location and the ventricles move into a more anterior position.

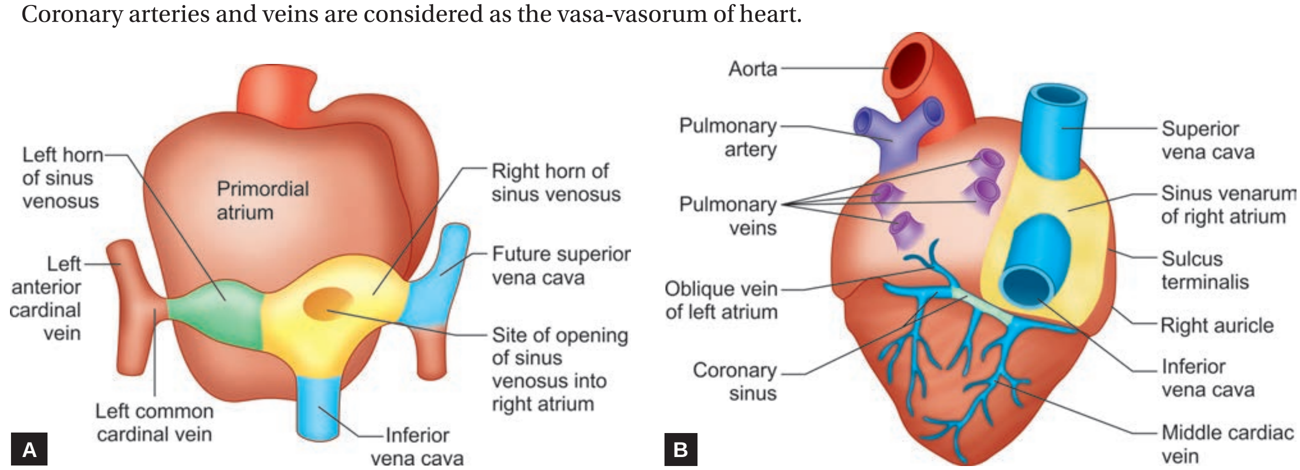
- Initially there is a dorsal mesocardium suspending the heart tube, which later develops transverse pericardial sinus (discussed later).



Figs. 8A to F: Development of the heart tube into adult components

The right horn of sinus venosus gets absorbed into the posterior aspect of primitive atrium to form the sinus venarum (posterior smooth wall of right atrium), whereas the rough anterior wall of right atrium develops from the primitive atrium anteriorly

- The sulcus terminalis is the junction of the smooth and rough (trabeculated) part of the right atrium, indicated internally by the crista terminalis.
- Crista terminalis is a vertical muscular ridge running anteriorly along the right atrial wall from the opening of the SVC to the opening of the IVC, providing the origin of the pectinate muscles.
- The left horn of sinus venosus forms the coronary sinus which opens into the posterior wall of right atrium.
- Superior vena cava and inferior vena cava develop from the cardinal veins and open into the right atrium.
- Pulmonary veins develop in the dorsal mesocardium and open into the posterior wall of left atrium.
- Coronary arteries and veins are considered as the vasa-vasorum of heart.



Figs. 9A and B: Posterior view of developing heart showing incorporation of sinus venosus into heart

The opening of sinus venosus into the primitive atrium is guarded by Left and Right Venous Valves (Fig. 10)

- Left venous valve along with septum spurium gets fused with the interatrial septum.
- The right venous valve is greatly stretched out and becomes subdivided into three parts by formation of two muscular bands: the superior and inferior limbic bands.

- Three parts of right venous valves (from above to downward) form: (a) crista terminals, (b) valve of IVC (Eustachian), and (c) valve of coronary sinus Thebesian.

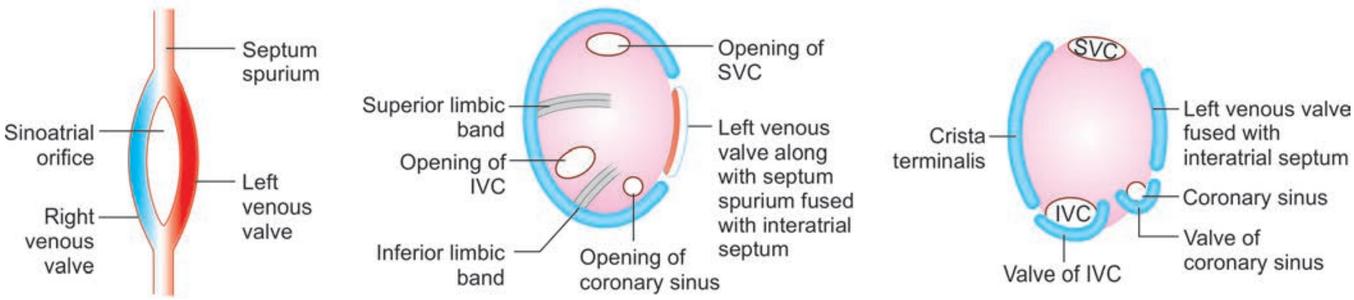


Fig. 10: Right and left venous valves and their derivatives

Inferior vena cava opening is guarded by a rudimentary semilunar valve called Eustachian valve, which develops partly from right venous valve and partly from sinus septum.

- Opening of coronary sinus has an incomplete semicircular valve called the Thebesian valve, which develops from the lower part of the right venous valve.

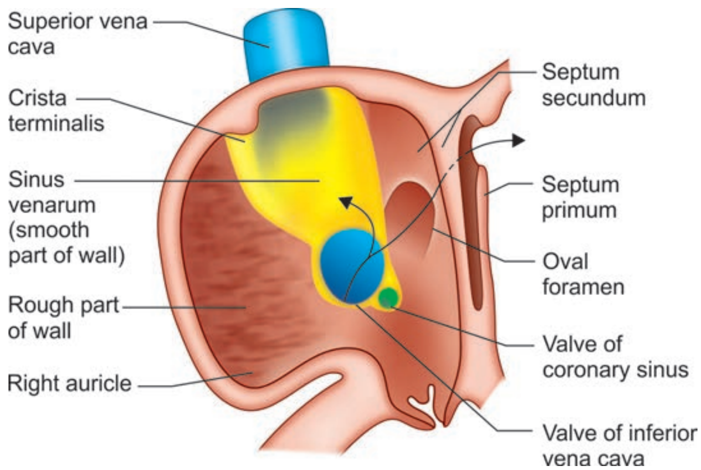


Fig. 11: Interior view of right atrium showing incorporation of sinus venosus into posterior wall

Septa Formation

Heart divides into its four chambers by formation of its septum and valves.

- Four main septa involved in dividing the heart include the AV septum ,the atrial septum, the IV septum and the AP septum.
- Septum formation in the heart in part arises from development of endocardial cushion tissue in that atrioventricular canal (atrioventricular cushions) and in the cono-truncal region (cono-truncal swellings).

AV Septum

Septum Formation in the Atrioventricular Canal.

- Four endocardial cushions surround the atrioventricular canal.
- The dorsal and ventral AV endocardial cushions fuse to form the AV septum, which divides the orifice into right and left atrioventricular canals.
- Cushion tissue then becomes fibrous and forms the mitral (bicuspid) valve on the left and the tricuspid valve on the right.

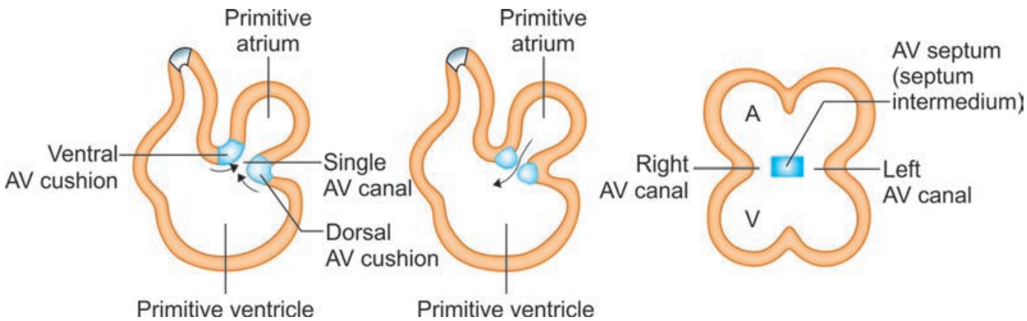


Fig. 12: Development of atrioventricular (AV) septum

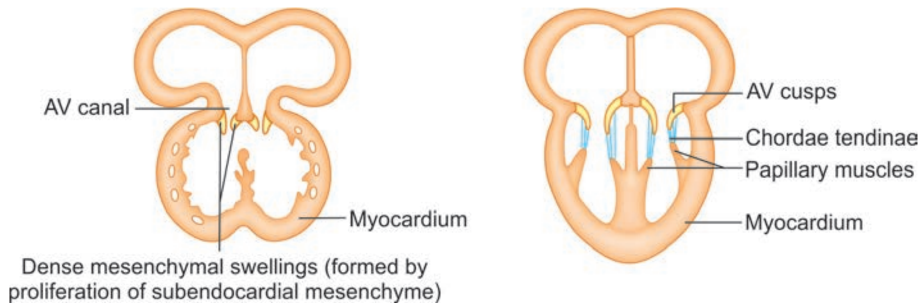


Fig. 13: Formation of atrioventricular valves.

Development of Atrium and Interatrial Septum

Atrial Development

Atrial development is dependent upon expansion of the original atrial region and incorporation of additional structures.

- On the right, the sinus venosus is incorporated and forms the smooth-walled portion of the right atrium, which is separated from the trabeculated portion by the crista terminalis.
- On the left, the pulmonary vein, which forms in the dorsal mesocardium, is positioned into the posterior wall of the left atrium when cells in the dorsal mesenchyme proliferate and accompany the septum primum as this structure grows toward the floor of the atrium.
- Later, the root of the pulmonary vein is incorporated into the left atrium by atrial expansion until the vein's four branches enter the atrium on its posterior wall. This portion constitutes the smooth-walled region of the left atrium.
- Development of the pulmonary vein begins in the midline and then shifts to the left.
- In heterotaxy the left-right patterning is disrupted and may result in variety of anomalies like total anomalous pulmonary venous return (TAPVR) in which the vein is shifted to the right and enters the right atrium (or superior vena cava/ brachiocephalic vein).

Table 3: Adult components of right and left atria and their embryonic source of development

Adult component	Embryonic sources of development
Right atrium	
• Rough trabeculated part (atrium proper) in front of crista terminalis	Primitive atrium (right half)
• Right auricle	
• Smooth part behind crista terminalis (sinus venarum)	Sinus venosus
• Crista terminalis valve of IVC and valve of coronary sinus	From right venous valve
• Most ventral smooth part	Right half of AV canal
Left atrium	
• Posterior smooth part between the openings of pulmonary veins	Absorption of pulmonary veins near the atria
• Anterior rough part and left auricle	Left half of primitive atrium
• Most ventral smooth part	Left half of the AV canal

Development of Inter-atrial Septum

- In fetal circulation, the oxygenated blood from placenta (mother) enters the right atrium and flows directly into the left atrium bypassing the lungs. (Lungs are non-functional in fetal stage).
- The primitive atrium is divided first by a septum primum, which grows down from the superior wall to the atrio-ventricular cushions.
- The septum primum is a sickle-shaped crest descending from the roof of the atrium, begins to divide the atrium in two but leaves a lumen, the ostium primum, for communication between the two sides.
- Later, when the ostium primum is obliterated by fusion of the septum primum with the endocardial cushions, the ostium secundum is formed by cell death that creates an opening in the septum primum.
- Rightward of the septum primum, a second septum secundum membrane grows down from the ventral-cranial wall toward—but not reaching—the cushions, and covering most, but not all, of the ostium secundum, resulting in a flap of the foramen ovale. Blood keep flowing from the right atrium to left continually.
- At birth, when pressure in the left atrium increases, the two septa press against each other and close the communication between the two atria, completed at around 3 months after birth.
- As the septum primum and septum secundum get fused with each other, foramen ovale in septum secundum is apposed and closed by septum primum.

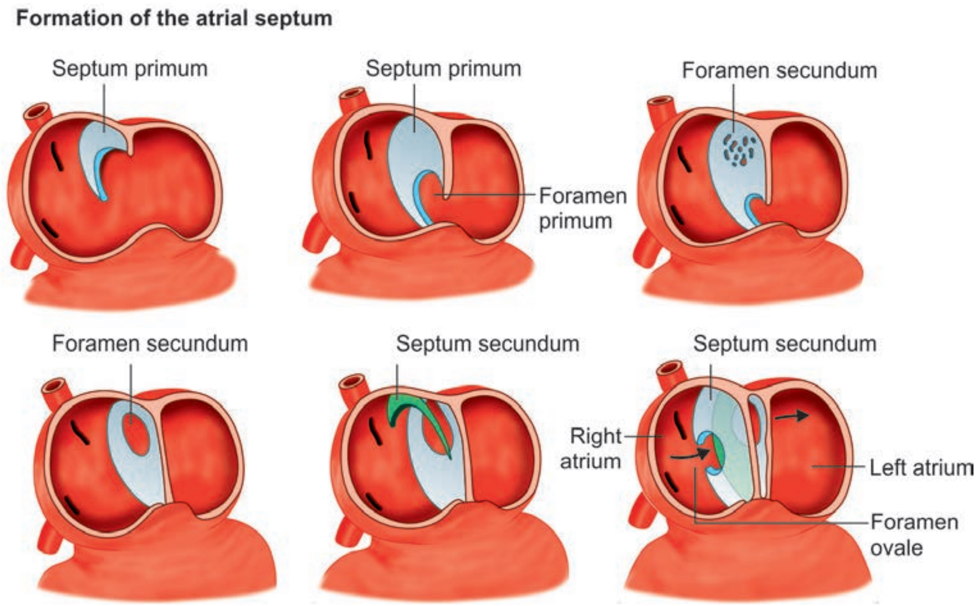


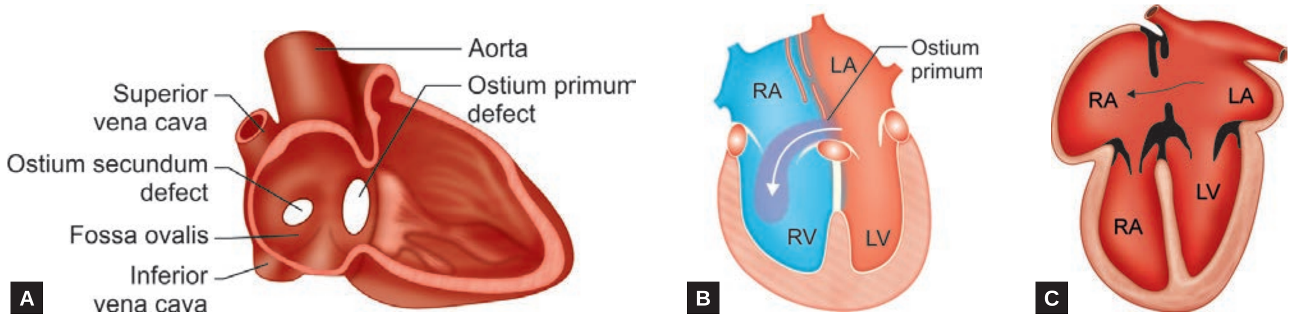
Fig. 14: Formation of the atrial septum. The arrows in 6 indicate the direction of blood flow from the right atrium to the left atrium across the fully developed atrial septum. Septum primum blue, septum secundum green.

Fossa ovalis is an oval depression on the interatrial portion consisting of the valve of the fossa ovalis (a central sheet of thin fibrous tissue) which is a remnant of septum primum.

- Limbus fossa ovalis is the prominent horseshoe-shaped margin of the fossa ovalis; it represents the edge of the fetal septum secundum.

ASD (Atrial Septal Defect): Shunts blood from the left atrium to the right atrium and causes hypertrophy of the right atrium, right ventricle, and pulmonary trunk, and thus mixing of oxygenated and deoxygenated blood, producing cyanosis. It is basically of two types:

- In ostium primum type ASD, blood keep flowing from left atrium into right atrium, through foramen (ostium) primum.
- If septum primum fails to fuse with endocardial cushions, the defect lies immediately above the atrioventricular (AV) boundary (may also be associated with a ventricular septal defect).
- It is less common than secundum ASD and is due to a failure of the septum primum to fuse with the endocardial cushions.
- ASD: Ostium secundum type ASD is the most common ASD.
- If septum secundum is too short to cover foramen secundum, it allows shunting of blood from left to right atrium, through foramen (ostium) secundum.
- It is caused by either an excessive resorption of the Septum primum (large foramen secundum) or an underdevelopment and reduced size of the Septum secundum (large foramen ovale).



Figs. 15A to C: Atrial septal defect (ASD) (A) Both types (B) Ostium primum type (C) Ostium secundum type.

Development of Pulmonary Veins

Pulmonary vein forms in the dorsal mesocardium and is incorporated into the left atrium by atrial expansion until the vein's four branches enter the atrium on its posterior wall.

- This portion constitutes the smooth-walled region of the left atrium.
- Some authorities believe that the pulmonary vein develops **as an outgrowth of the dorsal atrial wall,** just to the left of the septum primum.

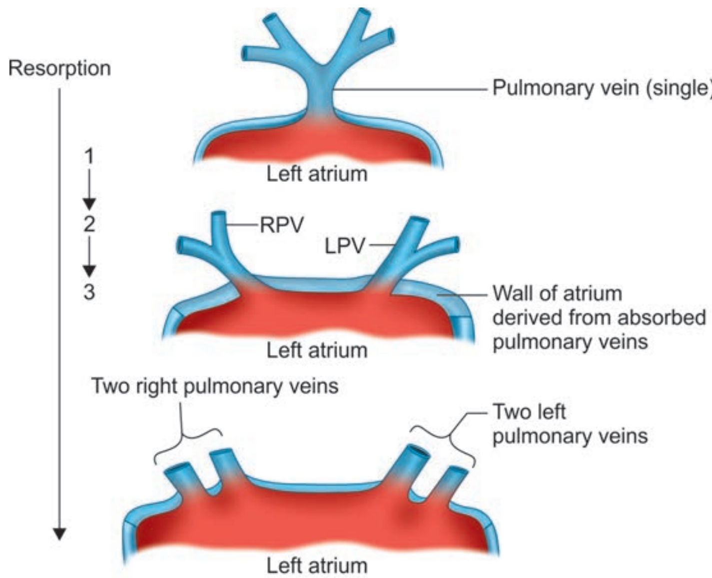


Fig. 16: Absorption of pulmonary veins into the left atrium. RPV = right pulmonary vein; LPV = left pulmonary vein.

Development of Ventricles and Interventricular Septum

- Partition of the Primitive Ventricle
  - Muscular IV septum develops as outgrowth of muscular wall in the floor of the primitive ventricle and grows toward the AV septum but stops to create the IV foramen, leaving the septum incomplete.
  - Membranous IV septum forms by (1) the inferior endocardial atrioventricular cushion, (2) the right conus swelling, and (3) the left conus swelling.
  - The membranous IV septum closes the IV foramen, completing partition of the ventricles

Table 4: Adult components of right and left ventricles and their embryonic source of development

Adult component	Embryonic source of development
Right ventricle	
• Inflowing rough part	Primitive ventricle
• Out flowing smooth part (infundibulum)	Bulbus cordis
Left ventricle	
• Inflowing rough part	Primitive ventricle
• Outflowing smooth part (aortic vestibule)	Bulbus cordis

Interventricular septum is formed by fusion of the bulbar ridges with the endocardial cushion, the AP septum, and the muscular part of the IV septum.

- If these three components fail to fuse, it may result in an open interventricular foramen (VSD).
- It occurs commonly in the membranous part of the IV septum, resulting in left-to-right shunting of blood through the IV foramen, which increases blood flow to the lungs and causes pulmonary hypertension and congestive heart failure.

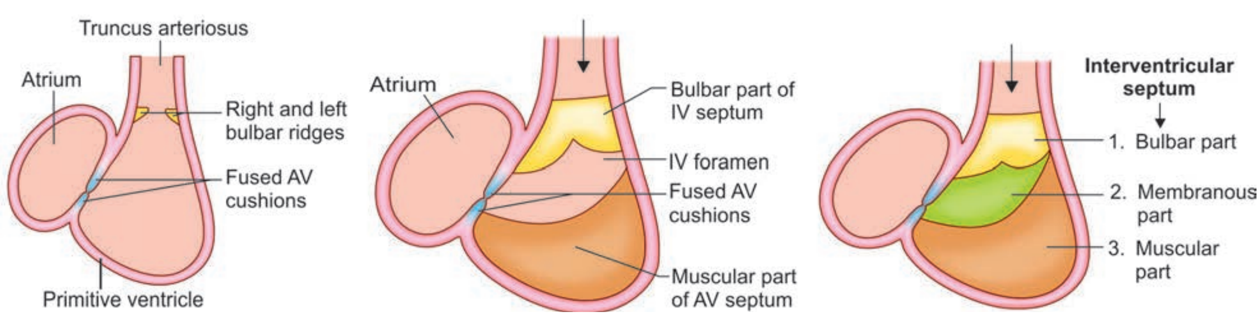


Fig. 17: Formation of interventricular septum.

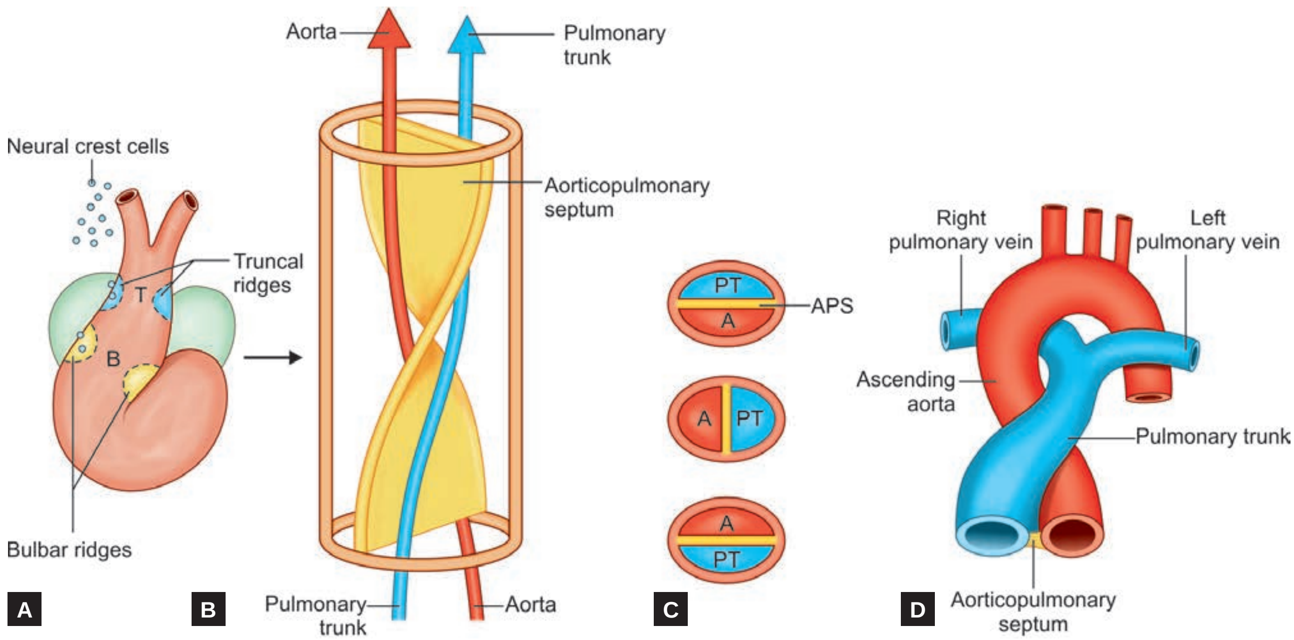
AP Septum and Anomalies

Partition of the Truncus Arteriosus and Bulbus Cordis

- The truncal ridges and the bulbar ridges (derived from **neural crest** mesenchyme) grow in a spiral fashion and fuse to form the AP septum.
- The **AP septum** divides the truncus arteriosus into the aorta and pulmonary trunk.

Septum Formation in the Bulbus

- The bulbus is divided into the smooth-walled portion of the right ventricle and the conus and truncus arteriosus.
- The truncus region is divided by the spiral aorticopulmonary septum into the proximal segments of the aorta and pulmonary artery.
- Neural crest cells contribute to the formation of APs (Aorta Pulmonary Septum) in the cono-truncal region.
- Conus cushions divide the outflow tract regions of the aortic and pulmonary channels from the left and right ventricles, respectively and also, together with tissue from the inferior endocardial cushion, close the inter-ventricular foramen.



Figs. 18A to D: Formation of Aorta-Pulmonary septum.

AP septum anomalies may result from abnormal division of the cono-truncal region.

- AP septum anomalies like PTA, TGV and TOF present with right to left shunt, blood reaches systemic circulation without proper oxygenation, hence leading to cyanosis.
- Persistent truncus arteriosus (PTA)
- Failure of cono-truncal ridge to fuse and descend towards the ventricles result in absence of AP septum – Persistent truncus arteriosus.
- There is absence of ascending aorta and pulmonary trunk, and the primitive truncus arteriosus is present with mixing of blood, resulting in cyanosis.

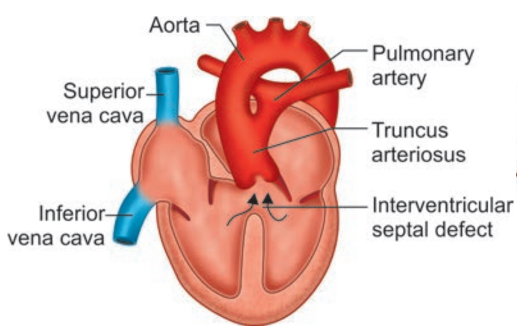


Fig. 19: Persistent truncus arteriosus (PTA).

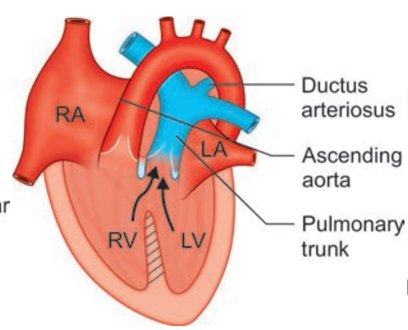


Fig. 20: Transposition of great vessels (TGV).

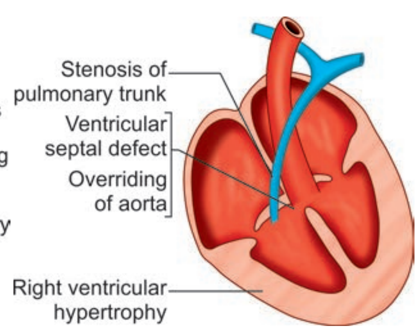


Fig. 21: Tetralogy of Fallot (TOF).

Transposition of great vessels (TGV)

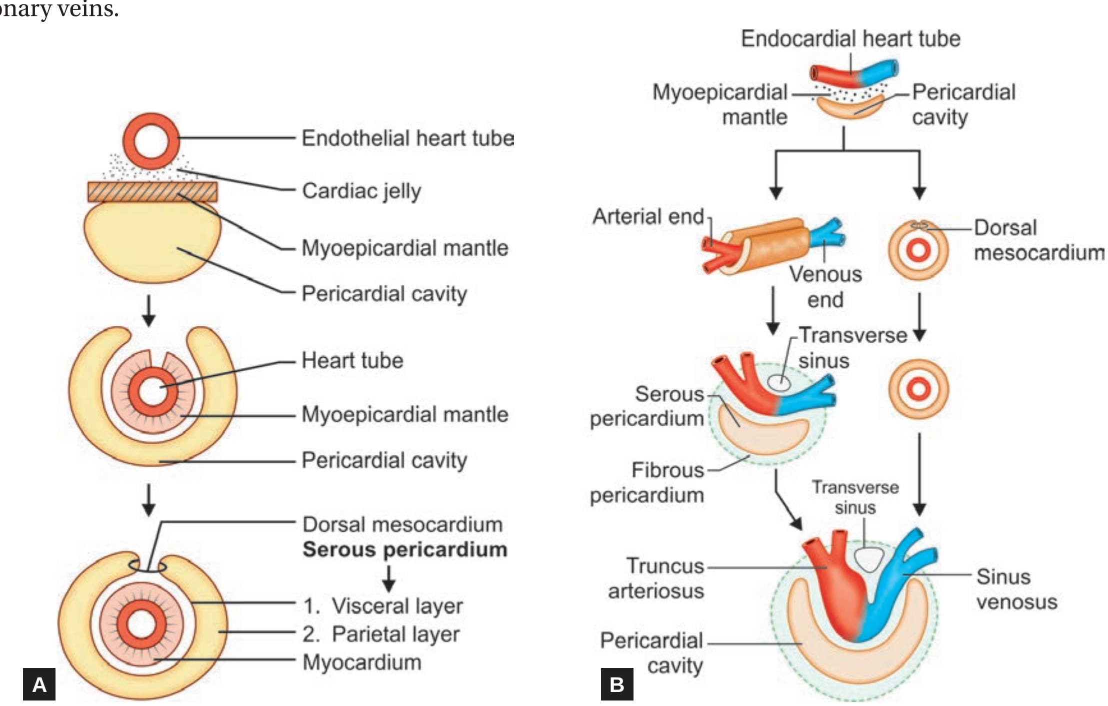
- If the AP septum is not spiral, the great vessels are not spiral and they open in the opposite ventricles (transposition of great vessels).
- The aorta arises from the right ventricle, and the pulmonary artery emerges leftward and posteriorly from the LV (two separate parallel circulations).

- This results in right-to-left shunting of blood and cyanosis and some communication between them must exist after birth to sustain life.
- Most patients have an interatrial communication, two-thirds have a patent ductus arteriosus, and about one-third have an associated VSD.

Tetralogy of Fallot (TOF)
- It occurs when the AP septum fails to align properly with the AV septum, resulting in (1) pulmonary stenosis (obstruction to right ventricular outflow), (2) VSD, (3) overriding aorta (dextraposition of aorta), and (4) right ventricular hypertrophy.
- It is characterized by right-to-left shunting of blood and cyanosis.
- Overriding aorta (dextraposition of aorta) is that the aorta (its outlet) lies over both ventricles (instead of over the left ventricle), directly above the VSD, causing the aorta to arise from both ventricles.

Pericardium and Cavities (Embryology)

The pericardial cavity is derived from the part of intraembryonic celom that lies in the midline cranial to prochordal plate and caudal to septum transversum.
- The heart tube invaginates the pericardial cavity from the dorsal aspect; hence it gets completely covered by myoepicardial mantle and a layer of the pericardial cavity.
- The myoepicardial mantle contributes to the wall of the heart and layer of the pericardial cavity applied to it forms the visceral layer of the pericardium (also called epicardium).
- Visceral layer of pericardium continues peripherally as parietal layer of pericardium, both enclosing the pericardial cavity.
- **Visceral** layer of serous pericardium is derived from **splanchnopleuric** mesoderm, whereas **parietal** layer of serous pericardium (and fibrous pericardium) is derived from **somatopleuric** mesoderm.
- The heart tube is suspended within the pericardial cavity by a double-layered fold of the layer of the pericardial cavity called dorsal mesocardium.
- With the folding (looping) of the heart tube, the arterial and venous ends come close.
- The dorsal mesogastrium disappears to form **transverse sinus** of pericardium.
- Later the parietal and visceral layers of serous pericardium become continuous with each other at the arterial and venous ends of the heart tube, i.e., serous pericardium gets arranged into two tubes: arterial - the one enclosing the aorta and pulmonary trunk, and venous: the other enclosing the superior vena cava, inferior vena cava, and four pulmonary veins.
- The two tubes are separated by the transverse sinus of pericardium.
- The definitive reflections of the pericardium in accordance with the rearrangement of SVC, IVC, and pulmonary veins at the venous end lead to the formation of an isolated pouch of pericardium called **oblique sinus** of the pericardium.
- **Oblique sinus is** a recess of serous pericardium that passes upward behind the left atrium and between the left and right pulmonary veins.



Figs. 22A and B: Formation of pericardial cavity and sinuses.

As the heart tube folds, a space develops between arterial and venous end—transverse pericardial sinus.
- Anterior to the sinus are two arteries derived from truncus arteriosus: ascending aorta and pulmonary trunk.
- Superior vena cava lies posterior to the sinus and bifurcation of pulmonary trunk is superior to it.

- During surgery on the aorta or pulmonary artery, a surgeon can pass a finger and make a ligature through the sinus between the arteries and veins, thus stopping the blood circulation with the ligature.

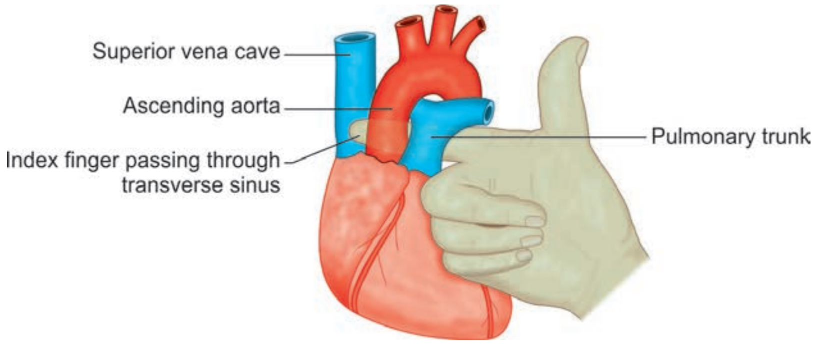


Fig. 23: Finger passing through the transverse pericardial sinus.

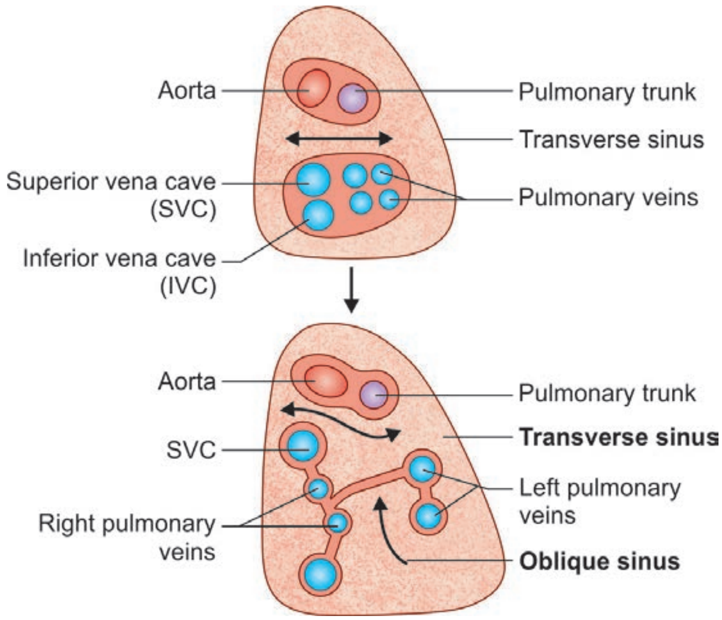


Fig. 24: Formation of pericardial sinuses.

ASSESSMENT QUESTIONS

1. What is TRUE about sinus venosus? *(NEET Pattern 2012)*
a. Forms rough wall of right atrium
b. Forms smooth wall of right atrium
c. Forms right coronary sinus
d. Forms left leaflet of coronary sinus

2. Coronary sinus develops from: *(NEET Pattern 2012)*
a. Truncus arteriosus
b. Conus
c. Sinus venosus
d. AV canal

3. UNTRUE about cardiac jelly: *(AIIMS 2006)*
a. Secreted by cardiac myocytes surrounding primitive heart tube
b. Found exterior to endothelium
c. Forms myocardium
d. Transforms into the connective tissue of the endocardium

4. Foramen ovale closes because of fusion of: *(NEET Pattern 2012)*
a. Septum primum + Endocardial cushion
b. Septum secundum + Endocardial cushion
c. Septum primum + Septum secundum
d. None

5. Fossa ovalis is a remnant of: *(NEET Pattern 2012)*
a. Septum primum
b. Septum secundum
c. Ductus arteriosus
d. Ductus venosus

6. All are essential components of tetralogy of Fallot EXCEPT: *(AIIMS 2007)*
a. Valvular pulmonic stenosis
b. Right ventricular hypertrophy
c. Infundibular stenosis
d. Aorta overriding

7. Transposition of great vessels occurs due to:
a. Failure of cono-truncal ridge to fuse and descend towards the ventricles
b. Anterior displacement of aortico-pulmonary septum
c. Aortico-pulmonary septum not following its spiral course
d. Migration of neural crest cells towards truncal and bulbar ridges

8. Cardiac defects causing right to left shunt, leading to early cyanosis are all EXCEPT:
a. Transposition of great vessels
b. Tetralogy of Fallot
c. Patent ductus arteriosus
d. Persistent truncus arteriosus

9. Absence of cono-truncal septum gives rise to:
a. Tetralogy of Fallot
b. Patent truncus arteriosus
c. Transposition of great vessels
d. Coarctation of aorta

10. Pentalogy of Fallot is characterized by:
a. Ventricular septal defect
b. Patent ductus arteriosus
c. Atrial septal defect
d. Pulmonary stenosis

11. Limbus fossa ovalis and floor of fossa ovalis represents:
a. Septum Primum
b. Septum secundum
c. Septum primum and septum secundum
d. Septum secundum and septum primum

12. As viewed from the right atrium, the floor of the fossa ovalis is formed by: *(NEET Pattern 2014)*
a. Septum primum
b. Septum secundum
c. Endocardial cushions
d. Tricuspid valve orifice

13. NOT true about right atrium: *(NEET Pattern 2015)*
a. Posterior part is smooth
b. Anterior part is derived from absorption of right horn of sinus venosus
c. Fossa ovalis represent remnant of foramen ovale
d. Anterior and posterior parts are divided by Crista terminalis

14. Pulmonary veins develop from:
a. Sixth aortic arch
b. Primitive left atrium
c. Left common cardinal vein
d. Left vitelline vein

15. The structure present anterior to transverse pericardial sinus is: *(NEET Pattern 2012)*
a. Inferior vena cava
b. Superior venae cava
c. Aorta
d. Pulmonary artery

16. Heart begins to beat in the week:
a. 4
b. 5
c. 6
d. 7

17. Unequal division of the conus cordis resulting from anterior displacement of the cono-truncal septum gives rise to:
a. Persistent truncus arteriosus *(AIIMS 2003)*
b. Coarctation of aorta
c. Tetralogy of Fallot
d. Transposition of great vessels

18. Heart is fully developed at which age of intrauterine life? *(NEET Pattern 2013)*
a. 3rd month
b. 4th month
c. 5th month
d. 6th month

19. Sinus venosus receives blood from all EXCEPT:
a. Vitelline vein *(NEET Pattern 2015)*
b. Umbilical vein
c. Common cardinal vein
d. Subcardinal vein

20. Ductus venosus connects: *(NEET Pattern 2012)*
a. Pulmonary trunk and descending aorta
b. Right atrium and left atrium
c. Portal vein and IVC
d. Pulmonary trunk and ascending aorta

21. Posterior to transverse pericardial sinus is: *(NEET Pattern 2015)*
a. Aorta
b. Pulmonary trunk
c. SVC
d. Left atrium

ANSWERS WITH EXPLANATIONS

1. b. Forms smooth wall of right atrium
- Sinus venosus is a paired structure but shifts towards right associating only with the right atrium as the embryonic heart develops.
- The left portion shrinks in size and eventually forms the coronary sinus and oblique vein of the left atrium, whereas the right part becomes incorporated into the right atrium to form the **sinus venarum** (smooth part of right atrium).

2. c. Sinus venosus
- The left horn of sinus venosus undergoes regression and forms the coronary sinus, which opens into the posterior wall of right atrium.

3. c. Forms myocardium
- Cardiac jelly is secreted by the cardiac myocytes (myocardium) around the endothelial lining of heart tube, and transforms into the connective tissue of **endocardium.**

4. c. Septum primum + Septum secundum
- At birth, when pressure in the left atrium increases, the septum primum and septum secundum press against each other and close the communication (foramen ovale) between the two atria, completed at around 3 months after birth.

5. a. Septum primum
- Fossa ovalis is an oval depression on the interatrial portion consisting of the valve of the **fossa ovalis (a central sheet of thin fibrous tissue)** which is a remnant of septum primum, and the limbus of the fossa ovalis (a horseshoe-shaped muscular rim), which is a remnant of the septum secundum.

6. a. Valvular pulmonic stenosis
- In tetralogy of Fallot **infundibular stenosis** occurs due to anterior migration of AP septum.

7. c. Aortico-pulmonary septum not following its spiral course
- If the AP septum is not spiral, the great vessels are not spiral and they open in the opposite ventricles (transposition of great vessels).
- The aorta arises from the right ventricle, and the pulmonary artery emerges leftward and posteriorly from the LV (two separate parallel circulations).

8. c. Patent ductus arteriosus
- Patent ductus arteriosus carries the blood towards the lungs and promotes oxygenation thus, reduces cyanosis.
- AP septum anomalies like PTA, TGV and TOF present with right to left shunt, blood reaches systemic circulation without proper oxygenation, hence leading to cyanosis.

9. b. Patent truncus arteriosus
- Absence of Aorta Pulmonary (AP) septum leads to persistent (patent) truncus arteriosus.
- Cono-truncal septum is the other name for AP septum.

10. c. Atrial septal defect
- Tetralogy plus ASD (Atrial Septal Defect) is a feature of pentalogy of Fallot.

11. d. Septum secundum and septum primum
- Limbus fossa ovalis is the margin of foramen ovale (present in septum secundum).
- As viewed from right atrium, the **floor of fossa ovalis** is formed by **septum primum**.

12. a. Septum primum
- Fossa ovalis is an oval depression on the interatrial portion consisting of the valve of the fossa ovalis (a central sheet of thin fibrous tissue) which is a remnant of septum primum, and the limbus of the fossa ovalis (a horseshoe-shaped muscular rim), which is a remnant of the septum secundum.

13. b. Anterior part is derived from absorption of right horn of sinus venosus
- Right horn of sinus venosus contributes to sinus venarum (posterior smooth part of right atrium).
- Anterior part of right atrium is rough (derived from the primitive atrium).

14. b. Primitive left atrium
- According to some authorities, pulmonary veins develop from the left atrial wall.
- There is no consensus about whether the pulmonary vein as a branch from the left atrium obtains a connection to the lung plexus or the pulmonary vein forms as a solitary vessel in the dorsal mesocardium and is only secondarily incorporated into the atrium.

15. c. Aorta
- As the heart tube folds, a space develops between arterial and venous end – transverse pericardial sinus.
- Anterior to the sinus are two arteries derived from truncus arteriosus: **ascending aorta** and **pulmonary trunk** (and not pulmonary artery).
- A finger can be put into the sinus to pull the two major arteries and a ligature put around, during cardio-thoracic surgeries.
- Superior vena cava lies posterior to the sinus and bifurcation of pulmonary trunk is superior to it.

16. a. 4
- Heart beat begins by day 22 post-ovulation and can be detected by Doppler ultrasound.
- It is week 4 post-ovulation (or fertilization) and week 6 from LMP (Last Menstrual Period).

17. c. Tetralogy of Fallot
- Anterior displacement of the cono-truncal septum leads to unequal division of truncus arteriosus and producing a narrow pulmonary trunk-pulmonic stenosis and a wide aorta. This leads to the complex of tetralogy of Fallot.
- Normally the truncus arteriosus (of primitive heart tube) develops a spiral AP septum (also called as cono-truncal septum) and this septum divides the trunk into pulmonary trunk and aorta.
- If the septum does not develop, there is no division of truncus arteriosus and leads to persistent truncus arteriosus.
- If the AP septum is not spiral, it leads to transposition of great arteries.

18. a. 3rd month
- The structural **development** of the **heart** which begins 16 days after fertilization is finished by the **10th week** of pregnancy.

19. d. Subcardinal vein

Sinus venosus is the venous end of the heart tube having right and left horns.
- Each horn receives blood from following three pair of veins. Vitelline veins (from yolk sac), Umbilical veins (from placenta) and common cardinal veins (from body wall).

20. c. Portal vein and IVC

In fetal circulation, ductus venosus shunts a portion of the left umbilical vein blood flow directly to the inferior vena cava.
- It allows oxygenated blood from the placenta to bypass the liver.
- The only related option appears to be choice c.

21. c. SVC
- Transverse pericardial sinus lies between the aorta and pulmonary trunk anteriorly and the superior vena cava posteriorly.

Respiratory System (Development)

A laryngotracheal groove appears in the floor of the pharynx (ventral wall of foregut), which evaginates to form the laryngotracheal (respiratory) diverticulum.
- A tracheoesophageal septum divides the foregut into a ventral portion, the laryngotracheal tube and a dorsal portion (primordium of the oropharynx and esophagus).
- The ventral portion forms the larynx, trachea, and lung buds.
- Laryngeal cartilages and muscles are derived from somitomeric mesoderm of pharyngeal arches 4 and 6, and thus, the laryngeal muscles are innervated by branches of the vagus nerve (superior laryngeal and recurrent laryngeal nerves).
- At the distal end of the laryngotracheal diverticulum, lung buds develop and divide into two bronchial buds, which further branch into the primary, secondary, and tertiary bronchi.
- The tertiary bronchi continue to divide to form respiratory bronchioles.
- Epithelium and glands in the respiratory tube are derived from the endoderm of foregut, whereas smooth muscles, connective tissue and visceral pleura are derived from visceral (splanchnic) lateral plate mesoderm.
- Parietal pleura is derived from somatic lateral plate mesoderm.

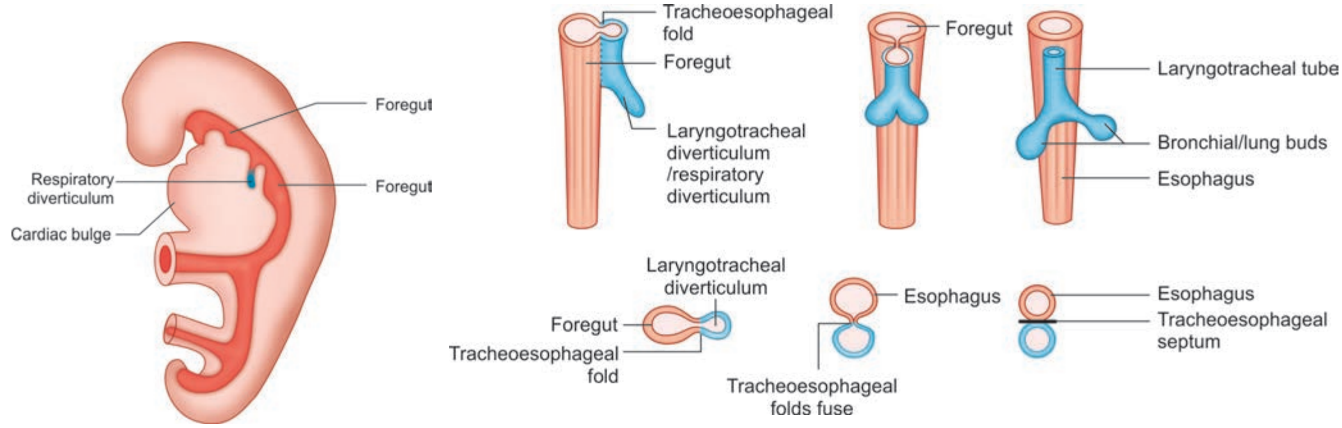


Fig. 25: Development of respiratory system.

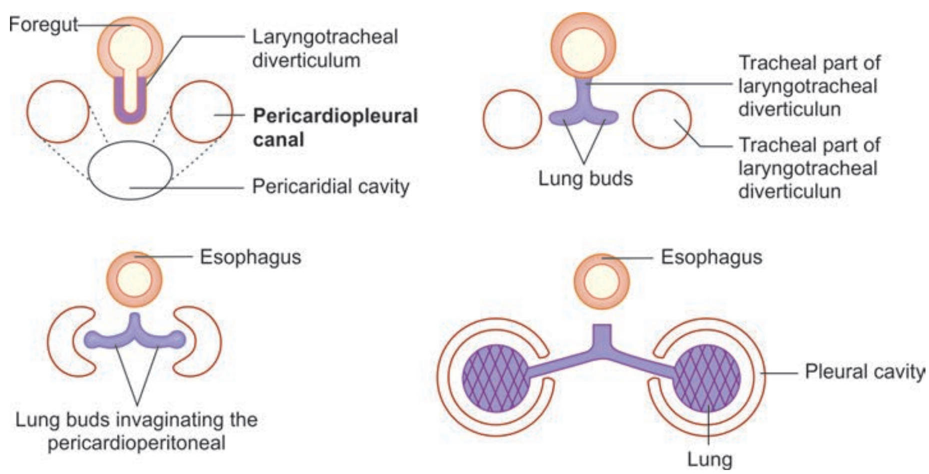


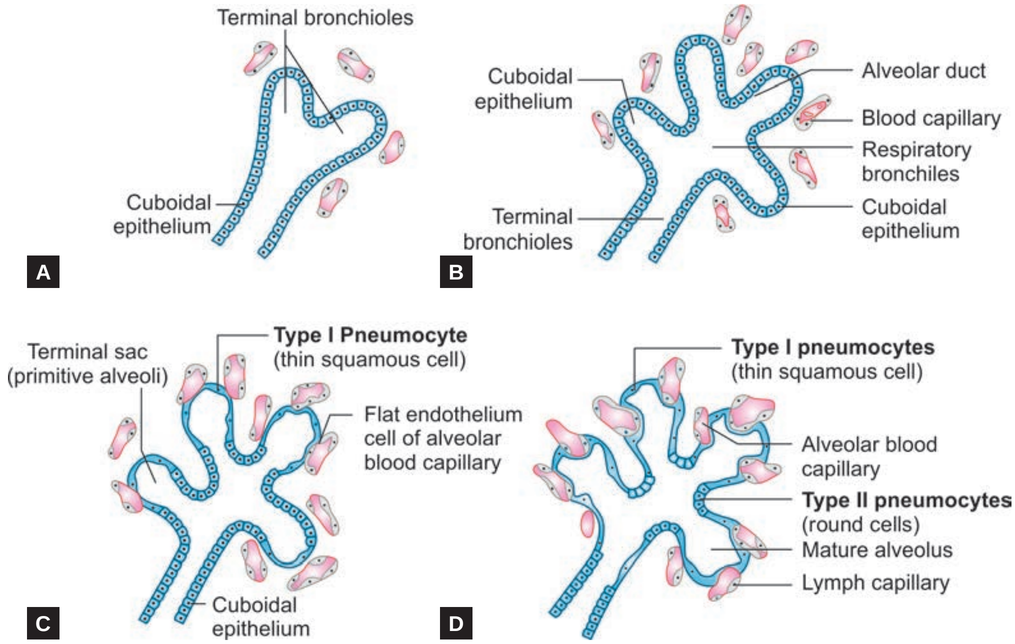
Fig. 26: Development of respiratory tube and pleural cavity.

After a pseudoglandular (5 to 17 weeks) and canalicular (13 to 25 weeks) phase, cells of the cuboidal-lined respiratory bronchioles change into thin, flat cells, type I alveolar epithelial cells, intimately associated with blood and lymph capillaries.

- In the seventh month, gas exchange between the blood and air in the primitive alveoli is possible.
- Before birth, the lungs are filled with fluid with little protein, some mucus, and surfactant, which is produced by type II alveolar epithelial cells and which forms a phospholipid coat on the alveolar membranes.
- At the beginning of respiration, the lung fluid is resorbed EXCEPT for the surfactant coat, which prevents the collapse of the alveoli during expiration by reducing the surface tension at the air-blood capillary interface.
- Absent or insufficient surfactant in the premature baby causes respiratory distress syndrome (RDS) because of collapse of the primitive alveoli (hyaline membrane disease).
- Growth of the lungs after birth is primarily due to an increase in the number of respiratory bronchioles and alveoli and not to an increase in the size of the alveoli. New alveoli are formed during the first 10 years of postnatal life.

Table 5: Development of Lungs: Four stages of development

Stage	Period of time	Developments
Pseudoglandular	5–17 weeks	The conducting airway system up to the terminal bronchioles develops. Respiration is not possible at this stage; hence premature borne fetuses cannot survive.
Canalicular	13–25 weeks	Luminal diameter of the conducting system increases, and respiratory bronchioles, alveolar ducts, and terminal sacs (primitive alveoli) are formed. Premature fetuses born before week 20 rarely survive.
Terminal sac (saccular)	24 weeks to birth	More terminal sacs form, and alveolar type I cells and surfactant-producing alveolar type II cells develop. Intimate contact develops between epithelium of sac and endothelium of capillary to permit adequate exchange of gases, premature infants can survive with intensive care.
Alveolar	8 months to 8 years	Formation of definitive (true) alveoli with an increase in their number Type II pneumocytes produce a sufficient amount of surfactant Free exchange of gasses across the blood—air barriers formed by epithelium of alveoli and endothelium of capillaries



Figs. 27A to D: Developmental stages of development of lungs.

Applied anatomy

- Tracheoesophageal fistula: Faulty partitioning of the foregut by the tracheoesophageal septum causes esophageal atresias and tracheoesophageal fistulas.

Azygous lobe of lung

- The azygos vein may sometimes course in a more lateral position, within a four-layered pleural septum within the superior lobe, creating an 'azygos lobe'.
- Azygous lobe is an anatomically separated part of the upper lobe, and not a true or accessory lobe of lung, as it has no bronchi, veins and arteries of its own.

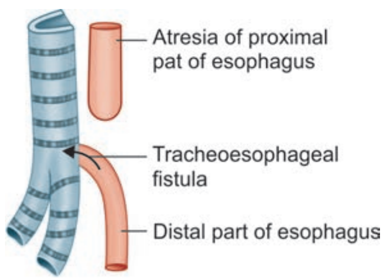


Fig. 28: Tracheo-oesophageal.

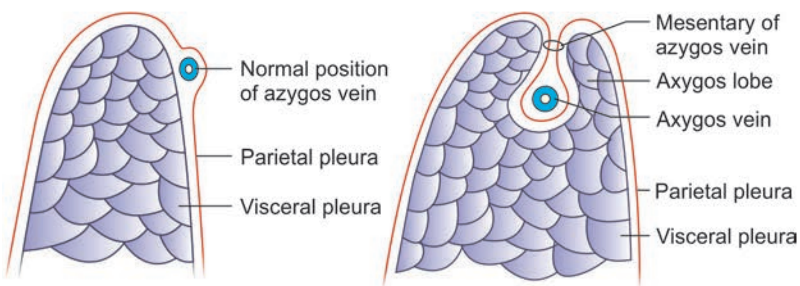


Fig. 29: Azygos lobe of the lung.

Bones

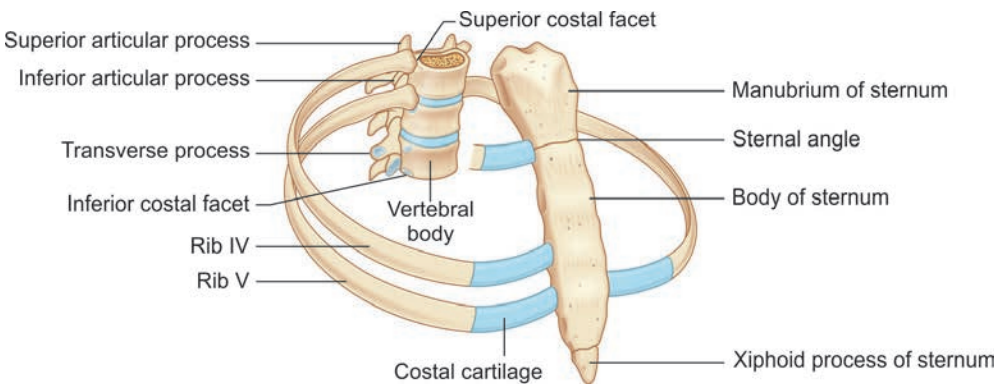


Fig. 30: Articulations of the ribs with the vertebrae and the sternum.

Ribs

- There are 12 pairs of ribs that articulate with the thoracic vertebrae, extend to or toward the sternum.
- They can Increase the anteroposterior and transverse diameters of the thorax by their movements.
- A typical rib consists of a head, neck, tubercle, and body.
  - The head articulates with the corresponding vertebral body, intervertebral disc and next higher (superjacent) vertebral body.
  - The body (shaft) turns sharply anteriorly at the angle and has a costal groove on the inferior and internal surface of rib and lodges the intercostal vessels and nerves.
  - The tubercle articulates with the transverse processes of the corresponding vertebrae (with the EXCEPTion of ribs 11 and12).

Classification of ribs

Types of ribs

- Typical ribs: 3–9
- Atypical ribs: 1, 2, 10, (11 and 12)

Types of ribs according to relation with the sternum:

- True ribs: 1-7 (i.e., upper 7 ribs)
- False ribs: 8-12 (i.e., lower 5 ribs)

Note: True ribs articulate with the sternum anteriorly, whereas false ribs do not. False ribs articulate with more superior costal cartilage and form the anterior costal margin.

Types of ribs according to articulation:

- Vertebro-sternal ribs: 1-7
- Vertebro-chondral ribs: 8-10
- Vertebral (floating) ribs: 11 and 12 (articulate with vertebral bodies but do not articulate with the sternum)

Note: The first 7 'true' ribs attach to the sternum by costal cartilages, whereas, the remaining lower 5 'false' ribs either join the respective costal cartilage (8–10) or 'float' free at their anterior ends (11–12).

Joints of ribs

- Ribs 2-7 attach with the sternum by **synovial** joints.
- Ribs 6-9 attach with each other by **synovial** joints (Interchondral joints).
- The **interchondral** joints between 7th rib and the 8, 9, 10 are **synovial** joints, at some points, there are **fibrous** joints as well.
- **First Rib** is the broadest and shortest of the true ribs.
- It has a single articular facet on its head, which articulates with the first thoracic vertebra, a scalene tubercle for the insertion of the anterior scalene muscle and two grooves for the subclavian artery and vein.

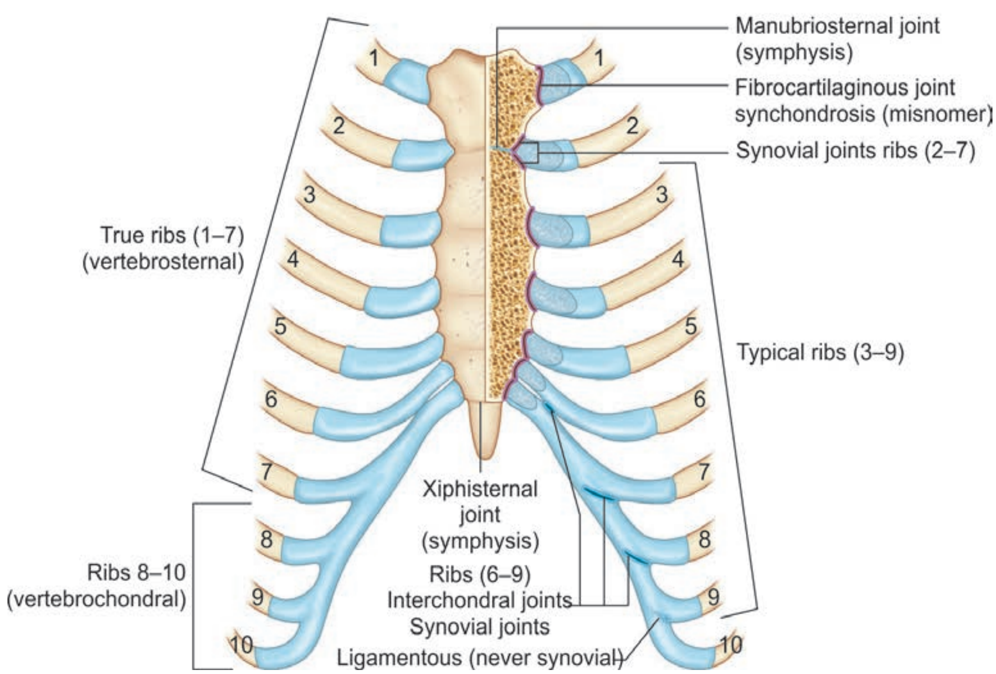


Fig. 31: Rib cage and joint types.

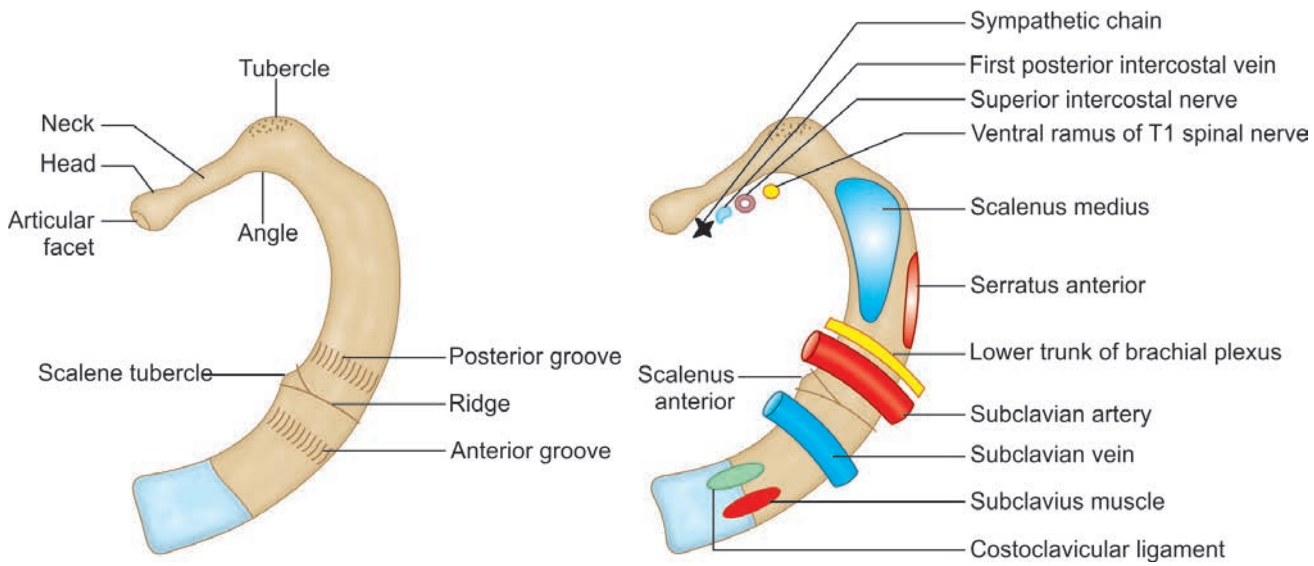


Fig. 32: Superior view of first rib showing attachments and relations.

- **SVAN** structures are present between first rib and apex of lung (medial to lateral)
- **S - Sympathetic trunk**
- **V - Vein (intercostal)**
- **A - Artery (superior intercostal)**
- **N – Nerve (T1 nerve)**
- Second Rib has two articular facets on its head, which articulate with the bodies of the first and second thoracic vertebrae. It is about twice as long as the first rib.
- Tenth Rib has a single articular facet on its head, which articulates with the 10th thoracic vertebra.
- Eleventh and Twelfth Ribs have a single articular facet on their heads, have no neck or tubercle.

ASSESSMENT QUESTIONS

1. Attachment to the first rib are all EXCEPT: *(PGIC 2014; NEET Pattern 2015)*
 a. Scalenus anterior
 b. Scalenus medius
 c. Scalenus posterior
 d. Suprapleural membrane

2. All of the following lie between the 1st rib and the apex of lung EXCEPT: *(NEET Pattern 2013)*
 a. Superior intercostal artery
 b. Thoracic duct
 c. First posterior intercostal vein
 d. Sympathetic trunk

3. Relationship of neurovascular bundle from above downward in intercostal space: *(NEET Pattern 2015)*
 a. Nerve → Artery → Vein
 b. Artery → Nerve → Vein
 c. Vein → Nerve → Artery
 d. Vein → Artery → Nerve

4. The order of neurovascular bundle in intercostal space from above to below is: vein-artery-nerve. This order is NOT observed in intercostal space: *(AIIMS 2013)*
 a. 1
 b. 2
 c. 11
 d. 12

5. False rib is: *(NEET Pattern 2014)*
 a. 1st
 b. 2nd
 c. 7th
 d. 10th

6. Scalene tubercle is a feature of: *(NEET Pattern 2015)*
 a. 1st rib
 b. 2nd rib
 c. 3rd rib
 d. 4th rib

7. The costal cartilages of these ribs do not reach the sternum: *(NEET Pattern 2015)*
 a. 1st and 2nd
 b. 6th and 7th
 c. 8th, 9th and 10th
 d. 11th and 12th

ANSWERS WITH EXPLANATIONS

1. c. Scalenus posterior
- Scalenus posterior attaches to second rib.
- Other attachments on first ribs are: Subclavius, serratus anterior, costoclavicular ligament

2. b. Thoracic duct
- **Thoracic duct** passes through superior thoracic aperture, but not between apex of lung and first rib.
- **SVAN** structures are present between first rib and apex of lung (medial to lateral): S - Sympathetic trunk, V- Vein (intercostal), A - Artery (superior intercostal), N – Nerve (T1 nerve).

3. d. Vein→ Artery → Nerve

- The arrangement of neurovascular bundle in the costal groove superior to inferior is posterior intercostal vein , posterior intercostal artery and intercostal nerve (VAN goes down, superior to inferior).

4. a. 1

- In first rib, the vein-artery-nerve order is medial to lateral.
- SVAN structures are sandwiched between the lung apex and first rib (medial to lateral). S – Sympathetic trunk, V – Vein (posterior intercostal), A – artery (posterior intercostal), N – Nerve (T – 1).

5. d. 10th

- 10th rib do not articulate with sternum anteriorly (false rib).
- The first seven 'true' ribs connect to the sternum by costal cartilages, whilst the remaining lower five 'false' ribs either join the superjacent costal cartilage (8–10) or 'float' free at their anterior ends as relatively small and delicate structures tipped with cartilage.

6. a. 1st rib

- Scalene tubercle is a small projection present at the medial (inner) border of 1st rib, between two grooves, which travel anteriorly for the subclavian vein and posteriorly for the subclavian artery.
- It provides insertion for scalenus anterior.

7. 8th, 9th and 10th > d. 11th and 12th

- Ribs 8 - 10 are vertebro-chondral with no direct articulation to sternum.
- Their costal cartilages articulate with each other and with 7th costal cartilage.
- Rib 11 and 12 have free anterior ends (floating ribs) and definitely they are never going to reach the sternum, but this statement is never mentioned in textbooks.

High Yield Points

- **8th rib** do not articulate with sternum and is a **vertebrocondral rib,** as it attaches to the costal cartilage of the next higher rib anteriorly. (NBEP 2014)
- **10th rib** is false rib, since it doesn't attach to the sternum (NBEP 2013

Vertebra

Thoracic vertebrae

- There are 12 thoracic vertebrae that have costal facets on their bodies for articulation with the heads of ribs, facets on their transverse processes for articulation with the tubercles of ribs and long spinous processes.
- According to the features, the thoracic vertebrae are classified into two types:
  1. Typical: Second to eighth.
  2. Atypical: First and ninth to twelfth

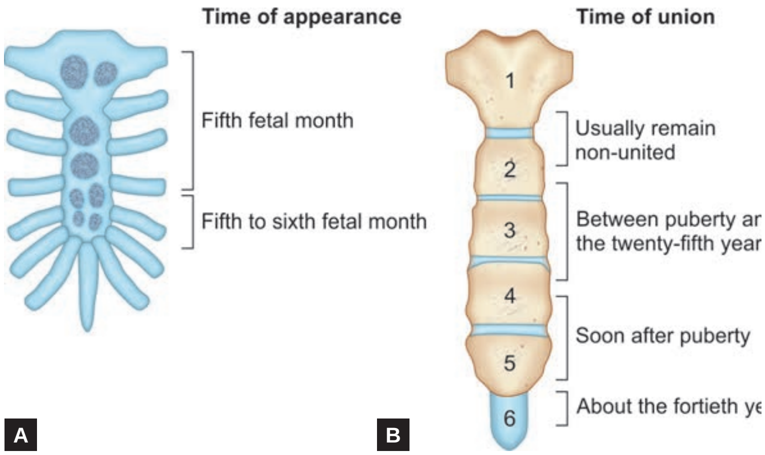
Table 6: Distinguishing features atypical thoracic vertebrae

Vertebra	Distinguishing features
T1	• Resembles 7th cervical vertebra • Superior costal facet is circular • Superior vertebral notch is deep and clearly seen
T9	Presence of only superior demifacet
T10	Presence of only single large complete costal facet
T11	• Presence of single large circular costal facet • Absence of articular facet on transverse process
T12	• Resembles 1st lumbar vertebra • Presence of single large circular facet extending onto the root of tubercle • Transverse process presents three tubercles: superior, inferior, and lateral

Sternum

- **Sternum** is a flat bone consisting three parts the **manubrium**, the **body**, and the **xiphoid process**.
- **Manubrium** has a superior margin, the jugular notch and a clavicular notch (for each clavicle).
- It also articulates with the cartilage of the first rib, the upper half of the second rib cartilage, and the body of the sternum at the manubriosternal joint (sternal angle of Louis).
- **Body of the Sternum** articulates with costal cartilages of ribs 2 to 7.
- It also articulates with the xiphoid process at the xiphisternal joint (at T9 vertebra level).
- **Xiphoid Process i**s a flat, cartilaginous process at birth that ossifies slowly from the central core and unites with the body of the sternum at about 40 year of age.
- It can be palpated in the epigastrium and attaches to the diaphragm and abdominal musculature via the linea alba

Note: Sternum possesses hematopoietic marrow throughout life and is a common site for bone marrow biopsy.



Figs. 33A and B: The ossification of the sternum (A) before birth. (B) After birth.

Lower two part of sternum fused by age of 14 years (AIIMS 2015).

Table 7: Muscles attached to sternum

Muscle attached on the anterior surface of the sternum	Muscles attached on the posterior surface of the sternum
• Sternal head of sternocleidomastoid	• Sternohyoid • Sternothyroid
• Pectoralis major	• Sternocostalis
• Rectus abdominis	• Diaphragm (sternal fibres)

Joints

- The **manubriosternal** joint (between the manubrium and sternal body) is usually a symphysis (may be synovial, synchondrotic or synostotic).
- The **xiphisternal** joint (between xiphoid process and body of the sternum) is a symphysis.
- It is usually transformed to a synostosis by the fortieth year.
- Some authors mention it as synchondrosis.
- **Sternoclavicular** Joint is a saddle-type synovial joint with two separate synovial cavities and provides the only bony attachment between the appendicular and axial skeleton.
- **Sternocostal** (Sternochondral) Joints are the articulation of the sternum with the first seven cartilages.
- The sternum (manubrium) forms synchondrosis with the first costal cartilage, whereas the second to seventh costal cartilages form synovial plane joints with the sternum.
- The sternocostal articulations (costosternal articulations), articulations of the cartilages of the true ribs with the sternum are **arthrodial** joints, with the exception of the first, in which the cartilage is directly united with the sternum, and which is, therefore, a **synarthrodial** articulation.

Table 8: Joints of thoracic wall

Joint	Type	Articulation	Ligaments	Comments
Intervertebral (of vertebrae T1–T2)	Symphysis (Secondary cartilaginous)	Adjacent vertebral bodies bound together by IV disc	Anterior and posterior longitudinal	Movement mostly limited to small degress of rotation
Costovertebral Joints of head of rib Costotranverse	Synovial plane joint	Head of each rib with superior demi or costal facet of vertebral body of same number and inferior demi- or costal facet of vertebral body superior to it and IV disc between them Tubercle of rib with transverse process of vertebra of same number	Radiate and intra-articular ligaments of head of rib Costotransverse; lateral and superior costotransverse	Head of 1st, 11th and 12th ribs (sometimes 10th) articulate only with vertebral body of same number
Costochondral	Primary (hyaline) cartilaginous joint	Lateral end of costal cartilage with sternal end of rib	Cartilage and bone bound together by periosteum	No movement normally occurs at this joint; costal cartilage provides flexibility
Interchondral	Synovial plane joint	Between costal cartilages of 6th and 7th, 7th and 8th, and 8th and 9th ribs	Interchondral ligaments	Articulation between costal cartilages of 9th and 10th ribs is fibrous
Sternocostal	1st; primary cartilaginous joint (synchondrosis) 2nd–7th: synovial plane joint	Articulation of 1st costal cartilages with manubrium of sternum Articulation of the 2nd–7th pairs of costal cartilages with sternum	Anterior and posterior radiate sternocostal; intra-articular	Articular cavities often absent; fibrocartilages covers articular surfaces

Joint	Type	Articulation	Ligaments	Comments
Sternoclavicular	Saddle type of synovial joint	Sternal end of clavicle with manubrium of sternum and 1st costal cartilage	Anterior and posterior sternoclavicular; costoclavicular	This joint is divided into two compartments by an articular disc
Manubriosternal	Secondary cartilaginous joint (symphysis)	Articulation between manubrium and body of sternum		These joints often fuse and become synostoses in order individuals
Xiphisternal	Primary cartilaginous joint (synchondrosis)	Articulation between xiphoid process and body of sternum		

High Yield Points

- The **interchondral** joints between 7th rib and the 8,9, 10 are **synovial** joints, at some points, there are **fibrous** joints also. *(NBEP 2013)*
- Manubriosternal and xiphisternal joints are 2° cartilaginous (symphysis) joints. (Gray's Anatomy Ed 41)

ASSESSMENT QUESTIONS

1. Dislocation of the vertebra is uncommon in thoracic region because in this region: *(AIIMS 2004)*
a. The articular process are interlocked
b. The vertebral body is long
c. Anterior longitudinal ligament is strong
d. Spinous process is long and pointed

2. All the direct articulation of true rib EXCEPT: *(AIPG)*
a. Costovertebral joint
b. Costochondral joint
c. Costotransverse joint
d. Costosternal joint

3. First sterno-costal joint is:
a. Synchondrosis
b. Synarthrosis
c. Synovial joint
d. Syndesmosis joint

4. The first costochondral joint is a: *(AIPG 2004)*
a. Fibrous joint
b. Synovial joint
c. Syndesmosis
d. Synchondrosis

5. 8, 9 and 10th ribs are attached to 7th rib by which joint? *(NEET Pattern 2014)*
a. Fibrous
b. Synovial
c. 1° cartilaginous
d. 2° cartilaginous

ANSWERS WITH EXPLANATIONS

1. a. The articular processes are interlocked
- The superior articular process is directed backward, upward and laterally (BUL) in the thoracic region.
- It interlocks with the corresponding inferior articular facet making a strong articulation rendering dislocation in the thoracic region uncommon.

2. d. Costosternal joint
- Ribs directly articulate with vertebral body by costovertebral joint, with transverse process by costotransverse joint and with costal cartilage by costochondral joint.
- It's the costal cartilage which attaches the ribs to the sternum, hence the costosternal joint is a misnomer, and correctly should be mentioned as chondrosternal joint.

3. b. Synarthrosis > a) Synchondrosis
- The first sterno-costal joint is an unusual variety of synarthrosis (fibrous) and is often inaccurately called a 1° cartilaginous (synchondrosis).

4. d. Synchondrosis
- All costochondral joints are 1° cartilaginous (synchondrosis).

5. b. Synovial
- Interchondral joints in the ribs 6-9 are synovial joints.

Nerve Supply

Table 9: Nerves of thorax

Nerve	Origin	Course	Distribution
Vagus (CN X)	8–10 rootlets from medulla of brainstem	Enters superior mediastinum posterior to sternoclavicular joint and brachiocephalic vein; gives rise to recurrent laryngeal nerve; continues into abdomen	Pulmonary plexus, esohageal plexus, and cardiac plexus
Phrenic	Anterior rami of C3–C5 nerves	Passes through superior thoracic aperture and runs between mediastinal pleura and pericardium	Central portion of diaphragm

Nerve	Origin	Course	Distribution
Inercostals (1–11)	Anterior rami of T1–T11 nerves	Run in intercostal spaces between internal and innermost layers of intercostal muscles	Muscles in and skin over intercostal space; lower nerves supply muscles and skin of anterolateral abdominal wall
Subcostal	Anterior ramus of T12 nerve	Follows inferior boder of 12th rib and passes into abdominal wall	Abdominal wall and skin of gluteal region
Recurrent laryngeal	Vagus nerver	Loops around subclavian artery on right; on left runs around arch of ascends in tracheo-esophageal groove	Intrinsic muscles of larynx (EXCEPT cricothyroid); sensory inferior to level of vocal folds
Cardiac plexus	Cervical and cardiac branches of vagus nerve and sympathetic trunk	From arch of aorta and posterior surface of heart, fibers extend along coronary arteries and to sinu-atrial node	Impulses pass to sinu-atrial node; parasympathetic fibers slow rate, reduce force of heartbeat, and constrict coronary arteries; sympathetic fibers have the opposite effect
Pulmonary plexus	Vagus nerve and sympathetic trunk	Forms on root of lung and extends along bronchial subdivisions	Parasympathetic fibers constrict bronchioles; sympathetic fibers dilate them; afferents convey reflexes
Esophageal plexus	Vagus nerve, sympathetic ganglia, greater splanchnic nerve	Distal to tracheal bifurcation; vagus and sympathetic nerves form a plexus around esophagus	Vagal sympathetic fibers to smooth muscle and glands of inferior two thirds of esophagus

Thoracic spinal nerves

- There are twelve pairs of thoracic spinal nerves, contributing to intercostal nerves, which are distributed primarily to the thoracic and abdominal walls.
- The greater part of the first thoracic ventral ramus passes into the brachial plexus, together with a variable proportion of the second.
- The next four ventral supply only the thoracic wall, and the lower five supply both thoracic and abdominal walls.
- The subcostal nerve is distributed to the abdominal wall and the gluteal skin.
- **Intercostal nerves** are the anterior primary rami of the first 11 thoracic spinal nerves (12th is the subcostal nerve, which runs beneath the 12th rib).
- These nerves run between the internal and innermost layers of muscles, with the intercostal veins and arteries.
- They are lodged in the costal grooves on the inferior surface of the ribs and give muscular branches and lateral and anterior cutaneous branches.

Classification

The intercostal nerves are classified into the following two groups:

- Typical intercostal nerves (3rd, 4th, 5th, and 6th).
- Atypical intercostal nerves (1st, 2nd, 7th, 8th, 9th, 10th and 11th).
  The **typical intercostal nerves** are those which remain confined to their own intercostal spaces.
- The **atypical spinal nerves** extend beyond the thoracic wall and partly or entirely supply the other regions.
  T1-T2 : Also supply upper limb via brachial plexus (T1) and intercostabrachial nerve (T2).
  T7-T11: Also supply abdominal wall.
  T12: Also supplies abdominal wall and skin of buttock.
- Subcostal nerve (T-12) runs along the lower border of 12th rib.
- **Intercostal nerve 2 is atypical nerve,** since it innervates upper limb**. (**by contributing to intercosto-brachial nerve) *(NEET Pattern 2013)*

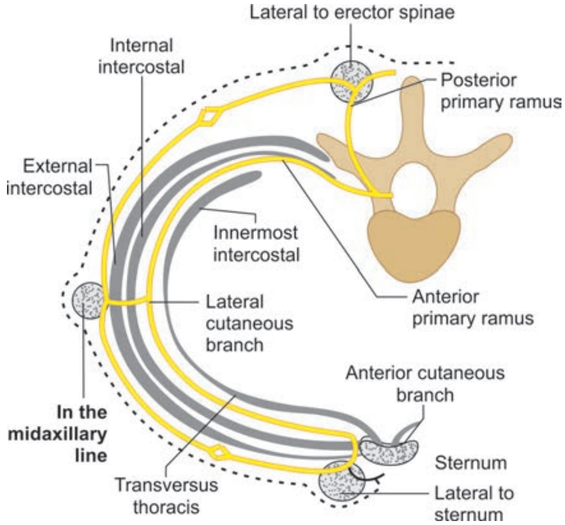


Fig. 34: Transverse view of thoracic region showing spinal nerve and intercostal nerve.

Phrenic nerve
- It takes origin from the anterior primary rami of C3-5 (chiefly C4) carries motor, sensory, and sympathetic fibers.
- It is the sole motor supply to diaphragm.
- It carries sensation from the central portion of diaphragm, peritoneum, pleura and pericardium along the course.
- It descends on the anterior surface of the scalene anterior muscle under cover of the sternocleidomastoid muscle, passes between the subclavian artery and vein at the root of the neck and enters the thorax by crossing in front of the origin of the internal thoracic artery, where it is joined by the pericardiophrenic branch of this artery.
- It then passes **anterior** to the root of the lung (hilum) lying between the mediastinal pleura and fibrous pericardium and supplying them.
- Eventually it reaches and supply the diaphragm, alongwith the associated pleura and peritoneum.
- Pain from an inflammation of the pericardium (pericarditis) is carried in the phrenic nerve.

ANS in Thorax

- The autonomic nervous system in the thorax consists of right and left sympathetic trunks and vagus nerves, and the cardiac, esophageal and pulmonary plexuses.
- Sympathetic trunks

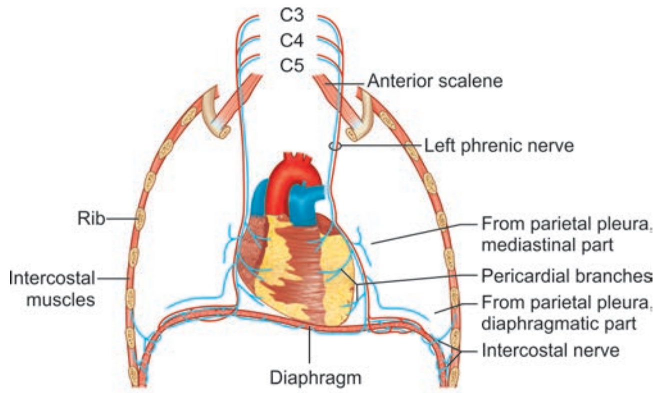


Fig. 35: Phrenic nerve: origin, course and supply.

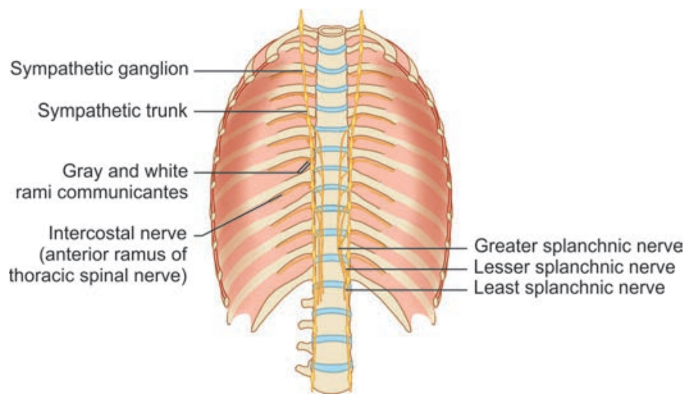


Fig. 36: Thoracic splanchnic nerves.

- The ganglionated sympathetic trunks lie **anterior to the heads of the ribs** and the posterior intercostal vessels.
- At the upper end sympathetic chain includes the cervicothoracic (or stellate) ganglion, which is formed by fusion of the inferior cervical ganglion with the first thoracic ganglion.
- At the lower end it enters the abdomen through the crus of the diaphragm or behind the medial lumbocostal arch.
- It gives rise to cardiac, pulmonary, mediastinal, and splanchnic branches and is connected to the thoracic spinal nerves by gray and white rami communicantes.
- **White Rami Communicantes c**ontain preganglionic sympathetic GVE (myelinated) fibers with cell bodies located in the lateral horn ((T1 to L2)) of the spinal cord and GVA fibers with cell bodies located in the dorsal root ganglia.
- They are connected to the spinal nerves, limited to the spinal cord segments between T1 and L2.
- **Gray Rami Communicantes c**ontain postganglionic sympathetic GVE (unmyelinated) fibers that supply the blood vessels, sweat glands, and arrector pili muscles of hair follicles.
- They are connected to every spinal nerve and contain fibers with cell bodies located in the sympathetic trunk.
- Many of the preganglionic axons that originate in the lower thoracic spinal segments (T5–12) do not synapse locally but enter the abdominal cavity as the thoracic splanchnic nerves; they synapse either in prevertebral ganglia, especially the coeliac ganglion, or around the medullary chromaffin cells of the suprarenal gland.
- **Thoracic Splanchnic Nerves** contain sympathetic preganglionic GVE fibers with cell bodies located in the lateral horn (intermediolateral cell column) of the spinal cord and GVA fibers with cell bodies located in the dorsal root ganglia.
- **Greater Splanchnic Nerve** arises usually from T5-9 sympathetic ganglia, perforates the crus of the diaphragm (or occasionally pass through the aortic hiatus), and ends in the celiac ganglion.
- **Lesser Splanchnic Nerve** is derived usually from the 10th and 11th thoracic ganglia, pierces the crus of the diaphragm, and ends in the aorticorenal ganglion.
- **Least Splanchnic Nerve i**s derived usually from the 12th thoracic ganglion, pierces the crus of the diaphragm, and ends in the ganglia of the renal plexus.

Parasympathetic Nervous System

- Vagus nerve contains the parasympathetic preganglionic fibers with cell bodies located in the medulla oblongata and the GVA fibers with cell bodies located in the inferior (nodose) ganglion.
- It carry preganglionic parasympathetic fibres from dorsal motor nucleus of the vagus in the medulla, contribute to pulmonary, cardiac and oesophageal plexuses and synapse in minute ganglia in the visceral walls.
- Cardiac branches are inhibitory to heart and vasoconstrictive.

- Pulmonary branches are motor (bronchoconstrictor) to the circular non-striated muscle fibres of the bronchi and bronchioles, and secretomotor to the mucous glands of the respiratory epithelium.
- Right Vagus Nerve descends at the right surface of the trachea and then posterior to the right main bronchus, forms the posterior vagal trunk (or gastric nerves) at the lower part of the esophagus and enters the abdomen through the esophageal hiatus.
- Left Vagus Nerve enters the thorax between the left common carotid and subclavian arteries and behind the left brachiocephalic vein and descends on the arch of the aorta.
  - It gives rise to the left recurrent laryngeal nerve, which hooks around the arch of the aorta to the left of the ligamentum arteriosum.
  - It ascends through the superior mediastinum and the neck in a groove between the trachea and esophagus.
  - It forms the anterior vagal trunk which enters the abdomen through the esophageal hiatus.

ASSESSMENT QUESTIONS

1. Intercostal nerve is a branch of: *(NEET Pattern 2015)*
a. Brachial plexus
b. Dorsal rami of thoracic spinal nerves
c. Ventral rami of thoracic spinal nerves
d. Ventral rami of cervical spinal nerves

2. All are true about intercostal nerves EXCEPT:
a. The relationship from above downward is nerve, vein, artery
b. T4, T5, T6 are called typical intercostal nerve
c. Lie between the innermost intercostal and internal intercostal muscle
d. T7 to T11 supply the abdominal wall

3. Intercostobrachial nerve is a branch of: *(JIPMER 2002)*
a. 1st intercostal nerve
b. 2nd intercostal nerve
c. 3rd intercostal nerve
d. Upper trunk of brachial plexus

4. TRUE about left phrenic nerve is: *(AIIMS)*
a. Arise from dorsal rami of C3,4,5
b. Descends in the left pleural space
c. Supplies mediastinal and diaphragmatic pleura on left side and diaphragmatic peritoneum
d. Passes through the vena caval opening in the diaphragm

5. All of the following are true about phrenic nerve EXCEPT:
a. It is a purely motor nerve
b. It arise mainly from C4 spinal nerve
c. It is formed at the lateral order of scalenus anterior
d. Accessory phrenic nerve is commonly a branch from the nerve to subclavius

6. A female come with complaints of chest pain. On examination she is found to have pericarditis with pericardial effusion. The pain is mediated by: *(AIIMS 2007)*
a. Deep cardiac plexus
b. Superficial cardiac plexus
c. Phrenic nerve
d. Subcostal nerve

7. All is true about phrenic nerve EXCEPT:
a. Right is shorter and more vertical
b. Sole motor supply to diaphragm
c. Passes anterior to scalenus anterior
d. Passes posterior to hilum of lung

8. Left phrenic nerve runs: *(AIIMS 2009)*
a. Anterior to scalenus anterior
b. Posterior to brachial plexus
c. Posterior to subclavian artery
d. Behind the left hilum

ANSWERS WITH EXPLANATIONS

1. c. Ventral rami of thoracic spinal nerves
- Anterior (ventral) primary ramus of upper 11th thoracic spinal nerves give intercostal nerves and ventral ramus of T12 is called subcostal nerve.

2. a. The relationship from above downward is nerve, vein, artery
- The relationship from above downward is vein, artery, nerve.

3. b. 2nd intercostal nerve
The lateral cutaneous branch of the 2nd intercostal nerve is called Intercostobrachial nerve.
- It supplies the skin of the floor of axilla and upper part of the medial aspect of arm.
- It is often the source of referred cardiac pain.
- The intercostabrachial nerve may sometimes divided in axillary node clearance (ANC), such as that done for breast cancer surgery which requires the removal of the axillary nodes.

4. c. Supplies mediastinal and diaphragmatic pleura on left side and diaphragmatic peritoneum
- Phrenic nerve arises from the anterior primary rami of C-2,3,4, descends lying between the mediastinal pleura and fibrous pericardium and supply diaphragm.

5. a. It is a purely motor nerve
- Phrenic nerve is a mixed (sensory motor nerve).

6. c. Phrenic nerve
- The pain of pericarditis originates in the parietal layer only and is transmitted by the **phrenic nerve**.
- The fibrous and parietal layer of serous pericardium are supplied by the phrenic nerve, visceral layer is insensitive.

7. d. Passes posterior to the hilum of lung
- Phrenic nerve passes anterior to the hilum of lungs, vagus nerve passes posterior to it.
- Diaphragm receives somatic motor fibers solely from the phrenic nerve; its central part receives sensory fibers from the phrenic nerve, whereas the peripheral part is supplied by intercostal nerves.
- Right dome of diaphragm is at higher level (pushed up by liver) and the left dome of diaphragm is lower (pushed down by heart).

8. a. Anterior to scalenus anterior
- Both the phrenic nerves pass anterior to the scalenus anterior muscle in the neck.
- The nerves also cross the subclavian artery anteriorly.
- The nerves lie medial to the trunks of brachial plexus in the neck.
- Both the phrenic nerves pass anterior to the hila of both the lungs respectively on each side.
- Vagus nerve passes posterior to the hilum of the lung.

Arterial Supply

Thoracic wall receive their blood supply from the internal thoracic artery (either directly or via the musculophrenic artery), the superior intercostal artery (from the costocervical trunk), superior thoracic artery (from the axillary artery), descending thoracic aorta, and the subcostal artery.

- Additional contributions come from vessels that supply the proximal muscles of the upper limb, namely: suprascapular, superficial cervical, thoraco-acromial, lateral thoracic and subscapular arteries.
- **Internal Thoracic Artery** arises from the first part of the subclavian artery and descends directly behind the first six costal cartilages, just lateral to the sternum.
  - It gives two anterior intercostal arteries in each of the upper six intercostal spaces and terminates at the sixth intercostal space by dividing into the musculophrenic and superior epigastric arteries.
  - Branches of internal thoracic artery are (i) mediastinal branches,(ii) pericardial branches,(iii) sternal branches, (iv) pericardiophrenic branches, (v) anterior intercostal arteries (in upper six spaces), (vi) perforating branches ,and (vii) two terminal branches ,musculophrenic and superior epigastric arteries.
- Pericardiophrenic artery accompanies the phrenic nerve between the pleura and the pericardium to the diaphragm and supplies the pleura, pericardium, and diaphragm (upper surface).
- Anterior intercostal arteries that supply intercostal spaces 1 to 6 are branches of the internal thoracic artery, 7 to 9 are given by the musculophrenic artery.
  - There are two anterior intercostal arteries in each of the intercostal spaces that run laterally, one each at the upper and lower borders of each space.
  - The upper artery in each intercostal space anastomoses with the posterior intercostal artery, and the lower one joins the collateral branch of the posterior intercostal artery.
  - They give muscular branches to the intercostal, serratus anterior, and pectoral muscles.
  - Their anterior Perforating Branches(second, third, and fourth) give medial mammary branches to breast.
- Musculophrenic Artery follows the costal arch on the inner surface of the costal cartilages, gives rise to two anterior arteries in the seventh, eighth, and ninth spaces; perforates the diaphragm; and ends in the 10th intercostal space, where it anastomoses with the deep circumflex iliac artery.
  - It supplies the pericardium, diaphragm, and muscles of the abdominal wall.
- Superior Epigastric Artery descends on the deep surface of the rectus abdominis muscle within the rectus sheath; supplies this muscle and anastomoses with the inferior epigastric artery.
  - It supplies the diaphragm, peritoneum, and anterior abdominal wall.
- Posterior intercostal arteries that supply intercostal spaces 1 and 2 are branches of the superior intercostal artery (that arises from the costocervical trunk of the subclavian artery), spaces 3 to 11 are branches of the thoracic aorta.
  - All posterior intercostal arteries give off a posterior branch, which travels with the dorsal primary ramus of a spinal nerve to supply the spinal cord, vertebral column, back muscles, and skin.
  - The posterior intercostal arteries anastomose anteriorly with the upper anterior intercostal arteries.
  - Right posterior intercostal arteries are longer than the left.

Table 10: Arterial supply of thoracic wall

Artery	Origin	Course	Distribution
Posterior intercostals	Superior intercostal artery (intercostal spaces 1 and 2) and thoracic aorta (remaining intercostal spaces)	Pass between internal and innermost intercostal muscles	Intercostal muscles, overlying skin, and parietal pleura
Anterior intercostals	Internal thoracic (intercostal spaces 1–6) and musculophrenic arteries (intercostal spaces 7–9)		
Internal thoracic	Subclavian artery	Passes inferiorly and lateral to sternum between costal cartilages and transversus thoracic muscle to divide into superior epigastric and musculophrenic arteries	By way of anterior intercostal arteries to intercostal spaces 1–6 and musculophrenic artery (lateral terminal branch)
Subcostal	Thoracic aorta	Courses along inferior border of 12th rib	Muscles of anterolateral abdominal wall

Aorta

Ascending Aorta arises from the left ventricle within the pericardial sac and ascends behind the sternum to end at the level of the sternal angle (approximately).

- It lies in the middle mediastinum, has three aortic sinuses located immediately above the cusps of the aortic valve, and gives off the right and left coronary artery.
- Arch of aorta continues from the ascending aorta. Its origin, slightly to the right, is level with the superior border of the right second sternocostal joint.
- It runs upwards, backwards, and to the left, in front of the bifurcation of the trachea then turns downwards behind the left bronchus finally descending to the left of the fourth thoracic vertebral body, continuing as the descending thoracic aorta.
- It terminates level with the sternal end of the left second costal cartilage and so lies wholly within the superior mediastinum (behind the lower half of manubrium sterni).
- It gives three branches: Brachiocephalic, left common carotid, and left subclavian arteries.
- Origin and termination of arch of aorta is at the same level (T4 vertebra).

Thoracic aorta begins at the level of the fourth thoracic vertebra.

- It descends on the left side of the vertebral column and then approaches the median plane to end in front of the vertebral column by passing through the aortic hiatus of the diaphragm (T12 vertebral level).
- It gives origin to nine pairs of posterior intercostal arteries and one pair of subcostal arteries.
- It also gives rise to pericardial, bronchial (one right and two left), esophageal, mediastinal, and superior phrenic branches.

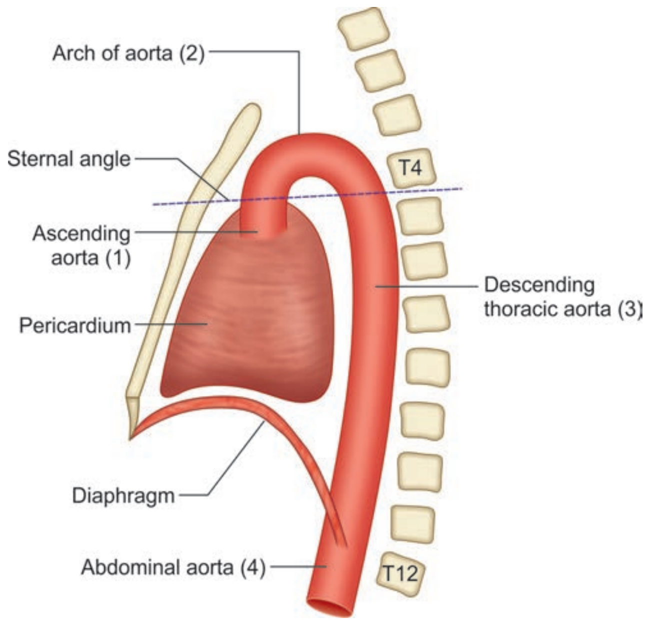
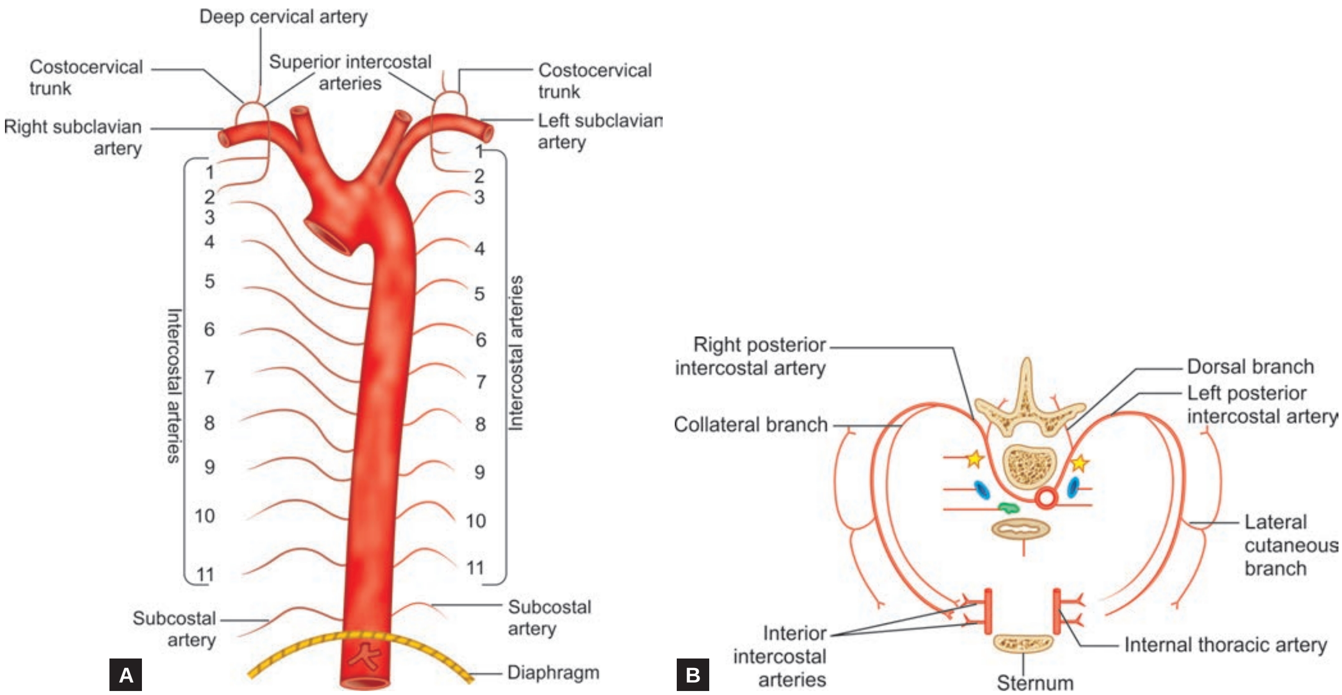


Fig. 37: Parts of the thoracic aorta.

Table 11: Aorta and its branches in thorax

Artery	Origin	Course	Branches
Ascending aorta	Aortic orifice of left ventricle	Ascends approximately 5 cm of sternal angle where it becomes arch of aorta	Right and left coronary arteries
Arch of aorta	Continuation of ascending aorta	Arches posteriorly on left side of trachea and esophagus and superior to left main bronchus	Brachiocephalic, left common carotid, left subclavian
Thoracic (descending) aorta	Continuation of arch of aorta	Descends in posterior mediastinum of left of vertebral column; gradually shifts to right to lie in median plane at aortic hiatus	Posterior intercostal arteries, subcostal, some phrenic arteries and visceral branches (e.g., esophageal)
Posterior intercostal	Posterior aspect of thoracic aorta	Pass laterally and then anteriorly parallel to ribs	Lateral and anterior cutaneous branches
Bronchial (1–2 branches)	Anterior aspect of aorta or posterior intercostal artery	Run with the tracheobronchial tree	Bronchial and peribronchial tissue, visceral pleura
Esophageal (4–5 branches)	Anterior aspect of thoracic aorta	Run anteriorly to esophagus	To esophagus
Superior phrenic (vary in number)	Anterior aspects of thoracic aorta	Arise at aortic hiatus and pass to superior aspect of diaphragm	To diaphragm



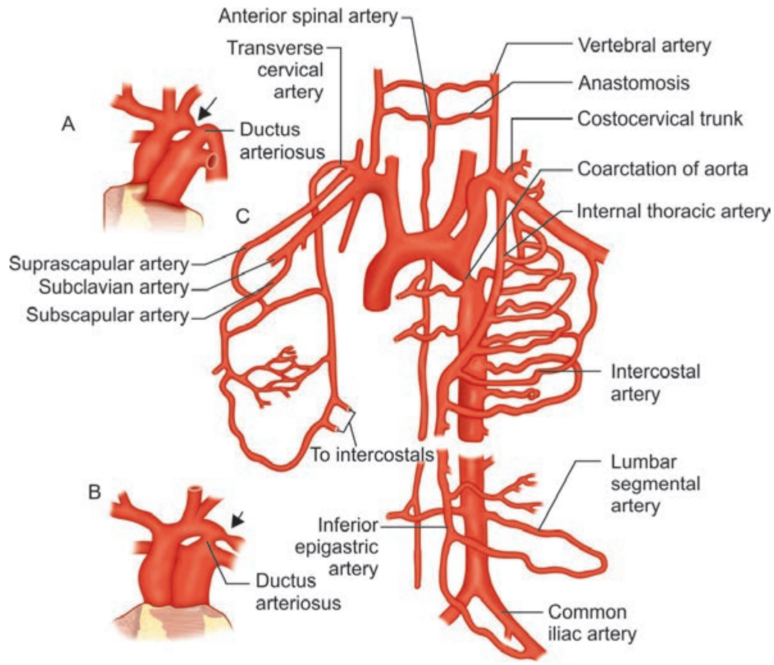
Figs. 38A and B: Posterior intercostal arteries: (A) Origin; (B) Course and relations.

Applied anatomy

- **Coarctation** (stenosis/narrowing) of aorta is due to defect in the tunica media, which forms a shelf-like projection into the lumen, most commonly in the region of the ductus arteriosus.
- It is of three types:
  1. Pre-ductal coarctation: The narrowing is proximal to the ductus arteriosus. If severe, blood flow to the aorta distal (to lower body) to the narrowing is dependent on a patent ductus arteriosus, and hence its closure can be life-threatening.
  2. Ductal coarctation: The narrowing occurs at the insertion of the ductus arteriosus. This kind usually appears when the ductus arteriosus closes.
  3. Post-ductal coarctation: The narrowing is distal to the insertion of the ductus arteriosus. Even with an open ductus arteriosus blood flow to the lower body can be impaired.

The postductal type of coarctation has been attributed to abnormal extension of the ductal tissue into the aortic wall, stenosing both vessels as the duct contracts after birth.

- This form may permit years of normal life, allowing the development of an extensive collateral circulation to the aorta distal to the stenosis.
- Arch of aorta → subclavian artery → internal thoracic artery → **anterior intercostal artery**→ **posterior intercostal artery**→ descending thoracic aorta→ thorax, abdomen, pelvis and lower limb.
- Arch of aorta → subclavian artery → costocervical trunk→ **superior intercostal artery**→ **third posterior intercostal artery** → descending thoracic aorta→ → thorax, abdomen, pelvis and lower limb.
- Scapular anastomosis → dorsal scapular artery→ **posterior intercostal artery**→ **descending thoracic aorta**→ thorax, abdomen, pelvis and lower limb.
- Arch of aorta → subclavian artery → internal thoracic artery→ **superior epigastric artery**→ **inferior epigastric artery** iliac artery→ Pelvis and lower limb.
- Arch of aorta → subclavian artery → **vertebral artery**→ **anterior spinal artery**→ segmental artery→ thoracic and abdominal aorta → thorax, abdomen, pelvis and lower limb.
- Clinical signs include hypertension and heart failure. It causes
  (a) A characteristic rib notching (3-8 ribs) and a high-risk of cerebral hemorrhage;
  (b) Tortuous and enlarged blood vessels, especially the internal thoracic, intercostal, epigastric, and scapular arteries; enlargement of the scapular vessels and anastomoses may lead to widespread interscapular pulsation (easily appreciated with the palm of the hand).
  (c) An elevated blood pressure in the radial artery and decreased pressure in the femoral artery; and
  (d) The femoral pulse to occur after the radial pulse (normally the femoral pulse occurs slightly before the radial pulse).



Figs. 39A to C: Collaterals in coarctation of aorta.

ASSESSMENT QUESTIONS

1. **Branches of internal thoracic artery are all EXCEPT:** *(NEET Pattern 2015)*
   a. Superior epigastric
   b. Musculophrenic
   c. Anterior intercostal
   d. Posterior intercostal

2. **Superior intercostal artery is a branch of:**
   a. Costocervical trunk
   b. Dorsal scapular artery
   c. Thyrocervical trunk
   d. Internal thoracic artery

3. **Upper two posterior intercostal arteries arise from:** *(NEET Pattern 2015)*
   a. Aorta
   b. Superior intercostal artery
   c. Internal mammary artery
   d. Bronchial artery

4. **True about anterior intercostal artery:** *(NEET Pattern 2015)*
   a. Present in 1st to 12th intercostal space
   b. Each intercostal space has two anterior intercostal arteries
   c. Branch of internal thoracic artery
   d. Branch of aorta

5. **Vasa Vasorum of ascending aorta arises from:** *(NEET Pattern 2015)*
   a. Left coronary artery
   b. Anterior interventricular artery
   c. Posterior interventricular artery
   d. Left atrium

6. **In post ductal coarctation of aorta, which of the following distal anastomotic artery is NOT involved?** *(AIIMS 2008)*
   a. Vertebral arteries
   b. Axillary arteries
   c. Subscapular/suprascapular artery
   d. Posterior intercostal artery

7. **In post-ductal Coarctation of the aorta, blood flow to the lower limbs in maintained by increased blood flow through:** *(AIIMS 2007)*
   a. Inferior Phrenic and pericardio phrenic artery
   b. Intercostal and Superior epigastric artery
   c. Sub costal and Umbilical artery
   d. Vertebral and anterior spinal artery

8. **In post ductal coarctation of aorta, collaterals are formed by all EXCEPT:** *(AIIMS 2008, AIPG 2010)*
   a. Vertebral artery
   b. Suprascapular artery
   c. Posterior Intercostal artery
   d. Internal Thoracic artery

ANSWERS WITH EXPLANATIONS

1. **d. Posterior intercostal**
   - Posterior intercostal arteries are branches of descending thoracic aorta.
2. **a. Costocervical trunk**
   - Superior (highest) intercostal artery is a branch of costocervical trunk and descends in front of the neck of the first two ribs and gives rise to posterior intercostal arteries to the first two intercostal spaces.
3. **b. Superior intercostal artery**
   - 1st and 2nd posterior intercostal arteries are branches of superior intercostal artery (a branch of costocervical trunk form 2nd part of subclavian artery).
4. **b. Each intercostal space has two anterior intercostal arteries**
   - Each of upper nine intercostal spaces (1 to 9) have one posterior and two anterior intercostal arteries.
   - The 10th and 11th spaces have one posterior intercostal artery, but no anterior intercostal artery.
   - Anterior intercostal arteries for upper six spaces arise from internal thoracic artery.
   - For 7th to 9th spaces, these are branches of musculophrenic artery.

5. a. Left coronary artery

Vasa vasorum originates from the coronary arteries in the ascending aorta, from the great vessels of the neck in the aortic arch, and from the intercostal arteries branches of the thoracic aorta.

6. a. Vertebral arteries

- This is a controversial question, with no answer, as all of the given arteries participate in the anastomosis.
- Since Gray's anatomy has no mention of vertebral artery in the topic, that has been taken as the answer of choice.

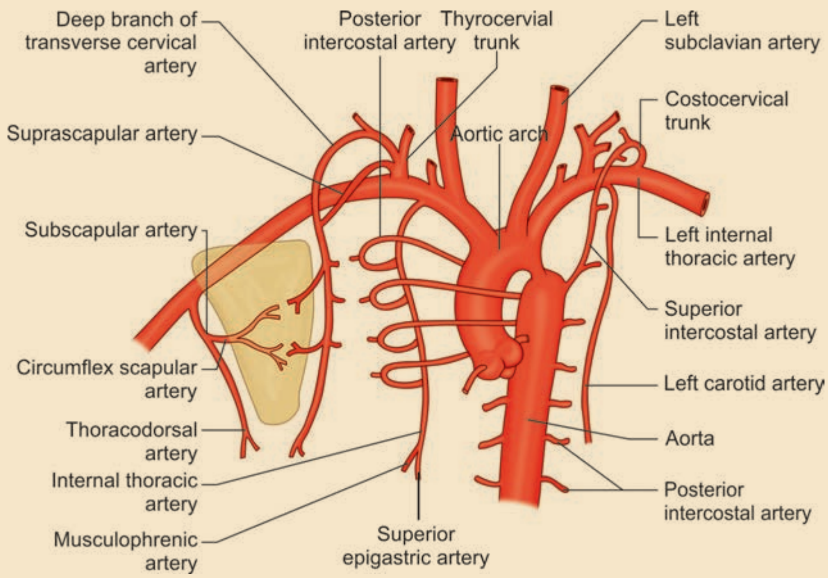


Fig. 40: Collaterals in co-arctation of aorta.

7. b. Intercostal and Superior epigastric artery > d. Vertebral and anterior spinal artery

- In post-ductal coarctation of aorta, an extensive collateral circulation develops involving the branches of subclavian and axillary arteries with the distal arteries given by aorta e.g., posterior intercostal arteries.
- The purpose of this extensive collateral circulation is to send blood into the distal branches of the aorta namely – posterior intercostals and iliac arteries.
- The enlarged branches of subclavian artery are suprascapular, costocervical trunk (first and second posterior intercostals) and the internal thoracic arteries.
- The branches of axillary artery involved are thoraco-acromial, lateral thoracic and the subscapular.
- The internal thoracic arteries give anterior intercostal arteries and the superior epigastric arteries.
- Anterior intercostals carry blood to the posterior intercostals and thence into the descending aorta.
- The superior epigastric artery anastomoses with the inferior epigastric (in the rectus sheath) and sends blood into the external iliac artery and thence mainly towards the lower limb.
- High vascularity is observed in the anterior thoracic wall as well as over the posterior thoracic wall, especially in the interscapular area.
- Scapular anastomosis is opened up and both the scapulae become pulsatile.
- Radiographic evidence of 'Rib notching' is seen in the inferior margins of the ribs due to greatly enlarged posterior intercostal arteries.
- Also the radiographic shadow of enlarged left subclavian artery is quite evident clinically.
- Lower limb may be supplied by the channel:
  - Arch of aorta → subclavian artery → internal thoracic artery → superior epigastric artery → inferior epigastric artery iliac artery → Pelvis and lower limb.
  - Arch of aorta → subclavian artery → internal thoracic artery → anterior intercostal artery → posterior intercostal artery → descending thoracic aorta → thorax, abdomen, pelvis and lower limb.
  - Arch of aorta → subclavian artery → vertebral artery → anterior spinal artery → segmental artery → thoracic and abdominal aorta → thorax, abdomen, pelvis and lower limb.

8. a. Vertebral artery

- This question has no answer, as all of the given arteries participate in the anastomosis.
- Since Gray's anatomy has no mention of vertebral artery in the topic, that becomes the answer of choice.

Venous Drainage

The intercostal veins accompany the similarly named arteries in the intercostal spaces.

- The small anterior intercostal veins are tributaries of the internal thoracic and musculophrenic veins; the internal thoracic veins drain into the appropriate brachiocephalic vein.
- The posterior intercostal veins drain backwards, and most drain directly or indirectly into the azygos vein on the right and the hemiazygos or hemiazygos veins on the left.
- **Internal Thoracic Vein** is formed by the confluence of the superior epigastric and musculophrenic veins, ascends on the medial side of the artery, receives the upper six anterior intercostal and pericardiophrenic veins, and ends in the brachiocephalic vein.

- **Thoracoepigastric Vein** is a venous communication between the lateral thoracic vein and the superficial epigastric vein (or femoral vein) that runs superficially on the anterolateral aspect of the trunk.
- This vein connects the inferior and superior caval areas of drainage and may be dilated and visible in cases of vena caval obstruction.
- **Superior Vena Cava** is formed by the union of the right and left brachiocephalic veins and drains blood from all structures superior to the diaphragm (EXCEPT the lungs and heart).
- It descends on the right side of the ascending aorta, receives the azygos vein, and enters the right atrium.
- Its upper (extra-pericardial) part lies in the superior mediastinum and lower (intra-pericardial) part in the middle mediastinum.
- Superior vena cava forms at right first costal cartilage, pierces the pericardium at the level of the right 2nd costal cartilage, and terminates into the right atrium at the lower border of the right 3rd costal cartilage (Mnemonic: 1, 2, 3).

Azygos venous system

- **Azygos** (unpaired) **vein** is formed by the union of the **right subcostal** and **right ascending lumbar** veins.
- Its lower end communicates with IVC.
- It enters the thorax by passing through the right crus of diaphragm (through the aortic opening sometimes).
- It arches over the root of the right lung and empties into the SVC (T4 vertebra; costal cartilage 2).
- It is the first tributary of SVC.
- Tributaries of the azygos vein are: Lower 7 right posterior intercostal veins, right superior intercostal vein (formed by union of 2nd, 3rd, and 4th right posterior intercostal veins), hemiazygos vein (at the level of T7/8 vertebra), accessory hemiazygos vein (at the level of T8/9 vertebra), right bronchial vein, esophageal veins, mediastinal veins, pericardial veins.

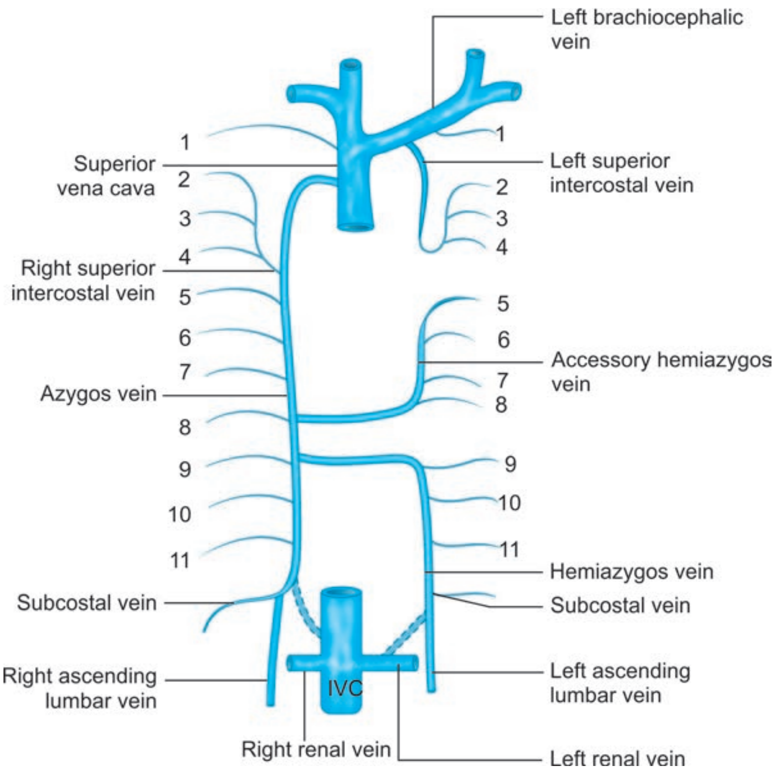


Fig. 41: Venous drainage of thoracic region: Azygous venous system.

- **Hemiazygos Vein** represents the left-sided equivalent of the more inferior part of the azygos vein.
- It **is** formed by the union of the left subcostal and ascending lumbar veins.
- Its lower end may be connected to the left renal vein.
- It ascends on the left side of the vertebral bodies, pass through the left crus of diaphragm, receives the lower posterior intercostal veins (9th, 10th, and 11th).
- It crosses the midline to drain into azygous vein (at the level of T8 vertebra).
- **Accessory Hemiazygos Vein** is the left-sided mirror image of the superior portion of the azygos vein.
- It begins at the fourth or fifth intercostal space; descends, receiving the 5th to 8th intercostal veins.
- It drains into azygous vein (at the level of T7/8 vertebra).
- **Superior Intercostal Vein i**s formed by the union of the 2nd to 4th posterior intercostal veins and drains into the azygos vein on the right and the brachiocephalic vein on the left.
- **Posterior Intercostal Veins** run in the costal groove of the rib and majorly drain the thoracic wall.

Table 12: Mode of termination of right and left posterior intercostal veins	
Right posterior intercostal veins	**Left posterior intercostal veins**
1st (highest) drains into the right brachiocephalic vein	1st (highest) drains into left brachiocephalic vein
2nd, 3rd, and 4th join to form right superior intercostal vein, which in turn drains into the azygos vein	2nd, 3rd, and 4th join to form left superior intercostal vein, which in turn drains into left brachiocephalic vein
5th-11th drain into the azygos vein	5th–8th drain into accessory azygos vein 9th–11th drain into hemiazygos vein
Subcostal vein drains into the azygos vein	Subcostal vein drains into the hemiazygos vein

Collateral pathways in **vena cava obstruction**

- The SVC may be obstructed at two sites: Above the opening of azygos vein (superior mediastinum) or below the opening of azygos vein (middle mediastinum).
- In case of SVC obstruction **above the opening of azygos vein**, the venous blood from the upper half of the body is shunted to right atrium through azygos vein.
- The collateral channel is: Subclavian vein→ Internal thoracic vein → anterior intercostal vein→ posterior intercostal vein → azygous vein → SVC.
- In case SVC obstruction is below the opening of the azygos vein, the venous blood from the upper half of the body is returned to the right atrium through inferior vena cava through various collateral pathways, formed between the tributaries of superior and inferior vena cavae (caval-caval shunt).
- The patient develops prominent subcutaneous anastomotic venous communications due to dilatation of various anastomotic venous channels between upper and lower body. Few of them are shown below:
  - SVC → Azygous vein → lumbar azygous vein/ ascending lumbar vein → IVC.
  - SVC → subclavian vein→ internal thoracic vein→ **superior epigastric vein**→ **inferior epigastric vei**n→ iliac vein→ IVC.
  - SVC → subclavian vein→ axillary vein→ lateral thoracic vein→ **thoracoepigastric vein** → superficial epigastric vein→ femoral vein→ IVC.
  - In a corresponding manner, in **IVC Obstruction** as well, the same anastomosing channels are dilated between IVC and SVC (caval–caval shunt) so that the blood could be returned to the right atrium.

Table 13: Veins draining into SVC and IVC	
Veins draining into SVC	**Veins draining into IVC**
• Superior epigastric - internal thoracic vein - subclavian vein • Lateral thoracic vein - axillary vein • Posterior intercostal vein- azygous and hemiazygous veins	• Inferior epigastric vein - external iliac vein • Superficial epigastric - great saphenous - femoral vein • Superficial circumflex iliac - femoral vein • Deep circumflex iliac - external iliac vein • Iliolumbar vein - common iliac vein

ASSESSMENT QUESTIONS

1. Left superior intercostal vein drains into: *(NEET Pattern 2015)*
a. Azygous vein
b. Hemiazygous vein
c. Left brachiocephalic vein
d. Innominate vein

2. In IVC obstruction, all of the following collaterals help EXCEPT: *(AIIMS 2006)*
a. Superior epigastric and inferior epigastric vein
b. Superficial epigastric and iliolumbar vein
c. Azygous and ascending lumbar vein
d. Lateral thoracic and prevertebral vein

3. Superior vena cava opens into right atrium at the level of: *(NEET Pattern 2012)*
a. T1
b. T3
c. T4
d. T5

4. IVC obstruction presents with:
a. Oesophageal varices
b. Haemorrhoids
c. Para-umbilical dilatation
d. Thoraco-epigastric dilatation

5. Which of the following veins drains into the brachiocephalic vein?
a. Internal thoracic vein
b. Hemiazygos vein
c. Right superior intercostal vein
d. Left superior intercostal vein

6. The last tributary of the azygos vein is: *(NEET Pattern 2014)*
a. Right superior intercostal vein
b. Hemi-azygos vein
c. Right bronchial vein
d. Accessory azygos vein

7. Hemiazygous vein crosses left to right at the level of: *(NEET Pattern 2012)*
a. T8
b. T10
c. T12
d. T6

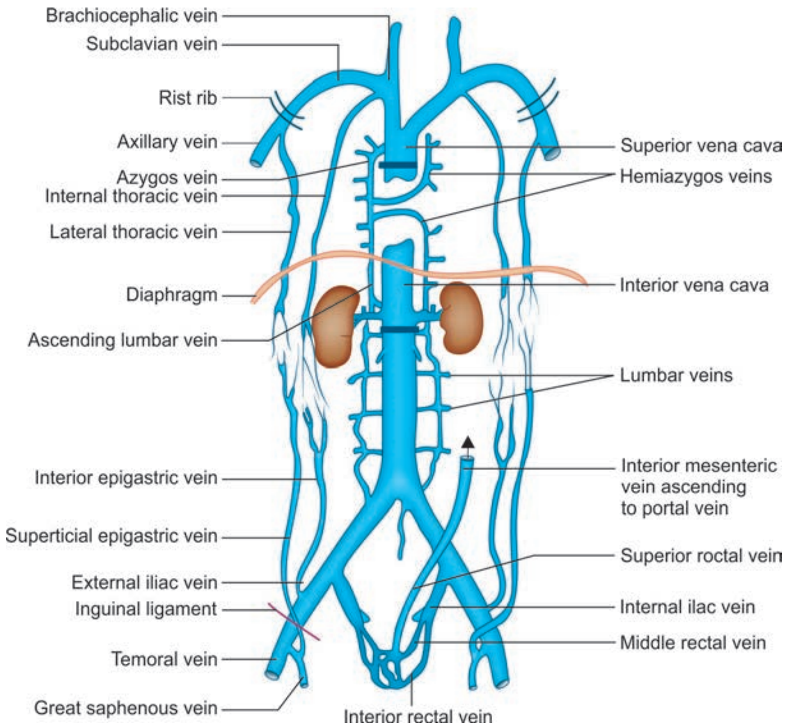


Fig. 42: Collaterals channels in SVC or IVC obstruction.

ANSWERS WITH EXPLANATIONS

1. c. Left brachiocephalic vein
- **Left superior intercostal vein** drains into the **left brachiocephalic vein,** whereas, right superior intercostal vein drains into azygous vein.

2. b. Superficial epigastric and iliolumbar vein
- In IVC obstruction, collaterals open up to drain blood into SVC and thence to the heart (right atrium).
- Since, **superficial epigastric and iliolumbar vein** both drain into IVC, they are not helping the cause.

3. d. T5
- Superior vena cava enters the right atrium at the level of T5 vertebra.
- Extent of the heart in supine posture is T5-8 vertebra.
- IVC opens into right atrium at the level of T8 vertebra.

4. d. Thoraco-epigastric dilatation
- In IVC obstruction the blood needs to be drained into SVC through various collaterals.
- One of the collateral channel is: IVC → femoral vein → superficial epigastric vein → **thoracoepigastric vein** → lateral thoracic vein → axillary vein → subclavian vein → SVC.

5. d. Left superior intercostal vein
- First posterior intercostal vein on each side drains into brachiocephalic vein.
- Posterior intercostal veins of left intercostal space 2, 3 and 4 drains into the left superior intercostal vein, which itself drains into the left brachiocephalic vein.
- Internal thoracic vein drains into subclavian vein.
- Hemi-azygous vein drains into azygous vein.

6. c. Right bronchial vein
- Right bronchial vein opens into the azygous vein near its termination into SVC.

7. a. T8
- At T8 vertebra hemiazygous vein turns to the right and crosses (in front of the vertebral column) posterior to the aorta, esophagus and thoracic duct to terminate in the azygos vein.

Lymphatic Drainage

Superficial lymphatic vessels of the thoracic wall ramify subcutaneously and converge on the axillary nodes.
- Lymph vessels from deeper tissues of the thoracic walls drain mainly to the parasternal, intercostal and diaphragmatic lymphatic nodes.
- Sternal or Parasternal (Internal Thoracic) nodes are placed along the internal thoracic artery.
- They receive lymph from the medial portion of the breast, intercostal spaces, diaphragm, and supraumbilical region of the abdominal wall.
- Their drainage is into the junction of the internal jugular and subclavian veins.

- Intercostal Nodes lie near the heads of the ribs, receive lymph from the intercostal spaces and the pleura and drain into the cisterna chyli or the thoracic duct.
- Phrenic Nodes lie on the thoracic surface of the diaphragm, receive lymph from the pericardium, diaphragm, and liver and drain into the sternal and posterior mediastinal nodes.

Thoracic Wall

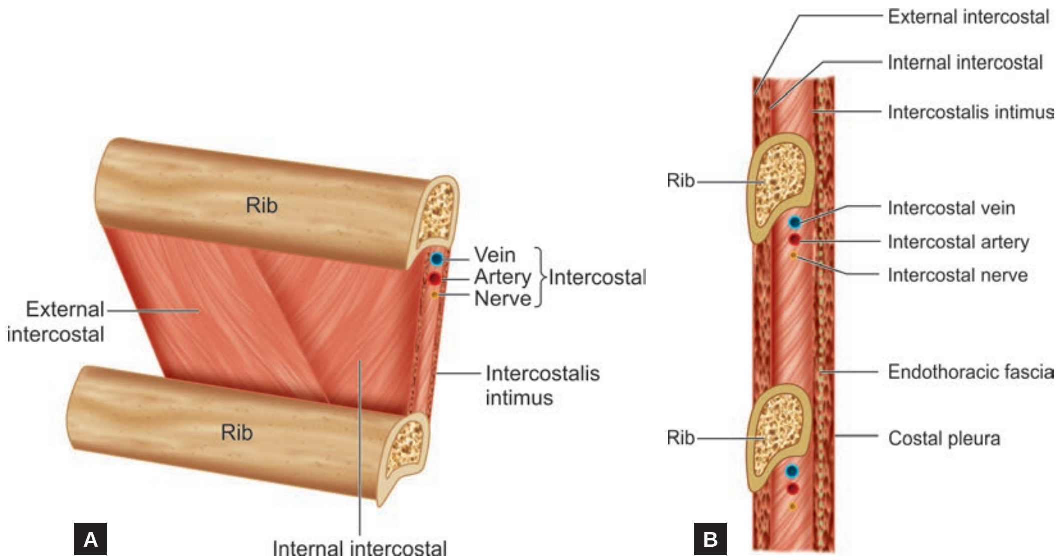
Intercostal space

There are eleven intercostal spaces that lie between the two adjacent ribs (and their costal cartilages). The 3rd–6th spaces are called typical intercostal spaces because the blood and nerve supply of 3rd–6th intercostal spaces is confined only to thorax.

Contents

Three intercostal muscles: External intercostal, internal intercostal and innermost intercostal (intercostalis intimi).

The neurovascular bundle (Intercostal nerves, arteries, veins and lymphatics) lies between the internal intercostal and innermost intercostal muscles. The arrangement of the structures is Intercostal Vein → Artery → Nerve (Mnemonic VAN goes down, superior to inferior).



Figs. 43A and B: (A) Contents of the intercostal space as seen in dissection; (B) Contents of the intercostal space as seen in vertical section.

Intercostal Drainage

- Thoracentesis (pleuracentesis or pleural tap) is a surgical procedure to collect pleural effusion for analysis. A needle or tube is inserted through thoracic wall into the pleural cavity posterior to the midaxillary line one or two intercostal spaces below the fluid level but not below the 9th space.
- The ideal site is seventh, eighth, or ninth intercostal space, as this site avoids possible accidental puncture of the lung, liver, spleen, and diaphragm. To avoid damage to the intercostal nerve and vessels, the needle is inserted superior to the rib, high enough to avoid the collateral branches.
- The needle penetrates the following structures: Skin → superficial fascia → serratus anterior muscle → external intercostal muscle→ internal intercostal muscle → innermost intercostal muscle → endothoracic fascia → parietal pleura.
- Few authors mention posterior mid-scapular line as a common site for aspiration.

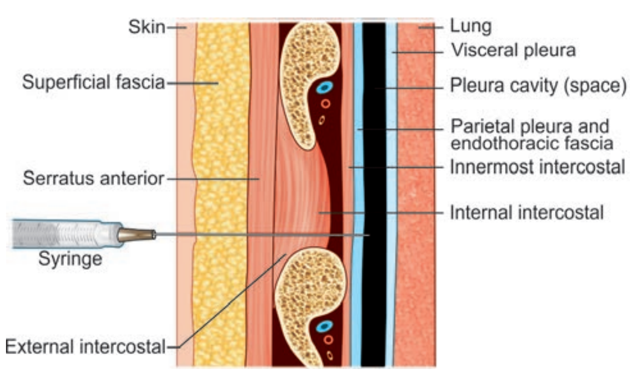


Fig. 44: Intercostal drainage for pleural aspiration.

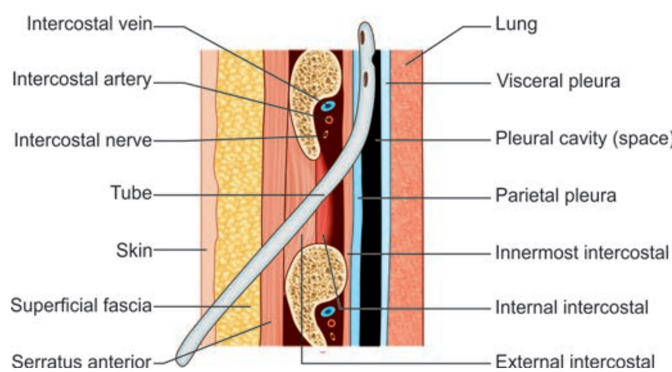


Fig. 45: Tube thoracostomy.

Chest drain insertion

The insertion site for a chest drain is usually the fifth intercostal space, just anterior to the mid-axillary line on the affected side. A 2 cm horizontal incision is followed by blunt dissection through the subcutaneous tissues to the top of the rib. The parietal pleura is punctured with the tip of a clamp, and a gloved finger is inserted into the pleural space to free up any adhesions. The chest drain (thoracostomy tube) is then inserted into the pleural space and attached to an underwater sealed container placed below the level of the lungs.

Tension pneumothorax

A needle is inserted into the second intercostal space in the mid-clavicular line on the side of the tension pneumothorax, with the patient in an erect position.

Intercostal Nerve Block is performed to relieve pain associated with a rib fracture or herpes zoster (shingles). A needle is inserted at the posterior angle of the rib along the lower border of the rib in order to inject the anaesthetic near the intercostal nerve. In addition, the collateral branches of the intercostal nerve are also anesthetized.

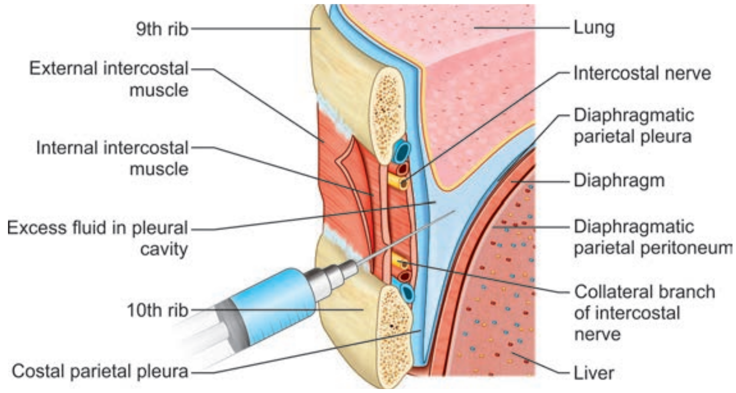


Fig. 46: Intercostal nerve block.

ASSESSMENT QUESTIONS

1. **While doing thoracentesis, it is advisable to introduce needle along:** *(AIPG)*
   a. Upper border of the rib
   b. Lower border of the rib
   c. In the center of the intercostal space
   d. In anterior part of intercostal space

2. **Pleural tapping in the mid axillary line, muscle not pierced is:** *(AIIMS 2007)*
   a. External intercostal
   b. Internal intercostal
   c. Innermost intercostal
   d. Transversus thoracis

ANSWERS WITH EXPLANATIONS

1. **a. Upper border of the rib**
   In thoracentesis, the needle should pass along the upper border of the rib (in the lower part of the space), to avoid injury to the neurovascular bundle running (in costal groove) close to the lower border of ribs .
   - While giving intercostal block, the needle is passed along the inferior border of rib (unlike pleural aspiration), so that the anaesthetic drug reaches the intercostal nerve well.
   - The intercostal nerve lies in the costal groove most inferiorly, below the corresponding vessels.

2. **d. Transversus thoracis**
   - **Transversus thoracis** lies anteriorly (**not** in the mid-axillary line).
   - Transverse thoracis originates from mediastinal surface of sternum and of xiphoid process and insert into cartilages of second to sixth ribs.
   - Inner most muscular plane has three named muscles: a) Innermost intercostals are at the side of the rib cage, b) Subcostalis are at the back and c) Transversus thoracis at the front of the thoracic cage.
   - Transversus thoracis muscle was formerly called as sterno-costalis, more exactly.
   - Recent literature describes transversus thoracis as including all the three inner layer muscles, namely - subcostalis, innermost intercostal (intercostalis intimi) and the sterno-costalis

Muscles

Intrinsic and extrinsic muscles

- The intrinsic muscles of the chest wall are the intercostal muscles, subcostalis, transversus thoracis, levator costarum and serratus posterior superior and inferior.
- The intercostal muscles occupy each of the intercostal spaces and are named according to their surface relations, i.e. external, internal and innermost.
- All EXCEPT levator costarum are innervated by the adjacent intercostal nerves derived from the ventral rami of the thoracic spinal nerves; levator costarum are supplied by the dorsal rami of the thoracic spinal nerves.

- The intrinsic muscles elevate or depress the rib and are active in forced respiration; primarily they stiffen the chest wall, preventing paradoxical movement during inspiration.
- Thoracic wall provides extensive attachment for muscles associated functionally with the neck, upper limbs, back and abdomen.
- Some of them (scalene, infrahyoid strap muscles, sternocleidomastoid, serratus anterior, pectoralis major and minor, external and internal oblique, and rectus abdominis) function as accessory muscles of respiration and are active only during forced respiration; scalenus medius is active in quiet inspiration.

Table 14: Muscles of thoracic wall

Muscle	Superior attachment	Interior attachment	Innervation	Main action
Serratus posterior superior	Nuchal ligament, spinous processes of C7 to T3 vertebrae	Superior borders of 2nd to 4th ribs	2nd to 5th intercostal nerve	Proprioception (elevate ribs)[b]
Serratus posterior inferior	Spinous processes of T11 to L2 vertebrae	Inferior borders of 8th to 12th ribs near their angles	Anterior rami to T9 to T12 thoracic spinal nerve	Proprioception (depress ribs)[b]
Levator costarum	Transverse processes of T7–11	Subjacent ribs between tubercle and angle	Posterior primary rami of C8–T11 nerves	Elevate ribs
External intercostal	Inferior border of ribs	Superior border of ribs below	Intercostal nerve	Elevate ribs during forced inspiration[a]
Internal intecostal				Interosseous part: depresses ribs Interchondral part: elevates ribs — During active (forced) respiration[a]
Subcostal	Internal surface of lower ribs near their angles	Superior borders of 2nd or 3rd ribs below		Probably act in same manner as internal intercostal muscles
Transversus thoracis	Posterior surface of lower sternum	Internal surface of costal cartilages 2–6		Weakly depress ribs[b] Proprioception?

[a]All intercostal muscles keep intercostal spaces rigid, thereby preventing them from bulging out during expiration and from being drawn in during inspiration. The role of individual intercostal muscles and accessory muscles of respiration in moving the ribs is difficult to interpret despite many electromyographic studies.
[b]Action traditionally assigned based on attachments; appear to be largely proprioceptive in function.

Diaphragm

Diaphragm is a curved musculotendinous sheet attached to the circumference of the thoracic outlet and to the upper lumbar vertebrae, which forms the floor of the thoracic cavity, separating it from the abdominal cavity.

- It is relatively flat centrally and domed peripherally, rising higher on the right side than on the left, an asymmetry that reflects the relative densities of the underlying liver and gastric fundus, respectively.
- Some authors mention the presence of heart leads to lower positioning of left dome of diaphragm.

Position

Table 15: Projections of the diaphragm on the chest wall

Structure	Position
Central tendon	Directly posterior to the xiphisternal joint
Right dome	Upper border of rib 5 in the midclavicular line (in forced expiration: fourth costal cartilage)
Left dome	Lower border of rib 5 in the midclavicular line

The right hemidiaphragm is found at the anterior end of the sixth rib on a properly inspired posteroinferior chest radiograph, the left hemidiaphragm 1.5–2.5 cm lower.

- During quiet respiration in the erect position, diaphragmatic excursion is about 2 cm, increasing to around 7 cm during deep breathing.
- The diaphragm is higher in the supine (compared to the erect) position, and the dependent half of the diaphragm is considerably higher than the uppermost one in the decubitus position.
- It is at the lowest position while sitting posture, allows maximum excursion of lungs and explains patients of asthma being most comfortable in sitting posture.

Attachments and Openings

Diaphragm takes origin from three parts : Sternal, costal and vertebral.

- Sternal part consists of two fleshy slips, which arise from the posterior surface of the xiphoid process.
- Costal part on each side consists of six fleshy slips, which arise from the inner surface of lower six ribs near their costal cartilages. Lumbar part arises by means of right and left crura of diaphragm and five arcuate ligaments.

- Insertion is into the central tendon of diaphragm.
- Diaphragm is the chief muscle of inspiration, descends when it contracts, causing an increase in thoracic volume by increasing the vertical diameter of the thoracic cavity.

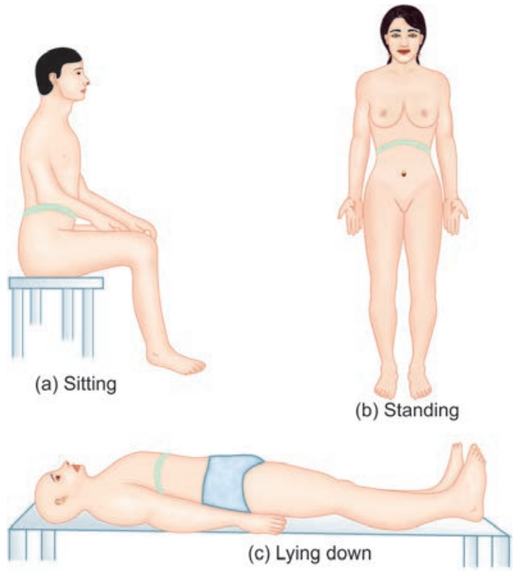


Fig. 47: Position of diaphragm in various postures.

- Crura
- Right crus attaches to anterior aspects of the upper three lumbar vertebrae and intervening intervertebral discs.
- Left crus (shorter in length) attaches to anterior aspects of the upper two lumbar vertebrae and intervening intervertebral discs.
- Medial fibres of the right crus embrace the oesophagus where it passes through the diaphragm, the more superficial fibres ascend on the left, and deeper fibres cover the right margin.
- In 30% population a superficial muscular bundle from the left crus contributes to the formation of the right margin of the hiatus.
- Arcuate ligaments
- **Median arcuate ligament** is an arched fibrous band connecting the upper ends of two crura.
- **Medial arcuate ligament** (Medial Lumbocostal Arch) is the thickened upper margin of the psoas sheath. It extends from the side of the body of L2 vertebra to the tip of the transverse process of L1 vertebra.
- **Lateral arcuate ligament** (Lateral Lumbocostal Arch) is the thickened upper margin of fascia covering the anterior surface of the quadratus lumborum. It extends from the tip of transverse process of L1 vertebra to the 12th rib.

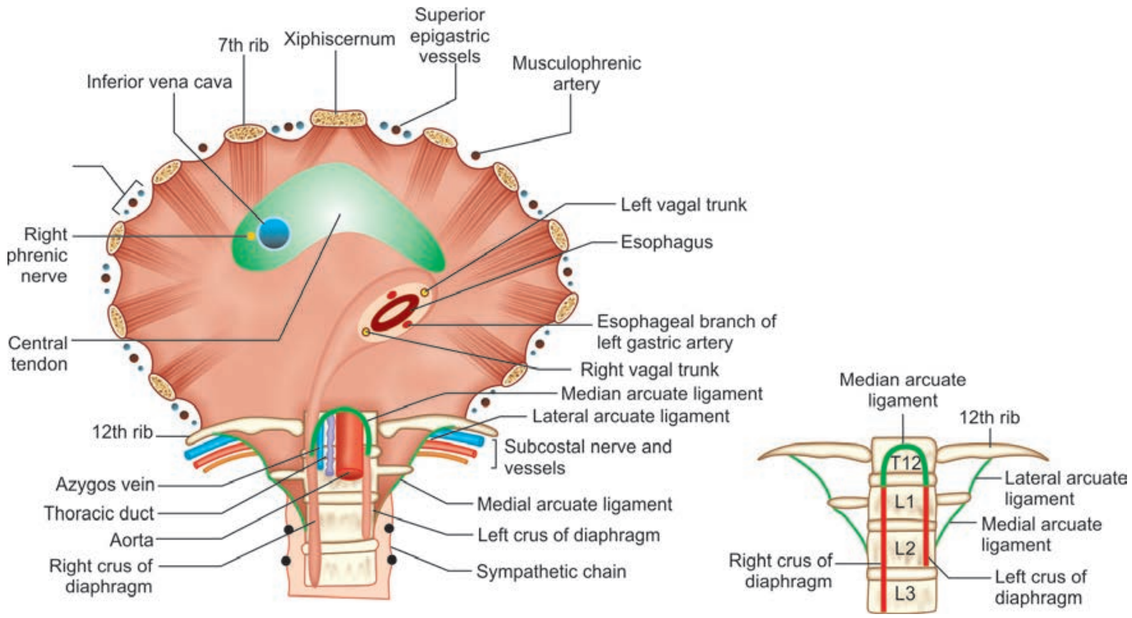


Fig. 48: Inferior view of diaphragm showing its multiple attachments, openings and the passing structures.

Table 16: Diaphragmatic openings				
Opening	**Location**	**Shape/type**	**Vertebral level**	**Structures passing through**
Vena caval (tendinous)	• Central tendon of diaphragm • Right side of midline • Between central and right posterior leaflet	Quadrangular/Square	T8 (lower border)	• **V**C • Branches of right phrenic nerve
Oesophageal (muscular)	• Left side of midline • Through the right crus of diaphragm	Oval/Elliptical	T10 (body)	• **O**esophagus • Right and left vagal trunk • Oesophageal branches of left gastric artery
Aortic hiatus (osseo-aponeurotic)	• Midline • Behind the diaphragm • Posterior to median arcuate ligament	Circular/round	T12 (lower border)	• **A**orta • Azygous vein (sometimes) • Thoracic duct

Mnemonic: VOA (Voice of Anatomy) at T8,10,12; V (IVC), O (Oesophagus), A (Aorta).

- According to a CT study, the inferior vena cava and the oesophagus traverse the diaphragm at the upper and lower borders, respectively, of the eleventh thoracic vertebra; these levels are lower than those based on cadaveric/radiographic studies (eighth and tenth thoracic vertebrae, respectively) (Mirjalili 2012a).

Minor Openings:

- Costo-xiphoid gap (space of Larry) is present between the muscular slips arising from xiphoid process and 7th costal cartilage. Superior epigastric vessels pass through it.
- Musculophrenic artery passes through the gap between the slips of origin from 7th to 8th ribs.
- Sympathetic chain passes deep to the medial arcuate ligament, subcostal nerves and vessels pass deep to the lateral arcuate ligament.
- Greater, lesser, and least splanchnic nerves pass by piercing the crus of diaphragm to enter the abdomen.
- Azygous vein pierces right crus of diaphragm to enter thorax, hemiazygos vein pierces the left crus.

Neurovascular Bundle

Table 17: Neurovascular structures of diaphragm		
Vessels and nerves	**Superior surface of diaphragm**	**Inferior surface of diaphragm**
Arterial supply	Superior phrenic arteries from thoracic aorta Musculophrenic and pericardiophrenic arteries from internal thoracic arteries	Inferior phrenic arteries from abdominal aorta
Venous drainage	Musculophrenic and pericardiacophrenic veins drain into internal thoracic veins; superior phrenic vein (right side) drains into IVC	Inferior phrenic veins; right vein drains into IVC; left vein doubled and drains into IVC and suprarenal vein
Lymphatic drainage	Diaphragmatic lymph nodes to phrenic nodes, then to parasternal and posterior mediastinal nodes	Superior lumbar lymph nodes; lymphatic plexuses on superior and inferior surfaces communicate freely
Innervation	Motor supply: phrenic nerves (C3–C5) Sensory supply: centrally by phrenic nerves (C3–C5), peripherally by intercostal nerves (T5–T11) and subcostal nerves (T12)	
IVC, inferior vena cava.		

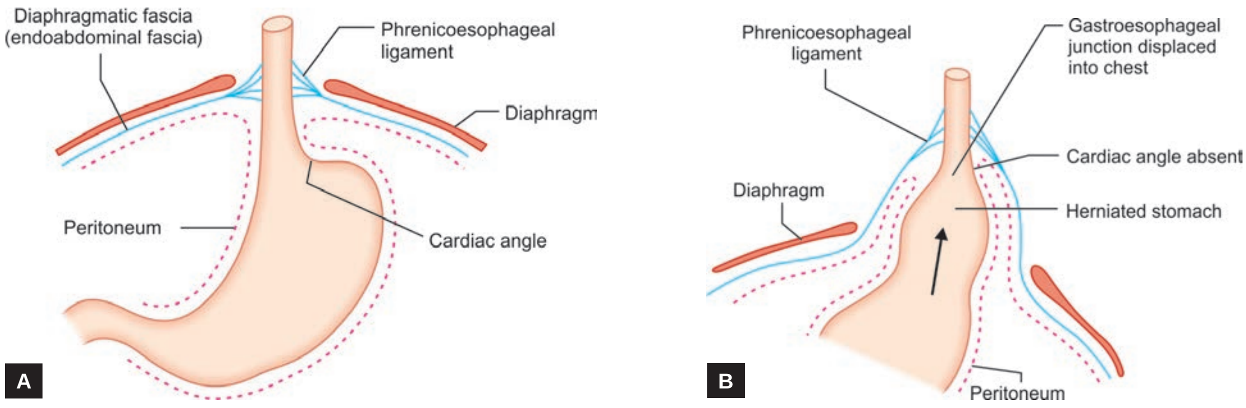
Clinical Correlation

Hernia

- **Sliding hernias** (90% cases) are typically acquired, found in more than 50% of patients with gastro-oesophageal reflux.
  - Laxity of the phreno-oesophageal ligament allows the stomach along with the GE junction herniate through the diaphragm into the thorax.
- **Para-oesophageal** (type II) hiatus hernia: Only the stomach herniates through the diaphragm into the thorax.
  - There is no reflux of gastric contents but strangulation or obstruction may occur.

Phrenic nerve lesion may result in paralysis and paradoxical movement of the diaphragm.

- The paralyzed dome of the diaphragm does not descend during inspiration and is consequently forced upward due to increased abdominal pressure.



Figs. 49A and B: Acquired hiatal (sliding) hernia: A. normal position of stomach; B. herniated stomach.

ASSESSMENT QUESTIONS

1. The opening in central tendon of diaphragm transmits: *(NEET Pattern 2013)*
a. Aorta
b. Oesophagus
c. Right phrenic nerve branch
d. Left gastric artery branch

2. Which of the following statements is/are TRUE about diaphragm: *(PGIC 2009)*
a. Left side pushed down by heart
b. Left side lower than the right
c. Right side lower than the left
d. Right side pushed up by liver

3. Oesophagus enters through: *(NEET Pattern 2014)*
a. Central tendon of diaphragm
b. Along aortic opening
c. Muscular part of diaphragm
d. Right Crus

4. Diaphragmatic hernia can occur through all the following EXCEPT: *(AIPG)*
a. Esophageal opening
b. Costovertebral triangle
c. Costal and sternal attachment of diaphragm
d. Inferior vena cava opening

5. Aortic hiatus contains: *(AIIMS 2009)*
a. Left gastric vein and thoracic duct
b. Thoracic duct and hemiazygos vein
c. Azygos vein and thoracic duct
d. Left vagus and thoracic duct

6. The structures passing posterior to diaphragm are all EXCEPT: *(AIIMS 2006)*
a. Aorta
b. Azygos vein
c. Thoracic duct
d. Greater splanchnic nerve

7. Structure NOT passing through oesophageal hiatus: *(AIIMS 2011)*
a. Left gastric artery branch
b. Right vagus nerve
c. Left vagus nerve
d. Left phrenic nerve

ANSWERS WITH EXPLANATIONS

1. c. Right phrenic nerve branch
- Central tendon of diaphragm has an opening for the passage of inferior venae cava (at T- 8 vertebrae level), along with that passes few **branches of right phrenic nerve**.
- **Aorta** passes through an intercrural gap posterior to the diaphragm (T-12 vertebra level).
- **Oesophagus** has an opening in diaphragm (T – 10 vertebra level). Along with that passes the branches of **left gastric artery** and vein.
- Hernia common on left because of weak origin

2. a. Left side pushed down by heart; b. Left side lower than the right; d. Right side pushed up by liver
- **Left side of diaphragm is lower**, since it is **pushed down by heart**, whereas **right side of diaphragm is higher**, since **pushed up by liver** (Subject experts in different fields have contradictory views, and the topic remains controversial).

3. c. Muscular part of diaphragm
- Oesophagus passes through muscular part of the diaphragm, surrounded by fibres of right crus and few fibres from left crus occasionally.

4. d. Inferior vena cava opening
- There is no description of hernia through tendinous opening for IVC in literature.

5. c. Azygos vein and thoracic duct
- The aortic hiatus transmits the aorta, thoracic duct, lymphatic trunks from the lower posterior thoracic wall and, sometimes, the azygos and hemiazygos veins.

6. d. Greater splanchnic nerve > b. Azygos vein
- Aorta and thoracic duct pass through the aortic hiatus, which lies posterior to the diaphragm.
- Azygous vein may pass through this opening sometimes, usually it pierces through the crus of diaphragm to enter the thorax.
- Greater splanchnic nerve usually pierce through the crus of diaphragm to enter the thorax.

7. d. Left phrenic nerve

- Oesophageal hiatus is an opening in the diaphragm, through which along with oesophagus, few other structures also pass, that is right and the left vagal trunk and a branch of left gastric artery.
- Left phrenic nerve does not pass through any specific opening in the diaphragm.

High Yield Points

- **Aorta and thoracic duct (and azygous vein sometime)** pass **posterior to the diaphragm,** whereas**, greater splanchnic nerve** does not**,** it pierces through the crus of the diaphragm to enter the abdomen. **(AIIMS 2006)**
- Most common site of **Morgagni hernia** is **right antero medial (RAM). (AIIMS 2009**

Tracheobronchial Tree

Conducting Portion of airway includes the nasal cavity, nasopharynx, larynx, trachea, bronchi, bronchioles (possess no cartilage), and terminal bronchioles.

- The respiratory portion includes the respiratory bronchioles, alveolar ducts, atria, and alveolar sacs.
- Oxygen and carbon dioxide exchange takes place across the wall (blood–air barrier) of lung alveoli and pulmonary capillaries.
- Trachea (Refer)
- Right principal bronchus is short (length), wide (lumen) and more vertical (in line with trachea), as compared with the left principal bronchus.
- It branches into 3 lobar bronchi (upper, middle, and lower) and finally into 10 segmental bronchi.
- The first branch, the superior lobar bronchus, then enters the right lung opposite the fifth thoracic vertebra.
- The azygos vein arches over it, and the right pulmonary artery lies at first inferior, then anterior to it (the eparterial bronchus).
- After giving off the superior lobar bronchus, which arises posterosuperior to the right pulmonary artery, the right principal bronchus crosses the posterior aspect of the artery, enters the pulmonary hilum posteroinferiorly, and divides into middle and inferior lobar bronchi.
- Left principal bronchus is narrower, longer, and more horizontal than the right.
- It is about 2 inches (5 cm) long and does not lie in line with the trachea.
- It runs inferolaterally inferior to the arch of the aorta, crosses anterior to the esophagus and thoracic aorta and posterior to the left pulmonary artery.
- It divides into 2 lobar or secondary bronchi, the upper and lower, and finally into 8 to 10 segmental bronchi.
- The branching of segmental bronchi corresponds to the bronchopulmonary segments of the lung.

The long axis of right principal bronchus deviates about 25° from the long axis of the trachea, whereas long axis of the left principal deviates about 45° from the long axis of the trachea.

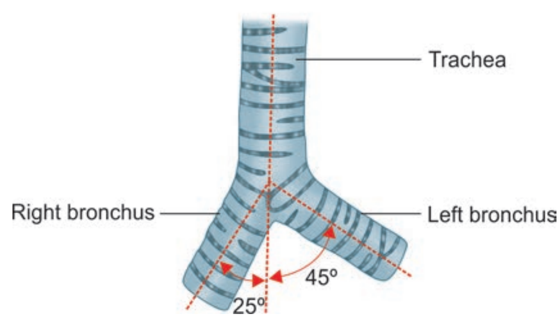


Fig. 50: Trachea and principal bronchi.

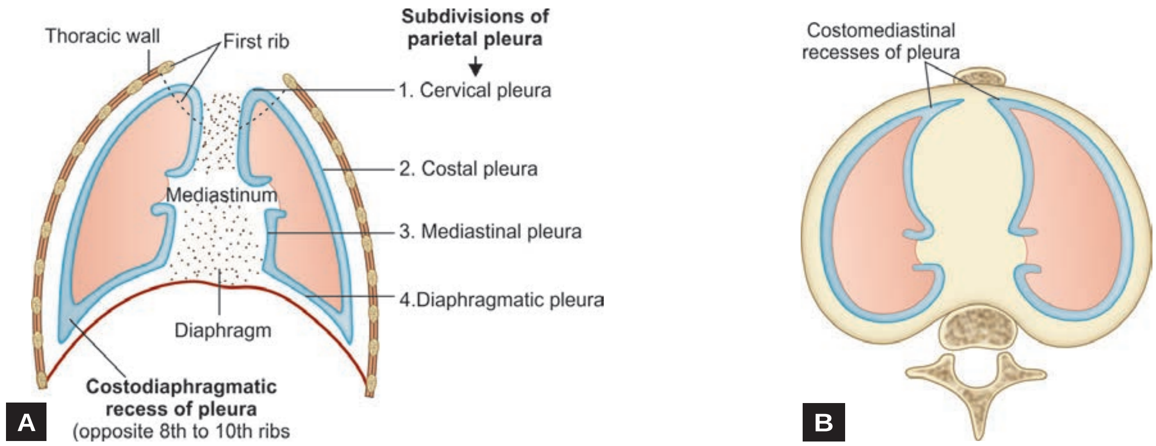
Pleura

Pleura is a thin serous membrane around the lungs that consists of a parietal and a visceral layers.

- Parietal Pleura lines the inner surface of the thoracic wall and the mediastinum and has costal, diaphragmatic, mediastinal, and cervical parts.
- Parietal pleura is separated from the thoracic wall by the endothoracic fascia, which is an extrapleural fascial sheet lining the thoracic wall.
- It forms the pulmonary ligament, a two-layered vertical fold of mediastinal pleura, which extends along the mediastinal surface of each lung from the hilus to the base (diaphragmatic surface) and ends in a free falciform border.
- It supports the lungs in the pleural sac by retaining the lower parts of the lungs in position.
- Visceral Pleura (Pulmonary Pleura) adheres intimately to the lung surfaces and dips into all of the fissures.
- It is reflected at the root of the lung and continues as parietal pleura.
- Pleural cavity is a potential space between the parietal and visceral pleurae.
- It contains a film of fluid that lubricates the surface of the pleurae and facilitates the movement of the lungs.

Pleural Recesses

- **Costodiaphragmatic recess** is slit-like space formed by the reflection of the costal and diaphragmatic parietal pleurae, allows expansion of the lungs inferiorly during inspiration.
  - Excess fluid within the pleural cavity accumulates in the costodiaphragmatic recess and costodiaphragmatic angle is blunted (PA radiograph) in erect posture.
- **Costomediastinal recess** is slit-like spaces between the costal and mediastinal parietal pleura.
  - During inspiration, the anterior borders of both lungs expand and enter the right and left costomediastinal recesses.
  - In addition, the lingula of the left lung expands and enters a portion of the left costomediastinal recess, causing that portion of the recess to appear radiolucent (dark) on radiographs.



Figs. 51A and B: Reflection of the pleura in thoracic cavity. (A) Vertical section; (B) transverse section.

According to the surface it lines parietal pleura is divided into the following four parts : Costal, diaphragmatic, mediastinal and cervical.

- The cervical pleura (cupula) is the dome of the pleura, projecting into the neck above the neck of the first rib.
- It is reinforced by Sibson fascia (suprapleural membrane), which is a thickened portion of the endothoracic fascia, and is attached to the first rib and the transverse process of the seventh cervical vertebra.

Table 18: Details of pleura of pleura

Type	Visceral	Parietal
Location	Lines the surface of the lung	Lines the thoracic wall and mediastinum
Development	Lateral plate mesoderm (Splanchnopleuric layer)	Lateral plate mesoderm (Somatopleuric layer)
Nerve supply	• Autonomic (pain insensitive)*: – Sympathetic (T1-5) – Parasympathetic (vagus)	• Somatic (pain sensitive): – **Intercostal nerves (T2-5)** supply peripheral costal pleura and peripheral portion of diaphragmatic pleura – **Phrenic nerve** supplies mediastinal central pleura and central portion of the diaphragmatic pleura
Arterial supply	• Internal thoracic • Superior phrenic • Posterior intercostal • Superior intercostal arteries	• Bronchial arteries
Venous drainage	Systemic veins	Pulmonary veins

*Visceral pleura is sensitive to stretch (may be involved in respiratory reflexes).

Clinical Correlations

- Pleuritis (inflammation) involving visceral pleura present with no pain, whereas parietal pleuritis is associated with sharp local pain and referred pain, felt in the thoracic wall (intercostal nerves) and root of the neck (phrenic nerve (C3,4,5).
- Surgical posterior approach to the kidney may damage the pleura in case rib 12 is very short and rib 11 is mistaken for rib 12.

Lungs

Lungs are attached to the heart and trachea by their roots and the pulmonary ligaments.

- The lung bases rest on the convex surface of the diaphragm, descend during inspiration, and ascend during expiration.
- Right Lung as an apex that projects into the neck and a concave base that sits on the diaphragm.

- It is larger and heavier than the left lung, but is shorter and wider because of the higher right dome of the diaphragm and the inclination of the heart to the left.
- It is divided into upper, middle, and lower lobes by the oblique and horizontal fissures.
- It has 3 lobar (secondary) bronchi and 10 segmental (tertiary) bronchi.
- The diaphragmatic surface consists of the middle lobe and lower lobe.
- There are specific impressions evident, created by various related structures (e.g., SVC, arch of azygos vein, esophagus).
- Left Lung is divided into upper and lower lobes by an oblique fissure, is usually more vertical in the left lung than in the right lung.
- Lingula is a tongue-shaped portion present in the upper lobe that corresponds to embryologic counterpart to the right middle lobe.
- Left lung has 2 lobar (secondary) bronchi and 8 to 10 segmental bronchi.
- It shows a cardiac impression, a cardiac notch (a deep indentation of the anterior border of the superior lobe), and grooves for various structures (e.g., aortic arch, descending aorta, left subclavian artery).

Hilum and Mediastinal Surface

The arrangement of structures in the hilum of left lung is remembered by the mnemonic ABV (Atal Bihari Vajpayi) in superior to inferior direction. Artery (pulmonary) → Bronchus (principal) → Vein (pulmonary).

- It is the same sequence in right lung as well but with the addition of a bronchus above the artery (epi-arterial bronchus).
- In all these structures bronchus is the most posterior structure at the lung hilum.
- There are 2 veins which are named anterior and inferior according to their location at the hilum. (Similar arrangement on both sides).
- Bronchus and bronchial arteries are always posterior most structures at the hila of both lungs

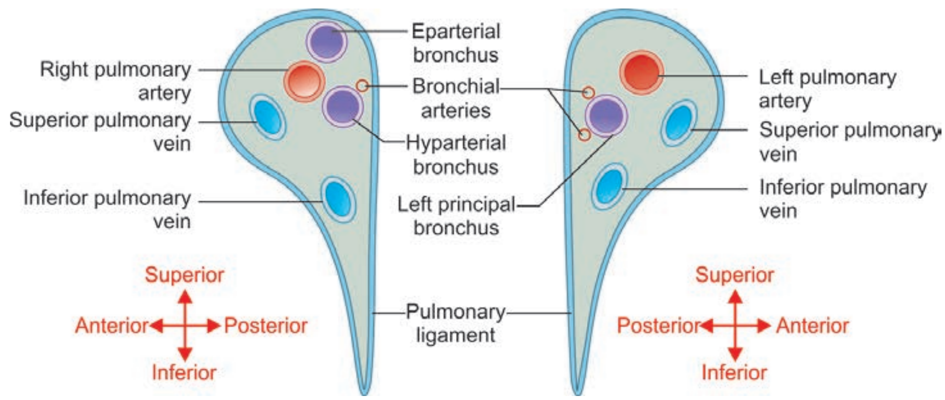


Fig. 52: Arrangement of structures in the roots of right and left lungs.

Table 19: Arrangement of structures at the lung hilum

Right side	Left side
• Eparterial	Pulmonary artery
• Pulmonary artery	Left principal bronchus
• Hyparterial bronchus	Inferior pulmonary vein
• Inferior pulmonary vein	

In situs solitus, the right principal bronchus is short and eparterial (its branch for the right upper lobe lies over the second branch of the right pulmonary artery) and the left principal bronchus is longer and hyparterial (it courses underneath the left pulmonary artery).

- A bilobed left lung and a trilobed right lung are typical in situs solitus.
- In situs inversus, there is a mirror imaging of the disposition seen in situs solitus.
- In situs ambiguus, the bronchi and lungs can display either a bilateral right morphology with bilateral trilobed lungs and bilateral eparterial bronchi (heterotaxy syndrome: incomplete or inappropriate lateralization of the thoracic and abdominal viscera, and asplenia) or a bilateral left morphology with bilateral bilobed lungs and bilateral hyparterial bronchi (heterotaxy syndrome and polysplenia).

Bronchopulmonary Segments

The bronchopulmonary segment is the anatomical, functional, and surgical unit of the lungs.

- It is the wedge shaped largest subdivision of a lobe, named according to the segmental bronchus supplying it, and is surgically resectable.
- It contains a segmental (tertiary or lobular) bronchus, a branch of the pulmonary artery, and a branch of the bronchial artery, which run together through the central part of the segment, surrounded by a delicate connective tissue (intersegmental) septum.
- The tributaries of **pulmonary veins** are intersegmental and lie at the margins of bronchopulmonary segments. They create surgical planes, which a surgeon can follow for segmental resection, with minimal tissue damage.

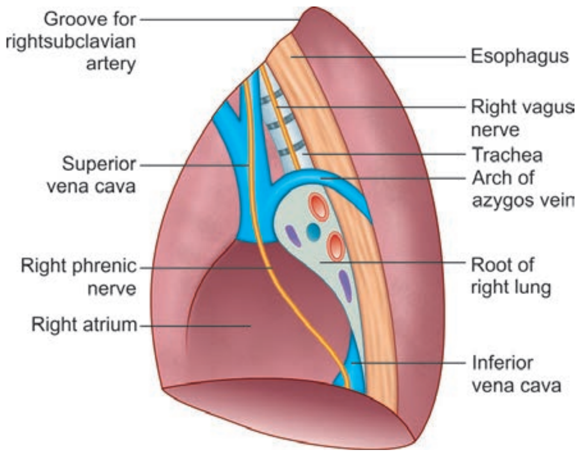


Fig. 53: Relations of the mediastinal surface of the right lung.

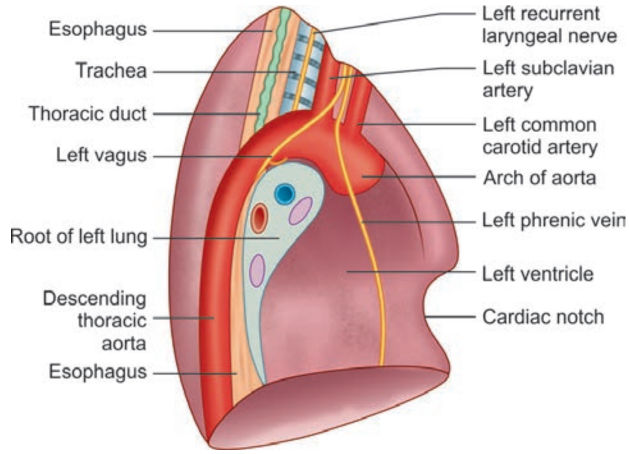


Fig. 54: Relations of the mediastinal surface of the left lung.

Table 20: Relations of the mediastinal surfaces of the right and left lungs	
Mediastinal surface of the right lung	**Mediastinal surface of the left lung**
Right atrium	Left ventricle
Superior and inferior vena cavae	Ascending aorta
Azygos vein	Arch of aorta and descending thoracic aorta
Right brachiocephalic vein	Left subclavian and left common carotid arteries
Esophagus and trachea	Esophagus and thoracic duct
Three neural structures	Four neural structures
• Right phrenic nerve	• Left phrenic vein
• Right vagus nerve	• Left vagus nerve
• Right sympathetic chain	• Left recurrent pharyngeal nerve
	• Left sympathetic chain

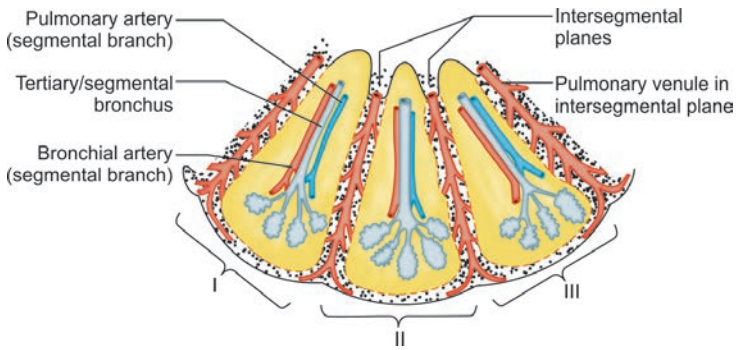
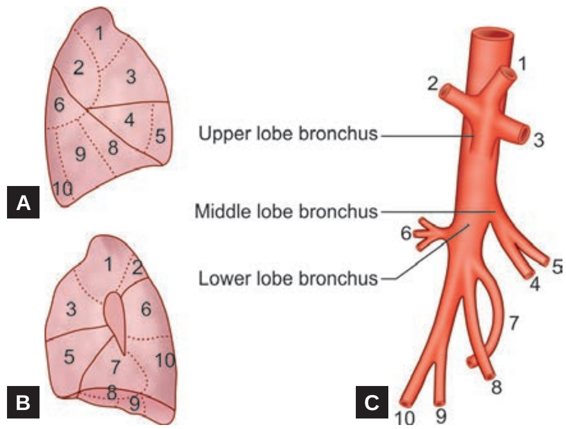


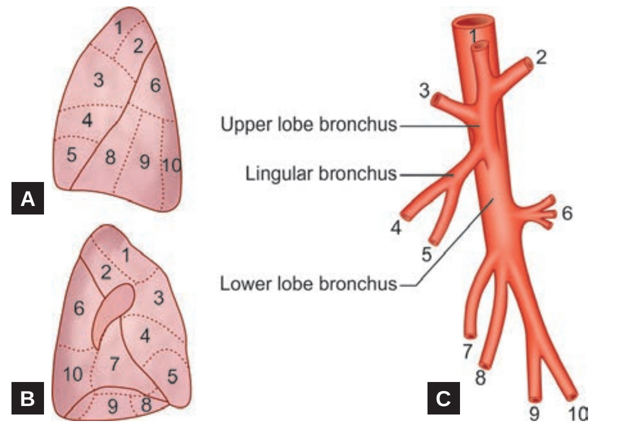
Fig. 55: Branchopulmonary segments.

Table 21: Bronchopulmonary segment in lungs		
	Right lung	**Left lung**
Upper lobe	Apical (I), Posterior (II); Anterior (III)	Apical (I), Posterior (II), Anterior (III), Superior lingular (IV); Inferior lingular (V)
Middle lobe	Lateral (IV); Medial (V)	Absent
Lower lobe	Superior/Apical (VI), Medial basal* (VII), Anterior basal (VIII), Lateral basal (IX); Posterior basal (X)	Superior/Apical (VI), Medial basal*** (VII), Anterior basal*** (VIII), Lateral basal (IX); Posterior basal (X)

Note: Medial basal (VII) is also called as the cardiac BPS of right lung.
Apical and posterior of left upper lobe typically combine into apicoposterior segment.
Anterior and medial basal of left lower lobe often combine into anteromedial basal segment.



Figs. 56A to C: Bronchopulmonary segments of the right lung. (A) lateral view; (B) medial view; (C) Lobar and segmental bronchi.



Figs. 57A to C: Bronchopulmonary segments of the left lung. (A) Lateral view; (B) medial view; (C) Lobar and segmental bronchi.

Clinical Correlations

- Foreign body aspiration:
- Location of the foreign body aspirate depends upon the posture of the patient and decided by the gravity factor as well (most dependent location).
- Most of the aspirations occur in supine posture (coma, post anaesthesia) and the aspirate moves into right lower lobar bronchus to be found in the apical (VI) BPS of right lower lobe. Some books additionally mention the collection in posterior (II) BPS of right upper lobe as well.
- If aspiration occur in erect (sitting or standing) posture, aspirated material most commonly enters the posterior basal (X) BPS of right lower lobe.
- If a person is lying in right lateral position, the aspirate most commonly enters the right upper lobar bronchus and lodges within the posterior (II) BPS of right upper lobe.
- In left lateral position aspirated material most commonly enters the left upper lobar bronchus and lodges within the inferior lingular (V) bronchopulmonary segment of the left upper lobe.

Vasculature

Lung is supplied by two arterial systems.

- Pulmonary System of Arteries
- **Pulmonary Trunk** extends upward from the conus arteriosus of the right ventricle of the heart and carries deoxygenated blood to the lungs for oxygenation.
  - It passes superiorly and posteriorly from the front of the ascending aorta to its left side for and bifurcates into the right and left pulmonary arteries within the concavity of the aortic arch at the level of the sternal angle (approximately).
  - Pulmonary trunk is contained within the fibrous pericardium.
- **Right** pulmonary artery runs horizontally toward the hilum beneath the arch of the aorta; posterior to the ascending aorta and SVC; and anterior to the right main bronchus.
- Left pulmonary artery is shorter and narrower than the right and is connected to the arch of the aorta by the ligamentum arteriosum.
- Pulmonary arteries branch to follow the airways to the level of the terminal bronchioles, at which point they form a pulmonary capillary plexus.

Bronchial System of Arteries

- Bronchial arteries carry oxygenated blood to the lung and the visceral pleura.
- Right bronchial artery is a branch of a posterior intercostal artery.
- There are two left bronchial arteries given by the descending thoracic aorta.
- Bronchial arteries branch to follow the airways till the level of the respiratory bronchioles, at which point they drain into the pulmonary capillary plexus (i.e., 70% of bronchial blood drains into the pulmonary capillary plexus).
- Bronchial arteries that supply large bronchi drain into bronchial veins (i.e., 30% of bronchial blood drains into the bronchial veins).

Lung is supplied by two venous systems.

- Pulmonary System of Veins
- Pulmonary veins carry oxygenated blood from the pulmonary capillary plexus and deoxygenated bronchial blood to the left atrium.
- Four pulmonary veins open into the posterior aspect of the left atrium.
- Within the lung pulmonary veins are intersegmental (found at the periphery of the bronchopulmonary segments), not accompanied by branches of bronchi, pulmonary arteries, or bronchial arteries.

Bronchial System of Veins

- Bronchial veins carry deoxygenated blood from the bronchial arteries that supply large bronchi.
- Right bronchial veins drain into the azygos vein, left into the accessory hemiazygos vein (or the left superior intercostal vein).
- Lymphatic vessels drain the bronchial tree, pulmonary vessels, and connective tissue septa.

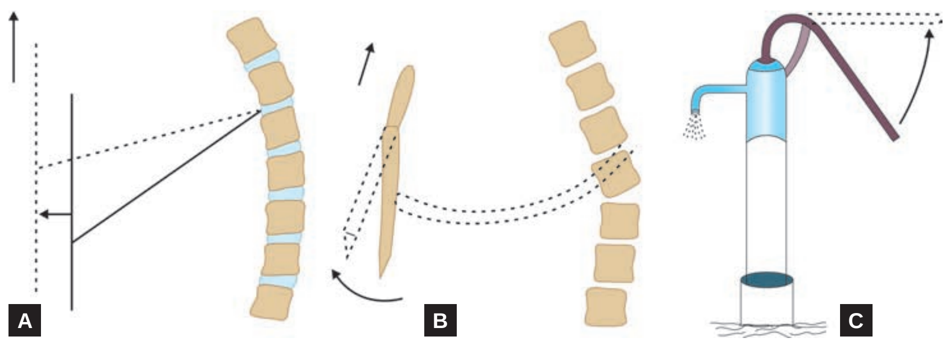
- They run along the bronchiole and bronchi toward the hilum to drain into the pulmonary and then bronchopulmonary nodes, which in turn drain to the inferior (carinal) and superior tracheobronchial nodes, the tracheal (paratracheal) nodes, bronchomediastinal nodes and trunks, and eventually to the thoracic duct (on the left) and right lymphatic duct (on the right).
- Lymphatics are absent in the walls of the pulmonary alveoli.

Nerve Supply

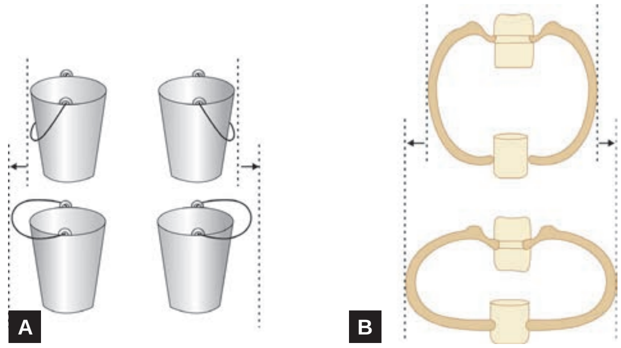
Pulmonary plexuses are anterior and posterior to the other structures at the hila of the lungs.
- They are formed by cardiac branches from the second to fifth (or sixth) thoracic sympathetic ganglia and from the vagus and cervical sympathetic cardiac nerves.
- The left plexus also receives branches from the left recurrent laryngeal nerve.
- Vagus nerve carrying parasympathetic fibers that innervate the smooth muscle and glands of the bronchial tree are excitatory (bronchoconstrictor and secretomotor).
- Vagus also carry sensation of stretching of the lung during inspiration and is concerned in the reflex control of respiration.
- Sympathetic fibers innervate blood vessels, smooth muscle, and glands of the bronchial tree are inhibitory (bronchodilator and vasoconstrictor).

Breathing

Breathing involves changing the thoracic volume by altering the vertical, transverse and anteroposterior diameters of the thorax. Diaphragm is the key muscle in this process. The intercostal muscles maintain the rigidity of the chest wall. The external and internal intercostals, transversus thoracis, subcostalis, levator costarum, serratus posterior superior and serratus posterior inferior can elevate or depress the ribs, and hence can act as accessory muscles of ventilation.
- Inspiration involves muscles (table) that elevate the thoracic cage (ribs and sternum) and accordingly, expiration involves the depression of the cage.
- Diaphragm is the chief muscle of inspiration, pulls the dome inferiorly into the abdomen, thereby increasing the vertical diameter of the thorax and expansion of lung (air moves in).
- Enlargement of the pleural cavities and lungs reduces the intrapulmonary pressure (creates a negative pressure), thus allowing air to rush into the lungs passively because of atmospheric pressure.
- Inspiration involves various muscles causing elevation of the ribs (superolateral movement), with the sternum moving anteriorly. It results in increased transverse and anteroposterior diameters of the thoracic cavity and abdominal volume is decreased with an increased abdominal pressure.
- Pump handle movement. Elevation of upper 6 ribs causes sternum to be pushed forward and upward, which increases the anteroposterior diameter of the thorax and lungs expand (inspiration).
- Bucket handle movement. The lower ribs elevate by swinging upward and laterally leading to an increase in the transverse (lateral) diameter of the thorax for lung expansion (inspiration).



Figs. 58A to C: Increase in anteroposterior diameter of the thoracic cavity due to movements of sternum (Analogy with pump-handle movement).



Figs. 59A and B: Increase in transverse diameter of the thoracic cavity due to bucket-handlemovements of vertebrochondral rib.

- Expiration is a passive process caused by the elastic recoil of the lungs. It involves relaxation of the diaphragm and other muscles; decrease in thoracic volume; and increase in the intrathoracic pressure. The abdominal pressure is decreased, and the ribs are depressed. Elastic recoil of the lungs produces a subatmospheric pressure in the pleural cavities and the air is expelled.
- Forced expiration requires contraction of the anterior abdominal muscles and few others

Table 22: Respiratory muscles

Type of respiration	Inspiration (rib elevators)	Expiration (rib depressors)
Quiet respiration	• Diaphragm (chief muscle) • External intercostal muscles	Passive
Deep inspiration	• **External intercostal muscles** • **Scalene muscles** • Sternocleidomastoid • Levator costarum • **Serratus posterior superior** • Innermost intercostal	Passive
Forced expiration	• Levator scapulae • Trapezius • Rhomboids • Pectoral muscles • **Serratus anterior**	• Anterior abdominals* • Quadratus lumborum • **Internal intercostal (costal part) muscles**** • Transverse thoracis • Serratus posterior inferior

- Anterior abdominals are : External and internal oblique muscles along with transversus abdominis.
- Internal intercostal (interchondral part) participates in inspiration.
- **Mnemonic:** Remember (SIT - Q depressors) for expiration: S – serratus posterior inferior, I – Internal intercostals, T – Transversus thoracis and Q – quadratus lumborum. They work along with anterior abdominals for expiration.

Table 23: Factors responsible for the increase in various diameters of the thoracic cavity during inspiration

Diameter	Factors responsible for increase
Vertical	Descent (contraction) of the diaphragm
Anteroposterior	**Pump-handle movement** of the sternum (brought about by the elevation of vertebrosternal ribs)
Transverse	**Bucket-handle movement** of the vertebrochondral ribs

ASSESSMENT QUESTIONS

1. All are accessory muscles of inspiration EXCEPT:
   a. Serratus anterior
   b. Serratus posterior
   c. Latissimus dorsi
   d. Scalene

2. Muscle of expiration: *(NEET Pattern 2015)*
   a. External intercostal
   b. Diaphragm
   c. Internal intercostal
   d. Serratus anterior

3. Which of the following do NOT elevate the ribs: *(NEET Pattern 2014)*
   a. Serratus posterior superior
   b. Serratus posterior inferior
   c. External intercostals
   d. Levator costarum

ANSWERS WITH EXPLANATIONS

1. c. Latissimus dorsi

Accessory muscles of inspiration are elevators of rib and increase the diameters of thoracic cavity.

2. c. Internal intercostal

Muscles of expiration are depressors of rib and decrease the diameters of thoracic cavity.
- Internal intercostal (costal part) helps in expiration, whereas the interchondral part participates in inspiration.
- Diaphragm is the chief muscle of inspiration, assisted by external intercostal and serratus anterior.

3. b. Serratus posterior inferior
- Muscles that elevate the ribs work for inspiration, whereas serratus posterior inferior depress the ribs (for expiration).
- Remember (SIT - Q depressors) for expiration: S – serratus posterior **inferior**, I – Internal intercostals, T – Transversus thoracis and Q – quadratus lumborum. They work along with anterior abdominals for expiration.

Pleura and Lung (Surface Marking)

Surface Marking for Pleura

- Apical pleura:
  - Starting in the midline at the sternal angle, the anterior reflections of the parietal pleura may be traced superiorly along a curved line that diverges from the midline and extends up and outwards to the apex of the lung and pleural cavity.
  - The line lies 3–4 cm above the anterior end of the first rib; the surface marking is posterior to the medial third of the clavicle in level with the seventh cervical vertebra.
- Anterior border of pleura:
  - The right and left pleurae are in contact retrosternally in the midline from the second to the fourth costal cartilages, at which point they diverge.
  - The pleura on the right descends vertically to the xiphisternum, whereas the pleura on the left deviates laterally by 3–5 cm and then passes inferiorly to cross the anterior end of the sixth rib.
  - This deviation produces an area between the heart and the sternum that is free of pleura; a needle puncture (pericardiocentesis) of the heart can be performed at this site without risk of damaging the pleura.
- Inferior border of pleura:
  - The **costodiaphragmatic reflections** of the right pleurae follows around the chest wall from the midpoint of xiphisternal angle anteriorly to the eighth rib in the mid-clavicular line, tenth rib in the mid-axillary line and twelfth rib at paravertebral line.
  - It is almost the same for left lung but with **one exception**: It begins from the sixth rib/costal cartilage anteriorly to the eighth rib in the mid-clavicular line, tenth rib in the mid-axillary line and twelfth rib at paravertebral line.
- Posterior border of pleura:
  - In posterior view, the medial edges of the pleurae lies along a line joining the transverse processes of the second to the twelfth thoracic vertebrae on either side.

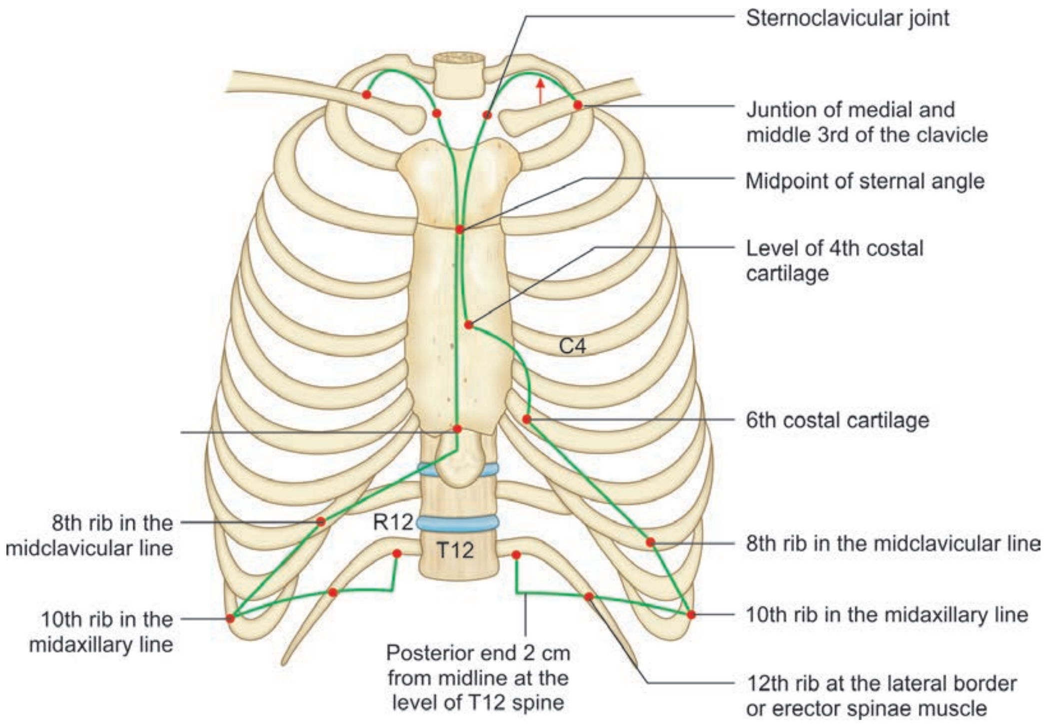


Fig. 60: Surface marking of pleura on bony cage.

Surface marking for lung

- The surface markings of both the apex and costovertebral border of the **lung** correspond to those of the **parietal pleura**.
  - However there are few differences between the two which need the detailed description.
  - Pleura lies two rib lower than lung to allow lung expansion during inspiration.

Table 24: Surface marking for lungs and pleural

Level	Costodiaphragmatic line (inferior border of pleura)	Lower border of lung (2 ribs higher)
Mid-clavicular line	8th rib	6th rib
Mid-axillary line	10th rib	8th rib
Paravertebral line	12th rib	10th rib

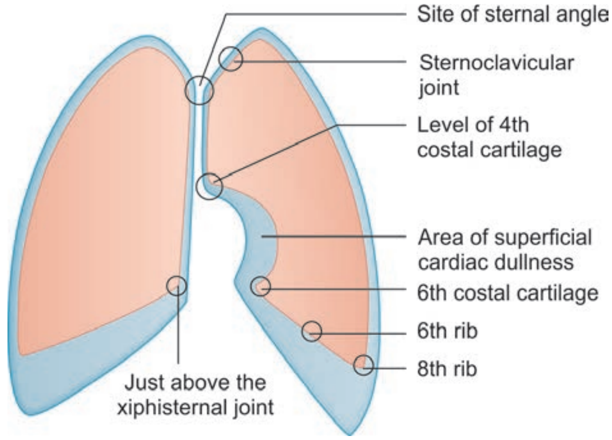


Fig. 61: Surface markings of the lung and pleura on the front.

- Conventionally, the surface projection of the lower border of the lung is represented by a curved line that crosses the mid-clavicular line at the sixth rib, the mid-axillary line at the eighth rib and the tenth rib just lateral to the vertebral column.
- CT data reveal considerable variation, redefining the lower lung border.
- Lower anterior border of the right lung is at seventh rib in the mid-clavicular line and left lung at fifth rib in the mid-clavicular line.
- Oblique fissure:
  - On each side, the upper and lower lobes of the lung are separated by the oblique fissure.
  - It is marked by a line that runs anteroinferiorly from the posterior end of the fourth rib (spinous process of the third thoracic vertebra), crosses the fifth rib in the mid-axillary line and continues inferiorly, crossing sixth rib on both sides at the mid-clavicular line (i.e. 7–8 cm lateral to the midline).
  - The oblique fissure follows the medial border of the scapula when the upper limb is in full abduction. The left oblique fissure may be slightly more vertical than the right.
- Horizontal fissure: It lies between the upper and middle lobes of the right lung.
  - It extends from the fourth costal cartilage at the right sternal border to intersect the oblique fissure at mid-axillary line.
- The right middle lobe may be projected on to the thoracic wall using three points namely: The fourth costal cartilage at the right parasternal edge, the fifth rib at the mid-axillary line and the sixth rib at the mid-clavicular line.
- The upper and middle lobes lie anterior to the oblique fissure and are clinically examined from in front and to the side.
- The lower lobes lie posteriorly and should be examined from behind.

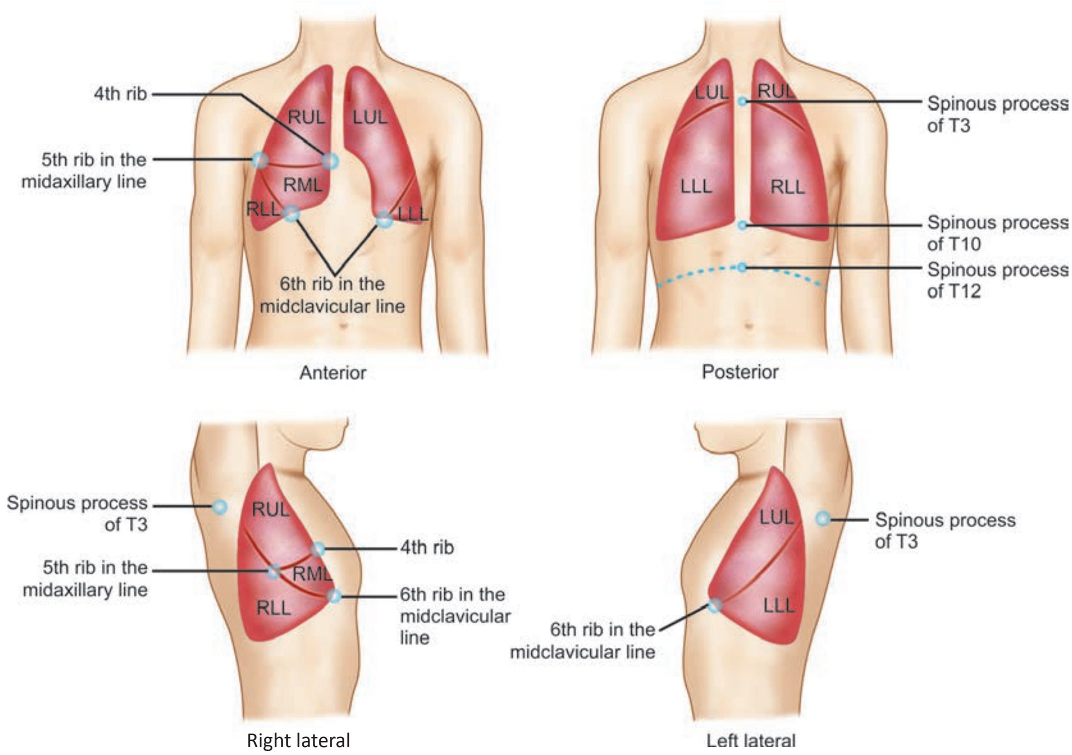


Fig. 62: Surface projection of different lobes of lungs (RUL = right upper lobe, LUL = left upper lobe, RML = right middle lobe, RLL = right lower lobe, LLL = left lower lobe).

ASSESSMENT QUESTIONS

1. Surface marking of the oblique fissure of lung include all EXCEPT: *(NEET Pattern 2013)*
a. T 3 vertebra
b. 5th rib
c. 7th rib
d. 6th costal cartilage

2. Pleural reflection on midaxillary line is in space:
a. 5
b. 6
c. 8
d. 10

3. The right costophrenic line extends up to the level of which rib in the mid-axillary line: *(NEET Pattern 2014)*
a. 6th
b. 8th
c. 10th
d. 12th

4. Which is NOT a lobe of lung: *(NEET Pattern 2015)*
a. Azygous
b. Superior
c. Inferior
d. Lingula

5. Which is the most superior structure at hilum of left lung? *(AIIMS 2007)*
a. Pulmonary vein
b. Pulmonary artery
c. Bronchus
d. Bronchial artery

6. Which of the following are related to the mediastinal part of right lung? *(NEET Pattern 2013)*
a. Arch of aorta
b. SVC
c. Pulmonary trunk
d. Left ventricle

7. Inferior most structure of right hilum is: *(NEET Pattern 2014)*
a. Bronchus
b. Inferior pulmonary vein
c. Pulmonary artery
d. Inferior bronchial vein

8. Hilum of the right lung is arched by: *(AIPG)*
a. Recurrent laryngeal nerve
b. Azygos vein
c. Thoracic duct
d. Vagus nerve

9. The root of the right lung does not lie behind which one of the following
a. Right atrium
b. Right vagus
c. Superior vena cava
d. Phrenic vein

10. Bronchopulmonary segments in right and left lungs respectively: *(NEET Pattern 2015)*
a. 9,11
b. 11,9
c. 10,10
d. 8,10

11. Which are segments of upper lobe in the right lung: *(NEET Pattern 2013)*
a. Anterior, posterior, medial
b. Apical, anterior posterior
c. Lateral, medial, superior
d. Basal, lateral, medial

12. Cardiac BPS of right lung is:
a. Medial
b. Lateral
c. Medial basal
d. Anterior basal

13. All of the following are characteristic of a broncho-pulmonary segment EXCEPT: *(AIIMS 2014)*
a. It is surgically resectable
b. It is named according to the segmental bronchus supplying it
c. It is drained by independent intrasegmental branch of pulmonary vein
d. It is the largest subdivision of a lobe

14. An inhaled foreign body is likely to lodge in the right lung due to all of the following features EXCEPT: *(AIPG)*
a. Right lung is shorter and wider left lung
b. Right principal bronchus is more vertical than the left bronchus
c. Tracheal bifurcation directs the foreign body to the right lung
d. Right inferior lobar bronchus is in continuation with the principal bronchus

15. A patient presents with chest pain due to aspiration pneumonitis. On examination there is dullness on percussion in area medial to the medial border of scapula on elevation of arm. Which part of the lung is most likely to be affected: *(AIIMS 2000)*
a. Right superior BPS
b. Right Posterior BPS
c. Left superior BPS
d. Right apical BPS

16. A bed-ridden patient on liquid diet develops aspiration pneumonia. Which of the following is bronchopulmonary segment is most likely affected:
a. Posterior of right upper lobe
b. Inferior lingular of left upper lobe
c. Apical of right lower lobe
d. Posterior of right lower lobe

17. Bronchial artery supplies lungs up to: *(AIPG 2008)*
a. Tertiary bronchioles
b. Respiratory bronchiole
c. Alveolar ducts
d. Terminal bronchiole

18. Rasmussen's aneurysm involves: *(AIIMS 2008)*
a. Bronchial artery
b. Pulmonary artery
c. Intercostal artery
d. Aorta

19. Which bronchopulmonary segment is absent in left lung?
a. Superior
b. Medial basal
c. Anterior basal
d. Apical

20. Untrue about visceral pleura: *(NEET Pattern 2013)*
a. Develops from splanchnopleuric mesoderm
b. Has three borders
c. Supplied by phrenic nerves
d. Pain insensitive

ANSWERS WITH EXPLANATIONS

1. d. 6th costal cartilage
- **6th costal cartilage** doesn't come in the surface marking of oblique fissure**.**
- Oblique fissure: Passes anteroinferiorly from the spinous process of the third thoracic vertebra to cross the fifth rib in the midaxillary line.
- It further continues inferiorly, crossing either the seventh rib on the right (fifth rib on the left), at the mid-clavicular line. (Gray's Ed41)

2. d. 10
- The lower border of the lung (midway between inspiration and expiration) crosses sixth rib in the midclavicular line, eighth rib in the midaxillary line and tenth rib at the lateral border of erector spinae (paravertebral line)

3. c. 10th
- Right costophrenic line measures approximately 5 cm vertically and extends from the eighth to the tenth rib along the mid-axillary line.
- The inferior margin of pleural reflection, which crosses 8th rib in the mid-clavicular line, **10th rib in the mid-axillary line** and 12th rib at the paravertebral line (lateral border of erector spinae).

4. d. Lingula
- Right lung has three lobes (superior, middle and inferior) and left lung has two (superior and inferior).
- Lingula is a portion of the left upper lobe.
- Azygous lobe is an anatomically separated part of the upper lobe, and not a true or accessory lobe of lung, as it has no bronchi, veins and arteries of its own.

5. b. Pulmonary artery
- The arrangement of structures in the hilum of left lung is remembered by the mnemonic ABV (Atal Bihari Vajpayi) in superior to inferior direction. Artery (pulmonary) → Bronchus (principal) → Vein (pulmonary).
- Pulmonary artery is uppermost whereas, pulmonary vein is inferior most.
- This applies for right lung as well, with just one additional bronchus located above the artery (and is called as ep-arterial bronchus). Hence, in the right lung the uppermost structure in the hilum will be a bronchus.
- There are 2 veins which are named anterior and inferior according to their location at the hilum (similar arrangement on both sides).
- Bronchus and bronchial arteries are always posterior most structures at the hila of both lungs.

6. b. SVC
- **Arch of aorta** and **left ventricle** are related to the mediastinal surface of left lung
- **Pulmonary trunk** is not related to any of the two lungs (mediastinal surfaces).

7. b. Inferior pulmonary vein
- Inferior pulmonary vein is the lowermost structure in the hila of each lung.

8. b. Azygos vein
- Hilum of right lung is arched by azygous vein and on left side by arch of aorta.

9. b. Right vagus
- Root of lung is related to phrenic nerve anterior and vagus nerve posterior.

10. c. 10,10
- Right principal bronchus branches into 3 lobar bronchi (upper, middle, and lower) and finally into 10 segmental bronchi (and bronchopulmonary segments).
- Left principal bronchus branches into 2 lobar or secondary bronchi, the upper and lower, and finally into 8 to 10 segmental bronchi (and bronchopulmonary segments)

11. b. Apical, anterior, posterior
- Upper lobe in the right lung has 3 bronchopulmonary segments**: apical, anterior and posterior**.

12. c. Medial basal
- Cardiac BPS of right lung is medial basal (VII) segment of middle lobe. This BPS may be absent in the left lung.

13. c. It is drained by independent intrasegmental branch of pulmonary vein
- The branches of **pulmonary veins** are intersegmental (not intra) and lie at the margins of bronchopulmonary segments and drain adjacent segments.
- Each segment drains into more than one vein and each vein drain more than one segment.

14. a. Right lung is shorter and wider left lung
- Foreign bodies are more likely to lodge in right lung because, right principal bronchus is shorter and wider and more vertical in disposition.
- Right lung being shorter and wider does not count as any of the deciding factor.

15. a. Right superior BPS
- Upon elevation of arm, medial border of scapula corresponds to the oblique fissure of lung on the posterior thorax .
- Medial to that lies the apex of lower lobe of the lung.
- This is the location of the apical (superior) BPS of right lower lobe, which is a common site of aspiration pneumonitis.
- Right posterior BPS is the posterior BPS of right upper lobe.
- Left superior BPS is the superior (apical) BPS of left lower lobe.
- Right apical BPS is apical BPS of right upper lobe, though it may also be the superior (apical) BPS of right lower lobe.

16. c. Apical of right lower lobe > a. Posterior of right upper lobe
- In erect/upright posture (sitting or standing) aspirated material most commonly enters the right lower lobar bronchus and lodges within the posterior basal bronchopulmonary segment (no. 10) of the right lower lobe.
- Aspiration in supine posture most commonly involves the right lower lobar bronchus and aspirate lodges within the superior(apical) bronchopulmonary segment of the right lower lobe. It is found at the posterior BPS of the right upper lobe as well (Harrison's Medicine Ed19).

17. b. Respiratory bronchioles
- Bronchial arteries are the direct/indirect branches from the descending thoracic aorta and supplies till the level of respiratory bronchiole.
- They perfuse the proximal air conducting pathways including tertiary and terminal bronchioles and reach till the beginning of respiratory unit.
- Pulmonary arteries alone vascularize the further distal pathways, including alveolar ducts and the alveoli.
- There are pre-capillary anastomoses between bronchial and pulmonary arteries, at the level of respiratory bronchioles, thus strengthening the dual vasculature of lungs.

18. b. Pulmonary artery
- Rasmussen's aneurysm refers to an aneurysm of the small to medium pulmonary artery branches that develop in the vicinity of a tuberculous cavity.
- Rasmussen's aneurysm is an inflammatory pseudo-aneurysmal dilatation of a branch of pulmonary artery adjacent to a tuberculous cavity.
- Life threatening massive hemoptysis from the rupture of a Rasmussen's aneurysm is an uncommon yet life threatening complication of cavitary tuberculosis.
- Bronchial arteries are the most common source and pulmonary artery account for <10% of hemoptysis.

19. b. Medial basal.
- **Medial basal** BPS may be absent in the left lung (Schwartz surgery).
- Medial basal is also called as **'cardiac'** BPS of right lung.

20. c. Supplied by phrenic nerves
- The visceral pleura develops from splanchnopleuric layer of the lateral plate of mesoderm, supplied by the autonomic (sympathetic) nerves (T1–T5) and is insensitive to pain.

High Yield Points

- The right lower lobar bronchus is most vertical, most nearly continues the direction of the trachea, and is larger in diameter than the left, and therefore, small aspirated objects commonly lodge and the fluid aspirations reach the right lower lobes more often.
- A BPS is aerated by tertiary bronchus (NEET Pattern - 2015

Heart and Pericardium

Pericardium and Cavity

Pericardium is a fibroserous sac that encloses the heart and the roots of the great vessels and occupies the middle mediastinum.

- It consists of three layers: fibrous pericardium, parietal layer of serous pericardium, and the visceral layer of serous pericardium.
  - Fibrous pericardium is the outer dense, fibrous layer that blends with the adventitia of the roots of the great vessels and the central tendon of the diaphragm.
  - Parietal layer of serous pericardium lines the inner surface of the fibrous pericardium, and reflects as the visceral layer on the outer surface of heart forming epicardium.
- Arterial supply: Pericardiophrenic, bronchial, and esophageal arteries.
- Nerve supply: Phrenic nerve, vagus nerves and the sympathetic trunks.
- Clinical correlation: Pain sensation carried by the phrenic nerves is often referred to the skin (C3 to C5 dermatomes) of the ipsilateral supraclavicular region.

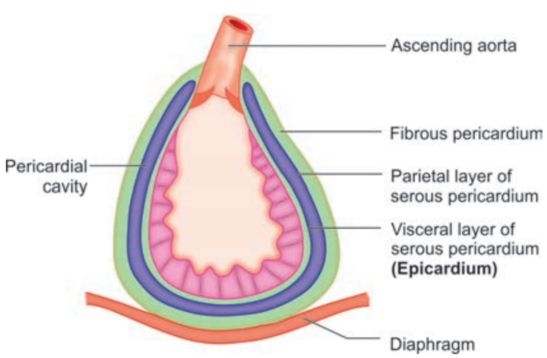


Fig. 63: Layers of the pericardium.

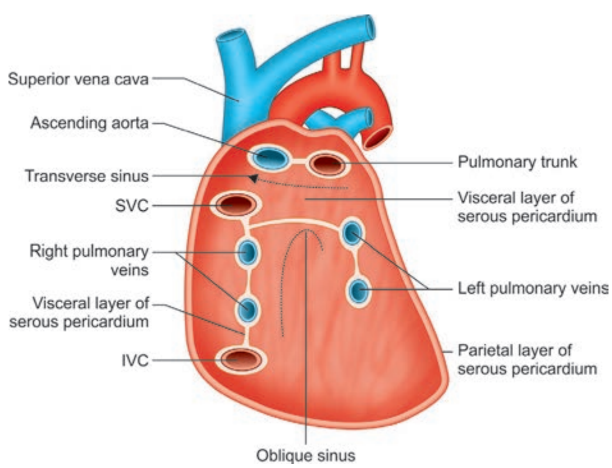


Fig. 64: Pericardial sinuses.

Table 25: Differences between the parietal and serous pericardium	
Parietal pericardium	**Visceral pericardium (epicardium)**
It is adherent to the fibrous pericardium	It is adherent to the myocardium of the heart
It develops from somatopleuric mesoderm	It develops from splanchnopleuric mesoderm
It is innervated by the somatic nerve fibers	It is innervated by the autonomic nerve fibers
It is sensitive to pain	It is insensitive to pain

Pericardial cavity is a potential space between the visceral and parietal layers of the serous pericardium, lined by mesothelium.

- It normally contains a small amount of pericardial fluid (20 mL), which allows friction-free movement of the heart during diastole and systole.
- The reflections of the serosal layer are arranged as two complex 'tubes'; the aorta and pulmonary trunk are enclosed in one, and the venae cavae and four pulmonary veins lie in the other.
- The perivenous tube is an inverted J; the cul-de-sac within its curve posterior to the left atrium is termed the oblique sinus.
- The transverse sinus is a passage between the two pericardial tubes; the aorta and pulmonary trunk are anterior, and the atria and their great veins are posterior.

Table 26: Pericardial sinuses		
Pericardial sinus	**Location**	**Relations**
Transverse	Lies between arterial and venous sleeves of pericardial reflection	• Anterior: Ascending aorta and pulmonary trunk • Posterior: Superior vena cava and atria • Superior: Bifurcation of pulmonary trunk • Inferior: Upper surface of left atrium
Oblique	It is a recess of serous pericardium behind the base of the heart, lies within the venous sleeve of pericardial reflection	• Anterior: Left atrium • Posterior: Parietal layer of pericardium* • Superior: Upper margin on left atrium • Left: Left pair of pulmonary veins • Right: Right pair of pulmonary veins and IVC

Pericardium separates the oblique sinus from esophagus.

Additionals

- Pericardiocentesisis a surgical puncture of the pericardial cavity for the aspiration of fluid.
- A needle is inserted into the pericardial cavity through the fifth intercostal space left of the sternum(costoxiphoid angle).
- The needle is passed 1–2 cm to the left of the costoxiphoid angle at 45° to the skin, and then up and backwards towards the tip of the scapula until it enters the pericardial sac.
- Because of the cardiac notch, the needle misses the pleura and lungs, but it penetrates the pericardium.
- The needle penetrates the following structures: Skin → superficial fascia → pectoralis major muscle → external intercostal membrane → internal intercostal muscle → transverse thoracic muscle → fibrous pericardium → parietal layer of serous pericardium.

High Yield Points

- The base of fibrous pericardium is broad and inseparably blended with the central tendon of diaphragm

Heart: Surface, Borders, Grooves and Chambers

The heart has the following four borders: Upper, right, lower (inferior) and left.

- Upper border of the heart is slightly oblique and atrial (mainly the left atrium).
  - Ascending aorta and the pulmonary trunk pass anterior to it (obscuring it) and at its right extremity, the superior vena cava enters the right atrium.
- Right border of the heart corresponds to the right atrium and is slightly convex to the right.
  - It extends from the right side of the opening of superior vena cava (SVC) to that of inferior vena cava (IVC) and separates the base from the sternocostal surface.
- Inferior border of the heart (acute margin) is sharp, thin and nearly horizontal.
  - It extends from the opening of IVC to the apex and is formed partly by right atrium, mainly by the right ventricle, with a small contribution from the left ventricle near the apex.
  - The inferior border separates the sternocostal(anterior) surface from the diaphragmatic (inferior) surface.
- Left border of the heart (obtuse margin) separates the sternocostal and left surfaces.
  - It descends obliquely, convex to the left, from the left atrial appendage to the cardiac apex.
  - It is round and mainly formed by the left ventricle and partly the left atrial appendage.

  The heart has the following three surfaces: Sternocostal (anterior), diaphragmatic (inferior) and left surface.
- **Anterior (sternocostal)** surface is formed mostly by right ventricle and right auricle and partly by left ventricle and left auricle.
  - Anterior interventricular groove is evident on this surface which separates right and left ventricle.
  - The left atrium is hidden on the front by the ascending aorta and pulmonary trunk.

- **The base** (posterior surface) is formed primarily by the left atrium (2/3) and partly by the posterior part of right atrium(1/3).
  - It is directed backwards and to the right (i.e., opposite to the apex).
  - It lies in front of the middle four thoracic vertebrae (T5–T8) in the lying-down position and descends one vertebra in the erect posture (T6–T9).
  - The base is separated from vertebral column by the oblique pericardial sinus, esophagus, and aorta.
  - Some authors consider the base of the heart as the upper border of the heart where great blood vessels (superior vena cava, ascending aorta and pulmonary trunk) are attached.
- Cardiac apex is the blunt rounded extremity of the heart formed by the left ventricle, which is directed anteroinferiorly and to the left.
  - It is overlapped by the left lung and pleura.
  - The apex is located most commonly behind the fifth left intercostal space, near or a little medial to the midclavicular line.
- Diaphragmatic surface is flat and rests on the central tendon of the diaphragm.
  - It is formed mainly by the left ventricle (2/3) and partly right ventricle (1/3) which are separated from each other by the posterior interventricular groove.
- Left surface is formed mainly by the left ventricle and partly by the left atrium and auricle.
  - It is directed upwards, backwards, and to the left.

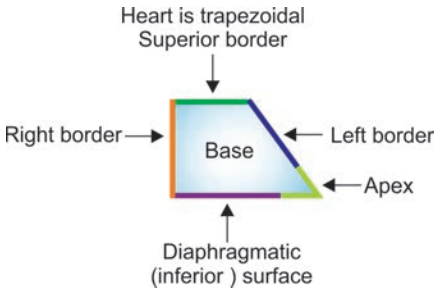


Fig. 65: Borders of heart.

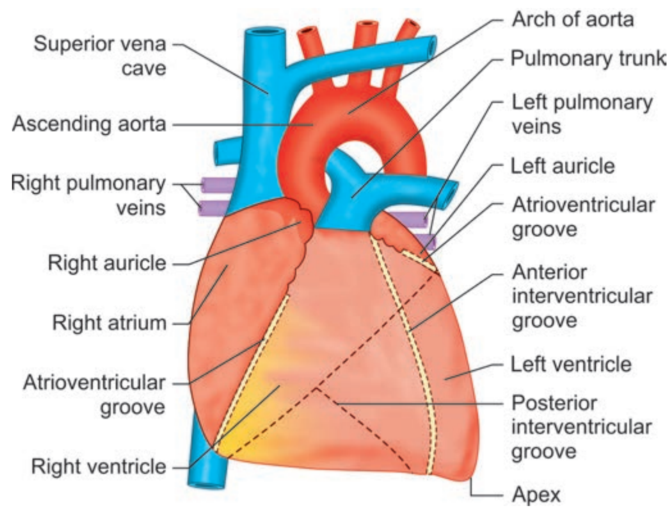


Fig. 66: Anterior (sternocostal) surface of the heart is formed mainly by the right ventricle and partly by the right atrium, left ventricle and left auricle.

The wall of the heart consists of three layers: inner endocardium, middle myocardium, and outer epicardium.

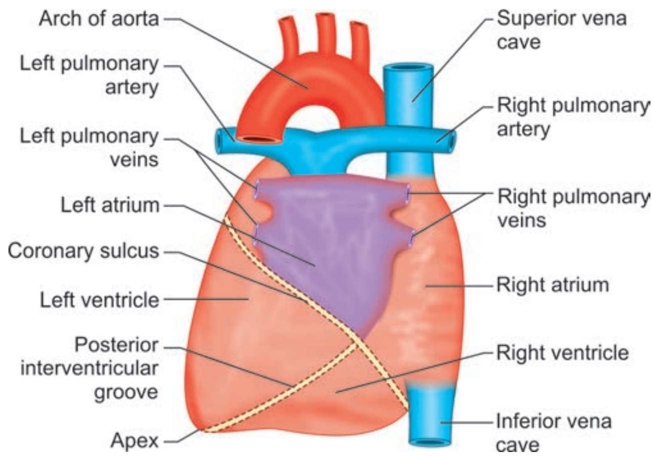


Fig. 67: Posterior aspect of the heart.

Grooves/sulci

- Coronary (atrioventricular) sulcus is present on the external surface of the heart, in a circumferential manner around the heart, marks the division between the atria and the ventricles.
- The crux is the point at which the interventricular and interatrial sulci cross the coronary sulcus.
- Coronary sulcus is divided into anterior and posterior parts.
- The right half of anterior part is large and lodges right coronary artery.
- Left half of anterior part is small and lodges circumflex branch of left coronary artery.

Table 27: Heart sulci and their contents		
Sulcus/Groove	**Location**	**Contents**
Coronary (atrioventricular) sulcus*	Between atria and ventricles, circumferentially around the heart	Right side • Right coronary artery • Small cardiac vein Left side • Left coronary artery • Circumflex artery • Great cardiac vein • Coronary sinus
Anterior interventricular sulcus	Between right and left ventricles; marks the interventricular septum, anteriorly	• Left anterior descending (anterior interventricular) artery • Great cardiac vein
Posterior interventricular sulcus	Delineates the interventricular septum posteriorly	• Posterior interior interventricular artery • Middle cardiac vein

*Coronary sulcus marks the annulosus fibrosus that supports the valves

ASSESSMENT QUESTIONS

1. **Base of the heart is formed by:** *(NEET Pattern 2013)*
   a. Left atrium
   b. Right atrium
   c. Left ventricle
   d. Right ventricle

2. **The base of the heart is formed by:**
   a. Left and right ventricle
   b. Left atrium and ventricle
   c. Right atrium and ventricle
   d. Left and right atrium

3. **True about atrioventricular groove are all EXCEPT:** *(NEET Pattern 2015)*
   a. Contains left anterior descending coronary artery
   b. Also called coronary sulcus
   c. Contains right coronary artery
   d. Contains circumflex branch of left coronary artery

ASNSWERS AND EXPLNATIONS

1. **a. Left atrium > b. Right atrium**
   - **Base of the heart** is formed by **left** and the **right atria**.
   - Left atrium has major contribution.
   - Base of the heart is the posterior surface of heart and extends from **T 5 to T 8 thoracic vertebra levels** in supine posture.
   - In standing posture gravity pulls it down by one vertebra (T6 to T9).

2. **d. Left and right atrium**
   - Base of the heart is the posterior surface of heart and is mainly contributed by left atrium and partly right atrium.
   - Diaphragmatic surface of heart is majorly contributed by left ventricle and partly right ventricle.
   - Anterior sternocostal surface has contributions from all the four chambers.

3. **a. Contains left anterior descending coronary artery**
   - Atrioventricular groove (coronary sulcus) separates atria from ventricles.
   - Right coronary artery lodges in right part of coronary sulcus and left coronary artery gives circumflex branch in left part of coronary sulcus.
   - Left anterior descending coronary artery runs in the anterior interventricular groove.

Heart Chambers

Right atrium has an anterior rough-walled portion (atrium proper and the auricle) lined with pectinate muscles and a posteriorly situated smooth-walled (sinus venarum) into which the two venae cavae open.

- Sulcus terminalis is a groove on the external surface of the right atrium (embryologic junction of the sinus venosus and primitive atrium) corresponding to crista terminalis on internal surface.
- Crista terminalis is a vertical muscular ridge running anteriorly along the right atrial wall from the SVC to IVC opening and provide the origin of the pectinate muscles.
- Pectinate muscles are the prominent ridges of atrial myocardium located in the interior of both auricles and the right atrium.

Table 28: Differences between the smooth and rough parts of the right atrium	
Smooth part (sinus venarum)	**Rough part (atrium proper)**
Developmetally it is derived from right horn of the sinus venosus	Development it is derived from primitive atrium
All the venous channels *EXCEPT* anterior cardiac veins open into this part (e.g., SVC, IVC, coronary sinus., and venae cordae minimi)	Presents series of transverse ridges, the musculi pectinati which arise from the *crista terminalis* and run forwards towards the auricle. The interior of auricle presents reticular sponge-like network of the muscular ridges

Right atrium is larger but thinner than the left atrium.

- Right auricle is the conical muscular pouch of the upper anterior portion of the right atrium, it covers the proximal part of the right coronary artery.
- Posterior smooth-wall (sinus venarum) receives the opening of SVC, IVC and coronary sinus.
- Eustachian valve of the IVC and the Thebesian valve of the coronary sinus are evident on the interior.
- Fossa ovalis is an oval-shaped depression in the interatrial septum and represents the site of the foramen ovale, through which blood runs from the right atrium to the left atrium in fetal circulation. It has an upper rounded (horseshoe-shaped) margin known as limbus fossa ovalis

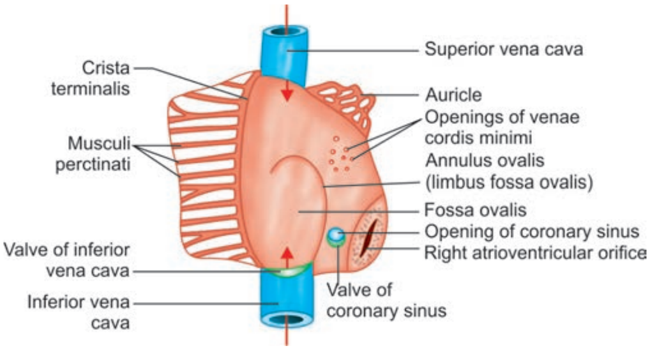


Fig. 68: Interior of the right atrium.

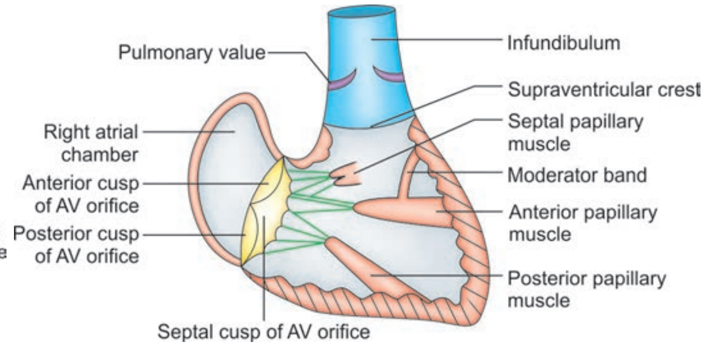


Fig. 69: Main features in the interior of right ventricle.

Left atrium has smooth wall, except for a few pectinate muscles in the auricle.

- It is the most posterior of the four chambers lying posterior to the right atrium but anterior to the esophagus and shows no structural borders on a posteroanterior (PA) radiograph.
- Four valveless pulmonary veins from lungs (oxygenated blood) open into the left atrium.

Right ventricle is largely evident anteriorly and contributes to the major portion of the sternocostal surface of the heart.

- The trabeculated inflow tract of the RV receives venous blood from the right atrium posteriorly through the tricuspid valve while the smooth outflow tract conus arteriosus (infundibulum) expels blood superiorly and to the left into the pulmonary trunk.
- Trabeculae carneae are irregular anastomosing muscular ridges, which form the trabeculated part of the ventricles (inflow tract) and develop embryologically from the primitive ventricle.
- Supraventricular crest (a C-shaped internal muscular ridge), marks the junction between the trabeculated part and smooth part of the right ventricle.
- Papillary muscles are cone-shaped muscles enveloped by endocardium, extend from the anterior and posterior ventricular walls and the septum, and their apices are attached to the chordae tendineae.
- These contract to tighten the chordae tendineae, preventing the cusps of the tricuspid valve from being everted into the atrium, preventing regurgitation of ventricular blood into the right atrium.
- Chordae tendineae extend from one papillary muscle to more than one cusp of the tricuspid valve.
- Septomarginal trabecula is an isolated band of trabeculae carneae that forms a bridge between the intraventricular (IV) septum and the base of the anterior papillary muscle of the anterior wall of the right ventricle.
- It is called the moderator band for its ability to prevent overdistention of the ventricle and carries the right limb (Purkinje fibers) of the atrioventricular bundle from the septum to the sternocostal wall of the ventricle.
- Interventricular septum gives origin of the septal papillary muscle. It has a small membranous upper part and lower muscular part.

Table 29: Differences of inflowing and outflowing parts of the right ventricle

Inflowing lower part	Outflowing upper part
It develops from primitive ventricle	It develops from bulbus cordis
It is large in size and lies below the supraventricular crest	It is small in size and lies above the supraventricular crest
It is rough due to presence of the muscular ridges—the *trabeculae carneae*. It forms most of the right ventricular chamber	It is smooth and forms upper 1 inch conical part of the right ventricular chamber—the infundibulum, which gives rise to pulmonary trunk

Left ventricle is mainly evident at the posterior view of the heart, its apex is directed downward, forward, and towards the left.

- The trabeculated inflow tract of the LV receives oxygenated blood from the left atrium through the mitral valve while the smooth outflow tract of the LV expels blood superoanteriorly into the ascending aorta.
- It is divided into the left ventricle proper and the aortic vestibule, which is the upper anterior part of the left ventricle, leading into the aorta.
- It has two papillary muscles (anterior and posterior) with their chordae tendineae and a meshwork of muscular ridges, the trabeculae carneae cordis.
- Left ventricle has a thicker (three times) wall, and is longer, narrower, and more conical-shaped than the right ventricle.

Table 30: Differences between the inflowing and outflowing parts of the left ventricle	
Inflowing part	**Outflowing part**
It develops from primitive ventricle	It develops from bulbus cordis
It lies below the aortic vestibule	It lies between the membranous part of the interventricular part of the interventricular septum and anterior cusp of the mitral valve
It is rough due to presence of trabeculae carneae and forms most of the left ventricular chamber	It is smooth and forms smooth small upper part—the aortic vestibule, which gives rise to the ascending aorta

Table 31: Differences between the right and left ventricles	
Right ventricle	**Left ventricle**
Receives deoxygenated blood from right atrium and pumps it to the lungs through pulmonary trunk	Receives oxygenated blood from left atrium and pumps it to the whole body through aorta
Wall of right ventricle is thinner than that of left ventricle (ratio 1: 3)	Wall of left ventricle is thicker than that of right ventricle (ratio 3:1)
Possesses three papillary muscles (anerior, posterior, and septal)	Possesses two papillary muscles (anterior and posterior)
Moderator band present	Moderator band absent
Cavity of righ ventricle is crescentic in shape in cross section	Cavity of left ventricle is circular in shape in cross section

ASSESSMENT QUESTIONS

1. WRONG statement about right atrium is: *(PGIC)*
   a. Related to central tendon of diaphragm at T10 level
   b. AV node is present in muscular atrioventricular septum
   c. Auricle is present superolaterally
   d. Crista terminalis divides right atrium in two parts
   e. Coronary sinus lies between fossa ovalis and IVC

2. Which of the following is situated in the upper part of crista terminalis? *(NEET Pattern 2015)*
   a. AV node
   b. Bundle of His
   c. Right bundle branch
   d. SA node

3. All the following openings in the right atrium are guarded valve EXCEPT:
   a. Superior vena cava
   b. Inferior vena cava
   c. Coronary sinus
   d. Atrioventricular opening

4. Torus aorticus is seen due to: *(NEET Pattern 2015)*
   a. Atrium bulging into the aorta
   b. Aortic sinus bulging into left atrium
   c. Aortic sinus bulging into right atrium
   d. Aortic wall tear

5. In TEE (transesophageal echocardiography), which chamber is most commonly evaluated: *(JIPMER 2016)*
   a. Left ventricle
   b. Left atrium
   c. Right atrium
   d. Right ventricle

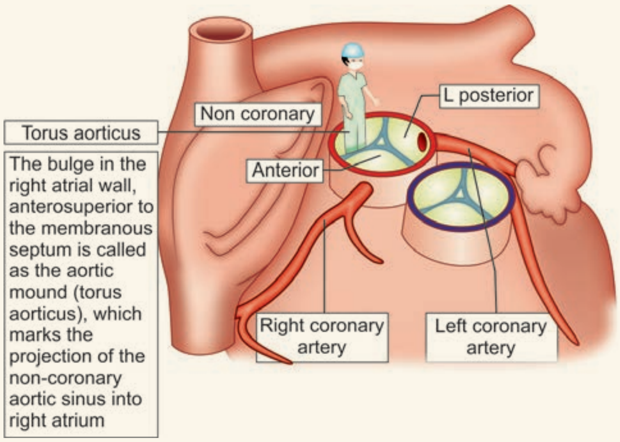
ANSWERS WITH EXPLANATIONS

1. a. Related to central tendon of diaphragm at T10 level, c. Auricle is present superolaterally, e. Coronary sinus lies between fossa ovalis and IVC
- Right atrium is related to central tendon of diaphragm at T8 vertebra level, at the IVC opening.
- AV node is present in atrial component of the muscular atrioventricular septum near the ostium of the coronary sinus.
- Auricle in the right atrium lies superomedially. Crista terminalis divides right atrium into smooth posterior part and rough anterior part.
- Coronary sinus opening lies between fossa ovalis and tricuspid orifice.

2. d. SA node
- Crista terminalis divides right atrium into smooth posterior part and rough anterior part (embryologically).
- SA node develops at the upper end of crista terminalis, in sub-epicardial region.

3. a. Superior vena cava
- Inferior vena cava opening is guarded by eustachian valve (rudimentary), coronary sinus by Thebesian valve and atrioventricular opening by tricuspid valve.

4. c. Aortic sinus bulging into right atrium
- Torus aorticus (aortic mound) is the prominent region of the right atrial septum, which marks the projection of the non-coronary aortic sinus into the right atrial wall.
- The bulge is superior to the coronary sinus and anterior to the fossa ovalis.
- The right coronary artery arises from the anterior ('right coronary') aortic sinus; The left coronary artery arises from the left posterior (left coronary) aortic sinus.



5. b. Left atrium

- Transesophageal echocardiography (TEE) uses high-frequency sound waves (ultrasound) to make detailed pictures of the heart and the arteries that lead to and from it.
- Unlike a standard echocardiogram, the echo transducer that produces the sound waves for TEE is attached to a thin tube that passes through mouth into esophagus.
- Because the esophagus is so close to the upper chambers of the heart, clear images of those heart structures and valves can be obtained.

Valves

- Heart valves are situated around the fibrous rings of the cardiac skeleton and are lined with endocardium.
- They incorporate leaflets or cusps, which close together to seal and prevent backflow.
- There are two pairs of valves in the heart: (a) a pair of atrioventricular valves, and (b) a pair of semilunar valves.
- Pulmonary valve is the semilunar valve that lies between the right ventricle and the pulmonary artery and has three cusps (anterior, right, and left).
- It is opened by ventricular systole and shut slightly after closure of the aortic valve.
- Aortic valve is the semilunar valve located between the left ventricle and the aorta and is composed of three cusps (posterior, right, and left).
- Its closure at the beginning of ventricular diastole causes the second (dup) heart sound.
- Tricuspid valve lies between the right atrium and ventricle, has anterior, posterior, and septal cusps, which are attached by the chordae tendineae to three papillary muscles that keep the valve closed.
- It is closed during the ventricular systole, the closure contributes to the first (lubb) heart sound.
- Mitral valve lies between the left atrium and ventricle, has two cusps: a larger anterior and a smaller posterior both of which are tethered to papillary muscles (anterolateral and posteromedial) by chordae tendineae.
- It is closed slightly before the tricuspid valve by the ventricular contraction the closure contributes to the first (lubb) heart sound.
- First (lubb) heart sounds is caused by the closure of the mitral and tricuspid valves (M1T1) at the onset of ventricular systole.
- Second (dup) heart sound is caused by the closure of the aortic and pulmonary valves (A2P2) at the onset of ventricular diastole.

Conduction System

Conduction system of the heart is constituted by the specialized cardiac muscle cells that lie immediately beneath the endocardium and carry impulses throughout the cardiac muscle, signaling the heart chambers to contract in the proper sequence.

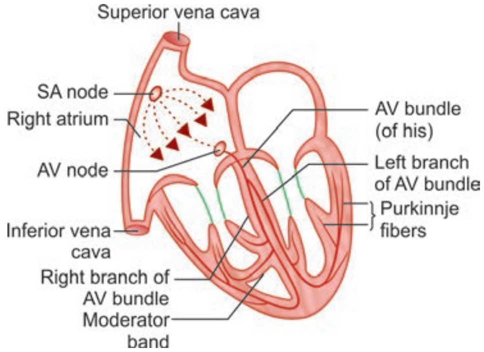


Fig. 70: Conducting system of the heart (SA = sinuatrial, AV = atrioventricular).

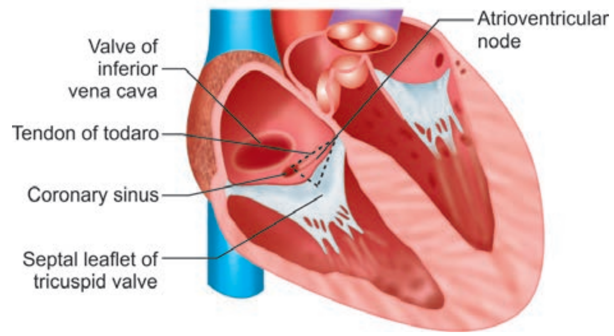


Fig. 71: Triangle of Koch, at the apex of which lies the atrioventricular node.

Sinuatrial node is located at the junction of the SVC and right atrium just beneath the epicardium.

- Embryologically it develops at the upper end of crista terminalis (junction between the sinus venosus and the atrium proper).
- It is crescent-shaped sub-epicardial tissue (having specialized myocardial fibers) with a head, body and tail.
- Starting sub-epicardially at the junction of the superior vena cava (SVC) and the right atrial (RA) appendage, it courses downward and to the left along the sulcus terminalis, to end subendocardially almost to the inferior vena cava (IVC).
- It surrounds the SA nodal artery, to a variable length. (Note: Nodal tissue does not occupy the full thickness of the right atrial wall from epicardium to endocardium but sits as a wedge of specialized subepicardial tissue.)
- SA node is the dominant pacemaker of the heart. It initiates the cardiac impulse, simply because it generates impulses slightly faster than the other areas with pacemaker potential.
- Its pace maker function is determined by its low maximum diastolic membrane potential and steep phase 4 spontaneous depolarization.
- Cardiomyocytes, like all muscle cells, have refractory periods following contraction during which additional contractions cannot be triggered; their pacemaker potential is overridden by the sinoatrial or atrioventricular nodes.
- Atrioventricular node is an oblique, half-oval atrial structure, located within the right side (atrial component) of the muscular atrioventricular septum near the ostium of the coronary sinus.
- It is present in the subendocardial region, more precisely in Koch's triangle.
- Triangle of Koch : A roughly triangular area on the septal wall of the right atrium, bounded by the septal leaflet of the tricuspid valve inferiorly, the anteromedial margin of the orifice of the coronary sinus as a base, and the tendon of Todaro superiorly.
- It contains the AV node and the proximal penetrated portion of the bundle of His.
- In a case of AV nodal re-entry tachycardia, radiofrequency ablation of this triangular area improves the symptoms.
- From the SA node, the impulse spreads throughout the right atrium and to the AV node via the anterior, middle, and posterior internodal tracts and to the left atrium via the Bachmann bundle.
- AV bundle of His begins at the AV node (at the apex of Koch's triangle) and runs along the right side of the membranous part of the interventricular septum.
- It splits into right and left branches, which descend into the muscular part of the interventricular septum.
- Left bundle branch (LBB) is thicker than the RBB.
- A portion of the RBB enters the moderator band (septomarginal trabecula) to reach the anterior papillary muscle.
- LBB divides into an anterior and posterior segment.
- Both bundle branches terminate in a complex network of intramural Purkinje myocytes to spread out into the ventricular walls.

Table 32: showing the components of conducting system and their location in heart

Component of conduction system	Location
SA node	• Subepicardial (? myocardium) • Right atrium – Upper end of crista terminalis – Near opening of SVC
AV node	• Triangle of Koch's – In the atrioventricular septum – Near lower part interatrial septum – Sub-endocardial
AV bundle of His	Membranous part of interventricular septum
RBB	Right surface of interventricular septum
LBB	Left surface of interventricular septum
Purkinje fibers	Sub-endocardial plexus of ventricular conduction cells

ASSESSMENT QUESTIONS

1. Boundary of Koch's triangle is NOT formed by: *(AIIMS; PGIC; NEET Pattern 2013)*
   a. Tricuspid valve
   b. Tendon of Todaro
   c. Limbus fossa ovalis
   d. Coronary sinus

2. SA node is located in:
   a. Pericardium
   b. Epicardium
   c. Myocardium
   d. Endocardium

3. The following statements are true regarding the SA node EXCEPT: *(AIIMS 2005)*
   a. Is located at the right border of the ascending aorta
   b. It contains specialized nodal cardiac muscle
   c. It is supplied by the atrial branches of the right coronary artery
   d. It initiates cardiac conduction

ANSWERS WITH EXPLANATIONS

1. c. Limbus fossa ovalis
- **Limbus fossa ovalis** is not in the boundary of Koch's triangle.
- The boundaries are: Septal cusp of tricuspid valve; tendon of Todaro (fibrous skeleton of heart) and coronary sinus opening.

2. c. Myocardium
- SA node is present in the sub-epicardial region. *Gray's Anatomy 41ed* (Some authors mention Myocardium).

3. a. Is located at the right border of the ascending aorta
- SA node is located at the right border of the superior vena cava and not ascending aorta.
- It contains specialized cardiac muscle having fastest rate of impulse generation and initiates the cardiac conduction. Hence it is called as pacemaker of the heart.
- SA node is supplied by the nodal branch of right coronary artery in about 65% of population, whereas, 35 % of the population receives the nodal branch from the circumflex branch of left coronary artery.

Heart: Fibrous skeleton

The fibrous skeleton is a dense framework of collagen within the heart that keeps the orifices of the atrioventricular (AV) valves and semilunar valve patent and provides an attachment site of the valve leaflets and cups.
- It also serves as the origin and insertion sites of cardiac myocytes, and forms an electrical "barrier" between the atria and ventricles so that they contract independently.
- The right and left fibrous rings of heart (annulus fibrosus cordis) surround the atrioventricular and arterial orifices.
- The right fibrous ring is known as the annulus fibrosus dexter cordis, and the left is known as the annulus fibrosus sinister cordis.
- The right fibrous trigone is continuous with the central fibrous body.

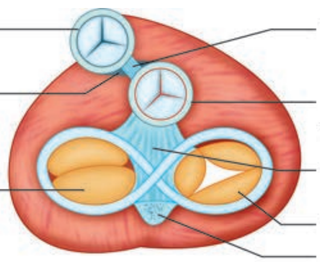


Fig. 72: Fibrous skeleton of heart.

Heart (Surface Marking)

Heart: the projection of the cardiac borders on the the anterior thoracic wall forms a trapezoid

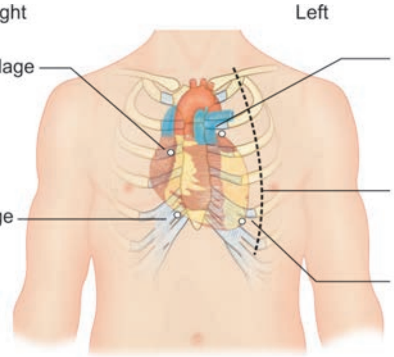


Fig. 73: Surface marking of heart **A-D:** Surface markings of the heart. A overlies the left second costal cartilage; B overlies the right third costal cartilage; C, right sixth costal cartilage; D, zone of location of the cardiac apex (fifth intercostal space).

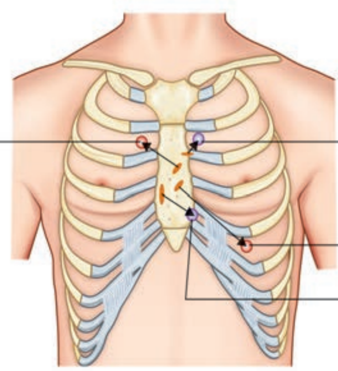


Fig. 74: Surface marking of heart valves.

Upper border; It slopes from the 2nd left costal cartilage to the 3rd right costal cartilage
- Right border: Is a curved line, convex to the right, running from the 3rd to the 6th right costal cartilages, usually 1–2 cm lateral to the sternal edge.
- Inferior (acute) border: Runs leftwards from the sixth right costal cartilage to the cardiac apex, located approximately 9 (8.7±1) cm lateral to the midline (in the left fifth intercostal space).

- Left (obtuse) border: Is convex laterally and extends from the cardiac apex to meet the 2nd left costal cartilage approximately 1 cm from the left sternal edge.

Table 33: Cardiac valves and auscultatory areas

Cardiac valves	Surface marking (orifice)	Auscultatory area
Pulmonary	Horizontal line (2.5 cm) over the superior border of the left third costal cartilage*	Sternal end of the left second intercostal space
Aortic	Oblique line (2.5 cm) running inferolaterally and to the right from the medial end of the left third intercostal space*	Sternal end of the right second intercostal space
Tricuspid	Vertical line (4 cm) that starts near the midline just below the level of the right (CC-4) fourth costal cartilage and passes down and slightly to the right*	Over the left lower sternal border at the level of the fifth intercostal space
Mitral	Oblique line (3 cm) opposite the left fourth costal cartilage and descending to the right*	Near the cardiac apex ~ 9 (8.7±1) cm lateral to the midline (in the left fifth intercostal space)

*and behind the corresponding region of the sternum

Note: Tricuspid valve lies behind the right half of the sternum opposite to the 4th and 5th intercostal spaces..

The cardiovascular silhouette (shadow), is the contour of the heart and great vessels seen on posterior–anterior chest radiographs.

- Its right border is formed by the SVC, the right atrium, and the IVC.
- The left border is formed by the aortic arch (which produces the aortic knuckle), the pulmonary trunk, the left auricle, and the left ventricle.
- Its inferior border is formed by the right ventricle, and the left atrium shows no border.

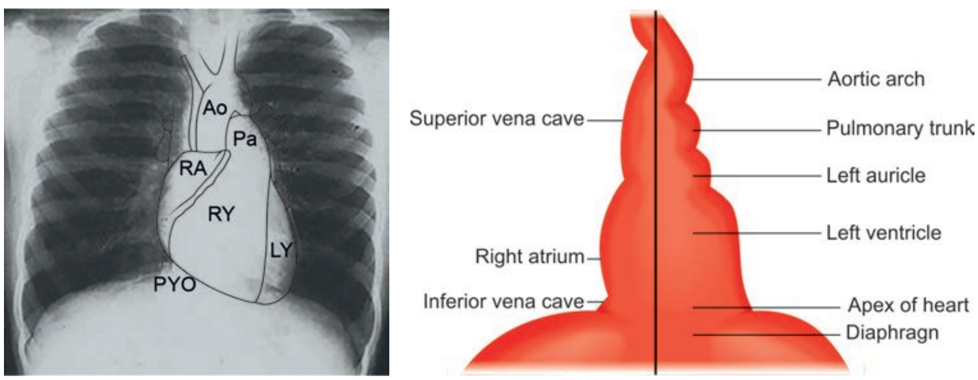


Fig. 75: Borders of cardiac silhouette on chest X-ray.

ASSESSMENT QUESTIONS

1. **Which of the following represents the surface marking of the aortic valve:** *(NEET Pattern 2012)*
   a. Sternal end of the left 3rd costal cartilage
   b. Sternal end of the right 3rd costal cartilage
   c. Besides the sternum in left 3rd intercostal space
   d. Besides the sternum in right 3rd intercostal space

2. **Surface marking of the mitral valve is:** *(NEET Pattern 2012)*
   a. Behind sternal end of the left 4th costal cartilage
   b. Behind sternal end of the right 4th costal cartilage
   c. Left 4th intercostal space in midclavicular line
   d. Left 3rd intercostal space in midclavicular line

3. **In PA view CXR, right border of the heart is contributed by:**
   a. Pulmonary trunk
   b. Ascending aorta
   c. Right auricle
   d. Right ventricle

ANSWERS WITH EXPLANATIONS

1. **c. Besides the sternum in left 3rd intercostal space**
   - Aortic valve is represented by an oblique line (2.5 cm) running inferolaterally and to the right from the medial end of the left third intercostal space (and behind the corresponding region of the sternum).

2. **a. Behind sternal end of the left 4th costal cartilage**
   - The orifice of the **mitral valve** is level with the left half of the sternum opposite the **left fourth costal cartilage** and is represented by an oblique line approximately 3 cm long and descending to the right.

3. **b. Ascending aorta**
   - Right border of heart is formed by the SVC, the right atrium, and the IVC.
   - Some authors mention ascending aorta in the right border of heart (Snell's anatomy)

Heart: arteries

Coronary arteries arise from the sinus (of Valsalva) in the ascending aorta and are filled with blood during the ventricular diastole.

- They have maximal blood flow during diastole and minimal blood flow during systole because of compression of the arterial branches in the myocardium during systole.
- **Right coronary artery** takes origin from the anterior (right) aortic sinus of the ascending aorta, runs between the root of the pulmonary trunk and the right auricle, and then descends in the right coronary sulcus, and majorly supplies the right atrium and ventricle. Branches (table)
- **Left coronary artery** takes origin from the left aortic sinus of the ascending aorta, just above the aortic semilunar valve.
  - It is shorter than the right coronary artery and usually is distributed to more of the myocardium.
- **Circumflex artery** is a branch of left coronary artery, runs in the coronary sulcus, gives off the left marginal artery, supplies the left atrium and left ventricle, and anastomoses with the terminal branch of the right coronary artery

Table 34: Arteries of heart and their area of distribution

Artery/branches	Distribution
Right coronary artery • Acute marginal • Posterior interventricular (posterior descending) • Right conus (infundibular) • SA nodal artery (65% population) • AV nodal artery (80% population) • Atrial, anterior and posterior ventricular	• Right ventricle • Right atrium • Interventricular septum (posterior 1/3) • Left ventricle (partly)* • SA Node (65% population) • AV node (20% population) • Bundle of His (partly) • Left bundle branch (partly)
Left coronary artery • Anterior interventricular (left anterior descending) • Circumflex • Left diagonal • Obtuse marginal (left marginal) • Left conus • SA nodal artery (35% population) • AV nodal artery (20% population) • Atrial, anterior and posterior ventricular	• Left ventricle • Left atrium • Interventricular septum (anterior 2/3) • Right ventricle (partly)** • SA Node (35% population) • AV node (80% population) • Bundle of His (major portion) • Left bundle branch • Right bundle branch
Small part of left ventricle adjoining posterior interventricular groove Small part of right ventricle adjoining anterior interventricular groove	

SA node receives blood supply from the SA node artery, a branch of the right coronary artery in the majority (about 60–70%) of hearts, and a branch of the left coronary artery (usually the left circumflex artery) in about 20–30% of hearts, fewer than 10% of nodes receive a bilateral supply.

Table 35: Arterial supply to conduction system

Part of conduction system	Arterial supply
SA node	Right coronary artery (65%) Left coronary artery (35%)
AV node	Right coronary artery (80%) Left coronary artery (20%)
AV bundle of His	Left coronary artery Right coronary artery (partly)
Left bundle branch	Left coronary artery Right coronary artery (partly)

Table 36: Arterial supply to heart

Artery/branch	Origin	Course	Distribution	Anastomoses
Right coronary artery (RCA)	Right aortic sinus	Follows coronary (AV) sulcus between atria and ventricles	Right atrium, SA and AV nodes, and posterior part of IVS	Circumflex and anterior IV branches of LCA
SA nodal`	RCA near its origin (60%)	Ascends of SA node	Pulmonary trunk and SA node	
Right marginal	RCA	Passes to inferior margin of heart and apex	Right ventricle and apex of heart	IV branches
Posterior interventicular	RCA (in 67%)	Runs in posterior IV groove to apex of heart	Right and left ventricles and posterior third of IVS	Anterior IV branch of LCA (at apex)

Artery/branch	Origin	Course	Distribution	Anastomoses
AV nodal	RCA near origin of posterior IV artery	Passes to AV node	AV node	
Left coronary artery (LCA)	Left aortic sinus	Runs in AV groove and gives off anterior IV and circumflex branches	Most of left atrium and ventricle, IVS, and AV bundles; may supply AV node	RCA
SA nodal	Circumflex branch of LCA (in 40%)	Ascends on posterior surface of left atrium to SA node	Lelf atrium and SA node	
Anterior interventricuar	LCA	Passes along anterior IV groove to apex of heart	Right and left ventricles and anterior two thirds of IVS	Posterior IV branch of RCA (at apex)
Circumflex	LCA	Passes to left in AV sulcus and runs to posterior surface of heart	Left atrium and left ventricle	RCA
Left marginal	Circumflex branch of LCA	Follow left border of heart	Left ventricle	IV branches
Posterior interventricular	LCA (in 33%)	Runs in posterior IV groove to apex of heart	Right and left ventricles and posterior third of IVS	Anterior IV branch of LCA (at apex)

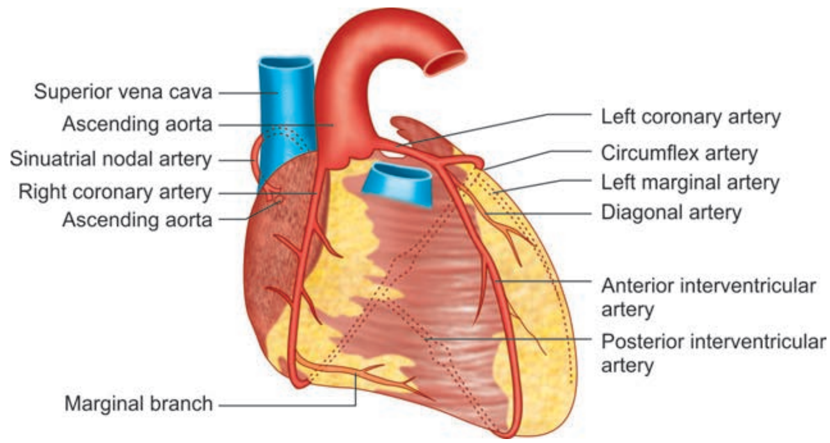


Fig. 76: Arterial supply of the heart.

SA nodal artery passes between the right atrium and the root of the ascending aorta, encircles the base of the SVC, and supplies the SA node and the right atrium.

- The first branch of right coronary artery is called as conus artery.
  - This is sometimes termed a 'third coronary' artery (may arise separately from the anterior aortic sinus in 36% ofindividuals or may be a branch of left coronary artery occasionally).

Applied anatomy:

Table 37: Sites of infarct in coronary artery blocks

Coronary artery lesions	Infarct location
Proximal LAD	Large anterior wall
More distal LAD	Anteroapical (Inferior wall if wrap around LAD)
Distal LAD	Anteroseptal
Early obtuse marginal	High lateral wall
More distal marginal, circumflex	Small lateral wall
Circumflex	Posterolateral
Distal RCA	Small inferior wall
Proximal RCA	Large inferior wall and posterior wall, some lateral wall
RCA	Right ventricular (usually inferior)

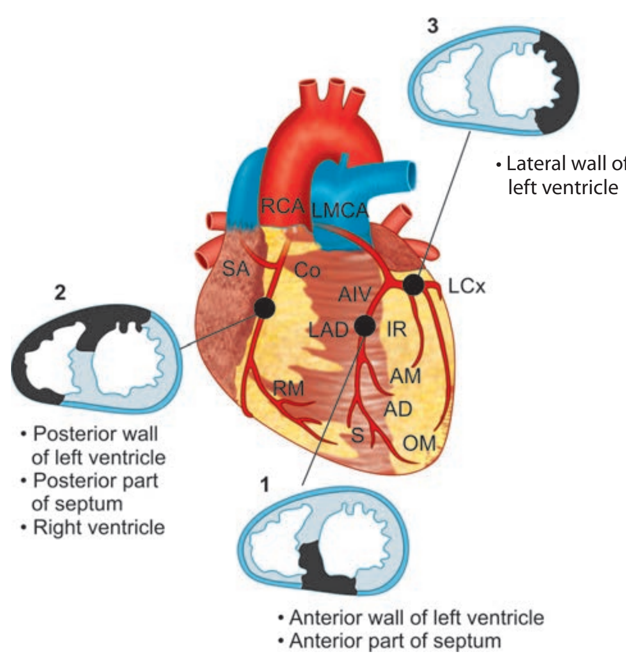


Fig. 77: Sites of infarct in coronary artery blocks.

Myocardial infarction due to thrombotic occlusion of a coronary artery involves a localized area, as depicted in the diagram. Most commonly involved is LAD-left anterior descending artery (50%), followed by the RCA—right coronary artery (30%), and then the LCx—left circumflex artery (15%). This is indicated by the numbers 1, 2, and 3.

ASSESSMENT QUESTIONS

1. Occlusion of the LAD will lead to infarction of which area: *(NEET pattern 2012)*
   a. Posterior part of the interventricular septum
   b. Anterior wall of the left ventricle
   c. Lateral part of the heart
   d. Inferior surface of right ventricle

2. Right coronary artery supplies all of the following parts of conducting system in the heart EXCEPT: *(NEET Pattern 2013)*
   a. SA node
   b. AV node
   c. AV bundle
   d. Right bundle branch

3. All of the following arteries are common sites of occlusion by a thrombus EXCEPT: *(AIIMS 2005)*
   a. Anterior interventricular
   b. Posterior interventricular
   c. Circumflex
   d. Marginal

4. Coronary dominance is determined by: *(NEET pattern 2013)*
   a. Posterior interventricular artery
   b. Anterior interventricular artery
   c. Circumflex artery
   d. Right coronary artery

5. Posterior interventricular artery is a branch of right coronary artery in most of the people (right dominance). In 10% population it arises from:
   a. Circumflex artery
   b. Left coronary artery
   c. Pulmonary artery
   d. Right coronary artery

6. If the circumflex artery gives off the posterior interventricular artery, then the arterial supply is called: *(AIIMS 2007)*
   a. Right dominance
   b. Left dominance
   c. Balanced dominance
   d. Co-dominance

7. Arterial supply of ventral 2/3rd of interventricular septum of heart is: *(NEET pattern 2015)*
   a. Right coronary artery
   b. Left coronary artery
   c. Posterior interventricular artery
   d. Marginal artery

8. TRUE statement about right coronary artery is/are: *(PGIC 2010)*
   a. Diameter less than LCA
   b. RCA arises from anterior aortic sinus
   c. RCA supplies major part of right atrium and right ventricle
   d. RCA gives rise to circumflex coronary branch
   e. RCA supplies RBB

9. Branch of right coronary artery is/are: *(PGIC)*
   a. Obtuse marginal
   b. Acute marginal
   c. Posterior interventricular
   d. Diagonal
   e. Conus artery

10. Artery supply to Koch's triangle is from: *(NEET Pattern 2012)*
   a. Right coronary artery
   b. Left coronary artery
   c. Left anterior descending artery
   d. Artery from anterior aortic sinus

11. INCORRECT statement about the coronary arteries:
   a. They arise from the aortic sinuses
   b. They don't nourish the endocardium of the heart
   c. They are filled mainly during diastole
   d. Branches of the right and left coronary arteries do no anastomose

ANSWERS WITH EXPLANATIONS

1. b. Anterior wall of left ventricle
- LAD (Left anterior descending) artery is also known as anterior interventricular artery and runs in the same named groove, supplying anterior 2/3 of interventricular septum lying deep to it and also the adjacent anterior wall of the left ventricle.
- Posterior part of the interventricular septum and inferior surface of right ventricle is supplied by PIVA (posterior interventricular artery).
- Left lateral surface of the heart is supplied by circumflex artery.

2. d. Right bundle branch
- **Right bundle** branch is present in that region of the interventricular septum, which is exclusively supplied by left coronary artery. (Note: Right coronary artery does not supply right bundle branch).
- SA node and AV node are supplied by right coronary artery in most of the population.
- Major portion of bundle of His is supplied by left coronary artery, and partly supplied by right coronary artery.

3. d. Marginal
- **Marginal** arteries are rarely the sites of coronary vaso-occlusive disease.
- There are two main marginal arteries: 1. Acute marginal (branch of right coronary) and 2. Obtuse marginal (branch of circumflex, left coronary artery).
- Anterior interventricular artery is a branch of left coronary artery and is the most common (50%) artery to be occluded by the thrombus in the coronary circulation.
- The second most common artery to be occluded is the main trunk of right coronary artery (30%).
- Posterior interventricular artery is a branch of right coronary artery and incidence of thrombosis is statistically less.
- The third most commonly thrombosed artery is circumflex artery—a branch of left coronary artery.

4. a. Posterior interventricular artery
- Coronary dominance is determined by posterior interventricular artery (PIVA).
- In about 65% of the population PIVA is given by right coronary artery alone (right cardiac dominance), in 10% cases it is a branch of left coronary artery alone (left cardiac dominance) and in the remaining 25 % it is given by both (balanced dominance).

5. a. Circumflex artery
- In 10 % population, PIVA is a branch of the circumflex artery, which itself is a branch of left coronary artery (left cardiac dominance).

6. b. Left dominance
- Usually the **posterior interventricular artery** (PIVA) is a branch of right coronary artery and such hearts are called as right dominant heart.
- In 10 % of the population PIVA is given by the circumflex artery (a branch of left coronary artery) and then the heart is called as **left dominant**.

7. b. Left coronary artery
- Anterior 2/3 rd of the interventricular septum is supplied by the left anterior descending artery, a branch of left coronary artery.

8. a. Diameter less than LCA, b. RCA; arises from anterior aortic sinus; c. RCA supplies major part of right atrium and right ventricle
- Right coronary artery has smaller lumen as compared with left coronary artery (left ventricle is thicker than right).
- The right coronary artery arises from the anterior aortic sinus, supplies major portion of right atrium and ventricle.
- Circumflex artery is a branch of left coronary artery and is the exclusive supply to the right bundle branch.

9. b. Acute marginal; c. Posterior interventricular; e. Conus artery
- Left coronary artery gives obtuse marginal artery, diagonal artery and left conus artery, in addition to few more.

10. a. Right coronary artery > b. Left coronary artery
- Koch's triangle (and AV node) is supplied by right coronary artery in majority of population.

11.d. Branches of the right and left coronary arteries do no anastomose > b) They don't nourish the endocardium of the heart
- Branches of right and left coronary arteries—they do have **anatomical** anastomosis.
  - Anastomoses do occur between branches of the coronary arteries, both subepicardial and myocardial but clinical experience suggests that anastomoses cannot rapidly provide collateral routes sufficient to circumvent sudden coronary obstruction.
  - So coronary arteries are functional end arteries.
  - Because capillary networks arising from penetrating arteries do not interconnect, the borders between viable and infarcted myocardium after coronary artery occlusion are distinct.
- **They don't nourish the endocardium of the Heart.**
  - This statement may be considered as true but endocardium does get affected in coronary artery blocks.
  - The coronary arteries initially course along the external surface of the heart (epicardial coronary arteries) and then penetrate the myocardium (**intramural** arteries).
  - Blood flow in the myocardium occurs inward from epicardium to endocardium.
  - Thus, as a general rule, the endocardium is most vulnerable to ischemia when flow through a major epicardial coronary artery is compromised, though the endocardium chiefly receive oxygen and nutrients by diffusion or microvasculature **directly** from the chambers of the heart.
- The right coronary artery (RCA) arises from the right (anterior) aortic sinus of the ascending aorta.
- The left coronary artery (LCA) arises from the left (posterior) aortic sinus of the ascending aorta.
- Coronary arteries are filled with blood during the ventricular diastole.
- They have maximal blood flow during diastole and minimal blood flow during systole because of compression of the arterial branches in the myocardium during systole.

Heart: Veins

Cardiac veins and coronary sinus
- Coronary sinus is the largest vein draining the heart lying in the coronary sulcus, that separates the atria from the ventricles.
- It opens into the right atrium between the opening of the IVC and the tricuspid valve opening.
- It has thebesian valve, which is one-cusp valve at the right margin of its aperture.
- Coronary sinus receives the great, middle, and small cardiac veins; the oblique vein of the left atrium; and the posterior vein of the left ventricle.
- Great cardiac vein begins at the apex of the heart and ascends in the anterior interventricular groove (along with the anterior interventricular branch of the left coronary artery), turns to the left to lie in the coronary sulcus and continues as the coronary sinus.
- Middle cardiac vein begins at the cardiac apex and ascends in the posterior interventricular groove (accompanying the posterior interventricular branch of the right coronary artery), drains into the right end of the coronary sinus.
- Small cardiac vein runs along the right margin of the heart in company with the acute marginal artery and then posteriorly in the coronary sulcus (along with right coronary artery) to end in the right end of the coronary sinus
- **Oblique vein** of the left atrium descends to enter the coronary sinus, near its left end.
- **Anterior cardiac veins** drain the anterior right ventricle, crosses the coronary groove, and enter into the anterior wall of right atrium.
- **Smallest cardiac veins** (venae cordis minimae) are multiple veins, begin in the substance (endocardium and innermost layer of the myocardium) of all four chambers and empty directly into the same chambers.

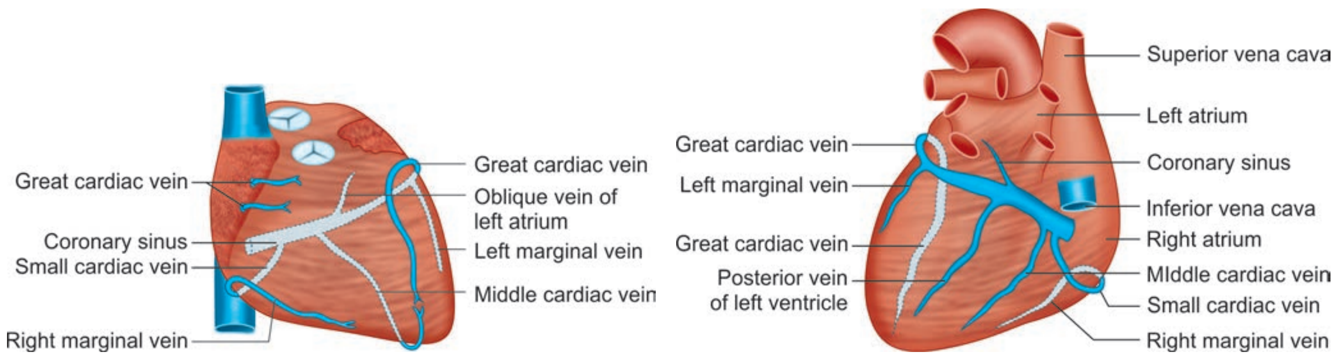


Fig. 78: Venous drainage of heart.

ASSESSMENT QUESTIONS

1. **All opens into coronary sinus EXCEPT:** *(NEET Pattern 2014)*
   a. Middle cardiac vein
   b. Small cardiac vein
   c. Anterior cardiac vein
   d. Great cardiac vein

2. **The coronary sinus:** *(JIPMER 2005)*
   a. Lies in anterior part of the coronary sulcus
   b. Ends in right atrium
   c. Has venae cordis minimae as its tributaries
   d. Develops from right anterior cardinal vein

3. **The great cardiac vein lies in which groove:**
   a. Anterior part of right coronary sulcus
   b. Posterior part of right coronary sulcus
   c. Anterior interventricular groove
   d. Posterior interventricular groove

4. **Bleeding comes from the vein that is accompanied by the posterior interventricular artery. Which of the following veins is most likely to be ruptured?**
   a. Great cardiac vein
   b. Middle cardiac vein
   c. Small cardiac vein
   d. Oblique veins of the left atrium

5. **Even if thrombosis is present in the coronary sinus, which of the following cardiac veins might remain normal in diameter:**
   a. Middle cardiac vein
   b. Anterior cardiac vein
   c. Small cardiac vein
   d. Oblique cardiac vein

6. **WRONG about venous drainage of heart:**
   a. Coronary sinus is guarded by Thebesian valve
   b. Middle cardiac vein lies in posterior atrioventricular groove
   c. Great cardiac vein accompany left anterior descending artery
   d. Venae cordis minimi open into all four chambers

ANSWERS WITH EXPLANATIONS

1. c. Anterior cardiac vein
- **Anterior cardiac veins** open into the anterior wall of right atrium.
- Most of the veins of heart drain into coronary sinus except few like **anterior cardiac veins** and **smallest cardiac veins**.
- Smallest cardiac veins (venae cordis minimi, Thebesian veins) drain into all the four chambers of heart.

2. b. Ends in right atrium
- Coronary sinus drains the venous blood of the heart into the **right atrium.**
- Coronary sinus **develops from the left horn of the sinus venosus**, lies in the **posterior part of coronary sulcus**.
- **Venae cordis minimi** drain directly into the nearest heart chamber (drain into all the 4 chambers).

3. c. Anterior interventricular groove
- Great cardiac vein runs along with the anterior interventricular artery (in anterior interventricular groove) and next with circumflex artery (in coronary sulcus), to drain eventually into coronary sinus.
- Middle cardiac vein runs in the posterior interventricular groove.

4. b. Middle cardiac vein
- Posterior interventricular artery is accompanied by middle cardiac vein, which itself drains into the coronary sinus.

5. b. Anterior cardiac vein
- Anterior cardiac veins drain directly into the right atrium and not into the coronary sinus, hence, they might remain normal in coronary sinus thrombosis.

6. b. Middle cardiac vein lies in posterior atrioventricular groove
- Middle cardiac vein lies in posterior interventricular (not atrioventricular) groove.

High Yield Points

- **Coronary sinus** is guarded by **Thebesian valve. (NEET Pattern 2013)**
- **Great cardiac vein** accompanies **anterior interventricular artery** (Left anterior descending artery) in the anterior interventricular groove. **(NEET Pattern 2013)**
- **Middle cardiac vein** accompanies **posterior interventricular artery** in the posterior interventricular groove. **(AIPG 2003)**

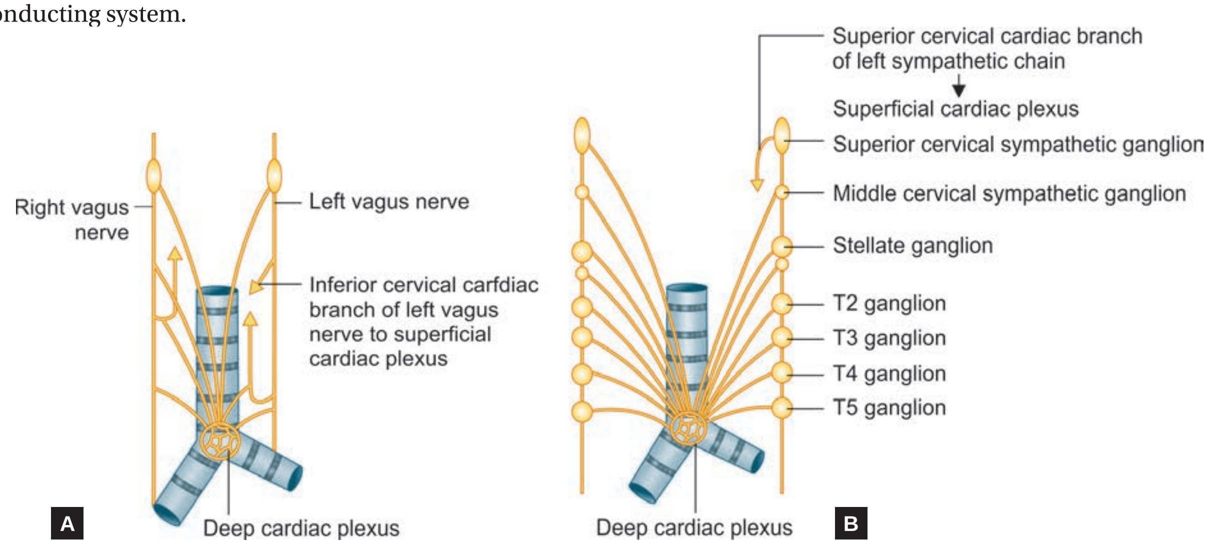
Lymphatics

Lymphatic vessels of the heart receive lymph from the myocardium and epicardium, follow the right coronary artery to empty into the anterior mediastinal nodes and the left coronary artery to empty into a tracheobronchial node.

Heart: Innervation

Initiation of the cardiac cycle is myogenic, originating in the SA node. It is modulated in rate, force and output by autonomic nerves.

- Preganglionic sympathetic axons arise from **T1-5 spinal segment**. Few fibers synapse in the corresponding thoracic sympathetic ganglia, others ascend to synapse in the cervical ganglia; postganglionic fibers from these ganglia form the **sympathetic cardiac nerves**. Sympathetic fibres cause cardio-stimulation and dilate the coronary arteries.
- Preganglionic parasympathetic fibers from **dorsal nucleus of vagus** (and nucleus ambigus) run in vagal cardiac branches to synapse in the cardiac plexuses and atrial walls. Postganglionic axons are distributed to the SA node, AV node, atrial myocytes (not ventricular myocytes), and smooth muscle of coronary arteries, causing cardio inhibition: Deceleration in the SA node (decrease in heart rate), decrease in speed of conduction through the AV node, decreased force of contraction of atrial myocytes and coronary vasoconstriction.
- Cardiac plexus receives the superior, middle, and inferior cervical and thoracic cardiac nerves from the sympathetic trunks and vagus nerves.
- **Superficial cardiac plexus** is located inferior to the aortic arch and anterior to the right pulmonary artery.
- It is contributed by: (a) superior cervical cardiac branch of left cervical sympathetic trunk, and (b) inferior cervical cardiac branch of left vagus nerve. The cardiac ganglion (of Wrisberg) is present in this plexus immediately below the aortic arch, to the right of the ligamentum arteriosum.
- **Deep cardiac plexus** is located posterior to the aortic arch and anterior to the tracheal bifurcation. It is contributed by: (a) all the cardiac branches derived from three cervical and upper 5 thoracic ganglia of the sympathetic chains and (b) all the cardiac branches of vagus and recurrent laryngeal nerves. The only cardiac nerves that do not join it are those that join the superficial part of the plexus.
- Right sympathetic and parasympathetic branches terminate chiefly in the region of the SA node, and the left branches end chiefly in the region of the AV node. The cardiac muscle fibers are devoid of motor endings and are activated by the conducting system.



Figs. 79A and B: Deep cardiac plexus: (A) Parasympathetic contribution; (B) sympathetic contribution.

Sensory Fibers

Chemoreception: The neuronal cell bodies are located in the inferior (nodose) ganglia of CN X. These neurons send a peripheral process to chemoreceptors (specifically the aortic bodies) via CN X and a central process to the **nucleus tractus solitarius** in the brain. These neurons transmit changes in the partial pressure of arterial oxygen (PaO2).

Pressoreception: The neuronal cell bodies are located in the inferior (nodose) ganglia of CN X. These neurons send a peripheral process to baroreceptors in the great veins, atria, and aortic arch via CN X and a central process to the **nucleus tractus solitarius** in the brain. These neurons transmit changes in blood pressure.

Nociception: The neuronal cell bodies are located in the dorsal root ganglia at T1 to T5 spinal cord levels. These neurons send a peripheral process to the heart via the sympathetic fibers and a central process to the spinal cord.

Cardiac nociceptive impulses enter the spinal cord in the first to fifth thoracic spinal nerves, mainly via the **middle and inferior cardiac nerves**, but some fibers pass through **thoracic splanchnic** (cardiac) nerves. The pain associated with angina pectoris may be referred over the T1 to T5 dermatomes (precordium and referred pain down the left arm). Cardiac pain may be referred to the neck and mandible, because of the connection of sympathetic fibers with the cervical nerves. Sometime it is felt retrosternal and in the epigastrium due to communicating fibers with greater splanchnic nerves (T5-9).

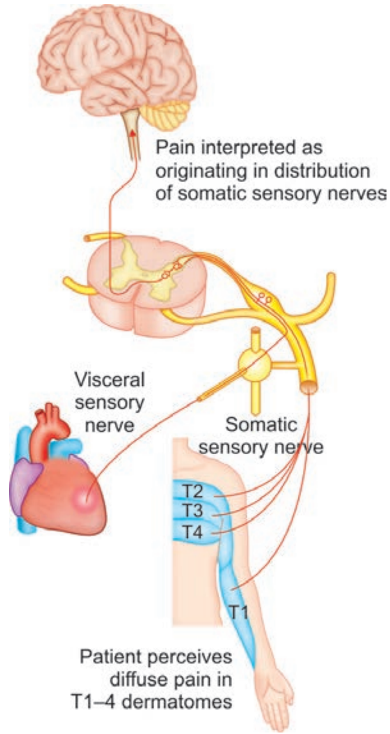


Fig. 80: Pain pathway for heart and referred pain to the precordium and upper inner arm.

ASSESSMENT QUESTIONS

1. Sympathetic innervation of heart is by: *(NEET Pattern 2012)*
   a. T1-T3
   b. T1-T5
   c. T3-T7
   d. L1-L5

2. Angina pectoris is carried by:
   a. Superior cervical cardiac nerve
   b. Middle and inferior cervical cardiac nerve
   c. Thoracic splanchnic nerve
   d. Vagus

3. In angina pectoris, the pain radiating down the left arm is mediated by increased activity in afferent fibers contained in the: *(AIIMS 2003)*
   a. Carotid branch of the glossopharyngeal nerve
   b. Phrenic nerve
   c. Vagus nerve and recurrent laryngeal nerve
   d. Thoracic splanchnic nerve

4. A 59-year-old man complains of recurrent attacks in the region of left shoulder radiating to sternum and the pit of stomach. The attacks of pain came at lengthy intervals until the last two days when it became continuous. The physician diagnosed it as an angina pectoris. In this case the pain pathway from the heart is carried by: *(AIIMS)*
   a. Superior cervical cardiac nerve
   b. Middle and inferior cervical cardiac nerve
   c. Thoracic splanchnic nerve
   d. Vagus

5. Cardiac ganglion is situated: *(NEET Pattern 2015)*
   a. Below arch of aorta
   b. Above arch of aorta
   c. Left side of ligamentum arteriosum
   d. Posterior to ligamentum arteriosum

6. True about SA node are all EXCEPT: *(NEET Pattern 2015)*
   a. Supplied by nodal artery
   b. Primary pacemaker
   c. Supplied by left vagus nerve
   d. Made up of nodal cells and connective tissue

7. The following statements are true regarding the SA node EXCEPT: *(AIIMS 2005)*
   a. Is located at the right border of the ascending aorta
   b. In contains specialized nodal cardiac muscle
   c. It is supplied by the atrial branched of the right coronary artery
   d. It initiates cardiac conduction

8. Purkinje fibres are: *(NEET pattern 2014)*
   a. Modified nerve fibers
   b. Modified smooth muscle
   c. Modified cardiac muscle
   d. Fibrous tissue

ANSWERS WITH EXPLANATIONS

1. b. T1-T5
- Sympathetic preganglionic neuronal cell bodies are located in the intermediolateral columns of the spinal cord at T1 to T5 levels. Preganglionic axons enter the paravertebral ganglia at T1 to T5 levels and some travel to the inferior, middle, and superior cervical ganglia.

2. b. Middle and inferior cervical cardiac nerve > c. Thoracic splanchnic nerve
- Angina pectoris sensory impulses enter the spinal cord in the first to fifth thoracic spinal nerves, mainly via the middle and inferior cardiac nerves, but some fibers pass through thoracic splanchnic (cardiac) nerves. (Gray's Anatomy Ed 41)

3. d. Thoracic splanchnic nerve
- Cardiac nociceptive impulses enter the spinal cord in the first to fifth thoracic spinal nerves, mainly via the middle and inferior cardiac nerves, but some fibers pass through thoracic splanchnic (cardiac) nerves.

4. c. Thoracic splanchnic nerve
- This is a case of inferior wall MI and the pain fibres are carried along the thoracic splanchnic nerve (greater splanchnic; T5-9), hence felt in retrosternal and epigastric (T7) region.
- Anginal pain fibers carried by cervical cardiac nerve may present with referred pain felt in the neck and mandible region.

5. a. Below arch of aorta
- The cardiac ganglion (of Wrisberg) is present in the superficial cardiac plexus immediately below the aortic arch to the right of the ligamentum arteriosum.

6. c. Supplied by left vagus nerve
- Of all the cells in the heart, those of the sinu-atrial node generate the most rapid rhythm, and therefore function as the cardiac pacemaker.
- It is supplied by SA nodal artery (generally a branch of right coronary artery).
- The heart receives parasympathetic input to the SA node via the right vagus nerve, and to the AV node via the left vagus nerve.
- Nodal cells are packed within a dense matrix of connective tissue as interlacing strands of myocytes.
- They are smaller, paler and more empty-looking than working atrial myocardial fibers.

7. a. Is located at the right border of the ascending aorta

SA node is located in the right atrium at the right side of superior vena cava.

8. c. Modified cardiac muscle
- Purkinje fibres are sub-endocardial plexus of ventricular conduction cells.

High Yield Points

- **Sympathetic** nerve supply to heart arises from **T1- 5** and is **excitatory to SA node.** *(NEET Pattern 2013, 14)*

Mediastinum

- Mediastinum is the space between the pleural cavities in the thorax, bounded laterally by the pleural cavities, anteriorly by the sternum, and posteriorly by the twelve thoracic vertebra.
  - It is divided into a superior division and an inferior division by a line from the sternal angle of Louis to the T4 to T5 intervertebral disc.
  - The inferior division is then further divided into the anterior, middle, and posterior divisions.
- Superior mediastinum lies between the manubrium sterni anteriorly and the upper thoracic vertebrae posteriorly.
  - Its inferior boundary is a slightly oblique plane that passes backwards from the manubriosternal joint to the lower part of the body of the fourth thoracic vertebra.
  - Contents: Aortic arch, upper half of the superior vena cava, the trachea, esophagus, thoracic duct, thymic remnants, brachiocephalic trunk and thoracic portions of the left common carotid and left subclavian arteries; the brachiocephalic veins, left highest intercostal vein; the vagus, cardiac, phrenic and left recurrent laryngeal nerves; and lymph nodes, lower ends of sternohyoid, sternothyroid and longus colli on each side.
- Inferior mediastinum is divided into three parts—anterior, in front of the pericardium; middle, containing the pericardium and its contents; and posterior, behind the pericardium.
  - Anterior mediastinum is bounded anteriorly by the sternum (and transversus thoracis muscle and the fifth to seventh left costal cartilages) and posteriorly by the pericardium.
    - Contents: Thymus, small mediastinal branches of the internal thoracic artery, lymphatic vessels and nodes, etc.
  - Middle mediastinum
    - Contents: Heart enclosed in the pericardium; the ascending aorta; the lower half of the superior vena cava (receiving the azygos venous arch posteriorly); the bifurcation of the trachea and the right and left principal bronchi; the pulmonary artery dividing into its two branches; the right and left pulmonary veins and phrenic nerves; the deep part of the cardiac plexus and the tracheobronchial lymph nodes; the short thoracic part of the inferior vena cava, etc.
  - Posterior mediastinum is bounded anteriorly by the pericardium above and the posterior surface of the diaphragm below, posteriorly from the fifth to the twelfth thoracic vertebrae.
    - Contents: Descending thoracic aorta (on the left side of the spine), the esophagus (median, but positioned anterior to the aorta inferiorly) and, more posteriorly, the azygos and hemiazygos venous systems, the thoracic duct, lymph nodes, right and left sympathetic chains and thoracic splanchnic nerves.

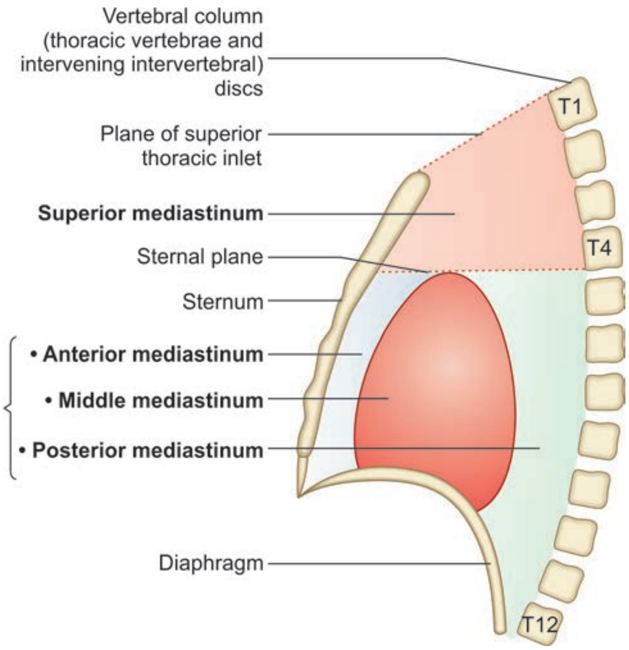


Fig. 81: Divisions of the mediastinum.

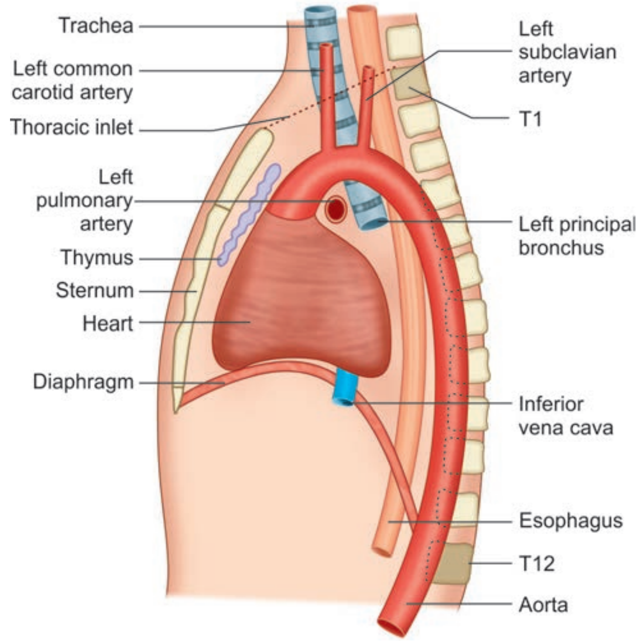


Fig. 82: Boundaries and contents of the mediastinum.

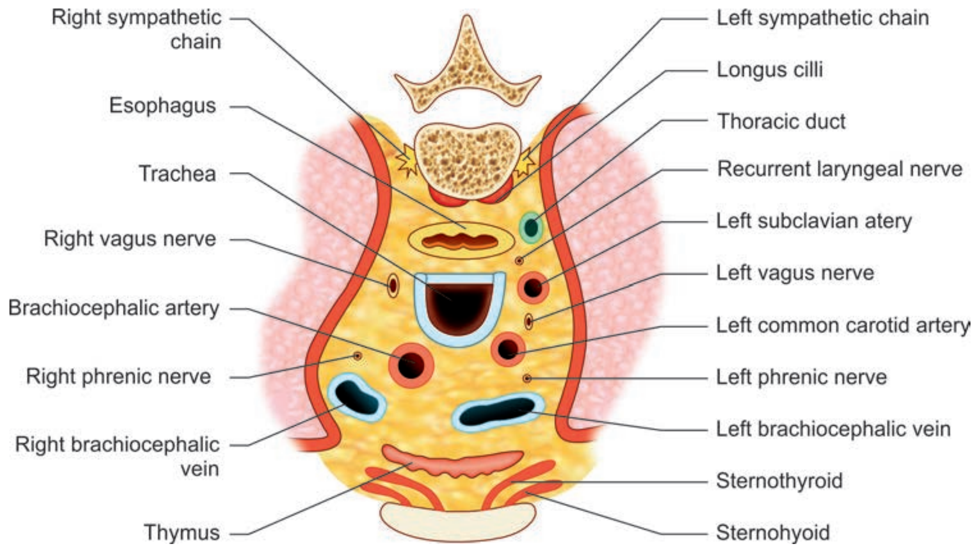


Fig. 83: Transverse section at the level of superior mediastinum, showing various structures.

Table 38: Major structures of the thoracic cavity

Mediastinum	Superior mediastinum		Thymus, great vessels, trachea, esophagus, and thoracic duct
	Inferior mediastinum	Anterior	Thymus
		Middle	Heart, pericardium, and roots of great vessels
		Posterior	Thoracic aorta, thoracic duct, esophagus, and azygos venous system

Table 39: Contents of the mediastinum

		Inferior mediastinum		
	Superior mediastrinum	**Anterior**	**Middle**	**Posterior**
Organs	• Thymus • Esophagus • Trachea	• Thymus	• Heart • Pericardium	• Esophagus
Arteries	• Aortic arch • Brachiocephalic trunk • Left common carotid artery • Left subclavian artery	• Smaller vessels	• Ascending aorta • Pulmonary trunk and branches • Pericardiacophrenic arteries	• Thoracic aorta and branches

	Superior mediastrinum	Anterior	Middle	Posterior
Veins and lymph vessels	• Superior vena cava • Brachiocephalic veins • Thoracic duct	• Smaller vessels, lymphatics, and lymph nodes	• Superior vena cava • Azygus vein • Pulmonary veins • Pericardiacophrenic veins	• Azygos v. • Hemiazygos v. • Thoracic duct
Nerves	• Vagus nerves • Left recurrent laryngeal nerve • Cardiac nerves • Phernic nerves	• None	• Phrenic nn.	• Vagus nerves

ASSESSMENT QUESTIONS

1. All are true about mediastinum EXCEPT: *(PGIC 2015)*
- a. Heart passes through superior mediastinum
- b. Heart passes through middle mediastinum
- c Thymus remnant may present in middle mediastinum
- d. Posterior boundary of posterior mediastinum corresponds to T1- T4 vertebrae
- e. Lower border of anterior mediastinum is extended more than posterior mediastinum

2. Trachea lies in which mediastinum:
- a. Superior
- b. Anterior
- c. Middle
- d. Posterior

3. Esophagus is present in all EXCEPT: *(NEET Pattern 2013)*
- a. Superior mediastinum
- b. Middle mediastinum
- c. Anterior mediastinum
- d. Posterior mediastinum

ANSWERS WITH EXPLANATIONS

1. a. Heart passes through superior mediastinum; c. Thymus remnant may present in middle mediastinum; d. Posterior boundary of posterior mediastinum corresponds to T1- T4 vertebrae; e. Lower border of anterior mediastinum is extended more than posterior mediastinum
- Heart is present in the middle mediastinum.
- Thymus remnants may be found in superior and anterior mediastinum.
- Posterior boundary of posterior mediastinum is from T5-12 vertebra.
- Lower border of posterior mediastinum extends quite inferior as compared with anterior mediastinum)

2. a. Superior
- Trachea and arch of aorta lies in the superior mediastinum.
- Esophagus lies in the superior mediastinum, passes through posterior mediastinum and eventually enters the abdomen.

3. c. Anterior mediastinum > b. Middle mediastinum
- Esophagus enters the **superior mediastinum** and lies between trachea (anterior) and vertebra (posterior).
- Inferiorly it continues into the **posterior mediastinum**, pass through the diaphragm and open into stomach.

Thoracic Outlet Syndrome

Superior thoracic aperture is also called as thoracic inlet (some authors call it thoracic outlet).
- It is bounded by manubrium anteriorly, first rib laterally, and the first thoracic vertebrae posteriorly.
- Structures passing through superior thoracic aperture are:
  - Muscles: Sternohyoid, sternothyroid, longus cervicis/longus colli.
  - Arteries: Right and left internal thoracic arteries, brachiocephalic trunk/artery, left common carotid artery, left subclavian artery, right and left superior intercostal arteries.
  - Nerves: Right and left vagus nerves, left recurrent laryngeal nerve, right and left phrenic nerves, right and left first thoracic nerves, right and left sympathetic chains.
  - Veins: Right and left brachiocephalic veins, right and left 1st posterior intercostal veins, inferior thyroid veins.
  - Lymphatics: Thoracic duct.
  - Viscera: Apices of lungs (with cervical pleura), trachea, esophagus.
  - Others: Anterior longitudinal ligament.

Thoracic outlet syndrome is the compression of neurovascular structures such as the subclavian artery, the brachial plexus (lower trunk or C8 and T1 nerve roots), or less often the axillary vein or subclavian vein, by thoracic outlet abnormalities such as a drooping shoulder girdle, a cervical rib or fibrous band, an abnormal first rib, or occasionally compression of the edge of the scalenus anterior muscle.
- Continual hyperabduction of the arm may cause another variety (hyperabduction syndrome).
- Arterial compression leads to ischemia, paresthesia, numbness, and weakness of the affected arm, sometimes with Raynaud phenomenon of the arm.

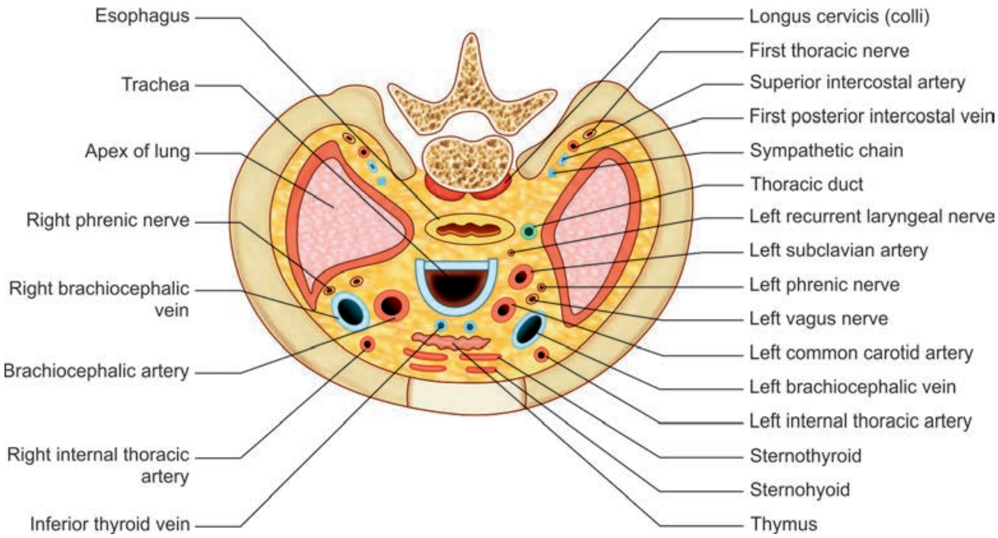
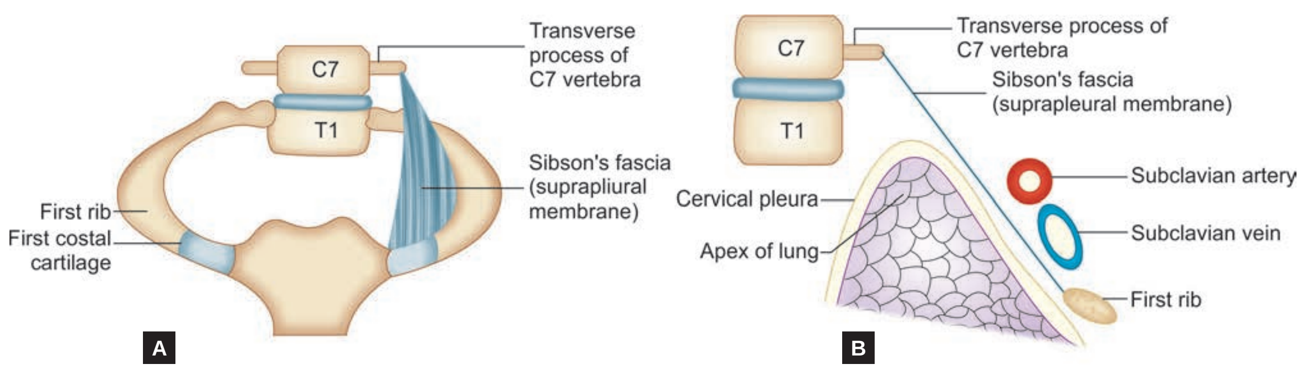


Fig. 84: Transverse section of thorax, structures passing through the thoracic inlet.

- Nerve compression causes atrophy and weakness of the muscles of the hand and, in advanced cases, of the forearm, with pain and sensory disturbances in the arm.
- **Cervical rib** is a small additional rib which may develop in the root of the neck in association with the seventh cervical vertebra.
  - It is often fibrous (may be ossified). It may cause compression of the neurovascular bundle, leading to pain, paraesthesia and even pallor of the affected upper limb in thoracic outlet syndrome.
- **Sibson's fascia** (suprapleural membrane) is a thickening of connective tissue that covers the apex of each human lung.
  - It is an extension of the endothoracic fascia that exists between the parietal pleura and the thoracic cage.
  - It attaches to the internal border of the 1st rib, its costal cartilage and the transverse processes of vertebra C7.
  - It extends approximately an inch more superiorly than the superior thoracic aperture, along with the lungs to extend higher than the top of the rib cage.
  - Morphologically, it is regarded as the flattened tendon of the scalenus minimus.



Figs. 85A and B: Suprapleural membrane (Sibson's fascia): (A) Attachments; (B) Relations.

ASSESSMENT QUESTIONS

1. Structures passing through superior thoracic aperture are all EXCEPT: *(AIIMS 2005)*
   a. Right recurrent laryngeal nerve
   b. Left common carotid artery
   c. Left sympathetic trunk
   d. Thoracic duct

2. Attachment of Sibson's fascia is at vertebra: *(NEET Pattern 2015)*
   a. C1
   b. C2
   c. C5
   d. C7

3. TRUE about attachment of suprapleural membrane: *(PGIC 2014)*
   a. Attached to clavicle
   b. Attached to 1st rib and its costal cartilage
   c. Attached to 2nd rib and its costal cartilage
   d. Attached to junction of manubrium and body of sternum
   e. Attached to tip of the transverse process of the 7th cervical vertebrae

4. Compression of cervical rib can cause: *(PGIC 2014)*
   a. Thenar hypertrophy
   b. Neurovascular symptom
   c. Raynaud's phenomenon
   d. C8;T1 paresthesia
   e. Weakness of forearm muscles

ANSWERS WITH EXPLANATIONS

1. a. Right recurrent laryngeal nerve
- **Left (and not right) recurrent laryngeal nerve** passes through the superior thoracic aperture.
- Right recurrent laryngeal nerve **hooks around the right subclavian artery** in the neck region and ascends up in the tracheo-esophageal groove to supply larynx.
- **Left common carotid artery** is given by the arch of aorta in the superior mediastinum (thorax). This artery has to pass the thoracic aperture to enter the neck region, where it bifurcates into external and internal carotid arteries.
- **Sympathetic trunk** begins at the foramen magnum, it passes through the thoracic aperture to reach the thorax, then go through opening in the diaphragm to reach the abdomen and terminates in front of the coccyx.
- **Thoracic duct** begins at the upper end of cisterna chyli in the abdomen, it passes posterior to the diaphragm to reach the thorax. It then passes through the thoracic aperture and enters the neck region, where it terminates in the neck veins.

2. d. C7
- Sibson's fascia (suprapleural membrane) attaches to the transverse processes of vertebra C7.

3. b. Attached to 1st rib and its costal cartilage; e. Attached to tip of the transverse process of the 7th cervical vertebrae
- Suprapleural membrane (Sibson's fascia) attaches to the internal border of the 1st rib, its costal cartilage and the transverse processes of vertebra C7.

4. b. Neurovascular symptom; c. Raynaud's phenomenon; d. C8;T1 paresthesia; e. Weakness of forearm muscles
- Cervical rib may result in thoracic outlet syndrome leading to compression of neurovascular structures such as the subclavian artery, the brachial plexus (lower trunk or C8 and T1 nerve roots).
- Arterial compression leads to ischemia, paresthesia, numbness, and weakness of the affected arm, sometimes with raynaud phenomenon of the arm. Nerve compression causes atrophy and weakness of the muscles of the hand and, in advanced cases, of the forearm, with pain and sensory disturbances in the arm.

Thymus

Thymus is a bilobed structure, lying in the neck anterior to the trachea and the anterior part of the superior mediastinum (may extend into anterior mediastinum), attains its greatest relative size in the neonate, continues to grow until puberty, and then undergoes a gradual involution (replaced by fat).

- It is supplied by the inferior thyroid and internal thoracic artery, and produces a hormone, thymosin, which promotes T-lymphocyte differentiation and maturation.

Radiology

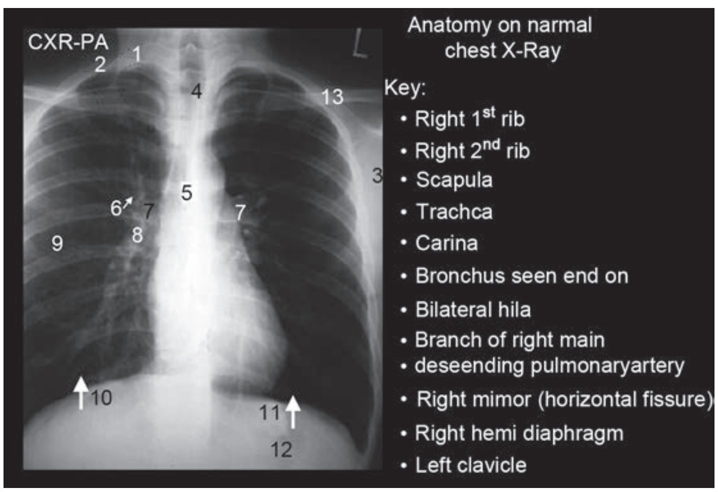
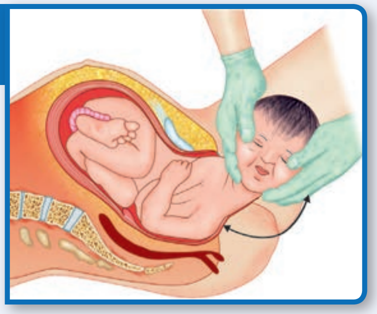


Fig. 86: Chest X-ray showing various landmark features of cardio-respiratory system and bones.

CHAPTER 8



Upper Limb

Embryology

- Upper limb buds ppear by the **end of week four** and are regulated by **Hox genes**.
- Bones are derived from **somatopleuric layer of lateral plate mesoderm** and muscles get their origin from **para-axial mesoderm** (somites).
- At weeks 7–9, the primary ossification centers are seen in the clavicle, humerus, radius, and ulnar bones.
- Upper limbs rotate **laterally by 90 degrees**, so that the thumb becomes lateral and little finger medial.
- The **flexor** compartment comes **anterior** and the extensor compartment becomes posterior.

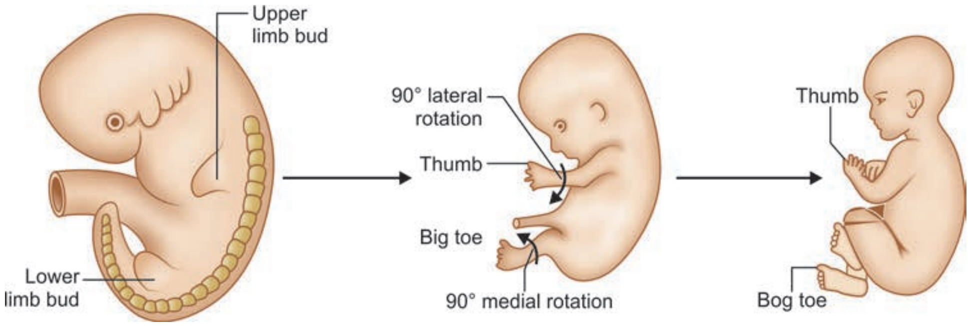


Fig. 1: Development of limbs

- Developmentally, **radius bone** is a preaxial bone and **radial artery** is preaxial artery. Ulna bone is postaxial bone with ulnar artery as postaxial artery.
- The preaxial vein becomes the **cephalic vein** and drains into the axillary vein in the axilla. The **postaxial vein** becomes the basilic vein, which passes deep in the arm to continue as the axillary vein.
- Subclavian artery represents the lateral branch of the **seventh intersegmental artery**. Its main continuation, the axial artery of the upper limb, becomes the axillary and brachial arteries.
- The original axial vessel ultimately persists as the **anterior interosseous artery** and the deep palmar arch.

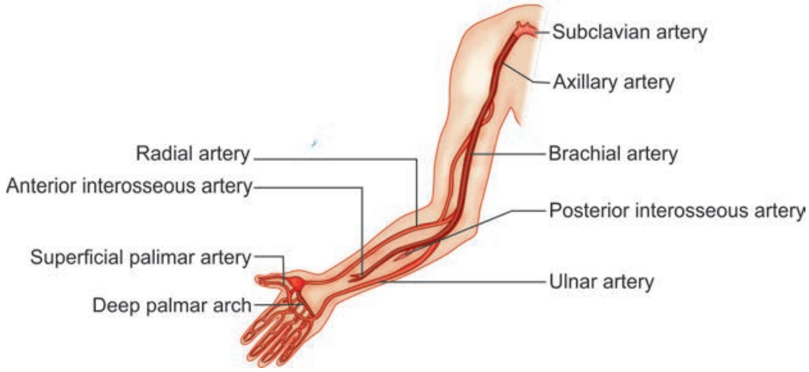


Fig. 2: Development of upper limb arteries

ASSESSMENT QUESTIONS

1. Limb buds appear at week:
  a. 3
  b. 4
  c. 5
  d. 6

2. During development, the scapula is formed by which of the following:
  a. Splanchnic lateral plate mesoderm
  b. Neural crest cells
  c. Axial mesoderm
  d. Somatic lateral plate mesoderm

ANSWERS AND EXPLANATIONS

1. **b. 4**
   - Upper limb buds appear by the end of week 4 and about 2 days later lower limb buds appear (beginning of week 5).
2. **d. Somatic lateral plate mesoderm**
   - Upper and lower limb bones (appendicular skeleton) develop from the somatic portion of lateral plate mesoderm, whereas muscles develop from paraaxial mesoderm.

Bones

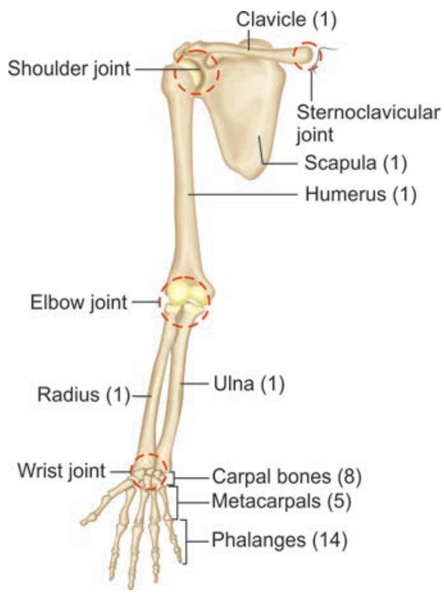


Fig. 3: Upper limb bones and joints

Clavicle

The only long bone, **positioned in a horizontal plane** and is **subcutaneous throughout** its extent.

- Has **no medullary cavity**. (**Gray's Anatomy** mentions: There is a medullary cavity in its medial two-thirds).
- A **nutrient foramen** is found in the lateral end of the subclavian groove, running in a lateral direction; the nutrient artery is derived from the **suprascapular artery**.
- **Ossification**.
  - Clavicle is the first bone to begin ossification (between the 5th and 6th week of intrauterine life) and is the **last bone to complete** it (at 25 years).
  - It is the only long bone which ossifies by **two primary centers**. It **ossifies mostly in membrane** except sternal and acromial zones (true cartilage). **Note**: Long bones generally ossify in cartilage.

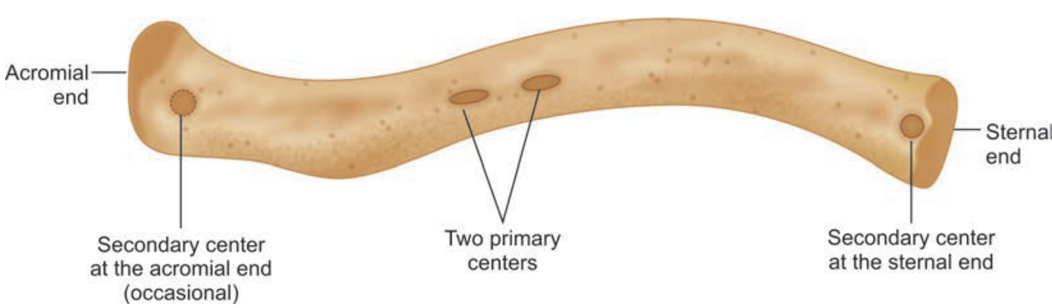


Fig. 4: Ossification of clavicle

Table 1: Ossification of the clavicle

Site of appearance	Time of apperance	Time of fusion
Two primary centres (medial and lateral) in the shaft	5–6 weeks of intrauterine life (IUL)	45th day of IUL
Secondary centre at sternal end	19–20 years (2 years earlier in female)	25th year
Secondary centre at the acromial end (occasional)	20th year	Fuses immediately

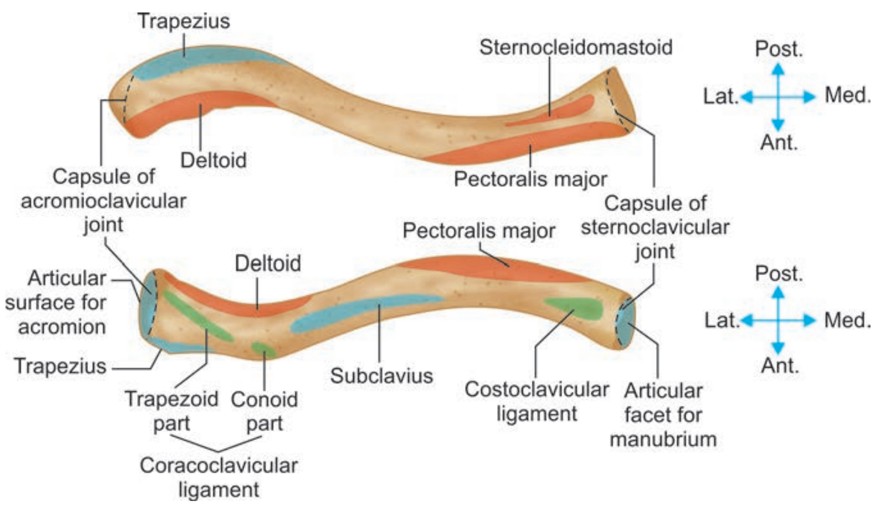


Fig. 5: Attachments on clavicle

Clinical Correlations

- Fracture of clavicle usually occurs in the middle third (at the junction of medial 2/3rd and lateral 1/3rd). (Gray's Anatomy mentions it as junction of the lateral two-fifths and medial three-fifths).
- It results in the upward displacement of the proximal fragment due to the pull of the sternocleidomastoid muscle and downward displacement of the distal fragment due to the pull of the deltoid muscle and gravity.

ASSESSMENT QUESTION

1. **False about clavicle:** *(NEET Pattern 2012)*
   a. Ossifies in membrane
   b. Horizontal bone
   c. No medullary cavity
   d. Most common site of fracture is the junction of medial 1/3rd with lateral 2/3rd

ANSWER AND EXPLANATION

1. **d. Most common site of fracture is the junction of medial 1/3rd with lateral 2/3rd**
   - The fracture clavicle is most often in the middle third (at the junction of lateral 1/3rd and medial 2/3rd) and results in upward displacement of the proximal fragment pulled by the sternocleidomastoid muscle and downward displacement of the distal fragment by the deltoid muscle and gravity.

High Yield Point

- Clavicle is the only long bone to be ossified intramembranously (other bones of the upper limb develop by endochondral ossification).

Scapula

Covers parts of the second to seventh ribs.

- The **lateral angle** is truncated to form an articular surface- the **glenoid cavity**.
- **Spine** provides origin for the **deltoid** and insertion for the **trapezius**.
- **Coracoid Process** provides the origin of the **coracobrachialis** and short head of **biceps brachii**, the insertion of the **pectoralis minor**, and the attachment site for various ligaments.
- **Scapular Notch** is bridged by the superior transverse scapular ligament and converted into a foramen that transmits the **suprascapular nerve**.
- **Spinoglenoid notch** lies between lateral border of the spinous process and the dorsal surface of the neck of scapula. Through this notch **suprascapular** nerve and vessels pass from supraspinous fossa to the infraspinous fossa.
- **Supraglenoid** and **infraglenoid** tubercles provide origins for the tendons of the long heads of the biceps brachii and triceps brachii muscles, respectively.

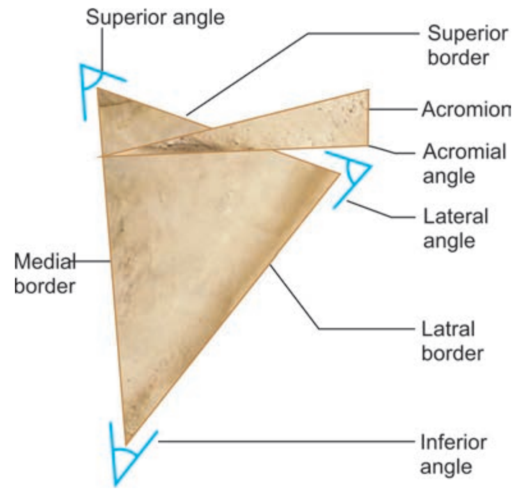


Fig. 6: Borders and angles of scapula

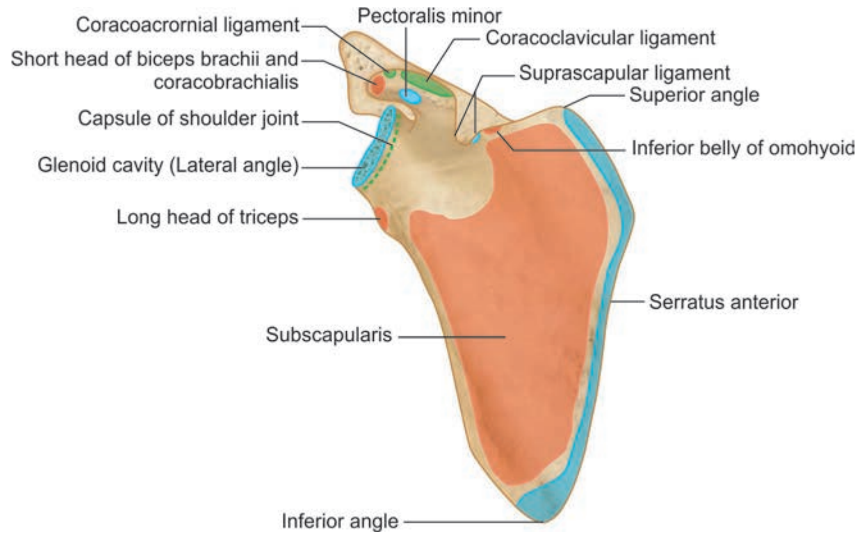


Fig. 7: Attachments on scapula (anterior aspect)

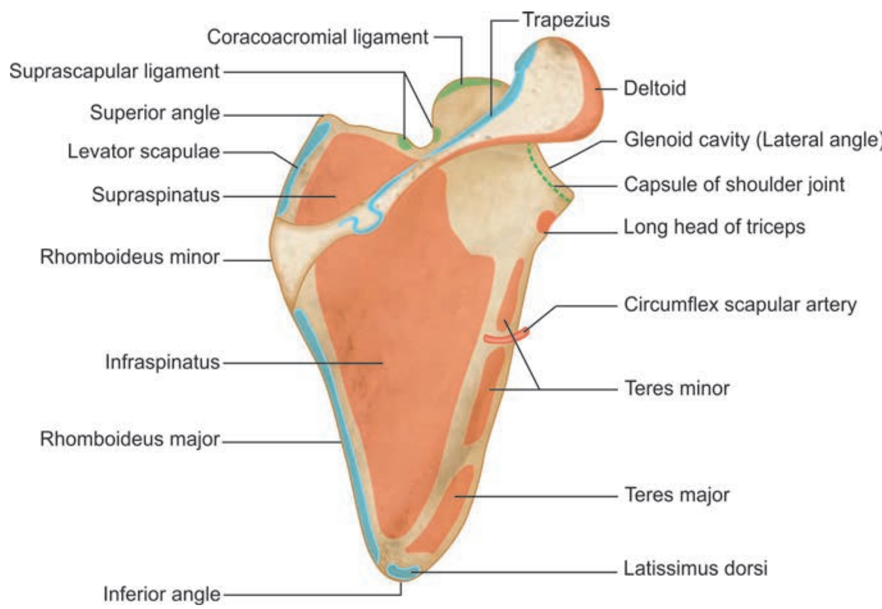


Fig. 8: Attachments on scapula (posterior aspect)

- **Ossification**
  - Has **eight** centres: one primary and seven secondary.
  - The **primary** centre appears in the body at eighth week of intrauterine life and fuse with the body at the age of 15 years.
  - The **secondary** centres appear as follows: coracoid process (2), acromion process (2), one centre each in the medial border, inferior angle, and lower part of the rim of glenoid cavity. These appear at about puberty and fuse by 20th year.
- **Surface marking**
  - **Superior angle** lies at the junction of superior and medial borders, and lies over the 2nd rib and second thoracic vertebra.
  - **Spine of the scapula**, lies opposite the spine of the third thoracic vertebra.
  - The **inferior angle** is opposite the spine of the seventh thoracic vertebra and overlies the inferior border of seventh rib.

ASSESSMENT QUESTIONS

1. Attachment on lateral border of scapula is:
  a. Teres minor
  b. Infraspinatus
  c. Subscapularis
  d. Long head of triceps

2. The following muscles are attached to the coracoid process of the scapula *EXCEPT:*
  a. Coracobrachialis
  b. Short head of biceps
  c. Pectoralis minor
  d. Long head of triceps

3. Which border of scapula is NOT palpable: *(NEET Pattern 2015)*
a. Medial
b. Lateral
c. Inferior
d. Superior

ANSWERS AND EXPLANATIONS

1. a. Teres minor > d. Long head of triceps
- Lateral border of scapula gives origin to **teres minor** muscle.
- **Long head of triceps** arises from the infraglenoid tubercle on the lateral border of scapula.
- Infraspinatus attaches to the dorsal surface and subscapularis to the ventral surface of scapula.

2. d. Long head of triceps
- **Long head of triceps** attaches to the infraglenoid tubercle.
- Tip of the coracoid process gives origin to **coracobrachialis** (medially) and **short head of the biceps** (laterally).
- The upper surface receives insertion of **pectoralis minor.** Three ligaments also attach to coracoid process: coracoacromial, coracoclavicular, and coracohumeral.

3. b. Lateral > d. Superior
- The **lateral border** separates the attachments of subscapularis and teres minor and major. These muscles project beyond the bone and, with latissimus dorsi below, cover it so completely that it **cannot be felt** through the skin.
- Even the **superior border** and angle of the scapula are deep to soft tissue and are not readily palpable.

High Yield Point
- The long head of biceps brachii takes origin from supraglenoid tubercle (**intracapsular** origin).

Humerus

- **Anatomic neck** is an indentation distal to the head and provides an attachment for the fibrous joint capsule.
- **Greater tubercle** lies lateral and distal to the anatomic neck and provides attachments for the **SIT** (supraspinatus, infraspinatus, and teres minor) muscles.
- Greater and lesser tubercles on humerus are produced due to traction by muscles (**traction epiphyses**).
- **Bicipital** (intertubercular) **groove**/sulcus
  - Lodges the tendon of the long head of the biceps brachii muscle, and is bridged by the transverse humeral ligament.
  - Forms the **lateral wall of the axilla**.
  - Three muscles are attached in the region of this groove: **Pectoralis Major** on the lateral lip of the groove, **teres major** on the medial lip of the groove and **latissimus dorsi** in the floor of the groove. (**Mnemonic**: Lady between two Majors).

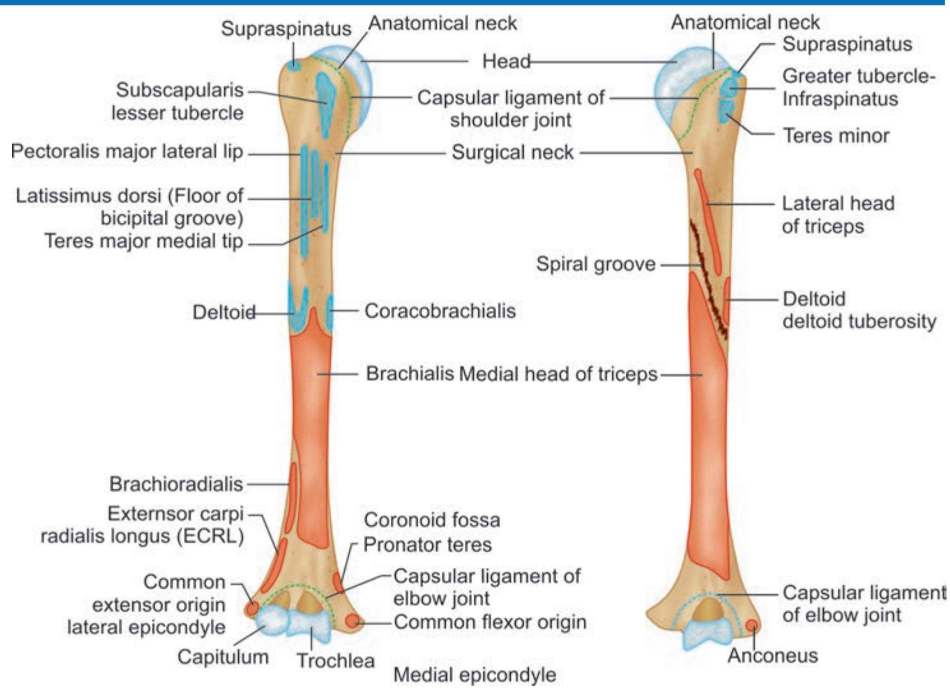


Fig. 9: Attachments on humerus (anterior and posterior aspect)

- **Surgical Neck** is a narrow area distal to the tubercles that is a common site of fracture and is in contact with the **axillary nerve** and the **posterior circumflex humeral artery**.
- **Deltoid Tuberosity** on the lateral aspect of the midshaft marks the insertion of the deltoid muscle.
- **Spiral** (radial) **groove** is present on the middle third of shaft on posterior aspect, separates the origin of the lateral head of the triceps above and medial head below. **Radial nerve** and **profunda brachii vessels** pass through it.

- **Coronoid Fossa** is an anterior depression above the trochlea that is occupied by the **coronoid process** of the ulna on flexion of the elbow joint.
- **Radial Fossa** is an anterior depression above the capitulum that is accommodates the **head of the radius** during full flexion of the elbow joint.
- **Lateral epicondyle** is a projection from the capitulum and provides the origin of the supinator and extensor muscles of the forearm (**common extensor origin**). Radial collateral ligament attaches here.
- **Medial epicondyle** projects from the trochlea and has a groove on the back for the **ulnar nerve** and superior ulnar collateral artery. It provides attachment sites for the ulnar collateral ligament, the pronator teres, and the forearm flexor muscles (**common flexor origin**). **Nutrient artery** is a branch of profunda brachii artery, arises near the **mid-level** of the upper arm and enters the nutrient canal near the attachment of coracobrachialis, posterior to the deltoid tuberosity; it is **directed distally**.
- Ossification:

Fig. 10: Three nerves closely related to the back of the humerus

Table 2: Ossification centres of the humerus

Site of appearance	Time of appearance	Time of fusion
Shaft	*8th week of IUL*	
Upper end • Head • Greater tubercle • Lesser tubercle	1st year 3rd year 5th year } Fuse together at 7th year to from a conjoint upper epiphysis	Join with shaft 20th year
Lower end • Capitulum and lateral flange of trochlea • Medial part of trochlea • Lateral epicondyle	2nd year 10th year 12th year } Fuse together at 14th year to form most of the lower epiphysis	Joins with shaft 16–17th year
• Medial epicondyle	6th year (from small part of the lower epiphysis)	18th year

Note: Distal end of humerus develops from 4 centres of ossification.

ASSESSMENT QUESTIONS

1. **Which of the following is NOT intracapsular:** *(NEET Pattern 2015)*
   a. Coronoid bone
   b. Radial fossa
   c. Olecranon fossa
   d. Lateral epicondyle

2. **Which nerve is NOT related to humerus:** *(NEET Pattern 2015)*
   a. Axillary
   b. Radial
   c. Ulnar
   d. Musculocutaneous

3. **Contents of bicipital groove are:** *(PGIC 2014)*
   a. Synovial membrane of shoulder joint
   b. Ascending branch of anterior circumflex artery
   c. Ascending branch of posterior circumflex artery
   d. Radial artery
   e. Coracobrachialis muscle

4. **Muscle NOT inserted on greater tubercle:** *(AIIMS 2015)*
   a. Teres minor
   b. Supra-spinatus
   c. Infra-spinatus
   d. Subscapularis

5. **Which muscle is inserted into the floor of the intertubercular sulcus of the humerus:** *(NEET Pattern 2012)*
   a. Latissimus dorsi
   b. Teres major
   c. Pectoralis major
   d. Deltoid

ANSWERS AND EXPLANATIONS

1. **d. Lateral epicondyle**
   - Lateral (and medial) epicondyles are **outside** the capsular ligament.
   - The capsular ligament of the elbow joint is attached to the lower end along a line that reaches the upper limits of the **radial** and **coronoid fossae** anteriorly and of the **olecranon fossa** posteriorly (these fossae are intracapsular).
2. **d. Musculocutaneous**
   - Musculocutaneous nerve is not directly in contact with the bone humerus.
   - The nerves related closely to the humerus are: **Axillary**, **radial**, **ulnar**.

3. **a. Synovial membrane of shoulder joint; b. Ascending branch of anterior circumflex artery**
   - **Synovial membrane** of shoulder joint forms a tubular sheath around the tendon of biceps brachii where it lies in the bicipital groove of the humerus.
   - **Anterior circumflex artery** sends an ascending branch upwards in the groove.

   Note: Tendon of long head of biceps is intracapsular, and extrasynovial, but enclosed in the synovial sheath.
4. **d. Subscapularis**
   - **Subscapularis** muscle attaches to lesser tubercle (and **not greater tubercle**).
   - SIT (**Supra-spinatus**, **Infraspinatus**, **Teres minor**) muscles 'sit' on greater tubercle.
5. **a. Latissimus dorsi**
   - **Latissimus dorsi** attaches to the floor of intertubercular sulcus.
   - **Pectoralis Major** on the lateral lip of the groove, **teres majo**r on the medial lip of the groove.

Bones of Forearm

Ulna

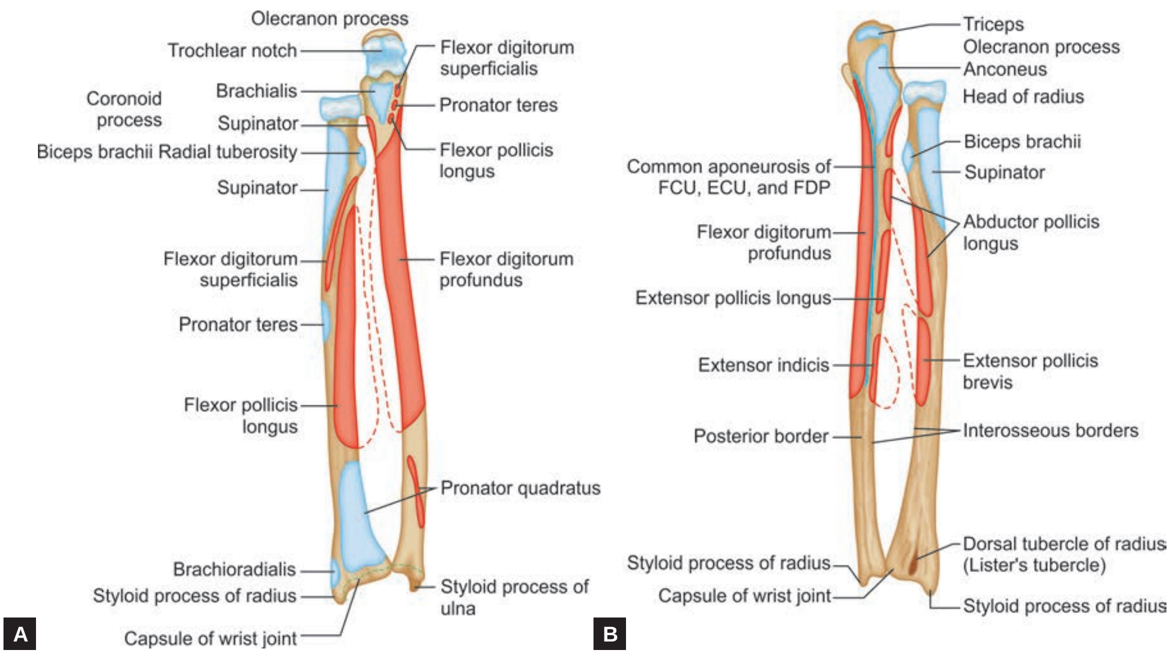
- **Olecranon process**, the curved projection on the back of the elbow, receives the insertion of **triceps**.
- **Coronoid process** is located below the trochlear notch and provides an attachment site for the **brachialis**.
- **Ulnar tuberosity** is present distal to the coronoid process and also receives the attachment of **brachialis**.
- **Radial notch** accommodates the head of the radius at the superior radioulnar joint.
- **Head** is present at the distal end, has a projection called **styloid process**. Head articulates with the articular disk of the Inferior radioulnar joint.

Radius

- **Radius head** is the proximal end that articulates with the **capitulum** of the humerus and the **radial notch** of the ulna (elbow joint) and is surrounded by the **annular ligament**.
- **Neck** is enclosed by the lower margin of the annular ligament. The head and neck are free from capsular attachment and can rotate freely within the socket.
- **Radial tuberosity** is a prominence just inferior, has the insertion of **biceps brachii** tendon.
- The **distal end** articulates with the **proximal row** of carpal bones (scaphoid, lunate, triquetral) but excluding pisiform.
- **Styloid Process** is a projection on the distal end of the radius (1 cm distal to that of the ulna) and receives the insertion of the **brachioradialis.** It lies at the **floor** of the anatomical snuffbox.
- Nutrient arteries to both ulna & radius are branches of **anterior interosseus artery** branch of ulnar artery.

Clinical Correlations

- **Colles** fracture of the wrist is a **distal** radius fracture in which the distal fragment is displaced (tilted) posteriorly, producing a characteristic bump described as **dinner fork deformity**. Radial and ulnar styloid process come to lie in the same line (1 cm difference is lost).
- If the distal fragment is displaced anteriorly, it is called a reverse Colles fracture (Smith fracture).



Figs. 11A and B: Attachments on radius and ulna bones (anterior and posterior aspect)

ASSESSMENT QUESTIONS

1. About radius bone TRUE is: *(NEET Pattern 2013)*
   a. Radial groove is present
   b. Major contributor to wrist joint
   c. Radial artery lies medial to styloid process of radius
   d. Medial bone of forearm

2. The structure that lies lateral to distal radial tubercle: *(NEET Pattern 2014)*
   a. Extensor pollicis longus
   b. Extensor carpi radialis longus
   c. Brachioradialis
   d. Extensor carpi ulnaris

3. Radial styloid process gives attachment to: *(NEET Pattern 2012)*
   a. ECU
   b. Brachioradialis
   c. ECR
   d. Anconeus

ANSWERS AND EXPLANATIONS

1. b. Major contributor to wrist joint > c. Radial artery lies medial to styloid process of radius
- Radius articulates with carpal bones to form radiocarpal (wrist) joint. It is the **major contributor** in the joint.
- The medial bone ulna is excluded from this articulation by an articular disc.
- Radial artery lies medial to styloid process of radius, then winds laterally around the styloid process to enter the anatomical snuff box.
- **Radial** (spiral) **groove** is present on humerus bone.

2. b. Extensor carpi radialis longus
- Distal end of radius has **Lister's tubercle** on the dorsal side.
- The tendon of **extensor carpi radialis longus** (and Brevis) pass lateral to the tubercle.
- The tendon of **extensor pollicis longus** passes medial to the Lister's tubercle.

3. b. Brachioradialis
- At the base of the radial styloid process, there is insertion of **brachioradialis** muscle.

Bones of Hand

MISCELLANEOUS QUESTION

1. All the pairs about bony attachments around shoulder joint are correctly matched *EXCEPT*
   a. Latissimus dorsi: Floor of intertubercular sulcus
   b. Short head of biceps: Tip of coracoid process
   c. Subscapularis: Lesser tubercle
   d. Teres major: Greater tubercle

ANSWER AND EXPLANATION

1. d. Teres major: Greater tubercle
- Attachment on greater tubercle is teres minor (and not major). Teres major attached to the medial lip of bicipital groove on humerus.

Joints

Joints of Upper Limb

Table 3: Types of joint in upper limb

Joint	Type
Sternoclavicular	Saddle
Acromioclavicular	Plane
Shoulder	Ball and socket
Elbow	Hinge
Superior and inferior radioulnar	Pivot (trochoid)
Joint	**Type**
Middle radioulnar	Syndesmosis
Wrist	Ellipsoid > Condylar
1st carpometacarpal	Saddle (sellar)
Metacarpophalangeal	Ellipsoid > Condylar
Intercarpal and midcarpal	Plane
Interphalangeal	Hinge

Table 4: Movements, corresponding muscles and their segmental innervation

Joint	Movement	Muscle	Innerveation	C3	C4	C5	C6	C7	C8	T1
Scapula	Elevation	Upper trapezius	Accessory n.							
		Levator scapulae	Dorasal scapular n.							
	Depression	Lower trapezius	Accessory n.							
	Retraction	Middle trapezius	Accessory n.							
		Rhomboids	Dorsal scapular n.							
Shoulder	Protraction	Serratus anterior	Long thoracic n.							
	Flexion	Anterior deltoid	Axillary n.							
		Pectoralis major (clavicular head)	Medial and lateral pectoral nn.							
		Pectoralis major (sternocostal head)	Medial and lateral pectoral n.							
		Coracobrachialis	Musculocutaneous n.							
	Extension	Posterior deltoid	Posterior deltoid							
		Infraspinatus	Suprascapular n.							
		Teres minor	Axillary n.							
		Teres major	Lower subscapular n.							
		Latissimus dorsi	Thoracodorsal n.							
	Vertical abduction	Middle deltoid	Axillary n.							
		Supraspinatus	Suprascapular n.							
	Vertical adduction	Pectoralis major (Sternocostal head)	Medial and lateral pectoral nn.							
		Latissimus dorsi	Thoracodorsal n.							
		Coracobrachialis	Musculocutaneous n.							
	Horizontal abduction	Posterior deltoid	Axillary n.							
	Horizontal adduction	Pectoralis major (clavicular head)	Medial and lateral pectoral nn.							
		Pectoralis minor	Medial and lateral pectoral nn.							
		Anterior deltoid	Axillary n.							
	Medial rotation	Subscapularis:	Upper and lower subscapular nn.							
		Teres major	Brachial plexus							
		Latissimus dorsi	Thoracodorsal n.							
		Anterior deltoid	Axillary n.							
	Lateral rotation	Infraspinatus	Suprascapular n.							
		Teres minor	Axillary n.							
		Posterior deltoid	Axillary n.							
Elbow	Flexion	Biceps brachii	Musculocutaneous n.							
		Brachialis	Musculocutaneous and radial nn.							
		Brachioradialis	Radial n.							
	Extension	Triceps brachii	Radial n.							
	Supination*	Biceps brachii	Musculocutaneous n.							
		Supinator	Posterior interosseous n.							
	Pronation*	Pronator quadratus	Anterior interosseous n.							
		Pronator teres	Median n.							

Joint	Movement	Muscle	Innervation	C3	C4	C5	C6	C7	C8	T1
Writs	Flexion	Flexor carpi radialis	Median n.							
		Palmaris longus	Median n.							
		Flexor carpi ulnaris	Ulnar n.							
	Extension	Extensor carpi radialis longus	Radial n.							
		Extensor carpi radialis brevis	Posterior interosseous n.							
		Extensor carpi ulnaris	Posterior interosseous n.							
	Abduction	Extensor carpi radialis longus	Radial n.							
		Extensor carpi radialis brevis	Posterior interosseous n.							
		Flexor carpi radialis	Median n.							
	Adduction	Extensor carpi ulnaris	Posterior interosseous n.							
		Flexor carpi ulnaris	Ulnar n.							
Fingers	Flexion (MP/PIP joints)	Flexor digitorum superficialis	Median n.							
		Dorsal interossei	Ulnar n.							
		Palmar interossei	Ulnar n.							
	Flexion (DIP joints)	Flexor digitorum profundus (lateral)	Anterior interosseous n.							
		Flexor digitorum profundus (medial)	Ulnar n.							
	Flexion (MP joints)	Flexor digiti minimi brevis	Ulnar n.							
	Extension (MP/PIP/DIP joints)	Extensor digitorum	Posterior interosseous n.							
		Extensor indicis	Posterior interosseous n.							
	Extension (MP/PIP/DIP joints)	Flexor digiti minimi	Posterior interosseous n.							
	Extension (PIP/DIP joints)	Lumbricals I and II	Usually Median n.							
		Lumbricals III and IV	Usually Ulnar n.							
	Abduction	Dorsal interossei	Ulnar n.							
	Abduction (thumb fixed)	Abductor pollicis brevis	Median n.							
	Abduction	Abductor digiti minimi	Ulnar n.							
	Adduction	Palmar interossei	Ulnar n.							
	Opposition	Opponens digit minimi	Ulnar n.							
Thumb	Flexion (IP joint)	Flexor pollicis longus	Anterior interosseous n.							
	Flexion/rotation (MP joint)	Flexor pollicis brevis	Median n. and/or ulnar n.							
	Extension (MP joint)	Extensor pollicis brevis	Posterior interosseous n.							
	Extension (IP joint)	Extensor pollicis longus	Posterior interosseous n.							
	Abduction	Abductor pollicis longus	Posterior interosseous n.							
	Abduction/rotation	Abductor pollicis brevis	Median n.							
	Adduction/rotation	Adductor pollicis	Ulnar n.							
	Adduction/flexion (MP joint)	Palmar interosseous I	Ulnar n.							
	Opposition	Opponens pollicis	Median n. and ulnar n.							

Note: Major components are marked in red. The darkest shade is the dominant root value.

Sternoclavicular and Acromioclavicular Joint

- The **sternoclavicular joint** has an intra-articular **fibrocartilaginous disc**. Fibrous capsule is reinforced by the anterior and posterior sternoclavicular, interclavicular, and costoclavicular ligaments. It allows elevation and depression, protraction and retraction, and **circumduction** of the shoulder.

- **Acromioclavicular Joint** allows a gliding movement when the scapula rotates and is reinforced by the **coracoclavicular ligament**, which consists of the **conoid** and **trapezoid** ligaments. It has significant contribution in movements during shoulder **abduction**.

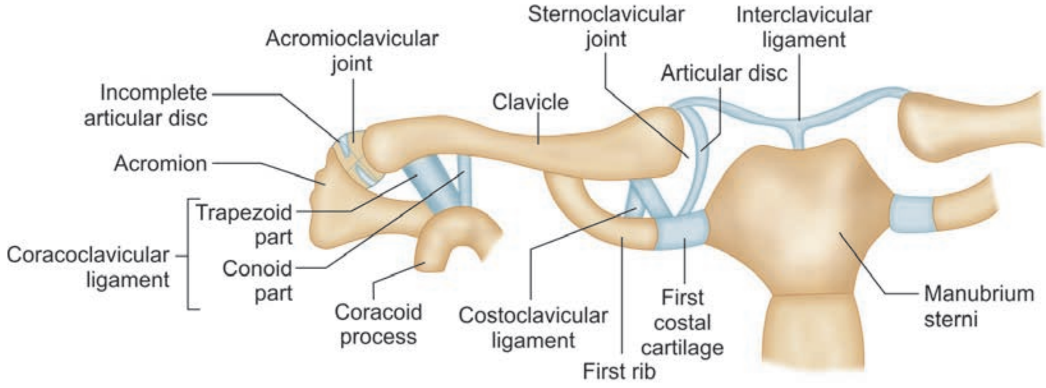


Fig. 12: Sternoclavicular and acromioclavicular joints

Shoulder (Glenohumeral) Joint

- **Ligaments**
  - **Capsule** is attached superiorly to the margin of the glenoid cavity and inferiorly to the **anatomic neck** of the humerus. It is reinforced by the **rotator cuff**, the glenohumeral ligaments, and the coracohumeral ligaments.
  - **Glenoid labrum** is a fibrocartilaginous structure to deepen the glenoid cavity.
  - **Other ligaments: Three glenohumeral Ligaments** (superior, middle and inferior); **transverse humeral ligament** extend between the greater and lesser tubercles and holds the tendon of the long head of the biceps in the intertubercular groove; **coracohumeral Ligament** extends from the coracoid process to the greater tubercle; **coracoacromial Ligament** extends from the coracoid process to the acromion, prevents superior displacement of humeral head; **coracoclavicular Ligament** extends from the coracoid process to the clavicle and consists of the trapezoid and conoid ligaments.

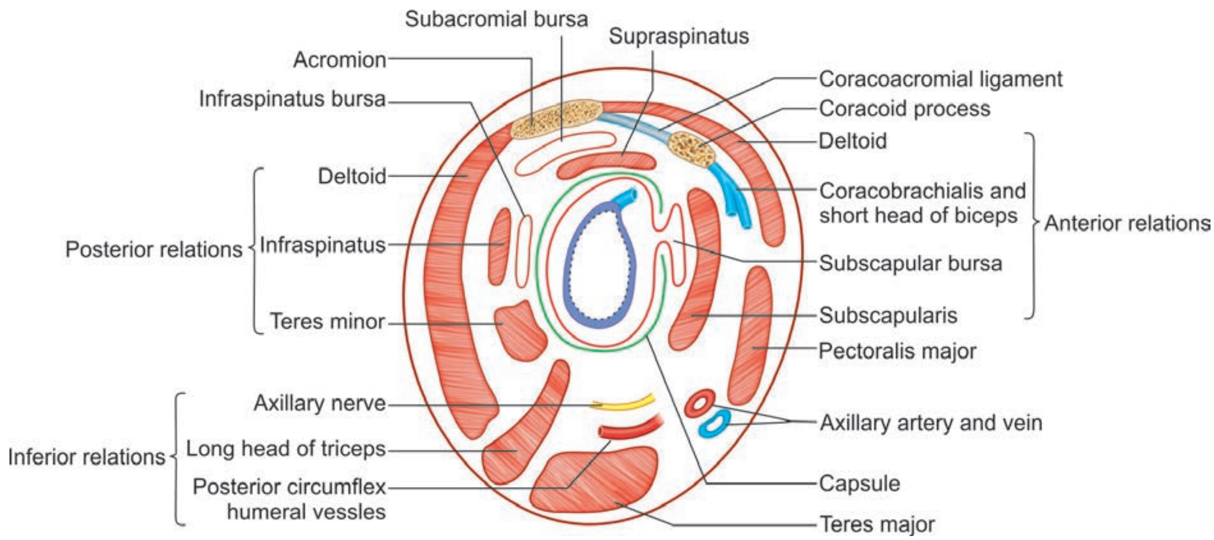


Fig. 13: Relations of shoulder joint

- **Bursae**
  - **Subacromial bursa** lies between the coracoacromial arch and the supraspinatus muscle, protects the supraspinatus tendon against friction with the acromion; **subdeltoid bursa** lies between the deltoid muscle and the shoulder joint capsule, usually communicates with the subacromial bursa, and facilitates the movement of the deltoid muscle over the joint capsule and the supraspinatus tendon; **subscapular bursa** lies between the subscapularis tendon and the neck of the scapula and **communicates with** the synovial cavity of the shoulder joint.
- **Arterial supply:** Suprascapular, anterior and posterior humeral circumflex, and circumflex scapular arteries.
- **Nerve supply:** Axillary, suprascapular, and lateral pectoral nerves.
- **Dislocation: Anterior–inferior** dislocation of the humerus is the most common type. The head of the humerus moves anterior and inferior to the coracoid process of the scapula and may damage the **axillary nerve** or **axillary artery**.

Movements

Table 5: Movement of glenohumeral joint

Movement	Prime mover(s)	Synergists	Additional points
Flexion	Pectoralis major (clavicular head); deltoid (clavicular and anterior acromial parts)	Coracobrachialis (assisted by biceps brachii)	From fully extended position to its own (coronal) plane, sternocostal head of pectoralis major is major force
Extension	Deltoid (spinal part)	Teres major; latissimus dorsi; long head of triceps brachii	Latissimus dorsi, (sternocostal head of pectoralis major, and long head of triceps brachii) act from fully flexed position to their own (coronal) planes
Abduction	Deltoid (as a whole, but especially acromial part)	Supraspinatus	Supraspinatus is particularly important in initiating movement; also, upward rotation of scapula occurs throughout movement, making a significant contribution
Adduction	Pectoralis major; latissimus dorsi	Teres major; long head of triceps brachii	In upright position and in absence of resistance, gravity is prime mover
Medial rotation	Subscapularis	Pectoralis major; deltoid (clavicular part); latissimus dorsi; teres major	With arm elevated. "synergists" become more important than prime movers
Movement	**Prime mover(s)**	**Synergists**	**Additional points**
Lateral rotation	Infraspinatus	Teres minor; deltoid (spinal part)	
Tensors of articular capsule (to hold head of humerus against the glenoid cavity)	Subscapularis; infraspinatus (simultaneously)	Supraspinatus; teres minor	Rotator cuff (SITS) muscles acting together; when "resting", their tonus adequately maintains integrity of joint
Resisting down-ward dislocation (shunt muscles)	Deltoid (as a whole)	Long head of triceps brachii; coracobrachialis; short head of biceps brachii	Used especially when carrying heavy objects (suitcases, buckets)

Shoulder Abduction

- The total range of shoulder abduction is 180°. Abduction up to 90° occurs at the **shoulder joint**, further 90° to 120° occurs as **humerus is rotated laterally**, 120° to 180° range is added by **lateral rotation of scapula**.
- **Supraspinatus** initiates abduction and causes initial 15° of abduction; **deltoid** is the main abductor from 15° to 90° of abduction, sequentially humerus is laterally rotated by the **infraspinatus and teres minor** muscles and next overhead abduction (90°–180°) is carried out by the 2 muscles mainly – **trapezius** and **serratus anterior**.
- During abduction, trapezius and serratus anterior cause lateral rotation of scapula and glenoid cavity eventually faces **upwards**.
- Humerus and scapula move in the **ratio of 2:1** during abduction, i.e., for every 15° elevation, the humerus moves 10° and scapula moves 5°.
- Abduction at shoulder involves **rotation of clavicle** at its longitudinal axis, which occurs at both the **sternoclavicular** and the **acromioclavicular** joints. This contributes about 60° rotation to the clavicle in total.

Gray's Anatomy (Ed41)

It is **conventionally** believed is that supraspinatus initiates abduction of shoulder and assist deltoid in abduction, but recently it has been established that both supraspinatus and deltoid are involved **throughout** the entire range of abduction, including the initiation of the movement and overhead abduction.

ASSESSMENT QUESTIONS

1. **Which of following muscle has NO action at shoulder joint?** *(NEET Pattern 2014)*
   a. Teres major
   b. Pectoralis minor
   c. Subscapularis
   d. Trapezius

2. **All the muscles are used to abduct the shoulder *EXCEPT:*** *(AIPG Pattern 2014)*
   a. Deltoid
   b. Supraspinatus
   c. Serratus anterior
   d. Pectoralis major

3. **TRUE about abduction at shoulder joint:** *(PGIC 2016)*
   a. Supraspinatus initiates abduction
   b. Serratus anterior and trapezius also help in abduction
   c. Multipennate deltoid clavicular fiber is main abductor
   d. Axillary nerve injury has no effect on abduction
   e. Musculotendinous cuff stabilizes shoulder joint

ANSWERS AND EXPLANATIONS

1. **b. Pectoralis minor**
   - **Pectoralis minor** is an accessory muscle of inspiration, which stabilizes scapula by pulling it anteriorly and inferiorly. It doesn't participate in shoulder joint movements as such.
2. **d. Pectoralis major**
   - **Pectoralis major** muscle doesn't function as an abductor at shoulder joint.
3. **a. Supraspinatus initiates abduction; b. Serratus anterior and trapezius also help in abduction; e. Musculotendinous cuff stabilizes shoulder joint**
   - Both **supraspinatus** and deltoid are involved throughout the range of abduction, including the initiation of the movement.
   - **Serratus anterior** and **trapezius** also help in overhead abduction.
   - The multipennate acromial (**not clavicular**) fibres of deltoid are the powerful abductors of arm at the shoulder joint.
   - **Axillary nerve injury** paralyses the deltoid, hence abduction is seriously compromised. **Musculotendinous rotator cuff** stabilizes the shoulder joints posterosuperiorly and partly anteriorly as well (but inferiorly it is deficient).

Radiology

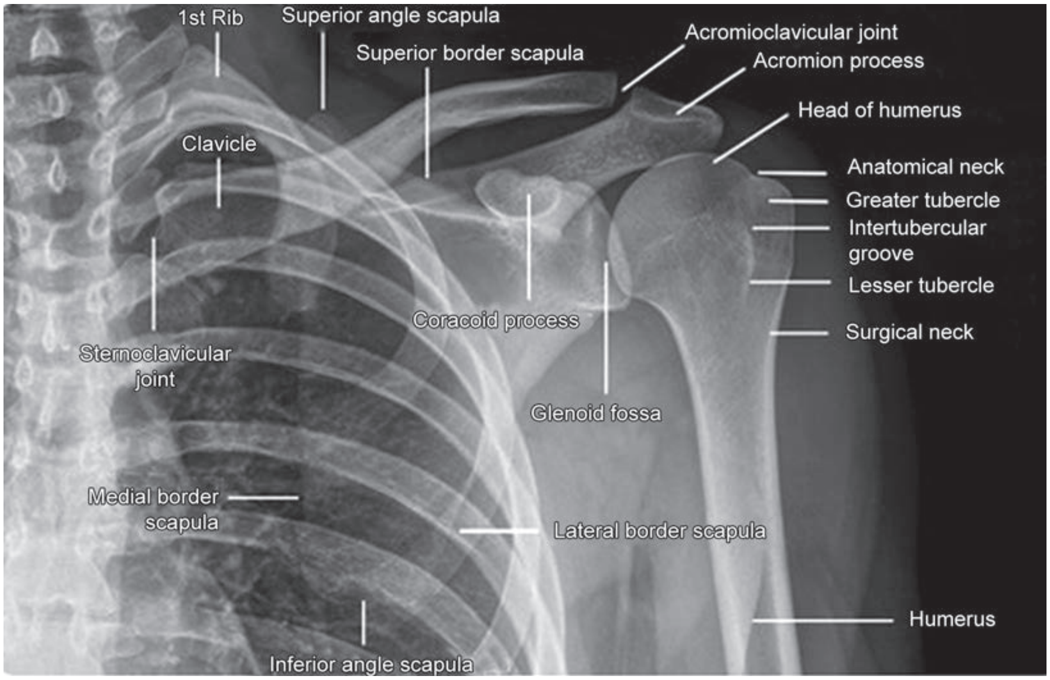


Fig. 14: X-ray showing skeletal land marks

Elbow

- Elbow joint
  - It is a **compound joint** formed by three bones. It includes a synovial **hinge** joint, consisting of the humeroradial and humeroulnar joints, that allows flexion and extension.
  - It also includes the proximal radioulnar (**pivot**) joint, within the common capsule.
- **Ligaments**
  - **Annular ligament** is a fibrous band that is attached to the anterior and posterior margins of the radial notch of the ulna and forms nearly four-fifths of a circle around the head of the radius, to hold it in position. It is fused with the articular capsule and radial collateral ligament.
  - **Radial collateral ligament** extends from the lateral epicondyle to the anterior and posterior margins of the radial notch of the ulna and the annular ligament of the radius.
  - **Ulnar collateral ligament** is triangular in shape having three bands - anterior, posterior, and oblique. It extends from the medial epicondyle to the coronoid and olecranon processes of ulna.
- **Bursae:** There are three olecranon bursae: **Subtendinous**, which is located between the olecranon and the triceps tendon; **Intratendinous**, which may be present in the tendon of triceps brachii and **Subcutaneous. Bicipitoradial bursa** separates the biceps tendon from, anterior part of the radial tuberosity.
- **Arterial supply:** Anastomosis formed by branches of the brachial artery and recurrent branches of the radial and ulnar arteries.
- **Nerve supply:** Musculocutaneous, median, radial and ulnar nerves.

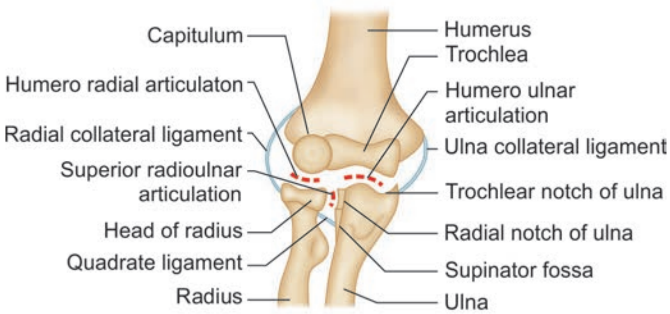
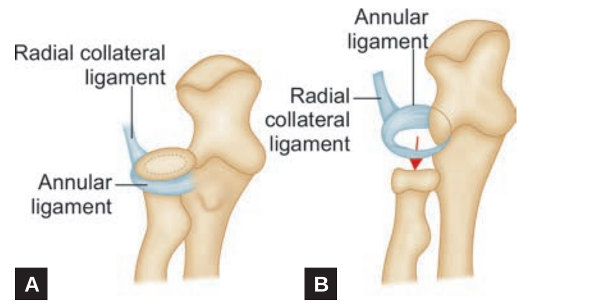


Fig. 15: Elbow joint



Figs. 16A and B: Pulled elbow: A, head of radius within cup-shaped annular ligament; B, head of radius pulled down from the annular ligament

Carrying Angle

- It is formed laterally by the axis of the arm and forearm when the elbow is extended, because the medial edge of the trochlea projects more inferiorly (**about 6 mm**) than its lateral edge.
- The transverse axis of elbow joint is not transverse but **oblique**, directed downwards and medially. The forearm deviated (**5–15 degrees**) laterally from a straight line of the arm.
- It is **wider** in women (than men) and disappears when the forearm is flexed or pronated.

Table 6: Movements and muscle involved at elbow joint

Movements	Muscles involved
Flexion	Primary muscles: Brachialis, biceps (in supination), brachioradialis (in mid prone). Supportive muscles: Pronator teres, flexor carpi radialis.
Extension	Triceps, Anconeus

There occurs 150° of extension and flexion, and 180° of pronosupination in conjunction with the distal radioulnar joint.

Clinical Correlations

- **Tennis elbow** (lateral epicondylitis) is caused by a chronic inflammation or irritation of the origin (tendon) of the extensor muscles of the forearm from the lateral epicondyle of the humerus as a result of repetitive strain. It is a painful condition and common in tennis players and violinists.
- **Golfer's elbow** (medial epicondylitis) is a painful condition caused by a small tear or an inflammation or irritation in the origin of the flexor muscles of the forearm from the medial epicondyle. Avoidance of repetitive bending (flexing) of the forearm is advised in order to not compress the ulnar nerve.
- **Nursemaid's elbow** or pulled elbow is a radial head subluxation and occurs in toddlers when the child is lifted by the wrist. It is caused by a partial tear (or loose) of the annular ligament and thus the **radial head to slip out** of position.

ASSESSMENT QUESTION

1. **Which are NOT the flexors of forearm?** *(PGIC 2010)*
   a. Pronater teres
   b. Brachialis
   c. Brachioradialis
   d. Anconeous
   e. Flexor pollicis longus

ANSWER AND EXPLANATION

1. **d. Anconeus; e. Flexor pollicis longus**
   - Anconeus muscle is an extensor at elbow joint (with triceps) and flexor pollicis longus muscle do not cross (and act) at elbow joint.
   - Biceps brachii is a powerful supinator and causes elbow flexion as well.
   - Brachioradialis is a flexor at elbow joint especially in mid-prone position.

Radiology

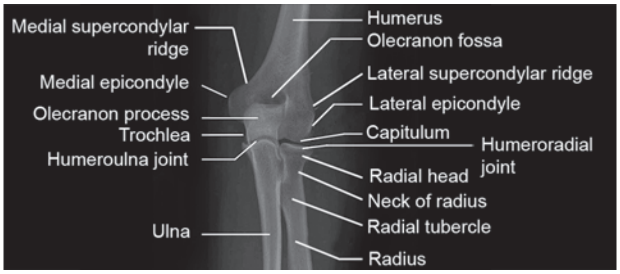


Fig. 17: X-ray showing skeletal land marks around elbow joint

Radioulnar

- Superior and inferior radioulnar joints are **pivot** synovial joints for the movements of **supination and pronation**.
- In **superior Radioulnar Joint** head of the radius articulates with the radial notch of the ulna, rotate within the encircling annular ligament and participate in pronation and supination. The joint cavity communicates with the cavity of elbow joint.
- **Inferior Radioulnar Joint** is between the head of the ulna and the ulnar notch of the radius and doesn't communicate with the wrist joint.

Table 7: Radioulnar joints: Movement and muscles involved

Movements	Muscles involved
Pronation	Pronator quadratus (strong pronator), pronator teres (Rapid pronator), brachioradialis*
Supination	Supinator (in extended elbow), Biceps (in flexed elbow), brachioradialis*

*Brachioradialis pronates/supinates the forearm to midprone position.

Note: Flexor carpi radialis, palmaris longus and gravity help in pronation.

Wrist (Radiocarpal) Joint

- It is a synovial, biaxial and **ellipsoid** joint. Some authors consider it as **condylar** variety.
- It is formed by articulation of the **distal end of the radius** and the **articular disc** of the triangular fibrocartilage with the **proximal row of carpal bones**- scaphoid, lunate, and rarely triquetrum.
- Its **capsule** is strengthened by radial and ulnar collateral ligaments and dorsal and palmar radiocarpal ligaments.
- Ulna bone **do not participate** in wrist joint and is excluded from this articulation by an articular disc.
- **Midcarpal Joint** is present between the proximal and distal rows of carpal bones and allows gliding and sliding movements. Together with wrist joint it is called as **wrist complex**.
- The **wrist complex** allows flexion and extension of about 140°, and 70° of adduction and abduction.

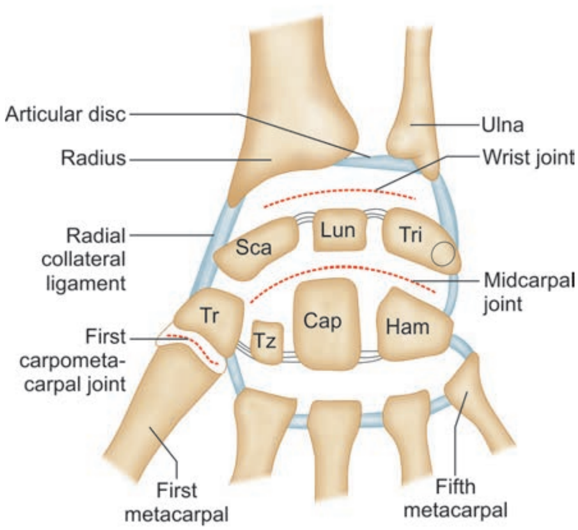


Fig. 18: Wrist joint

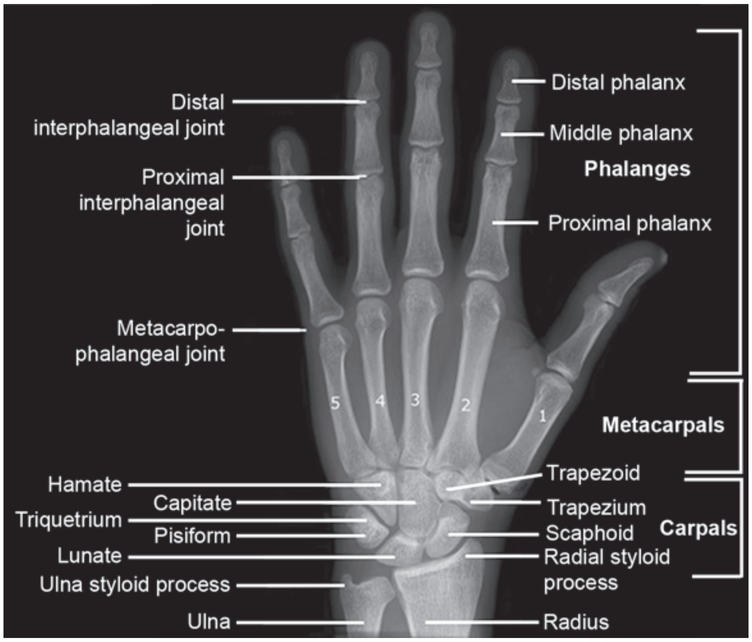


Fig. 19: X-ray showing skeletal landmarks around hand

Table 8: Wrist joint: Movement and muscles involved

Movements	Joint involved	Muscles involved
Flexion	Midcarpal and wrist (in order of involvement)	Flexor carpi radialis, flexor carpi ulnaris, palmaris longus assisted by flexor digitorum superficialis and profundus, and flexor pollicis longus
Extension (dorsiflexion)	Wrist and midcarpal joint (in order of involvement)	Extensor carpi radialis longus and brevis, extensor carpi ulnaris, assisted by extensor digitorum, extensor pollicis longus, extensor indicis and extensor digiti minimi

Movements	Joint involved	Muscles involved
Adduction (Ulnar deviation)	Wrist	Flexor carpi ulnaris and extensor carpi ulnaris
Abduction (Radial deviation)	Mainly occurs at midcarpal joint	Flexor carpi radialis, extensor carpi radialis longus and brevis, abductor pollicis longus and extensor pollicis brevis
*Wrist adduction has greater range than abduction.		

ASSESSMENT QUESTIONS

1. **Wrist is which type of synovial joint:**
   a. Condylar
   b. Ellipsoid
   c. Hinge
   d. Trochoid

2. **Adduction of hand at wrist is done by:** *(PGIC 2000)*
   a. Flexor carpi radialis
   b. Palmaris longus
   c. Flexor digitorum profundus
   d. Flexor carpi ulnaris
   e. Flexor digitorum superficialis

3. **Abduction of Hand is caused by:** *(NEET Pattern 2015)*
   a. Flexor carpi radialis
   b. Flexor carpi ulnaris
   c. Flexor digitorum profundus
   d. Flexor digitorum superficialis

ANSWERS AND EXPLANATIONS

1. **b. Ellipsoid > a. Condylar**
   - The wrist (radiocarpal) joint is a ellipsoid type of synovial joint, though some authors consider it as **condylar** variety.

2. **d. Flexor carpi ulnaris**
   - Flexor carpi ulnaris causes flexion at the wrist joint and ulnar deviation (adduction) as well.

3. **a. Flexor carpi radialis**
   - Abduction of the hand occurs at the wrist joint, carried out by the muscles like Flexor carpi radialis.
   - Flexor carpi ulnaris works for adduction of hand at wrist joint.

Weight Transmission

- Weight of the upper limb is transmitted to the axial skeleton by various bones, joints and ligaments.
- Weight of the hand is transmitted to the radius via the wrist joint. From radius the line of transmission of weight passes to the ulna via interosseous ligament (**middle radioulnar joint**). From ulna the weight is transmitted to the humerus via elbow joint.
- Humerus transmits the weight to the scapula via the shoulder joint. Scapula transmits the **weight of upper limb** to the clavicle via the **coracoclavicular ligament** and acromioclavicular joint.
- Clavicle transmits the weight of the upper limb to the **axial skeleton** (rib and sternum) via the sternoclavicular joint and ligaments like **costoclavicular ligament**.

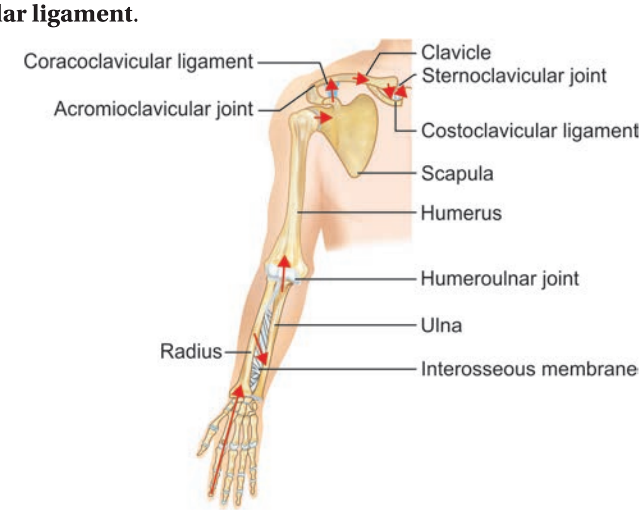


Fig. 20: Line of weight transmission: Hand → Radius→ Ulna→Humerus→Scapula→Clavicle→Sternum and ribs→Vertebral column

ASSESSMENT QUESTIONS

1. **The weight of the upper limb is transmitted to the axial skeleton by:** *(NEET Pattern 2013)*
   a. Coracoclavicular ligament
   b. Coracoacromial ligament
   c. Costoclavicular ligament
   d. Coracohumeral ligament

2. **Weight transmission from upper limb to axial skeleton is done by all *EXCEPT*:** *(AIIMS)*
   a. Costoclavicular ligament
   b. Coracoacromial ligament
   c. Coracoclavicular ligament
   d. Interclavicular ligament

ANSWERS AND EXPLANATIONS

1. **c. Coracoclavicular ligament**
   - There are numerous ligaments which help in weight transmission of upper limb to the axial skeleton, frequently mentioned is coracoclavicular, attached the conoid tubercle and trapezoid line, transmit the weight of the upper limb to the clavicle.

2. **b. Coracoacromial ligament**
   - Coracoacromial ligaments attaches to bone scapula at different points and is not attached to the previous or next bone in line of weight transmission.
   - Ligaments involved in weight transmission connect one bone with the next bone, in line of weight transmission.

High Yield Point

- Coracoclavicular ligament is the major ligament to transmits weight of upper limb to axial skeleton (mainly clavicle). Next is costoclavicular ligament that assist transmitting the weight of upper limb to 1st rib and sternum

ASSESSMENT QUESTIONS

1. **The weight of the upper limb is transmitted to the axial skeleton by:** *(NEET Pattern 2013)*
   a. Coracoclavicular ligament
   b. Coracoacromial ligament
   c. Costoclavicular ligament
   d. Coracohumeral ligament

2. **Weight transmission from upper limb to axial skeleton is done by all *EXCEPT*:** *(AIIMS)*
   a. Costoclavicular ligament
   b. Coracoacromial ligament
   c. Coracoclavicular ligament
   d. Interclavicular ligament

3. **Which of the following is a synovial joint of the condylar variety?**
   a. First carpometacarpal joint
   b. Metacarpophalangeal joint
   c. Interphalangeal joint
   d. Radiocarpal joint

4. **Which of the following movements DOESN'T happen in abduction of shoulder?** *(AIIMS 2008; AIPG 2010)*
   a. Medial rotation of scapula
   b. Elevation of humerus
   c. Rotation of Clavicle at the sternoclavicular joint
   d. Rotation at the axis of acromioclavicular joint

5. **Movements of pronation and supination occurs in all the following joints *EXCEPT*:** *(AIIMS 2006; AIPG 2007)*
   a. Superior radioulnar joint
   b. Middle radioulnar joint
   c. Inferior radioulnar joint
   d. Radiocarpal joint

ANSWERS AND EXPLANATIONS

1. **c. Coracoclavicular ligament**
   - There are numerous ligaments which help in weight transmission of upper limb to the axial skeleton, frequently mentioned is coracoclavicular, attached the conoid tubercle and trapezoid line, transmit the weight of the upper limb to the clavicle.

2. **b. Coracoacromial ligament**
   - Coracoacromial ligaments attaches to bone scapula at different points and is not attached to the previous or next bone in line of weight transmission.
   - Ligaments involved in weight transmission connect one bone with the next bone, in line of weight transmission.

3. **b. Metacarpophalangeal joint.**
   - **Metacarpophalangeal** joint is an **ellipsoid** > condylar synovial joint.
   - Wrist (radiocarpal) joint and knuckle (metacarpophalangeal) joints are **ellipsoid** synovial joints.
   - Some authorities consider them as condylar synovial joints as well.
   - First carpometacarpal joint is **saddle** synovial and Intercarpal joints are **hinge** synovial joints.

4. **a. Medial rotation of scapula**
   - **Lateral** (and not medial) rotation of scapula occurs during abduction of shoulder. This is carried out by the serratus anterior and the upper fibres of trapezius.
   - **Elevation** of the humerus is an integral part of abduction at shoulder and is carried out by the deltoid muscle. This elevation occurs along with the scapular rotation and makes the humerus go into its secondary socket, i.e. sub-acromial space.
   - Abduction at shoulder involves rotation of clavicle at its longitudinal axis. This rotation occurs at both the **sternoclavicular** and the **acromioclavicular** joints.

5. b. Middle radioulnar joint
- Supination and pronation mainly occurs at the **superior** radioulnar and **inferior** radio-ulnar joint. The wrist plays an essential in role the transmission of pronosupination movements.
- Action of Extensor carpi radialis: during extension scaphoid extends and supinates on the radius; lunate extends and pronates on the radius (Kapandji AI et al. and Roux JL et al.).
- **Middle** radio-ulnar joint is a syndesmosis (fibrous) joint mainly helps in binding radius and ulna together. The other function of this joint is weight transmission from radius towards ulna.

Nerve Supply

- There is a **segmental pattern** to the innervation of the upper limb. The most **proximal muscles** are supplied by branches of the **uppermost** rami (C-5,6) of brachial plexus, and the most distal muscles are supplied by branches derived from lower rami: C8 and T1.
- The segmental pattern of innervation is also evident in the **cutaneous supply**.

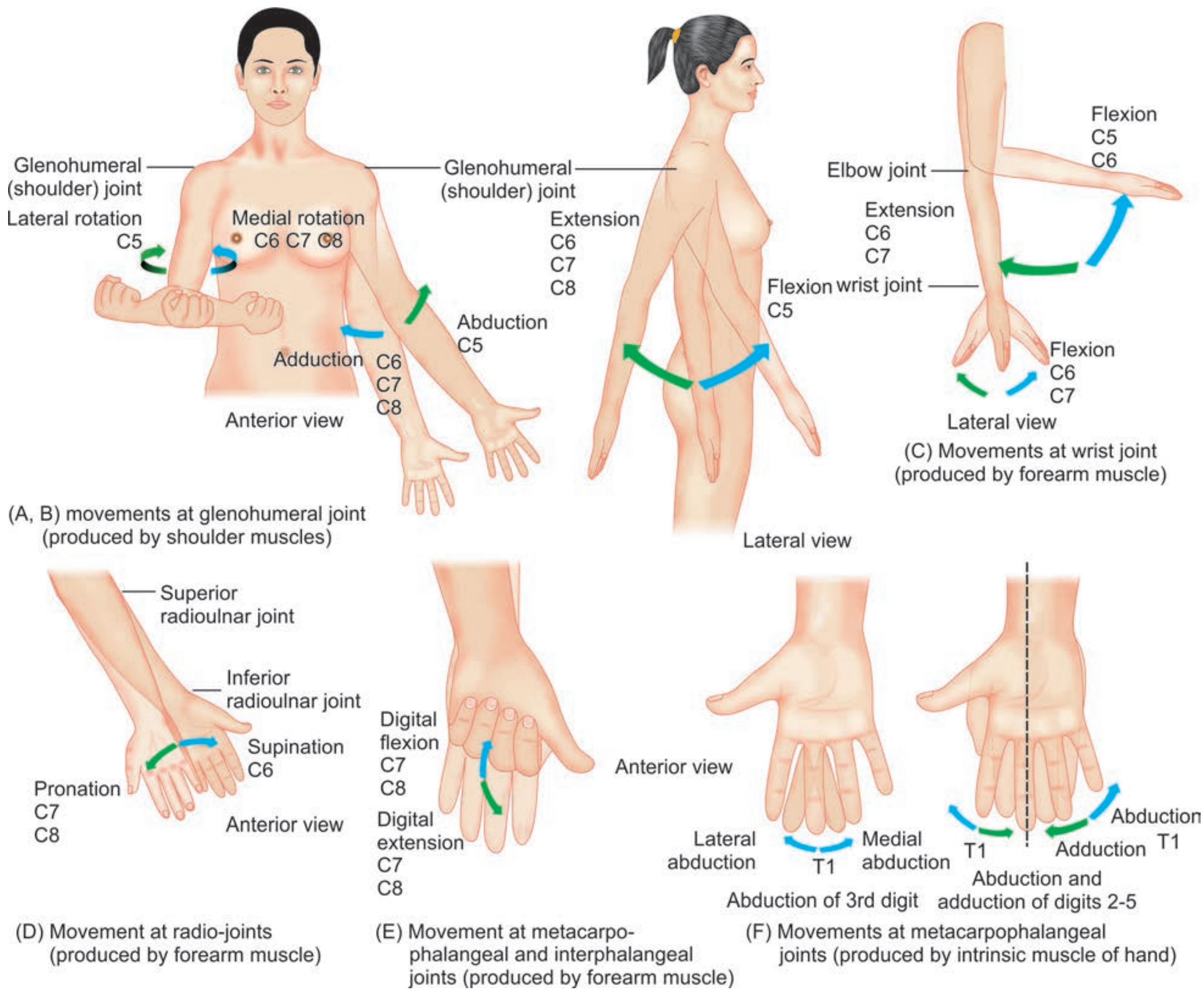


Fig. 21: Movements and respective root values in upper limb

Table 9: Segmental innervation of the muscles of the upper limb

Nerves	Muscles
C3, 4	Trapezius, levator scapulae
C5	Rhomboids, deltoids, supraspinatus, infraspinatus, teres minor, biceps
C6	Serratus anterior, latissimus dorsi, subscapularis, teres major, pectoralis major (clavicular head), biceps, coracobrachialis, brachialis, brachioradialis, supinator, extensor carpi radialis longus
C7	Serratus anterior, latissimus dorsi, pectoralis major (sternal head), pectoralis minor, triceps, pronator teres, flexor carpi radialis, flexor digitorum superficialis, extensor digit minimi

Nerves	Muscles
C8	Pectoralis major (sternal head), pectoralis minor, triceps, flexor digitorum superficialis, flexor digitorum profundus, flexor pollicis longus, pronator quadratus, flexor carpi ulnaris, extensor carpi ulnaris, abductor pollicis longus, extensor pollicis longus, extensor pollicis brevis, extensor Indicis, abductor pollicis brevis, flexor pollicis brevis, opponens pollicis
T1	Flexor digitorum profundus, intrinsic muscles of the hand (except abductor pollicis brevis, flexor pollicis brevis, opponens pollicis)

Table 10: Muscles and their root values in upper limb joints

Territory	Muscles	Nerves
Shoulder	Abductors and lateral rotators Adductors and medial rotators	C5 C6–8
Elbow	Flexors Extensors	C5, 6 C7, 8
Forearm	Supinators Pronators	C6 C7, 8
Wrist	Flexors and extensors	C6, 7
Digits	Long flexors and extensors	C7, 8
Hand	Intrinsic muscles	C8, T1

- **Autonomic nerves**
  - The **preganglionic sympathetic** inflow to the upper limb is derived from neurones in the **intermediolateral horn** of spinal cord segments T2–6/7.
  - **Myelinated preganglionic** axons pass from the spinal nerves to the **thoracic sympathetic chain** via white rami communicates. They pass up the chain to the middle cervical and inferior cervical (stellate or cervicothoracic) ganglia, where they relay.
  - The **unmyelinated postganglionic** fibres are distributed by grey rami communicantes to the nerves of origin of the **brachial plexus**. T1 not only receives a grey ramus from the inferior cervical ganglion but also contributes a white ramus to it.
  - Interruption of this white ramus is one cause of **Horner's (Bernard-Horner) syndrome**.

Brachial Plexus

- **Brachial plexus** is contributed by the ***ventral* primary rami** of the lower four cervical nerves and the first thoracic nerves (C5–8; T1).
- It has roots and trunks (in the **neck**), divisions (passing behind clavicle), cords and branches (in the **axilla**).
- It is covered by a prolongation of **prevertebral fascia** (axillary sheath) around the nerves in the axilla.
- The rami enter the **posterior triangle of the neck** between scalenus anterior and medius.
- **Upper trunk** is formed by C5 and C6, where these nerves emerge from deep to scalenus anterior. The **middle trunk** is the continuation of C7. The **lower trunk** is contributed by C8 and T1, where these nerves cross anterior to the first rib.
- The trunks divide into anterior and posterior **divisions**, which pass behind the clavicle to enter the axilla.

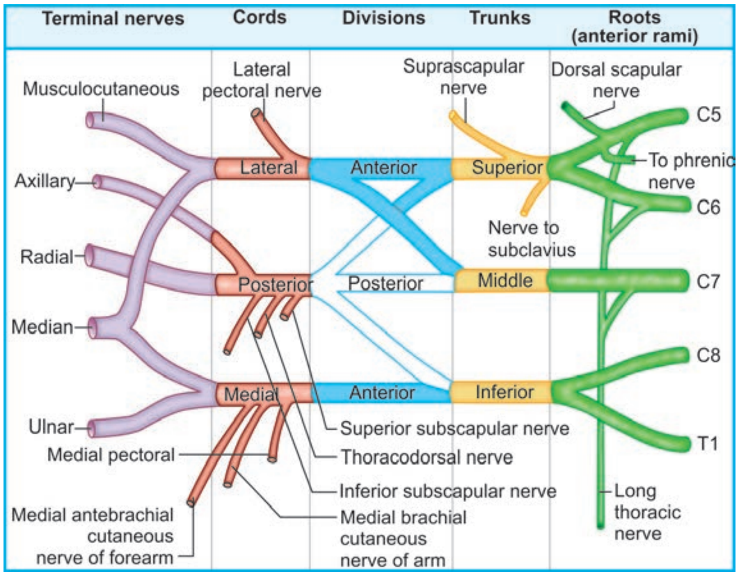


Fig. 22: Brachial plexus

- The **cords** are formed by the confluence of divisions: the **lateral cord** from the anterior divisions of the upper and middle trunks; the **posterior cord** by all three posterior divisions; and the **medial cord** by the anterior division of the lower trunk.
- The **posterior** divisions and posterior cord innervate **postaxial** (extensor) musculature; the anterior divisions and the lateral and medial cords innervate preaxial (flexor) musculature.

Branches

- **Two** branches are given directly from the **roots** in the neck:
  - **Dorsal scapular nerve** (C5), which supplies **rhomboid major and minor** and **levator scapulae** muscles descends along with the dorsal scapular artery on the deep surface of the rhomboid muscles along the medial border of the scapula.
  - **Long thoracic nerve of Bell** (C5–C7), which is given in the neck, enters axilla and descends on the external surface of the ***serratus anterior*** muscle and supplies it.
- **Upper Trunk** gives rise to two branches:
  - **Suprascapular** Nerve (C5–C6) passes deep to the trapezius and joins the suprascapular artery in a course towards the shoulder. Passes through the scapular notch under the superior transverse scapular ligament and supplies the supraspinatus and infraspinatus muscles.
  - **Nerve to the Subclavius** (C5) descends in front of the plexus and behind the clavicle to innervate the subclavius.
- Branches from the **cords** are mentioned in the table.
  - **Radial nerve** is a branch of posterior cord (STARS) and supplies posterior (**extensor**) compartment of upper limb.
  - **Ulnar** nerve is a branch of medial cord (UM4) and runs on the ulnar (medial) side of the limb.
  - **Median nerve** runs in the midline of the limb and has contributions from **both** medial and lateral cords.

Table 11: Branches of the cords of brachial plexus

Lateral cord (LML)	Lateral pectoral Musculocutaneous Lateral root of median	C5, 6, 7 C, 6, 7 C(5), 6, 7
Medial cord (UM4)	Medial pectoral Medial cutaneous of forearm Medial cutaneous of arm Ulnar Medial root of median	8, T1 C8, T1 C8, T1 C(7), 8, T1 C8, T1
Posterior cord (STARS)	Upper subscapular Thoracodorsal Lower subscapular Axillary Radial	C5, 6 C6, 7, 8 C5, 6 C5, 6 C5, 6, 7, 8, (T1)

Table 12: Posterior cord of brachial plexus gives five branches (STARS)

Mnemonic	Nerve	Muscles supplied
S	Subscapular (upper)	Subscapularis
T	Thoracodorsal	Latissimus dorsi
A	Axillary	Deltoid and teres minor
R	Radial	Posterior (extensor) compartment muscles
S	Subscapular (lower)	Subscapularis and teres major

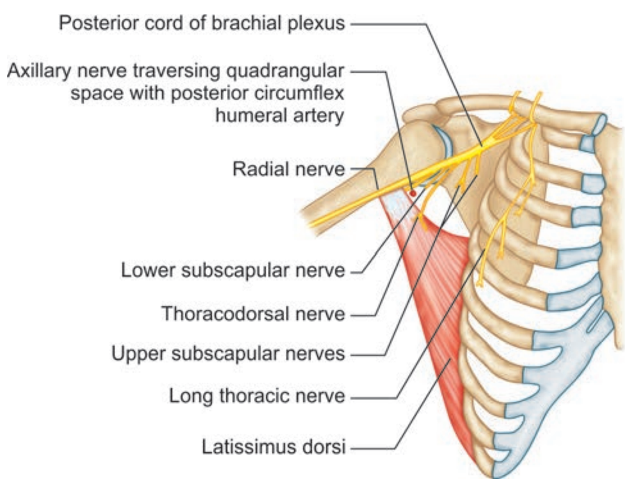


Fig. 23: Branches of posterior cord of brachial plexus

Table 13: Brachial plexus and nerves of upper limb			
Nerve	**Origin**[a]	**Course**	**Structures innervated**
Supraclavicular branches			
Dorsal scapular	Posterior aspect of anterior ramus of **C5** with a frequent contribution from C4	Pierces middle scalene; descends deep to levator scapulae and rhomboids	Rhomboids; occasionally supplies levator scapulae
Long thoracic	Posterior aspect of anterior rami of **C5, C6**, C7	Passes through cervicoaxillary canal, descending posterior to C8 and T1 roots of plexus (anterior rami); runs inferiorly on superficial surface of serratus anterior	Serratus anterior
Suprascapular	Superior trunk, receiving fibers from **C5**, C6 and often C4	Passes laterally across lateral cervical region (posterior triangle of neck), superior to brachial plexus, then through scapular notch interior to superior transverse scapular ligament	Supraspinatus and infraspinatus muscles; glenohumeral (shoulder) joint
Subclavian nerve (nerve to subclavius)	Superior trunk, receiving fibers from C5, **C6** and often C4	Descends posterior to clavicle and anterior to brachial plexus and subclavian artery often giving an accessory root to phrenic nerve	Subclavius and sternoclavicular joint (accessory phrenic root innervates diaphragm)
Infraclavicular branches			
Lateral pectoral	Side branch of lateral cord, receiving fibers from C5, C6, C7	Pierces costocoracoid membrane to reach deep surface of pectoral muscles; a *communicating branch to the medial pectoral nerve* passes anterior to axillary artery and vein	Primarily pectoralis major; but some lateral pectoral nerve fibers pass to pectoralis minor via branch to medial pectoral nerve
Musculocutaneous	Terminal branch of lateral cord, receiving fibers from C5 to C7	Exits axilla by piercing coracobrachialis descends between biceps brachii and brachialis, supplying both; continues as *lateral cutaneous nerve of forearm*	Muscles of anterior compartment of arm (coracobrachialis, biceps brachii and brachialis) skin of lateral aspect of forearm
Median	**Lateral root of median nerve** is a terminal branch of lateral cord (C6, C7)	Lateral and medial roots merge to form median nerve lateral to axillary artery; descends through arm adjacent to brachial artery, with nerve gradually crossing anterior to artery to lie medial to artery in cubital fossa	Muscles of anterior forearm compartment (except for flexor carpi ulnaris and ulnar half of flexor digitorum profundus), five intrinsic muscles in thenar half of palm and palmar skin
Medial pectoral	Side branches of medial cord, receiving fibers from C8, T1	Passes between axillary artery and vein; then pierces pectoralis minor and enters deep surface of pectoralis major; although it is called *medial* for its orgin from medial cord, it lies lateral to lateral pectoral nerve	Pectoralis minor and sternocostal part of pectoralis major
Medial cutaneous nerve of arm		Smallest nerve of plexus; runs along medial side of axillary and brachial veins; communicates with *inercostobrachial nerve*	Skin of medial side of arm, as for distal as medial epicondyle of humerus and olecranon of ulna
Median cutaneous nerve of forearm		Initially runs with ulnar nerve (with which it may be confused) but pierces deep fascia with basilic vein and enters subcutaneous tissue, dividing into anterior and posterior branches	Skin of medial side of forearm, as far distal as wrist
Ulnar	Larger terminal branch of medial cord, receiving fibers from C8, T1 and often C7	Descends medial arm; passes posterior to medial epicondyle of humerus; then descends ulnar aspect of forearm to hand	Flexor carpi ulnaris and ulnar half of flexor digitorum profundus (forearm); most intrinsic muscles of hand; skin of hand medial to axial line of digit 4
Upper subscapular	Side branch of posterior cord, receiving fibers from **C5**	Passes posteriorly, entering subscapularis directly	Superior portion of subscapularis
Lower subscapular	Side branch of posterior cord, receiving fibers from **C6**	Passes inferolaterlly, deep to subscapular artery and vein	Infrior portion of subscapularis and teres major
Thoracodorsal	Side branch of posterior cord, receiving fibers from C6, **C7**, C8	Arises between upper and lower subscapular nerves and runs inferolaterally along posterior axiallary wall to apical part of latissimus dorsi	Latissimus dorsi

Nerve	Origin[a]	Course	Structures innervated
Axillary	Terminal branch of posterior cord, receiving fibers from **C5**, C6	Exits axillary fossa posteriorly, passing through quadrangular space with posterior circumflex humeral artery gives rise to *superior lateral brachial cutaneous nerve;* then winds around surgical neck of hurnerus deep to deltoid	Glenohurneral (shoulder) joint; teres minor and deltoid muscles skin of superolateral arm (over inferior part of deltoid)
Radial	Larger terminal branch of posterior cord (largest branch of plexus), receiving fibers from C5 to T1	Exits axillary fossa posterior to axillary artery; passes posterior to humerus in radial groove with deep brachial artery, between lateral and medial heads of triceps; perforates lateral intermuscular septum; enters cubital fossa, dividing into superficial (cutaneous) and *deep* (motor) *radial nerves*	All muscles of posterior cokpartments of arm and forearm skin of posterior and inferolateral arm, posterior forearm, and dorsum of hand lateral to axial line of digit 4

ASSESSMENT QUESTIONS

1. Which among the following is a branch from the trunk of brachial plexus? *(NEET Pattern 2013,16)*
   a. Suprascapular nerve
   b. Long thoracic nerve
   c. Anterior thoracic nerve
   d. Nerve to subclavius

2. Which of the following nerve does NOT have root valve C5, 6, 7? *(NEET Pattern 2015)*
   a. Lateral pectoral nerve
   b. Musculocutaneous nerve
   c. Lateral root of median nerve
   d. Ulnar nerve

3. Which of the following nerves carries fibres from all the roots of brachial plexus? *(NEET Pattern 2013)*
   a. Axillary
   b. Ulnar
   c. Median
   d. Musculocutaneous

4. All are true about branchial plexus *EXCEPT*: *(NEET pattern 2014)*
   a. Lower trunk is formed by root C8 and T1
   b. Lateral cord is formed by upper and middle trunk
   c. Posterior cord is formed by posterior divisions of all three trunks
   d. C4 root is post fixed to plexus

5. Dorsal scapular nerve supplies: *(JIPMER 2007; NEET Pattern 2014)*
   a. Levator scapulae and rhomboids
   b. Supraspinatus and infraspinatus
   c. Latissimus dorsi
   d. Serratus anterior

6. Posterior cord of brachial plexus is formed by: *(NEET Pattern 2015)*
   a. Ventral division of upper trunk
   b. Dorsal division of upper front
   c. Ventral divisions of upper, middle and lower trunks
   d. Dorsal divisions of upper, middle and lower trunks

7. All are infraclavicular branches of brachial plexus *EXCEPT*: *(NEET Pattern 2013)*
   a. Ulnar nerve
   b. Long thoracic nerve
   c. Axillary nerve
   d. Thoracodorsal nerve

8. All are branches of the posterior cord of brachial plexus *EXCEPT*: *(JIPMER 2010; NEET Pattern 2014)*
   a. Axillary nerve
   b. Radial nerve
   c. Long thoracic nerve
   d. Thoracodorsal nerve

9. Posterior cord supplies: *(NEET Pattern 2015)*
   a. Teres minor
   b. Pectoralis minor
   c. Coracobrachialis
   d. Long head of biceps

10. Root value of thoracodorsal nerve is: *(NEET Pattern 2013)*
   a. C5, 6, 7
   b. C8; T1
   c. C6, 7, 8
   d. T1, 2

ANSWERS AND EXPLANATIONS

1. d. Nerve to subclavius > a. Suprascapular nerve
- Most of the authors mention two branches of from the upper trunk of brachial plexus: **Suprascapular nerve** and **nerve to subclavius.**
- **Gray's anatomy** mentions that the slender nerve to subclavius (C5, 6) springs from the upper trunk.
- Suprascapular nerve (C5, 6) usually arises as the first branch of the upper trunk but it frequently springs directly from the ventral primary ramus of C5. It innervates supra and infraspinatus muscles.

2. d. Ulnar nerve
- Branches of the **uppermost rami** (C-5,6,7) supply more **proximal** muscles, and the more distal muscles are supplied by branches derived from lower rami (C8 and T1).
- **Hand muscles** are distal muscles, supplied by ulnar nerve - C(7),8; T1.

3. c. Median
- Radial nerve & median nerve carry all the five root values of brachial plexus.
- Median nerve is contributed by two roots given by lateral cord: C(5) 6, 7 and medial cord: C8; T1.

4. d. C4 root is post fixed to plexus
- Contribution by C4 to brachial plexus is **pre-fixed brachial plexus**. Post-fixed brachial plexus has contribution by T2
- **Upper trunk** has C5,6; **Middle trunk:** C7 and **Lower trunk:** C8 and T1 root values.
- **Lateral cord** is formed by anterior divisions of upper and middle trunk.
- **Medial cord** by anterior division of lower trunk and **Posterior cord** by posterior divisions of upper, middle and lower trunks.

5. a. Levator scapulae and rhomboids
- **Dorsal scapular nerve** arises above the clavicle from the proximal segment of the ventral primary ramus of C5, given in the neck region. It descends along the anterior border of the rhomboid muscles about 1.5 cm medial to the vertebral border of the scapula and is closely related to the dorsal scapular artery.
- The dorsal scapular nerve innervates the **rhomboid muscles** and, together with branches from C3 and C4, it supplies **levator scapulae.**

6. d. Dorsal divisions of upper, middle and lower trunks
- Upper, middle and lower trunks **dorsal divisions** join to form the **posterior cord** of brachial plexus.

7. b. Long thoracic nerve
- The roots of C-5, 6, 7 contribute to the **long thoracic nerve** (of Bell) in the neck region (**supraclavicular portion** of brachial plexus).
- While it descends upon and supply the serratus anterior muscle it is accompanied by a branch of the thoracodorsal artery, and trends posterolaterally towards the mid-axillary line.

8. c. Long thoracic nerve
- **Long thoracic nerve** arises *directly* from the *roots* of brachial plexus (C- 5,6,7).

9. a. Teres minor
- Posterior cord gives five branches, including axillary nerve which supplies teres minor muscle.

10. c. C6, 7, 8
- Thoracodorsal nerve (C6, 7, 8) is a branch of the posterior cord of brachial plexus, supplies latissimus dorsi—an upper limb muscle which has migrated to lower back muscle for improved functionality.

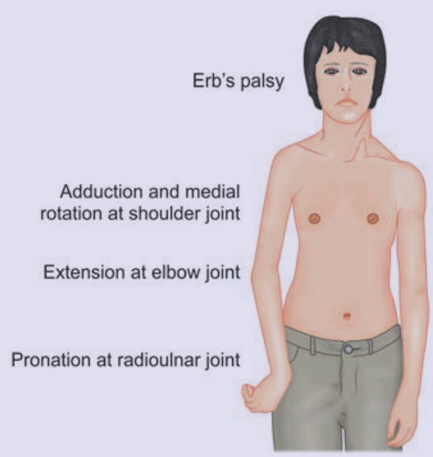
High Yield Points

- **Largest** branch of brachial plexus is **radial** nerve (NEET pattern 2014)
- Roots of brachial plexus are present in neck region (and not axilla) (NEET Pattern 2013)
- Arterial supply to brachial plexus is from the branches of **subclavian** and **vertebral** arteries.
- **Erb's point** is at the junction of C5 and C6 roots. (NEET Pattern 2013)
- **Ulnar nerve** carries root value**: C-7, 8; (T-1).**

Lesions of Brachial Plexus

- **Erb-Duchenne paralysis**
  - It is injury to **upper trunk** of brachial plexus caused due to **undue separation** of head and neck as may happen during a breech delivery or a violent displacement of the head from the shoulder (e.g., a fall from a motorcycle).
  - It results in a **loss** of abduction, flexion, and lateral rotation of the arm, producing a **policeman/waiter's tip hand deformity**, in which the arm tends to lie in medial rotation, forearm in extension and pronation.

Table 14: Erb's palsy

Nerves involved	Cause of injury	Clinical features
Erb-Duchenne palsy (upper turnk; C-5L, 6 injury) • Supra-scapular nerve • Axillary nerve • Musculocutaneous nerve • Radial	Undue separation of head and neck • Fall on shoulder • Birth injury  	Policeman tip hand deformity 

- **Klumpke's paralysis**
  - It occurs due to **lower trunk** injury, may be caused **hyperabduction** at shoulder during a difficult breech delivery, sports injury, by a cervical rib (cervical rib syndrome), or by abnormal insertion or spasm of the anterior and middle scalene muscles (scalene syndrome).
  - The patient presents with paralysed hand muscles (lumbrical and interossei) leading to **claw hand deformity** and **Horner syndrome** (due to lesioned T1 sympathetic fibres).

Table 15: Klumpke's palsy

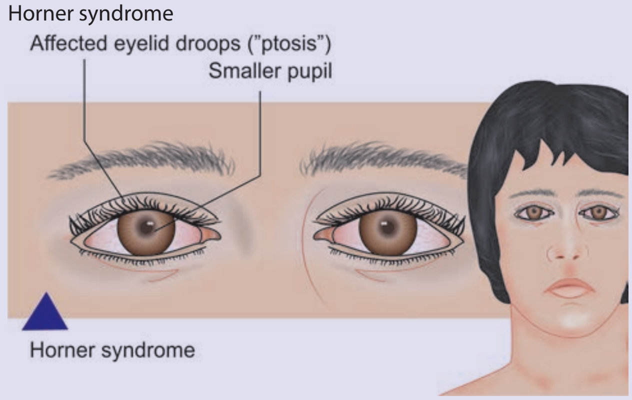
Nerves involved	Cause of injury	Clinical features
(**Lower trunk**; C-8; T-1 injury) • Median nerve • Ulnar nerve • T-1 Sympathetic fibres	**Hyper-abduction** of arm • Holding a branch while fall from a tree • Birth injury  	**Claw hand deformity**  Horner syndrome 

Table 16: Features of Erb's and Klupmke's paralyses

Nerve roots involved	C5 and C6	C8 and T1
Muscles paralysed	Deltoid, supraspinatus infraspinatus, biceps brachii, brachialis, brachioradialis, supinator and extensor carpiradialis longus	All intrinsic muscles of the hand
Position of the upper limb/hand	Policeman's tip/Porter's tip/Waiter's tip position	Claw hand
Sensory loss (Sometimes)	Along the outer aspect of the arm	Along the medial border of forearm and hand
Autonomic signs	Absent	Present (Horner's syndrome)

ASSESSMENT QUESTIONS

1. All of the following muscles undergo paralysis after injury to C5 and C6 spinal nerves *EXCEPT*: *(AIIMS 2004)*
   a. Biceps
   b. Coracobrachialis
   c. Brachialis
   d. Brachioradialis

2. Injury to the upper trunk of brachial plexus results in: *(PGIC 2012)*
   a. Supination of forearm
   b. External rotation of arm
   c. Inability to initiate abduction
   d. Decreased sensation on medial side of hand
   e. Paralysis of deltoid muscle

3. TRUE about the upper trunk of brachial plexus:
   a. Carries root value C-5, 6, 7
   b. Can be blocked medial to scalenus anterior muscle
   c. Long thoracic nerve arises from it
   d. Lesion leads to partial injury of radial nerve

4. FALSE regarding Klumpke's paralysis is: *(JIPMER 2008)*
   a. Claw hand deformity
   b. Intrinsic muscles of hand involved
   c. Horner's syndrome
   d. Upper trunk of brachial plexus involved

5. **A 19-year-old boy fell from the motorbike on his shoulder. The doctor diagnosed him a case of Erb's paralysis. The following signs and symptoms will be observed *EXCEPT*:** *(AIIMS 2002)*
   a. Loss of abduction at shoulder joint
   b. Loss of lateral rotation
   c. Loss of pronation at radioulnar joint
   d. Loss of flexion at elbow joint

6. **A young boy who was driving motorcycle at a high speed collided with a tree and was thrown on his right shoulder. Though there was no fracture, his right arm was medially rotated and forearm pronated. The following facts concerning this patient are correct, *EXCEPT*:** *(AIIMS 2004)*
   a. The injury was at Erb's point
   b. A lesion of C5 and C6 was present
   c. The median and ulnar nerves were affected
   d. Supraspinatus, infraspinatus, subclavius and biceps brachii were paralysed

7. **Concerning brachial plexus, which of the following facts are true?** *(PGIC 2015)*
   a. Formed by spinal nerve C4-C7
   b. Most common site of injury is upper trunk
   c. Injury may occur during breech delivery
   d. Radial nerve is branch of medial cord
   e. Lower trunk injury results in hand deformity

ANSWERS AND EXPLANATIONS

1. **b. Coracobrachialis**
   - **Coracobrachialis** (a flexor and adductor of the abducted arm) is innervated through the anterior division of C5, 6 and (predominantly) 7 segmental levels **(Gray's Anatomy Ed 41)**. Hence, a lesion at C5 and 6 may not paralyse coracobrachialis completely.
   - **Biceps** and **brachialis** are supplied by the musculocutaneous nerve with root value C5 and 6 chiefly and are paralysed.
   - **Brachioradialis** is supplied by the radial nerve with root value C5 and 6 is paralysed.

2. **c. Inability to initiate abduction; e. Paralysis of deltoid muscle**
   - Injury to upper trunk of brachial plexus results in **Erb's palsy** and **policeman tip hand deformity:** Adduction and medial **(internal)** rotation at shoulder joint; extension at elbow joint and **pronation** at radioulnar joint. **Initiation of shoulder abduction** (supraspinatus paralysed) and raising the arm to 90° **(deltoid paralysed)** is not possible.
   - Outer **(lateral)** surface of the upper limb (C-5, 6 dermatome) has sensory disturbance.
   - **Decreased sensation on medial side of hand** (C-8 dermatome) occurs in Klumpke's palsy.

3. **d. Lesion leads to partial injury of radial nerve**
   - **Upper trunk** of brachial plexus carries C-5, 6 root values.
   - Trunks of brachial plexus pass in the scalene triangle bounded by **scalenus anterior** and medius muscle, It lies lateral **(and not medial)** to the scalenus anterior muscle, where a **block** can be carried out.
   - **Long thoracic nerve** arises directly from the roots of brachial plexus (C-5, 6, 7).
   - Lesion of upper trunk of brachial plexus (e.g., Erb's palsy) leads to **partial (C5,6) injury of radial nerve** (C-5, 6, 7, 8; T1).

4. **d. Upper trunk of brachial plexus involved**
   - In Klumpke's palsy there is a lesion in the **lower trunk** of brachial plexus, leading to claw hand deformity due to paralysis of hand muscles, including intrinsic muscles like lumbrical and interossei. Features of Horner syndrome are evident due to injury of T1 sympathetic fibres.

5. **c. Loss of pronation at radioulnar joint**
   - Pronation at the radioulnar joint is carried by the pronator teres and pronator quadratus muscle, supplied by the median nerve with root value C-7 mainly. Hence, there will be **no loss of pronation** in Erb's paralysis.
   - In Erb's palsy there is a weakness of supination due to the paralysed biceps brachii secondary to the lesioned musculocutaneous nerve (C-5 and 6).

6. **c. The median and ulnar nerves were affected**
   - Erb's palsy leads is due to injury of C5,6 roots at Erb's point and doesn't involve ulnar nerve (C7,8;T1).
   - It results in partial injury of median nerve (C-6,7,8;T1).
   - Only the C6 root has been compromised. Injury of suprascapular nerve (C5,6) leads to paralysis of supraspinatus and infraspinatus muscles.
   - Nerve to subclavius (C5,6) is also involved.
   - There is partial injury of musculocutaneous nerve (C5,6,7) and leads to paralysis of biceps brachii (C-5,6) muscle.

7. **b. Most common site of injury is upper trunk, c. Injury may occur during breech delivery, e. Lower trunk injury results in hand deformity**
   - Brachial plexus is contributed by the **spinal nerve C5-8; T1. Radial nerve** is a branch of the **posterior cord** of brachial plexus.

Axillary Nerve

- **Axillary** (circumflex) **nerve** is a branch of **posterior cord** of brachial plexus given in the axilla, pass almost horizontally through the **quadrangular space**, accompanied by the posterior circumflex humeral vessels.
- It innervates **teres minor** and **deltoid**, and the skin on the lateral aspect of the shoulder overlying lower half of deltoid.
- **Injury** to the axillary nerve may be caused by a **fracture of the surgical neck** of the humerus or **inferior dislocation** of the humerus results in the weakness of abduction and lateral rotation of the arm.

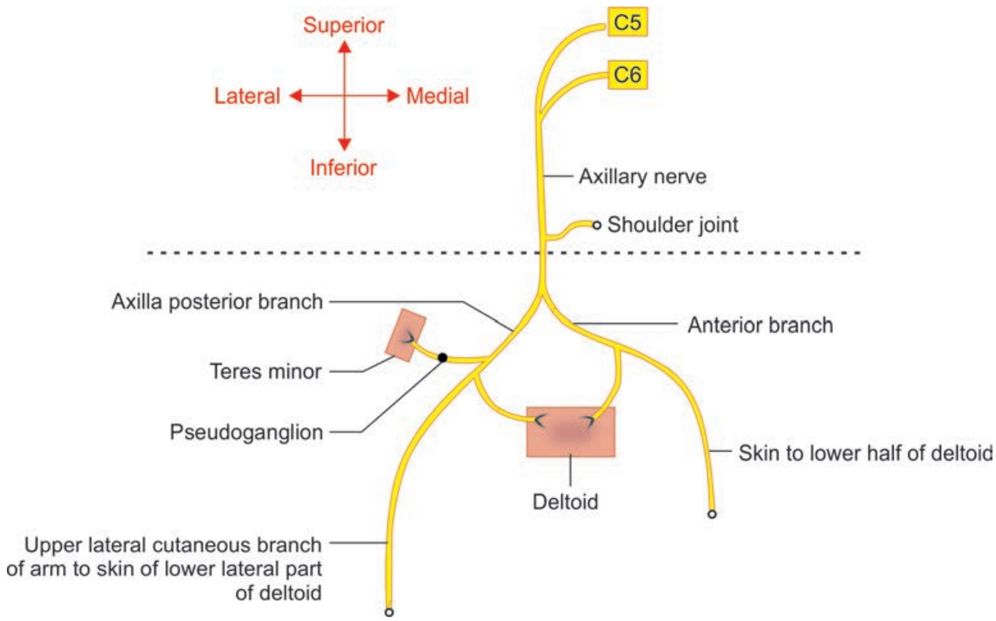


Fig. 24: Formation, course and distribution of the axillary nerve

Musculocutaneous Nerve

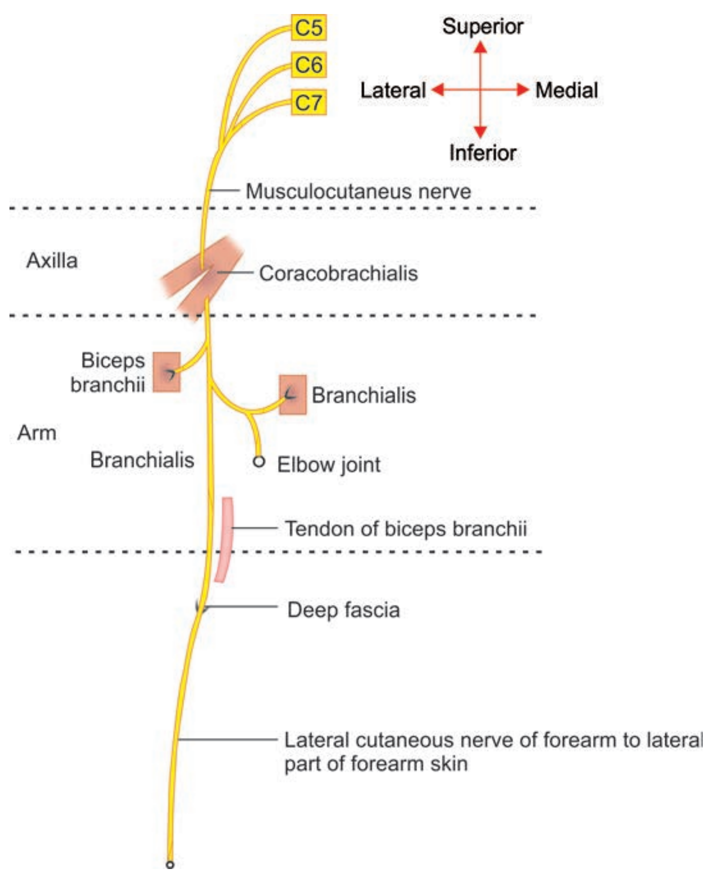


Fig. 25: Formation, course and distribution of radial nerve

- **Musculocutaneous nerve** (C5, 6, 7) is one of the two terminal branches of the **lateral cord**), the other being the lateral root of the median nerve.
- It supplies **coracobrachialis**, both heads of **biceps brachii** and most of **brachialis**, and continues as the **lateral cutaneous nerve of forearm**, deep to biceps, before emerging lateral to it about 11 cm above the lateral epicondyle, and then running down the lateral aspect of the forearm.

- **Injury** to the musculocutaneous nerve results in **weakness** of supination (biceps) and flexion (biceps, brachialis, and coracobrachialis) of the forearm and **loss of sensation** on the lateral side of the forearm.

Radial Nerve

- **Radial nerve** is a continuation of the **posterior cord** of brachial plexus in the axilla, carries fibres from **all the roots** (C5-8; T1) of brachial plexus.
- It is **the largest nerve** in the upper limb and the **most commonly damaged**.
- In the axilla it lies **posterior** to the third part of the axillary artery. It gives three branches in the axilla: **Posterior cutaneous nerve of arm** (cutaneous innervation on the back of the arm up to the elbow); **nerve to the long head of triceps** and **nerve to the medial head of triceps.**
- It enters the arm at the lower border of the teres major and passes between the long and medial heads of triceps to enter the **lower triangular space**, through which it reaches the **radial** (spiral) **groove** along with profunda brachii vessels and lies in direct contact with the humerus.
- In the radial groove, it gives **five branches**: Lower lateral cutaneous nerve of the arm (innervation on the lateral surface of the arm up to the elbow); posterior cutaneous nerve of the forearm (innervation down the middle of the back of the forearm up to the wrist); nerve to lateral head of triceps; nerve to medial head of triceps and nerve to anconeus (passes through medial head of triceps to reach the anconeus).
- At the lower end of the spiral groove, radial nerve **pierces the lateral muscular septum** of the arm, enters the anterior compartment of the arm and give nerve to **brachialis** (small lateral part).
- Nerve to **brachioradialis** is given about three fingers' breadths above the lateral epicondyle, and the nerve to **extensor carpi radialis longus** 1 cm more distally. One nerve to **extensor carpi radialis brevis** leaves the main nerve about 1 cm proximal to the lateral epicondyle, and another leaves at the site of division into **two terminal branches**.
- Radial nerve is a **content of cubital fossa** and in front of the lateral epicondyle terminates into two branches: Superficial (**cutaneous**) and Deep (**motor**).
- The **deep branch** supplies two muscles, extensor carpi radialis brevis and supinator, passes through supinator to enter and supply the posterior compartment of the forearm, named as **posterior interosseous nerve**. It also gives articular branches to the distal radioulnar, wrist, and carpal joints.
- The **superficial branch** descends inferiorly deep to brachioradialis, passes posteriorly at about 7 cm above wrist, emerge from under the tendon of brachioradialis, proximal to the radial styloid process and then passes over the tendons and roof of **anatomical snuff-box** (subcutaneously) and supply skin over the lateral part of the dorsum of hand and dorsal surfaces of lateral 3½ digits (**excluding** the nail beds).

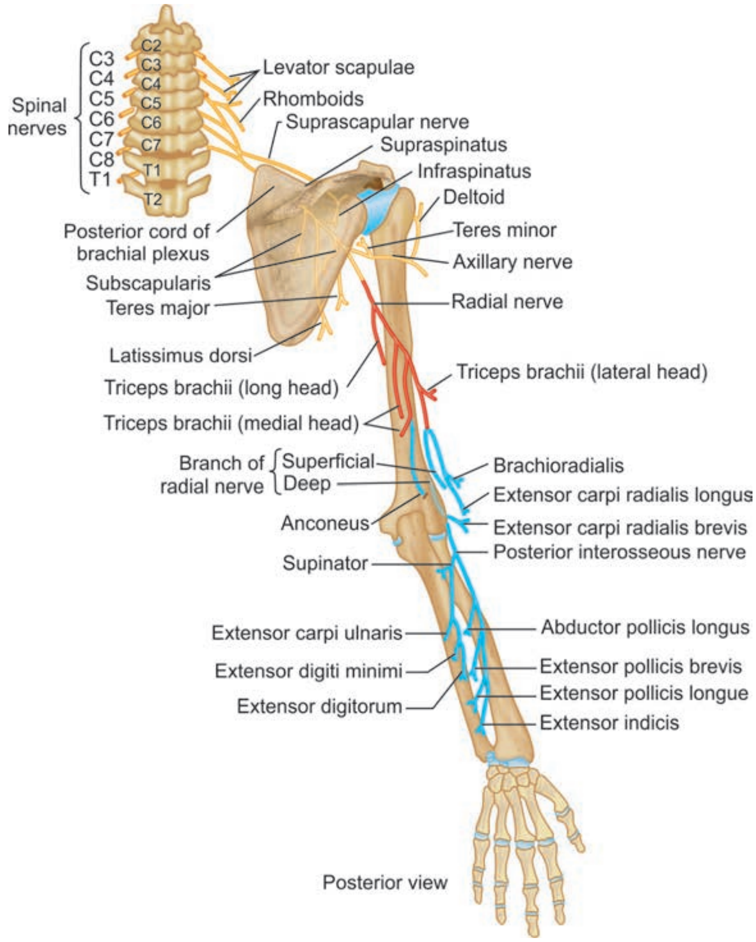


Fig. 26: Origin, course and distribution of radial nerve

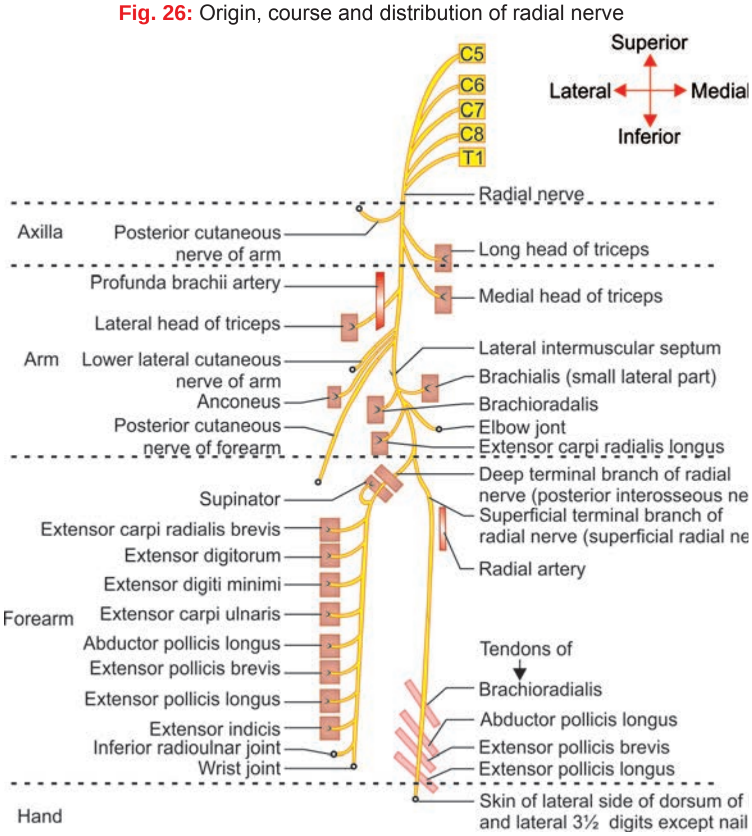


Fig. 27: Formation, course and distribution of radial nerve

Table 17: Radial nerve injuries

Site of injury	Lesion	Motor loss	Sensory loss
Axilla (Very high lesion)	• Crutch palsy • Saturday night palsy (arm draped over chair)	• Loss of elbow extension (triceps paralysis) • Wrist drop (loss of wrist extension)  • Finger drop (loss of finger extension) • Difficulty in supination*	• Over the posterior surface of the lower part of the arm and forearm • Over the lateral part of the dorsum of hand and dorsal surfaces of lateral 3½ digits (excluding the nail beds), especially a small patch on the dorsum around the anatomical snuffbox.
Spiral groove (High lesion)	• Fracture midshaft of humerus • IM injection • Saturday night palsy	• Elbow extension possible (triceps spared) • Wrist drop (loss of wrist extension) • Finger drop (loss of finger extension) • Difficulty in supination*	• Over the lateral part of the dorsum of hand and dorsal surfaces of lateral 3½ digits (excluding the nail beds), especially a small patch on the dorsum around the anatomical snuffbox.
At the elbow (Low lesion)	• Fracture/dislocations • Entrapment injury (radial tunnel syndrome)	• No wrist drop (ECRL spared)** • Finger drop (loss of finger extension) • Difficulty in supination	• No cutaneous loss

* Difficulty in supination in extended elbow (supinator and brachioradialis paralysis); supination is possible in flexed elbow (functional biceps brachii).

Wrist extension is preserved because the branch to the extensor carpi radialis longus **arises proximal to the elbow.

Note: In radial nerve injuries there is weakness of abduction and adduction of the hand (paralysed extensor carpi and ulnaris muscles).

High Yield Point

- In radial nerve injuries, extension at PIP and DIP may be possible carried out by **lumbrical and interossei** (supplied by median and ulnar nerve).

ASSESSMENT QUESTIONS

1. Which of the following is NOT seen with lower radial nerve injury? *(AIPG 2008)*
a. Weakness of brachioradialis
b. Inability to extend fingers
c. Paralysis of extensor carpi radialis brevis
d. Loss of sensations over dorsum of hand

2. All is true about Radial nerve *EXCEPT*:
a. Continuation of lateral cord of brachial plexus
b. Root value is C5,6,7,8 and T1
c. Damaged in fracture shaft of humerus
d. Cock up splint is used for its injury in radial groove

3. The following muscles are supplied by radial nerve below the spiral groove *EXCEPT*: *(JIPMER 2009)*
a. Brachialis
b. Brachioradialis
c. Extensor carpi radialis longus
d. Anconeus

4. TRUE about radial nerve: *(PGIC 2010)*
a. Branch of posterior cord
b. Nerve of extensor compartment of forearm
c. Arise from C5 to 8;T1
d. Anterior interosseous nerve is a branch
e. Supply skin of extensor compartment

5. Radial nerve passes through the radial groove, the other is: *(NEET Pattern 2014)*
a. Ulnar nerve
b. Median nerve
c. Musculocutaneous nerve
d. Lower lateral cutaneous nerve of arm

6. Division of radial nerve occurs at which level? *(NEET Pattern 2015)*
a. Anterior part of medial epicondyle
b. Anterior part of lateral epicondyle
c. Posterior part of medial epicondyle
d. Posterior part of lateral epicondyle

7. Finger drop with no wrist drop is caused by lesion of: *(NEET Pattern 2015)*
a. Radial nerve in the radial groove
b. Posterior interosseous nerve
c. Anterior interosseous nerve
d. Ulnar nerve behind medial epicondyle

8. All are affected in low radial nerve palsy *EXCEPT*: *(AIPG 2011)*
a. Extensor carpi radialis longus
b. Extensor carpi radialis brevis
c. Finger extensors
d. Sensation on dorsum of hand

9. **Injury to radial nerve in lower part of spiral groove may result in all *EXCEPT*:** *(AIIMS 2003)*
   a. Spare nerve supply to extensor carpi radialis longus
   b. Results in paralysis of anconeus muscle
   c. Leaves extension at elbow joint intact
   d. Weakens supination movement

10. **Injury to radial nerve at wrist leads to:**
   a. Wrist drop
   b. Sensory loss on dorsum of 1st web space
   c. Paralysis of adductor pollicis
   d. Loss of supination in extended position

11. **Damage to the radial nerve in the spiral groove spares which muscle?**
   a. Lateral head of biceps
   b. Long head of triceps
   c. Medial head of triceps
   d. Anconeus

ANSWERS AND EXPLANATIONS

1. **a. Weakness of brachioradialis**
   - **Lower radial nerve injury** means damage to the nerve just before its terminal divisions at the front of humeral lateral epicondyle. It **spares the brachioradialis** as it is supplied by the nerve after it exits the radial groove and the branch lies quite higher than the lateral epicondyle.
   - Radial nerve at its lower end supplies extensor carpi radialis brevis and then divides into two terminal branches.
   - Posterior interosseous nerve (**muscular**) and superficial **cutaneous** branch of radial nerve.
   - Posterior interosseous nerve supplies the finger extensors, which have got paralysed in this case.
   - The superficial cutaneous branch of radial nerve supplies the lateral **dorsum of hand**, showing sensory loss in this injury.
   - Lower radial nerve injury also leads to paralysis of extensor carpi radialis brevis as its radial branch is quite low.
   - Fracture lower end of humerus may have such type of clinical presentation.
2. **a. Continuation of lateral cord of brachial plexus**
   - Radial nerve is continuation of the **posterior cord** of brachial plexus.
   - **Lateral cord** continues as musculocutaneous nerve.
   - Radial nerve has **all the five** root values of brachial plexus (C5-8 and T1).
   - **Fracture midshaft** of humerus damagers the radial nerve in the radial groove leading to **wrist drop**, the patient is given **cock-up splint** to prevent the resulting deformities.
3. **d. Anconeus**
   - Radial nerve gives branch to anconeus muscle in the groove (**not below the groove**).
4. **a. Branch of posterior cord, b. Nerve of extensor compartment of forearm, c. Arise from C5 to 8; T1, e. Supply skin of extensor compartment**
   - Radial nerve is continuation of **posterior cord** of brachial plexus (C5-8; T1), is the nerve of posterior compartment in upper limb (muscles and skin). It gives posterior (**and not anterior**) interosseous nerve to supply muscles of posterior forearm.
5. **d. Lower lateral cutaneous nerve of arm**
   - Two cutaneous nerves, the **lower lateral cutaneous nerve of the arm** and the **posterior cutaneous nerve of the forearm** are given by radial nerve in the radial groove.
6. **b. Anterior part of lateral epicondyle**
   - Radial nerve reaches cubital fossa and **in front of the lateral condyle of humerus** divides into two terminal branches.
7. **b. Posterior interosseous nerve**
   - Injury to posterior interosseous nerve results in paralysis of extensor muscles in the posterior forearm.
   - **Finger drop** (loss of finger extension at metacarpophalangeal joint) occurs, along with weakening of wrist extension.
   - Wrist extension is still possible (**no wrist drop**) because of the functional ECRL (Extensor Carpi Radialis Longus) muscle, a powerful wrist extensor, already supplied by a branch of radial nerve proximal to the site of injury.
8. **a. Extensor carpi radialis longus**
   - **Low radial nerve injuries** occur *around the elbow joint* (e.g., fracture humerus at lower end) and may spare the ECRL (Extensor Carpi Radialis Longus) muscle.
   - All the muscles supplied by radial nerve distal to the lesion get paralysed and there is sensory loss over the dorsum of hand.
9. **a. Spare nerve supply to extensor carpi radialis longus**
   - Injury to **radial nerve** in lower part of radial groove results in paralysis **(not** sparing**)** of ECRL (Extensor Carpi Radialis Longus).
   - The muscle **spared is triceps**, and **elbow extension** is still possible.
   - **Anconeus** may (or may not) be paralysed, depending upon the involvement of the branch in the fracture.
   - Supinator muscle is paralysed, hence there will be **difficulty in supination**.
10. **b. Sensory loss on dorsum of 1st web space**
    - Radial nerve gives has no motor fibres at the level of wrist, hence there will be only sensory disturbances in this patient. Radial nerve divides into 2 terminal branches at the elbow joint: **Deep muscular** - posterior interosseous nerve (PIN) and **Superficial – cutaneous branch** supplying the dorsum of hand especially first web space.
    - Superficial cutaneous branch of radial nerve passes on the roof of anatomical snuff box, and is **the nerve injured at wrist**.
    - Wrist drop occurs due to the injury of main trunk of radial nerve before it divides into terminal branches.
    - Supination in extended position of elbow is carried out by the supinator which is supplied by the posterior interosseous nerve (deep branch of radial nerve given at elbow joint).
11. **b Long head of triceps > c. Medial head of triceps**
    - Radial nerve in radial groove gives branches to **long head of triceps** and **medial head of triceps** as well.

Median Nerve

- **Median nerve** is formed by the union of the lateral root (C5, 6, 7) from the **lateral cord**, and the medial root (C8, T1) from the **medial cord**, which meet **anterior** to the third part of the axillary artery.
- It enters the arm at the lower border of teres major, **initially** lies lateral to brachial artery and **then crosses in front** of the artery from lateral to medial side **at the level of midhumerus** (i.e., level of insertion of coracobrachialis).
- After crossing, it runs downwards to **enter cubital fossa**, lies medial to the brachial artery and tendon of biceps brachii and gives muscular branches to supply all the superficial flexors of the forearm (flexor carpi radialis, palmaris longus, and flexor digitorum superficialis) **except** flexor carpi ulnaris. It leaves the fossa by passing between the two heads of **pronator teres** and gives off anterior interosseous nerve.
- **Anterior interosseous nerve** is a pure motor nerve, accompanied by the anterior interosseous vessels, dives deeply to pass down **along the interosseous membrane** and supplies 2½ muscles: Flexor pollicis longus, pronator quadratus and **lateral half** of the flexor digitorum profundus (FDP).
- In the forearm, the **median nerve** runs deep to the flexor digitorum superficialis (FDS). About 5 cm proximal to the flexor retinaculum, it emerges from the lateral side of the FDS and becomes superficial, **lying lateral to the tendons of FDS** and palmaris longus.
- The **palmar cutaneous nerve** arises about 3-7 cm proximal to the flexor retinaculum (and proximal wrist crease), passes lateral to the main nerve and **superficial to the flexor retinaculum** to supply the skin over the thenar eminence and lateral aspect of the palm.

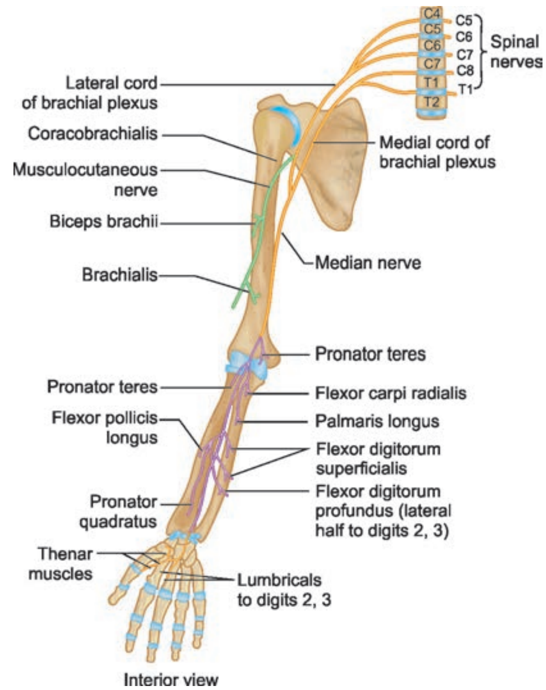


Fig. 28: Origin, course and distribution of musculocutaneous and median nerves

- Median nerve enters the palm by passing through carpal tunnel where it lies **deep to flexor retinaculum** and superficial to the tendons of FDS, FDP, and FPL and their associated ulnar and radial bursae.
- In the palm, the median nerve divides into lateral and medial divisions. The lateral division gives a **recurrent branch**, which curls upwards to supply thenar muscles except the deep head of flexor pollicis brevis.
- It gives five **palmar digital nerves** which supply first and second lumbricals and skin of the palmar aspect of the lateral 3½ digits and skin on the dorsal aspect of distal phalanges (**nail beds**).

Median nerve is also called as **Labourer's nerve** as it supplies the anterior forearm muscles and anterior thumb muscles. These muscles help to **push, pull, lift heavy loads** by the labourers and if the nerve is damaged they are helpless to carry out all such movements.

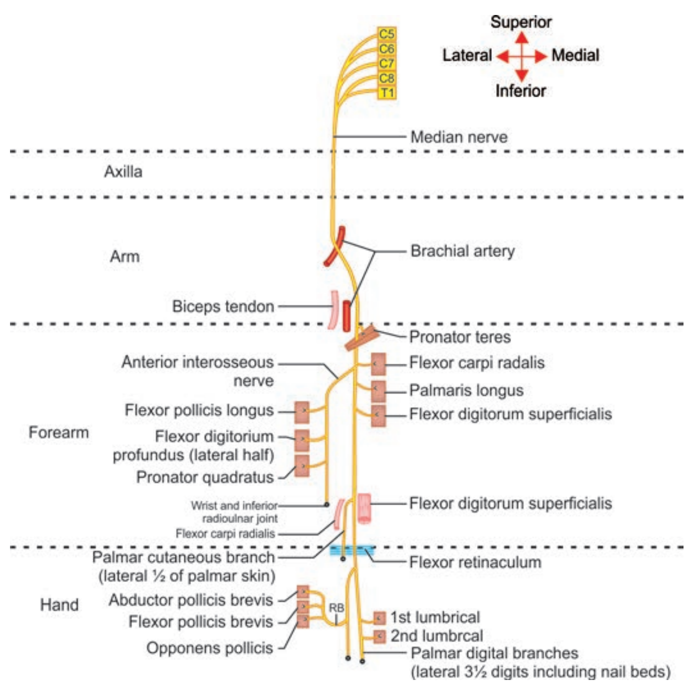


Fig. 29: Formation, course and distribution of median nerve

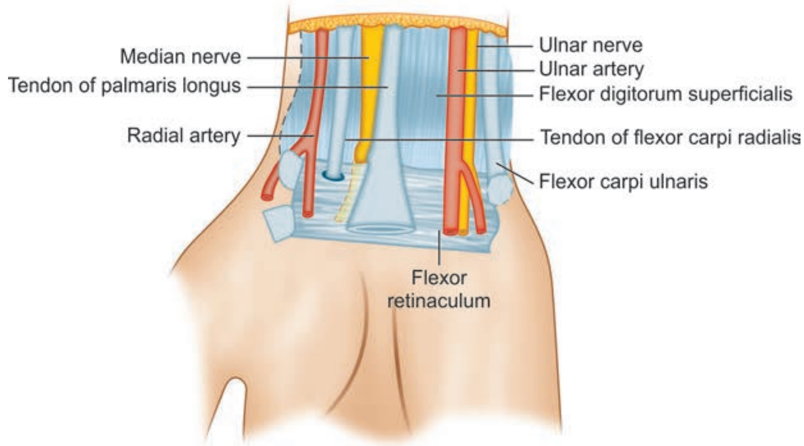


Fig. 30: Median nerve at wrist

Table 18: Median nerve injuries

Site of injury	Lesion	Motor loss	Sensory loss/disturbance
• Around Elbow (high lesion)	• Supracondylar fracture of humerus • Pronator teres Syndrome (entrapment between two heads)	• Forearm in supine position (paralysed pronator teres). • Weak wrist flexion (paralysed forearm flexors except medial half of FDP and flexor carpi ulnaris) • Ulnar deviation on attempted flexion (paralysed FCR and unopposed FCU) • Loss of interphalangeal flexion at index and middle fingers - Benediction hand* • Pointing index finger (Ochsner's clasping test)** • Loss of flexion of terminal phalanx of thumb (paralysed flexor pollicis longus) • Pinch defect (instead of pinching with the thumb and index fingertips flexed, the distal joints stay in full extension) • Paralysis of two lumbricals (index and middle fingers) and thenar muscles • Ape thumb deformity***	• Lateral half of the palm • Lateral 3½ digits (nail beds included)
• Distal forearm/Wrist	• Wrist slash injury/suicidal attempts	• Paralysis of two lumbricals (index and middle fingers) and thenar muscles • Ape thumb deformity	• Lateral half of the palm • Lateral 3½ digits (nail beds included)
• Carpal tunnel (syndrome)	• Tenosynovitis of flexor tendons due to repeat stress injury (e.g., data entry) • Myxedema (deficiency of thyroxine) • Oedema in pregnancy • Anterior dislocation of lunate bone • Osteoarthritis at wrist • Rheumatoid arthritis	• Paralysis of two lumbricals (index and middle fingers) and thenar muscles • Ape thumb deformity (later stages)	• Lateral 3½ digits (nail beds included) • No sensory loss over the lateral half of the palm (palmar cutaneous branch is spared)

*__Benediction hand__: When patient attempts to make a fist, the index and middle fingers remain straight (loss of flexion at PIP and DIP joints due to paralysed superficial and deep flexors).

**__Pointed index finger__: When the patient is asked to clasp both his hands. The index finger on the affected side will stand pointing out instead of being flexed.

***__Ape thumb deformity__ presents with thenar atrophy and thumb remains laterally rotated and adducted (paralyzed thenar muscles and intact adductor pollicis).

Note: Division of the median nerve **distal** to the origin of its palmar cutaneous branch, arises 3 and 7 cm proximal to the flexor retinaculum, leave intact the sensation over the thenar eminence and radial side of the proximal part of the hand.

- **Benediction hand deformity**
  - It may result due to median nerve injury. **While trying to make a fist**, patient can only partially flex index and middle finger.

- The ability to flex the digits 2–3 at the metacarpophalangeal joints is **lost** as is the ability to flex the proximal and distal interphalangeal joints. This is due to the loss of innervation of the **lateral 2 lumbricals** of the hand and the **lateral half of the flexor digitorum profundus** which are supplied by the median nerve.
- Flexion at the proximal interphalangeal joints of digits 4–5 is **weakened**, but flexion at the metacarpophalangeal joints and distal interphalangeal joints remains **intact**.
- The extensor digitorum is left **unopposed** and the metacarpophalangeal joints of **digits 2–3 remain extended** while attempting to make a fist.

Fig. 31: Benediction hand deformity

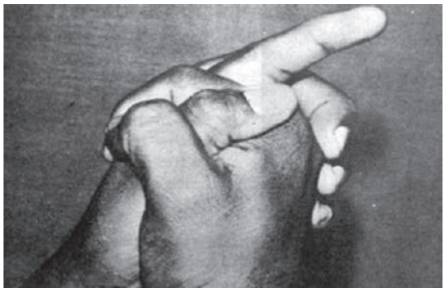


Fig. 32: Ochsner's clasping test

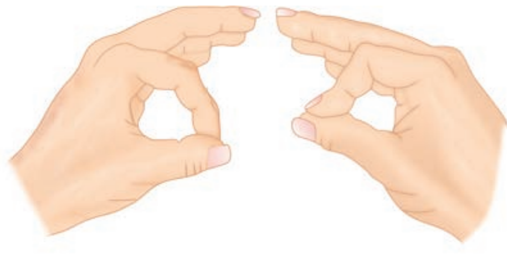


Fig. 33: Clinical testing for median nerve injury

Note: Some authors use the term '**hand of benediction**' to include both the condition described above and **ulnar clawing**, which is a common source of confusion. Both signs have similar presentations, but the term '**hand of benediction**' more frequently refers only to damage to the median nerve and is seen with attempted flexion of all the digits (leaving the 2nd and 3rd digits extended), while '**ulnar claw**' refers exclusively to damage to the ulnar nerve and is seen with attempted extension of all the digits (leaving the 4th and 5th digits flexed).

Table 19: Camparative analysis between ulnar claw hand and hand of benediction

	Ulnar claw	Hand of benediction
Nerve involved	Lesion of ulnar nerve at the wrist	Lesion of the median nerve at the elbow or at the wrist
Typical presentation	Appears in long standing cases	Appears when patient attempts to make a fist
Digits affected	Little and ring	Middle and index
Muscles paralysed	• Medial two lumbricals	• Lateral two lumbricals • Lateral half of the FDP
Movements involved	Unopposed extension t the MCP joints Unopposed flexion at the IP joints	***Inability*** to flex at the MCP and IP joints of the middle and index fingers ***Voluntary*** flexion at the MCP and IP joints of the ring and little fingers

- **Ochsner's clasping test** assesses the function of the median nerve for lesions in the cubital fossa or above, by testing for the function of long flexors to index finger (flexor digitorum superficialis and profundus). When the **patient is asked to clasp both his hands**, the index finger on the affected side will stand **pointing out** instead of being flexed.
- **Pinch defect**: Instead of pinching with the thumb and index fingertips flexed, the distal joints **stay in full extension**. It is observed in median nerve injury, due to **paralysis of long flexors** to thumb and digits.
- **Carpal tunnel syndrome**
  - It is caused by compression of the median nerve due to the reduced size of the osseofibrous carpal tunnel, resulting from **inflammation or thickening** of the synovial sheaths of the flexor tendons (tenosynovitis) due to repeat stress injury (e.g., data entry), inflammation of the flexor retinaculum, or arthritic changes in the carpal bones (particularly rheumatoid arthritis).
  - It is usually **idiopathic** though it is associated with soft tissue thickening, as may occur in **myxoedema** and **acromegaly**; it may also be associated with oedema, obesity or **pregnancy**. Anterior dislocation of lunate may compress the median nerve leading to features of carpal tunnel syndrome.
  - It leads to pain and paresthesia (tingling, burning, and numbness) in the hand in the area supplied by the median nerve, **worse at night** and on gripping objects. It may also lead to **atrophy** of the thenar muscles in cases of severe compression. However, **no paresthesia occurs over the thenar eminence** of skin because this area is supplied by the palmar cutaneous branch of the median nerve, **already given** before the nerve enters tunnel.
  - The structures that pass **through the carpal tunnel** include the flexor digitorum superficialis tendons, flexor digitorum profundus tendons, flexor pollicis longus tendon, and median nerve. No arteries pass through the carpal tunnel.

- **Clinical signs** include sensory loss on the palmar aspects of the index, middle, and half of the ring fingers and palmar aspect of the thumb. Patient presents with **ape thumb deformity**, **Tinel** & **Phalen test** are positive (see following sections for detail). Treatment is usually **surgical decompression** of the nerve by dividing the flexor retinaculum, if conservative management (like splinting at night) fails.

- **Phalen test**: The size of the carpal tunnel is **reduced** by holding the affected hand with the wrist fully flexed or extended for 30 to 60 seconds, or by placing a sphygmomanometer cuff on the involved arm and inflating to a point between diastolic and systolic pressure; appearance of numbness or paresthesia indicates **carpal tunnel syndrome**.

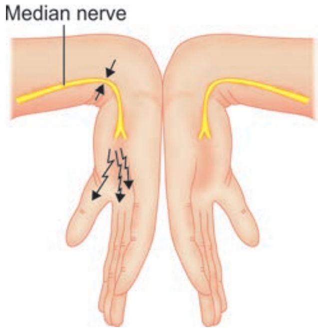


Fig. 34: Phalen test

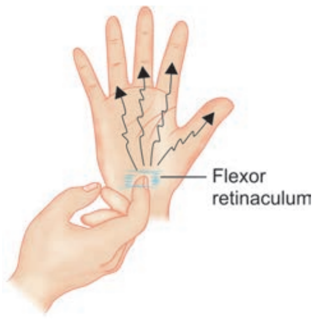


Fig. 35: Tinel's sign

Fig. 36: Ape thumb deformity

- **Tinel's sign**: In nerve injuries, **percussion** of the skin over a nerve in which axons have been ruptured evokes sensations like a wave or surge of pins and needles into the cutaneous distribution of the nerve. Tinel's sign can be detected for 'motor' nerves (like posterior interosseous nerve) as well - the sensory symptoms radiate into muscular territory rather than into skin. It indicates a **partial** lesion or the **beginning regeneration** of the nerve.
- **Ape thumb deformity** (median nerve injury) presents with **thenar atrophy** and thumb remains laterally rotated and adducted (**paralysed** abductor pollicis brevis and opponens pollicis; **intact** adductor pollicis).
- **Wrist slash injury** (suicidal attempts)
  - A deep laceration on the radial side of the wrist may cut the following structures: Radial artery, **median nerve**, flexor carpi radialis tendon, and palmaris longus tendon.
  - A deep laceration on the ulnar side of the wrist may cut the following structures: Ulnar artery, **ulnar nerve**, and flexor carpi ulnaris tendon.

ASSESSMENT QUESTIONS

1. All is true about carpal tunnel syndrome *EXCEPT*:
a. Most common entrapment mononeuropathy
b. Rheumatoid arthritis is a cause
c. Wasting and weakness of adductor pollicis
d. Numbness in lateral 3½ fingers

2. A patient is trying to make a fist, but can only partially flex index and middle finger. Which nerve is damaged most probably? *(AIIMS; JIPMER pattern 2016)*
a Median
b Ulnar
c Radial
d Anterior interosseous nerve

3. Carpal tunnel syndrome caused by all *EXCEPT*: *(AIIMS)*
a. Hypothyroidism
b. Addison's disease
c. Diabetes mellitus
d. Amyloidosis

4. Median nerve supplies all *EXCEPT*: *(JIPMER 2012)*
a. Adductor pollicis
b. Abductor pollicis
c. Opponens pollicis
d. Flexor pollicis brevis

5. Median nerve injury at wrist, is commonly tested by:
a. Contraction of abductor pollicis brevis
b. Contraction flexor pollicis brevis
c. Contraction opponens pollicis
d. Loss of sensation on palm

6. One of the following is supplied by median nerve: *(JIPMER 2009)*
a. 1st and 2nd lumbricals
b. Hypothenar muscles
c. Palmar interossei
d. Dorsal interossei

7. Median nerve lesion cause paralysis of all of the following *EXCEPT*: *(AIPG 2010)*
a. Thenar muscles
b. Adductor pollicis
c. Lumbrical index finger
d. Lumbrical middle finger

8. Which of the following muscle is supplied by median nerve? *(PGIC 2016)*
a. Opponens pollicis
b. Adductor pollicis
c. Lateral half of the flexor digitorum profundus
d. Superficial head of flexor pollicis brevis
e. Deep part of flexor pollicis brevis

ANSWERS AND EXPLANATIONS

1. c. Wasting and weakness of adductor pollicis
- Carpal tunnel syndrome results in median nerve injury and **not** ulnar nerve (adductor pollicis is not affected).

2. a. Median
- Median nerve injury leads to 'benediction hand' deformity.

3. b. Addison's disease
- **Addison's disease** has not been co-related with carpal tunnel syndrome in clinical studies.
- **Hypothyroidism** leads to Myx-oedema, and leads to increase in the thickness (myxomatous) of tendons passing under the flexor retinaculum. This compromises the carpal tunnel space, leading to compression of the median nerve passing through it.
- **Diabetes mellitus** leads to nerve pathology, makes them weak and fragile, hence prone to any compression injury (including carpal tunnel syndrome).
- Amyloid deposits make the space of carpal tunnel compromised, thus predisposing to median nerve compression under the flexor retinaculum.

4. a. Adductor pollicis
- Adductor pollicis is supplied by ulnar nerve.

5. a. Contraction of abductor pollicis brevis
- Median nerve injury at wrist is commonly subjected to **pen test**—the patient lies his hand flat on a table with his palm facing upwards.
- The patient is asked to abduct his thumb to touch the examiner's pen which is held above it. This test is for the function of **abductor pollicis brevis**, supplied by median nerve.
- Flexor pollicis brevis and opponens pollicis have dual nerve supply: supplied by median and ulnar nerve.

6. a. 1st and 2nd lumbricals
- Median nerve supplies the **lateral two lumbricals**. All the **interossei** muscle are solely supplied by ulnar nerve.

7. b. Adductor pollicis
- **Adductor pollicis** is supplied by the ulnar nerve hence will be spared in median nerve injury.
- Thenar muscles are mainly supplied by the median nerve and its damage leads to their paralysis.
- Lumbricals of the index finger and middle finger are supplied by median nerve and hence they are found paralysed in this patient.

8. a. Opponens pollicis; c. Lateral half of the flexor digitorum profundus; d. Superficial head of flexor pollicis brevis
- **Opponens pollicis** is usually mentioned to innervated by the lateral terminal branch of the median nerve (but **Gray's anatomy** mentions that it also receives a branch of the deep terminal branch of the ulnar nerve).
- Adductor pollicis is supplied by ulnar nerve.
- Lateral half of the Flexor digitorum profundus is supplied by the median nerve, whereas ulnar nerve supplies the medal half.
- The superficial head of **flexor pollicis brevis** is innervated by the lateral terminal branch of the median nerve and the deep part by the deep branch of the ulnar nerve.

Ulnar Nerve

- **Ulnar nerve** is the continuation of the **medial cord** of brachial plexus (**C8 and T1**) and receives a contribution from the ventral ramus of **C7** (which supply flexor carpi ulnaris).
- It does not give any branch in the axilla and in the arm. In the axilla it lies **medial** to third part of axillary artery (between axillary artery and vein).
- In the arm, it runs distally along the medial side of the brachial artery up to the **midarm** (level of insertion of coracobrachialis), inclines posteromedially to **perforate** the medial intermuscular septum (10 cm proximal to the medial epicondyle) and passes through a fibrous canal, the 'a**rcade of Struthers**' (length-5 cm).
- The walls of the canal include the medial intermuscular septum and the fascial sheath investing the medial head of triceps brachii. It is accompanied by the **superior collateral ulnar vessels** in the lower third of the arm and distally by the **posteroinferior ulnar collateral vessels**.
- Behind the **medial epicondyle**, it is lodged in a groove where it can be easily palpated. The groove is converted into '**cubital tunnel**' by a fibrous band extending between medial epicondyle and olecranon process. The **ulnar nerve** crosses the ulnar collateral ligament in the **floor** of the tunnel.
- It enters the forearm by passing **between** the two heads of flexor carpi ulnaris, descend down in the forearm with ulnar artery on the lateral side.
- **Branches**
  - In **upper** forearm: Flexor carpi ulnaris, and medial half of flexor digitorum profundus.
  - In **distal** forearm: Dorsal cutaneous branch (given 6 cm proximal to the wrist), supply dorsum of medial third of the hand and medial 1½ fingers.
  - Near the wrist: Palmar cutaneous branch, passes superficial to flexor retinaculum & supply hypothenar eminence.

- Ulnar nerve pass **superficial** to the flexor retinaculum lying just lateral to the pisiform, covered by a fascial band (volar carpal ligament) through the **Guyon's ulnar tunnel.** Just distal to pisiform, the ulnar nerve divides into its terminal superficial and deep branches.
  - The **superficial** terminal branch supplies palmaris brevis and provide sensory innervation to the skin on the palmar surface of medial 1½ fingers.
  - The **deep** branch of ulnar nerve runs laterally within concavity of deep palmar arterial arch, is purely motor and supplies all the intrinsic muscles of the hand (except first two lumbricals & abductor pollicis brevis).

Ulnar nerve is called as '**musician's nerve**' as it innervates most of the intrinsic muscles involved in the **fine intricate** finger movements for playing musical instruments.

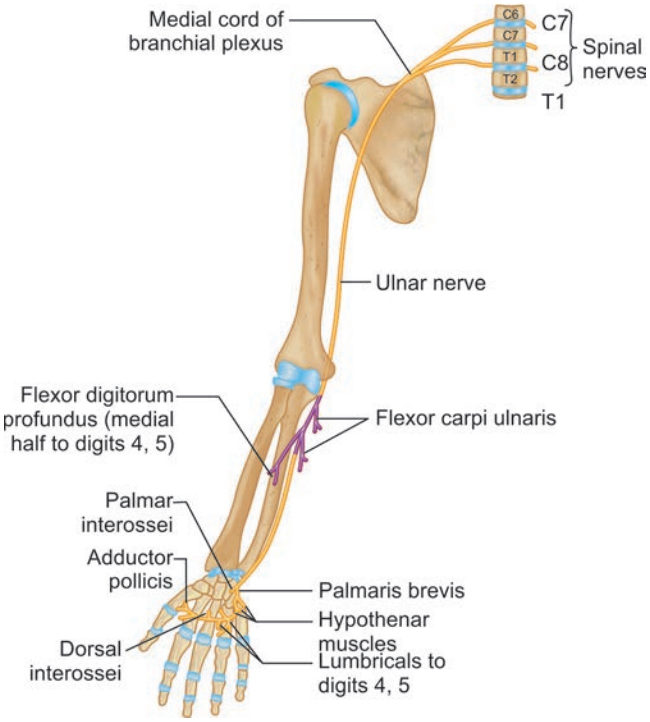


Fig. 37: Origin, course and distribution of ulnar nerve

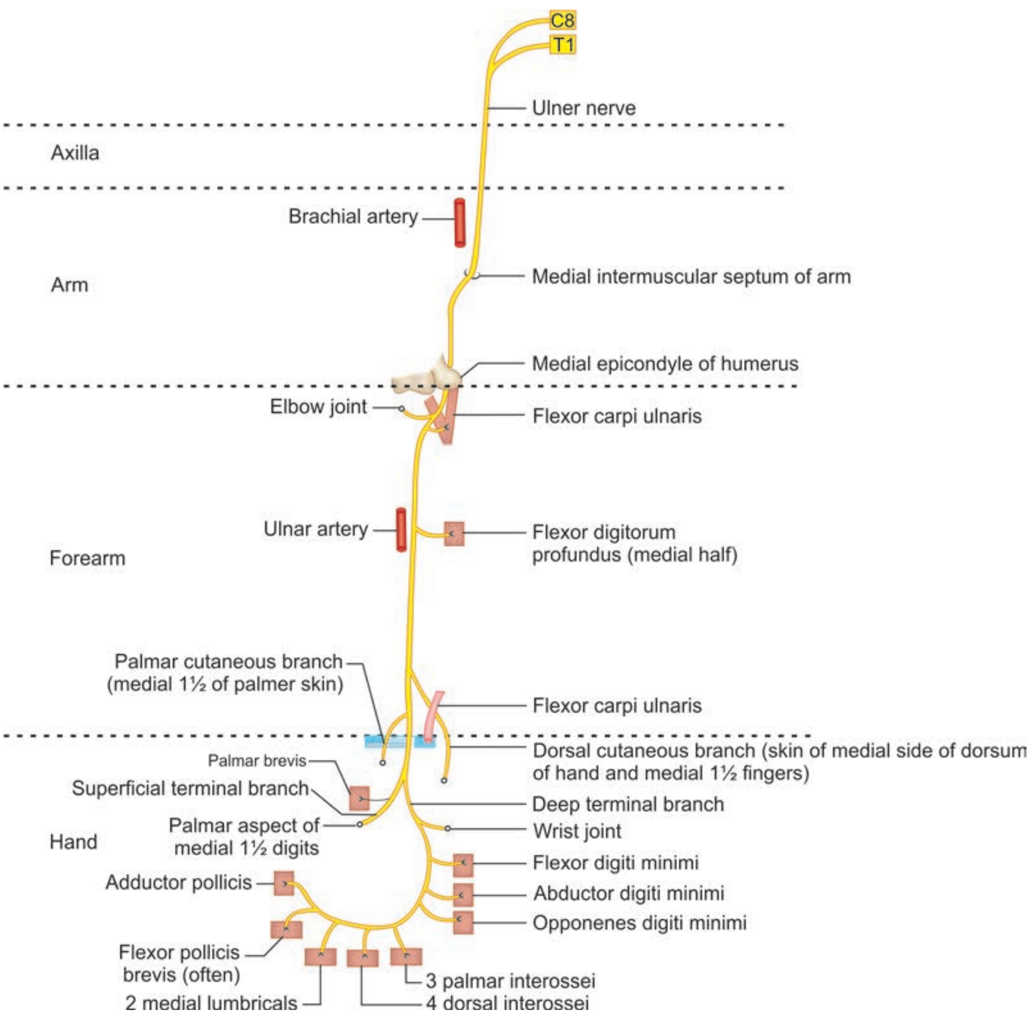


Fig. 38: Formation, course and distribution of the ulnar nerve

Table 20: Ulnar nerve injuries

Site of injury	Lesion	Motor loss	Sensory loss/disturbance
Elbow (high lesion)	• Fracture/dislocation of the medial epicondyle (humerus) • Cubital tunnel syndrome • Compression between the two heads of flexor carpi ulnaris • Tardy ulnar nerve palsy (valgus deformity)	• Claw-hand deformity*  • Hypothenar and interosseous wasting • Loss of – Abduction and adduction of the fingers (card test positive) – Flexion of the metacarpophalangeal joints – Adduction of the thumb (Froment sign positive) • Weakness of wrist flexion (hand deviates to radial side upon flexion)	• Over the palmar and dorsal surfaces of medial third of the hand and medial 1½ fingers (little finger and the ulnar half of the ring finger)
Wrist (low lesion)	• Wrist laceration/slashing • Guyon's canal syndrome	• Claw hand deformity (more pronounced)** • Hypothenar and interosseous wasting • Loss of – Abduction & adduction of the fingers (card test positive) – Adduction of the thumb (Froment sign positive)	• Over the palmar and dorsal surfaces of medial 1½ fingers (little finger and the ulnar half of the ring finger) • No sensory loss over the ulnar aspect of the dorsum of the hand (dorsal cutaneous branch is spared)

*__Claw-hand deformity__ (main en griffe) affecting ring and little fingers. Extension at metacarpophalangeal joint & flexion at the interphalangeal joints.

Claw hand deformity is **more pronounced in low injury, since FDP (flexor digitorum profundus) is not paralysed; therefore there is a marked flexion of DIP joints. The sensation over the ulnar aspect of the dorsum of the hand is **spared** because the dorsal branch of the ulnar nerve is given off approximately 5 cm proximal to the wrist joint.

- **Cubital tunnel syndrome**
  - It may results from **compression on the ulnar nerve** in the cubital tunnel behind the medial epicondyle, causing **numbness and tingling** in the ring and little fingers.
  - The cubital tunnel is formed by the **medial epicondyle**, ulnar collateral ligament, and two heads of the flexor carpi ulnaris, and transmits the ulnar nerve and **superior ulnar collateral artery**.
- **Guyon's canal** (pisohamate tunnel)
  - It is a fibro-osseous canal, 4 cm long, on the anteromedial side of the wrist for passage of **ulnar artery and nerve** into the hand.
    - **Ulnar** boundary: Pisiform bone, flexor carpi ulnaris and abductor digiti minimi
    - **Medial** boundary: Hook of hamate, extrinsic flexor tendons, the transverse carpal ligament.
    - **Roof**: Palmar carpal ligament and palmaris brevis.
    - **Floor**: Flexor retinaculum and pisohamate ligaments (more distally, pisometacarpal ligaments and flexor digiti minimi)
    - **Contents**: Ulnar nerve and artery
  - Ulnar nerve **divides within it** at the level of the hook of the hamate into a **deep, lateral motor** branch and a **superficial, medial sensory** branch. If the nerve is compressed in the tunnel, both modalities will be affected.
  - **Guyon's canal syndrome**
    - Entrapment of the **ulnar nerve** in the Guyon's canal, causing pain, numbness, and tingling in the ring and little fingers, and motor weakness in later stages.
    - It is seen in cases of prolonged pressure upon the outer part of the palm like long distance **cyclists** and road workers using **vibrating drills**. It can be treated by **surgical decompression** of the nerve.
- **Froment's sign**
  - The patient is instructed to grasp a book/paper **between the thumb and index finger**. Normally he grasps the book firmly with thumb extended, taking full advantage of the **adductor pollicis** and the first dorsal interosseous muscles.
  - In ulnar nerve **injury**, powerful flexion of the thumb interphalangeal joint signals **weakness of adductor pollicis** and first dorsal interosseous with overcompensation by the flexor pollicis longus (supplied by median nerve).

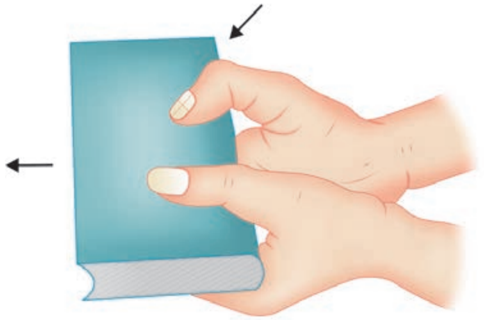


Fig. 39: Froment's sign (book test)

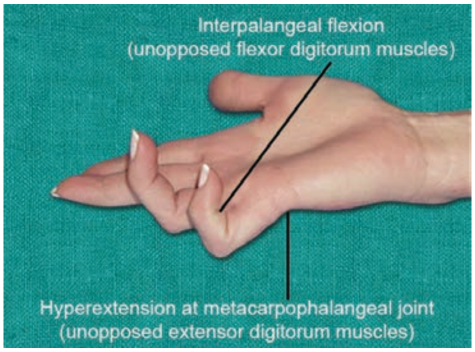


Fig. 40: Ulnar claw hand

Ulnar Claw Hand

- Injury to ulnar nerve presents with ulnar claw hand: **hyperextension** of metacarpophalangeal and **flexion** of interphalangeal joints of ring and little finger.
- Ulnar nerve supplies medial 2 lumbricals (ring and little finger) in the hand. Lumbricals have a combined action of MCP (Metacarpophalangeal) flexion and IP (Interphalangeal) extension (glass holding posture).
- In **ulnar nerve injury**, since the lumbricals are not functional, the **forearm muscles are unopposed**. MCP joint goes into **hyperextension** (unopposed activity of extensor digitorum muscles, posterior forearm) and IP joints go into **flexion** (unopposed activity of flexor digitorum muscles, anterior forearm) and they bring the deformity called **ulnar claw hand**.

Ulnar Paradox

- The **higher** the lesion of the ulnar nerve injury, the **less prominent** is the deformity and vice versa, because in higher lesions the long finger flexors are also paralysed (which were causing interphalangeal flexion/clawing). The loss of finger flexion makes the deformity look less obvious/less clawing.
- Ulnar nerve injury at wrist causes '**more**' clawing (severe interphalangeal flexion deformity, due to unopposed flexor digitorum profundus).
- Ulnar nerve injury at elbow paralyses flexor digitorum profundus and leads to '**less**' clawing (less interphalangeal flexion deformity).

This is known as the '**ulnar paradox**' – normally we would **expect** a more pronounced deformity, due to ulnar nerve injury at elbow (as compared with wrist level) but in fact the **opposite** is observed.

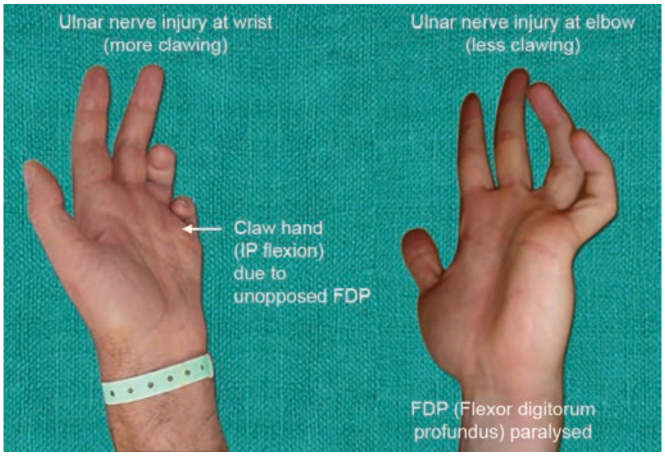


Fig. 41: Ulnar paradox

Simply put, as **reinnervation** occurs along the ulnar nerve after a high lesion, the deformity will get **worse** (FDP reinnervated) as the patient recovers - hence the use of the term 'paradox'.

ASSESSEMENT QUESTIONS

1. All are true about ulnar nerve *EXCEPT*: *(PGIC 2014)*
   a. Root value C8;T1
   b. Pass through flexor digitorum superficialis
   c. Supply flexor digitorum superficialis
   d. Supply flexor carpi ulnaris
   e. Passes behind medial epicondyle

2. In arm ulnar nerve gives muscular branch to which muscle? *(NEET Pattern 2013)*
   a. FCU
   b. FDP
   c. Both
   d. None

3. FALSE regarding ulnar nerve is: *(PGIC 2014)*
   a. C7 fibers arise from lateral cord
   b. Root value: C7,8; T1
   c. No branch in arm
   d. Passes between supinator heads
   e. Lies superficial to FDP and flexor retinaculum

4. Froment test is to check which muscle?
   a. Opponens pollicis
   b. Flexor pollicis brevis
   c. Flexor pollicis longus
   d. Adductor pollicis

5. Ulnar paradox means: *(NEET Pattern 2016)*
   a. High level injury- less severe claw hand
   b. Low level injury -less severe claw hand
   c. High level injury- more severe claw hand
   d. Low level- more severe claw hand

6. Ulnar injury in the arm leads to all *EXCEPT*: *(AIIMS 2007)*
   a. Sensory loss of the medial 1/3rd of the hand
   b. Weakness of the hypothenar muscles
   c. Claw hand
   d. Adduction of thumb

7. Superficial branch of ulnar nerve supplies: *(JIPMER 2010, 13)*
a. Palmaris brevis
b. Abductor pollicis
c. Abductor digiti minimi
d. Opponens pollicis

8. TRUE about Guyon's canal: *(PGIC 2011)*
a. Convey ulnar nerve
b. Lies at wrist
c. Lies behind medial epicondyle
d. Located between 2 heads of pronator teres
e. Located between 2 heads of flexor carpi ulnaris

ANSWERS AND EXPLANATIONS

1. b. Pass through flexor digitorum superficialis; c. Supply flexor digitorum superficialis
- Ulnar nerve carries the root value C(7),8;T1. It Passes through the cubital tunnel behind the medial epicondyle and enters the forearm by passing between the two heads of flexor carpi ulnaris and innervates it. It doesn't pass through or supply flexor digitorum superficialis.

2. d. None
- Ulnar nerve supplies flexor carpi ulnaris (FCU and medial half of flexor digitorum profundus (FDP) in the forearm, not in the arm.

3. d. Passes between supinator heads
- Ulnar nerve is the continuation of medial cord (C8; T1), may receive C7 fibres from lateral cord.
- It gives no branch in arm, enters the forearm by passing between the two (humeral and ulnar) heads of origin of flexor carpi ulnaris, descends on the medial side of forearm lying superficial to flexor digitorum profundus and deep to flexor carpi ulnaris, runs with ulnar artery to pass superficial to flexor retinaculum to enter the palm.

4. d. Adductor pollicis
- **Froment sign:** Abnormal flexion of the **distal phalanx** of the thumb when a sheet of paper is held between the thumb and the radial surface of the index finger; a sign of a lesion of the **ulnar nerve**.
- Froment sign indicates thumb **adductor weakness** and consists of **flexion of the thumb** at the interphalangeal joint when attempting to oppose the thumb against the lateral border of the second digit.

5. a. High level injury- less severe claw hand
- Ulnar paradox—The higher the lesion of the median and ulnar nerve injury, the less prominent is the deformity and vice versa, because in higher lesions the long finger flexors are also paralysed (which were causing interphalangeal flexion/clawing).
- The loss of finger flexion makes the deformity look less obvious/ less clawing.

6. d. Adduction of thumb
- **Ulnar nerve** supplies the Adductor pollicis muscle and hence it will be paralysed in its lesion.
- Hence, adduction of thumb is not a clinical finding in ulnar nerve palsy.

7. a. Palmaris brevis
- The superficial branch of ulnar nerve in hand supplies palmaris brevis muscle and palmar aspect of medial 1 1/2 fingers.

8. a. Convey ulnar nerve, b. Lies at wrist
- Guyon's canal is present at the wrist to allow passage of ulnar nerve and artery into the hand. Lies between pisiform bone and hook of hamate (also called pisohamate tunnel). Entrapment of the ulnar nerve in the pisohamate tunnel (Guyon's canal) is often seen in long-distance cyclists who lean with the pisiform pressing on the handlebars.

High Yield Points

- The medial part of the elbow where ulnar nerve passes behind medial epicondyle of humerus is termed '**funny bone**' because as it hits a hard surface, tingling funny sensations is felt along the ulnar side of the forearm and hand.
- Ulnar nerve **division at the wrist** paralyses all the intrinsic muscles of the hand (apart from the radial two lumbricals, abductor pollicis brevis, and part of flexor pollicis brevis and opponens pollicis).

CUTANEOUS INNERVATION

- Developmentally, **radius bone** is a **preaxial bone** and ulna is postaxial. Similarly, **radial artery** is preaxial along with **cephalic vein**, whereas ulnar artery is postaxial along with the basilic vein.

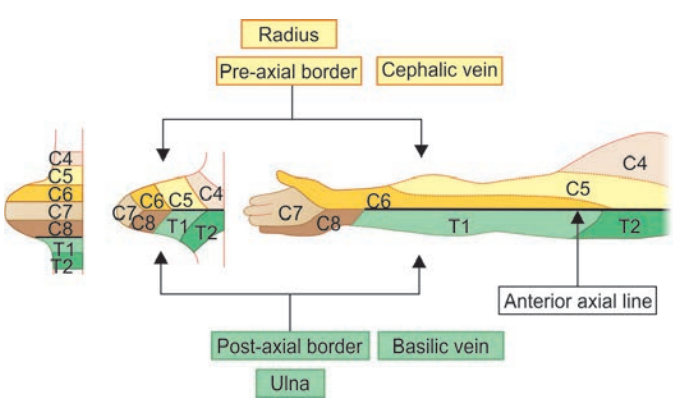


Fig. 42: Upper limb dermatome developmental pattern

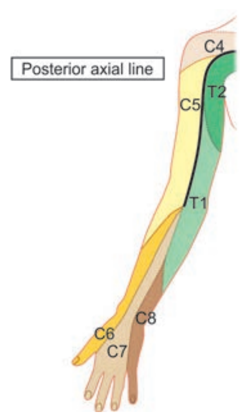


Fig. 43: Dermatomal pattern of upper limb

- The **anterior axial line** reaches till the **wrist joint**, whereas posterior axial lines stops at the elbow joint.
- Five root values of brachial plexus (C5-8; T1) are pulled into the upper limb bud and distributed in a definite **segmental pattern**.
- Lateral aspect of upper limb (**superior aspect** of the abducted arm) has **upper dermatomes** (C-5,6) and medial (inferior aspect of abducted arm) has lower dermatomes (C-8; T1).

Table 21: Dermatomal pattern

Spinal segment/Nerve	Dermatomal area
C3, 4	Region at the base of neck, extending laterally over tip of shoulder
C5	Lateral aspect of arm (superior aspect of the abducted arm)
C6	Lateral forearm and thumb
C7	Middle three fingers and centre of posterior aspect of forearm
C8	Little finger, medial side of hand and forearm (inferior aspect of abducted arm)
T1	Medial aspect of the forearm and arm
T2	Medial aspect of arm and axilla

Note: Angina pain is felt radiating down the **medial side** of the left arm (T1,2).

Table 22: Cutaneous nerves of upper limb

Cutaneous nerve	Contributing spinal nerves	Source	Course and distribution
Supraclavicular nerves	C3, C4	Cervical plexus	Pass anterior to clavicle, immediately deep to platysma, and supply skin over clavicle and superolateral aspect of pectoralis major
Superior lateral cutaneous nerve of arm	C5, C6	Terminal branch of axillary nerve	Emerges from beneath posterior margin of deltoid and supplies skin over lower part of this muscle and on lateral side of mid arm
Inferior lateral cutaneous nerve of arm	C5, C6	Radial nerve (or posterior cutaneous nerve of arm)	Perforates lateral head of triceps, passing close to cephalic vein to supply skin over inferolateral aspect of arm
Posterior cutaneous nerve of arm	C5–C6	Radial nerve (in axilla)	Crosses posterior to and communicates with intercostobrachial nerve and supplies skin on posterior arm as far as olecranon
Posterior cutaneous nerve of forearm	C5–C8	Radial nerve (with inferior lateral cutaneous nerve of arm)	Perforates lateral head of triceps, descends laterally in arm, then runs along and supplies posterior forearm to wrist
Lateral cutaneous nerve of forearm	C6–C7	Musculocutaneous nerve (terminal branch)	Emerges lateral to biceps tendon deep to cephalic vein, supplying skin of anterolateral forearm to wrist
Medial cutaneous nerve of forearm	C8, T1	Medial cord of brachial plexus (in axilla)	Descends medial to brachial artery, pierces deep fascia with basilic vein in midarm, dividing into anterior and posterior branches that enter forearm and supply skin of anteromedial aspect to wrist
Medial cutaneous nerve of arm	C8–T2	Medial cord of brachial plexus (in axilla)	Communicates with intercostobrachial nerve, continuing to supply skin of medial aspect of distal arm
Intercostobrachial nerve	T2	Second intercostal nerve (as its lateral cutaneous branch)	Extends laterally, communicating with posterior and medial cutaneous nerves of arm, supplying skin of axilla and medial aspect of proximal arm

- Sensations on the palmar aspect of lateral $3\frac{1}{2}$ fingers (including nail beds) are carried by **median nerve**.
- Palmar aspect of medial $1\frac{1}{2}$ fingers (including nail beds) is supplied by **ulnar nerve.**
- Lateral $3\frac{1}{2}$ fingers (excluding nail beds) on the dorsum of hand is supplied by **radial nerve** and medial $1\frac{1}{2}$ fingers by **ulnar nerve**.

Note: As a variation, some individuals have lateral $2\frac{1}{2}$ fingers on the dorsum of hand supplied by **radial nerve** and medial $2\frac{1}{2}$ fingers by **ulnar nerve.**

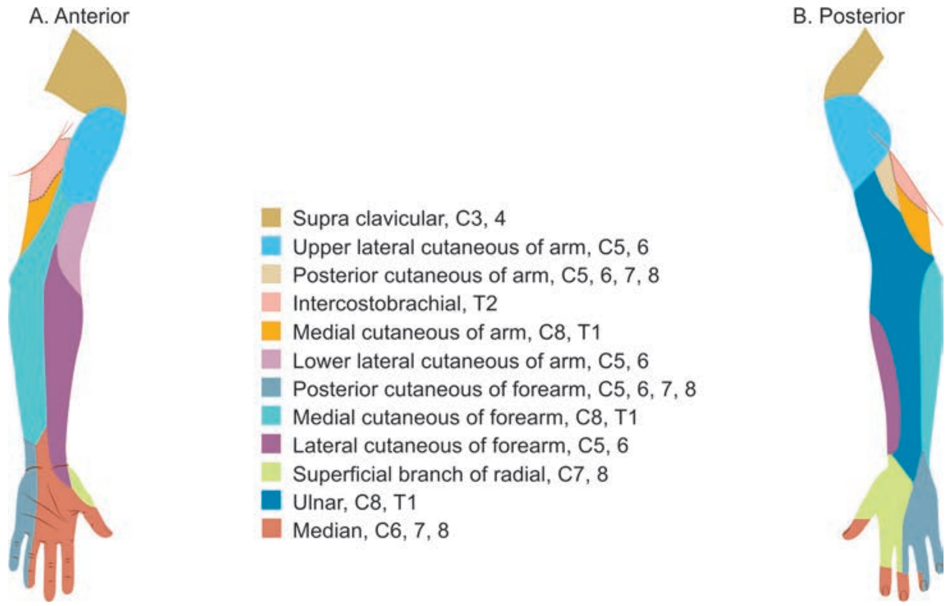


Fig. 44: Upper limb cutaneous supply

ASSESEMENT QUESTIONS

1. Anterior axial line reaches till:
a. Shoulder
b. Elbow
c. Wrist
d. Knuckle

2. Dermatome of thumb and index finger is: *(AIIMS 2013)*
a. C5; C6
b. C6; C6
c. C6; C7
d. C7; C7

3. Base of little finger is supplied by: *(AIPG 2012)*
a. C- 6
b. C- 7
c. C- 8
d. T- 1

4. The nerve supply of nail bed of index finer is: *(NEET Pattern 2013)*
a. Superficial branch of radial nerve
b. Deep branch of radial nerve
c. Median nerve
d. Ulnar nerve

5. Injury at C7 root, leads to sensory loss at: *(NEET Pattern 2013)*
a. Upper medial arm
b. Lower medial arm
c. Posterior arm
d. Posterior forearm

6. There is loss of sensation of lateral 3 and 1/2 finger. The likely nerve injured is/are: *(PGIC 2013)*
a. Only median nerve
b. Median nerve plus ulnar nerve only
c. Median nerve plus radial nerve only
d. Ulnar and radial nerve only
e. Median, radial and ulnar nerve

ANSWERS AND EXPLANATIONS

1. c. Wrist
- An **axial line** is the junction between two dermatomes supplied by discontinuous spinal nerves. Anterior axial line starts from sternal angle (2nd rib) and reaches the **wrist joint** level. Posterior axial line begins at shoulder and reaches the elbow joint level.

2. c. C6; C7
- Dermatomal pattern is highly variable and we should follow the description of Gray's anatomy Ed 41.
- Thumb has C6 and the middle three fingers have C7 dermatome.

3. c. C-8
- The dermatome of middle three fingers is C-7 and the little finger has C8 dermatome.

4. c. Median nerve
- Cutaneous innervation of lateral (radial) $3\frac{1}{2}$ fingers (palmar aspect and nail beds) is by median nerve.

5. d. Posterior forearm
- C7 dermatome is evident near the midline of the posterior aspect of forearm.

6. e. Median, radial and ulnar nerve
- Sensations on the palmar aspect of lateral $3\frac{1}{2}$ fingers (including nail beds) are carried by median nerve. Palmar aspect of medial $1\frac{1}{2}$ fingers (including nail beds) is supplied by ulnar nerve. Lateral $3\frac{1}{2}$ fingers (excluding nail beds) on the dorsum of hand is supplied by radial nerve and medial $2\frac{1}{2}$ fingers by ulnar nerve.

Nerves of Forearm

Table 23: Nerves of forearm

Nerve	Origin	Course in forearm
Median	By union of lateral root of median nerve (C6 and C7), from lateral cord of brachial plexus) with medial root (C8 and T1) from medial cord	Enters cubital fossa medial to brachial artery; exits by passing between heads of pronator teres; descends in fascial plane between flexors digitorum superficialis and profundus; runs deep to palmaris longus tendon as it approaches flexor retinaculum to traverse carpal tunnel
Anterior interosseous	Median nerve in distal part of cubital fossa	Descends on anterior aspect of interosseous membrane with artery of same name, between FDP and FPL, to pass deep to pronator quadratus
Palamar cutaneous branch of median nerve	Median nerve in middle to distal forearm, proximal to flexor retinaculum	Passes superficial to flexor reticulum to reach skin of central palm
Ulnar	Larger terminal branch of medial cord of brachial plexus (C8 and T1, often receives fibers from C7)	Enters forearm by passing between heads of flexor carpi ulnaris, after passing posterior to medial epicondyle of humerus; descends forearm between FCU and FDP; becomes superficial in distal forearm
Palmar cutaneous branch of ulnar nerve	Ulnar nerve near middle of forearm	Descends anterior to ulnar artery; perforates deep fascia in distal forearm; runs in subcutaneous tissue to palmar skin medial to axis of 4th digit
Dorsal cutaneous branch of ulnar nerve	Ulnar nerve in distal half of forearm	Passes posteroinferiorly between ulna and flexor carpi ulnaris; enters subcutaneous tissue to supply skin of dorsum medial to axis of 4th digit
Radial	Larger terminal branch of posterior cord of brachial plexus (C5—T1)	Enters cubital fossa between brachioradialis and brachialis; anterior to lateral epicondyle divides into terminal superficial and deep branches
Posterior cutaneous nerve of forearm	Radial nerve, as it traverses radial groove of posterior humerus	Perforates lateral head of triceps; descends along lateral side of arm and posterior aspect of forearm to wrist
Superficial branch of radial nerve	Sensory terminal branch of radial nerve, in cubital fossa	Descends between pronator teres and brachioradialis, emerging from latter to arborize over anatomical snuff box and supply skin of dorsum lateral to axis of 4th digit
Deep branch of radial/ posterior interosseous nerve	Motor terminal branch of radial nerve, in cubital fossa	Deep branch exits cubital fossa winding around neck of radius, penetrating and supplyhing supinator; emerges in posterior compartment of forearm as posterior interosseous; descends on membrane with artery of same name
Lateral cutaneous nerve of forearm	Continuation of musculocutaneous nerve distal to muscular branches	Emerges lateral to biceps brachii on brachialis, running initially with cephalic vein; descends along lateral border of forearm to wrist
Medial cutaneous nerve of forearm	Medial cord of brachial plexus, receiving C8 and T1 fibers	Perforates deep fascia of arm with basilic vein proximal to cubital fossa; descends medial aspect of forearm in subcutaneous tissue to wrist

Nerves of Hand

Table 24: Nerves of hand

Nerve	Origin	Course	Distribution
Median Nerve	Arises by two roots, one from lateral cord of brachial plexus (C6, C7 fibers) and one from medial cord (C8, T1 fibers)	Becomes superficial proximal to wrist; passes deep to flexor retinaculum (transverse carpal ligament as it passes through carpal tunnel to hand)	Thenar muscles (except adductor pollicis and deep head of flexor pollicis brevis) and lateral lumbricals (for digits 2 and 3); provides sensation to skin of palmar and distal dorsal aspects of lateral (radial) 3½ digits and adjacent palm
Recurrent (thenar) branch of median nerve	Arises from median nerve as soon as it has passed distal to flexor retinaculum	Loops around distal border of flexor retinaculum; enters thenar muscles	Abductor pollicis brevis; opponens pollicis; superficial head of flexor pollicis brevis
Lateral branch of median nerve	Arises as lateral division of median nerve as it enters palm of hand	Runs laterally to palmar aspect of thumb and radial side of 2nd digit	1st lumbrical; skin of palmar and distal dorsal aspects of thumb and radial half of 2nd digit
Medial branch of median nerve	Arises as medial division of median nerve as it enters palm of hand	Runs medially to adjacent sides of 2nd–4th digits	2nd lumbrical; skin of palmar and distal dorsal aspects of adjacent sides of 2nd–4th digits
Palmar cutaneous branch of median nerve	Arises from median nerve just proximal to flexor retinaculum	Passes between tendons of palmaris longus and flexor carpi radialis; runs superficial to flexor retinaculum	Skin of central palm

Nerve	Origin	Course	Distribution
Ulnar nerve	Terminal branch of medial cord of brachial plexus (C8 and T1 fibers; often also receives C7 fibers)	Becomes superfician in distal forearm, passing superficial to flexor retinaculum (transverse sarpal ligament) to enter hand	The majority of intrinsic muscles of hand (hypothenar, interosseous, adductor pollicis, and deep head of flexor pollicis brevis, plus the medial lumbricals [for digits 4 and 5]); provides sensation to skin of palmar and distal dorsal aspects of medial (ulnar) 1½ digits and adjacent palm
Palmar cutaneous branch of ulnar nerve	Arises from ulnar nerve near middle of forearm	Descends on ulnar artery and perforates deep fascia in the distal third of forearm	Skin at base of medial palm, overlying the medial carpals
Dorsal branch of ulnar nerve	Arises from ulnar nerve about 5 cm proximal to flexor retinaculum	Passes distally deep to flexor carpiulnaris, then dorsally to perforate deep fascia and course along medial side of dorsum of hand, dividing into two to three dorsal digital nerves	Skin of medial aspect of dorsum of hand and proximal portions of little and medial half of ring finger (occasionally also adjacent sides of proximal portions of ring and middle fingers)
Superficial branch of ulnar nerve	Arise from ulnar nerve at wrist as they pass between pisiform and hamate bones	Passes palmaris brevis and divides into two common palmar digital nerves	Palmaris brevis and sensation to skin of the palmar and distal dorsal aspects of digits 5 and of the medial (ulnar) side of digit 4 and proximal proximal of palm
Deep branch of ulnar nerve		Passes between muscles of hypothenar eminence to pass deeply across palm with deep palmar (arterial) arch	Hypothenar muscles, (abductor, flexor, and opponens digit minimi), lumbricals of digits 4 and 5, all interossei, adductor pollicis, and deep head of flexor pollicis brevis
Radial nerve, superficial branch	Arises from radial nerve in cubital fossa	Courses deep to brachioradialis, emerging from beneath it to pierce the deep fascia lateral to distal radius	Skin of the lateral (radial) half of dorsal aspect of the hand and thumb, the proximal portions of the dorsal aspects of digits 2 and 3, and of the lateral (radial) half of digit 4

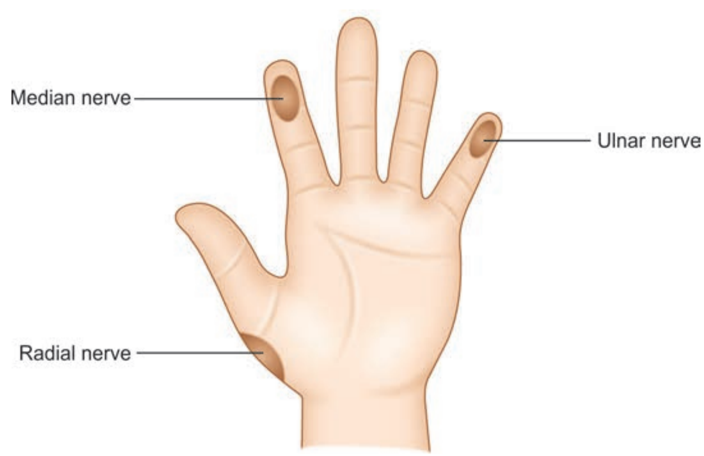


Fig. 45: The autonomous sensory areas of the hand

ASSESEMENT QUESTIONS

1. **Claw hand is caused by lesion of:** *(AIPG 2007)*
   a. Ulnar nerve
   b. Median nerve
   c. Axillary nerve
   d. Radial nerve

2. **A person is unable to adduct his thumb. The nerve involved is characterized by:** *(JIPMER 2013)*
   a. Having C7,8 T1 root value
   b. Arise from medial cord of brachial plexus
   c. Arise from lateral cord of brachial plexus
   d. Arise from posterior cord of brachial plexus
   e. Supplies 1st two lumbricals

3. **Following an incised wound in the front of wrist, the subject is unable to oppose the tips of the little finger and the thumb. The nerve(s) involved is/are:**

(NBEP Pattern 2014)

a. Ulnar nerve alone
b. Median nerve alone
c. Median and ulnar nerves
d. Radial and ulnar nerves

4. **A boy presents with injury to medial epicondyle of the humerus. Which of the following would NOT be seen?**

(AIIMS 2002)

a. Weakness of the ulnar deviation and flexion
b. Complete paralysis of the IIIrd and IVth digits
c. Atrophy of the hypothenar eminence
d. Decreased sensation of the hypothenar eminence

ANSWERS AND EXPLANATIONS

1. **a. Ulnar nerve > b. Median nerve**
   - Claw hand (Main en griffe occurs due to the paralysis of the lumbricals, which flex the metacarpophalangeal joints and extend the inter-phalangeal joints. The patient has hyperextension at the metacarpophalangeal joints (due to unopposed long extensors of posterior forearm) and flexion at the inter-phalangeal joints (due to unopposed long flexors of anterior forearm). In ulnar nerve palsy, only the medial two fingers develop clawing, while in median and ulnar nerve palsies all the four fingers develop clawing (total claw hand).
2. **a. Having C7,8 T1 root value > b. Arise from medial cord of brachial plexus**
   - Adductor pollicis is supplied by the ulnar nerve, a branch of medial cord of brachial plexus, bearing root value C8; T1. Additional C7 is received from the ventral ramus of C7.
3. **c. Median and ulnar nerves**
   - Incised wounds in front of the wrist damages median nerve often, but ulnar nerve may also get involved. Opposition of the tips of little finger and thumb requires opponens pollicis (median nerve and opponens digiti minimi (ulnar nerve as well.
4. **b. Complete paralysis of the IIIrd and IVth digits**
   - Injury to medial epicondyle damages ulnar nerve, leading to paralysis of flexor carpi ulnaris (loss of ulnar deviation) and medial half of flexor digitorum profundus (loss of DIP flexion).
   - It also leads to hypothenar muscle paralysis (and atrophy) and sensory loss on the hypothenar eminence.
   - But flexor digitorum superficialis (supplied by median nerve for finger flexion) and extensor digitorum (supplied by radial nerve for finger extension) are still functional.

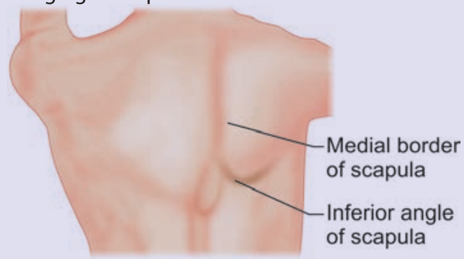
Nerve Injuries

Table 25: Movements and muscles tested to determine the location of a lesions the upper limb

Arm movement	Muscle	Upper motor neurone	Root	Reflex	Nerve
Shoulder abduction	Deltoid	++	C5		Axillary
Elbow flexion	Biceps		C5/6	+	Musculocutaneous
	Brachioradialis		C6		Radial
Elbow extension	Triceps	+	C7	+	Radial
Radial wrist extensor	Extensor carpi radialis longus	+	C6		Radial
Finger extensors	Extensor digitorum	+	C7	(+)	Posterior interosseous
Finger flexors	Flexor pollicis longus and flexor digitorum profundus, index		C8	+	Anterior interosseous
	Flexor digitorum profundus, ring and little				Ulnar
Finger abduction	First dorsal interosseous	++	T1		Ulnar
	Abductor pollicis brevis		T1		Median

The muscles listed in the 'Upper motor neurone' column are those that are preferentially affected in upper motor neurone lesions. The root level is he principal supply to a muscle.

Table 26: Nerve injuries

Nerve involved	Cause of injury	Clinical features	Deformity
Long thoracic nerve	• Mastectomy • Stab injury	• Compromised • Protraction of scapula • Overhead abduction	Winging of scapula 

Nerve involved	Cause of injury	Clinical features	Deformity
Axillary nerve	• Fracture surgical neck humerus • Shoulder dislocation	• Compromised shoulder abduction, especially (15-90°) • Sensory loss on the skin over lower part of deltoid (C5)	

Table 27: Characteristics of radial, median, and ulnar nerves of the upper limb

Nerve	Radial nerve	Median nerve (syn. Laborer's nerve)	Ulnar nerve (syn. Musician's nerve)
Origin	Posterior cord of brachial plexus	Medial and lateral cords of brachial plexus	Medial cord of brachial plexus
Root value	C5–T1	C5–T1	C8–T1
Motor innervation	Supplies all the muscles on the back of arm and forearm	Supplies • All the muscles on the front of forearm except flexor carpi ulnaris and medial half of flexor digitorum profundus • Muscle of thenar eminence and first two lumbricals	Supplies • One-and-half muscles of the forearm (flexor carpi ulnaris and medial half of the flexor digitorum profundus) • All the intrinsic muscles of the hand, except first two lumbricals and muscles of thenar eminence
Sensory innervation	• Posterior surface of the arm and forearm • Dorsal aspect of lateral 2/3rd of hand and lateral 3½ digits	Palmar aspect of lateral 2/3rd of hand, and lateral 3½ digits including their dorsal tips	Palmar aspect of medial 1/3rd hand and medial 1½ fingers
Effects of lesion	• Wrist drop • Absence of extension of MP joints of digits • Loss of sensation to a variable small area over the root of the thumb	• Ape-thumb deformity (Simian's hand) • Wasting of thenar eminence • Absence of abduction of thumb • Pointing index finger • Absence of opposition of thumb • Loss of sensation of the palmar aspect of lateral part of hand and lateral 3½ digits	• Claw-hand deformity *(main en griffe)* • Wasting of hypothenar eminence • Absence of abduction and adduction of fingers • Loss of sensation of the ulnar side of the hand and medial 1½ digits

ASSESSEMENT QUESTIONS

1. In an accident, the musculocutaneous nerve was completely severed, but still the person was able to weakly flex the elbow joint. All of the following muscles are responsible for this flexion *EXCEPT*: *(AIIMS 2004)*
a. Brachioradialis
b. Flexor carpi radialis
c. Ulnar head of pronator teres
d. Flexor carpi ulnaris

2. A patient arrives in the emergency room after having attempted suicide by lacerating his wrist. No major artery was damaged, but the nerve that is immediately lateral to the flexor digitorum superficialis tendon is cut. Which of the following actions will no longer be possible?
a. Abduction of the second digit
b. Adduction of the second digit
c. Flexion at the interphalangeal joint of the thumb
d. Opposition of the thumb

3. A 16 years old girl failed in her final examination disgusted with life, she cut across the front of wrist at the flexor retinaculum. She was rushed to hospital. The surgeon noticed that cut was superficial. All the following structures would have been damaged *EXCEPT*: *(AIIMS 2002)*
a. Ulnar nerve
b. Median nerve
c. Palmar cutaneous branch of median nerve
d. Superficial branch of radial artery

4. Most common nerve damaged in supracondylar fracture is:
a. Median
b. Anterior interosseous
c. Radial
d. Ulnar

5. A young boy who was driving motorcycle at a high speed collided with a tree & was thrown on his right shoulder. Though there was no fracture, his right arm was medially rotated and forearm pronated. The following facts concerning this patient are correct, *EXCEPT*: *(AIIMS 2004)*
a. The injury was at Erb's point
b. A lesion of C5 and C6 was present
c. The median and ulnar nerves were affected
d. Supraspinatus, infraspinatus, subclavius & biceps brachii were paralyzed

6. After radical mastectomy there was injury to the long thoracic nerve. The integrity of the nerve can be tested at the bedside by asking the patient to: *(AIIMS 2002; NEET Pattern 2012)*
a. Shrug the shoulders
b. Raise the arm above the head on the affected side
c. Touch the opposite shoulder
d. Lift a heavy object from the ground

7. During knife fight a person gets injured in the neck region and presents to emergency department with weakness in raising right arm above head. On further examination winging of right scapula is noted. The injury has damaged:
a. Spinal accessory nerve
b. Long thoracic nerve of Bell
c. Suprascapular nerve
d. Dorsal scapular nerve

8. Pronator teres syndrome is due to involvement of which of the following nerve? *(NEET Pattern 2013; AIIMS 2015)*
a. Radial nerve
b. Anterior interosseous nerve
c. Ulnar nerve
d. Median nerve

9. Nerve injury causing hyperextension of metacarpophalangeal and flexion of interphalangeal joints of ring and little finger: *(AIIMS 2015)*
a. Radial nerve
b. Ulnar nerve
c. Anterior interosseus nerve
d. Posterior interosseus nerve

10. A patient is unable to adduct his thumb. The nerve involved is characterized by: *(PGIC 2013)*
a. Having C7,8; T1 root value
b. Arise from medial cord of brachial plexus
c. Arise from the medial and lateral cord of brachial plexus
d. Musician's nerve
e. Supply first two lumbricals

11. An Injection was given in the deltoid muscle and has injured a nerve. Which of the following statements are TRUE? *(PGIC 2012)*
a. Loss of rounded contour of shoulder
b. Loss of sensation on skin over the upper half of deltoid
c. Loss of overhead abduction
d. Atrophy of deltoid muscle
e. Axillary nerve injury

12. A patient is brought to the emergency with history of trauma to his right upper limb. Extension of metacarpo-phalangeal is lost. There is no wrist drop and extension of IP joint is normal. The most likely nerve involved is:
a. Ulnar nerve
b. Median nerve
c. Radial nerve
d. Posterior interosseous nerve

13. Pointing index finger is seen in injury to: *(NEET Pattern 2014)*
a. Median nerve
b. Ulnar nerve
c. Radial nerve
d. Musculocutaneous nerve

14. Injury of ulnar nerve at the wrist would cause all *EXCEPT*:
a. Paralysis of 3rd and 4th lumbrical(s)
b. Paralysis of dorsal interossei
c. Adductor pollicis paralysis
d. Flexor pollicis brevis paralysis

15. In a wrist cut injury near flexor retinaculum, nerve commonly injured is:
a. Median
b. Ulnar
c. Musculocutaneous
d. Radial

16. Wrist drop is caused by lesion of:
a. Radial nerve in the radial groove
b. Posterior interosseous nerve
c. Anterior interosseous nerve
d. Ulnar nerve behind medial epicondyle

17. Patient exhibits weakness of Pinch grip; other thumb movements are normal. There is no sensory loss in the hand. The probable cause is damage to:
a. Posterior interosseous nerve
b. Anterior interosseous nerve
c. Deep branch of ulnar nerve
d. Median nerve proximal to flexor retinaculum

18. A lesion involving C8 nerve root will affect: *(JIPMER 2007)*
a. Extensors of wrist and fingers
b. Flexors of wrist and fingers
c. Small muscles of hand
d. None of the above

19. Medial epicondyle fracture leads to: *(PGIC 2011)*
a. Loss of sensation of thenar eminence
b. Atrophy of hypothenar eminence
c. Wrist drop
d. Radial deviation of hand on attempted flexion
e. Ulnar deviation of hand on attempted flexion

20. Loss of extension of little and ring finger, along with hypothenar atrophy is seen in injury of: *(AIIMS 2012)*
a. Radial nerve
b. Median nerve
c. Posterior interosseus nerve
d. Ulnar nerve

21. A patient presents with numbness in little and ring fingers along with atrophy of hypothenar eminence. Which of the following is injured: *(AIIMS)*
a. Posterior cord of the brachial plexus
b. Palmar cutaneous branch of the ulnar nerve
c. Deep branch of the ulnar nerve
d. Ulnar nerve before division into superficial and deep branches

22. A bookshelf falls on a person's arm laterally. He presents with inability to extend his wrist. On examination he is unable to make a strong hand grip and there is loss of sensation on dorsum of the hand and fingers. Which of the following nerve is injured? *(AIIMS 2012)*
a. Brachial plexus
b. Radial nerve
c. Posterior cord
d. Ulnar nerve

23. A patient woke up from sleep with difficulty in extending fingers. He can make a grip and hold a pen. Wrist extension was possible. No sensory disturbance was found, injury could be at: *(AIIMS 2013)*
a. C8, T1
b. Posterior interosseous nerve
c. Lower part of brachial plexus
d. Hand area in motor cortex

24. A 30-year-old male underwent excision of the right radial head. Following surgery, the patient developed in ability to extend the fingers and thumb of the right hand. He did not have any sensory deficit. Which one of the following is the most likely cause?
a. Injury to posterior interosseus nerve
b. Iatrogenic injury to common extensor origin
c. Injury to anterior interosseus nerve
d. High radial nerve palsy

25. Median nerve injury at the wrist leads to all *EXCEPT*: *(AIIMS 2008)*
a. Loss of function of the lumbrical to the index finger
b. Loss of function of the lumbrical to the middle finger
c. Effect on muscles on the thenar eminence
d. Loss of adduction of the thumb

26. All of the following muscles undergo paralysis after injury to the C5-C6 roots of brachial plexus *EXCEPT*:
a. Biceps
b. Coracobrachialis
c. Brachialis
d. Brachioradialis

27. A person while skiing catches a tree to stop and suffered a hyperabduction injury. The neural involvement is/are: *(PGIC 2012)*
a. C8;T1 nerve root
b. Upper trunk of brachial plexus
c. Lower trunk of branchial plexus
d. Ulnar nerve
e. Median nerve

ANSWERS AND EXPLANATIONS

1. c. Ulnar head of pronator teres
- Ulnar head of pronator teres do not cross (or act) at elbow joint.
- Elbow flexion is carried out by brachialis and biceps brachii muscles (supplied by musculocutaneous nerve). are paralysed in this patient.
- Brachioradialis (radial nerve), flexor carpi radialis (median nerve), flexor carpi ulnaris (ulnar nerve) are accessory muscles for elbow flexion.

2. d. Opposition of the thumb
- **Median nerve** gets damaged more often in **suicidal wrist slashing**, which lies lateral to the tendon of flexor digitorum superficialis.
- Opponens pollicis has been paralysed due to the injured median nerve at wrist leading to **loss** of **opposition** of the thumb.
- **Abduction and adduction** of digits is carried out by the interossei, which are supplied by the ulnar nerve.
- Flexion at the interphalangeal joint of thumb is carried out by the flexor pollicis longus, supplied by the anterior interosseous nerve (given by median nerve in the forearm).

3. a. Ulnar nerve
- Statistically it has been observed that the median nerve is cut more often than the ulnar in suicidal wrist slashing.
- In wrist slashing the attempted cuts are made proximal to the flexor retinaculum and mostly in radial to ulnar direction. The median nerve lies quite superficial in this region, before it enters the carpal tunnel and is frequently cut here.
- Wrist slashing injures the superficial branch of radial artery and the palmar cutaneous branch of median nerve very often.

4. b. Anterior interosseous
- **Anterior interosseous nerve** is the most common nerve to be injured in supracondylar fracture. The fracture damages few axons of the median nerve which enter the anterior interosseous branch.
- Radial nerve may also get damaged, but less often.
- Ulnar nerve is damaged rarely, in this fracture, and most of the time it is iatrogenic injury, while inserting the nail, to treat the fracture (percutaneous pinning through the medial epicondyle).

5. c. The median and ulnar nerves were affected
- This is a case of Erb's paralysis, where C-5 and 6 roots are damaged.
- Median nerve carries the root value C5-8; T-1 and ulnar nerve has the root value C-7, 8; T-1. Hence it is evident that ulnar nerve escapes in such a lesion, whereas, median nerve is partially injured (left with some residual functionality).
- Supraspinatus, infraspinatus, subclavius and biceps brachii are all supplied by the nerves carrying root value C-5,6 are paralysed.

6. b. Raise the arm above the head on the affected side
- Injury to long thoracic nerve paralyses serratus anterior and the patient finds difficulty in overhead abduction.
- Shrugging of shoulder is mainly carried out by trapezius, which is supplied by the spinal accessory nerve and works with serratus anterior for overhead-abduction.
- Pectoralis major causes flexion at the shoulder joint and is involved in touching the opposite shoulder.

7. a. Spinal accessory nerve > b. Long thoracic nerve of Bell
- Spinal accessory nerve is quite superficial in the neck region and is damaged more often as compared to long thoracic nerve of Bell (which gets damaged in the axilla region more commonly).
- Both the muscles are involved in overhead abduction (90-180°)
- Both the muscles (Serratus anterior and Trapezius) if paralysed can produce winging of scapula.

8. d. Median nerve
- **Pronator teres syndrome** is a nerve entrapment syndrome, caused by compression of the **median nerve** near the elbow.
- The nerve may be compressed between the heads of the pronator teres as a result of trauma, muscular hypertrophy, or fibrous bands.
- Patient presents with pain and tenderness in the proximal aspect of the anterior forearm, and hypoesthesia (decreased sensation) of palmar aspects of the lateral three and half fingers and adjacent palm.
- Symptoms often follow activities that involve repeated pronation.
- The patient may also present with weakness in the distal anterior forearm muscles (flexor and pronator) and thumb (thenar) muscles supplied by median nerve.

9. b. Ulnar nerve

- Injury to **ulnar nerve** presents with *ulnar claw hand*: hyperextension of metacarpophalangeal and flexion of interphalangeal joints of ring and little finger
- Ulnar nerve supplies medial 2 lumbricals (ring and little finger) in the hand. Lumbricals have a combined action of MCP (Metacarpo-phalangeal) flexion and IP (Interphalangeal) extension (glass holding posture).
- In ulnar nerve injury, since the lumbricals are not working, the forearm muscles are unopposed. MCP joint goes into hyperextension (unopposed activity of *extensor digitorum* muscles, posterior forearm) and IP joints go into flexion (unopposed activity of *flexor digitorum* muscles, anterior forearm) and they bring the deformity called **ulnar claw hand**.

10. a. Having C-8; T-1 root value; b. Arise from medial cord of brachial plexus; d. Musician's nerve

- Loss of thumb adduction occurs due to paralysis of adductor pollicis (**ulnar nerve** lesion). Ulnar nerve has C(7), 8; T1 root value, is the continuation of **medial cord** of brachial plexus, supplies intrinsic muscles of the hand like all interossei and medial **two lumbricals**, hence controls finer movement of fingers for playing musical instruments (appropriately called **musician's nerve**).

11. a. Loss of rounded contour of shoulder, d. Atrophy of deltoid muscle, e. Axillary nerve injury

- This patient has damage of **axillary nerve** leading to paralysis of **deltoid** muscle. Since deltoid undergoes **atrophy, rounded contour** of shoulder is lost. Loss of sensation is on skin over the lower half of deltoid (C5).

12. d. Posterior interosseous nerve

- Extension of metacarpophalangeal (knuckle joint is carried out by the posterior interosseous nerve-PIN).
- PIN supplies the posterior forearm muscles including the extensor digitorum, which help in extension at 4 joints – Wrist, MCP, PIP and DIP.
- **PIN** is the deep branch of the radial nerve, which winds to the back of the forearm around the lateral side of the radius between the two planes of fibers of the Supinator, and continues distally between the superficial and deep layers of muscles, to the middle of the forearm.
- It supplies all the muscles on the radial side and dorsal surface of the forearm, except the anconeus, brachioradialis, and extensor carpi radialis longus (already supplied by the radial nerve-main trunk).
- **In this patient** the injury must be below the lateral epicondyle of humerus, where main trunk of radial nerve terminates as 2 branches, one of them being a muscular branch-**PIN** and other a cutaneous.
- ECRL is functional in the patient because it is supplied it the main trunk of radial nerve and not PIN. ECRL is a strong extensor at wrist joint so, **no wrist drop** is evident here.
- **Extension at MCP** is the job of posterior forearm muscles supplied by **PIN**, hence, it is **lost.**
- Extension at interphalangeal joint(s) is carried by the **dorsal digital expansion** present on the dorsal aspect of digits. This expansion is a modification of extensor digitorum, and receives the contributions from 12 muscles of the palm (8 interossei and 4 lumbricals).
- Here extension of IP joint is normal because the 12 muscles of the palm (supplied by the median & ulnar nerves) are still functional, despite the paralysed extensor digitorum (PIN).

13. a. Median nerve

- Ochsner's clasping test assesses the function of the median nerve for lesions in the cubital fossa or above, by testing for the function of long flexors to index finger (flexor digitorum superficialis and profundus).
- When the patient is asked to clasp both his hands. The index finger on the affected side will stand pointing out instead of being flexed.

14. d. Flexor pollicis brevis paralysis

- Flexor pollicis brevis is supplied by median nerve. Deep part of the muscle is supplied by the ulnar nerve.
- Hence, injury of ulnar nerve will produce weakness in the FPB but not paralysis.

15. a. Median

- Median nerve is the most commonly damaged nerve in wrist slash injuries. Ulnar nerve may also be cut, though less commonly.
- These cuts are usually due to suicidal wrist slashing and the blade is moved repetitively from radial to medial side at the wrist.
- Ulnar nerve crosses the flexor retinaculum superficially but more towards the medial side and usually the blade doesn't reach that site.

16. a. Radial nerve in the radial groove

- **Extensor carpi radialis longus** is a strong extensor at the wrist joint and will be paralysed in radial nerve injury at the radial groove, leading to **wrist drop**.
- Posterior interosseous nerve injury **doesn't** produce wrist drop as ECRL is still functional.

17. b. Anterior interosseous nerve

- Weakness of pinch grip is due to involvement of Flexor Pollicis Longus (FPL) and Flexor digitorum profundus (FDP) of index finger.
- **Anterior interosseous nerve** supplies FDP to index and middle finger and FPL.
- Median nerve injury proximal to retinaculum results in loss of sensation to palmar radial $3\frac{1}{2}$ digits. Thumb opposition (OP), abduction of thumb (APB) and flexion of MCP joint thumb (FPB) also get affected.
- Question clearly says that other movements of thumb are not affected (i.e., abduction and opposition are normal) and no sensory loss, so median nerve injury above wrist is ruled out.

18. b. Flexors of wrist and fingers

- Small muscles of hand are supplied by C8;T1, more precisely T1.
- Wrist (and Finger) extensors—C6(7)
- Wrist (and Finger) flexors—C7(8)
- Intrinsic muscles of hand—C8; T1

19. b. Atrophy of hypothenar eminence, d. Radial deviation of hand on attempted flexion
- Fracture at medial epicondyle may damage the ulnar nerve, leading to atrophy of hypothenar muscles.
- Since flexor carpi ulnaris supplied by ulnar nerve is paralysed, on attempted flexion at wrist, radial deviation occurs (unopposed flexor carpi radialis muscle).

20. d. Ulnar nerve
- Ulnar nerve injury leads to hypothenar atrophy with paralysis of lumbrical and interossei, leading to loss of extension of little and ring fingers at interphalangeal joints, resulting in claw hand (flexion at interphalangeal joints due to unopposed long flexors of forearm).

21. d. Ulnar nerve before division into superficial and deep branches
- Medial cord of brachial plexus gives ulnar nerve which has been injured before it divides into two terminal branches in the hand (inside Guyon's canal). The deep branch supplies hypothenar muscles and superficial branch innervates skin of palmar surface of little finger and medial half of ring finger.

22. b. Radial nerve
- Loss of wrist extension occurs in radial nerve injury, in this case, it has been injured in radial groove.
- For making a strong hand grip by long flexors, slight dorsiflexion of wrist is required (carried out by ECRL and ECRB). In this case ECRL and ECRB are paralysed, hence the hand grip is not strong.

23. b. Posterior interosseous nerve
- Injury to posterior interosseous nerve leads to loss of finger extension at metacarpophalangeal joint.
- Lower part of brachial plexus carries C-8; T1 root value and supplies long flexors of finger and intrinsic muscles of hand for making a grip and holding a pen.

24. a. Injury to posterior interosseus nerve
- The patient has a motor nerve injury in the proximity to radial head - posterior interosseous nerve, hence leading to paralysis of posterior forearm muscles (extensors of thumb and fingers).

25. d. Loss of adduction of the thumb
- Adduction of thumb is carried out by the adductor pollicis, which is a deep muscle of the thumb and is supplied by the deep branch of ulnar nerve. Hence, in median nerve injury it remains functional and there is no loss of adduction of thumb.
- Lumbricals to the index and middle finger are supplied by the median nerve and have lost their function in this injury.
- Thenar muscles are mainly innervated by the median nerve and are paralysed in this patient.

26. b. Coracobrachialis
- Coracobrachialis is supplied equally by all the three root values (C-5,6,7), and may not be paralysed (due to the sparing of C-7 root value). Brachioradialis is supplied by root value C-5 and 6, and hence is paralysed and so are biceps brachii (C-5,6) and brachialis: C-5,6,7 (But the dominant vale is C-6).

27. a. C8;T1 nerve root; c. Lower trunk of branchial plexus; d. Ulnar nerve; e. Median nerve
- This is a case of Klumpke's paralysis, which may be caused by hyperabduction of the arm, as occurs in catching a tree to stop, while in fast motion. The **lower trunk of brachial plexus** is pulled and compromises **first thoracic** nerve is usually torn, though often **C8** is also injured. The nerve fibres from this segment run in **ulnar** and **median nerves** to supply the small muscles of the hand.

Reflexes

- **Biceps jerk** (C5, 6) The elbow is flexed to a right angle and slightly pronated. A finger is placed on the biceps tendon and struck with a knee hammer; this should elicit flexion and slight supination of the forearm.
- **Triceps jerk** (C6–8) The arm is supported at the wrist and flexed to a right angle. Triceps tendon is struck with a knee hammer just proximal to the olecranon; this should elicit extension of the elbow.
- **Radial jerk** (C7, 8) The radial jerk is a periosteal, not a tendon, reflex. The elbow is flexed to a right angle and the forearm placed in the mid pronation/supination position. The radial styloid is struck with the knee hammer. This elicits contraction of **brachioradialis**, which causes **flexion** of the elbow.

ASSESSMENT QUESTION

1. **Root value of supinator jerk:** *(NEET Pattern 2015)*
   a. C3, 4
   b. C4, 5
   c. C5, 6
   d. C8; T1

ANSWER AND EXPLANATION

1. c. C5, 6
- **Supinator reflex** is elicited by striking the **brachioradialis** tendon at its insertion at the base of the wrist into the radial styloid process with knee hammer, while the forearm is supported in midprone position. This reflex is carried by the radial nerve (C5,6) and results in supination along with slight wrist extension and radial deviation, and slight elbow flexion as well.

High Yield Point

- Injury to the **suprascapular nerve** is characterized by atrophy of the supraspinatus and infraspinatus muscles. Deficits will include difficulty in initiation of arm abduction and weakness in external rotation of the arm.

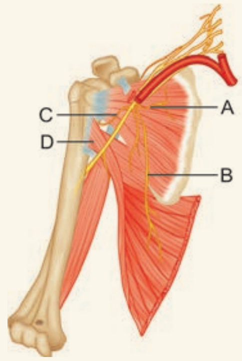
- Injury to the **long thoracic nerve** results in paralysis of the serratus anterior muscle, causing a **winged scapula** (the medial border of the scapula moves or protrudes posteriorly away from the thoracic wall) when pushing against resistance. It may also cause difficulty in raising the arm above the head.
- Posterior interosseous nerve has **pseudoganglion** at the termination.

ASSESSMENT QUESTIONS

1. Largest branch of brachial plexus is: *(NEET Pattern 2013)*
a. Ulnar
b. Medial
c. Radial
d. Axillary

2. Axillary nerve is accompanied by which artery? *(NEET Pattern 2015)*
a. Axillary
b. Subscapular
c. Anterior circumflex humeral
d. Posterior circumflex humeral

3. Identify the nerve at marker 'B':
a. Long thoracic nerve
b. Thoracodorsal nerve
c. Intercostobrachial nerve
d. Lower subscapular



4. All of the following muscles have dual nerve supply, *EXCEPT*: *(AIPG)*
a. Brachialis
b. Pectineus
c. Flexor digitorum superficialis
d. Flexor digitorum profundus

5. All of the following muscles strictly receive nerve supply from anterior interosseous nerve *EXCEPT*:
a. Pronator quadrates
b. Flexor pollicis longus
c. Flexor digitorum profundus of index finger
d. Flexor digitorum profundus of middle finger

6. Following pairs describe the muscles producing flexion at elbow joint and their respective nerve. Choose the WRONG pair: *(AIPG)*
a. Biceps brachii: Musculocutaneous nerve
b. Brachioradialis: Median nerve
c. Flexor carpi ulnaris: Ulnar nerve
d. Flexor carpi radialis: Median nerve

7. Erb's point is at the junction of:
a. C5,6
b. C6,7
c. C7,8
d. C8,T1

8. Ulnar collateral nerve is: *(NEET Pattern 2013)*
a. Branch of ulnar nerve
b. Branch of radial nerve supplying medial head of triceps
c. Branch of radial nerve supplying long head of triceps
d. Branch of radial nerve supplying lateral head of triceps

9. Lower lateral cutaneous nerve of arm is a branch of: *(NEET Pattern 2014)*
a. Radial nerve
b. Axillary nerve
c. Median nerve
d. Musculocutaneous nerve

10. Which of the following is also known as the labourer's nerve? *(NEET Pattern 2012)*
a. Ulnar nerve
b. Median nerve
c. Anterior interosseous nerve
d. Radial nerve

11. Finger by which all three major nerves of the upper limb can be tested: *(PGIC)*
a. Index
b. Ring
c. Thumb
d. Middle
e. Little

ANSWERS AND EXPLANATIONS

1. c. Radial
- Radial nerve is the largest branch of brachial plexus and is the continuation of posterior cord (C5-8; T1).

2. d. Posterior circumflex humeral
- Axillary nerve passes through the quadrangular space accompanied by the posterior circumflex humeral vessels.

3. b. Thoracodorsal nerve

- Marker 'B' is showing **thoracodorsal nerve**, which is a branch of posterior cord of brachial plexus to supply the lower back muscle called latissimus dorsi.
- This diagram shows the five branches of the posterior cord of brachial plexus **(STARS)**: S - Subscapular nerve (Upper), T - Thoracodorsal nerve, A - Axillary nerve, R - Radial nerve and S - Subscapular nerve (Lower)
- Marker 'A' is the **upper subscapular nerve** to supply the sub-scapular muscle.
- Marker 'C' is showing axillary nerve passing in the 'quadrangular space' to wind around the 'surgical neck' of humerus, and supply deltoid and teres minor muscle.
- Marker 'D' is shows the **radial nerve**, which supplies the extensor muscles of the upper limb.

4. c. Flexor digitorum superficialis

- Flexor digitorum superficialis is supplied by only one nerve—the median nerve.
- Brachialis is mainly supplied by the musculocutaneous nerve and receives proprioceptive fibres from the radial nerve.
- Pectineus receives branches from femoral nerve in addition to the main supply –obturator nerve.
- Flexor digitorum profundus has median and ulnar nerves (dual innervation).

5. d. Flexor digitorum profundus of middle finger

- **Flexor digitorum profundus** of middle finger is supplied by the **ulnar** nerve in 20% of the population.
- Anterior interosseous nerve (**AIN)**, a branch of median nerve, supplies all the deep muscles of the anterior forearm **except** part of the flexor digitorum profundus.
- Flexor digitorum profundus (**FDP**) gives 4 tendons to the 4 fingers (except finger no. 1 – the thumb).
- FDP of Finger no. 2 and 3 are controlled by the AIN and 4 and 5 by the ulnar nerve (**2:2 ratio**) in 60% of the population. It is evident that the middle finger is mostly supplied by the AIN.
- In 20% of the population the ratio is **3:1** (AIN supplying the finger no. 2, 3, 4 whereas, ulnar supplying only the finger 5). It is evident that even the ring finger is being supplied by AIN here.
- In the remaining 20% of the population the ratio is **1:3**, that is , AIN supplies finger no. 2, whereas 3, 4, 5 are supplied by the ulnar nerve. Here it is evident that FDP of middle finger is being supplied by the ulnar nerve.
- Hence, FDP of middle finger is supplied by the AIN in 80% of the population, but in 20% of the population it is supplied by the **ulnar** nerve.

6. b. Brachioradialis: Median nerve

- Brachioradialis muscle belongs to posterior compartment of forearm, supplied by radial nerve branch.
- Muscles crossing the elbow joint anteriorly, cause flexion e.g., biceps brachii, brachialis, flexor carpi radialis, flexor carpi ulnaris, pronator teres etc.
- **Brachioradialis**, flexor of the forearm, is unusual in that it is located in the posterior compartment, but crosses the elbow joint anteriorly.

7. a. C5,6

- Erb's point is a meeting point of **six** nerves: ventral rami of C-5 root, ventral rami of C-6 root, suprascapular nerve, nerve to subclavius, anterior division of upper trunk and posterior division of upper trunk.
- Damage to this region produces Erb's palsy.

8. b. Branch of radial nerve supplying medial head of triceps

- A long, slender branch of radial nerve (to medial head of triceps), lies close to the ulnar nerve as far as the lower third of the arm, is frequently called as ulnar collateral nerve.

9. a. Radial nerve

- Radial nerve gives numerous sensory branches: posterior cutaneous nerve of arm, posterior cutaneous nerve of forearm, lower lateral cutaneous nerve of arm and superficial terminal branch.

10. b. Median nerve

- Median nerve is also called as Labourer's nerve as it supplies the anterior forearm muscles and anterior thumb muscles. These muscles help to push, pull, lift heavy loads by the labourers and if the nerve is damaged they are helpless to carry out all such movements.

11. c. Thumb

- Thumb movements are varied and all the three major nerves work for that.

Movements	Muscles involved (nerve supply)
Flexion (accompanied by medial rotation)	Flexor pollicis brevis (median and ulnar nerves), flexor pollicis longus (median nerve). Opponens pollicis (median and ulnar nerves)
Extension (accompanied by lateral rotation)	Extensor pollicis longus (radial nerve). Extensor pollicis brevis (radial nerve). Abductor pollicis longus (radial nerve).
Abduction	Abductor pollicis brevis (median nerve). Abductor pollicis longus (radial nerve).
Adduction	Adductor pollicis (ulnar nerve).
Opposition	Abductor pollicis brevis (median nerve)→ Opponens pollicis (median and ulnar nerve)→ Flexor pollicis brevis (median and ulnar nerves)

Muscles

Table 28: The relationship between functional muscle grouping and actions of the pectoral girdle*

Functional group	Specific muscles	Action
Occipitospinoscapular Thoracoscapular Spinoclavicular Thoracoclavicular	Trapezius Pectoralis minor Trapezius Subclavius	Scapular suspension Position and motion of the acromioclavicular joint in relation to the thorax and (neur) axis Deceleration of the lateral clavicle during motion
Thoracoscapular (medial border)	Levator scapulae Rhomboid minor Rhomobid major Serratus anterior Serratus posterior superior Serratus posterior inferior	Scapular motion Postion and motion of the glenohumeral joint in relation to the thorax and (neur) axis
Thoracohumeral	Pectoralis major Latissimus dorsi	Thoracobrachial motion Position of the arm
Scapulohumeral	Deltoid Coracobrachialis Biceps brachii (short head) Teres minor Infraspinatus Supraspinatus Subscapularis Teres major Triceps brachii (long head) Biceps brachii (long head)	Concavity compression of the glenohumeral joint Coordination of shoulder and elbow motion

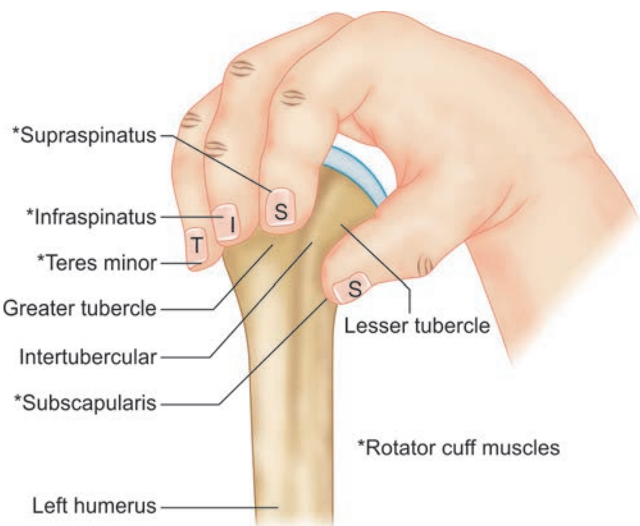
*As a principle a muscle will act on a motion segment to alter the position of the distal extent of that segment in space. As an example, deltoid acts on the shoulder joint but its effect is to move the distal extent of the humerus, i.e., the elbow.

Scapulohumeral Muscles

Table 29: Scapulohumeral (Interinsic shoulder) muscles

Muscle	Proximal attachment	Distal attachment	Innervation	Muscle action
Deltoid	Lateral third of clavicle; acromion and spine of scapula	Deltoid tuberosity of humerus	Axillary nerve (**C5**, C6)	Clavicular (anterior) part: felxes and medially rotates arm Acromial (middle) part: abducts arm Spinal (posterior) part: extends and laterally rotates arm
Supraspinatus	Supraspinous fossa of scapula	Superior facet of greater tubercle of humerus	Suprascapular nerve (C4, C5, C6)	Initiates and assists deltoid in abduction of arm and acts with rotators cuff muscles
Infraspinatus	Infraspinous fossa of scapula	Middle facet of greater tubercle of humerus	Suprascapular nerve (**C5**, C6)	Laterally rotates arm; and acts with rotator cuff muscles
Teres minor	Middle part of lateral border of scapula	Inferior facet of greater tubercle of humerus	Axillary nerve (**C5**, C6)	Laterally rotates arm; and acts with rotator cuff muscles
Teres major	Posterior surface of inferior angel of scapula	Medial lip of intertubercular sulcus of humerus	Lower subscapular nerve (C5, **C6**)	Adducts and medially rotates arm
Subscapularis	Subscapular fossa (Most of anterior surface of scapula)	Lesser tubercle of humerus	Upper and lower subscapular nerves (C5, **C6**, C7)	Medially rotates arm; as part of rotator cuff, helps hold head of humerus in glenoid cavity

- **Rotator (Musculotendinous) cuff**
  - It fuses with the joint capsule, formed by blending of tendons of four muscles (**SITS**): **S**upraspinatus (superiorly); **I**nfraspinatus and **T**eres minor (posteriorly) and **S**ubscapularis (anteriorly). It is a **dynamic stabilizer** of shoulder joint.
  - The four muscles **grasp and hold** the head of the humerus in the glenoid fossa during movements and stabilizes the shoulder joint. It reinforces the capsule posterosuperiorly, but weak anteroinferiorly—Shoulder dislocations are more commonly **anteroinferior**.
  - The most common tendon injured in rotator cuff injury is **supraspinatus**. Complete tear of supraspinatus is characterized by **difficulty to initiate abduction**, but further abduction is possible if limb is abducted passively to 15°.
- Rotator cuff injury (also called subacromial bursitis or **painful arc syndrome**. Most commonly it involves the tendon of the supraspinatus muscle and the subacromial bursa. It presents in middle-aged men with pain upon lifting the arm above the head. Commonly a tear is present in the supraspinatus tendon insertion at the greater tuberosity.
- **Impingement syndrome** is a type of overuse injury with progressive pathologic changes resulting from mechanical impingement by the acromion, coracoacromial ligament, coracoid process, or acromioclavicular joint against the rotator cuff (especially **supraspinatus** muscle); changes may include reversible edema and hemorrhage, fibrosis, tendinitis, pain, bone spur formation, and tendon rupture.



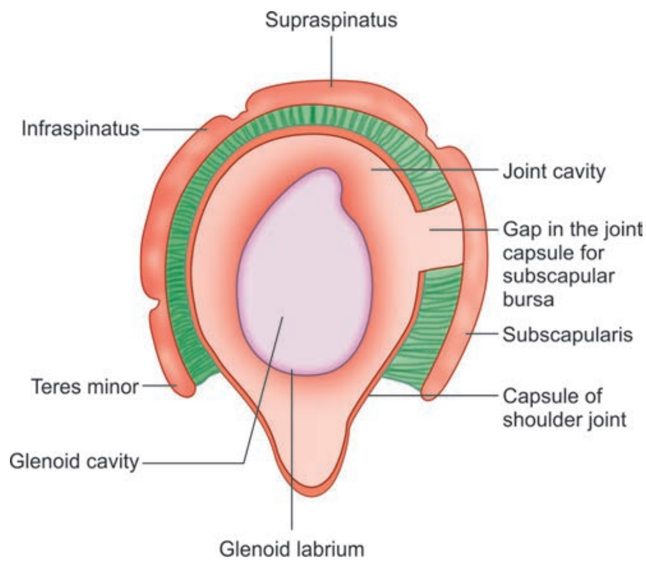


Fig. 46: Rotator cuff

ASSESSMENT QUESTIONS

1. **All are true about proximal humerus attachment *EXCEPT*:** *(NEET Pattern 2013)*
   a. Supraspinatus at lesser tubercle
   b. Subscapularis at lesser tubercle
   c. Teres minor at greater tubercle
   d. Infraspinatus at greater tubercle

2. **Rotator cuff muscles following considered as forgotten muscle:** *(AIIMS 2013)*
   a. Subscapularis
   b. Supraspinatus
   d. Infraspinatus
   d. Teres minor

3. **Deltoid muscle causes all *EXCEPT*:** *(NEET Pattern 2015)*
   a. Flexion of shoulder
   b. Extension of shoulder
   c. Internal rotation of shoulder
   d. Adduction of shoulder

ANSWERS AND EXPLANATIONS

1. **a. Supraspinatus at lesser tubercle**
   - SIT (Supraspinatus, Infraspinatus, Teres minor) muscles sit on greater tubercle of humerus and subscapularis muscle attaches to lesser tubercle. Together they contribute to rotator cuff at the shoulder joint.

2. **a. Subscapularis**
   - Subscapularis is the major and most powerful muscle of the rotator cuff and works for the glenohumeral stability and dynamic activity.
   - But often it is neglected in the clinical literature, some authors have even tagged the subscapularis tendon hypercritically as the "forgotten tendon".

3. **d. Adduction of shoulder**
   - Deltoid muscle is a powerful abductor at shoulder joint, using middle (lateral) fibres.
   - It causes flexion and medial rotation (by anterior fibres) and extension & lateral rotation (by posterior fibres).

Axioappendicular Muscles

Table 30: Anterior axioappendicular muscles

Muscle	Proximal attachment	Distal attachment	Innervation	Main action
Pectoralis major	Clavicular head: Anterior surface of medial half of clavicle Sternocostal head: anterior surface of sternum, superior six costal cartilages, aponeurosis of external oblique muscle	Lateral lip of intertubercular sulcus of humerus	Lateral and medial pectoral nerves; clavicular head (C5, **C6**), sternocostal head (**C7, C8**, T1)	Adducts and medially rotates humerus; draws scapula anteriorly and inferiorly Acting alone, clavicular head flexes humerus and sternocostal head extends it from the flexed position
Muscle	**Proximal attachment**	**Distal attachment**	**Innervation**	**Main action**
Pectoralis minor	3rd-5th ribs near their costal cartilages	Medial border and superior surface of coracoid process of scapula	Medial pectoral nerve (C8, T1)	Stabilizes scapula by drawing it inferiorly and anteriorly against thoracic wall
Subclavius	Junction of 1st rib and its costal cartilage	Inferior surface of middle third of clavicle	Nerve to subclavius (C5, C6)	Anchors and depresses clavicle
Serratus anterior	External surfaces of lateral parts of 1st–8th ribs	Anterior surface of medial border of scapula	Long thoracic nerve (c5, C6, C7)	Protracts scapula and holds it against thoracic wall; rotates scapula

Table 31: Posterior axioappendicular muscles

Muscle	Proximal attachment	Distal attachment	Innervation	Muscle action
Superficial posterior axioappendicular (extrinsic shoulder) muscles				
Trapezius	Medial third of superior nuchal line; external occipital protuberance; nuchal ligament; spinous processes of C7–T12 vertebrae	Lateral third of clavicle; acromion and spine of scapula	Spinal accessory nerve (CN XI) (motor fibers) and C3, C4 spinal nerves (pain and proprioceptive fibers)	Descending part elevates; ascending part depresses; and middle part (or all parts together) retracts scapula; descending and ascending parts act together to rotate glenoid cavity superiorly
Latissimus dorsi	Spinous processes of inferior 6 thoracic vetebrae, thoracolumbar fascia, iliac crest, and inferior 3 or 4 ribs	Floor of intertubercular sulcus of humerus	Thoracodorsal nerve (**C6, C7**, C8)	Extends, adducts, and medially rotates humerus; raises body towards arms during climbing
Deep posterior axioappendicular (extrinsic shoulder) muscles				
Levator scapulae	Posterior tubercles of transverse processes of C1–C4 vertebrae	Medial border of scapula superior to root of scapular spine	Dorsal scapular (C4, C5) and cervical (C3, C4) nerves	Elevates scapula a its glenoid cavity in rotating scapula
Rhomboid minor and major	Minor: nuchal ligament; spinous processes of C7 and T1 vertebrae Major: spinous processes of T2–T5 vertebrae	Minor: smooth traingular area at medial end of scapular spine Major: medial border of scapula from level of spine to inferior angle	Dorsal scapular nerve (C4, **C5**)	Retract scapula an its glenoid cavity in scapula to thoracic

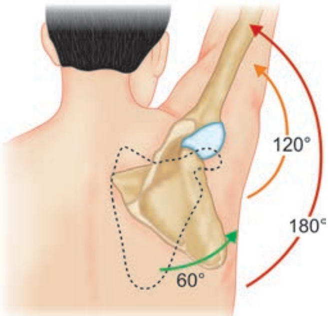


Fig. 47: Shoulder abduction (range of movement)

Scapulo-humeral rhythm. The scapula and humerus move in 1:2 ratio. When the arm is abducted 180 degrees, 60 degrees occurs by rotation of the scapula, and 120 degrees by rotation of the humerus at the shoulder joint

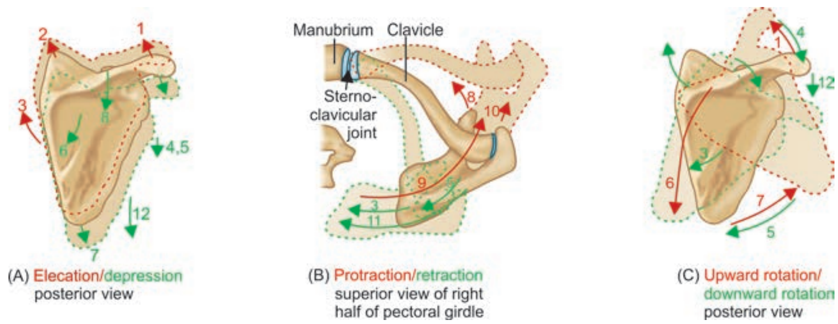


Fig. 48: Scapular movements associated with pectoral girdle

Table 32: Movements of scapula

Movement of scapula	Muscles producing movement	Nerve to muscles	Range of movement (angular rotation; linear displacement)
Elevation	**Trapezius, descending part** (1) Levator scapulae (2) Rhomboids (3)	Spinal accessory (CN XI) **Dorsal scapular**	
Depression	**Gravity** (12) Pectoralis major, inferior sternocostal head (4) Latissimus dorsi (5) Trapezius, ascending part (6) Serratus anterior, inferior part (7) Pectoralis minor (8)	Pectoral nerves Thoracodorsal Spinal accessory (CN XI) Long thoracic Medial pectoral	10–12 cm
Protraction	**Serratus anterior** (9) Pectoralis major (10) Pectoralis minor (8)	Long thoracic Pectoral nerves medial pectoral	
Retraction	**Trapezius, middle part** (11) Rhomboids (3) Latissimus dorsi (5)	**Spinal accessory (CN XI)** Long thoracic	40–45°; 15 cm
Upward rotation[b]	**Trapezius, descending part** (1) Trapezius, ascending part (6) **Serratus anterior, inferior part** (7)	**Spinal accessory (CN XI)** Long thoracic	
Downward rotation	Gravity (12) Levator scapulae (2) Rhomboids (3) **Latissimus dorsi** (5) Pectoralis minor (8) Pectoralis major, inferior sternocostal head (4)	Dorsal scapular Thoracodorsal Medial pectoral Medial and lateral pectoral nerves	60°; inferior angle: 10–12 cm, superior angle: 5–6 cm

[a]Numbers refer to Figure 48.
[b]The glenoid cavity moves superiorly, as in abduction of the arm.
[c]The glenoid cavity moves inferiorly, as in adduction of the arm.

ASSESSMENT QUESTIONS

1. All of the following muscles causes retraction of scapula *EXCEPT*: *(AIIMS 2010; NEET Pattern 2014)*
a. Trapezius
b. Levator scapulae
c. Rhomboideus major
d. Rhomboideus minor

2. After surgery on right side of neck, a person could not raise his arm above head and also could not shrug the shoulder. What are the possible causes: *(PGIC 2013)*
a. Damage to spinal accessory nerve
b. Paralysis of trapezius muscle
c. Injury to axillary nerve
d. Paralysis of latissimus dorsi
e. Paralysis of deltoid muscle

3. Nerve supply of rhomboideus major: *(NEET Pattern 2015)*
a. Spinal accessory nerve, cranial nerve
b. Spinal accessory nerve, spinal part
c. Dorsal scapular nerve
d. Thoracodorsal nerve

4. INCORRECT about serratus anterior: *(NEET Pattern 2015)*
a. Forms medial wall of axilla
b. Causes protraction of scapula
c. Causes rotation of scapula
d. Supplied by thoracodorsal nerve

5. **Which of the following is climber's muscle?** *(NEET Pattern 2015)*
   a. Serratus anterior
   b. Latissimus dorsi
   c. Rhomboideus major
   d. Subscapularis

6. **Trapezius is attached to all structures *EXCEPT*:** *(AIPG)*
   a. First rib
   b. Clavicle
   c. Scapula
   d. Occiput

7. **True about trapezius are all *EXCEPT*:** *(NEET Pattern 2015)*
   a. Elevates the scapula
   b. Originates for C7
   c. Supplied by cranial part of accessory nerve
   d. Causes overhead abduction

ANSWERS AND EXPLANATIONS

1. **b. Levator scapulae**
   - **Levator scapulae** muscle is mainly an elevator **(not retractor)** of scapula.
     - **Actions** of levator scapulae: If the head is fixed, the levator scapulae **raises** the medial angle of the scapula. If the shoulder is fixed, the muscle **inclines** the neck to the corresponding side and rotates it in the same direction. The levator scapulae, along with the trapezius muscle, makes a **shrug** at shoulder possible.
     - **Retraction** of scapula brings the scapula back to the midline. The main retractors of scapula are: **Trapezius, rhomboideus major and minor.**
     - **Protraction** of scapula takes scapula away from midline as happens in pushing a wall in front. The protractors of scapula are: Serratus anterior, pectoralis minor muscles.
2. **a. Damage to spinal accessory nerve, b. Paralysis of trapezius muscle**
   - **Spinal accessory nerve** runs very superficial in the posterior triangle of neck and is prone to iatrogenic injury, leading to **paralysis of trapezius** muscle and difficulty shrugging the shoulder, as well as overhead abduction.
3. **c. Dorsal scapular nerve**
   - **Rhomboid muscles** and **levator scapulae** are supplied by the **dorsal scapular nerve.**
4. **d. Supplied by thoracodorsal nerve**
   - **Long thoracic nerve** (of Bell) supplies serratus anterior muscle.
   - Serratus anterior pulls the scapula forward **(protraction)**. It also pulls on the inferior angle of scapula to help in **lateral scapular rotation**, the glenoid cavity is turned to face more directly upwards as the arm is raised from the side and carried above the head against gravity.
5. **b. Latissimus dorsi**
   - The muscle which becomes more evident due to contraction while climbing (like trees) is latissimus dorsi and hence is the name.
6. **a. First rib**
   - **Origin:** occipital bone, ligamentum nuchae, spinous processes of seventh cervical and all thoracic vertebrae;
   - **Insertion:** Clavicle, acromion, spine of scapula;
   - **Innervation:** Spinal accessory nerve and cervical plexus;
   - **Action:** Laterally rotates scapula to raise shoulder in abduction of arm (90–180°), draws scapula backward (retraction) and shrugs the shoulder.
7. **c. Supplied by cranial part of accessory nerve**
   - **Trapezius** is supplied by the **spinal part** of accessory nerve. Cranial part of accessory nerve supplies muscles of palate, pharynx and larynx.

Muscles of Arm

Table 33: Muscles of arm

Muscle	Proximal attachment	Distal attachment	Innervation	Muscle action
Biceps brachii	*Short head:* tip of coracoid process of scapula *Long head:* supraglenoid tubercle of scapula	Tuberosity of radius and fascia of forearm via bicipital aponeurosis	Musculocutaneous nerve (C5, **C6**, C7)	Supinates forearm and, when it is supine. Flexes forearm; short head resists dislocation of shoulder
Coracobrachialis	Tip of coracoid process of scapula	Middle third of medial surface of humerus		Helps flex and adduct arm; resists dislocation of shoulder
Brachialis	Distal half of anterior surface of humerus	Coronoid process and tuberosity ulna	Musculocutaneous nerve (C5, C6) and radial nerve (C5, C7)	Flexes forearm in all positions

Muscle	Proximal attachment	Distal attachment	Innervation	Muscle action
Triceps brachii	*Long head:* infraglenoid tubercle of scapula *Lateral head:* posterior surface of humerus, superior to radial groove *Medial head:* posterior surface of humerus, inferior to radial groove	Proximal end or olecranon of ulna and fascia of forearm	Radial nerve (C6, **C7**, **C8**)	Chief extensor of forearm; long head resists dislocation of humerus; especially important during adduction
Anconeus	Lateral epicondyle of humerus	Lateral surface of olecranon and superior part of posterior surface of ulna	Radial nerve (C7, C8, T1)	Assists triceps in extending forearm; stabilizes elbow joint; may abduct ulna during pronation

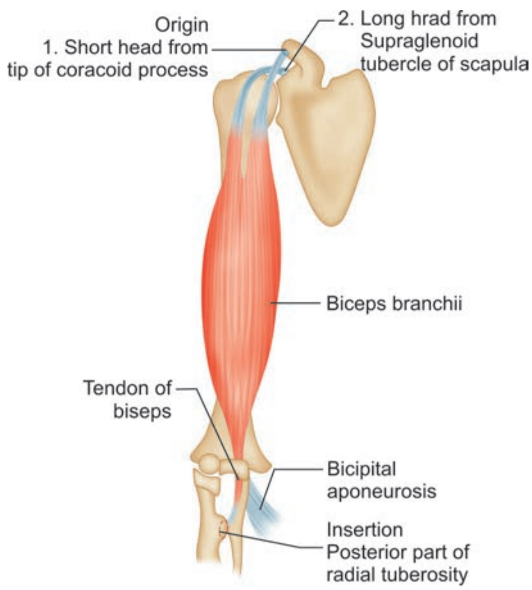


Fig. 49: Origin and insertion of biceps brachii

ASSESSMENT QUESTIONS

1. Short head of biceps attached to: *(JIPMER 2007, 10, 11)*
a. Coracoid process
b. Supraglenoid tubercle
c. Acromion process
d. Bicipital groove

2. Biceps brachii does NOT arise from: *(NEET Pattern 2015)*
a. Supraglenoid tubercle
b. Glenoid labrum
c. Coracoid process
d. Front of humerus

3. Intracapsular but extrasynovial is: *(NEET Pattern 2015)*
a. Long head of triceps brachii
b. Long head of biceps brachii
c. Short head of biceps brachii
d. Medial head of biceps brachii

4. Muscle of arm with additional supinator action: *(NEET Pattern 2015)*
a. Brachialis
b. Biceps
c. Coracobrachialis
d. Triceps

5. Muscle NOT supplied by musculocutaneous nerve: *(NEET Pattern 2012)*
a. Biceps
b. Extensor carpi radialis longus
c. Brachialis
d. Coracobrachialis

6. Coracobrachialis is pierced by which nerve: *(NEET Pattern 2013)*
a. Axillary
b. Median
c. Musculocutaneous
d. Ulnar

7. True about anconeus muscle is: *(NEET Pattern 2014)*
a. Posterior forearm muscle
b. Helps in screwing movement
c. Helps in forearm supination
d. Supplied by ulnar nerve

ANSWERS AND EXPLANATIONS

1. **a. Coracoid process**
   - Biceps brachii short head takes origin from the tip of coracoid process and the long head from the supraglenoid tubercle. Insertion is into the radial tuberosity.
2. **d. Front of humerus**
   - Biceps brachii short head takes origin from the tip of coracoid process and the long head from the supraglenoid tubercle of scapula.
3. **b. Long head of biceps brachii**
   - Origin of long head of biceps brachii is intracapsular and extrasynovial, but enclosed by a prolongation of synovial membrane of shoulder joint.
4. **b. Biceps**
   - Biceps brachii is a flexor at elbow joint, but it is also a powerful supinator.
5. **b. Extensor carpi radialis longus**
   - Musculocutaneous nerve supplies the flexor compartment of arm region. Extensor carpi radialis longus is supplied by radial nerve.
6. **c. Musculocutaneous**
   - Coracobrachialis is pierced and supplied by musculocutaneous nerve.
7. **b. Screwing movements**
   - Anconeus assists triceps in extending forearm (major action); stabilizes elbow joint; may abduct ulna during pronation. Some authors mention it helping in screwing movements as well.
   - It is a small muscle on the posterior aspect of the elbow joint, in posterior compartment of arm.
   - It originates from the humerus (posterior surface of lateral condyle and inserts into ulna (on posterior surface and olecranon).
   - It is innervated by a branch of the radial nerve (C7,8) in the radial groove of the humerus.

High Yield Points

- **Biceps brachii** is a *powerful* supinator at the radioulnar joint and helps in screw driving movements
- Anconeus muscle: Assists triceps in extending forearm; stabilizes elbow joint; may abduct ulna during pronation.

Muscles of Forearm

Table 34: Muscles of anterior compartment of forearm

Muscle	Proximal attachment	Distal attachment	Innervation	Chief action
Superficial (first) layer				
Pronator teres				
Ulnar head	Coronoid process	Middle of convexity of lateral surface of radius	Median nerve (C6, **C7**)	Pronates and flexes forearm (at elbow)
Humeral head	Medial epicondyle of humerus (common flexor origin)			
Flexor carpi radialis (FCR)		Base of 2nd metacarpal		Flexes and abducts hand (at wrist)
Palmaris longus		Distal half of flexor retinaculum and apex of palmar aponeurosis	Median nerve (C7, C8)	Flexes hand (at wrist) and tenses palmar aponeurosis
Flexor carpi ulnaris (FCU)				
Humeral head			Ulnar nerve (C7, **C8**)	Flexes and adducts hand (at wrist)
Ulnar head	Olecranon and posterior border of ulna (via aponeurosis)	Pisiform, hook of hamate, 5th metacarpal		
Intermediate (second) layer				
Flexor digitorum superficialis (FDS)				
Humeroulnar head	Medial epicondyle (common flexor orgin and coronoid process)	Shafts of middle phalanges of medial four digits	Median nerve (C7, C8, T1)	Flexes middle phalanges at proximal interphalangeal joints of middle four digits; acting more strongly, it also flexes proximal phalanges at metacarpophalangeal joints
Radial head	Superior half of anterior border			

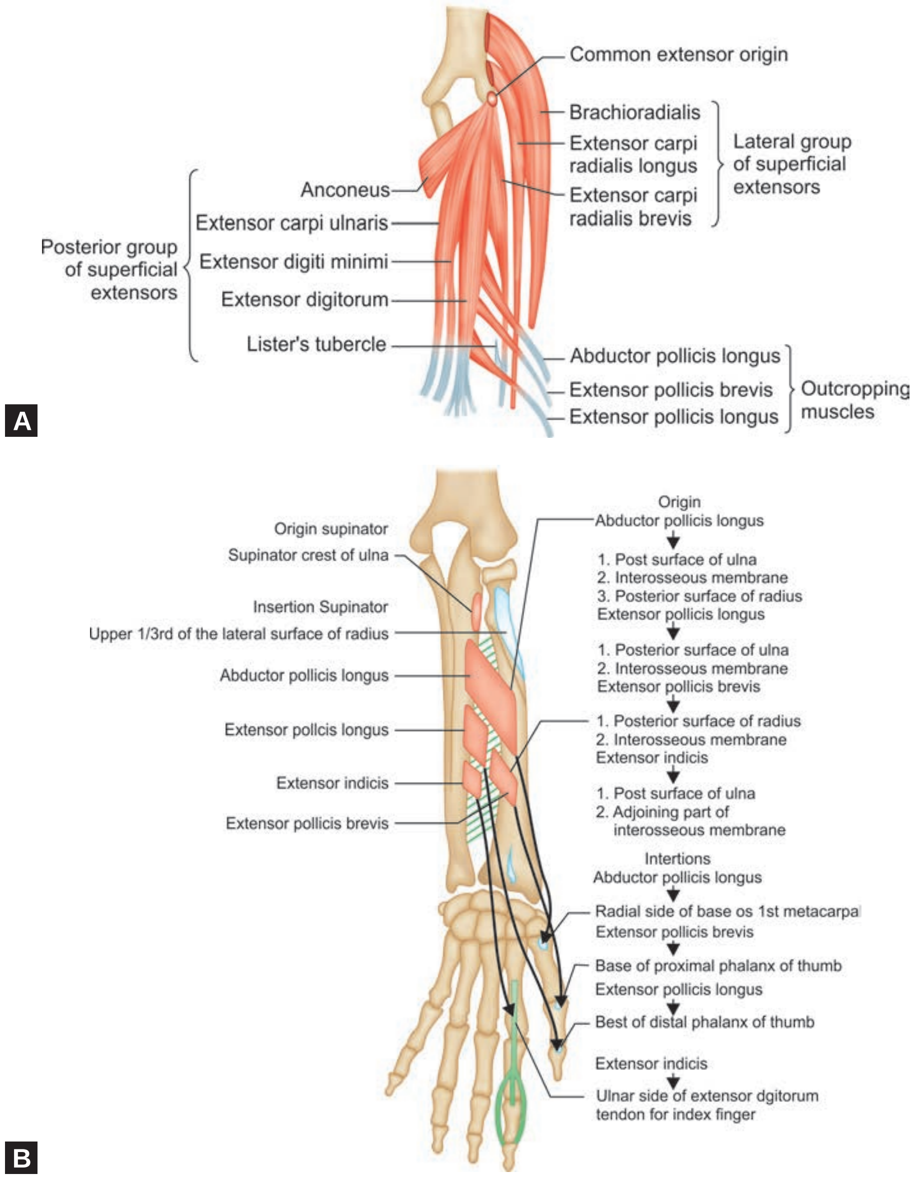
Muscle	Proximal attachment	Distal attachment	Innervation	Chief action
Deep (third) layer				
Flexor digitorum profundus (FDP)				
Medial part	Proximal three quarters of medial and anterior surface of ulna and interosseous membrane	Bases of distal phalanges of 4th and 5th digits	Ulnar nerve (C8, **T1**)	Flexes distal phalanges 4 and 5 at distal interphalangeal joints
Lateral part		Bases of distal phalanges of 2nd and 3rd digits	Anterior interosseous nerve, from median nerve (**C8**, T1)	Flexes distal phalanges 2 and 3 at distal interphalangeal joints
Flexor pollicis longus (FPL)	Anterior surface of radius and adjacent interosseous membrane	Base of distal phalanx of thum		Flexes phalanges of 1st digit (thumb)
Pronator quadratus	Distal quarter of anterior surface of ulna	Distal quarter of anterior surface of radius		Pronates forearm; deep fibers bind radius and ulna together

Flexor digitorum superficialis tendon splits into medial and lateral bands, which pass around the flexor digitorum profundus tendon and insert on the base of the middle phalanx, while the flexor digitorum profundus tendon inserts on the base of the distal phalanx as a single tendon.

Table 35: Muscles of posterior compartment of forearm

Muscle	Proximal attachment	Distal attachment	Innervation	Main action
Superficial layer				
Brachioradialis	Proximal two-thrids of supra-epicondylar ridge of humerus	Lateral surface of distal end of radius proximal to styloid process	Radial nerve (C5, **C6**, C7)	Relatively weak flexion of forearm; maximal when forearm is in midpronated position
Extensor carpi radialis longus (ECRL)	Lateral supra-epicondylar ridge of humerus	Dorsal aspect of base of 2nd metacarpal	Radial nerve (C6, C7)	Extend and abduct, hand at the wrist joint; ECRL active during clenching
Extensor carpiradialis brevis (ECRB)	Lateral epicondyle of humerus (common extensor origin)	Dorsal aspect of base of 3rd metacarpal	Deep branch of radial nerve (C7, C8)	
Extensor digitorum		Extensor expansions of medial four digits		Extends medial four digits primarily at metacarpophalangeal joints
Extensor digitiminimi (EDM)		Extensor expansion of 5th digit		Extends 5th digit primarily at metacarpophalangeal joint, secondarily at interphalangeal joint
Extensor carpiulnaris (ECU)	Lateral epicondyle of humerus; posterior border of ulna via a shared aoneurosis	Dorsal aspect of base of 5th metacarpal		Extends and adducts hand at wrist joint (also active during fist clenching)
Deep layer				
Supinator	Lateral epicondyle of humerus; radial collateral and anular ligaments; supinator fossa; crest of ulna	Lateral, posterior, and anterior surfaces of proximal third of radius	Deep branch of radial nerve (C7, **C8**)	Supinates forearm; rotates radius to turn palm anteriorly or superiorly (if elbow is flexed)
Extensor indicis	Posterior surface of distal third of ulna and interosseous membrane	Extensor expansion of 2nd digit	Posterior interosseous nerve (**C7**, C8), continuation of deep branch of radial nerve	Extends 2nd digit (enabling its independent extension); helps extend hand at wrist
Outcropping muscles of deep layer				

Muscle	Proximal attachment	Distal attachment	Innervation	Main action
Abductor pollicis longus (APL)	Posterior surface of proximal halves of ulna, radius, and interosseous membrane	Base of 1st metacarpal	Posterior interosseous nerve (C7, C8), continuation of deep branch of radial nerve	Abducts thumb and extends it at carpometacarpal joint
Extensor pollicis longus (EPL)	Posterior surface of middle third of ulna and interosseous membrane	Dorsal aspect of base of distal phalanx of thumb		Extends distal phalanx of thumb at interphalangeal joint; extends metacarpophalangeal and carpometacarpal joints
Extensor pollicis brevis (EPB)	Posterior surface of distal third of radius and interosseous membrane	Dorsal aspect of base of proximal phalanx of thumb		Extends proximal phalanx of thumb at metacarpophalangeal joint; extends carpometacarpal joint



Figs. 50A and B: Posterior forearm muscles (origin and insertion)

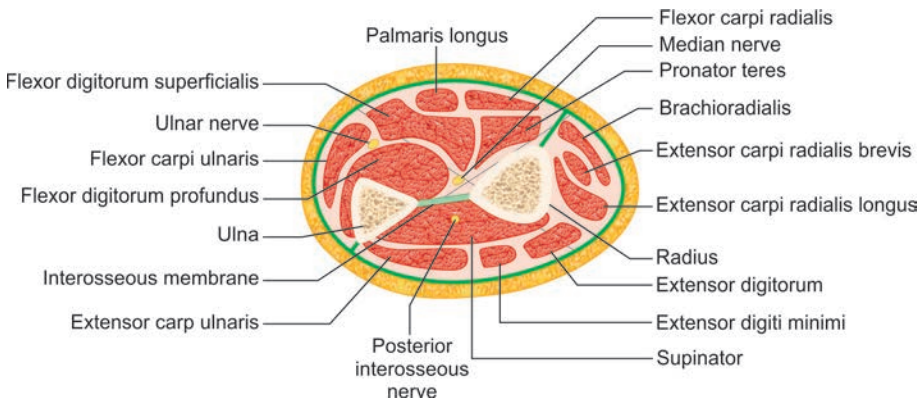


Fig. 51: Transverse section of forearm region

ASSESSMENT QUESTIONS

1. The pronator quadratus has the same innervation as of the following muscle: *(AIIMS 2003)*
a. Flexor digitorum superficialis
b. Palmaris longus
c. Flexor pollicis longus
d. Flexor digitorum profundus of middle finger

2. Muscle in extension compartment of forearm which causes flexion of elbow? *(NEET Pattern 2014)*
a. Brachioradialis
b. Abductor pollicis longus
c. Extensor pollicis longus
d. Extensor carpi radialis longus

3. The nerve supply to pronator muscle of distal radioulnar joint is: *(JIPMER 2003)*
a. Median nerve
b. Ulnar nerve
c. Anterior interosseous nerve
d. Posterior interosseous nerve

4. Which of the following is NOT the muscles of superficial anterior compartment of forearm? *(NEET Pattern 2013)*
a. FDS
b. FPL
c. FCR
d. Palmaris longus

ANSWERS AND EXPLANATIONS

1. c. Flexor pollicis longus
- Pronator quadratus is supplied by deep branch of median nerve—the anterior interosseous nerve, which also innervates flexor pollicis longus.
- Flexor digitorum profundus of middle finger is usually supplied by the anterior interosseous nerve but may be supplied by the ulnar nerve in 20% of the population (a variation). Hence, we exclude choice d here, as it is less appropriate than choice c.
- Flexor digitorum superficialis and palmaris longus are supplied by the main trunk of median nerve.

2. a. Brachioradialis
- Muscle of extensor compartment but causing elbow flexion in midprone position is brachioradialis muscle.

3. c. Anterior interosseous nerve
- Pronator teres muscle (median nerve) causes pronation at proximal radioulnar joint.
- Pronation at distal radioulnar joint is carried out by pronator quadratus, supplied by the anterior interosseous nerve.

4. b. FPL
- Muscles of superficial anterior compartment of forearm: FCR, FDS, FCU pronator teres and palmaris longus.
- Muscles of deep anterior compartment of forearm: FDP, FPL, pronator quadratus.

Muscles of Hand

ASSESSMENT QUESTIONS

1. Muscles causing supination of forearm: *(AIPG - 2015 Pattern)*
a. Biceps brachii
b. Brachioradialis
c. FDS
d. Anconeus

2. All of the following muscles have dual nerve supply *EXCEPT*: *(NEET Pattern 2015)*
a. Subscapularis
b. Pectoralis major
c. Pronator teres
d. Flexor digitorum profundus

3. Which of the following muscle has dual nerve supply?
a. Flexor digitorum profundus
b. Interossei
c. Palmaris brevis
d. Flexor carpi ulnaris

4. Which muscle originates from tendon of other muscle? *(NEET Pattern 2015)*
a. Palmaris longus
b. FCR
c. Lumbricals
d. Adductor pollicis

5. A person is able to abduct his arm, internally rotate it, place the back of hand on the lumbosacral joint, but is not able to lift it from back. What is the etiology? *(AIIMS 2010)*

a. Subscapularis tendon tear
b. Teres major tendon tear
c. Long head of biceps tendon tear
d. Acromioclavicular joint dislocation

6. When a heavy object in hand is lowered, the extension at the elbow is brought about by: *(AIIMS 2003)*

a. Active shortening of the extensors.
b. Passive shortening of the extensors
c. Active lengthening of the flexors
d. Active shortening of the flexors

7. While carrying a heavy suitcase the downward dislocation of glenohumeral joint is resisted by the following muscles *EXCEPT*: *(AIIMS 2002)*

a. Deltoid
b. Coracobrachialis
c. Short head of biceps
d. Latissimus dorsi

8. C8,T1 supplies following muscles *EXCEPT*:

a. Extensor indicis
b. 3rd and 4th lumbrical(s)
c. Abductor pollicis brevis
d. Palmar interossei

9. 'Dropped shoulder' occurs due to paralysis of: *(NEET Pattern 2014)*

a. Deltoid
b. Teres major
c. Trapezius
d. Serratus anterior

10. Winging of scapula is due to paralysis of: *(NEET Pattern 2012)*

a. Rhomboids
b. Trapezius
c. Latissimus dorsi
d. Serratus anterior

11. A 50-year-old female has undergone mastectomy for Ca Breast. After mastectomy, patient is not able to extend, adduct and internally rotate the arm. Nerve supply to which of the following muscles is damaged? *(AIIMS 2012)*

a. Pectoralis major
b. Teres minor
c. Latissimus dorsi
d. Long head of Triceps

12. Teres major muscle is supplied by: *(NEET Pattern 2014)*

a. Upper subscapular nerve
b. Lower subscapular nerve
c. Dorsal scapular nerve
d. Axillary nerve

13. The muscle that crosses both shoulder and elbow joint is:

a. Coracobrachialis
b. Medial head of triceps
c. Biceps brachii
d. Brachialis

14. Oblique cord is related to: *(NEET Pattern 2014)*

a. Supinator
b. Long flexors
c. Short flexors
d. Lumbricals

15. Anatomically a muscle of upper limb, but functionally related to the trunk is: *(AIIMS 2013)*

a. Rhomboideus major
b. Latissimus dorsi
c. Trapezius
d. Levator scapulae

16. A man cannot do abduction and internal rotation of arm. Which of the following muscle is responsible for the both movements? *(PGIC 2013)*

a. Pectoralis major
b. Subscapularis
c. Deltoid
d. Supraspinatus
e. Teres major

ANSWERS AND EXPLANATIONS

1. a. Biceps brachii > b. Brachioradialis

- Biceps brachii is a powerful supinator, especially when the elbow is in flexion.
- Supination in extended elbow is carried out by supinator muscle.
- Brachioradialis causes elbow flexion, especially in mid-prone position. It can bring the forearm in midprone position by carrying out slight pronation and supination. It is the muscle tested for supinator reflex.

2. c. Pronator teres

- Pronator teres is supplied by median nerve.

Muscles	Dual nerve supply
Brachialis	Musculocutaneous (motor) and radial nerve (proprioceptive)
Pectoralis major	Medial pectoral nerve Lateral pectoral nerve
Subscapularis	Upper subscapular nerve Lower subscapular nerve
Flexor digitorum profundus	Medial half - Ulnar nerve Lateral half - Anterior interosseus nerve
Flexor pollicis brevis	Superficial head - Median nerve Deep head - Deep branch of ulnar nerve
Opponens pollicis	Median and ulnar nerve

3. **a. Flexor digitorum profundus**
   - Hybrid (composite) muscles have more than motor nerve supply, e.g., lateral half of flexor digitorum profundus is supplied by median nerve and the medial half by ulnar nerve.

4. **c. Lumbricals**
   - The four tendons of flexor digitorum profundus give origin to four lumbricals.

5. **a. Subscapularis tendon tear**
   - This test is called **'lift off'** test and is to check medial rotation at shoulder joint done by subscapularis muscle.

   Test:
   - The patient has to first place the back of the hand on lumbosacral joint at the back region.
   - Now he is asked to lift the back of the hand from the lumbosacral joint (requires medial rotation at shoulder joint)
   - In **subscapularis tendon tear**, the test becomes positive and the patient is unable to lift off the hand from the back.

   Belly press' test another test to check the integrity of subscapularis muscle.
   - The hand is placed on the abdomen in maximal internal rotation.
   - The patient is then asked to press against the abdomen with his hand in attempt to maintain maximum internal rotation.
   - Now, if the arm falls back and the patient is unable to maintain internal rotation, the test is considered positive.

6. **c. Active lengthening of the flexors**
   - When a heavy object in hand is lowered, the extension at the elbow is brought about by active relaxation (lengthening) of the flexors - biceps (antagonist).
   - The antagonist muscle opposes (antagonizes) the concerned movement to makes it more controlled and precise. Though it is opposing the movement but does it with partial resistance, so that the resultant movement becomes smooth. For example, biceps opposing extension at elbow partially, so that extension becomes slow and smooth, as occurs in lowering down a heavy object in hand.
   - Normal extension at the elbow is by active contraction (shortening) of the extensor - triceps (agonist).

7. **d. Latissimus dorsi**
   - The axis of pull of latissimus dorsi doesn't cross the shoulder joint and cannot have a shunt action on the joint.
   - Shunt muscles are those which stabilise the corresponding joint, when they are not producing a movement at the joint.
   - For example while carrying a heavy suitcase the downward dislocation of glenohumeral joint is resisted by the muscles like deltoid, coracobrachialis and short head of biceps.

8. **a. Extensor indicis**
   - The muscle of the back of forearm, extensor indicis is supplied by the radial nerve branch-PIN (posterior interosseous nerve - C7, 8 fibres).
   - All the hand muscles like 3 and 4 lumbricals, abductor pollicis brevis, palmar interossei are supplied by C-8 and T-1 root values.

9. **c. Trapezius**
   - Scapula is positioned and maintained on the posterior wall of the thorax by the tone and balance of the muscles attached to it. If trapezius muscle is paralyzed. the balance is upset resulting in dropped shoulder.

10. **d. Serratus anterior > b. Trapezius > a. Rhomboids**
    - Winging of scapula is undue prominence of medial border of scapula, especially when an attempt is made for scapular protraction, occurs due to paralysis of serratus anterior muscle.
    - Secondary to serratus anterior palsy, a winged scapula is also caused by trapezius and rhomboid palsy involving the accessory nerve and the dorsal scapular nerve, respectively.

11. **c. Latissimus dorsi**
    - Mastectomy may damage thoracodorsal nerve leading to paralysis of latissimus dorsi. The patient finds difficulty in shoulder extension, medial rotation and adduction.

12. **b. Lower subscapular nerve**
    - Teres major is supplied by the lower subscapular nerve, which also supplies subscapularis muscle.

13. **c. Biceps brachii**
    - Long head of biceps brachii takes origin from the supraglenoid tubercle of scapula, crosses the shoulder joint and subsequently elbow joint to insert into the radial tuberosity of bone radius.

14. **a. Supinator**
    - Oblique cord is a small fibrous band on the deep head of supinator which extends lateral side of ulnar tuberosity to the lower part of radial tuberosity. Its fibres run inferolaterally (opposite to the interosseous membrane).
    - It is considered as the degenerate tendon of flexor pollicis longus. Function unclear.

15. **b. Latissimus dorsi**
    - Latissimus dorsi is a muscle of upper limb (supplied by brachial plexus) but has migrated to the trunk region for better functionality.

16. **c. Deltoid**
    - Deltoid is a power abductor at the shoulder joint, which is carried out by the lateral fibres.
    - Anterior fibres of deltoid act for flexion and medial rotation at shoulder joint and posterior fibres for extension and lateral rotation.
    - Pectoralis major work for adduction (not abduction).
    - Subscapularis and teres major muscles are not involved in abduction, though both of them carry out medial rotation.

Arterial Supply

- The axial vessel for the upper limb is the **subclavian artery,** which arises from the brachiocephalic trunk on the right and directly from the arch of the aorta on the left.
- It is divided into **three parts** that are successively anterior, deep and lateral to **scalenus anterior**. The second and third parts are in close relation to the primary ventral rami of C7, C8 and T1, and to the middle and lower trunks of the brachial plexus.
- The subclavian artery becomes the axillary artery at the lateral border of the first rib. The axillary artery passes along with the divisions of the brachial plexus deep to the clavicle, and is intimately related to the cords below it. It passes deep to pectoralis minor (which divides it into three parts) and becomes the brachial artery at the lower border of teres major.
- The **brachial artery** is closely related to the median nerve in the arm, both **reach cubital fossa**, on the anterior aspect of the elbow, lying medial to the tendon of biceps brachii and deep to the bicipital aponeurosis. The artery divides into the **radial** and **ulnar** arteries in the cubital fossa, just distal to the elbow.
- The larger branch **ulnar artery** gives common interosseous artery arises close to its origin and subsequently divides into the anterior and posterior interosseous arteries. **Anterior interosseous artery** (and nerve) descend inferiorly on the anterior aspect of interosseous membrane. The posterior interosseous artery is separated from the membrane by the deep extensor muscles.
- Ulnar artery is the **major artery** to hand and continues as **superficial palmar arch**, whereas radial artery contributes to deep palmar arch.
- **Collateral circulation**
  - Collateral circulation formed by branches of the thyrocervical trunk with the circumflex humeral and subscapular arteries allow survival of **upper limb** in cases of blockage in subclavian or axillary arteries.
  - Profunda brachii accompanies the radial nerve and contributes to the collateral circulation **about the elbow** with the ulnar collateral and recurrent vessels and the radial collateral and recurrent vessels.
  - Anastomosis between superficial and deep palmar arches **in hand.**
  - **Thyrocervical trunk** is a branch from the *first part* of subclavian artery. It gives three branches **SIT**: S – Supra-scapular artery; I – Inferior thyroid artery and T – Transverse cervical artery.
- **Suprascapular Artery** is a branch of the thyrocervical trunk, passes over the superior transverse scapular ligament. It supplies the supraspinatus and infraspinatus muscles and the shoulder and acromioclavicular joints. It also participates in **scapular anastomosis**.
- **Dorsal Scapular Artery:** In the majority of population, the dorsal scapular artery arises from the **third** (or less often the second) part of the subclavian artery. Occasionally it is given by **first** part of subclavian artery. It may be given by first part of subclavian via thyrocervical trunk → transverse cervical artery (deep branch) → dorsal scapular artery. It is **accompanied by** the dorsal scapular nerve and supplies the levator scapulae, rhomboids, and serratus anterior muscles.

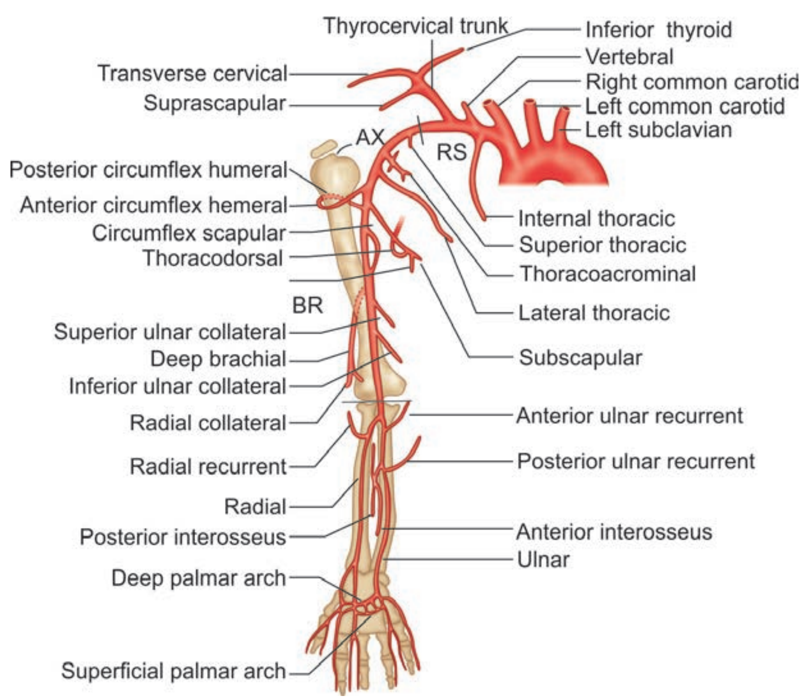


Fig. 52: Arterial supply (upper limb). RS - Right subclavian artery; Ax - Axillary artery; BR - Brachial artery

Table 36: Arteries or proximal upper limb (shoulder region and arm)		
Artery	**Origin**	**Course**
Internal thoracic	Inferior surface of the first part — Subclavian artery	Descends, inclining anteromedially, posterior to sternal end of clavicle and first costal cartilage; enters thorax to descend in parasternal plane; gives rise to perforating branches, anterior intercostal, musculophrenic, and superior epigastric arteries
Thyrocervical trunk	Anterior surface of first part — Subclavian artery	Ascends as a short, stout trunk, giving rise to four branches; suprascapular, ascending cervical, inferior thyroid arteries, and the cervicodorsal trunk
Suprascapular	Thyrocervical (or as direct branch of subclavian artery)	Passes inferolaterally crossing anterior scalene muscle, phrenic nerve, subclavian artery, and brachial plexus running laterally posterior and parallel to clavicle; next it passes over transverse scapular ligament to supraspinous fossa; then lateral to scapular spine (deep to acromion) to infraspinous fossa on posterior surface of scapula
Superior thoracic	First part (as only branch) — Axillary artery	Runs anteromedially along superior border of pectoralis minor; then passes between it and pectoralis major to thoracic wall; helps supply 1st and 2nd intercostal spaces and superior part of serratus anterior
Thoraco-acromial	Second part (first branch) — Axillary artery	Curls around superomedial border of pectoralis minor; pierces costocoracoid membrane (clavipectoral fascia); divides into four branches; pectoral, deltoid, acromial, and clavicular
Lateral thoracic	Second part (second branch) — Axillary artery	Descends along axillary border of pectoralis minor; follows it ontothoracic wall, supplying lateral aspect of breast
Circumflex humeral (anterior and posterior)	Third part (sometimes via a common trunk) — Axillary artery	Encircle surgical neck of humerus, anastomosing with each other laterally; larger posterior branch traverses quadrangular space
Subscapular	Third part (largest branch of any part) — Axillary artery	Descends from level of inferior border of subscapularis along lateral border of scapula, dividing within 2–3 cm into terminal branches, the circumflex scapular and thoracodorsal arteries
Circumflex scapular	Subscapular artery	Curves around lateral border of scapula to enter infraspinous fossa, anastomosing with suprascapular artery
Thoracodorsal	Subscapular artery	Continues course of subscapular artery, descending with thoracodorsal nerve to enter apex of latissimus dorsi
Profunda brachii (deep artery of arm)	Near its origin — Brachial artery	Accompanies radial nerve along radial groove of humerus, supplying posterior compartment of arm and participating in periarticular arterial anastomosis around elbow joint
Superior ulnar collateral	Near middle of arm — Brachial artery	Accompanies ulnar nerve to posterior aspect of elbow; anastomoses with posterior ulnar recurrent artery
Inferior ulnar collateral	Superior to medial epicondyle of humerus — Brachial artery	Passes anterior to medial epicondyle of humerus to anastomose with anterior ulnar collateral artery

High Yield Point

- Suprascapular artery passes over the **superior** transverse scapular ligament, whereas the suprascapular nerve passes **under** the ligament.

Axillary Artery

- **Axillary artery** extends from the **lateral border** of the first rib to the **lower border** of the teres major muscle, where it becomes the **brachial artery**. The axillary artery is followed by the **axillary vein on medial side**, is divided into three parts by the **pectoralis minor** muscle.
- It has three parts and **six branches**. First part (1 branch – superior thyroid artery); second part (2 branches – thoracoacromial and lateral thoracic artery) and third part (3 branches – anterior and posterior circumflex humeral arteries and subscapular artery).
  - **Superior Thoracic Artery** supplies the intercostal muscles in the first and second anterior intercostal spaces.

- **Thoracoacromial Artery** is a short branch from the second part of the axillary artery and has pectoral, clavicular, acromial, and deltoid branches. It **pierces the clavipectoral fascia**.
- **Lateral Thoracic Artery** runs along the lateral border of the pectoralis minor muscle, supplies the pectoralis major, pectoralis minor, serratus anterior muscles and send branches to **mammary gland**.
- **Subscapular Artery** is the largest branch of the axillary artery, divides into the thoracodorsal and circumflex scapular arteries.
  - **Thoracodorsal Artery** accompanies the thoracodorsal nerve and supplies the latissimus dorsi muscle and the lateral thoracic wall.
  - **Circumflex Scapular Artery** passes posteriorly into the **upper triangular space**, ramifies in the infraspinous fossa and **anastomoses** with branches of the dorsal scapular and suprascapular arteries.
- **Anterior Humeral Circumflex Artery** passes anteriorly around the surgical neck of the humerus, anastomoses with the posterior humeral circumflex artery.
- **Posterior Humeral Circumflex Artery** runs posteriorly with the axillary nerve through the **quadrangular space**, anastomoses with the anterior humeral circumflex artery and an ascending branch of the profunda brachii artery.

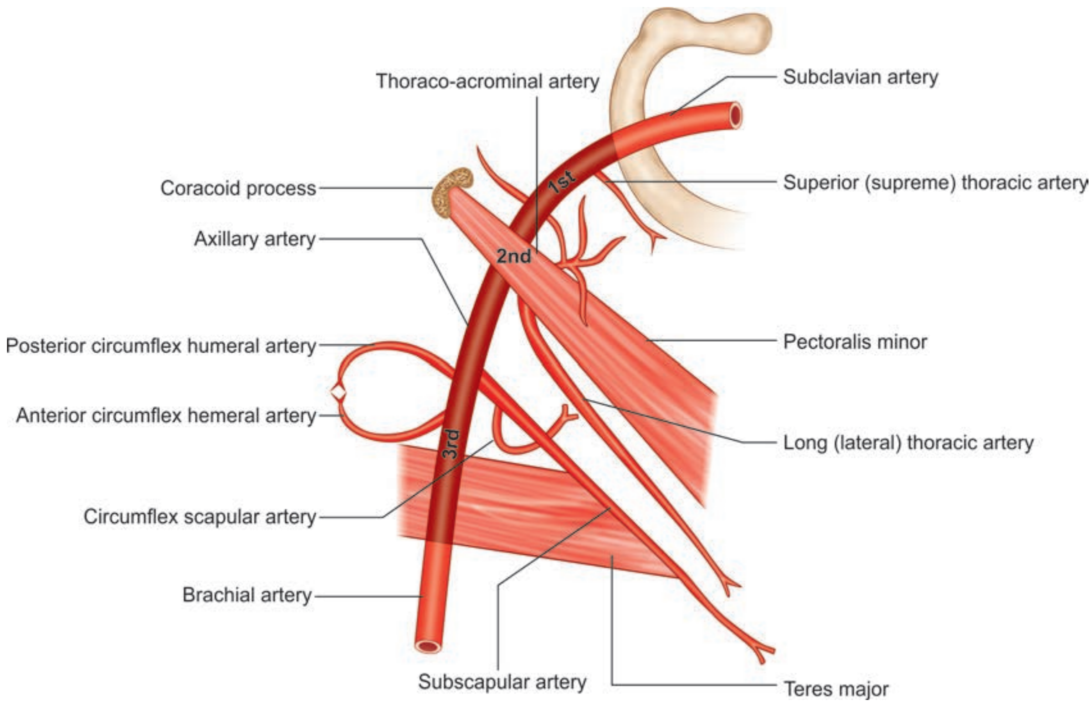
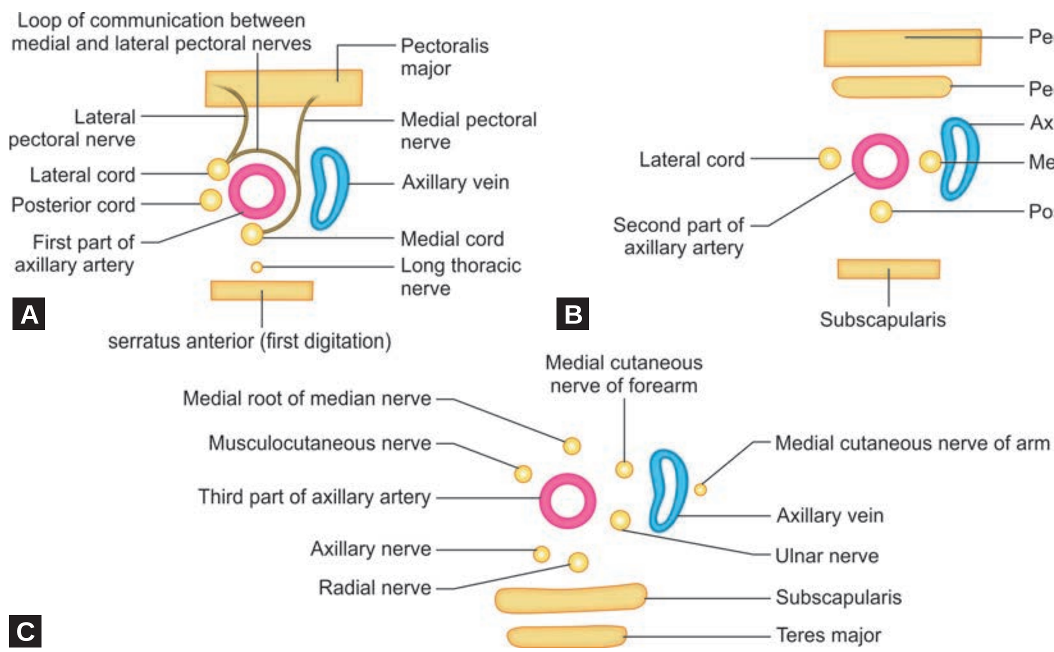


Fig. 53: Axillary artery extent and branches

Relations of Axillary Artery

Table 37: Relations of the axillary artery

Part	Anterior	Posterior	Medial	Lateral
First part	• Pectoralis major (clavicular part) • Loop of communication between lateral and medial pectoral nerves	• Medial cord of brachial plexus • Long thoracici nerve • Serratus anterior (first digitation)	Axially vein	Lateral and posterior cords of brachial plexus
Second part	Pectoralis minor	• Posterior cord of brachial plexus • Subscapularis	• Medial cord of brachial plexus • Axillary vein	Lateral cord of brachial plexus
Third part	Medial root of medial nerve	• Radial nerve • Axillary nerve • Subscapularis (in the upper part) • Teres major (in the lower part)	• Axillary vein • Medial cutaneous nerve of forearm • Ulnar nerve	Musculocutaneous nerve



Figs. 8.54A to C: Relations of the axillary artery: A, first part; B, second part; C, third part

ASSESSMENT QUESTION

1. **Which of the following statement(s) is TRUE regarding axillary artery?** *(PGIC 2015)*
   a. Start from upper border of clavicle
   b. Ulnar nerve lies medially to distal 1/3 of artery
   c. Radial nerve lies posteriorly distal 1/3 of artery
   d. Axillary vein lies laterally to proximal 1/3 of the artery
   e. End at lower border of pectoralis minor.

ANSWER AND EXPLANATION

1. **b. Ulnar nerve lies medially to distal 1/3 of artery; c. Radial nerve lies posteriorly distal 1/3 of artery**
   - Subclavian artery crosses the **outer border of first rib** to continue as axillary artery, which itself continue as brachial artery at the **lower border of teres major.**
   - It is crossed and covered by pectoralis minor, which divides the artery into three parts.
   - Axillary vein lies medial **(not lateral)** to the distal part of the artery in the axilla.

Scapular Anastomosis

- **Scapular anastomosis** is an arterial system connecting each **subclavian artery** and the corresponding **axillary artery**, forming a collateral circulation around the scapula.
- It allows blood to flow past the shoulder joint regardless of the position of the arm and also provides a **collateral** pathway towards the limb in case of **blockage** at the subclavian or axillary artery.
- The participating arteries are:
  - Branches from the **subclavian artery**
    - Suprascapular artery
    - Dorsal scapular artery
  - Branches from the **axillary artery**
    - Subscapular artery (and its branch circumflex scapular artery)
    - Anterior circumflex humeral artery
    - Posterior circumflex humeral artery
- There are numerous anastomosing arteries but **two major channels** are prominent.
  - Subclavian artery (Ist part) → thyrocervical trunk → suprascapular artery → circumflex scapular artery → subscapular artery → axillary artery (IIIrd part)
  - Subclavian artery (IIIrd part) → dorsal scapular artery → subscapular artery → axillary artery (IIIrd part)
- In the majority of population, the **dorsal scapular artery** arises from the third (or less often the second. part of the subclavian artery. **Occasionally** it is given by first part of subclavian via thyrocervical trunk → transverse cervical artery (deep branch) → dorsal scapular artery → subscapular artery → axillary artery (scapular anastomosis).

- A minor anastomosis is present **on the acromion process** between acromial branches of
  - Suprascapular artery (branch of 1st part of subclavian artery)
  - Thoracoacromial artery (branch of 2nd part of axillary artery)
  - Posterior circumflex humeral artery (branch of 3rd part of axillary artery)

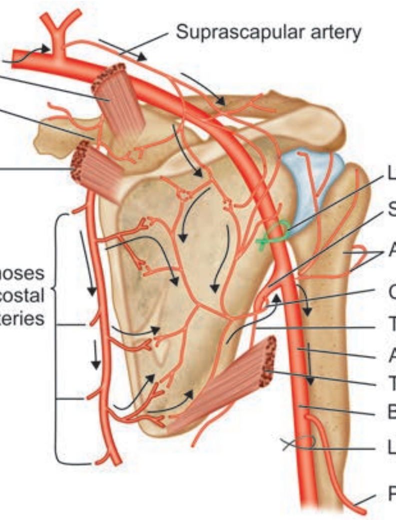


Fig. 55: Scapular anastomosis

ASSESSMENT QUESTIONS

1. In a subclavian artery block at the outer border of first rib all of the following arteries help in maintaining the circulation to upper limp *EXCEPT*: *(AIIMS 2008; 2011)*
a. Thyrocervical trunk
b. Suprascapular
c. Subscapular
d. Superior thoracic

2. Which branch of subclavian contributes to scapular anastomosis?
a. Vertebral
b. Internal thoracic
c. Thyrocervical truck
d. Dorsal scapular

3. Occlusion occurs at the 2nd part of axillary artery, blood flow is maintained by anastomosis between: *(AIIMS 2007)*
a. Anterior and posterior circumflex humeral artery
b. Circumflex scapular and posterior circumflex humeral artery
c. Deep branch of transverse cervical artery and subscapular artery
d. Anterior circumflex humeral and subscapular artery

4. Anastomosis around the shoulder is between branches of: *(NEET Pattern 2014)*
a. 1st part of subclavian and 1st part of axillary artery
b. 1st part of subclavian and 3rd part of axillary artery
c. 3rd part of subclavian and 2nd part of axillary artery
d. 3rd part of subclavian and 3rd part of axillary artery

ANSWERS AND EXPLANATIONS

1. d. Superior thoracic
- Scapular anastomosis maintains circulation to the upper limb in this clinical situation, which doesn't involve **superior thoracic** artery.
- A block of subclavian artery distally at the outer border of first rib (e.g., Cervical rib) or **axillary artery** proximally (e.g., axillary metastasis of Ca Breast) compromises blood supply to the upper limb.
- Collateral circulation (scapular) opens up to maintain the circulation to the ischaemic zones.

2. d. Dorsal scapular > c. Thyrocervical truck
- Conventionally described the deep transverse cervical artery (a branch of the thyrocervical trunk of the first part of the subclavian artery) takes part in the scapular anastomosis.
- Recently it has been established that the dorsal scapular artery (a branch of third part of subclavian artery) being more constant than the deep cervical artery, takes part in scapular anastomosis.
- **Thyrocervical trunk** also participate in scapular anastomosis by giving suprascapular artery and transverse cervical artery.

3. c. Deep branch of transverse cervical artery and subscapular artery
- Scapular anastomosis is present between branches of subclavian artery **(deep branch of transverse cervical)** and axillary artery **(subscapular)**, which continue supplying the distal ischemic region.
- **Anterior and posterior circumflex arteries** are branches of third part of axillary artery.
- **Circumflex scapular and posterior circumflex humeral artery** are branches of third part of axillary artery.
- **Anterior circumflex humeral and subscapular** are branches of third part of axillary artery.

4. b. 1st part of subclavian and 3rd part of axillary artery > d. 3rd part of subclavian and 3rd part of axillary artery
- Anastomosis around the shoulder (scapular anastomosis) is generally mentioned between first part of subclavian artery and third part of axillary artery. But since dorsal scapular artery is more often a branch of third part of subclavian artery, it is also an anastomosis between third part of subclavian artery and third part of axillary artery.

High Yield Points

- Anastomosis around the scapula is formed by the dorsal scapular (occasionally arising as deep branch of the transverse cervical), suprascapular, and subscapular and circumflex scapular branch arteries.

Brachial Artery

- Brachial artery extends from the **inferior border** of the teres major muscle to its bifurcation in the cubital fossa.
- It is accompanied by the basilic vein in the middle of the arm, descends down to the center of the cubital fossa, **medial to the biceps tendon**, lateral to the median nerve, deep to the bicipital aponeurosis.
- The **stethoscope** is placed on this artery while taking **blood pressure** and listening to the arterial pulse. It divides into the **radial** and **ulnar arteries** at the level of the radial neck (1 cm below elbow bend) in the cubital fossa.
- It gives three branches in the arm:
  - **Profunda** (deep) **Brachial artery** descends posteriorly in the **radial groove** (with radial nerve. and gives off an ascending branch, which anastomoses with the descending branch of the posterior humeral circumflex artery. It divides into two branches:
    - Middle collateral artery (posterior descending branch of the profunda brachii artery)
    - Radial collateral artery (anterior descending branch of the profunda brachii artery)
  - **Superior Ulnar Collateral Artery** pierces the medial intermuscular septum and accompanies the ulnar nerve behind the septum and medial epicondyle.
  - **Inferior Ulnar Collateral Artery** (supratrochlear artery) arises just above the elbow and descends in front of the medial epicondyle.

Radial Artery

- **Radial artery** is the smaller lateral branch of the brachial artery in the **cubital fossa** and descends laterally under cover of the brachioradialis muscle, with the superficial radial nerve on its lateral side.
- It curves over the radial side of the carpal bones **deep to the tendons of** the abductor pollicis longus muscle, the extensor pollicis longus and brevis muscles, and over the surface of the scaphoid and trapezium bones.
- It becomes **a content of anatomical snuffbox** and enters the palm by passing between the two heads of the first dorsal interosseous muscle and then between the heads of the adductor pollicis muscle, and divides into the **princeps pollicis artery** and the **deep palmar arch** (refer).
- **Branches**:
  - **Radial Recurrent Artery** arises from the radial artery just below its origin and anastomoses with the radial collateral branch of the profunda brachii artery.
  - **Palmar Carpal Branch** joins the palmar carpal branch of the ulnar artery and forms the palmar carpal arch.
  - **Superficial Palmar Branch** passes through the thenar muscles and anastomoses with the superficial branch of the ulnar artery to complete the **superficial palmar arterial arch**.
  - **Dorsal Carpal Branch** joins the dorsal carpal branch of the ulnar artery and the dorsal terminal branch of the anterior interosseous artery to form the dorsal carpal rete.
  - **Princeps Pollicis** descends along the ulnar border of the first metacarpal bone and divides into two proper digital arteries for each side of the thumb.
  - **Radialis Indicis** may arise from the deep palmar arch or the princeps pollicis artery.

Ulnar Artery

- **Ulnar artery** is the **larger** medial branch of the brachial artery **in the cubital fossa**. It descends in the forearm and enters the hand **anterior to the flexor retinaculum**, lateral to the pisiform bone, and medial to the hook of the hamate bone.
- It divides into the **superficial palmar arch** (refer) and the deep palmar branch (which join the radial artery to complete the deep palmar arch.
- Branches:
  - **Anterior Ulnar Recurrent Artery** anastomoses with the inferior ulnar collateral artery.
  - **Posterior Ulnar Recurrent Artery** anastomoses with the superior ulnar collateral artery.
  - **Common Interosseous Artery** arises from the lateral side of the ulnar artery and divides into the anterior and posterior interosseous arteries.
    - **Anterior Interosseous Artery** descends with the anterior interosseous nerve in front of the interosseous membrane, perforates the interosseous membrane **to anastomose with** the posterior interosseous artery and join the dorsal carpal network.

- **Posterior Interosseous Artery** gives rise to the interosseous recurrent artery, which anastomoses with a middle collateral branch of the profunda brachii artery. It descends behind the interosseous membrane in company with the posterior interosseous nerve and **anastomoses with** the dorsal carpal branch of the anterior interosseous artery.

- **Palmar Carpal Branch** joins the palmar carpal branch of the radial artery to form the palmar carpal arch.
- **Dorsal Carpal Branch** passes around the ulnar side of the wrist and joins the dorsal carpal rete.

Elbow Anastomosis and Forearm Arteries

Table 38: Arteries of forearm and wrist

Artery	Origin	Course in forearm
Ulnar	As larger terminal branch of brachial artery in cubital lossa	Descends inferomedially and then directly inferiorly, deep to superficial (pronator teres and palmaris longus) and intermediate (flexor digitorum superficialis) layers of flexor muscles to reach medial side of forearm; passes superficial to flexor retinaculum at wrist in ulnar (Guyon) canal to enter hand
Anterior ulnar recurrent artery	Ulnar artery just distal to elbow joint	Passes superiorly between brachialis and pronator teres, supplying both; then anastomoses with inferior ulnar collateral artery anterior to medial epicondyle
Artery	**Origin**	**Course in forearm**
Posterior ulnar recurrent artery	Ulnar artery distal to anterior ulnar	Passes superiorly, posterior to medial epicondyle and deep to tendon of flexor; then recurrent artery anastomoses with superior ulnar collateral artery
Common interosseous	Ulnar artery in cubital fossa, distal to bifurcation of brachial artery	Passes laterally and deeply, terminating quickly by dividing into anterior and posterior interosseous arteries
Anterior interosseous	As terminal branches of common interosseous artery, between radius and ulna	Passes distally on anterior aspect of interosseous membrane to proximal border of pronator quadratus; pierces membrane and continues distally to joint dorsal carpal arch on posterior aspect of interosseous membrane
Posterior interosseous		Passes to posterior aspect of interosseous membrane, giving rise to recurrent interosseous artery; runs distally between superficial and deep extensor muscles, supplying both; replaced distally by anterior interosseous artery
Recurrent interosseous	Posterior interosseous artery, between radius and ulna	Passes superiorly, posterior to proximal radioulnar joint and capitulum, to anastomose with middle collateral artery (from deep brachial artery)
Palmar carpal branch	Ulnar artery in distal forearm	Runs across anterior aspect of wrist, deep to tendons of flexor digitorum profundus, to anastomose with the palmar carpal branch of the radial artery, forming palmar carpal arch
Dorsal carpal branch	Ulnar artery, proximal to pisiform	Passes across dorsal surface of wrist, deep to extensor tendons, to anastomose with dorsal carpal branch of radial artery, forming dorsal carpal arch
Radial	As smaller terminal branch of brachial artery in cubital fossa	Runs inferolaterally under cover of brachioradialis; lies lateral to flexor carpi radialis tendon in distal forearm; winds around lateral aspect of radius and tendon in distal forearm; winds around lateral aspect of interosseous muscle
Radial recurrent	Lateral side of radial artery, just distal to brachial artery bifurcation	Ascends between brachioradialis and brachialis, supplying both (and elbow joint); then anastomoses with radial collateral artery (from profunda brachii artery)
Palmar carpal branch	Distal radial artery near distal border of pronator quadratus	Runs across anterior wrist deep to flexor tendons to anastomose with the palmar carpal branch of ulnar artery to form palmar carpal arch
Dorsal carpal branch	Distal radial artery in proximal part of snuff box	Runs medially across wrist deep to pollicis and extensor radialis tendons, anastomoses with ulnar dorsal carpal branch forming dorsal carpal arch

- **Elbow anastomosis**: Collateral Circulation Around the Elbow involves the following pathways.
  - Superior ulnar collateral artery → posterior ulnar recurrent artery
  - Inferior ulnar collateral artery → anterior ulnar recurrent artery
  - Radial collateral artery → recurrent radial artery
  - Middle collateral artery → recurrent interosseus artery
- Detailed description:
  - Anterior to medial epicondyle:
    - Inferior ulnar collateral artery and branch from the superior ulnar collateral artery (branches of the brachial artery), anastomose with anterior ulnar recurrent artery (branch of the ulnar artery)

- Posterior to medial epicondyle:
  - Superior ulnar collateral artery and a branch from the inferior ulnar collateral artery (branches of brachial artery), anastomose with posterior ulnar recurrent artery (branch of the ulnar artery)
- Anterior to lateral epicondyle:
  - Radial collateral artery (anterior descending branch of the profunda brachii artery), anastomose with radial recurrent artery (branch of the radial artery)
- Posterior to lateral epicondyle:
  - Middle collateral artery (posterior descending branch of the profunda brachii artery), anastomose with recurrent interosseous artery (branch of the posterior interosseous artery, a branch of common interosseous artery, a branch of the ulnar artery)
- Superior to olecranon fossa:
  - Middle collateral artery (branch of the profunda brachii artery), anastomose with transverse branch from the posterior division of the inferior ulnar collateral artery

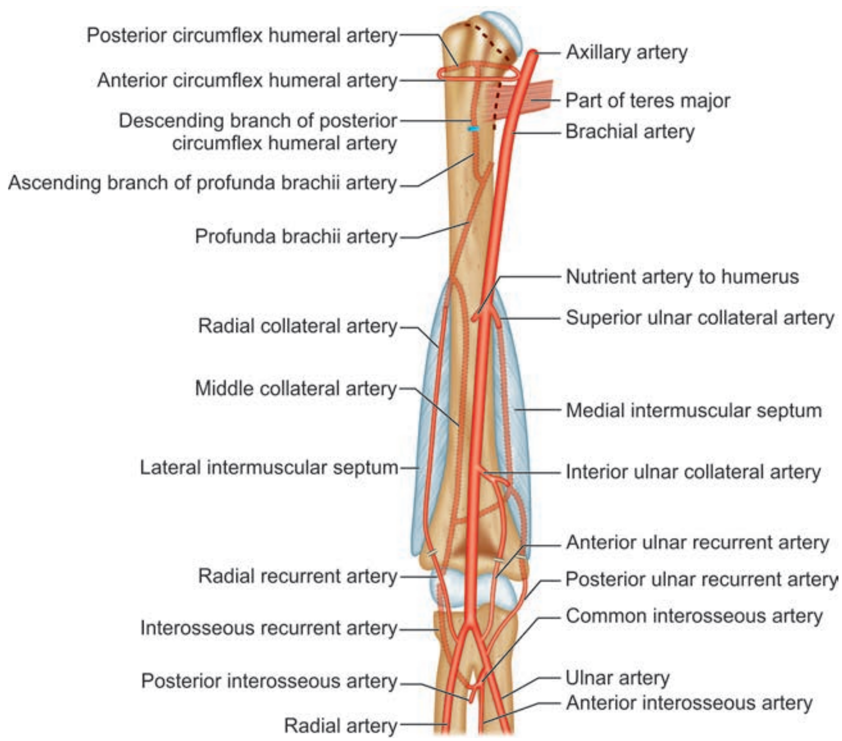


Fig. 56: Elbow anastomosis

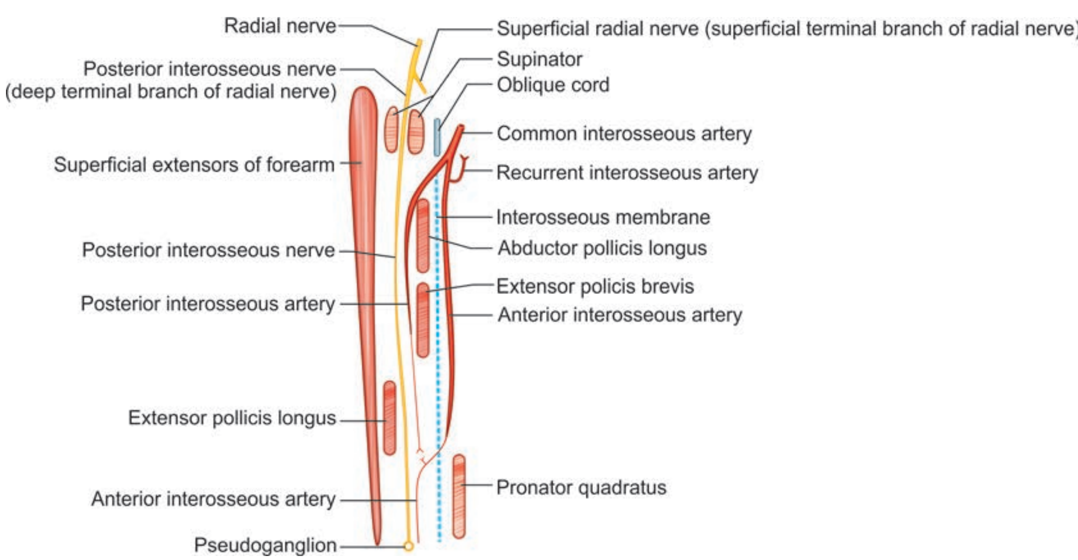


Fig. 57: Interosseous arteries in the forearm and their relations

ASSESSMENT QUESTION

1. Interosseous membrane of forearm is pierced by: *(NEET Pattern 2013)*
a. Brachial artery
b. Anterior interosseous artery
c. Posterior interosseous artery
d. Ulnar recurrent artery

ANSWER AND EXPLANATION

1. b. Anterior interosseous artery
- Anterior interosseous artery (a branch of common interosseous artery) runs on the anterior surface of interosseous membrane.
- At the proximal border of pronator quadratus, it pierces the interosseous membrane to reach posterior forearm and anastomose with posterior interosseous artery.

Palmar Arches

ASSESSMENT QUESTIONS

1. Axillary artery is divided into three parts by: *(NEET Pattern 2015)*
a. 1st rib
b. Clavicle
c. Pectoralis minor muscle
d. Teres minor muscle

2. Branches of brachial artery are all *EXCEPT*: *(NEET Pattern 2014)*
a. Profunda brachii
b. Superior ulnar collateral
c. Inferior ulnar collateral
d. Radial collateral

3. Artery forming anastomosis around the surgical neck of humerus is a branch of: *(NEET Pattern 2014)*
a. 1st part of axillary artery
b. 2nd part of axillary artery
c. 3rd part of axillary artery
d. Subclavian artery

4. Interosseous recurrent artery is a branch of: *(NEET Pattern 2014)*
a. Anterior interosseous artery
b. Posterior interosseous artery
c. Common interosseous artery
d. Radial artery

5. Posterior interosseous artery is a branch of: *(NEET Pattern 2015)*
a. Radial artery
b. Ulnar artery
c. Brachial artery
d. Axillary artery

ANSWERS AND EXPLANATIONS

1. c. Pectoralis minor muscle
- Axillary artery passes posterior to the **pectoralis minor muscle**, which divides the artery into **three parts**.

2. d. Radial collater
- **Radial collateral** artery is anterior descending branch of the profunda brachii artery, **not a direct** branch of brachial artery.

3. c. 3rd part of axillary artery
- Arteries forming anastomosis around the surgical neck of humerus are *anterior and posterior circumflex humeral arteries* (branches from **3rd part of axillary artery**).

4. b. Posterior interosseous artery
- Ulnar artery gives common interosseous artery, which divides into anterior and posterior interosseous arteries.
- Posterior interosseous artery gives the interosseous recurrent artery.

5. b. Ulnar artery
- Ulnar artery gives common interosseous artery, which divides into anterior and posterior interosseous arteries.

Pulses

- **Pulses**
  - Pulsation of the **subclavian artery** is palpable on the first rib at the lateral margin of sternocleidomastoid and the artery **can blocked by thumb pressure** against the first rib.
  - **Axillary artery** pulse is felt in front of the teres major and the **brachial artery** on the brachialis but medial to the biceps tendon.
  - **Radial artery** pulse is felt proximal to wrist, in front of the distal end of the radius between the tendons of the brachioradialis and flexor carpi radialis. It may also be palpated in the anatomical snuffbox between the tendons of the extensor pollicis longus and brevis muscles.
  - **Ulnar artery** anterior to the flexor retinaculum on the lateral side of the pisiform bone.

Venous Drainage

- The upper limb is drained by **superficial** and **deep** groups of vessels. Superficial veins are subcutaneous and deeper veins accompany the arteries, usually as venae comitantes. The deep group of veins drains the tissues beneath the deep fascia of the upper limb and is connected to the superficial system by **perforating veins.**
- **Superficial Veins**
  - The **dorsal venous network** located on the dorsum of the hand gives rise to the **cephalic vein** and **basilic vein**. The palmar venous network located on the palm of the hand gives rise to the median antebrachial vein.
- **Cephalic Vein** begins as a radial continuation of the dorsal venous arch, runs on **roof of anatomical snuff box**, courses along the anterolateral surface of the forearm and arm and then between the deltoid and pectoralis major muscles along the **deltopectoral groove** (alongwith deltoid branch of the thoracoacromial artery). It pierces the costocoracoid membrane (of **clavipectoral fascia**) and ends in the axillary vein. It is often connected with the basilic vein by the **median cubital vein** in front of the elbow.
  - **Basilic vein** drains the ulnar end of the arch, passes along the medial aspect of the forearm, pierces the deep fascia at the elbow, and joins the **venae comitantes** of the brachial artery to form the **axillary vein**, at the lower border of the teres major muscle.
- **Median Cubital Vein** connects the cephalic vein to the basilic vein at the **roof of cubital fossa**. It lies superficial to the bicipital aponeurosis and is **used for intravenous injections**, blood transfusions, and withdrawal.
  - **Median Antebrachial Vein** arises in the palmar venous network, ascends on the front of the forearm, empties into the basilic vein or median cubital vein.
  - **Dorsal Venous arch** is a network of veins formed by the dorsal metacarpal veins that receive dorsal digital veins and continues proximally as the cephalic vein and the basilic vein.
- **Deep veins**
  - The **radial veins** receive the dorsal metacarpal veins. The **ulnar veins** receive tributaries from the deep palmar venous arches. The **brachial veins** are the vena comitantes of the brachial artery and are joined by the **basilic vein** to form the **axillary vein** and subsequently the **subclavian vein**.
  - Axillary Vein is formed at the lower border of the teres major muscle by the union of the brachial veins (venae comitantes of the brachial artery) and the basilic vein and ascends along the medial side of the axillary artery. It continues as the subclavian vein at the lateral border of the first rib.
  - Subclavian vein is the continuation of the axillary vein. It starts at the inferior margin of the first rib, crosses superiorly, joins the internal jugular vein to form the brachiocephalic behind the sternoclavicular joint.

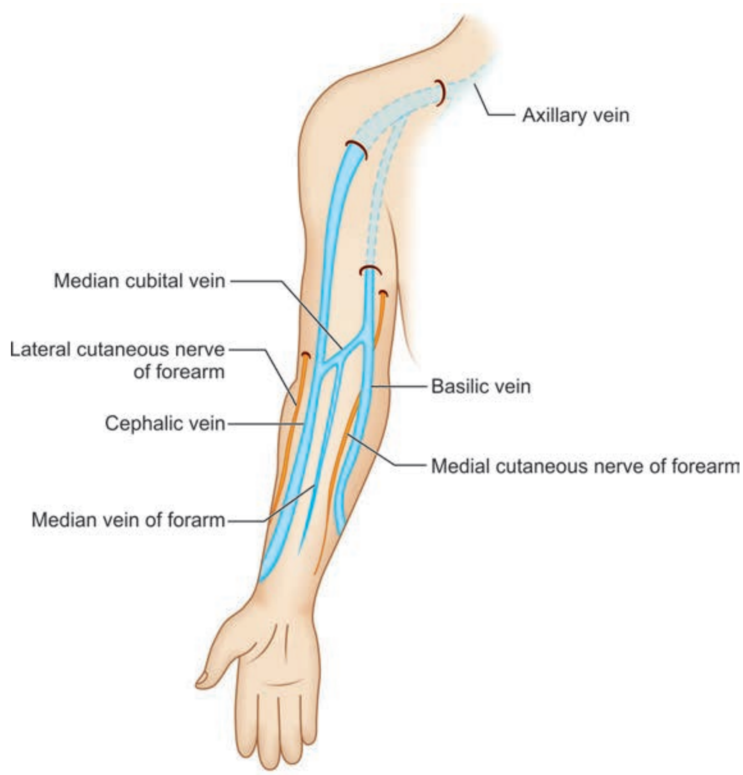


Fig. 58: Venous drainage of upper limb

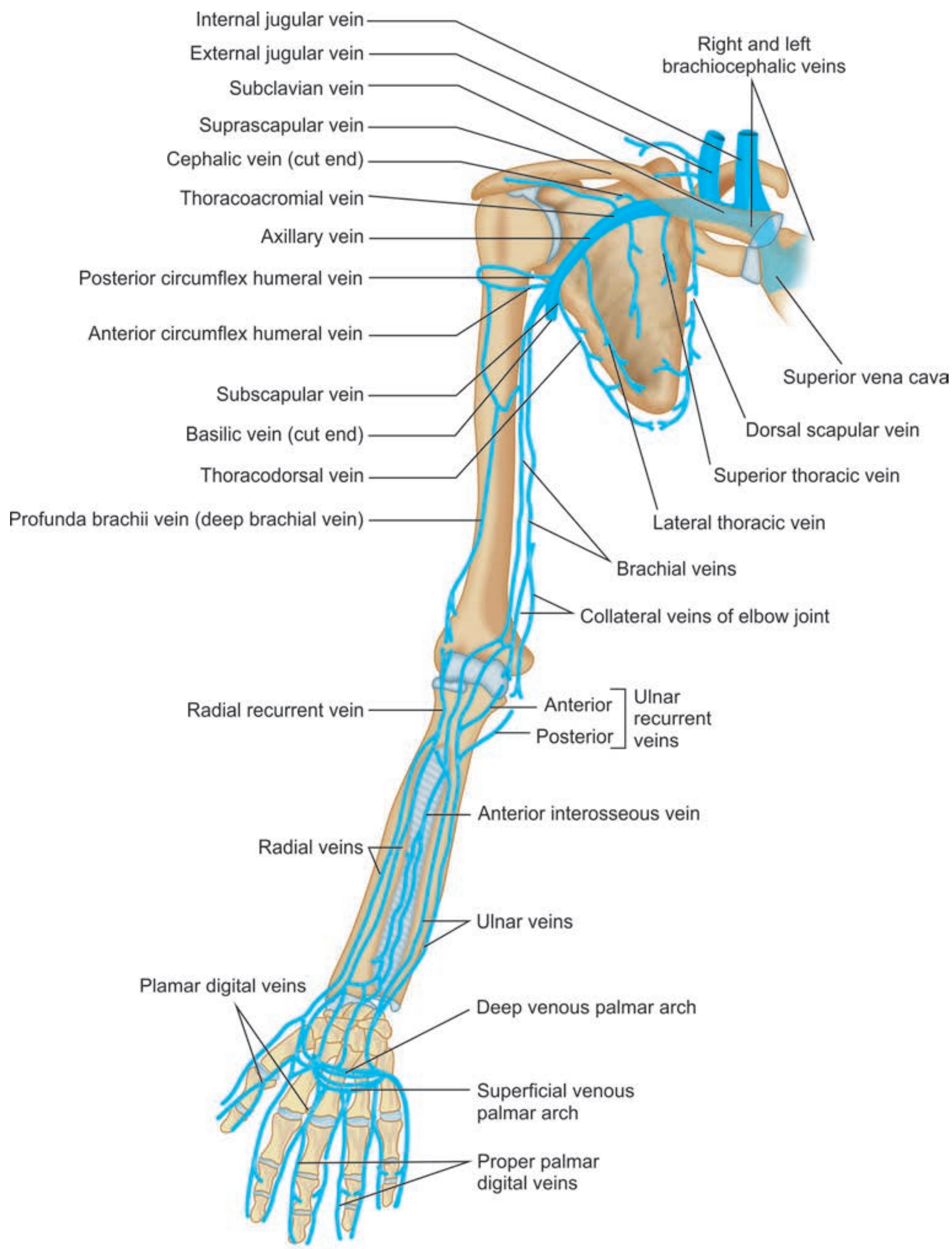


Fig. 59: Venous drainage of upper limb (detailed)

ASSESSMENT QUESTIONS

1. Cephalic vein drains into: *(NEET Pattern 2013)*
   a. Brachial vein
   b. Subclavian vein
   c. Axillary vein
   d. Basilic vein

2. All of the following are postaxial veins *EXCEPT*:
   a. Cephalic vein
   b. Basilic vein
   c. Axillary vein
   d. Subclavian vein

ANSWERS AND EXPLANATIONS

1. c. Axillary vein > d. Basilic vein
- Cephalic vein drains into axillary vein by two routes:
  a. Cephalic vein drains into axillary vein after piercing clavipectoral fascia.
  b. Some amount of venous blood is drained into basilic vein through median cubital vein.
  c. Basilic vein joins brachial veins to drain into axillary vein eventually.

2. a. Cephalic vein
- **Cephalic** vein is a preaxial vein, embryologically, runs with the preaxial bone radius.

Lymphatic Drainage

- Finger lymphatics drain into the plexuses which form the **medial** and **lateral** lymph vessels.
  - **Medial lymphatics** accompanies the **basilic vein**; passes through the cubital or supratrochlear nodes; and ascends to enter the **lateral** axillary nodes, which drain first into the **central** axillary nodes and then into the **apical** axillary nodes.
  - **Lateral lymphatics** accompanies the **cephalic vein** and drains into the **lateral** axillary nodes and also into the deltopectoral (infraclavicular) node, which then drain into the **apical** axillary nodes.
- Axillary lymph nodes - Refer

Spaces around Shoulder Region

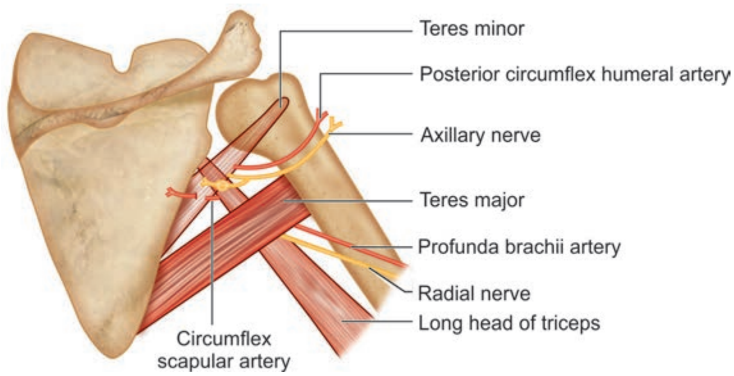


Fig. 60: Shoulder region spaces

Table 39: Spaces around shoulder region

Space	Boundary	Contents
Quadrangular (foramen of Velpeau)	Superior: **Teres minor** (and capsule of shoulder joint) Inferior: Teres major Medial: Long head of triceps Lateral: Surgical neck of humerus	**Axillary nerve** and **posterior circumflex humeral** vessels
Upper triangular	Superior: Teres minor Inferior: Teres major Lateral: Long head of triceps	**Circumflex scapular** vessels
Space	**Boundary**	**Contents**
Lower triangular	Superior: Teres major Medial: Long head of triceps Lateral: Shaft of humerus (and medial head of triceps)	**Radial nerve** and the **profunda brachii** (deep brachial) vessels

***Subscapularis muscle** is anterior relation to all the three spaces and teres minor posterior. The posterior relation of lower triangular space is teres major.

ASSESSMENT QUESTIONS

1. Boundaries of quadrilateral space include all *EXCEPT*: *(NEET Pattern 2014)*
   a. Teres major
   b. Long head of triceps
   c. Neck of humerus
   d. Deltoid

2. Boundaries of upper triangular space include all *EXCEPT*: *(NEET Pattern 2012)*
   a. Teres minor
   b. Teres major
   c. Subscapularis
   d. Triceps

3. The accompanying artery with axillary nerve in the quadrangular space is:
   a. Anterior circumflex humeral artery
   b. Posterior circumflex humeral artery
   c. Profunda brachii artery
   d. Circumflex scapular artery

4. Structure related to deltopectoral groove: *(NEET Pattern 2015)*
   a. Axillary artery
   b. Cephalic vein
   c. Basilic vein
   d. Radial nerve

ANSWERS AND EXPLANATIONS

1. d. Deltoid
- The quadrangular space is bounded by the teres minor (superiorly), teres major (inferior), triceps (medial), and the humerus (laterally).

2. c. Subscapularis
- Subscapularis muscle is anterior relation of upper triangular space.

3. **b. Posterior circumflex humeral artery**
   - **Axillary nerve** and **posterior circumflex humeral artery** pass through **quadrangular space** and then wind around the surgical neck of humerus.

4. **b. Cephalic vein**
   - Deltopectoral groove is an indentation between the deltoid muscle and pectoralis major, through which the cephalic vein passes and where the coracoid process is most easily palpable.

Axilla

- Axilla (armpit) is a **pyramid-shaped** space between the upper thoracic wall and the arm.

Table 40: Axilla: Boundaries and contents

Anterior wall	Pectoralis major and minor and subclavius muscle; clavipectoral fascia
Posterior wall	Subscapularis, teres major and latissimus dorsi
Medial wall	Serratus anterior and ribcage*
Lateral wall	Inter-tubercular sulcus and coracobrachialis and short head of biceps muscle
Apex	Interval between the clavicle, first rib, and upper border of the scapula
Base	Axillary fascia and skin
Contents	• Axillary artery, vein and lymphatics • Brachial plexus (cords and branches) • Long thoracic nerve, intercostobrachial nerve • Axillary tail (of Spence)**

*Medial wall includes upper 4 ribs and intercostal muscles.
**Axillary tail (of Spence) is a superolateral extension of the mammary gland.

During **sentinel lymph node biopsy** the nerves at risk are: **intercostobrachial nerve** (most common), long thoracic nerve, thoracodorsal nerve.

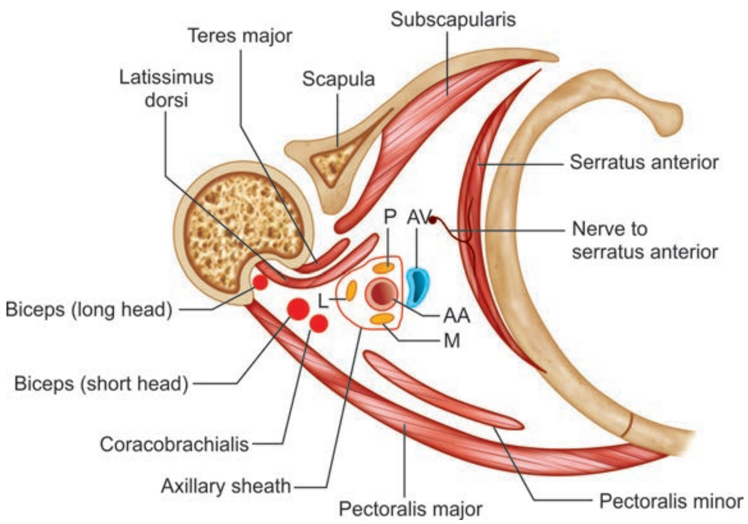


Fig. 61: Contents of axilla. P - Posterior cord, L - Lateral cord, M - Medial cord of brachial plexus; AA - Axillary artery; AV - Axillary vein

ASSESSMENT QUESTION

1. **Muscle forming the medial wall of axilla is:**
   a. Subscapularis
   b. Teres major
   c. Pectoralis minor
   d. Serratus anterior

ANSWER AND EXPLANATION

1. **d. Serratus anterior**
   - Medial wall of the axilla has upper 4 ribs on the thoracic wall and the serratus anterior muscle.

High Yield Points

- **Axillary sheath**, **axillary vessels**, **axillary tail of breast** is present in the axilla (but **not roots** of brachial plexus).
- Axillary sheath is a continuation of **prevertebral fascia**, which encloses cords and branches of brachial plexus and axillary artery. Axillary vein is **outside** the axillary sheath.

Fascia

- **Axillary Sheath** is a tubular fascial prolongation of the **prevertebral layer of the deep cervical fascia** into the axilla, enclosing the axillary artery and the brachial plexus.
- **Axillary Fascia** forms the floor of axilla and is continuous anteriorly with the **pectoral** and **clavipectoral fasciae** (suspensory ligament of the axilla), laterally with the **brachial fascia**, and posteromedially with the fascia over the latissimus dorsi.
- **Clavipectoral fascia** (costocoracoid membrane; coracoclavicular fascia)
  - It is situated under cover of the clavicular portion of the pectoralis major and **occupies the interval between** the pectoralis minor and subclavius, and **protects** the axillary vein and artery, and axillary nerve.

It is the cranial continuation of the deep lamina of the **pectoral fascia** and the medial continuation of the parietal layer of the **subscapular bursal fascia.**

Its lower part splits to enclose the pectoralis minor muscle. Below this muscle it extends downwards as the **suspensory ligament of axilla**, which is attached to the dome of the axillary fascia. The suspensory ligament keeps the dome of axillary fascia pulled up, thus maintaining the concavity of the axilla.

Superiorly	Fuses with cervical fascia
Inferiorly	Fuses with axillary fascia
Laterally	Continuous with coracoacromial ligament (above and lateral to coracoid) Envelops coracoid process, short head of biceps and coracobrachialis
Medially	Attached to first rib and costoclavicular ligament Blends with external intercostal membrane of upper two intercostal spaces

- The clavipectoral fascia is traversed by:
  - Lymphatics: passing between infraclavicular and apical nodes of the axilla
  - Cephalic vein
  - Lateral pectoral nerve
  - Thoracoacromial vessels

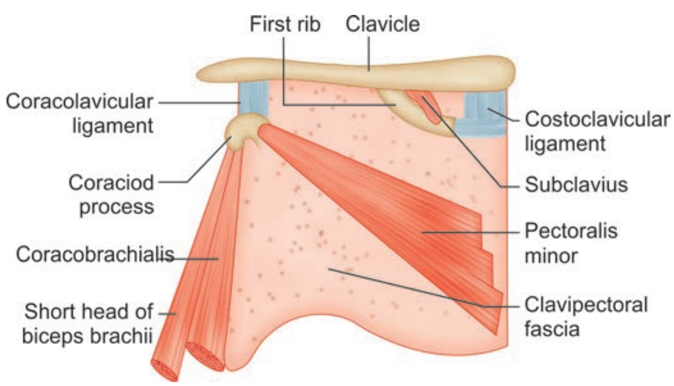


Fig. 62: Clavipectoral fascia: A, as seen in sagittal section of anterior axillary wall; B, as seen from front

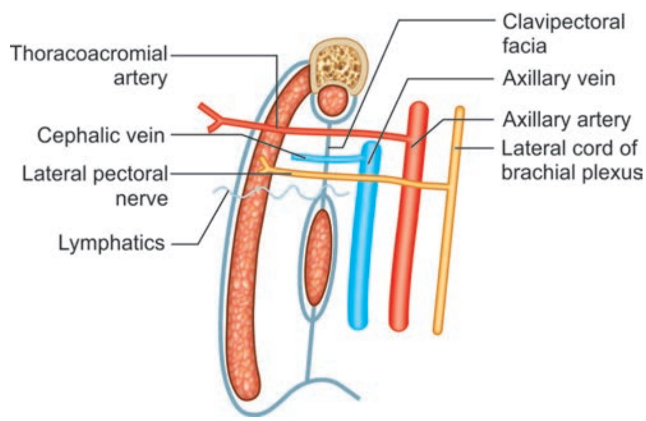


Fig. 63: Structures piercing clavipectoral fascia

ASSESSMENT QUESTIONS

1. All of the following structures pierce the clavipectoral fascia *EXCEPT*:

a. Lateral pectoral nerve
b. Lateral thoracic artery
c. Cephalic vein
d. Axillary lymphatics

2. Clavipectoral fascia is derived from which ligament: *(NEET Pattern 2013)*

a. Coracoacromial
b. Coracoclavicular
c. Costoclavicular
d. Costocoracoid

3. **Clavipectoral fascia splits to enclose subclavius and pectoralis minor, and continues as:** *(NEET Pattern 2015)*
   a. Axillary sheath
   b. Costocoracoid ligament
   c. Costoclavicular ligament
   d. Suspensory ligament

4. **WRONG about clavipectoral fascia:** *(PGIC)*
   a. Situated under clavicular portion of the pectoralis minor
   b. Fuses with the deep cervical fascia superiorly
   c. Costocoracoid membrane is a modification
   d. Continue downward to join the axillary fascia
   e. Laterally joins fascia over the short head of the biceps brachii

5. **Fascia around nerve bundle of brachial plexus is derived from:** *(AIIMS 2008)*
   a. Prevertebral fascia
   b. Clavipectoral fascia
   c. Deep cervical fascia
   d. Pectoral fascia

ANSWERS AND EXPLANATIONS

1. **b. Lateral thoracic artery**
   - Acromiothoracic (not lateral thoracic), artery passes through the clavipectoral fascia.
   - **Clavipectoral fascia** extends between the coracoid process, clavicle, and the thoracic wall and envelops the subclavius and pectoralis minor muscles. It has a costocoracoid membrane, which lies between the subclavius and pectoralis minor muscles and is pierced by the **cephalic vein**, the **thoracoacromial artery**, and the **lateral pectoral nerve.**

2. **d. Costocoracoid**
   - Occasionally, the clavipectoral fascia thickens to form a band between the first rib and coracoid process, the costocoracoid ligament, under which the lateral cord of the brachial plexus is closely applied.

3. **d. Suspensory ligament**
   - Below pectoralis minor muscle, clavipectoral fascia extends downwards as the suspensory ligament of axilla, which attach and pulls up the dome of the axillary fascia (and maintain the concavity of the axilla).

4. **a. Situated under clavicular portion of the pectoralis minor**
   - Clavipectoral fascia is situated under clavicular portion of the pectoralis major, it splits to enclose pectoralis minor.

5. **a. Prevertebral fascia**
   - Fascia around the brachial plexus is called as axillary sheath and is a derivative of prevertebral fascia. Prevertebral fascia (PVF) covers the anterior vertebral muscles and lies on the anterior aspect of scalenus anterior and medius, thus forming the floor of posterior triangle of neck.
   - Brachial plexus and subclavian artery emerge between scalenus and medius in the neck and pass behind the clavicle to reach the axilla. In that course they carry an extension of PVF over them as a cover (the axillary sheath) towards the axilla.
   - Subclavian/Axillary veins lie outside the axillary sheath and therefore can distend freely.
   - Neck infections behind the PVF are usually due to tuberculosis of cervical vertebra and may form chronic retropharyngeal abscess – a bulging in the posterior wall of pharynx. The pus may track into the axilla via the axillary sheath and point in the posterior/lateral wall of axilla. Pus may also extend into the superior mediastinum but doesn't reach the posterior mediastinum, since the PVF fuses to the fourth thoracic vertebra.
   - PVF is separated from the pharynx/buccopharyngeal fascia by the retropharyngeal space. Neck infections in front of PVF in the retropharyngeal space forms acute retropharyngeal abscess which bulges forward in the paramedian position. This is due to attachment of PVF with Buccopharyngeal fascia in the median plane. his infection may spread to the posterior mediastinum via the superior mediastinum.

High Yield Point

- The portion of clavipectoral fascia extending from the first rib to the coracoid process is called costo-coracoid ligament.

Cubital Fossa

- **Cubital fossa** is a triangular space on the anterior aspect of the elbow that is bounded by the **brachioradialis** muscle laterally, **pronator teres** muscle medially, and superiorly by **an imaginary horizontal line** connecting the two epicondyles of the humerus.
- At the floor are **brachialis** and **supinator** muscles. The **contents** (in medial to lateral order) are the **median nerve, brachial artery, biceps tendon** and **radial nerve.**
- **Ulnar nerve** passes behind the medial epicondyle (**not a content** of cubital fossa). At its lower end, the **brachial artery** divides into the **radial** and **ulnar arteries**.
- From medial to lateral, the **basilic**, **median cubital** and **cephalic veins** lie in the superficial fascia (at the roof). Fascial roof is strengthened by the bicipital aponeurosis on which runs the a**ntecubital vein** draining cephalic vein into the basilic vein.

Clinical Correlations

- **Supracondylar Fracture** may lead to posterior displacement of the distal fragment of humerus as well as the radius and ulna. The contents of the cubital fossa are compromised specifically the median nerve and brachial artery.

- **Volkmann contracture** is an ischemic muscular contracture (flexion deformity) of the fingers and sometimes of the wrist, resulting from reduced blood flow and necrosis of the forearm flexor muscles, caused by a pressure injury, such as compartment syndrome, or a tight cast. The muscles are replaced by fibrous tissue, which contracts, producing the flexion deformity.

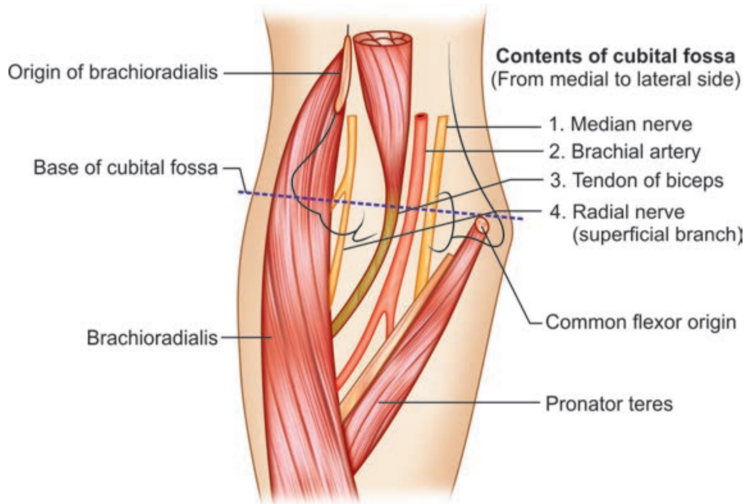


Fig. 64: Cubital fossa: Boundaries and contents

ASSESSMENT QUESTIONS

1. **The cubital fossa is bounded medially by the muscle:** *(NEET Pattern 2015)*
   a. Brachioradialis
   b. Pronator teres
   c. Brachialis
   d. Supinator

2. **All are contents of cubital fossa *EXCEPT*:** *(NEET Pattern 2012)*
   a. Median nerve
   b. Biceps tendon
   c. Brachial artery
   d. Ulnar nerve

3. **Bicipital aponeurosis lies over which structure in cubital fossa:** *(NEET Pattern 2015)*
   a. Median cubital vein
   b. Radial nerve
   c. Brachial artery
   d. Anterior interosseous artery

4. **TRUE about cubital fossa is/are:** *(PGIC)*
   a. Medial boundary is flexor carpi ulnaris
   b. Base is imaginary line connecting humeral epicondyles
   c. Floor is brachialis muscle
   d. Brachial artery is medial to biceps tendon
   e. Antecubital vein is a content is a content

ANSWERS AND EXPLANATIONS

1. **b. Pronator teres**
   - The medial boundary of cubital fossa is pronator teres muscle.
2. **d. Ulnar nerve**
   - Ulnar nerve passes behind the medial epicondyle of humerus and is not a content of cubital fossa.
3. **c. Brachial artery**
   - Bicipital aponeurosis passes superficial to the brachial artery and median nerve. It lies deep to superficial veins.
   - It provides some protection for the deeper structures during venipuncture at cubital fossa.
4. **b. Base is imaginary line connecting humeral epicondyles, d. Brachial artery is medial to biceps tendon**

Mammary Gland

- **Breast**
  - It lies in the **superficial fascia** of the anterior chest wall overlying the **pectoralis major** and **serratus anterior** muscles.
  - Extends over the **second to sixth ribs** and from the sternum to the midaxillary line, **nipple** lies at the level of the **fourth intercostal space**.
  - It is divided into four (upper and lower lateral and medial) **quadrants**.
- The **mammary gland**
  - Is a modified **sweat gland** of **apocrine** variety.
  - It lies in the superficial fascia, supported by the **suspensory ligaments (of Cooper)**, strong fibrous attachments, that run from the dermis of the skin to the deep layer of the superficial fascia **(pectoral fascia)** running through the breast.

- It is separated from the deep fascia covering the underlying muscles by **retromammary space** (allows movement of breast over the pectoralis major muscle).
- It has the **axillary tail**, a small part of the mammary gland that extends superolaterally through the deep fascia to **enter the axilla**.
- There are **15 to 20 lobes** of glandular tissue, which are separated by fibrous septa that radiate from the nipple. Each lobe opens by a **lactiferous duct** onto the tip of the nipple, which enlarges to form a lactiferous sinus (stores milk).
- During surgery **radial incisions** should be put to avoid damaging the lactiferous ducts.
- **Arterial supply:**
  - Internal thoracic artery (branch of first part of subclavian artery)
  - Branches of **axillary artery** (all the three parts)
    - Superior thoracic artery
    - Thoraco-acromial trunk
    - Lateral thoracic artery
    - Subscapular artery
  - Posterior intercostal arteries (branches of **descending thoracic aorta**)

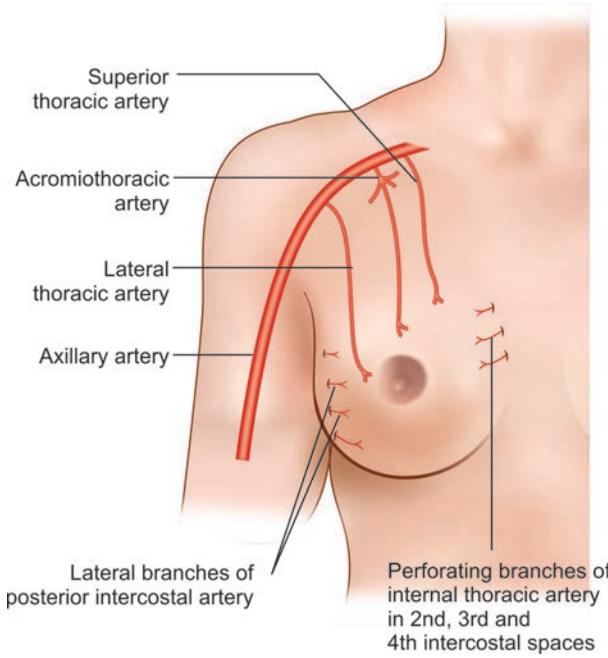


Fig. 65: Arterial supply to breast

- **Venous drainage**: Drained by the identically named veins accompanying the arteries, mainly into the **axillary vein** via **lateral thoracic vein**. Additional venous drainage from the breast is to the **internal thoracic vein** via medial mammary veins, **anterior intercostal veins**, and **posterior intercostal veins** (drain into the azygos system).

Metastasis of breast carcinoma to the brain may occur by the following route: Cancer cells enter an intercostal vein → external vertebral venous plexuses → internal vertebral venous plexus → cranial dural sinuses.

- Nerve supply: Anterior and lateral cutaneous branches of the **second to the sixth intercostal nerves**.

Lymphatics

- Lymph Drainage from the **Lateral Quadrant**
  - Majority of the lymph (>75%) drains as follows: Axillary nodes (humeral, subscapular, pectoral, central, and apical) → infraclavicular and supraclavicular nodes → right subclavian lymph trunk (for the right breast) or left subclavian lymph trunk (for the left breast).
  - Remaining (25%) of lymph drainage occurs via the interpectoral, deltopectoral, supraclavicular, and inferior deep cervical nodes.
- Lymph Drainage From the **Medial Quadrant**
  - Parasternal nodes → right bronchomediastinal lymph trunk (for the right breast) or left bronchomediastinal lymph trunk (for the left breast).
  - May also drain into the opposite breast.
- Lymph Drainage From the **Inferior Quadrant**
  - Into the nodes of the upper abdomen (e.g., inferior phrenic lymph nodes).

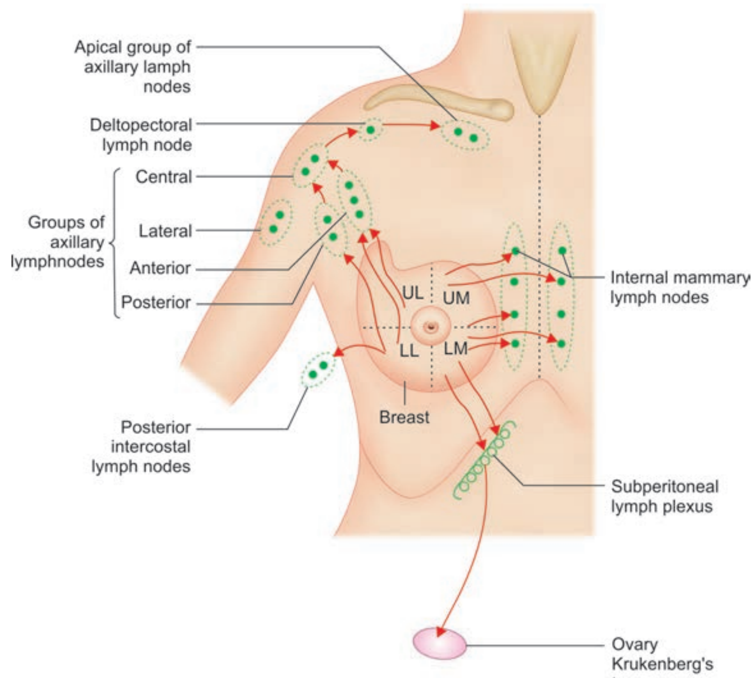


Fig. 66: Lymphatic drainage of the breast (UL, Upper lateral quadrant; LL, Lower lateral quadrant: UM, Upper medial quadrant; LM, Lower medial quadrant)

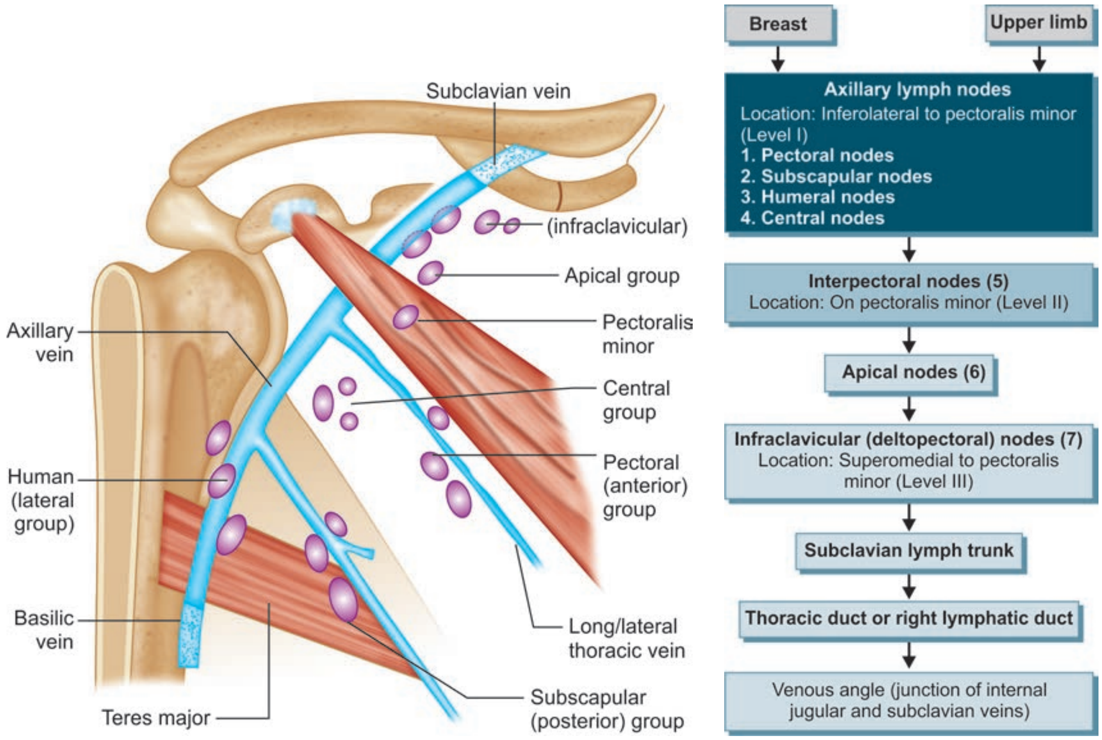


Fig. 67: Axillary lymph nodes

- **Breast cancer in advanced stages:** Infiltrates Cooper's ligaments, produces shortening of the ligaments, causing depression or dimpling of the overlying skin. Advanced sign of inflammatory breast cancer, **peau d'orange** (texture of orange peel) is the edematous swollen and pitted breast skin due to **obstruction** of the subcutaneous **lymphatics.**

High Yield Points

- Potter's interpectoral lymph nodes in mid-axilla belong to level II metastasis.
- Lymphatic drainage of **upper lateral quadrant** in breast drains into **anterior axillary lymph nodes.**
- Sentinel node is the first lymph node(s) to which cancer cells are likely to spread from the primary tumor.

ASSESSMENT QUESTIONS

1. All is true about mammary gland *EXCEPT*: *(NBEP Pattern 2013)*
   a. Is a modified sweat gland
   b. Extends from the 2-6 ribs vertically
   c. Supplied by internal mammary artery
   d. Nipple is supplied by sixth intercostal nerve

2. How many lactiferous ducts open in nipple: *(NEET Pattern 2015)*
   a. 0–10
   b. 15–20
   c. 25–50
   d. 50–75

3. Lymphatic drainage of upper outer quadrant of breast: *(NEET Pattern 2013)*
   a. Anterior axillary
   b. Posterior axillary
   c. Para tracheal
   d. None of the above

4. All are true regarding axillary lymph nodes *EXCEPT*: *(AIPG Pattern 2013)*
   a. Posterior group lies along subscapular vessels
   b. Lateral group lies along lateral thoracic vessels
   c. Apical group lies along axillary vessels
   d. Apical group is terminal lymph nodes

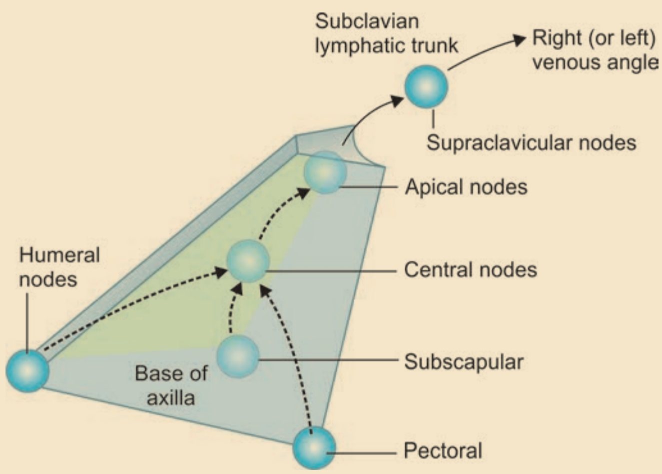
5. Peau d'orange appearance orange occurs due to: *(AIIMS 2015)*
   a. Haematogenous dissemination
   b. Adherence of Cooper's ligament
   c. Blockade of sub-dermal lymphatics
   d. Chest wall fixation

6. The terminal axillary lymph nodes are: *(AIIMS 2005)*
   a. Apical
   b. Central
   c. Lateral
   d. Pectoral

7. Mammary gland is supplied by: *(PGIC 2012)*
   a. Subscapular artery
   b. Musculophrenic artery
   c. Internal mammary artery
   d. Superior thoracic artery
   e. Superior epigastric artery

ANSWERS AND EXPLANATIONS

1. **d. Nipple is supplied by sixth intercostal nerve**
   - Nipple lies in the fourth intercostal space and is supplied by **fourth intercostal nerve.**
2. **b. 15–20**
   - The parenchyma of the breast consists of about 15–20 lobes arranged in a radial fashion and converge towards the nipple as lactiferous ducts.
3. **a. Anterior axillary**
   - Lymphatics from upper outer quadrant of breast drain into anterior (pectoral) axillary lymph nodes.
4. **b. Lateral group lies along lateral thoracic vessels**
   - Lateral group of axillary lymph nodes lie along the axillary vein.
5. **c. Blockade of sub-dermal lymphatics**
   - Advanced sign of inflammatory breast cancer, peau d'orange (texture of orange peel) is the edematous swollen and pitted breast skin due to obstruction of the subcutaneous lymphatics.
6. **a. Apical**
   - Anterior (pectoral), posterior (subscapular) and lateral (humeral) groups drain the lymph into the central group of lymph nodes, which eventually drain into the terminal apical lymph nodes (near the apex of axilla).



7. **a. Subscapular artery, c. Internal mammary artery, d. Superior thoracic artery**
   - **Mammary gland** receives blood from the **axillary artery** branches (lateral thoracic artery, thoracoacromial artery); the **posterior intercostal arteries** and the **internal thoracic** (mammary) artery branches.
   - The terminal branches of internal thoracic artery: superior epigastric artery and musculophrenic artery do not supply the mammary gland.

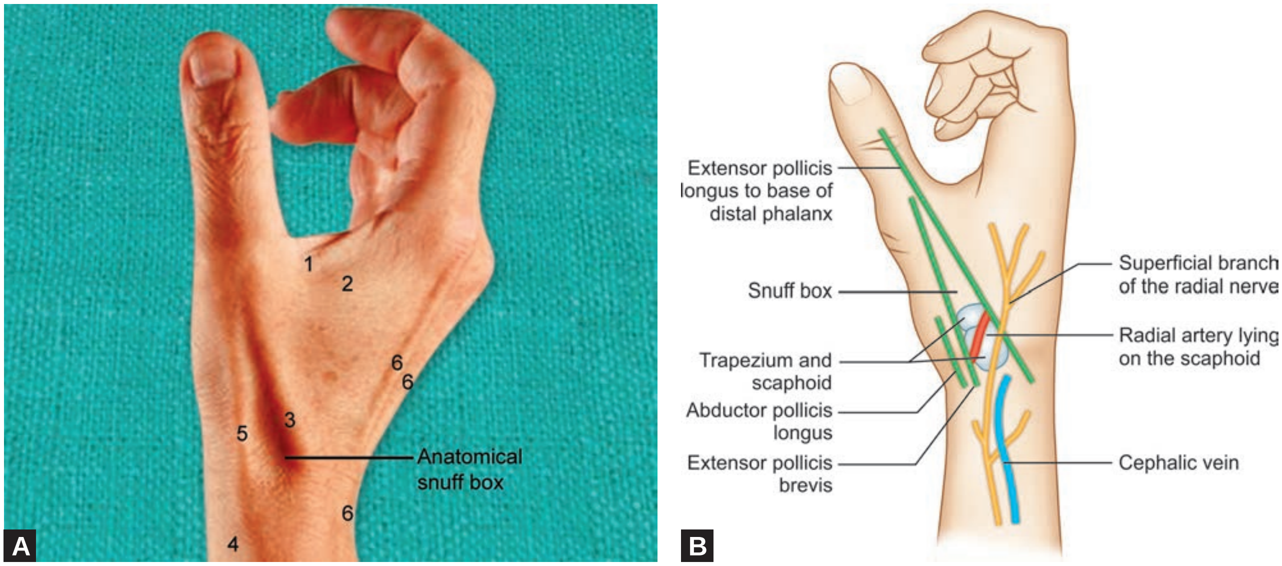
Anatomical Snuff Box

- The **anatomical snuff box** is an elongated triangular depression seen on lateral aspect of the wrist immediately distal to the radial styloid process, gets **more prominent when** the thumb is fully extended.

Boundaries	• Anterolaterally (Radial) – Tendons of abductor pollicis longus – Extensor pollicis brevis • Posteromedially (ulnar) – Tendon of extensor pollicis longus
Borders	• Proximal border – Styloid process of the radius • Distal border – Apex of the schematic snuffbox isosceles triangle
Floor	Scaphoid, trapezium and base of first metacarpal bone*
Roof	• Skin and superficial fascia • Cephalic vein (subcutaneous) • Radial nerve branches (subcutaneous)
Contents	Radial artery (pulse)
* At the floor, two joints are partly evident - the wrist joint and the first carpometacarpal joint.	

The distal ends of ECRR and ECRB are also present at floor.

Note: The superficial radial nerve, can be rolled from side to side on the tendon of extensor pollicis brevis.



Figs. 68A and B: Anatomical snuff box

Clinical Correlations

- The tenderness in the anatomical box indicates fracture of scaphoid bone.
- **De Quervain's tenosynovitis**: Inflammation of the two tendons forming anterolateral boundary of *anatomical snuff box*. The tendons involved are **abductor pollicis longus** and **extensor pollicis brevis** and **Finkelstein test** becomes positive.

ASSESSMENT QUESTIONS

1. **Artery in anatomical snuff box:** *(AIPG 2009)*
   a. Radial
   b. Brachial
   c. Ulnar
   d. Interosseous

2. **Boundaries of anatomical snuff box are all *EXCEPT*:** *(JIPMER 2010; NEET Pattern 2015)*
   a. Abductor pollicis longus
   b. Extensor pollicis longus
   c. Extensor pollicis Brevis
   d. Extensor carpi ulnaris

3. **Contents of anatomical snuff box are:** *(PGIC 2015)*
   a. Radial Artery
   b. Tendon of Abductor pollicis longus
   c. Tendon of extensor pollicis brevis
   d. Scaphoid bone
   e. Superficial cutaneous branch of radial nerve

4. **Regarding anatomical snuff box, which of the following is true:** *(AI 2000)*
   a. Abductor pollicis longus forms the posterior wall
   b. Abductor pollicis longus and extensor pollicis brevis form the anterior wall
   c. Basilic vein forms the roof
   d. Floor is formed by extensor carpi longus and brevis tendons

ANSWERS AND EXPLANATIONS

1. a. Radial

- Anatomical box has the radial artery as one of its contents. Radial artery pulsations can be felt in the ASB over the scaphoid and trapezium bones in the floor.
- Brachial artery is the content of cubital fossa. It divides into radial and ulnar artery in the fossa itself.
- Ulnar artery is a branch of brachial artery which is present in the cubital fossa and passes superficial to the flexor retinaculum to reach the palm.
- Ulnar artery gives common interosseous artery which further gives the branches—anterior and posterior interosseous arteries.
- None of the interosseous arteries enter the anatomical snuff box.

2. d. Extensor carpi ulnaris

3. a. Radial Artery

- **Anatomic snuff box** is a triangular interval bounded anterolaterally by the **abductor pollicis longus** (and extensor pollicis brevis) and posteromedially by the tendon of the extensor pollicis longus.
- It has a **floor** formed by the styloid process of the radius, scaphoid, trapezium and the base of first metacarpal bone.
- Radial artery is the **content** of the fossa, whereas, **cephalic vein** and cutaneous branch of **radial nerve** lies on the **roof.**

4. b. Abductor pollicis longus and extensor pollicis brevis form the anterior wall > d. Floor is formed by extensor carpi longus and brevis tendons

- **Abductor pollicis longus** and **extensor pollicis brevis** form the anterolateral wall of anatomical snuff box.
- Cephalic vein is present on the **roof**.
- **Floor** is formed by bones (proximal to distal): radial styloid process, scaphoid, trapezium, base of first metacarpal.
- The distal ends of ECRR and ECRB are also present at floor.

Wrist Retinacular Region and Carpal Tunnel

- **Flexor Retinaculum**
  - It forms the carpal (osteofascial) tunnel on the anterior aspect of the wrist, is attached **medially** to the triquetrum, the pisiform, and the hook of the hamate and **laterally** to the tubercles of the scaphoid and trapezium. It serves as an origin for muscles of the thenar eminence.
  - Structures passing **superficial** to flexor retinaculum are:
    - Ulnar artery and nerve
    - Palmar cutaneous branch of median nerve
    - Tendon of Palmaris longus muscle
  - Structures passing **deep** to flexor retinaculum are:
    - **Median nerve**
    - Tendons of **Flexor digitorum superficialis and profundus muscles**
    - Tendon of flexor pollicis brevis
    - Ulnar and radial bursae

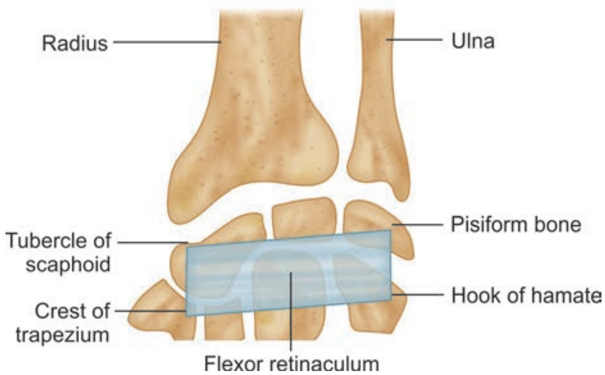


Fig. 69: Carpal tunnel and flexor retinaculum

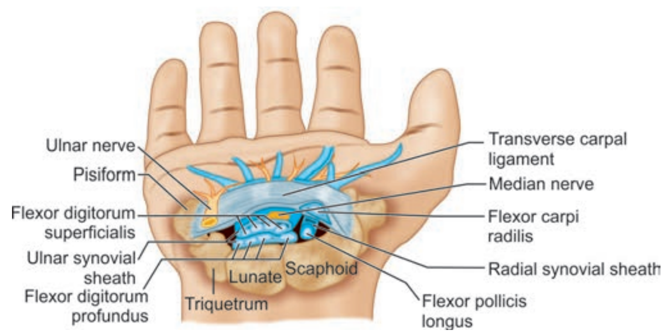


Fig. 70: Carpal tunnel and flexor retinaculum

- **Extensor Retinaculum**
  - It is a thickening of the antebrachial fascia on the **back of the wrist**, subdivided into compartments, and places the **extensor tendons beneath** it.
  - It extends from the lateral margin of the radius to the styloid process of the ulna, the pisiform, and the triquetrum and is crossed superficially by the **superficial branch of the radial nerve**.

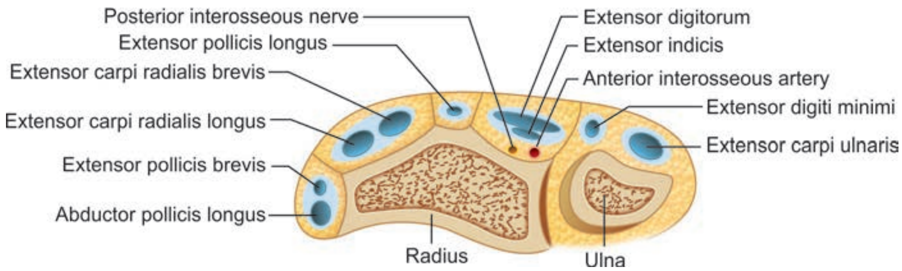


Fig. 71: Extensor retinaculum compartments and contents

Table 41: Extensor retinaculum, compartments and structures passing through them

Compartment	Structure/structures, passing through
I	• Abductor pollicis longus (APL) • Extensor pollicis brevis (APB)
II	• Extensor carpi radialis longus (ECRL) • Extensor carpi radialis brevis (ECRB)
III	• Extensor pollicis longus (EPL)
IV	• Extensor digitorum (ED) • Extensor indicis (EI) • Posterior interosseous nerve • Anterior interosseous artery
V	• Extensor digiti minimi (EDM)
VI	• Extensor carpi ulnaris (EUC)

ASSESSMENT QUESTION

1. **The carpal tunnel contains all of the following important structures *EXCEPT*:** *(AIPG 2005)*
   a. Median Nerve
   b. Flexor pollicis longus
   c. Flexor carpi radialis
   d. Flexor digitorum superficialis

2. **First extensor compartment of wrist has which of the following structures:** *(PGIC 2008)*
   a. Extensor pollicis brevis
   b. Extensor carpi radialis longus
   c. Extensor carpi radialis brevis
   d. Extensor digiti minimi
   e. Abductor pollicis longus

3. **Posterior interosseous nerve runs under which compartment of extensor retinaculum:**
   a. 1st
   b. 2nd
   c. 3rd
   d. 4th

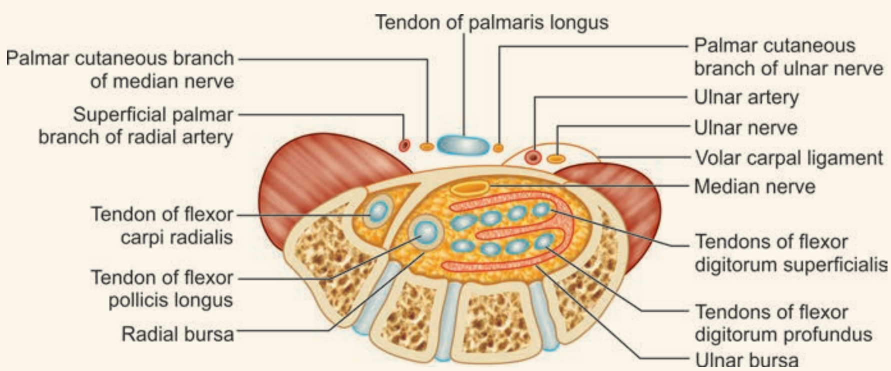
4. **Carpal tunnel contains all *EXCEPT*:** *(NEET Pattern 2015)*
   a. Median nerve
   b. FDS tendon
   c. FPL tendon
   d. FCU tendon

5. **3rd extensor compartment of wrist contains tendon of:** *(NEET Pattern 2015)*
   a. ECRL
   b. ECRB
   c. EPL
   d. EPB

6. **Kanavel's sign is seen in:** *(AIIMS 2007)*
   a. Tenosynovitis
   b. Dupuytren's contracture
   c. Carpal tunnel syndrome
   d. Trigger finger

ANSWERS AND EXPLANATIONS

1. **c. Flexor carpi radialis**
   - The tendon of flexor carpi radialis passes through a tunnel created by a fascial slip on the roof of flexor retinaculum.
   - It passes neither superficial nor deep to the flexor retinaculum, it is actually embedded within the retinaculum.
   - Median nerve, Flexor pollicis longus and flexor digitorum superficialis all pass deep to the flexor retinaculum and are contents of carpal tunnel.



Section of hand showing spaces and contents, related to flexor retinaculum

2. **a. Extensor pollicis brevis, e. Abductor pollicis longus**
   - First extensor compartment of wrist has two tendons: **Abductor pollicis longus** and **extensor pollicis brevis.**
   - These two tendons form the *anterolateral boundary* of **anatomical snuff box** and are involved in **de Quervain's tenosynovitis.**
   - **Extensor carpi radialis longus and brevis** lie in the second compartment**.**
   - **Extensor digiti minimi** is located in the fifth compartment.

3. **d. 4th**
   - 4th compartment has the extensor digitorum and extensor indicis tendons pass through the 4th compartment along with the posterior interosseous nerve and anterior interosseous artery.

4. **d. FCU tendon**
   - Nine flexor tendons pass under the flexor retinaculum along with the median nerve.
   - FCU insertion is into the pisiform bone and then via ligaments into the hamate bone (pisohamate ligament) and 5th metacarpal bone-forming pisometacarpal ligament.

5. **c. EPL**
   - **Third compartment** of extensor retinaculum let pass the tendon of **extensor** pollicis longus.

6. **a. Tenosynovitis**
   - Kanavel's sign, a point of maximum tenderness in the palm 2.5 cm proximal to the base of the little finger in infection of tendon sheath. The goal is to distinguish infectious tenosynovitis from superficial or localized abscess.
   - Kanavel's sign is present in patients with infection of a flexor tendon sheath in the hand (flexor tenosynovitis). It has four components: The affected finger is held in slight flexion, there is uniform swelling over the affected tendon, tenderness over the affected tendon and pain on passive extension of the affected finger.

Hand

Surface Anatomy

- **Tubercle of scaphoid**—can be felt just lateral to the tendon of flexor carpi radialis, located deep to the lateral part of distal transverse crease of the wrist.
- **Crest of trapezium** is felt distolateral to the tubercle of scaphoid.
- **Pisiform bone** lies deep to medial end of distal transverse crease of the wrist.
- **Hook of hamate**—can be felt one finger's breadth distal to the pisiform.
- **Distal wrist crease** corresponds to the proximal border of the flexor retinaculum.
- Radial longitudinal crease partly encircles the thenar eminence.
- Midpalmar longitudinal crease indicates the lateral limit of the hypothenar eminence.
- Proximal transverse palmar crease begins at the lateral border of the palm in common with the radial longitudinal crease, superficial to the head of the second metacarpal, extends medially superficial to the shafts of the 3, 4 and 5th metacarpals.
- Distal transverse palmar crease begins at interdigital cleft between the index and little fingers and crosses the palm superficial to the shafts of the 3, 4 and 5th metacarpals.

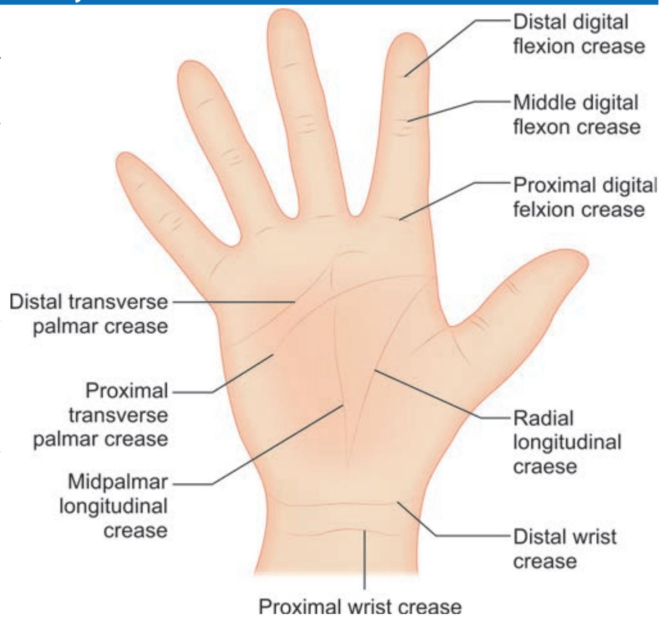


Fig. 72: Flexor creases on the palmar aspect of wrist, palm, and digits

Bones

- **Carpal Bones**: There are 8 carpal bones in the upper limb. **Mnemonic:** She Looks Too Pretty; Try To Catch Her.
  - **Proximal row** (lateral to medial): Scaphoid, Lunate, Triquetral, Pisiform
  - **Distal row:** Trapezium, Trapezoid, Capitate, Hamate
- **Metacarpals** are miniature long bones consisting of bases (proximal ends), shafts (bodies), and heads (form knuckles).
- **Phalanges** are miniature long bones, three each fingers and two in thumb.

Carpal bone	Identification feature
Scaphoid	• Boat shape • Tubercle on distal (palmar aspect)
Lunate	• Moon (crescent) shape
Triquetral	• Pyramid shape • Oval facet (palmar) for pisiform
Pisiform	• Pea shape • Sesamoid bone (flexor carpi ulnaris) • Oval facet (dorsal) for triquetral
Trapezium	• Groove and crest (palmar aspect)
Trapezoid	• Shoe shape
Capitate	• Largest carpal
Hamate	• Wedge shape • Hook (palmar aspect)

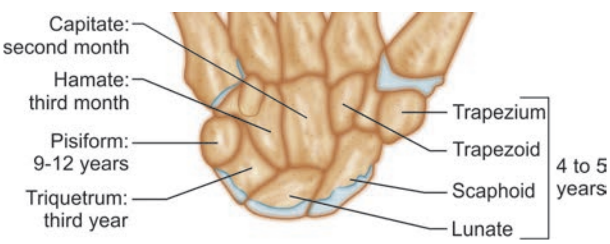


Fig. 73: Age of appearance of ossification centres in hand bones. Capitate begins to ossify in the second month; the hamate at the end of the third month; the triquetrum in the third year; and the lunate, scaphoid, trapezium and trapezoid in the fourth year in females (fifth year in males). The pisiform begins to ossify in the ninth or tenth year in females, and the twelfth in males. Some authors mention: Lunate-fourth year, Scaphoid and trapezoid—fifth year and trapezium-sixth year

Clinical Correlations

- Scaphoid is the **most commonly fractured** carpal bone. A fracture leads to **osteonecrosis** of the scaphoid bone (proximal fragment) because the blood supply to the scaphoid bone flows from distal to proximal.
- There is **tenderness** at the floor of the anatomical snuff box.

ASSESSMENT QUESTIONS

1. Which is NOT a carpal bone? *(PGIC 2012)*
a. Capitate
b. Scaphoid
c. Navicular
d. Cuneate
e. Cuboid

2. TRUE about blood supply of scaphoid: *(NEET Pattern 2015)*
a. Mainly through ulnar artery
b. Major supply from ventral surface
c. Major supply from dorsal surface
d. Proximal supply in antegrade fashion

3. The ossification center of pisiform bone appears at the age of:
a. 10–11 years
b. 12–13 years
c. 14–15 years
d. 15–16 years

4. Which of the following has epiphysis at head? *(NEET Pattern 2013)*
a. Distal phalanx
b. Middle phalanx
c. Thumb metacarpal
d. Third metacarpal

5. Capitate bone articulates with all *EXCEPT*: *(NEET Pattern 2016)*
a. Second metacarpal
b. Lunate
c. Trapezium
d. Scaphoid

6. TRUE statement about lunate bones is:
a. Lies in the proximal row of carpal bones
b. Ossification centre appears at 9-12 years
c. Is a sesamoid bone
d. The largest carpal bone

7. WRONG about the first metacarpal is: *(NEET Pattern 2013)*
a. Epiphysis is at the head
b. Base is convexo-concave for sellar synovial joint
c. Doesn't articulate with other metacarpals
d. More anterior and medially rotated

ANSWERS AND EXPLANATIONS

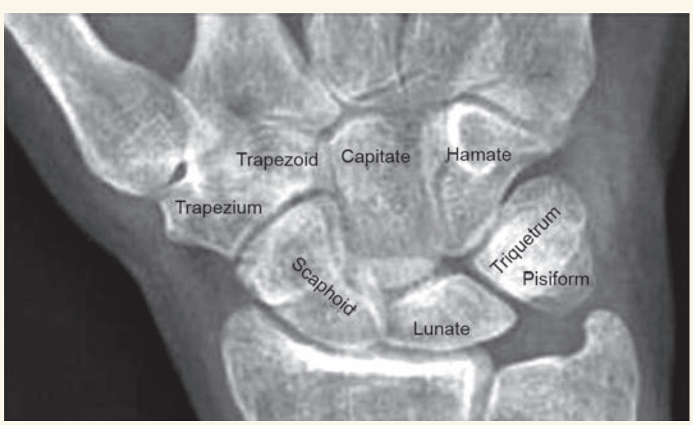
1. c. Navicular, d. Cuneate. e. Cuboid
- Navicular and cuboid bones are tarsal bones. Cuneiform (and not cuneate) is a carpal bone.

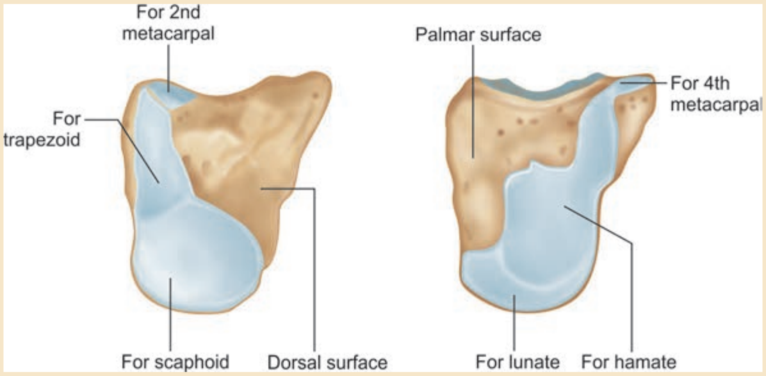
2. c. Major supply from dorsal surface
- Major blood supply (~80%) of scaphoid comes through dorsal surface via dorsal branches of radial artery.
- The artery enters just distal to waist area and supply the proximal part in retrograde fashion.

3. a. 10-11 years
- Pisiform bone ossifies at 9-12 years.

4. d. Third metacarpal
- All metacarpals have distal (head. Epiphysis except the first metacarpal.
- **Aberrant epiphyses** are deviations from the norm (not always present). Epiphysis at the head of the first metacarpal bone is an example.

5. c. Trapezium
- The capitate bone is the largest of the carpal bones in the human hand, and occupies the center of the wrist. It articulates with trapezoid (not trapezium) bone.





Articulations for capitate bone

6. **a. Lies in the proximal row of carpal bones**
   - The carpal bones in the proximal row are scaphoid, lunate, triquetral and pisiform.
   - Ossification centre for lunate appears at 4 years.
   - Pisiform (a sesamoid bone) ossifies at 9-12 years of age.
   - Largest carpal bone is Capitate.

7. **a. Epiphysis is at the head**
   - Epiphysis is present on the heads of all metacarpals, except first metacarpal (epiphysis is at the base).
   - Epiphysis at the head of the first metacarpal bone is an example of aberrant epiphysis, which is a deviation from the norm (and rarely found).
   - First metacarpal is shortest and stoutest of all metacarpals, rotated medially through 90 degrees with respect to other metacarpals.
   - The base of the first metacarpal bone has a convexo-concave articular surface to make a saddle synovial joint with trapezium (first carpometacarpal joint).

Joints

- **Midcarpal Joint** is a **plane** synovial plane joint between the proximal and distal rows of carpal bones and allows gliding and sliding movements.
- **First Carpometacarpal Joint** is a **saddle** synovial joint between trapezium and the first metacarpal bone, allowing flexion and extension, abduction and adduction, and circumduction.
- Plane synovial joints are present between the carpal bones and the medial four metacarpal bones, allowing a simple gliding movement.
- **Metacarpophalangeal Joints** are **ellipsoid** (> condyloid) joints that allow flexion and extension, and abduction and adduction. It has 120° of flexion and extension, about 40° of abduction and adduction, and some rotation possible.
- **Interphalangeal Joints** are **hinge** synovial joints that allow flexion and extension.

ASSESSMENT QUESTION

1. **Metacarpophalangeal joint is:**
   a. Condylar
   b. Ellipsoid
   c. Saddle
   d. Hinge

ANSWER AND EXPLANATION

1. **b. Ellipsoid > a. Condylar**
   - Metacarpophalangeal joints are Ellipsoid > Condylar synovial joint.
   - It has a condyle with elliptical articular surface.

Fascia

- **Palmar aponeurosis** is a triangular fibrous layer overlying the tendons in the palm and protects the superficial palmar arterial arch and palmar digital nerves. It is continuous with the palmaris longus tendon.

Clinical Correlations

- **Dupuytren's** contracture is a progressive thickening, shortening, and fibrosis of the palmar fascia, especially the **palmar aponeurosis**, producing a fixed flexion deformity of fingers in which the fingers are pulled toward the palm (inability to fully extend fingers), especially the ring and little fingers.

Fig. 74: Dupuytren's contracture

Table 42: Intrinsic muscles of hand

Muscle	Proximal attachment	Distal attachment	Innervation	Main action
Thenar muscles				
Opponens pollicis	Flexor retinaculum and tubercles of scaphoid and trapezium	Lateral side of 1st metacarpal	Recurrent branch of median nerve (**C8**, T1)	To oppose thumb, it draws 1st metacarpal medially to center of palm and rotates it medially
Abductor pollicis brevis		Lateral side of base of proximal phalanx of thumb		Abducts thumb; helps oppose it
Flexor pollicis brevis				Flexes thumb
Superficial head				
Deep head			Deep branch of ulnar nerve (C8, **T1**)	
Adductor pollicis				Adducts thum toward lateral border of palm
Oblique head	Bases of 2nd and 3rd metacarpals, capitate, and adjacent carpals	Medial side of base of proximal phalanx of thumb		
Transverse head	Anterior surface of shaft of 3rd metacarpal			
Hypothenar muscles				
Abductor digitiminimi	Pisiform	Medial side of base of proximal phalanx of 5th digit	Deep branch of ulnar nerve (C8, **T1**)	Abducts 5th digit; assists in flexion of its proximal phalanx
Flexor digiti minmi brevis	Hook of hamate and flexor retinaculum			Flexes proximal phalanx of 5th digit
Opponens digiti		Medial border of 5th metacarpal		Draws 5th metacarpal anterior and rotates it, bringing 5th digit into opposition with thumb
Short muscles				
Lumbricals				
1st and 2nd	Lateral two tendons of flexor digitorum profundus (as unipennate muscles)	Lateral sides of extensor expansions of 2nd-5th digits	Median nerve (C8, **T1**)	Flex metacarpophalangeal joints; extend interphalangeal joints of 2nd-5th digits
3rd and 4th	Medial three tendons of flexor digitourm profundus (as bipennate muscles)		Deep branch of ulnar nerve (C8, **T1**)	
Dorsal interossei, 1st–4th	Adjacent sides of two metacarpals (as bipennate muscles)	Bases of proximal phalanges; extensor expansions of 2nd-4th digits		Abduct 2nd-4th digits from axial line; act with lumbricals in flexing metacarpophalangeal joints and extending interphalangeal joints
Palmar interossei, 1st–3rd	Palamar surfaces of 2nd, 4th and 5th metacarpals (as unipennate muscles)	Bases of proximal phalanges; extensor expansions of 2nd, 4th and 5th digits		Addcut 2nd, 4th and 5th digits toward axial line; assist lumbricals in flexing metacarpophalangeal joints and extending interphalangeal joints; extensor expansion of 2nd–4th digits

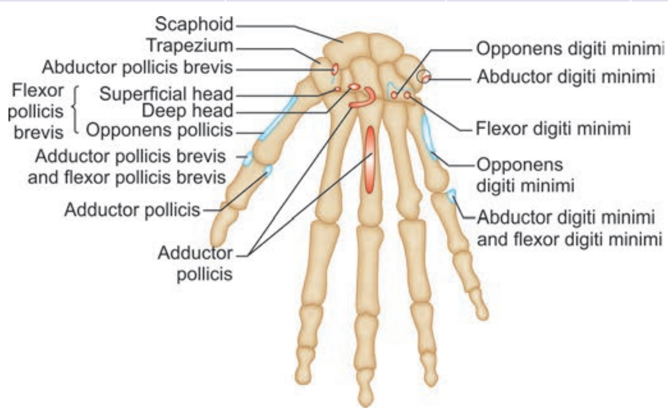


Fig. 75: Hand muscles (origin and insertion)

- Muscle attached to hook of hamate are flexor digiti minimi and opponens pollicis
- **Thumb Opposition:** A succession of activity occurs in the thenar muscles during the movement of opposition. Three subgroups of **radial** (abductor pollicis longus and extensor pollicis brevis), **central** (abductor pollicis brevis and opponens pollicis) and **ulnar** (flexor pollicis brevis) muscles are involved.

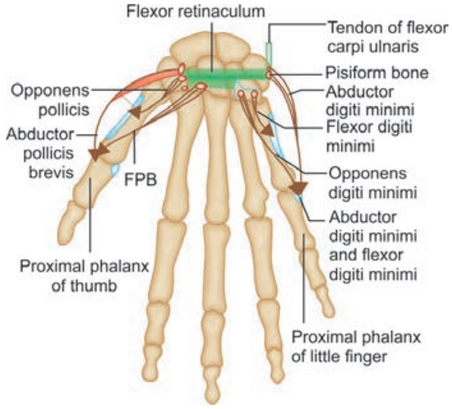


Fig. 76: Hand muscles (origin and insertion)

Lumbrical and Interossei

- **Lumbrical muscles**:
  - Lumbricals take their **origin** from the tendons of flexor digitorum profundus and **insert** into dorsal digital expansion for interphalangeal extension.

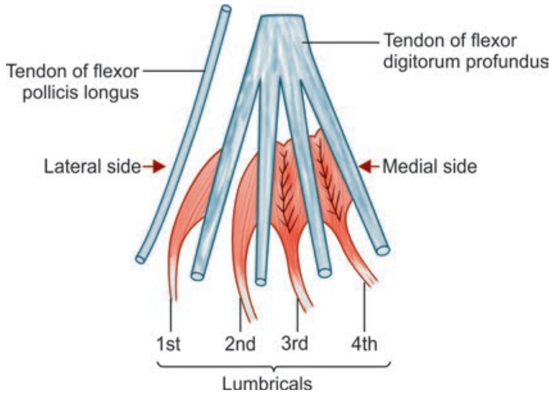


Fig. 77: Lumbrical muscles

  - Pinching the index finger against the thumb **without a lumbrical** would result in a nail-to-nail contact.
  - Lumbricals 1 and 2 arise from **lateral side** of lateral two tendons of the flexor digitorum profundus.
  - Lumbricals 3 and 4 take origin from **adjacent sides** of medial three tendons of the flexor digitorum profundus.
  - The tendons of lumbricals cross the **lateral side** of metacarpophalangeal joints to be inserted into the **lateral side** of dorsal digital expansion of the corresponding digit from second to fifth.
- **Interossei**
  - **P**almar interossei bring about **ADD**uction **(PAD)** at metacarpophalangeal joints.
  - **D**orsal interossei do **AB**duction (**DAB**).
- **Card Test** is for palmar interossei (adductors) of the fingers.
  - Patient is asked to tightly hold a card between the fingers while the examiner tries to pull it out.
- Egawa's Test is for dorsal interossei (abductors) of the fingers.
  - Patient is asked to abduct fingers against examiner's resistance palm facing downward.

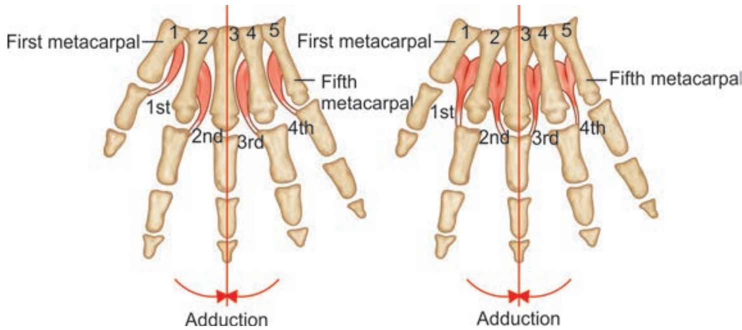
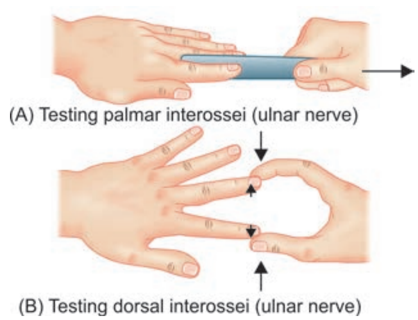


Fig. 78: Palmar and dorsal interossei



Figs. 79A and B: Clinical testing of palmar and dorsal interossei

Dorsal Digital Expansion

- **Dorsal digital expansion** forms a functional unit to coordinate the actions of long extensors, long flexors, lumbricals and interossei on the digit.
- Extensor digitorum sends a **single central band** which inserts on the base of the middle phalanx, whereas **two lateral bands** join to form a single terminal band to insert on the base of the distal phalanx.
- The tendons of **lumbricals** and **interossei** are inserted into this expansion.
- On the index finger and little finger, the expansion is strengthened by extensor indicis and extensor digiti minimi, respectively, which blends with it.

Clinical Correlations

- **Mallet finger** (hammer or baseball finger) is a finger with **permanent flexion of the distal phalanx** due to an avulsion of the **lateral bands** of the extensor tendon to the distal phalanx. It occurs due to A forceful blow on the tip of the finger causing **sudden and strong flexion** of the phalanx.

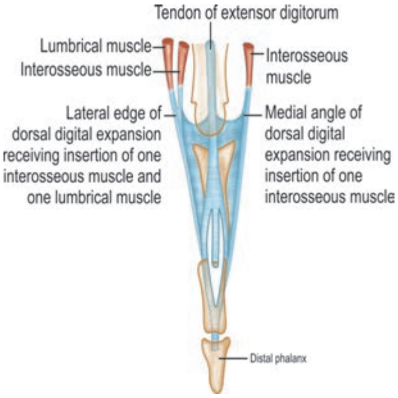


Fig. 80: Dorsal digital expansion on the dorsum of finger

Fig. 81: Mallet finger with swan neck deformity

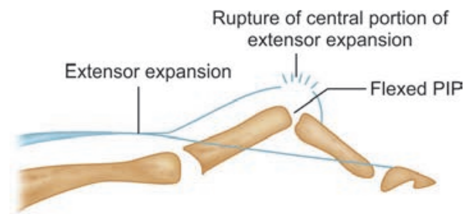


Fig. 82: Boutonniere buttonhole deformity. Proximal interphalangeal (PIP) joint pokes through the extensor expansion

- **Boutonnière (button-hole) deformity** is characterized by **flexion** of proximal interphalangeal joint and **hyperextension** of distal phalanx. It occurs when the flexed PIP joint pokes through the extensor expansion following rupture of its 'central' band of dorsal digital expansion due to a direct end on trauma to the finger. It is **opposite** to mallet finger deformity.

ASSESSMENT QUESTIONS

1. Which muscle does NOT take part in dorsal digital expansion? *(NEET Pattern 2013)*

a. Interossei
b. Lumbricals
c. Extensor digitorum
d. Adductor pollicis

2. 'Mallet finger' is a common traumatic lesion resulting in flexion deformity of distal interphalangeal joint. The basic pathology of this condition is: *(UPSC)*

a. Avulsion fracture of middle phalanx
b. Rupture of collateral slips of extensor expansion
c. Rupture of central slip of extensor expansion
d. Dislocation of distal interphalangeal joint

ANSWERS AND EXPLANATIONS

1. d. Adductor pollicis

- **Dorsal digital expansion** is a tendinous modification of **extensor digitorum** and receives attachment of **lumbricals, interossei** but not *adductor pollicis*.

2. b. Rupture of collateral slips of extensor expansion

- **'Mallet finger'** describes the characteristic drooping of the finger observed with injury to the extensor digitorum at its insertion at the base of the distal phalanx (the **collateral** slips).
- A mallet finger may result from direct trauma to the fingertip or more commonly, by forcibly bending the finger in extension, for example, when catching a ball - hence, the synonym, "**baseball finger**."
- In older patients, the associated trauma may be minor for example, catching the tip of the finger whilst changing the sheets on the bed.
- The extensor mechanism is disrupted. The finger is held flexed at the distal interphalangeal joint. There is no active movement but passive movement is unimpaired. In time, the proximal phalanx may become hyperextended.
- **Extensor expansion** (dorsal expansion, dorsal hood) refers to the flattened tendons (aponeurosis) of extensor muscles that run into the back of the hand.
- At the distal end of the metacarpal, the extensor tendon will expand to form a hood, which covers the back and sides of the head of the metacarpal and the proximal phalanx.
- The expansion soon divides into three bands:

* Two **lateral** bands pass on either side of the proximal phalanx and stretch all the way to the **distal** phalanx. The lumbricals of the hand, the palmar and dorsal interossei of the hand, also insert on these bands.
* A single median band passes down the middle of the finger along the back of the proximal phalanx, ending at the base of the middle phalanx.

High Yield Points

- The tip of the hook gives attachment to the flexor retinaculum.

ASSESSMENT QUESTIONS

1. **Pen test in the hand is performed to assess the neuromuscular status of:**
   a. Opponens pollicis
   b. Flexor pollicis brevis
   c. Abductor pollicis brevis
   d. 1st palmar interossei

2. **Nerve supply to dorsal interossei are by:**
   a. Radial
   b. Ulnar
   c. Median
   d. Ulnar and median

3. **Action of dorsal interossei:**
   a. Extension at metacarpophalangeal joint
   b. Adduction at metacarpophalangeal joint
   c. Flexion at metacarpophalangeal joints
   d. Flexion at interphalangeal joints

4. **Claw hand is hyperextension at metacarpophalangeal joint and flexion at the interphalangeal(s). Which muscles have become non-functional?**
   a. Lumbricals
   b. Lumbricals and palmar interossei
   c. Lumbricals and dorsal interossei
   d. Lumbricals and all interossei

5. **Flexion of MCP joint and extension of IP joints is the major action of:** *(NEET Pattern 2015)*
   a. Palmar interossei
   b. Dorsal interossei
   c. Lumbricals
   d. FDS

6. **Card test is done to check the function of:** *(AIIMS 2015)*
   a. Lumbricals
   b. Palmar interossei
   c. Dorsal interossei
   d. Adductor pollicis

7. **FALSE statement regarding adductor pollicis muscle:** *(JIPMER 2008)*
   a. Has 2 heads
   b. Supplied by median nerve
   c. Causes adduction of thumb
   d. Arterial supply is from arteria princeps pollicis

8. **A patient with leprosy presents with ulnar nerve involvement and clumsiness of hand, due to palsy of which muscle:** *(AIIMS 2000)*
   a. Extensor carpi ulnaris
   b. Abductor pollicis brevis
   c. Opponens pollicis
   d. Interosseous muscle

9. **Function of lumbricals are:** *(PGIC 2015)*
   a. Flexion at MCP joint
   b. Extension at IP joints
   c. Adduction of the fingers
   d. Abduction of the fingers
   e. Flexion at IP joints

10. **Palmaris brevis is:**
    a. Involuntary muscle
    b. Modification of deep fascia
    c. Remnant of panniculus carnosus
    d. All of the above

11. **Small muscles of hand are supplied by:** *(NEET Pattern 2015)*
    a. C4, 5
    b. C5, 6
    c. C8; T1
    d. T1, 2

12. **Following a deep cut overlying the hypothenar eminence, patient cannot hold a sheet of paper between the 2nd and 3rd digits. Which of the following nerves is most likely damaged:**
    a. Deep branch of ulnar nerve
    b. Deep branch of radial nerve
    c. Superficial branch of ulnar nerve
    d. Median nerve

13. **Compression of a nerve within the carpal tunnel products inability to:** *(AIIMS; NEET Pattern 2014)*
    a. Abduct the thumb
    b. Adduct the thumb
    c. Flex the distal phalanx of the thumb
    d. Oppose the thumb

14. **Power grip of hand is due to:** *(NEET Pattern 2014)*
    a. Palmaris
    b. Long flexors
    c. Short flexors
    d. Lumbricals

ANSWERS AND EXPLANATIONS

1. **c. Abductor pollicis brevis**
   - Pen test is to check *anterior abduction* of thumb, carried out by **abductor pollicis brevis** (**median nerve** supply).

2. **b. Ulnar**
   - All the 8 interossei are supplied by the ulnar nerve.

3. c. Flexion at metacarpophalangeal joints

- Digital abduction is a function of the 4 dorsal interossei **('DAB'-dorsal abduction)** and digital adduction is a function of 4 palmar interossei **('PAD'-palmar adduct).**
- The 8 interossei muscles work along with 4 lumbricals for MCP flexion and IP extension (glass holding position).

4. d. Lumbricals and all interossei

- 12 muscles: 4 lumbricals and 8 interossei (4 dorsal and 4 palmar) act together to achieve **glass holding position**: MCP (meta-carpo-phalangeal) flexion and IP (inter-phalangeal) extension.
- Paralysis of these 12 muscles results in comparative increased activity of antagonistic **(opposite)** muscles, leading to Claw hand deformity: hyperextension at MCP and flexion at IP joints.

5. c. Lumbricals

- This is a wrong question since it has multiple answers.
- Lumbricals and interossei work together for metacarpophalangeal flexion and interphalangeal extension.
- The major action of lumbricals is to cause extension at interphalangeal joint. They also cause weak metacarpophalangeal flexion.
- Palmar interossei adduct (PAD) the fingers towards the longitudinal axis of the middle finger and dorsal interossei abduct (DAB) the fingers away from the longitudinal axis of the middle finger.
- Interossei contribute strongly to metacarpophalangeal joint flexion and interphalangeal extension.

6. b. Palmar interossei

- Card test - A card is placed between the two fingers of the patient to grasp. As the palmar interossei are weak, patient cannot do palmar adduction to grasp [palmar interossei are adductors of the fingers - PAD].

7. Ans: b. Supplied by median nerve

- Adductor pollicis muscle has two heads, both supplied by the ulnar nerve.

8. d. Interosseous muscle

- Clumsiness of hand occurs due to paralysis of intrinsic muscles of hand like lumbricals and interossei.

9. a. Flexion at MCP joint, b. Extension at IP joints

- Lumbrical muscle cause flexion at metacarpophalangeal joints and extension at interphalangeal joints.

10. c. Remnant of panniculus carnosus

- Palmaris brevis is a subcutaneous muscle on the hypothenar region supplied by ulnar nerve. It is a remnant of panniculus carnosus, which itself is a sheath of dermal (skin) muscle, that allows the movement of the skin independent of the movement of deeper muscle masses.

11. c. C8; T1

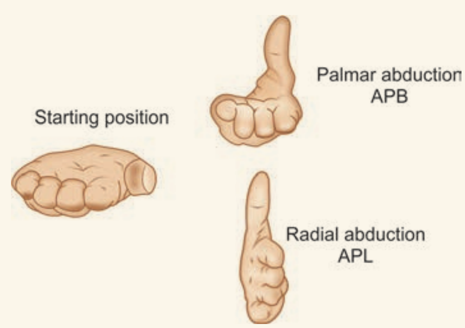
- Small hand muscles are supplied by branches of the lower trunk of brachial plexus (C8; T1).

12. a. Deep branch of ulnar nerve

- Holding a paper between fingers require adduction, carried out by the palmar interossei (PAD) - Card test. All the interossei are supplied by deep branch of ulnar nerve.

13. d. Oppose the thumb

- Carpal tunnel syndrome leads to compression of median nerve, paralysing the abductor pollicis brevis, hence loss of thumb opposition.
- Thumb opposition has three components:
  1. Anterior abduction of thumb (abductor pollicis brevis supplied by median nerve)
  2. Medial rotation of thumb (opponens pollicis supplied by median and ulnar nerve)
  3. Flexion of thumb (flexor pollicis brevis supplied by median and ulnar nerve)
- Paralysis of abductor pollicis brevis leads to loss of the first component of thumb opposition, plus thumb remains in adduction deformity (unopposed adductor pollicis supplied by ulnar nerve).
- In this patient there is loss of anterior abduction (abductor pollicis brevis; median nerve) but lateral abduction of thumb (abductor pollicis longus supplied by posterior interosseous nerve, radial nerve) is still possible.



- Adduction of thumb is carried out by the adductor pollicis (ulnar nerve).
- Since the compression of median nerve is in the carpal tunnel (paralysing the distal muscles in hand) the proximal muscles of forearm are still functional. Flexion of distal phalanx (flexor pollicis longus supplied by anterior interosseous nerve, median nerve) is possible.

14. b. Long flexors > d. Lumbricals

- In power grip while the wrist is fixed in dorsiflexion (by extensor muscles) long finger flexors and intrinsic muscles of hand (like lumbricals) work to grip the object.

Nerves

- **Motor**
  - The superficial head of **flexor pollicis brevis** is innervated by the recurrent motor branch of the median nerve, and the deep head by the deep branch of the ulnar nerve.
  - **Abductor pollicis brevis** is innervated by the recurrent motor branch of the median nerve and is the only thenar muscle that is constantly supplied by the median nerve.
  - **Opponens pollicis** is usually mentioned to innervated by the lateral terminal branch of the median nerve (but **Gray's anatomy** mentions that it also receives a branch of the deep terminal branch of the ulnar nerve).
  - **Adductor pollicis**, **abductor digiti minimi, flexor digiti minimi brevis, opponens digiti minimi** and all the **interossei** are innervated by the deep branch of the ulnar nerve; the first dorsal interosseous and adductor pollicis are supplied by its most distal portion.
  - **Palmaris brevis** is innervated by the superficial branch of the ulnar nerve.
  - The **first and second lumbricals** are innervated by the median nerve, and the **third and fourth lumbricals** by the deep terminal branch of the ulnar nerve. The third lumbrical frequently receives a supply from the median nerve. The first and second lumbricals are, occasionally, innervated by the deep terminal branch of the ulnar nerve.
- **Cutaneous**
  - **Median nerve** supplies lateral half of the palm and lateral 3½ digits (nail beds included).
  - **Ulnar nerve** supplies over the palmar and dorsal surfaces of medial third of the hand and medial 1½ fingers (little finger and the ulnar half of the ring finger).
  - **Radial nerve** innervates the skin over the lateral part of the dorsum of hand and dorsal surfaces of lateral 3½ digits (excluding the nail beds).

Arteries

- The **ulnar artery** is the major contribution to the **superficial palmar arterial arch**, whereas the radial artery is the major contribution to the deep palmar arch.

Table 43: Arteries in Hand

Artery	Origin	Course
Superficial palmar arch	Direct continuation of ulnar artery; arch is completed on lateral side by superficial branch of radial artery or another of its branches	Curves laterally deep to palmar aponeurosis and superficial to long flexor tendons; curve of arch lies across palm at level of distal border of extended thumb
Deep palmar arch	Direct continuation of radial artery; arch is completed on medial side by deep branch of ulnar artery	Curves medially, deep to long flexor tendons; is in contact with bases of metacarpals
Common palmar digital	Superficial palmar arch	Pass distally on lumbricals to webbing of digits
Proper palmar digital	Common palmar digital arteries	Run along of 2nd–5th digits
Princeps pollicis	Radial artery as it turns into palm	Descends on palmar aspect of 1st metacarpal; divides at base of proximal phalanx into two branches that run along sides of thumb
Radialis indicis	Radial artery but may arise from princeps pollicis artery	Passes along lateral side of index finger to its distal end
Dorsal carpal arch	Radial and ulnar arteries	Arches within fascia on dorsum of hand

Palmar Arches

Table 44: Palmar arches

	Superficial palmar arch (SPA)	Deep palmar arch (DPA)
Formation	It is the direct continuation of ulnar artery (beyond flexor retinaculum), usually completed laterally by anastomosis with the small superficial palmar branch of the radial artery.*	Is formed by the main termination of the radial artery and is completed medially by the small deep palmar branch of the ulnar artery (at the base of the fifth metacarpal).
Relations	Superficial: • Palmar aponeurosis Deep: • Long flexor tendons • Digital branches of the median and ulnar nerves	Superficial: • Long flexor tendons of the fingers • Lumbricals Deep: • Proximal parts of shafts of the metacarpals • Interosseous muscles

	Superficial palmar arch (SPA)	Deep palmar arch (DPA)
Branches	• Three common palmar digital arteries** • One proper digital artery runs along the medial side of the little finger. • Cutaneous branches	• Three palmar metacarpal arteries** • Three perforating arteries, which anastomose with dorsal metacarpal arteries • Recurrent branches run proximally in front of carpus to end in the palmar carpal arch
Surface anatomy	It is convex distally and level with a transverse line through the distal border of the fully extended base of the thumb	Lies about 1 cm proximal to the superficial palmar arch. In its concavity, running laterally, is the deep branch of the ulnar nerve.

*As a variation, SPA may be completed by radialis indicis artery or princeps pollicis artery occasionally.
** In the interdigital clefts, the common palmar digital arteries (from SPA). Are joined by the palmar metacarpal arteries (from DPA)

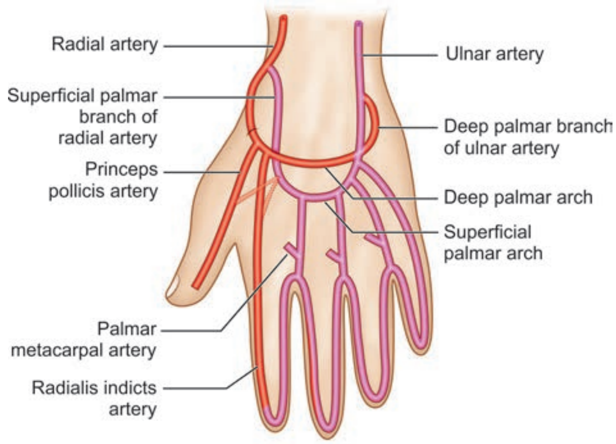


Fig. 83: Palmar arterial arches

ASSESSMENT QUESTION

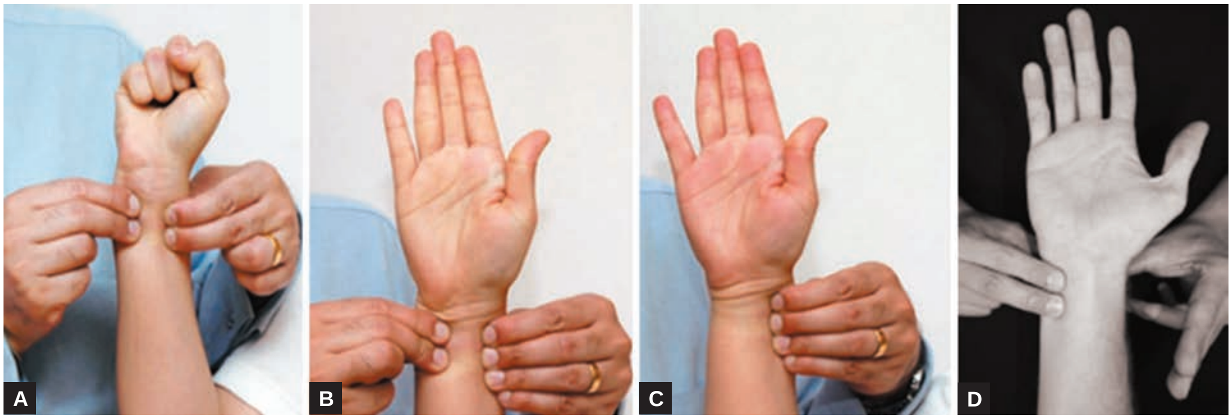
1. **TRUE about deep palmar arch:** *(NEET Pattern 2015)*
   a. Main contribution is by ulnar artery
   b. Lie superficial to lumbricals
   c. Gives three perforating branches
   d. Gives four palmar metacarpal arteries

ANSWER AND EXPLANATION

1. **c. Gives three perforating branches**
   - Deep palmar arch is mainly fed by radial artery, lies deep to lumbricals and gives three perforating and three palmar metacarpal arteries.

Allen Test

- **Allen test** is done to check the interconnection (integrity) between the superficial and deep palmar arches and patency of the **radial and ulnar** arteries at the wrist and so determines whether each individual artery is sufficient to maintain the arterial supply to the hand **in isolation.**
- **Procedure:** The patient **makes a tight fist** so as to express the blood from the skin of the palm and fingers; the examiner **digitally compresses both** the ulnar and radial arteries. Next the patient opens the fist to reveal the **pale palm**. As the ulnar artery compression is removed in next step, the **palm turns red**, including the thumb zone. **If blood fails to return to the thumb zone** it reveals that the anastomosis between the two palmar arches is inadequate and **Allen test is positive**. Radial artery cannulation is **not advisable** in such patient, since it puts the thumb zone at risk of injury.
- **Anatomical basis:** The hand is normally supplied by blood from the ulnar and radial arteries. The arteries undergo anastomosis in the hand. Thus, if the blood supply from one of the arteries is cut off, the other artery can supply adequate blood to the hand. A **minority** of people lack this dual blood supply.
- It is performed **prior to radial arterial blood sampling** or cannulation. An uncommon complication of radial arterial blood sampling/cannulation is disruption of the artery (obstruction by clot), placing the hand at risk of ischemia.
  Those people who lack the dual supply are at much **greater risk of ischemia.**
- **Reverse Allen test** is done to check the **patency of radial artery**, as the compression on the radial artery is removed the palm should turn red, even if the ulnar artery compression was in place.



Figs. 84A to D: The Allen test (A-C); D. Reverse Allen test

ASSESSMENT QUESTION

1. **Allen's test is done for checking:**
   a. Neural disorders
   b. Patency of ulnar artery
   c. Patency of radial artery
   d. Blood flow in cephalic vein

ANSWER AND EXPLANATION

1. **b. Patency of ulnar artery > c. Patency of radial artery**
   - Allen test is done to check the patency of both radial and ulnar artery. To check the radial artery, we name it as reverse Allen test.

Spaces in Hand

- Fascial spaces of the palm are deep to the *palmar aponeurosis* and divided by a midpalmar (oblique septum attached to third metacarpal) into the **thenar** space and the **midpalmar** space.
  - **Thenar Space** is the lateral space that contains the flexor pollicis longus tendon and the other flexor tendons of the index finger.
  - **Midpalmar Space** is the medial space that contains the flexor tendons of the medial three digits.
  - The tendons of the second, third, and fourth digits have separate synovial sheaths so that the infection is confined to the infected digit, but *rupture* of the proximal ends of these sheaths allows the infection to spread to the **midpalmar space.**
  - **First lumbrical space** communicates with **thenar space** whereas, 2, 3 and 4 lumbrical canals are continuous with midpalmar space. Infection from thumb and index finger passes towards the thenar space along the **first lumbrical canal.**
  - Middle, ring finger and little finger drain towards **midpalmar space** along the 2, 3 and 4th lumbrical canals.
- **Ulnar bursa** is the common synovial flexor sheath which envelops the tendons of both the flexor digitorum superficialis and profundus muscles.
  - The synovial sheath of the **little finger** is usually continuous with the common synovial sheath (**ulnar bursa**), and thus, tenosynovitis may spread to the common sheath and thus through the palm and carpal tunnel to the forearm
- **Radial Bursa** is the synovial flexor sheath for flexor pollicis longus.
  - Tenosynovitis in the **thumb** may spread through the synovial sheath of the flexor pollicis longus (**radial bursa**).
- **Forearm space of Parona** lies proximal to the flexor retinaculum and is continuous with the radial and ulnar bursa. Flexor retinaculum separates forearm space of Parona from the thenar and midpalmar space and they are non-continuous.

Note: Bursa is defined as a potential space lined by synovial membrane.

Table 45: Spaces in Hand

Structure/ Space	Features	Boundaries	Communications/ Extensions	Clinical correlates
Thenar space	• Triangular, located under the lateral half of the hollow of the palm. • Contains the flexor pollicis longus tendon and the other flexor tendons of the index finger	• Anterior: Palmar aponeurosis, radial bursa, first lumbrical. • Lateral: Lateral palmar septum*** • Medial: Intermediate palmar septum • Posterior: Fascia covering the transverse head of adductor pollicis	• Proximally: Limited by the fusion of anterior and posterior walls in the carpal tunnel. • Distally: Communicates with the first web space through the first lumbrical canal.	• Infection: From radial bursa or synovial sheath of the index finger. • Drainage: incision in the web space of the thumb.

Structure/ Space	Features	Boundaries	Communications/ Extensions	Clinical correlates
Midpalmar space	• Triangular, located under the medial half of hollow of the palm. • Contains the flexor tendons of the medial three digits	• Anterior: Palmar aponeurosis, superficial palmar arch, ulnar bursa, medial three lumbricals. Posterior: Fascia covering interossei and medial three metacarpals. Lateral: Intermediate palmar septum* Medial: Medial palmar septum**	• Proximally: Continuous with the forearm space of Parona. • Distally: Continuous with the medial three web-spaces through medial three lumbrical canals.	• Infection: Ulnar bursa is the inlet and lumbrical canals are outlets of infection in this space. • Pus drainage: incisions in the medial two web spaces.
Ulnar bursa	Common synovial flexor sheath which envelops the tendons of both the flexor digitorum superficialis and profundus muscles		• Proximally: Extends into the forearm about 5 cm proximal to the flexor retinaculum • Distally: Extends in the palm up to the middle of the shafts of the metacarpal bones; medial end is continuous with the digital synovial sheath of the little finger	• Pus drainage: Incision on radial margin of hypothenar eminence
Radial bursa	Synovial flexor sheath for flexor pollicis longus		• Proximally: Extends into the forearm about 5 cm proximal to the flexor retinaculum. • Distally: Continuous with digital synovial sheath of the thumb	• Pus drainage: Incision on medial margin of thenar eminence
Forearm space of Parona	Fascial interval underneath the flexor tendons on the front of distal part of the forearm	• Anterior: Ulnar bursa and radial bursa	• Proximally: Continuous with the intermuscular spaces of the forearm • Distal: Reaches the level of wrist.	• Infection: From ulnar bursa. • Pus drainage: Vertical incisions should on the distal part of forearm
Pulp space	Subcutaneous spaces on the palmar side of tips of the fingers and thumb.	• Superficial: Skin and superficial fascia. • Deep: Distal two-third of distal phalanx.		

*Intermediate palmar septum extending obliquely from near the medial edge of the palmar aponeurosis to the third metacarpal bone. This septum separates the midpalmar space from the thenar space.
**Medial palmar septum extending from medial edge of palmar aponeurosis to the fifth metacarpal.
This septum separates the midpalmar space from hypothenar space occupied by the hypothenar muscles.
***Lateral palmar septum extending from lateral edge of palmar aponeurosis to the first metacarpal.

Note: The radial bursa is usually a separate from that of ulnar bursa but may communicate with ulnar bursa deep to flexor retinaculum.

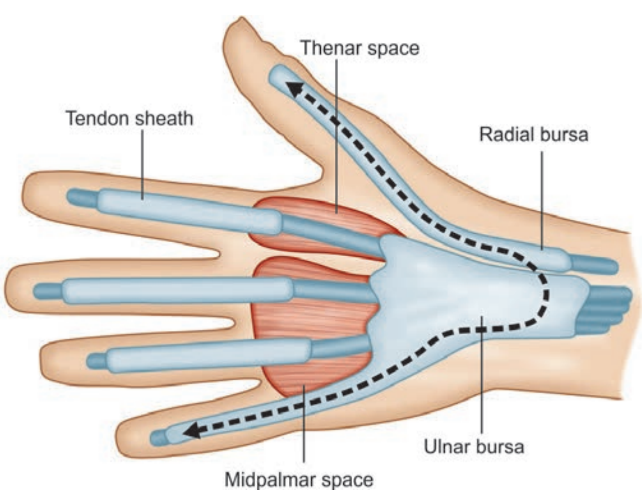


Fig. 85: Palmar spaces

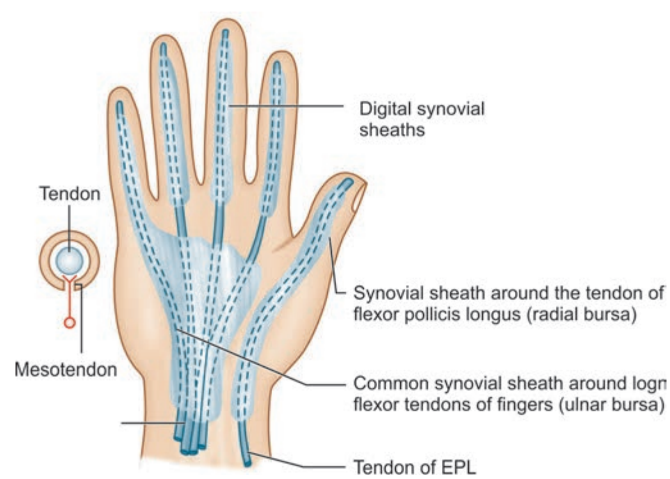


Fig. 86: Palmar spaces

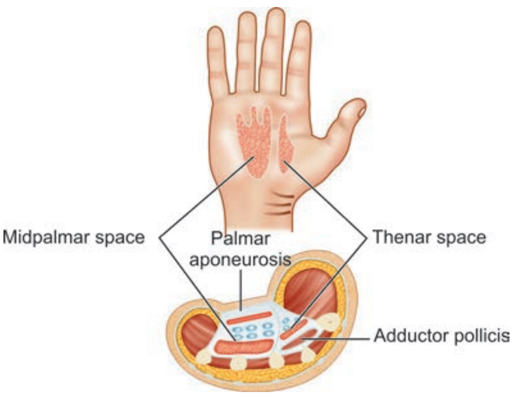


Fig. 87: Palmar spaces

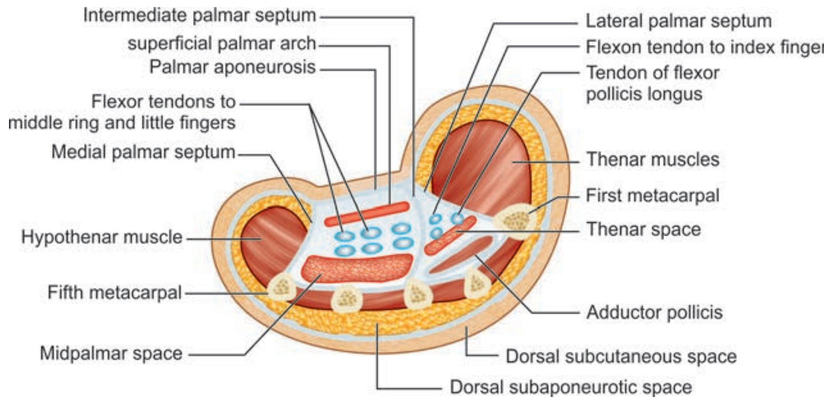


Fig. 88: Palmar spaces

- **First lumbrical** is related to the **thenar space** as it arises from the flexor digitorum profundus tendon for **index finger.**

ASSESSMENT QUESTIONS

1. **Content of midpalmar space are all *EXCEPT*:** *(NEET Pattern 2012)*
   a. FDP of 4th finger
   b. FDP of 3rd finger
   c. 2nd lumbrical
   d. 1st lumbrical

2. **Midpalmar space communicates with all *EXCEPT*:** *(Delhi 2006)*
   a. Forearm space
   b. Fascial sheath of first lumbrical
   c. Fascial sheath of second lumbrical
   d. Fascial sheath of third lumbrical

3. **Infection draining the index finger goes to:** *(NEET Pattern 2014)*
   a. Thenar space
   b. Midpalmar space
   c. Ulnar bursa
   d. Radial bursa

4. **Radial bursa is the synovial sheath covering the tendon of:** *(NEET Pattern 2013)*
   a. FDS
   b. FDP
   c. FPL
   d. FCR

5. **Midpalmar space of hand communicates with all *EXCEPT*:**
   a. Forearm space
   b. Fascial sheath of 1st lumbrical
   c. Fascial sheath of 2nd lumbrical
   d. Fascial sheath of 3rd lumbrical

ANSWERS AND EXPLANATIONS

1. **d. 1st lumbrical**
   - **First lumbrical** arises from the FDP (flexor digitorum profundus) tendon of **index finger** and communicates with the **thenar space.**
   - FDP of middle (3), ring (4) and little (5) fingers lies in the mid-palmar space and hence the lumbricals 2, 3 and 4 are present in **midpalmar space**.
2. **b. Fascial sheath of first lumbrical**
   - **First lumbrical** arises from the FDP (flexor digitorum profundus) tendon of **index finger** and communicates with the **thenar space.**
   - FDP of middle (3), ring (4) and little (5) fingers lies in the mid-palmar space and hence the lumbricals 2,3 and 4 are present in **mid-palmar space**.
3. **a. Thenar space**
   - Ring finger pus drains towards the thenar space.
4. **c. FPL**
   - Radial bursa is the synovial sheath covering the tendon of flexor pollicis longus.
5. **b. Fascial sheath of 1st lumbrical**
   - Midpalmar space is continuous with the medial three web-spaces through medial three lumbrical canals.
   - Fascial sheath of first lumbrical is continuous with thenar space

Arches of Hand

- **Transverse carpal arch** is formed by the **concavity of the carpus** with flexor retinaculum stretching between its pillars.
- **Transverse metacarpal arch** is formed by the **heads of the metacarpal bones**, which are bound together by the deep metacarpal ligaments.
- **Longitudinal arch** is formed by the **palmar concavity of the metacarpals** and normal slightly flexed posture of the digits.

Applied Anatomy

- **Trigger** finger results from **stenosing tenosynovitis** or occurs when the flexor tendon develops a nodule or swelling that **interferes with its gliding through** the pulley at metacarpophalangeal joint, causing an audible clicking or snapping. The condition is caused by rheumatoid arthritis, repetitive trauma, and wear and tear of aging of the tendon.

- **Jersey finger** (Rugby finger or Sweater finger) is a type of injury **due to avulsion** of the flexor digitorum profundus (FDP) at the **base of the distal** interphalangeal joint.
- Bennett fracture is a fracture of the **base of the metacarpal** of the thumb.
- **Boxer's** fracture is a fracture of the necks of the **second and third metacarpals**, seen in professional boxers, and typically of the fifth metacarpal in unskilled boxers.
- **Gamekeeper's thumb** is a disruption of the **ulnar collateral ligament** of the metacarpophalangeal joint of the thumb often associated with an avulsion fracture at the **base of the proximal phalanx of the thumb.** This occurs in skiing falls where the thumb gets entangled with the ski pole.

ASSESSMENT QUESTIONS

1. **A cricketer gets injured in his right thumb, while trying to catch a ball. He presents with pain at the base of his right thumb. He should be examined immediately to rule out which specific damage:** *(AIIMS 2011)*
   a. Extensor pollicis brevis
   b. Abductor pollicis longus
   c. Volar plate
   d. Ulnar collateral ligament

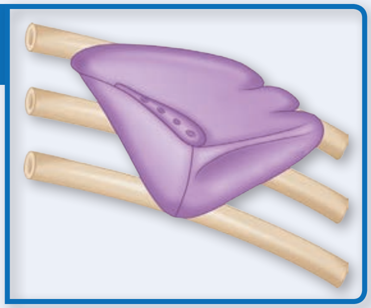
2. **In trigger finger the level of tendon sheath constriction is found at the level of:**
   a. Middle phalanx
   b. Proximal interphalangeal joint
   c. Proximal phalanx
   d. Metacarpophalangeal joint

ANSWERS AND EXPLANATIONS

1. **d. Ulnar collateral ligament**
   - **Gamekeeper's thumb** (also known as skier's thumb) is a type of injury to the **ulnar collateral ligament** (UCL) of the thumb.
     – The UCL is torn at (or in some cases even avulsed from) its insertion site into the proximal phalanx of the thumb. There might be an accompanying fracture with the tear.
     – The patient will often manifest a weakened ability to grasp objects or perform such tasks as tying shoes and tearing a piece of paper.
     – Other complaints include intense pain experienced upon catching the thumb on an object, such as when reaching into a pants pocket.
   - *__Volar plates__ are the ligaments at the anterior aspect of the joints in hand, also referred to as palmar or volar ligaments.
   - *__Extensor pollicis brevis__ inserts into the base of proximal phalanx.
   - *__Abductor pollicis longus__ inserts into the base of the first metacarpal.
   - *Both these tendons make the anterior boundary of the anatomical snuff box.

2. **d. Metacarpophalangeal joint**
   - Trigger finger, or digital flexor stenosing tenosynovitis, is a condition characterized by localized restriction of extension in a digit other than the thumb. There is a mismatch between the size of the tendon and its Fibrous flexor sheath making it difficult for the tendon to pass through it.
   - Usually, flexion is normal but beyond a certain range of motion, the sufferer has difficulty extending the flexed finger. A snap is frequently felt as the obstruction is passed. There may be pain at the point of obstruction.
   - Clinically, a discrete nodule may be palpated along the line of the flexor tendon at the level of the MCP joint. Alternatively, there may just be tenderness at this site.
   - The most commonly affected digits are the ring and middle fingers.
   - The most commonly affected level is at **MCP joint** but occasionally it may occur at distal joints also. The index finger is affected rarely.
   - Similar pathological processes may occur in the flexor pollicis longus tendon - trigger thumb.
   - Initially, the treatment of trigger finger may be medical, but frequently surgery provides definitive relief.

CHAPTER 9



Abdomen

Introduction

Abdomen region stretches from the thoraco-abdominal diaphragm to the pelvic brim.

Contents - Digestive tract: Stomach, small intestine, large intestine with cecum and appendix; Accessory organs of the digestive tract: Liver, gallbladder and pancreas; Urinary system: Kidneys and ureters (retro peritoneal); Other organs: Spleen; Blood vessels: Aorta, Inferior vena cava etc.

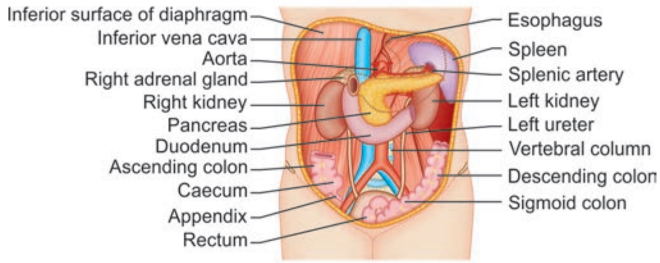


Fig. 1: Arrangement of organs in the abdominal cavity

Surface Marking and Landmarks

Abdomen

Landmarks

Murphy's point lies below the right costal margin at the mid-clavicular line (the approximate location of the fundus of gallbladder). *The point is at the **intersection** of the right linea semilunaris and right costal margin, at the tip of the right 9th costal cartilage. *In **acute cholecystitis**, when the anterior abdominal wall is pressed below this point the patient **winces** (while taking a deep breath) due to pain.

McBurney's point lies over the right side of the abdomen, at the junction of the medial 2/3rd and lateral 1/3rd of the line joining the umbilicus with the anterior superior iliac spine. *It corresponds to the most common location of the base of the appendix (where it is attached to the cecum) and is is the site of **maximum tenderness** in acute appendicitis.

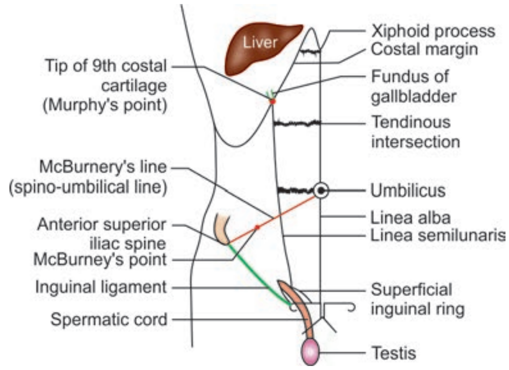


Fig. 2: Various landmarks in the abdomen region in relation with gallbladder, appendix, and spermatic cord.

Mid-inguinal Point

- The **mid-inguinal point** lies at the midpoint of a line between the pubic symphysis and the anterior superior iliac spine. In adults, it is the approximate surface marking of the **femoral artery** (just below the ligament) and the **deep inguinal ring** (just above the ligament).
- The deep inguinal ring is an opening in the transversalis fascia, approximately **midway** between the anterior superior iliac spine and the pubic symphysis, and about 1 cm above the inguinal ligament.

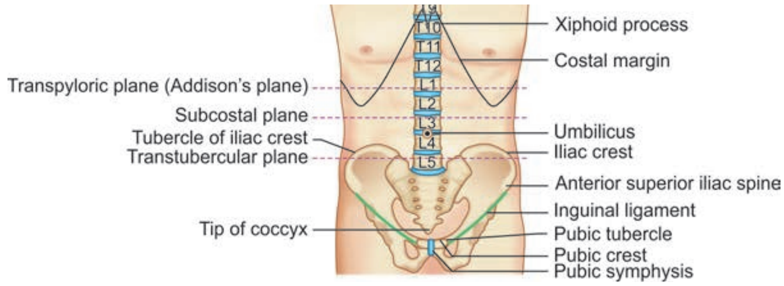


Fig. 3: Bony landmarks and planes of the abdomen

Abdominal Planes

- Transpyloric: Lower border of L1
- Subcostal: Upper border of L3
- Trans-umbilical: Intervertebral disc between L3 - 4 vertebra
- Trans-tubercular: Upper border of L5
- Interspinous: Body of S1
- These regions are bounded vertically by two midclavicular lines and horizontally by the subcostal plane and the Transtubercular plane.
- The abdomen can also be topographically divided into four quadrants, namely, the right upper quadrant, right lower quadrant, left upper quadrant, and left lower quadrant. These quadrants are bounded vertically by the median plane and horizontally by the transumbilical plane.

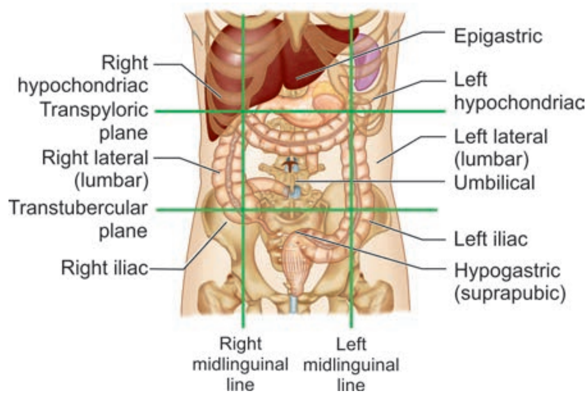


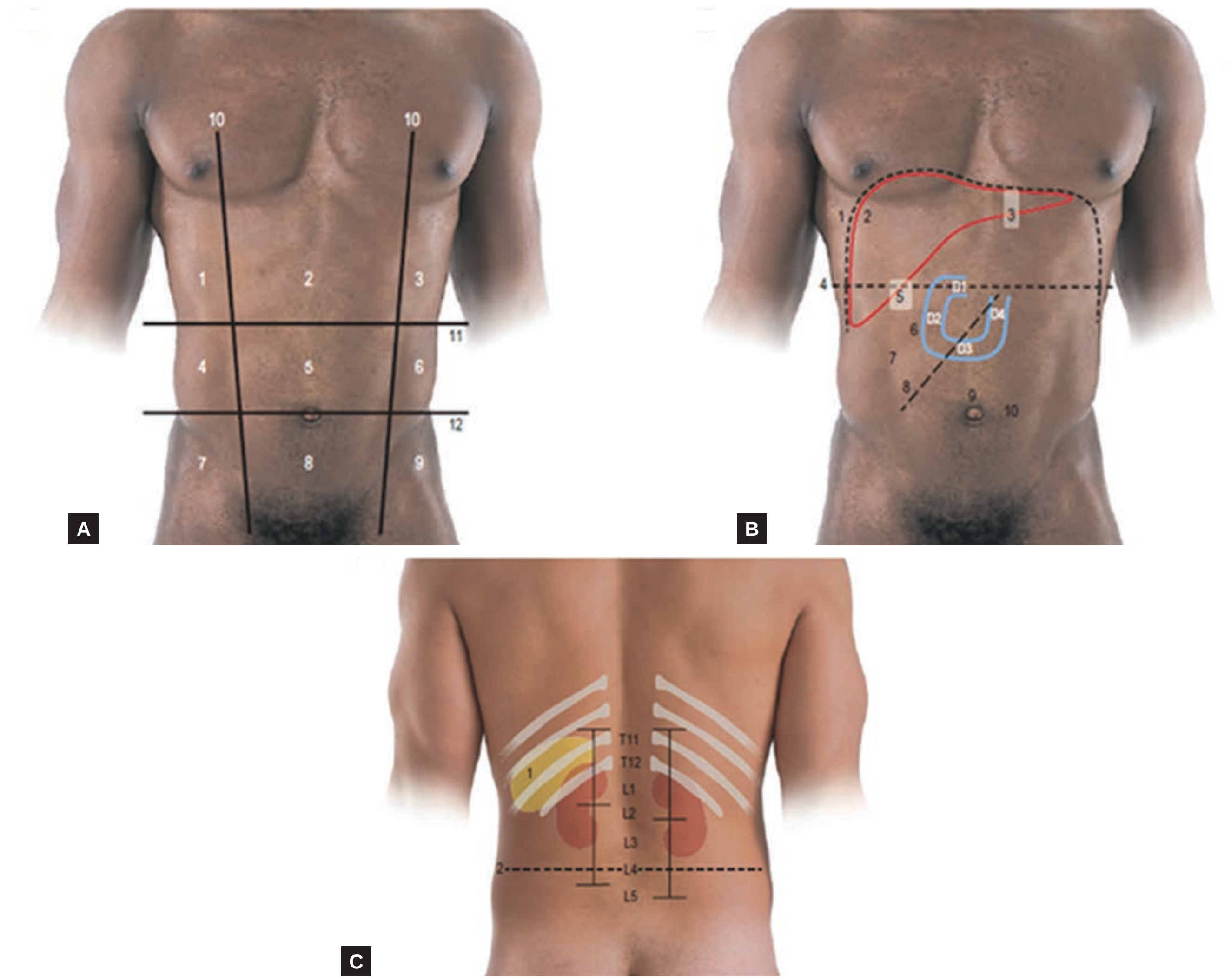
Fig. 4: Planes of subdivision of the abdomen.

Table 1: Abdominal regions and their main contents

Region	Contents
Right hypochondrium	• Liver • Gallbladder
Epigastric region	• Stomach • Pancreas • Duodenum
Left hypochondrium	• Spleen • Left colic flexure
Right lumbar region	• Right kidney • Right ureter • Ascending colon
Umbilical region	• Loops of small intestine • Aorta • Inferior vena cava
Left lumbar region	• Left kidney • Left ureter • Descending colon
Right iliac fossa	• Caecum • Appendix
Hypogastric region	• Coils of small intestine • Urinary bladder (if distended) • Uterus (in enlarged)
Left iliac fossa	• Sigmoid colon

Transpyloric Plane

- It lies **midway** between the suprasternal notch of the manubrium and the upper border of the pubic symphysis. This corresponds to a plane that is approximately **midway** between the xiphisternal joint and the umbilicus.
- Posteriorly, the plane intersects the **lower border of L1 vertebra**. Anteriorly, it intersects the costal at the ninth costal cartilage, where the linea semilunaris crosses.
- Following structures lie approximately within the transpyloric plane:
  - Origin of the superior mesenteric artery
  - Origin of the portal vein (from the confluence of the superior mesenteric and splenic veins behind the neck of the pancreas)
  - Hilum of the left kidney (the hilum of the right kidney is slightly lower)
  - Origin of the renal arteries
  - Duodenojejunal flexure
  - Termination of adult spinal cord.
  - Pylorus of stomach (not a constant feature).



Figs. 5A to C: (A) Nine regions of the anterior abdominal wall : 1. Right hypochondrium; 2. Epigastrium; 3. Left hypochondrium; 4. Right lumbar; 5. Umbilical/central; 6. Left lumber; 7. Right iliac fossa; 8. Suprapubic/hypogastrium; 9. Left iliac fossa; 10. Paramedian line; 11. Subcostal plane; 12. Transtubercular plane. (B) The surface projection of the abdominal viscera: 1. Diaphragm position; right dome level with fifth intercostal space and left dome with sixth rib; 2. Liver: mapped between three points: right fifth rib/intercostal space mid-clavicular line, left fifth intercostal space/sixth rib mid-clavicular line and right tenth costal cartilage mid-axillary line; 3. Zone of gastrooesophageal junction position (white): minaly located posterior to left seventh costal cartilage, at approximately T11; 4. Transpyloric plane; 5. Zone of gallbladder fundus postion (white); 6. Duoderum: four parts marked D1–D4; 7: Linea semilunaris; 8. Position of small intestine mesentery; 9. Linea alba; 10. tendinous intersection of rectus abdominis. (C) The surface position of the spleen and kidneys: 1. Spleen; sits deep to ribhs 10–12 with long axis aligned with rib 11; 2, Supracristal plane.

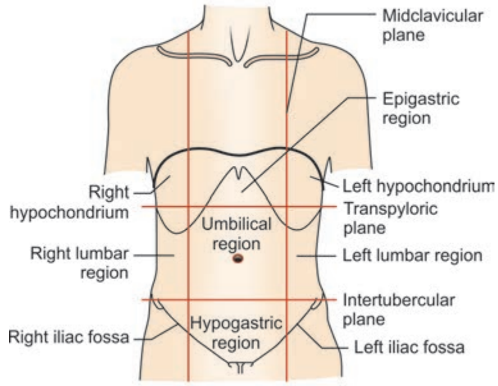


Fig. 6: Nine regions of the abdomen

Kidneys

The posterior aspects of the superior poles of the kidneys lie on the diaphragm and are anterior to the twelfth rib on the right, and to the eleventh and twelfth ribs on the left.

ASSESSMENT QUESTIONS

1. **Transpyloric plane separates:** *(NEET Pattern 2015)*
   a. Hypogastrium from lumbar region
   b. Hypochondrium from lumbar region
   c. Iliac fossa from lumbar region
   d. Umbilical region from lumbar region

2. **Transtubercular plane lies at which vertebral level?** *(NEET Pattern 2013)*
   a. L1
   b. L3
   c. L5
   d. S3

3. **Which of the following structure is not present in transpyloric plane?** *(Punjab 11)*
   a. First lumbar vertebra
   b. Fundus of gallbladder
   c. Hilum of right kidney
   d. Inferior mesenteric vein

4. **Fundus of gallbladder at which vertebral level:** *(NEET Pattern 2015)*
   a. L1
   b. L3
   c. S1
   d. S3

5. **Iliac crest at the level of (highest point):** *(NEET Pattern 2014)*
   a. L3
   b. L4
   c. L5
   d. S1

6. **Transtubercular plane lies at which vertebral level?** *(NEET Pattern 2013)*
   a. L1
   b. L3
   c. L5
   d. S3

7. **NOT present at transpyloric plane:**
   a. L1 vertebra
   b. Inferior mesenteric vein
   c. Fundus of gallbladder
   d. Hilum of right kidney

8. **NOT present at the transpyloric plane:**
   a. L-1 vertebra
   b. Right suprarenal gland
   c. Tip of ninth cartilage
   d. Fundus of gallbladder

9. **Renal angle lies between:** *(AIIMS 2007)*
   a. 12th rib and lateral border of sacrospinalis
   b. 11th rib and lateral border of sacrospinalis
   c. 12th rib and lateral border of quadratus lumborum
   d. 11th rib and lateral border of quadratus lumborum

ANSWERS WITH EXPLANATIONS

1. **b. Hypochondrium from lumbar region.*Transpyloric plane separates hypochondrium from lumbar region and epigastrium from umbilical region.**
2. **c. L5 * Transtubercular (or intertubercular) plane is a lower transverse line midway between the upper transverse and the upper border of the pubic symphysis. It corresponds to that passing through the iliac tubercles; behind, its plane cuts the body of the fifth lumbar vertebra.**
3. **d. Inferior mesenteric vein**

   *Superior (not inferior) mesenteric artery lies at the transpyloric plane.

   *Transpyloric (Addison's) Plane, is an upper transverse line, located halfway between the jugular notch and the upper border of the pubic symphysis.

   *It lie roughly a hand's breadth beneath the xiphoid process of the human sternum.

   *It passes through pylorus of the stomach, hila of each kidney, the tips of the ninth costal cartilages and the lower border of the first lumbar vertebra.
4. **a. L1.*Fundus of gall bladder is present at the transpyloric plane (L1 lower border).**
5. **b. L4 *Highest point of iliac crest lies at the level of spine of L4 vertebra.**
6. **c. L5**
   - Transtubercular plane is a horizontal plane transecting the trunk at the level of the iliac tubercles; which lies at the upper border of **L5 vertebra.**

7. b. Inferior mesenteric vein
- Transpyloric plane is present at the lower border of **L1 vertebra** and **inferior mesenteric vein** is not located there.
- The pylorus of stomach may be found in the transpyloric plane but is not a constant feature.
- **Hila of each kidney** is present at this plane.
- **Fundus of gallbladder** is touched at this plane (Murphy's sign)

8. b. Right suprarenal gland
- Right suprarenal gland lies at a higher level.
- **Fundus of gallbladder** is touched at this plane (Murphy's sign), by keeping the finger at the tip of the 9th costal cartilage at transpyloric plane.

9. a. 12th rib and lateral border of sacrospinalis
- **Renal angle** is present between lower border of 12th rib and the lateral border of sacrospinalis, a part of erector spinae.
- Pain on applying pressure over this angle, is suggestive of pathology in the kidney.

Abdominal Wall

The anterior abdominal wall is firm and elastic. It consists of eight layers.

- From superficial to deep, these are:
  - Skin.
  - Superficial fascia.
  - External oblique muscle.
  - Internal oblique muscle.
  - Transversus abdominis muscle.
  - Fascia transversalis.
  - Extra-peritoneal tissue.
  - Parietal layer of peritoneum

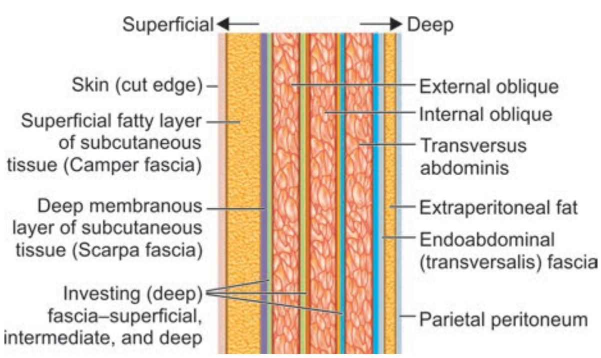


Fig. 7: Six layers of anterior and abdominal wall

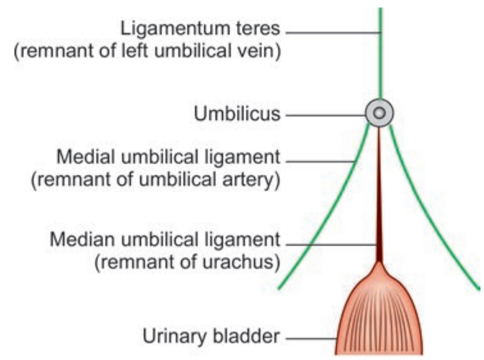


Fig. 8: Four embryological remants at the umbilicus

- The umbilicus is a fibrous cicatrix that lies a little below the midpoint of the linea alba, and is covered by an adherent area of skin.
- It consists of skin, a fibrous layer (representing the area of fusion between the round ligament of the liver, the median umbilical ligament, and two medial umbilical ligaments), the transversalis fascia, the umbilical fascia surrounding the urachal remnant, and peritoneum.

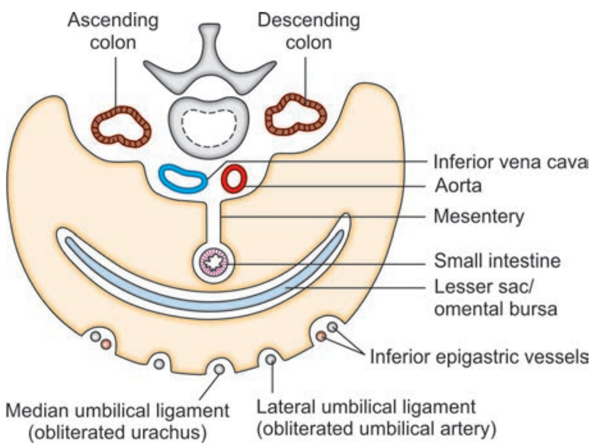


Fig. 9: Horizontal section through infracolic compartment of the abdomen showing horizontal disposition of peritoneum

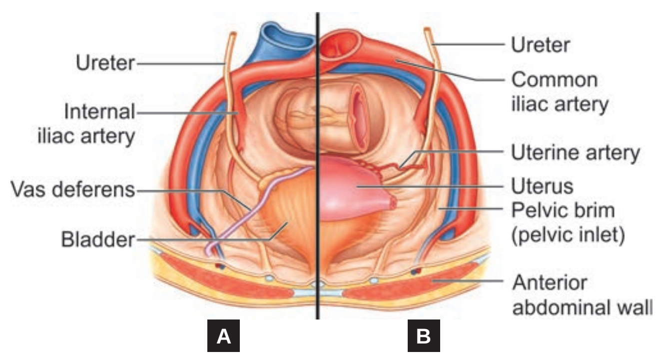


Fig. 10: Relations of the lower ureter, seen from above. (A) The male pelvis. (B) The female pelvis

Fascia

Superficial Fascia

- The 'superficial fascia' of the abdominal wall lies between the dermis and the muscles, and is conventionally divided into a superficial fatty layer (Camper's fascia) and a deep membranous layer (Scarpa's fascia). In reality, there are three layers, with a further layer of adipose tissue deep to the membranous layer. These three layers are particularly well defined in the child. Lying within the superficial fascia are blood vessels, lymphatics, nerves and, in the region of the groin, superficial inguinal lymph nodes.

Superficial Adipose Layer

- The superficial layer contains a variable amount of fat that is partitioned by fibrous septa connecting the dermis with the deeper membranous layer. Inferiorly, it is continuous with the superficial fascia of the thigh, and medially, it is continuous over the linea alba. In the male, this layer continues over the external genitalia, where it becomes thin and pale red, and contains very little adipose tissue.
- In the scrotum it also contains the smooth muscle fibres of the dartos muscle. In the female, it continues from the suprapubic region of the abdomen into the labia majora and perineum.

Membranous Layer

- The membranous layer is a variably developed entity composed of connective tissue and elastic fibres. In the adult, its thickness varies over the anterior abdominal wall, becoming thinner in the upper abdomen.
- Measured histologically, it is between 0.5 and 1 mm thick but it appears thicker on computed tomography (CT) scans.
- It is loosely connected to the underlying external oblique aponeurosis and rectus sheath by oblique fibrous septa. Superiorly, it is continuous with the superficial fascia over the remainder of the trunk.
- In the midline, it is adherent to the linea alba and pubic symphysis.
- Inferiorly, it fuses with the iliac crest, extends superficial to the inguinal ligament and fuses with the fascia lata at the inguinal flexure or skin crease of the thigh. In the male, it extends on to the dorsum of the penis, forming part of the superficial ligament of the penis, and on to the scrotum, where it becomes continuous with the membranous layer of superficial fascia of the perineum (Colles' fascia).
- In female, it continues into the labia majora and is continuous with the fascia of the perineum.
- In boys, the testis can frequently be retracted out of the scrotum into the loose areolar tissue between the membranous layer of superficial fascia over the inguinal canal and the external oblique aponeurosis. This 'space' is sometimes called the superficial inguinal pouch.

Deep Adipose Layer

- The thickness of the deep adipose layer is more variable than the superficial fatty layer.
- It is thin or absent where the membranous layer fuses with bony prominences and the linea alba, and becomes markedly thick in the morbidly obese.
- Its adipocytes show different metabolic activities to those in the superficial adipose layer.
- Liposuction preferentially removes this layer of fat with relative preservation of the superficial adipose layer in order to avoid skin dimpling and other skin contour irregularities.

Transversalis Fascia

- The transversalis fascia is a thin layer of connective tissue lying between the deep surface of transversus abdominis and the extraperitoneal fat.
- It is part of the general layer of thin fascia between the peritoneum and the abdominal wall.
- Posteriorly, it fuses with the anterior layer of the thoracolumbar fascia and anteriorly, it forms a continuous sheet.
- Superiorly, it blends with the fascia covering the inferior surface of the diaphragm. Inferiorly, it is continuous with the iliac and pelvic parietal fasciae, and is attached to the iliac crest between the origins of transversus abdominis and iliacus, and to the posterior margin of the inguinal ligament between the anterior superior iliac spine and the femoral sheath. Medial to the femoral sheath it is thin and fused to the pubis behind the conjoint tendon.
- An inferior extension of the transversalis fascia forms the anterior part of the femoral sheath.
- The fascia displays a discrete thickening known as the iliopubic tract (also called the deep crural arch), which runs parallel to the inguinal ligament it consists of transverse fibres that fan out laterally towards the anterior superior iliac spine to blend with the iliopsoas fascia and run medially behind the conjoint tendon to the pubic bone.
- The iliopubic tract is recognized as an important structure during open and laparoscopic inguinal hernia repair.
- A further thickening of the transversalis fascia, the interfoveolar ligament, runs inferior to the inguinal ligament at the medial margin of the deep inguinal ring; it may contain muscle fibres.
- The transversalis fascia is prolonged as the internal spermatic fascia over the structures that pass through the deep inguinal ring (the testicular vessels and vas (ductus) deferens in the male and the round ligament of the uterus in the female).

Extraperitoneal Connective Tissue

- The extraperitoneal connective tissue lying between the peritoneum and the fasciae lining the abdominal and pelvic cavities contains a variable amount of fat.
- The fat is especially abundant on the posterior wall of the abdomen around the kidneys (particularly in obese men) and scanty above the iliac crest and in much of the pelvis.

Fasciae and Ligaments of the Anterior Abdominal Wall

- Are organized into superficial (tela subcutanea) and deep fasciae. The superficial fascia has two layers: the superficial fatty layer (Camper fascia) and the deep membranous layer (Scarpa fascia).

A. Superficial Fascia

1. Superficial (Fatty) Layer of the Superficial Fascia (Camper Fascia)
   - Continues over the inguinal ligament to merge with the superficial fascia of the thigh.
   - Continues over the pubis and perineum as the superficial layer of the superficial perineal fascia.
2. Deep (Membranous) Layer of the Superficial Fascia (Scarpa Fascia)
   - Is attached to the fascia lata just below the inguinal ligament.[Q]
   - Continues over the pubis and perineum as the membranous layer (Coll' fascia) of the superficial perineal fascia.
   - Continues over the penis as the superficial fascia of the penis and over the scrotum as the tunica dartos, which contains smooth muscle.
   - May contain extravasated urine between this fascia and the deep fascia of the abdomen, resulting from rupture of the spongy urethra.

B. Deep Fascia

- Covers the muscles and continues over the spermatic cord at the superficial inguinal ring as the external spermatic fascia.
- Continues over the penis as the deep fascia of the penis (Buck fascia) and over the pubis and perineum as the deep perineal fascia.

C. Linea Alba

- Is a tendinous median raphe between the two rectus abdominis muscles, formed by the fusion of the aponeuroses of the external oblique, internal oblique, and transverse abdominal muscles.
- Extends from the xiphoid process to the pubic symphysis and, at its lower end, the superficial fibres attach to pubic symphysis, and deeper fibres to the pubic crests.
- In pregnancy, it becomes a pigmented vertical line (linea nigra), probably due to hormone stimulation to produce more melanin.
- Epigastric hernia is a protrusion of extraperitoneal fat or a small piece of greater omentum through a defect in the linea alba above the umbilicus and may contain a small portion of intestine.

D. Linea Semilunaris

- Is a curved line along the lateral border of the rectus abdominis.

E. Linea Semicircularis (Arcuate Line)

- Is a crescent-shaped line marking the inferior limit of the posterior layer of the rectus sheath just below the level of the iliac crest.

Thoracolumbar Fascia

- The thoracolumbar fascia is composed of a complex arrangement of multiple fascial layers that is most prominent at the caudal end of the lumbar spine. In the lumbar region, it is often described as having three layers**.**
- The posterior layer is attached medially to the spines of the lumbar vertebrae and to the supraspinous ligament; it has a superficial lamina (the aponeurosis of latissimus dorsi) and a deep lamina that covers the posterior surface of the paraspinal muscles.
- The middle layer is attached medially to the tips of the transverse processes of the lumbar vertebrae and extends laterally behind quadratus lumborum; inferiorly, it attaches to the iliac crest, and superiorly to the lower border of the twelfth rib.
- The anterior layer covers the anterior surface of quadratus lumborum and is attached medially to the transverse processes of the lumbar vertebrae behind psoas major. Laterally, it fuses with the transversalis fascia and the aponeurosis of transversus abdominis.
- Inferiorly, it is attached to the iliolumbar ligament and adjoining iliac crest.
- Superiorly, it is attached to the inferior border of the twelfth rib and extends to the transverse process of the first lumbar vertebra, forming the lateral arcuate ligament of the diaphragm.
- The posterior and middle layers of the thoracolumbar fascia fuse at the lateral margin of the paraspinal muscles (the so-called 'lateral raphe'), thereby enclosing the paraspinal muscles in an osteofascial compartment.
- Although contained in layers of thoracolumbar fascia, the paraspinal muscles are conceptualized as part of 'the back'.
- The aponeurosis of transversus abdominis fuses with both the anterior layer of thoracolumbar fascia at the lateral margin of quadratus lumborum and with the lateral raphe behind quadratus lumborum.

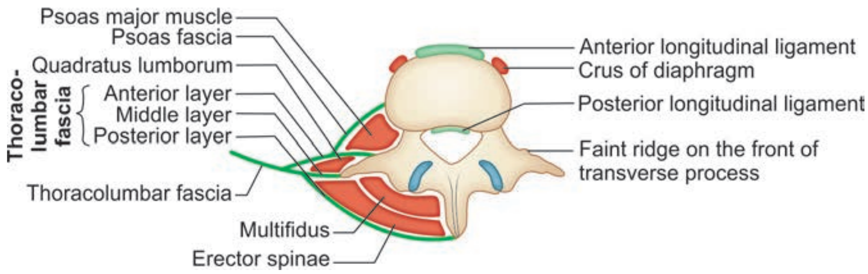


Fig. 11: Attachments of the lumbar vertebra

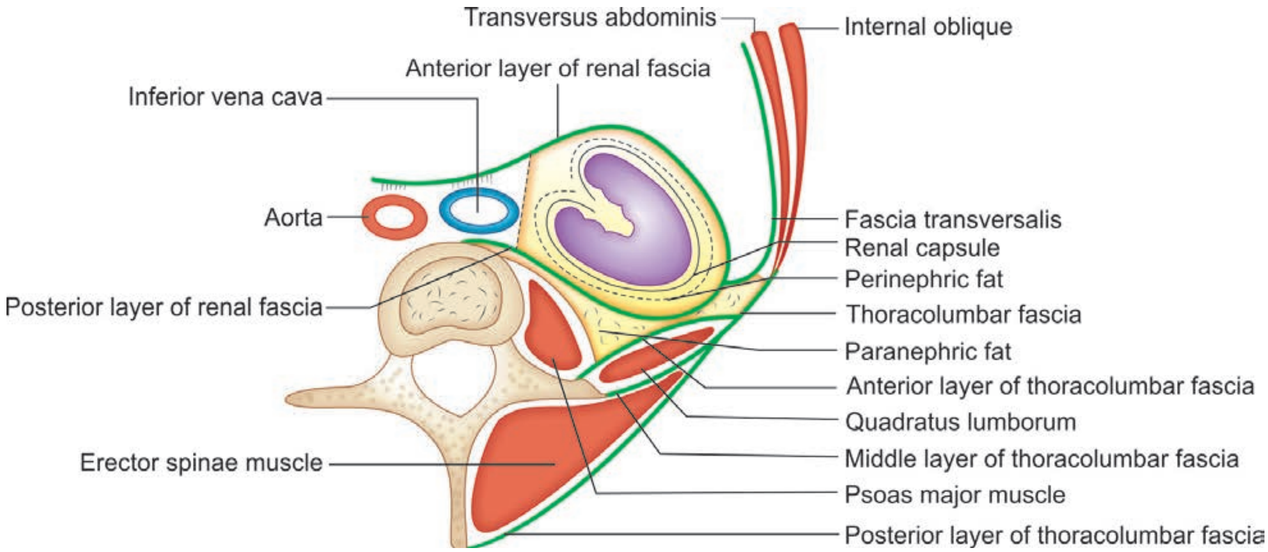


Fig. 12: Transverse section through lumbar region showing transverse disposition of of thoracolumbar fasica and coverings of the kidney

Rectus Sheath

Rectus Sheath

- Rectus abdominis on each side is enclosed by a fibrous sheath.
- The anterior portion of this sheath extends the entire length of the muscle and fuses with periosteum and ligaments at sites of the muscle's attachments.
- The posterior part of the sheath is complete behind the upper two-thirds of the muscle but absent below this level, which corresponds to approximately one-third of the distance between the umbilicus and the pubis.
- The termination of the posterior rectus sheath is usually gradual but may be abrupt and marked by a clearly visible curved horizontal line known as the arcuate line (of Douglas).
- Below this level, rectus abdominis lies on the transversalis fascia and extraperitoneal connective tissue.
- The rectus sheath is formed from the aponeuroses of all three lateral abdominal muscles: namely, external oblique, internal oblique and transversus abdominis.
- Each aponeurosis is bilaminar; the fibres from all three anterior leaves run obliquely upwards, whereas the posterior leaves run obliquely downwards at right angles to the anterior leaves.
- Above the arcuate line, the anterior rectus sheath is composed of both leaves of the aponeurosis of external oblique and the anterior leaf of the aponeurosis of internal oblique fused together.
- The posterior rectus sheath is composed of the posterior leaf of the aponeurosis of internal oblique and both leaves of the aponeurosis of transversus abdominis.
- Thus, both the anterior and posterior layers of the rectus sheath consist of three layers of fibres with the middle layer running at right angles to the other two.
- At the midline, the anterior and posterior layers are closely approximated.
- Fibres from each layer decussate to the opposite side of the sheath, forming a continuous aponeurosis with the contralateral muscles.
- Fibres also decussate anteroposteriorly, crossing from the anterior sheath to the posterior sheath.
- The dense fibrous line caused by this decussation is called the linea alba.
- The external oblique, internal oblique and transversus abdominis muscles can therefore be regarded as digastric muscles with a central tendon comprising the linea alba.
- The decussating fibres at the linea alba can be used to identify the midline during surgical incisions. Below the arcuate line, all three aponeuroses from the oblique and transversus abdominis muscles pass into the anterior rectus sheath

Rectus Sheath

- Is formed by fusion of the aponeuroses of the external oblique, internal oblique, and transverse muscles of the abdomen.
- Encloses the rectus abdominis and sometimes the pyramidal muscle.
- Also contains the superior and inferior epigastric vessels and the ventral primary rami of thoracic nerves 7 to 12.
- Anterior Layer of the Rectus Sheath
  - Above the level of costal margin: Aponeurosis of external oblique only.
  - Between costal margin and above the arcuate line: aponeuroses of the external and internal oblique muscles.
  - Below the arcuate line: aponeuroses of the external oblique, internal oblique, and transverse muscles.
- Posterior Layer of the Rectus Sheath
  - Above the level of costal margin: Is deficient and rectus muscle lies directly on the 5th, 6th, and 7th costal cartilages.
  - Between costal margin and above the arcuate line: aponeuroses of the internal oblique and transverse muscles.
  - Below the arcuate line: Is deficient and rectus abdominis is in contact with the transversalis fascia.

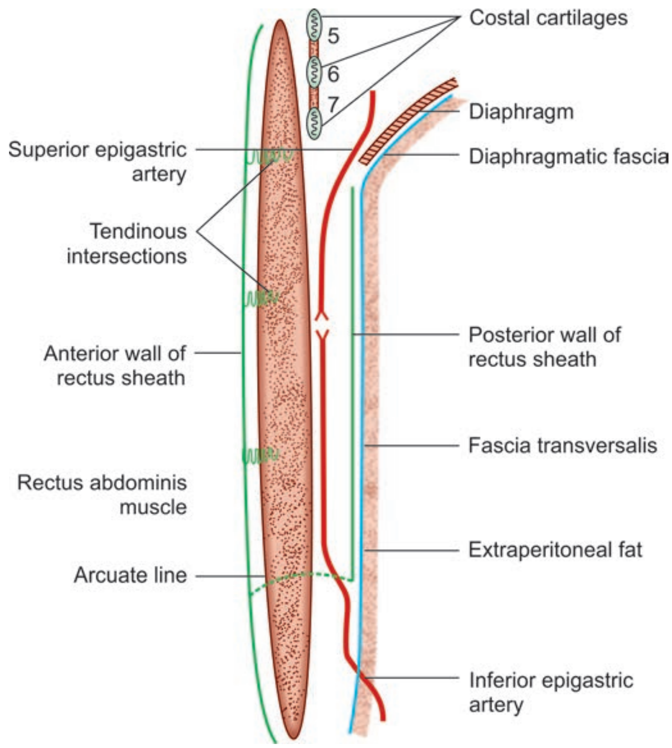
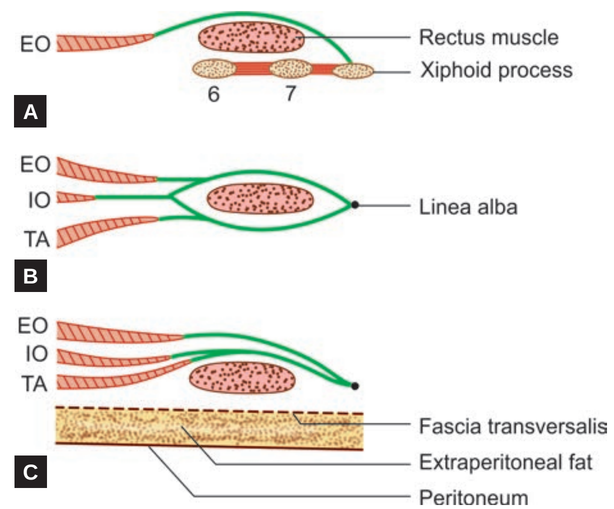


Fig. 13: Sagittal section of rectus sheath showing anterior and posterior wall. Tendinous intersections are attached only to the anterior wall.



Figs. 14A to C: Formation of the rectus sheath as seen in transverse sections through rectus abdominis and its sheaths at three different levels: A. above the costal margin; B. between costal margin and arcuate line; C. Below the arcuate line (EO = external oblique, IO = internal oblique, TA = transversus abdominis)

Note: Recently some authors mention the aponeuroses of all the three muscles (external, internal, and transversus) are bilaminar thus giving six laminae in all. The three layers form anterior wall and three layers form posterior wall of the rectus sheath. The laminae decussate with other laminae across the midline, i.e., in the region of linea alba and continue as the laminae of contralateral muscles.

- In rectus sheath superior epigastric artery (branch of internal thoracic artery) anastomose with inferior epigastric artery (branch of external iliac artery). (PGIC 2008)

ASSESSMENT QUESTIONS

1. **Scarpa's fascia is attached to:** *(JIPMER 10)*
   a. Inguinal ligament
   b. Fascia lata of thigh
   c. Conjoint tendon
   d. Pubic crest

2. **True about Scarpa's fascia:** *(NEET Pattern 2015)*
   a. Deep fascia of anterior abdominal wall
   b. Also called Buke's fascia
   c. Attached to Iliotibial tract
   d. Forms suspensory ligament of penis

3. **In patients with penile injury, Colle's fascia prevents extravasation of urine in:** *(NEET Pattern 2012)*
   a. Ischiorectal fossa
   b. Perineum
   c. Abdomen
   d. None

4. **The rectus sheath contains all of the following EXCEPT:**
   a. Pyramidalis muscle
   b. Genitofemoral nerve
   c. Inferior epigastric vessels
   d. Superior epigastric vessels

5. **In rectus sheath which branch of aorta make anastomosis with superior epigastric artery:** *(PGIC 2008)*
   a. Subclavian artery
   b. External iliac artery
   c. Internal iliac artery
   d. External carotid A

6. **All are true about Thoracolumbar facia EXCEPT:** *(AIPG 2000)*
   a. Attached to spinus process of lumbar vertebra
   b. Attached to transverse process of lumbar vertebra
   c. The fascia lies posterior to posterior abdominal wall muscles.
   d. Gives attachment to Transverse abdominal and internal oblique

ANSWERS WITH EXPLANATIONS

1. **b. Fascia lata of thigh**

   *Scarpa's fascia after crossing the inguinal ligament is attached to fascia lata of thigh along Holden's line (below and parallel to inguinal ligament).

2. d. Forms suspensory ligament of penis

*Scarpa's fascia forms the suspensory ligament of penis or clitoris in median plane.

3. a. Ischiorectal fossa

*Colle's fascia prevent the passage of extravasated urine due to rupture of urethra backward into ischeoractal fossa.

4. b. Genitofemoral nerve

5. b. External iliac artery In rectus sheath superior epigastric artery (branch of internal thoracic) anastomoses with inferior epigastric artery(a branch of external iliac artery).

6. c. The fascia lies posterior to posterior abdominal wall muscles.

*Thoracolumbar fascia lies posterior as well as anterior to the posterior abdominal wall.*Posterior abdominal wall muscles (e.g., psoas major and minor, iliacus, quadratus lumborum) are enclosed within layers of thoracolumbar fascia.

Muscles

Table 2: Muscles of anterolateral abdominal wall

Muscle	Origin	Insertion	Innervation	Main Action[a]
External oblique (A)	External surfaces of 5th 12th ribs	Linea alba, pubic tubercle, and anterior half of iliac crest	Thoracoabdominal nerves (T7–T11 spinal nerves) and subcostal nerve	Compresses and supports abdominal viscera,[b] flexes and rotates trunk
Internal oblique (B)	Thoracolumbar fascia, anterior two-thirds of iliac crest, and connective tisue deep to lateral third of inguinal ligament	Inferior borders of 10th–12th ribs, linea alba, and pecten pubis via conjoint tendon	Thoracoabdominal nerves (anterior rami or T6–T12 spinal nerves) and first tumbar nerves	
Transversus abdominis (C)	Internal surfaces of 7th-12th costal cartilages, thoracolumbar fasdcia, iliac crest, and connective tissue deep to lateral third of inguinal ligament	Linea alba with aponeurosis of internal oblique, pubic crest, and pecten pubis via conjoint tendon		Compresses and supports abdominal viscera[b]
Rectus abdominis (D)	Pubic symphysis and pubic crest	Xiphoid process and 5th–7th costal cartilages	Thoracoabdominal nerves (anterior rami of T6–T12 spinal nerves)	Flexes trunk (lumbar vertebrae) and compresses abdominal viscera;[b] stabilizes and controls tilt of pelvis (antilordosis)

[a]Approximately 80% of people have an insignificant muscle, the *pyramidalis,* which is located in the rectus sheath anterior to the most inferior part of the rectus abdominis. It extends from the pubic crest of the lip bone to the linea alba. This small muscle draws doen on the linea alba.
[b]In so doing, these muscles act as antagonists of the diaphragm to produce expiration.

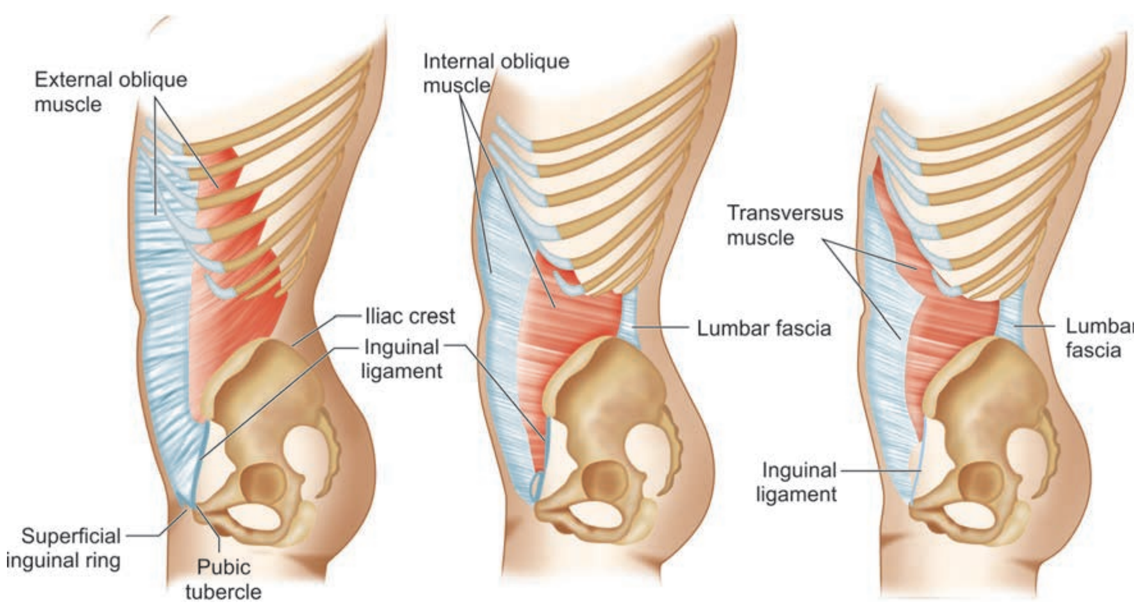


Fig. 15: External oblique, internal oblique, and transversus muscles of the anterior abdominal wall

Muscles

The muscles of the abdominal wall include the **rectus abdominis, transverse abdominis, internal oblique, and external oblique**.

Clinical Procedure

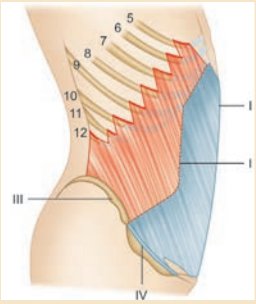
Paracentesis is a procedure whereby a needle is inserted through the layers of the abdominal wall to withdraw excess peritoneal fluid. Knife wounds to the abdomen will also penetrate the layers of the abdominal wall.

Flank Approach

- The needle or knife will pass through the following structures in succession: **Skin → superficial fascia (Camper and Scarpa) → external oblique muscle → internal oblique muscle → transverse abdominis muscle → transversalis fascia → extraperitoneal fat → parietal peritoneum.**

ASSESSMENT QUESTIONS

1. **Which of the following is the correct matching, regarding the attachments of external oblique muscle?** *(AIIMS 2016)*
   a. I - Linea alba, II - Linea semilunaris, III - Inner lip of iliac crest, IV - Inguinal ligament
   b. I - Linea alba, II - Linea semilunaris, III - Outer lip of iliac crest, IV - Inguinal ligament
   c. I - Linea semilunaris, II - Linea alba, III - Outer lip of iliac crest, IV - Inguinal ligament
   d. I - Linea semilunaris, II - Arcuate line, III - Inner lip of iliac crest, IV - Inguinal ligament



2. **TRUE statement about lower 1/4 anterior abdominal wall:** *(PGIC 2006, 2007)*
   a. Linea alba is poorly formed
   b. Rectus abdominis is divided
   c. Two layers of rectus sheath present
   d. External oblique muscle is poorly formed
   e. External oblique muscle is well developed

3. **Posterior wall of rectus sheath below the level of anterior superior iliac spine is formed by?**
   a. Internal oblique
   b. Transversus abdominis
   c. Lacunar ligament
   d. Fascia transversalis

4. **Pyramidalis is supplied by:** *(NEET Pattern 2015)*
   a. Subcostal nerve
   b. Ilioinguinal nerve
   c. Iliohypogastric nerve
   d. Genitofemoral nerve

5. **Rectus adominis is inserted into:** *(PGI 98)*
   a. Xiphoid process
   b. Median raphae
   c. Linea alba
   d. 1-4 ribs

ANSWERS WITH EXPLANATIONS

1. **b. I - Linea alba, II - Linea semilunaris, III - Outer lip of iliac crest, IV - Inguinal ligament**
   - External oblique muscle takes origin from the external surfaces of lower 8 (5-12th) ribs.
   - It inserts into the linea alba (marker 'I'), pubic tubercle, and outer lip of the anterior two-thirds of the iliac crest (marker 'III').
   - At linea semilunaris (marker 'II') the muscular fibres of muscle become aponeurotic.
   - The free lower border of the aponeurosis is rolled inward on itself to form the inguinal ligament (marker 'IV').

2. **a. Linea alba is poorly formed; d. External oblique muscle is poorly formed**
   - Linea alba is wider and more obvious above the umbilicus, and is almost linear and less visible below this level.
   - External oblique muscle is aponeurotic in the lower part.
   - Tendinous intersections divide rectus abdominis muscle, but this is not a feature in the lower part.
   - Posterior layer of rectus sheath is deficient in the lower part.

3. **d. Fascia transversalis**
   - Rectus abdominis lies on the transversalis fascia below the arcuate line.
   - The rectus sheath is the fibrous condensation of the aponeurotic layers on the anterior aspect of the abdominal wall investing the rectus abdominis muscle.
   - It also encloses the epigastric vessels, the inferior five intercostal and subcostal vessels and nerves, and occasionally pyramidalis.
   - It is incomplete posteriorly at a level inferior to the arcuate line and superiorly above the costal margin.
   - The anterior wall is formed from the external oblique aponeurosis and a superficial layer of the internal oblique aponeurosis where it divides at the lateral edge of the rectus abdominis muscle.
   - The posterior wall is formed from the aponeurosis of the transversus abdominis muscle where it joins the deeper layer of the internal oblique aponeurosis. Together, both walls form the linea alba.
   - Since the tendons of the Obliquus internus and Transversus only reach as high as the costal margin, it follows that above this level the sheath of the Rectus is deficient behind, the muscle resting directly on the cartilages of the ribs, and being covered merely by the tendon of the Obliquus externus.
   - The Rectus, in the situation where its posterior sheath is deficient (below arcuate line), is separated from the peritoneum only by the transversalis fascia, in contrast to the upper layers, where part of the internal oblique also runs beneath the rectus. Because of the thinner layers below, this region is more susceptible to herniation.

4. a. Subcostal nerve

5. a. Xiphoid process

High Yield Points

- Rectus abdominis muscle is not attached to the median raphe- linea alba[Q].
- Pyramidalis muscle is supplied by subcostal nerve (T12).

Abdominal Wall Hernia

Umbilical Hernia

- The most extreme variety of umbilical hernia is known as an omphalocele or exomphalos, a congenital malformation in which abdominal viscera, covered by a membrane, protrude through a wide umbilical defect.
- The defect arises from a failure of closure of the umbilical ring after return of the herniated midgut loop in the embryo.
- The most common variety of umbilical hernia is caused by a weakness of the umbilical scar tissue, and is often seen in babies, especially those of African descent.
- The vast majority of these will close spontaneously during early childhood.
- Most umbilical hernias in adults are acquired as a result of stretching of the supporting umbilical fascia and are due to obesity and chronically increased intra-abdominal pressure (e.g. from multiple pregnancies or ascites).

Spigelian Hernia

- A spigelian hernia is a protrusion of preperitoneal fat or a peritoneal sac through a congenital or acquired defect in the abdominal wall in

Neurovasculature

- The ventral rami of the sixth to eleventh intercostal nerves, the subcostal nerve (twelfth thoracic) and first lumbar nerve (iliohypogastric and ilioinguinal nerves) supply the muscles and skin of the anterior abdominal wall (Rozen et al 2008).
- The seventh to the twelfth thoracic ventral rami continue anteriorly from the intercostal and subcostal spaces into the abdominal wall.
- Approaching the costal margin, the seventh to tenth nerves curve medially across the deep surface of the costal cartilages between the digitations of the diaphragm and transversus abdominis.
- The subcostal nerve gives a branch to the first lumbar ventral ramus (dorsolumbar nerve) that contributes to the lumbar plexus.
- It accompanies the subcostal vessels along the inferior border of the twelfth rib, passing behind the lateral arcuate ligament and kidney, and anterior to the upper part of the quadratus lumborum.
- All these segmental nerves run anteriorly within a thin layer of fascia in the neurovascular plane between transversus abdominis and internal oblique, where they branch and interconnect with adjacent nerves.
- Muscular branches innervate transversus abdominis and internal and external oblique.
- Cutaneous branches supply the skin of the lateral and anterior abdominal walls.
- The thoracic nerves enter the rectus sheath at its lateral margin and pass posterior to rectus abdominis, where they again intercommunicate.
- Each nerve then pierces rectus abdominis from its posterior aspect and gives off muscular branches to this muscle (and a branch to pyramidalis from the subcostal nerve), and cutaneous branches that pierce the anterior rectus sheath to supply overlying skin.
- The ninth intercostal nerve supplies skin above the umbilicus, the tenth supplies skin that consistently includes the umbilicus, and the eleventh supplies skin below the umbilicus.
- The subcostal nerve supplies the anterior gluteal skin just below the iliac crest, and the skin of the lower abdomen and inguinal region (overlapping with the L1 dermatome in this region)
- The ventral rami of the lower intercostal and subcostal nerves also provide sensory fibres to the costal parts of the diaphragm and parietal peritoneum.
- The transversus abdominis plane (TAP) block is a regional anaesthetic technique for abdominal surgery.
- Using ultrasound imaging guidance, local anaesthetic is injected into the neurovascular plane between internal oblique and transversus abdominis, targeting the segmental nerves of the anterolateral abdominal wall.

Lesions of the Intercostal Nerves

- The anterolateral abdominal wall muscles are innervated by several segmental nerves and injury to a single nerve does not produce a clinically detectable loss of muscle tone.
- The overlap between sequential dermatomes means that significant cutaneous anaesthesia is appreciated only after sectioning at least two sequential nerves.

Nerves

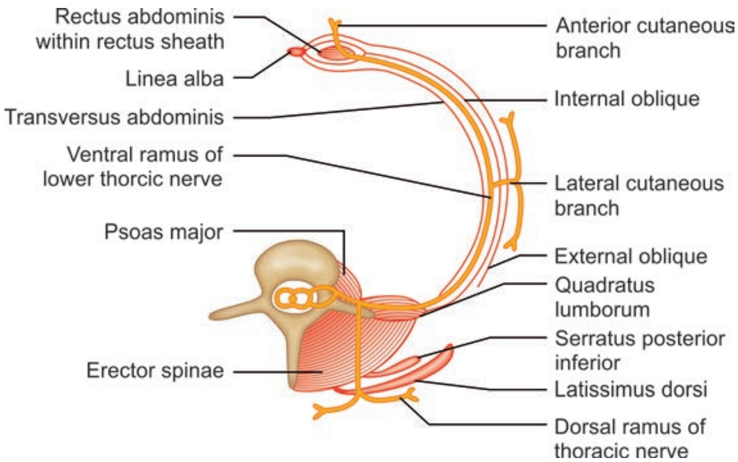


Fig. 16: Muscles and nerves in abdominal walls

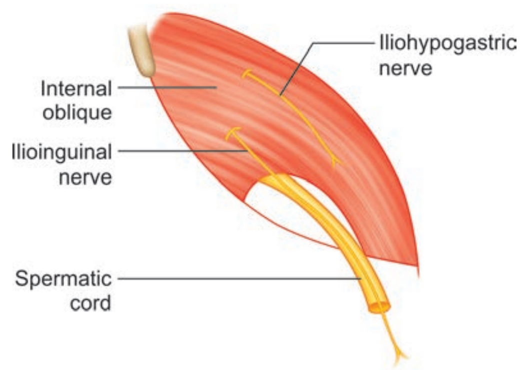


Fig. 17: Iliohypogastric and ilioinguinal nerves

Table 3: Nerves anterolateral abdominal wall

Nerves	Origin	Course	Distribution
Thoracoabdominal (T7–T11)	Continuation of lower (7th–11th) intercostal nerves distal to costal margin	Run between econd and third layer or abdominal muscles; branches enter subcutaneou tis ue a lateral cutaneous branches of T10-T11 (in anterior axillary line) and anterior cutaneous branches of T7-T11 (parasternal line)	Muscle of anterolateral abdominal wall and overlying skin
7th-9th lateral cutaneous branches	7th-9th intercostal nerves (anterior rami of spinal nerves T7-T9)	Anterior division ion continue acros costal margin in subcutaneou tissue	Skin of right and left hypochondriac regions
Subcostal (anteior ramu of T12)	Spinal nerve T12	Run along inferior border of 12th rib: then passes onto subumbilical subumbilical wall between second and third layer of abdominal muscles	Muscles of anterolateral abdominal wall (including most inferior slip of external oblique) and overlying skin, Superior to Iliac crest and inferior to umbilicus
Iliohypogastric (L 1)	A supeflor terminal branch of anterior ramu of plnal nerve L 1	Pierces transversus abdominis muscle to course between second and third layers of abdominal muscles; branches pierce external oblique aponeuroses of most inferior abdominal wall	Skin overlying iliac crest, upper inguinal, and hypogastric regions; internal oblique and transversus abdominis muscles
Ilio-inguinal (L1)	As inferior terminal branch of anterior ramus of spinal nerve L1	Passes between second and third layers of abdominal muscles, then traverses inguinal canal	Skin of lower inguinal region, mons pubis, anterior scrotum or labium majus, and adjacent medial thigh; inferior most internal oblique and transversus abdominis

Iliohypogastric Nerve

- It is derived from the anterior primary ramus of the L1 spinal nerve.
- It runs in the neurovascular plane (i.e., between the internal oblique and transversus abdominis) and pierces the internal oblique about 2.5 cm in front of the anterior superior iliac spine.
- It becomes cutaneous by piercing the external oblique aponeurosis about 2.5 cm above the superficial inguinal ring. It does not enter the rectus sheath and its lateral cutaneous branch supplies the skin of the gluteal region.

Ilioinguinal Nerve

- It is the anterior primary ramus of L1 spinal nerve.
- It pierces the internal oblique muscle from below and enters the inguinal canal lateral to the iliohypogastric nerve, and runs along the inferolateral side of the spermatic cord.
- It comes out through the superficial inguinal ring. It has no lateral cutaneous branch.

Arteries

Superior Epigastric Artery and Veins

- The superior epigastric artery is a terminal branch of the internal thoracic artery.
- It arises at the level of the sixth costal cartilage and descends between the costal and xiphoid slips of the diaphragm, accompanied by two or more veins that drain to the internal thoracic vein.
- The vessels pass anterior to the lower fibres of transversus thoracis and the upper fibres of transversus abdominis before entering the rectus sheath, where they run inferiorly behind rectus abdominis.
- They anastomose with the inferior epigastric arteries, usually above the level of the umbilicus, in one of several potential branching patterns.
- Branches supply rectus abdominis and perforate the anterior lamina of the rectus sheath to supply the abdominal skin.
- A branch given off in the upper rectus sheath passes anterior to the xiphoid process of the sternum and anastomoses with a corresponding contralateral branch.
- This vessel may give rise to bleeding during surgical incisions that extend up to and alongside the xiphoid process.
- The superior epigastric artery also gives small branches to the anterior part of the diaphragm.
- On the right, small branches reach the falciform ligament, where they anastomose with branches from the hepatic artery.

Inferior Epigastric Artery and Veins

- The inferior epigastric artery (Often referred to as the deep inferior epigastric artery in clinical practice in order to distinguish it from the superficial (inferior) epigastric artery) originates from the medial aspect of the external iliac artery just proximal to the inguinal ligament.
- Its accompanying veins, usually two, unite to form a single vein that drains into the external iliac vein.
- It curves forwards in the anterior extraperitoneal tissue and ascends obliquely along the medial margin of the deep inguinal ring.
- It lies posterior to the spermatic cord, separated from it by the transversalis fascia.
- It pierces the transversalis fascia and enters the rectus sheath by passing anterior to the arcuate line. In this part of its course, it is visible through the parietal peritoneum of the anterior abdominal wall and forms the lateral umbilical fold.
- Disruption of the artery at this site by surgical incisions (e.g. insertion of laparoscopic ports or abdominal drains) may result in a haematoma that can expand to considerable size because of the absence of adjacent tissue against which the bleeding can be tamponaded.
- The inferior epigastric arteries ascend and anastomose with their superior counterpart without branching in about 30% of cases.
- Branching into two vessels before anastomosis is the most common pattern, accounting for almost 60% of cases, with a trifurcation being present in the remainder.
- The inferior epigastric arteries have an average diameter of approximately 3 mm at their origin, compared to an average diameter of 1.6 mm at the origin of the superior epigastric arteries, presumably explaining why the inferior epigastric arteries provide the 'dominant' supply to rectus abdominis.
- Preliminary ligation of the inferior epigastric artery is often performed when preparing a myocutaneous flap using the mid or lower rectus abdominis based on the superior epigastric artery; this encourages the augmentation of the superior epigastric arterial supply.
- Branches of the inferior epigastric artery anastomose with branches of the superior epigastric artery within the rectus sheath posterior to rectus abdominis at a variable level above the umbilicus.
- Other branches anastomose with terminal branches of the lower five posterior intercostal, subcostal and lumbar arteries at the lateral border of the rectus sheath.
- Inferolaterally, branches anastomose with the deep circumflex iliac artery.
- The inferior epigastric artery ascends along the medial margin of the deep inguinal ring.
- The vas deferens in the male, or the round ligament in the female, passes medially after hooking around the artery at the deep inguinal ring.
- The artery forms the lateral border of Hesselbach's inguinal triangle, an important landmark in laparoscopic inguinal hernia repair; the inferior border of the triangle is formed by the inguinal ligament, and the medial border is formed by the lateral margin of rectus abdominis.
- The inferior epigastric artery also gives off the cremasteric artery, a pubic branch, and muscular and cutaneous branches.
- The cremasteric artery accompanies the spermatic cord in males, supplies cremaster and the other coverings of the cord and anastomoses with the testicular artery.
- In females, the artery is small and accompanies the round ligament.
- A pubic branch, near the femoral ring, descends posterior to the pubis and anastomoses with the pubic branch of the obturator artery.
- The pubic branch of the inferior epigastric artery may be larger than the obturator artery and supply most of the obturator artery territory in the thigh, in which case it is referred to as the aberrant obturator artery.
- It lies close to the medial border of the femoral ring and may be damaged in medial dissection of the ring during femoral or laparoscopic inguinal hernia repair or with pelvic fractures.
- Muscular branches supply the abdominal muscles and peritoneum, and anastomose with the circumflex iliac and lumbar arteries.
- Cutaneous branches perforate the aponeurosis of external oblique, supply the skin and anastomose with branches of the superficial epigastric artery.

- These musculocutaneous perforators have been mapped in detail because they are particularly important to plastic surgeons undertaking reconstructive surgery with (myo)cutaneous flaps.
- Occasionally, the inferior epigastric artery arises from the femoral artery.
- It then ascends anterior to the femoral vein to follow its usual abdominal course.
- Rarely, it arises from the external iliac artery in common with an aberrant obturator artery or from the obturator artery.
- The superior and inferior epigastric arteries are important sources of collateral blood flow between the internal thoracic artery and the external iliac artery when aortic blood flow is compromised.
- Small tributaries of the inferior epigastric vein draining the skin around the umbilicus anastomose with terminal branches of the umbilical vein draining the umbilical region via the falciform ligament.
- These portosystemic anastomoses may open widely in cases of portal hypertension, when portal venous blood may drain into the systemic circulation via the inferior epigastric veins.
- The pattern of dilated superficial veins radiating from the umbilicus is referred to as the 'caput medusae'.
- **Posterior intercostal, subcostal and lumbar arteries**
- The tenth and eleventh posterior intercostal arteries, the subcostal artery, and the lumbar arteries pierce the posterior aponeurosis of transversus abdominis to enter the neurovascular plane of the abdominal wall deep to internal oblique.
- The location of these arteries and their accompanying segmental nerves is of clinical importance when creating myofascial flaps during abdominal wall reconstruction.
- The arteries on either side run forwards, giving off muscular branches to the overlying internal and external oblique, before anastomosing with the lateral branches of the superior and inferior epigastric arteries at the lateral border of the rectus sheath.
- Perforating cutaneous vessels run vertically through the muscles to supply the overlying skin and subcutaneous tissue.
- A small contribution to the supply of the lower abdominal muscles comes from branches of the deep circumflex iliac arteries.
- The anterior abdominal wall is also supplied by branches of the femoral artery: namely, the superficial epigastric, superficial circumflex iliac, and superficial external pudendal arteries, and by the deep circumflex iliac artery arising from external iliac artery.

Table 4: Arteries of anterolateral abdominal wall

Artery	Origin	Course	Distribution
Musculophrenic	Internal thoracic artery	Descends along costal margin	Superficial and deep abdominal wall of hypochondriac region; anterolateral diaphragm
Superior epigastric		Descends in rectus sheath deep to rectus adbominis	Rectus abdominis muscle; superficial and deep abdominal wall of epigastric and upper umbilical regions
10th and 11th posterior intercostal arteries	Aorta	Arteries continue beyond ribs to descend in abdominal wall between internal oblique and transversus abdominis muscles	Superificial and deep abdominal wall of lateral (lumbar or flank) region
Subcostal artery			
Deep Inferior epigastric circumflex iliac	External iliac artery	Runs superiorly and enters rectus sheath; runs deep to rectus abdominis	Rectus abdominis muscle; deep abdominal wall of pubic and inferior umbilical regions
		Runs on deep aspect of anterior abdominal wall, parallel to inguinal ligament	Iliacus muscle and deep abdominal wall of inguinal region; iliac fossa
Superficial circumflex iliac	Femoral artery	Runs in subcutaneous tissue along inguinal ligament	Superficial abdominal wall of inguinal region and adjacent anterior thigh
Superificial epigastric		Runs in subcutaneous tissue toward umbilicus	Superficial abdominal wall of pubic and inferior umbilic regions

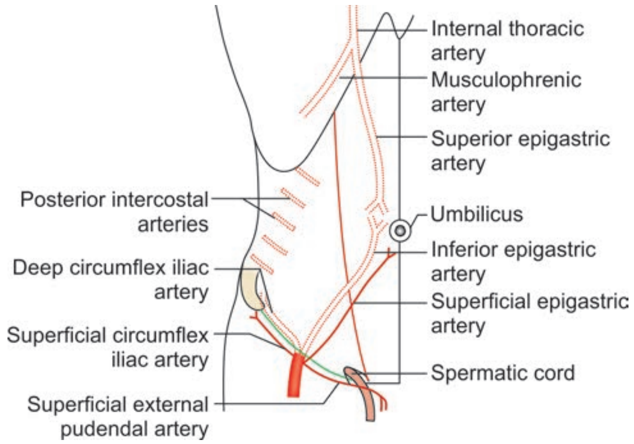


Fig. 18: Arteries of the anterior abdominal wall

Veins

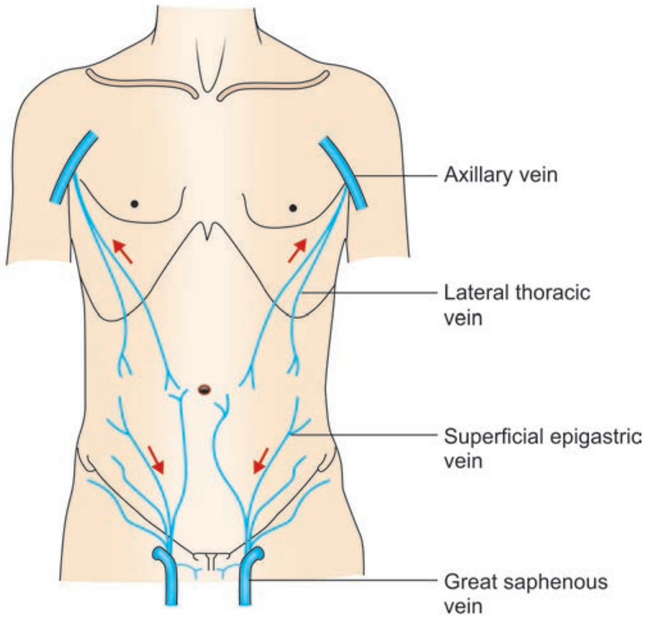
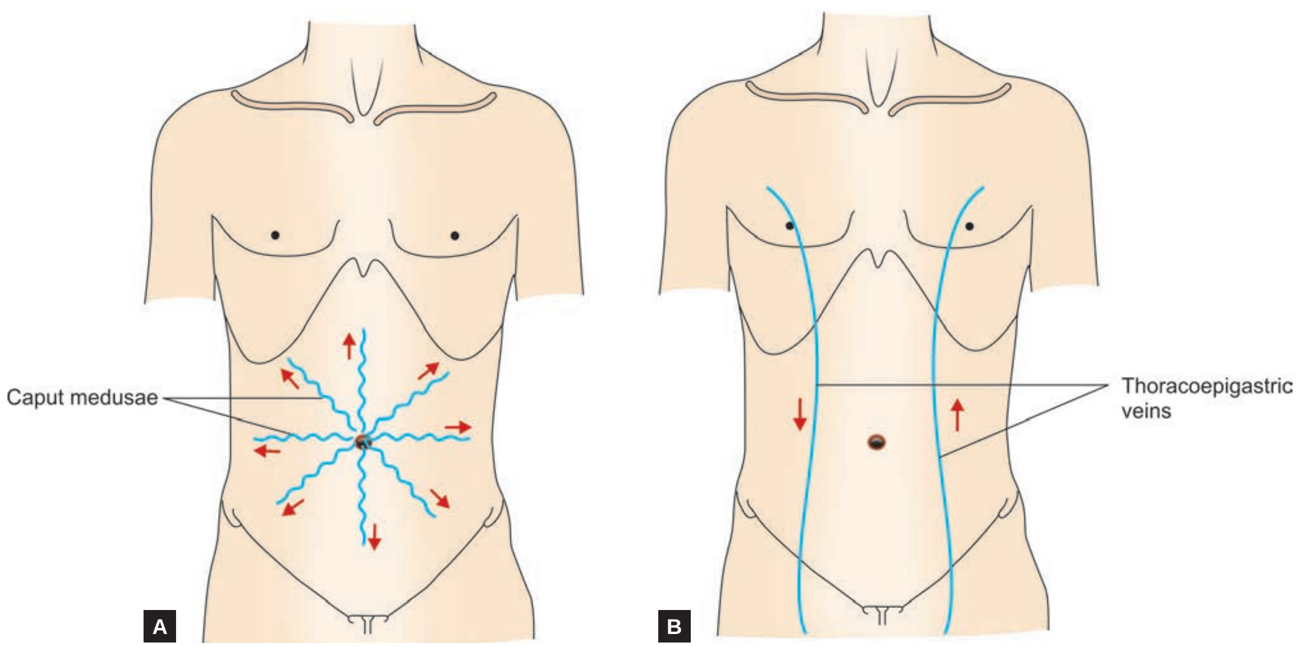


Fig. 19: Superficial veins of the anterior abdominal wall



Figs. 20A and B: Subcutaneous venous collateral circulation: (A) Formation of caput medusae in portal obstruction; (B) Formation of thoraco-epigastric vein in caval obstruction. (The arrows indicate the direction of blood flow in superior vena cava obstruction on the right side and in inferior vena cava obstruction on the left side.)

Lymphatics

- Superficial lymphatic vessels accompany the subcutaneous blood vessels immediately below the dermis
- Vessels from the lumbar and gluteal regions run with the superficial circumflex iliac vessels, and those from the infra-umbilical skin run with the superficial epigastric vessels.
- Both drain into superficial inguinal nodes.
- The supraumbilical region is drained by vessels draining to axillary and parasternal nodes.
- The deep lymphatic vessels accompany the deeper arteries.
- Laterally, they run either with the lumbar arteries to drain into the lateral aortic nodes, or with the intercostal and subcostal arteries to posterior mediastinal nodes.
- Lymphatics in the upper anterior abdominal wall run with the superior epigastric vessels to parasternal nodes while those in the lower abdominal wall run with the deep circumflex iliac and inferior epigastric arteries to external iliac nodes.

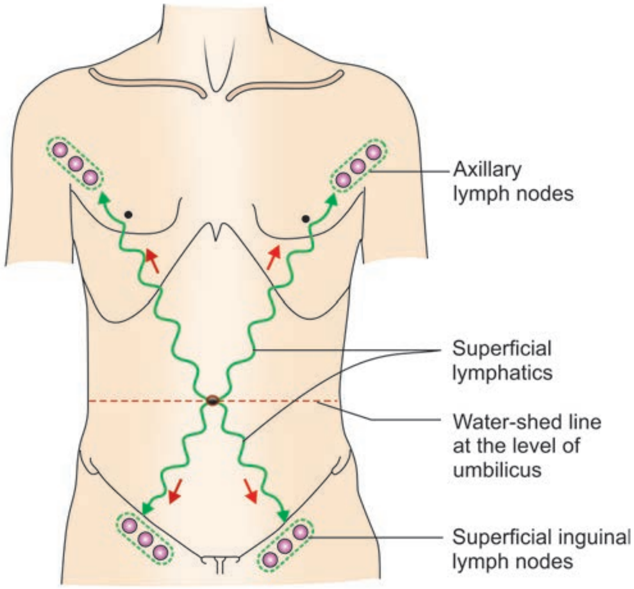


Fig. 21: Superficial lymphatics of the anterior abdominal wall

Lymphatic drainage of the anterolateral abdominal wall follows the following patterns:

- Superficial lymphatic vessels accompany the subcutaneous veins; those superior to the transumbilical plane drain mainly to the axillary lymph nodes and parasternal lymph nodes. Superficial lymphatic vessels inferior to the transumbilical plane drain to the superficial inguinal lymph nodes.
- The deep lymphatic vessels accompany the deeper arteries. Laterally, they run either with the lumbar arteries to drain into the lateral aortic nodes, or with the intercostal and subcostal arteries to posterior mediastinal nodes. Lymphatics in the upper anterior abdominal wall run with the superior epigastric vessels to parasternal nodes while those in the lower abdominal wall run with the deep circumflex iliac and inferior epigastric arteries to external iliac nodes.

ASSESSMENT QUESTIONS

1. **Lymphatic drainage of umbilicus is towards:** *(PGIC 2014)*
   a. Axillary lymph nodes only
   b. Inguinal lymph nodes only
   c. Both axillary and inguinal lymph nodes
   d. Coeliac lymph nodes
   e. Aortic lymph nodes

2. **Lymphatic drainage of umbilicus is towards:** *(UPSC 2009)*
   a. Axillary and inguinal
   b. External and internal iliac
   c. Pre and para aortic
   d. Inter aorta-caval

3. **Neurovascular bundle in anterior abdominal wall is:** *(NEET Pattern 2012)*
   a. Between external oblique and internal oblique
   b. Between internal oblique and transverses abdominis
   c. Dee to transversus abdominis
   d. Superficial to external oblique

4. **What is the nerve supply to the skin around the umbilicus?** *(Kerala 2k)*
   a. 10th thoracic ventral ramus
   b. 11th thoracic ventral ramus
   c. Subcostal nerve
   d. Iliohypogastric nerve
   e. Ilioinguinal nerve

ANSWERS WITH EXPLANATIONS

1. **c. Both axillary and inguinal lymph nodes; e. Aortic lymph nodes**
   - Umbilicus drains into both the directions, supra-umbilically into **axillary** lymph nodes and infra-umbilically into **inguinal** lymph nodes.
   - The deep lymph vessels follow the arteries and drain into the internal thoracic, external iliac, posterior mediastinal, and **para-aortic** (lumbar) nodes.

2. **a. Axillary and inguinal**
   - Umbilicus drains supra-umbilically into **axillary** and infra-umbilically into **inguinal** lymph nodes.
   - It also drains into **external** and common iliac (not **internal iliac**) and into **para-aortic** (not **pre-aortic**) lymph nodes.

3. **b. Between internal oblique and transverse abdominis**
   - Neurovascular bundle run forward in a plane between the internal oblique and transversus abdominis muscle.

4. **a. 10th thoracic ventral ramus**

High Yield Point

- The nerve supply to the skin around the umbilicus is 10th thoracic ventral ramus.

Posterior Abdominal Wall

Muscles

Table 5: Muscles of posterior abdominal wall

Muscle	Supeior Attachment	Inferior Attachment	Innervation	Main Action
Psoas major[a]	Transverse processes of lumbar vertebrae; sides of bodies of T12–L5 vertebrae and intervening intervertebral discs	By a strong tendon to lesser trochanter of femur	Anterior rami of lumbar nerves **L1, L2, L3**	Acting inferiorly with iliacus, it flexes thigh; acting superiorly it flexes vertebral column laterally; it is used to balance the trunk; when sitting it acts inferiorly with iliacus to flex trunk
Iliacus[a]	Superior two-thirds of iliac fossa, ala of sacrum, and anterior sacro-iliac ligaments	Lesser trochanter of femur and shaft inferior to it, and to psoas major tendon	Femoral nerve **(L2–L4)**	Flexes thigh and stabilizes hip joint; acts with psoas major
Quadratus lumborum	Medial half of inferior border of 12th ribs and tips of lumbar transverse processes	Iliolumbar ligament and internal lip of iliac crest	Anterior branches of T12 and L1–L4 nerves	Extends and laterally flexes vertebral column; fixes 12th rib during inspiration

*Psoas minor and iliacus muscles merge inferiorly; collectively form iliopsoas muscle.

Nerve Supply

Iliohypogastric Nerve

- Originates from the (T12), L1, runs forwards between transversus abdominis and internal oblique (including conjoint tendon).
- It also supplies the skin on posterolateral gluteal region and suprapubic region.
- The nerve is occasionally injured by a surgical incision in the right iliac fossa (e.g. during an inguinal hernia repair, open appendectomy)

Ilioinguinal Nerve

- Originates from the (T12), L1 (L2) and emerges from the lateral border of psoas major, with or just inferior to the iliohypogastric nerve, passes obliquely across quadratus lumborum and the upper part of iliacus.
- It enters transversus abdominis about 3 cm medial and 4 cm inferior to the anterior superior iliac spine, where it is readily blocked by local anaesthetic.
- It pierces internal oblique a little lower down, supplies it, and then traverses the inguinal canal superficial to the spermatic cord or round ligament. It emerges with the cord from the superficial inguinal ring and divides into terminal sensory branches.
- The ilioinguinal and genitofemoral nerves may interconnect within the inguinal canal and, consequently, each innervates the skin of the genitalia to a variable extent.
- The ilioinguinal nerve supplies motor nerves to transversus abdominis and internal oblique.
- It innervates the skin of the proximal medial thigh and the skin over the root of the penis and upper part of the scrotum in males, or the skin covering the mons pubis and the adjoining labium majus in females.
- The nerve may be injured or entrapped during inguinal surgery, particularly for inguinal hernia, leading to sensory disturbances and pain over the skin of the genitalia and upper medial thigh.

Genitofemoral Nerve

- Originates from the L1 and L2 ventral rami, descends obliquely forwards through the psoas major muscle to emerge on its anterior surface nearer the medial border, opposite the third or fourth lumbar vertebra.
- It then descends beneath the peritoneum on psoas major, crosses obliquely behind the ureter, and divides into genital and femoral
- The **genital branch** enters the inguinal canal through the deep ring and accompanies the spermatic cord or round ligament. It exits the superficial inguinal ring, usually dorsal to the spermatic cord or round ligament, and supplies the cremaster muscle and skin of the external Genitalia (scrotum, mons pubis, labia majora). Like the ilioinguinal nerve, the genital branch may be injured during inguinal surgery (open and laparoscopic), leading to neuralgic pain.

- The **femoral branch** pass behind the inguinal ligament (occasionally, through it) and enter the femoral sheath lateral to the femoral artery. It pierces the anterior layer of the femoral sheath and fascia lata, and supplies the skin of the upper part of the femoral triangle. It also innervate the anteromedial skin of the thigh via its femoral branch.

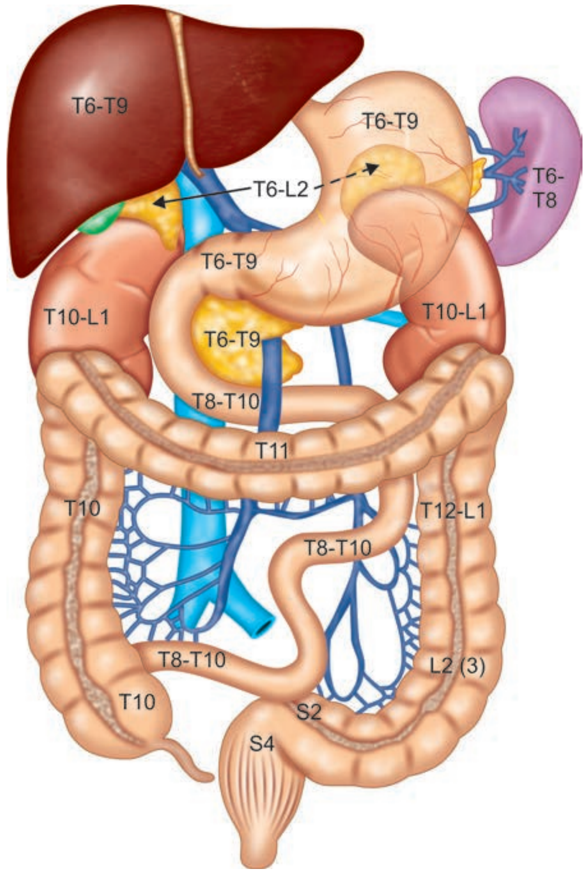


Fig. 22: Segmental innervation of abdominal viscera. Approximate spinal cord segments and spinal sensory ganglia involved in sympathetic and visceral afferent (pain) innervation of abdominal viscera are shown

Table 6: Autonomic innervation of abdominal viscera (Splanchnic nerves)

Splanchnic Nerves	Autonomic Fiber Type[a]	System	Origin	Destination
A. Cardiopulmonary (cervical and upper thoracic)	Postsynaptic		Cervical and upper thoracic sympathetic trunk	Thoracic cavity (viscera superior to level of diaphragm)
B. Abdominopelvic 1. Lower thoracic a. Greater b. Lesser c. Least 2. Lumbar 3. Sacral	Presynaptic		Lowre thoracic and abdominopelvic sympathetic trunk: 1. Thoracic sympathetic trunk a. T5–T9 or T10 level b. T10–T11 level c. T12 level 2. Abdominal sympathetic trunk 3. Pelvic (sacral) sympathetic trunk	Abdomiopelvic cavity (prevertebral ganglia serving viscera and suprarenal glands inferior to level of diaphragm) 1. Abdominal prevertebral ganglia: a. Celiac ganglia b. Aorticorenal ganglia c. and 2. Other abdominal preventebral ganglia (superior and interior mesenteric, and of intermesenteric/hypogastric plexuses) 3. Pelvic prevertebral ganglia
C. Pelvic	Presynaptic	Parasympathetic	Anterior rami of S2–S4 spinal nerves	Intrinsic ganglia of descending and sigmoid colon, rectum, and pelvic viscera

[a]Splanchnic nerves also convey visceral afferent fibers, which are not part of the autonomic nervous system.

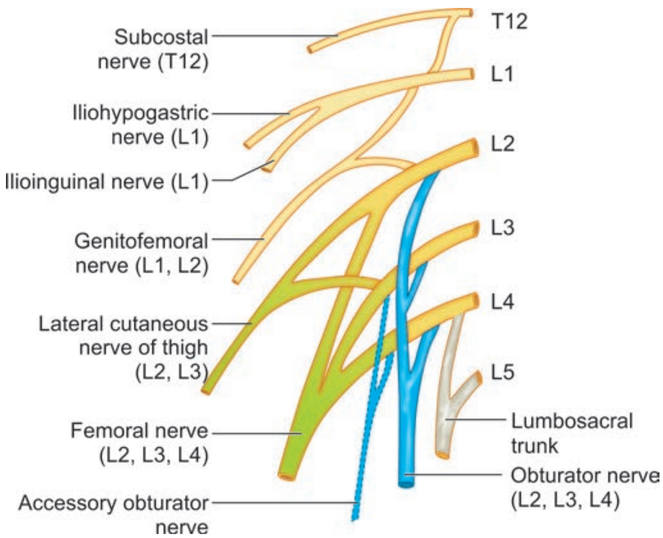


Fig. 23: Lumbar plexus of nerves: The dorsal divisions are shown by green colour and ventral divisions by blue color

Table 7: Branches of the lumbar plexus

Branches	Root value
• Iliohypogastric nerve	• L1
• Ilioinguinal nerve	• L1
• Genitofemoral nerve	• L1, L2 (ventral divisions)
• Lateral cutaneous nerve of the thigh	• L2, L3 (dorsal divisions)
• Femoral nerve	• L2, L3, L4 (dorsal divisions)
• Obturator nerve	• L2, L3, L4 (ventral divisions)
• Accessory obturator nerve (occasional)	• L3, L4 (ventral divisions)

ANS in abdomen

- Two components:
  1. Sympathetic chains.
  2. Autonomic plexuses on the posterior abdominal wall.

Sympathetic chain in the abdomen

- It is a ganglionated chain situated on either side of the lumbar vertebrae.
- It begins deep to the **medial arcuate ligament** of the diaphragm (as the continuation of the thoracic sympathetic chain).
- It runs vertically downward along the **sides** of bodies of the lumbar vertebrae overlapped on the right side by the IVC and on the left side by the abdominal aorta. The lumbar arteries lie deep to the chain but the lumbar veins may cross superficial to it.
- The chain enters the pelvis in front of the ala of Sacrum beneath the common iliac vessels, where it continues as the sacral sympathetic chain in front of the sacrum.
- The right and left sympathetic chain converges and unites in front of the coccyx to form the ganglion impar.
- Each lumbar sympathetic chain possesses four ganglia, the first and second often being fused together.
- The cell bodies of neurons of the sympathetic supply of the abdomen and pelvis lie in the intermediolateral grey matter of T1-12 and L1-2 spinal segments.
- **White ramus** communicans: Myelinated axons from these neurons travel in the ventral ramus of the spinal nerve of the same segmental level, leaving it via a white ramus communicans to enter a thoracic or lumbar paravertebral sympathetic ganglion.
- **Splanchnic nerves**: Visceral branches convey preganglionic motor and visceral sensory (pain) fibres may exit at the same level or ascend or descend several levels in the sympathetic chain before exiting; they leave the ganglia without synapsing and pass medially, giving rise to the paired greater, lesser and least splanchnic nerves, and the lumbar and sacral splanchnic nerves.

Note: G**rey ramus** communicans: Axons destined to supply somatic structures (like skin) synapse in the sympathetic ganglion of the same level, and postganglionic, unmyelinated axons leave the ganglion as one or more grey rami communicantes to enter the spinal nerve of the same segmental level.

Greater splanchnic nerve

- Root value: T5-9.
- It enters the abdomen through the fibres of the ipsilateral crus of the diaphragm, to enter the superior aspect of the coeliac ganglion, where most of the preganglionic fibres synapse (but not those destined for the suprarenal medulla).

Lesser splanchnic nerve

- Root value: T10-11 (or T9-10).
- It enters the abdomen running through the lowermost fibres of the ipsilateral crus of the diaphragm or under the medial arcuate

Ligament

- It joins the aorticorenal ganglion and may give branches to the lateral aspect of the coeliac ganglion.

Least splanchnic nerve

- Root value: T-11 and/or T-12.
- It enters the abdomen medial to the sympathetic chain under the medial arcuate ligament of the diaphragm and runs inferiorly to join the renal plexus.
- The trunk of the nerve enters the aorticorenal ganglion and may give branches to the lateral aspect of the coeliac ganglion.

Lumbar splanchnic nerves

- They contribute to the superior and inferior hypogastric plexuses to innervate the bladder neck, ductus deferens and prostate, among other structures. Damage to these nerves, e.g. during aortoiliac surgery, can result in sexual dysfunction.
- Four lumbar splanchnic nerves pass as medial branches from the ganglia to join the coeliac, inferior mesenteric and superior hypogastric plexuses.
- The first lumbar splanchnic nerve, from the first ganglion, gives branches to the coeliac, renal and inferior mesenteric plexuses.
- The second nerve joins the inferior part of the intermesenteric or inferior mesenteric plexus.
- The third nerve arises from the third or fourth ganglion and joins the superior hypogastric plexus.
- The fourth lumbar splanchnic nerve from the lowest ganglion passes anterior to the common iliac vessels to join the lower part of the superior hypogastric plexus, or the hypogastric nerves.

Pelvic sympathetic chain

- It converges caudally to form a solitary retroperitoneal structure, the ganglion impar (of Walther), which lies at a variable level between the sacrococcygeal joint and the tip of the coccyx.
- Ganglion impar conveys sympathetic efferents to and nociceptive afferents from the perineum and terminal urogenital. Regions and it is blocked to treat intractable perineal pain of sympathetic origin in patients with pelvic cancers.

Somatic and vascular branches

- Grey rami communicantes containing postganglionic sympathetic nerves pass from the pelvic sympathetic ganglia to the sacral and coccygeal spinal nerves. There are no white rami communicantes at this level.
- The postganglionic fibres are distributed via the sacral and coccygeal plexuses.
- Thus, sympathetic fibres in the tibial nerve are conveyed to the popliteal artery and its branches in the leg and foot, whilst those in the pudendal and superior and inferior gluteal nerves accompany these arteries to the perineum and buttocks.

Sacral splanchnic nerves

- Sacral splanchnic nerves pass directly from the ganglia to the inferior hypogastric plexus and, from there, to pelvic viscera; they usually arise from the first two sacral sympathetic ganglia.

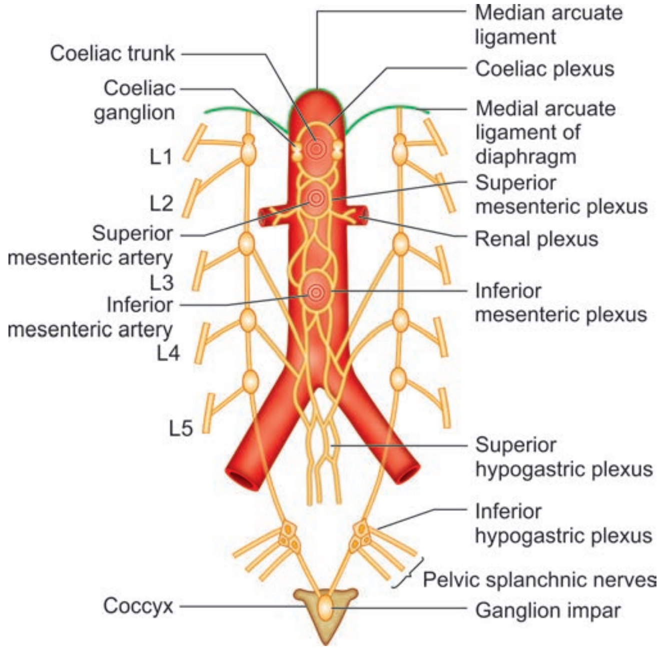


Fig. 24: Lumbar sympathetic chain and autonomic plexuses of the posterior abdominal wall

- Autonomic plexus on the posterior abdominal wall
- The preganglionic and postganglionic sympathetic fibres, preganglionic parasympathetic fibres, and visceral afferent fibres form a plexus of nerves around the abdominal aorta.
- It is constituted by two plexuses: coeliac and superior hypogastric plexuses.

Coeliac (solar) plexus

- The coeliac plexus is located at the level of the T-12 and L1 vertebrae, and is the largest major autonomic plexus.
- It lies **anterolateral to the aorta** and surrounds the coeliac artery and the root of the superior mesenteric artery.
- It is posterior to the stomach and lesser sac, and anterior to the crura of the diaphragm and the beginning of the abdominal aorta, and lies medial to the suprarenal glands.
- The plexus and ganglia receive the **greater** and **lesser splanchnic nerves** and branches from the **vagal** trunks. The plexus is in continuity with small branches along adjacent arteries and is connected to the phrenic, splenic, hepatic, superior mesenteric, suprarenal, renal and gonadal plexuses.
- Visceral afferents in the coeliac plexus convey pain and other sensations from upper abdominal viscera. Coeliac plexus block is undertaken to treat intractable pain from pancreatic disorders.

Coeliac and Aorticorenal Ganglia

- The coeliac ganglia receive greater splanchnic nerve in the upper part and the lesser splanchnic nerve joins the lower part.
- The lowermost part of each ganglion forms the aorticorenal ganglion, which receives the ipsilateral lesser splanchnic nerve and gives origin to the majority of the renal plexus.

Superior Mesenteric Plexus and Ganglion

- The superior mesenteric plexus lies in the pre-aortic connective tissue posterior to the pancreas, around the origin of the superior mesenteric artery.
- It is an inferior continuation of the coeliac plexus, and includes branches from the posterior vagal trunk and coeliac plexus.
- Its branches accompany the superior mesenteric artery and its divisions.
- The superior mesenteric ganglion lies superiorly in the plexus, usually above the origin of the superior mesenteric artery.

Intermesenteric Plexus

- Like other parts of the abdominal aortic autonomic plexus, the intermesenteric plexus is not a discrete structure but is part of a continuous periarterial nerve plexus connected to the gonadal, inferior mesenteric, iliac and superior hypogastric plexuses.
- It lies on the lateral and anterior aspects of the aorta, between the origins of the superior and inferior mesenteric arteries, and consists of numerous fine, interconnected nerve fibres and a few ganglia continuous superiorly with the superior mesenteric plexus and inferiorly with the superior hypogastric plexus.
- It is not well characterized but receives parasympathetic and sympathetic branches from the coeliac plexus and additional sympathetic rami from the first and second lumbar splanchnic nerves.

Inferior mesenteric plexus

- The inferior mesenteric plexus lies around the origin of the inferior mesenteric artery and is distributed along its branches.
- It is formed predominantly from the aortic plexus, supplemented by sympathetic fibres from the first and second lumbar splanchnic nerves and ascending pelvic parasympathetic fibres from the inferior hypogastric plexus (via the hypogastric nerves and superior hypogastric plexus).
- Disruption of the inferior mesenteric plexus alone rarely causes clinically significant disturbances of autonomic function.

Superior hypogastric plexus

- The superior hypogastric plexus lies anterior to the aortic bifurcation.
- The plexus is formed by branches from three main sources: the aortic plexus (sympathetic and parasympathetic), lumbar splanchnic nerves (sympathetic) and pelvic splanchnic nerves (parasympathetic), which ascend from the inferior hypogastric plexus via the right and left hypogastric nerves.
- The superior hypogastric plexus conveys branches to the inferior mesenteric plexus and to the ureteric, gonadal and common iliac nerve plexuses; additional small branches turn abruptly forwards into the upper mesorectum to travel with the superior rectal artery.

Inferior Hypogastric Plexus

- The inferior hypogastric plexus lies on the pelvic side wall anterolateral to the mesorectum, postero lateral to the base of the urinary bladder.
- The inferior hypogastric plexus is formed mainly from pelvic splanchnic (**parasympathetic**) and sacral splanchnic (**sympathetic**) branches; a smaller contribution is derived from sympathetic fibres (from the lower lumbar ganglia), which descend into the plexus from the superior hypogastric plexus via the hypogastric nerves.
- It supply the vas deferens, seminal vesicles, prostate, accessory glands and penis in males; the ovary, Fallopian tubes, uterus, uterine cervix and vagina in females; and the urinary bladder and distal ureter in both sexes. The plexus plays a key role in continence and sexual function.
- **Hypogastric nerves** The hypogastric nerves are usually paired nerve bundles but may consist instead of multiple filaments. They contain sympathetic fibres (mostly descending from the superior hypogastric plexus) and parasympathetic fibres (ascending from the inferior hypogastric plexus). The nerves run between the superior and inferior hypogastric plexuses on each side.

Table 8: Pain referral from abdominal viscera

Organ	Referral Area	Pathway
Diaphragm:		
Central	C3–C5: neck and shoulder	Phrenic nerve
Marginal	T5–T10: thorax	Intercostal nerves
Foregut:		
Stomach, gallbladder, liver, bile duct, superior duodenum	T5–T9: lower thorax, epigastric region	Celiac plexus to greater splanchnic nerve
Midgut:		
Inferior duodenum, jejunum, ileum, appendix, ascending colon, transverse colon	T10–T11: umbilical region	Superior mesenteric plexus to lesser splanchnic nerve
(Kidney, upper ureters, gonads)	T12–L1: lumbar and ipsilateral inguinal	Aorticorenal plexus to least splanchnic nerve regions
Hindgut:		
Descending colon, sigmoid colon, mid-ureters	L1–L2: suprapubic and inguinal regions, anterior secretum or labia, anterior thigh	Aortic plexus to lumbar splanchnic nerves

Table 9: Pain referral from pelvic viscera		
Organ	**Referral areas**	**Pathway**
Testes and ovaries	T10–T12: umbilical and pubic regions	Gonadal nerves to aortic plexus and then to lesser and least splanchnic nerves
Middle ureters, urinary bladder, uterine body, uterine tubes	L1˜L2: pubic and inguinal regions, anterior scrotum or labia, anterior thigh	Hypogastric plexus to aortic plexus and then to lumbar splanchnic nerves
Rectum, superior anal canal, pelvic ureters, cervix, epididymis, vas deferens, seminal vesicles, prostate gland	S2–S5: perineum and posterior thigh	Pelvic plexus to pelvic splanchnic nerves

Table 10: Pelvic visceral afferent innervation			
Organ	**Afferent pathway**	**Level**	**Referral areas**
Kidneys Renal pelvis Upper ureters	Aorticorenal plexus, least splanchnic nerve, white ramus of T12, subcostal nerve	T12	Subcostal and pubic regions
Descending colon Sigmoid colon Mid-ureters Urinary bladder Oviducts Uterine body	Aortic plexus, lumbar splanchnic nerves, white rami of L1–L2, spinal nerves L1–L2	L1–L2	Lumbar and inguinal regions, anterior mons and labia, anterior scrotum, anterior thigh
None	No white rami between L3–S1	L3–S1	No visceral pain refers to dermatomes L3–S1
Cervix Pelvic ureters Epididymis Vas deferens Seminal vesicles Prostate gland Rectum Proximal anal canal	Pelvic plexus, pelvic splanchnic nerves, spinal nerves S2–S4	S2–S4	Perineum, thigh, lateral leg and foot

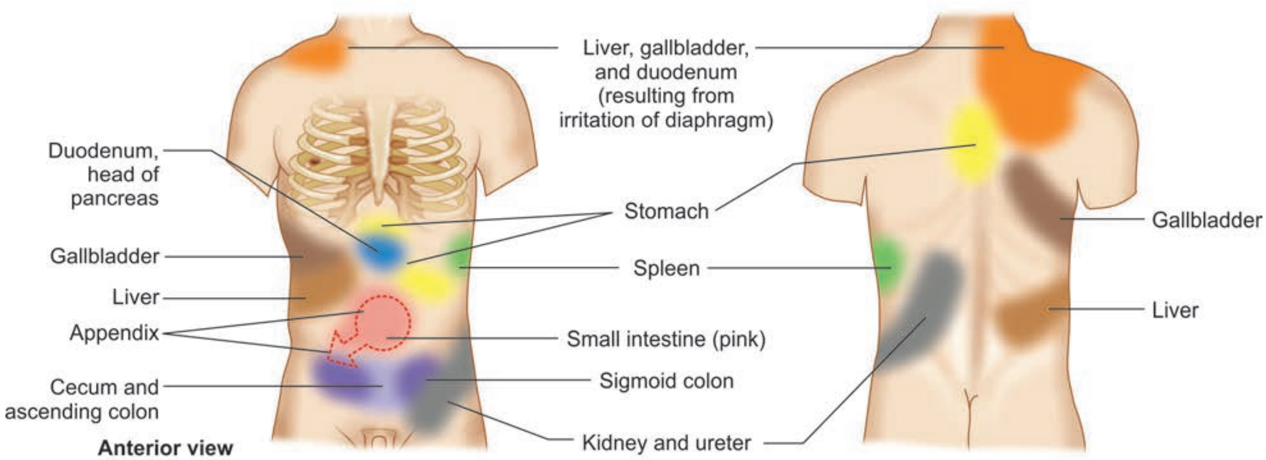


Fig. 25: Referred pain of various on the body surface

Parasympathetic innervation

- The parasympathetic neurons innervating the abdomen and pelvis are present in the dorsal motor nucleus of the vagus nerve and in the intermediolateral grey matter of the second, third and fourth sacral spinal segments.
- The vagus nerves supply parasympathetic innervation to the abdominal viscera as far as the distal transverse colon, i.e. they supply the foregut and midgut.
- The hindgut is supplied by parasympathetic fibres travelling via the pelvic splanchnic nerves.
- The vagal trunks are derived from the oesophageal plexus and enter the abdomen via the oesophageal hiatus.
- The anterior vagal trunk is mostly derived from the left vagus and the posterior from the right vagus. The nerves supply the intra-abdominal oesophagus and stomach directly.
- The anterior trunk gives off a hepatic branch, which innervates the liver parenchyma and vasculature, the biliary tree including the gallbladder, and the structures in the free edge of the lesser omentum.

- The posterior trunk supplies branches to the coeliac plexus; these fibres frequently constitute the largest portion of the fibres contributing to the plexus. They arise directly from the posterior vagal trunk and from its gastric branch, and run beneath the peritoneum, deep to the posteriorwall of the upper part of the lesser sac, to reach the coeliac plexus. Their synaptic relays with postganglionic neurons are situated in the myenteric (Auerbach's) and submucosal (Meissner's) plexuses in the wall of the gut.

Pelvic splanchnic nerves

- They travel in the anterior rami of the second, third and fourth sacral spinal nerves. They leave the nerves as they exit the anterior sacral foramina.
- Most pass anterolaterally into the network of nerves that form the inferior hypogastric plexus; from here, they pass to the pelvic viscera. Some join directly with the hypogastric nerves and ascend out of the pelvis, as far as the superior hypogastric plexus; from here, they are distributed with branches of the inferior mesenteric artery.
- The pelvic splanchnic nerves are motor to the smooth muscle of the hindgut and bladder wall, supply vasodilator fibres to the erectile tissue of the penis and clitoris, and are secretomotor to the hindgut.

Applied Anatomy:

- Visceral pain: The viscera are insensitive to cutting, crushing, or burning but visceral pain does occur following excessive distension, spasmodic contraction of smooth muscles, and ischemia of the viscera. The visceral pain is usually referred to the skin supplied by same segmental nerves (referred pain).
- Lumbar sympathectomy: It is done for vaso-occlusive disease of lower limb (Buerger's disease). Usually the second, third, and fourth lumbar ganglia are excised along with intermediate chain. This causes adequate vasodilation of the lower limb. Consequently the skin of the lower limb Clinical correlation becomes warm, pink, and dry. The first lumbar ganglion is preserved because it plays an important role in ejaculation (keeps the sphincter vesicae closed during ejaculation). Removal of first lumbar sympathetic ganglion results in dry coitus.

ASSESSMENT QUESTIONS

1. Relation of celiac plexus: *(AIIMS 2010)*
   a. Anterolateral to aorta
   b. Posteromedial to aorta
   c. Anteromedial to lumbar sympathetic chain
   d. Posterolateral to lumbar sympathetic chain

2. Which nerve supplies celiac plexus: *(NEET Pattern 2012)*
   a. Phrenic nerve
   b. Greater splanchnic nerve
   c. Iliohypogastric nerve
   d. Inguinal nerve

3. Which of the following statements is TRUE about the autonomic nervous system: *(AIPG 2003)*
   a. The sympathetic outflow from the CNS is through both the cranial nerves and the sympathetic chain
   b. The parasympathetic outflow from the CNS is through cranial nerves only
   c. The superior hypogastric plexus is located at the anterior aspect of the aortic bifurcation and fifth lumbar vertebra
   d. The superior hypogastric plexus contains sympathetic fibers only

4. In first stage of labour the referred pain from uterus is carried to the dermatome: *(AIIMS)*
   a. T-10, 11
   b. T-12; L-1
   c. L-1, 2
   d. S-2, 3

5. To provide pain relief during first stage of labour which sensory level should be blocked:
   a. T8 to L1
   b. T9 to L2
   c. T10 to L1
   d. T11 to L2

ANSWERS WITH EXPLANATIONS

1. a. Anterolateral to aorta > Anteromedial to lumbar sympathetic chain
- Celiac plexus is present on the anterior side of the aorta around the beginning of celiac trunk .
- It lies over the anterolateral surface of the aorta at the T12 / L1 vertebral level.
- Celiac plexus is retroperitoneal and located behind the stomach and the omental bursa, and in front of the crura of the diaphragm.
- In pictorial representation it appear anteromedial to sympathetic trunks as well, though no such statement is mentioned in standard textbooks.
- Frequently celiac plexus block (fluoroscopically guided injection) is performed by pain management specialists and radiologists is performed via CT guidance.
- Intractable pain related to chronic pancreatitis is an important indication for celiac plexus ablation.

2. b. Greater splanchnic nerve
- The celiac plexus receive preganglionic sympathetic fibers contributed by the greater and lesser splanchnic nerves.
- Parasympathetic fibres are contributed by vagus nerve. Postganglionic fibres accompany the respective blood vessels to the target organs.

3. c. The superior hypogastric plexus is located at the anterior aspect of the aortic bifurcation and fifth lumbar vertebra
- Superior hypogastric plexus is located at the anterior aspect of the aortic bifurcation.
- It is chiefly sympathetic but some parasympathetic fibres from pelvic splanchnic nerves ascend from the inferior hypogastric plexus via the right and left hypogastric nerves to reach the superior hypogastric plexus.
- The sympathetic outflow is thoracolumbar (T1-L2) and doesn't involve cranial nerves.
- Parasympathetic flow is craniosacral and involves cranial nerves (3,7,9,10) and sacral nerves (S2,3,4).

4. b. T-12; L-1

- Pain during **first stage of labour** is initially confined to T11-T12 dermatomes (latent phase), but eventually labour enters active phase and much of the pain is due to dilatation of cervix and lower uterine segment and pain passes through hypogastric plexus and aortic plexus before entering the spinal cord at T10-L1 nerve roots.
- Stretching and compression of the pelvic and perineal structures involves pudendal nerve (S2-4), so pain during second stage of labour involves T10-S4 dermatomes.

5. c. T10 to L1

- Pain during **first stage of labour** is initially confined to T11-T12 dermatomes (latent phase), but eventually labour enters active phase and much of the pain is due to dilatation of cervix and lower uterine segment and pain passes through hypogastric plexus and aortic plexus before entering the spinal cord at T10-L1 nerve roots.
- Spinal anesthesia up to spinal nerve **T10** is necessary to block pain for **vaginal** delivery and up to spinal nerve **T4** for **cesarean** section (due to the sympathetic fibre levels being at higher level than motor or sensory blockade) **(William's Obstetrics and Morgan's Obstetric Anaesthesia**).

Vasculature - Arteries

Table 11: Key anatomical reference points for umbilical arterial catheterization

Structure	Vertebral level
Ductus arteriosus	T4–5
Coeliac artery	T12
Superior mesenteric artery	T12–L1
Renal artery	L1
Inferior mesenteric artery	L3
Aortic bifurcation	L4–5

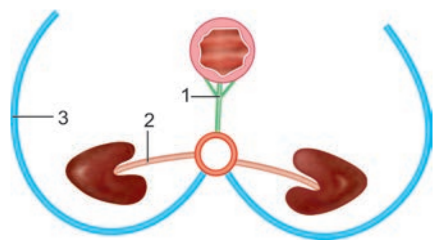
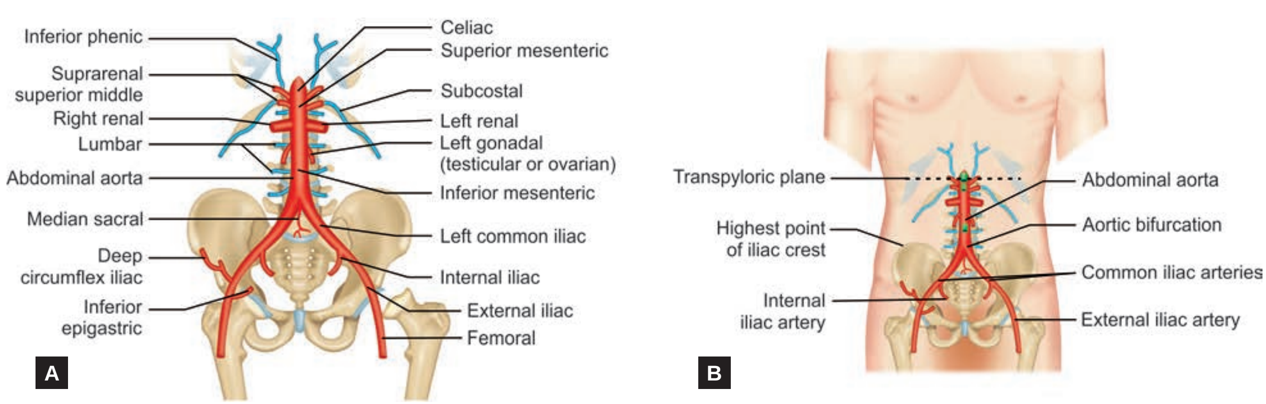


Fig. 26: Arteries of posterior abdominal wall—branches of the aorta.

Table 12: Branches of abdominal aorta

Vascular plane	Class	Distribution	Abdominal Branches (Arteries)	Vertebral Level
• Anterior midline	Unpaired visceral	Digestive tract	celiac	T12
			Superior mesenteric	L1
			Inferior mesenteric	L3
• Lateral	Paired visceral	Urogenital and endocrine organs	Suprarenal	L1
			Renal	L1
			Gonadal (testicular or ovarian)	L2
Posterolateral	Paired parietal (segmental)	Diaphragm; body wall	Subcostal	L2
			Inferior phrenic	T12
			Lumbar	L1–L4



Figs. 27A and B: A. Anterior view B. Anterior view

The abdominal aorta begins at the level of the body of the T-12 vertebra as it passes through aortic hiatus. It descends and bifurcates at L4 vertebra just to the left of the midline.

- IVC-L5

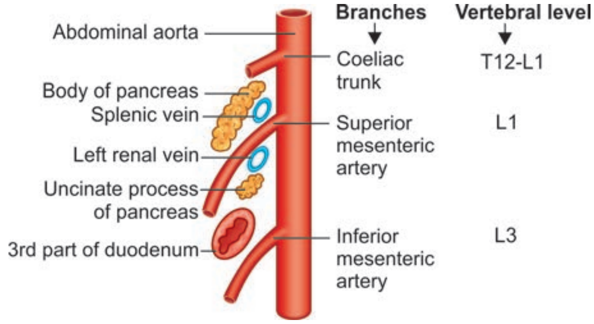


Fig. 28: Three ventral branches of the abdominal aorta as seen in left lateral view of a sagittal section through the abdominal aorta. Note: Superior mesenteric artery at its origin is sandwiched between splenic and left renal veins.

Abdominal Aorta

A. Major Branches

1. **Celiac Trunk** is located at **T12** vertebral level and supplies viscera that derive embryologically from the **foregut** (i.e., intra-abdominal portion of esophagus, stomach, upper part of duodenum, liver, gallbladder, and pancreas). The celiac trunk further branches into the following.
   a. Left gastric artery
   b. Splenic artery
   c. Common hepatic artery
- **Superior Mesenteric Artery** is located at **L1** vertebral level and supplies viscera that derive embryologically from the **midgut** (i.e., lower part of duodenum, jejunum, ileum, cecum, appendix, ascending colon, and proximal two-thirds of transverse colon)
3. **Renal Arteries** supply the kidneys.
4. **Gonadal Arteries** supply the testes or ovary.
5. **Inferior Mesenteric Artery** is located at **L3** vertebral level and supplies viscera that derive embryologically from the **hindgut** (i.e., distal one-third of transverse colon, descending colon, sigmoid colon, and upper portion of rectum).
6. **Common Iliac Arteries** are the terminal branches of the abdominal aorta.
- **Collateral Circulation.** The abdominal vasculature has a fairly robust collateral circulation. Any blockage between the superior mesenteric artery at L1 vertebral level and inferior mesenteric artery at L3 vertebral level will cause blood to be diverted along two routes of collateral circulation. The first route uses the middle colic artery (a branch of superior mesenteric artery) which anastomoses with the left colic artery (a branch of inferior mesenteric artery). The second route uses the marginal artery.

Abdomen—vascular and nerve supply

Abdominal aorta

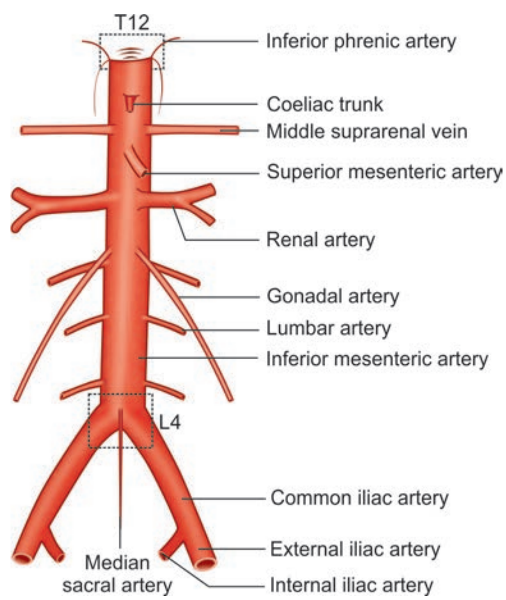


Fig. 29: Course and branches of the abdominal aorta

- 1. Three anterior visceral branches
  - a. Celiac artery
    - Left gastric artery
    - Splenic artery
      - Short gastric arteries (six)
      - Splenic arteries (six)
      - Left gastroepiploic artery
    - Hepatic artery
      - Cystic artery
      - Right gastric artery
      - Gastroduodenal artery
        - Right gastroepiploic artery
        - Superior pancreaticoduodenal artery
      - Right hepatic artery
      - Left hepatic artery
  - b. Superior mesenteric artery
    - Jejunal and ileal arteries
    - Inferior pancreaticoduodenal artery
    - Middle colic artery
    - Right colic artery
    - Ileocolic artery
      - Anterior cecal artery
      - Posterior cecal artery—Appendicular artery
      - Ileal artery
      - Colic artery
  - c. Inferior mesenteric artery
    - Left colic artery
    - Sigmoid arteries (Two or Three)
    - Superior rectal artery
- 2. Three lateral visceral branches
  - a. Suprarenal artery
  - b. Renal artery
  - c. Testicular or ovarian artery
- 3. Five lateral abdominal wall branches
  - a. Inferior phrenic artery
  - b. Four lumbar arteries
- 4. Three terminal branches
  - a. Two common iliac arteries
    - External iliac artery
    - Internal iliac artery
  - b. Median sacral artery

Fig. 30: Branches of abdominal aorta

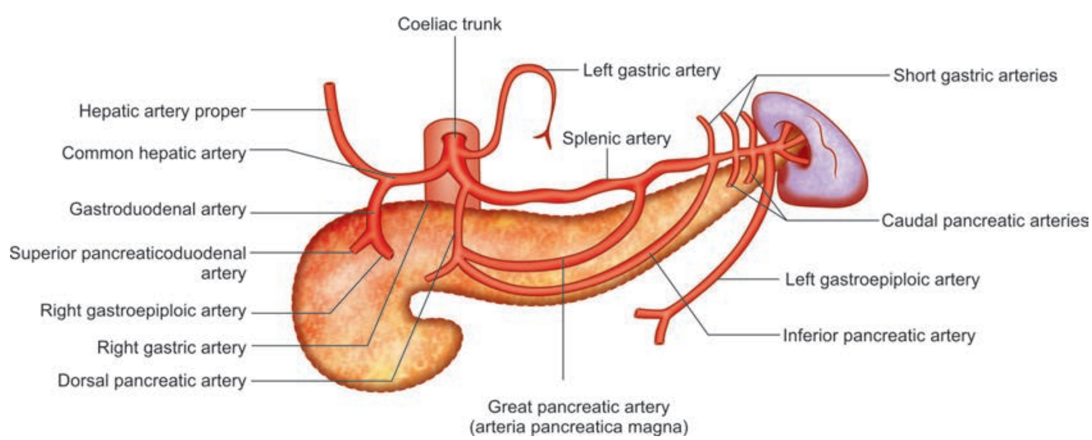


Fig. 31: Coeliac trunk

Table 13: Arterial supply to abdominal foregut derivatives: Esophagus, stomach, liver, gallbladder, pancreas, and spleen

Artery	Origin	Course	Distribution
Celiac trunk	Abdominal aorta (at level of aortic hiatus)	After short anteroinferior course, bifurcates into splenic and common hepatic arteries	Esophagus, stomach. proximal duodenum, liver/giving apparatus, pancreas
Left gastric	Celiac trunk	Ascends retroperitoneally to esophageal hiatus, giving rise to an esophagial branch; then descending along lesser curvature to anastomose with right gastric artery	Distal (Mostly abdominal) part of esophagus and lesser curvature of stomach

Splenic		Runs retroperitoneally along superior border of pancreas; traverses splenorenal ligament to hilium of spleen	Body of pancreas, spleen, and greater curvature and posterior stomach body
Posterior gastric	Splenic artery posterior to stomach	Ascends retroperitoneally along posterior wall of lesser omental bursa to enter gastrophrenic ligament	Posterior wall and fundus of stomach
Left gastro-omental (left gastroepiploic)	Splenic artery in hilum spleen	Passes between layers of gastrosplenic ligament to stomach. The along greater curvature in greater omentum to anastomose with right gastro-omental artery	Left portion of greater curvature of stomach
Short gastric (n = 4–5)		Passes between layers of gastrosplenic ligament to fundus of stomach	Fundus of stomach
Hepatic	Celiac trunk	Passes retroperitoneally to reach hepatoduodenal ligament; passing between layers to porta hepatis; bifurcates into right and left hepatic arteries	Liver, gallbladder and biliary ducts, stomach, duodenum, pancreas, and respective lobes of liver
Cystic	Right hepatic artery	Arises within hepatoduodenal ligament (in cystohepatic triangle of Calot)	Gallbladder and cystic duct
Right gastric	Hepatic artery	Runs along lesser curvature of stomach to anastomose with left gastric artery	Right portion of lesser curvature of stomach
Gastroduodenal		Descends retroperitoneally, posterior to gastroduodenal junction	Stomach, pancreas, first part of duodenum, and distal part of bile duct
Right gastro-omental (right gastroepiploic)	Gastroduodenal artery	Passes between layers of greater omentum along greater curvature of stomach to anastomose with left gastro-mental artery	Right portion of greater curvature of stomach
Superior pancreaticoduodenal		Divides into anterior and posterior arteries that descend on each side of pancreatic head, anastomosing with similar branches of inferior pancreaticoduodenal artery	Proximal portion of duodenum and superior part of head of pancreas
Inferior pancreaticoduodenal	Superior mesenteric artery	Divides into anterior and posterior arteries that ascend on each side of pancreatic head, anastomosing with similar branches of superior pancreaticoduodenal artery	Distal portion of duodenum and head of pancreas
For descriptive purposes, the hepatic artery is often divided into the common hepatic artery, from its origin to the origin of the gastroduodenal artery, and hepatic artery proper, made up of the remainder of the vessel.			

ASSESSMENT QUESTIONS

1. **All are branches of splenic artery EXCEPT:** *(AIPG 2009)*
   a. Short gastric
   b. Hilar
   c. Arteria pancreatica magna
   d. Right gastro epiploic

2. **All are true about coeliac trunk EXCEPT:** *(NEET Pattern 2012)*
   a. Ventral branch of aorta
   b. Surrounded by a plexus of nerves
   c. Lies at lower border of pancreas
   d. Left gastric artery is a branch

3. **All are branches of inferior mesenteric artery EXCEPT:** *(NEET Pattern 2012)*
   a. Left colic
   b. Sigmoidal artery
   c. Middle rectal
   d. Superior rectal

4. **Which of the following arteries is a direct branch of the gastroduodenal artery:** *(JIPMER 2005; AIIMS 2009)*
   a. Right gastric artery
   b. Left gastric artery
   c. Inferior pancreaticoduodenal artery
   d. Right gastroepiploic artery

5. **The gastroduodenal artery is derived from:** *(AIIMS 2005)*
   a. Celiac artery
   b. Hepatic artery
   c. Splenic artery
   d. Cystic artery

6. **All of the following statements about the splenic artery are true except that it:** *(AIIMS Nov 15)*
   a Has a tortuous course
   b. Is a branch of the celiac trunk
   c. Has branches that anastomose freely within the spleen
   d. Supplies the greater curvature of stomach

7. **All of the following are branches of splenic artery, EXCEPT:** *(AI 09)*
   a. Short gastric artery
   b. Hilar branches
   c. Right gastroepiploic artery
   d. Arteria pancreatica magna

8. **Arteria pancreatic magna is a branch of which artery:** *(CET July 15 Pattern)*
   a. Left gastric
   b. Right gastric
   c. Common hepatic
   d. Splenic

9. **Which of the following is true about splenic artery:** *(SGPGI 05)*
   a. Smaller than left gastric artery
   b. Gives short gastric arteries along the fundus
   c. Curves around the fundus
   d. Arises form abdominal aorta

10. **Short gastric artery is a branch of:** *(All India Dec 13 Pattern)*
    a. Esophageal artery
    b. Splenic artery
    c. Hepatic artery
    d. None

11. **Posterior gastric artery is a branch of:** *(All India Dec 14 Pattern)*
    a. Left gastric artery
    b. Right gastric artery
    c. Splenic artery
    d. Hepatic artery

12. **Absence of which amongst the following is the most common variation:** *(AIIMS May 14)*
    a. Right colic artery
    b. Middle colic artery
    c. Left colic artery
    d. Superior rectal artery

ANSWERS WITH EXPLANATIONS

1. **d. Right gastroepiploic**
   - Right gastroepiploic artery is a branch of gastroduodenal artery.
   - Splenic artery gives the left gastroepiploic artery.
   - Short gastric arteries are the branches of splenic artery, which travel in the gastrosplenic ligament and supply the fundus of stomach.
   - Splenic artery runs posterior to the superior border of pancreas and supplies the organ by giving pancreatic branches) like arteria pancreatica magna.
   - It reaches the hilum of the kidney and gives the hilns branches, which enter the spleen as end arteries.
     - These branches do not anastomose any further in the spleen (end arteries).
     - Splenic artery is the largest branch of the coeliac artery and has a tortuous close due to its running course on the irregular surface of the pancreas. This tortuosity allows for the movements of spleen.

2. **c. Lies at lower border of pancreas**
   - Coeliac trunk lies at the superior border of pancreas.

3. **c. Middle rectal**
   - Middle rectal artery usually arises with the inferior vesical artery, a branch of the internal iliac artery.
   - It is distributed to the rectum, anastomosing with the inferior vesical artery, superior rectal artery, and inferior rectal artery.
   - In males, the middle rectal artery may give off branches to the prostate and the seminal vesicles, while in females it gives off branches to the vagina.

4. **d. Right gastroepiploic artery**
   - Right gastroepiploic (gastro-omental artery) artery is one of the two terminal branches of the gastroduodenal artery.
   - It runs from right to left along the greater curvature of the stomach, between the layers of the greater omentum, anastomosing with the left gastroepiploic artery, a branch of the splenic artery.

5. **b. Hepatic artery**
   - Gastroduodenal artery is derived from the common hepatic artery. Common hepatic artery is a branch of coeliac artery and divides into proper hepatic artery and gastroduodenal artery.
   - Coeliac artery is a branch of the abdominal artery, which also gives the splenic artery and left gastric artery.
   - Cystic artery is a branch to the gallbladder and is given by the right hepatic branch of proper hepatic artery.

6. **c. Has branches that anastomose freely within the spleen**
   - Splenic artery is the largest branch of celiac trunk, with a tortous course to allow for movement of spleen.It supply body and tail of pancreas via pancreatic branches;stomach via short gastric and left gastroepiploic branches and spleen via non anatomasing straight vessels called penicilli allipsoids and arterial capillaries.

7. **c. Right gastroepiploic artery**

8. **d. Splenic**

9. **b. Gives short gastric arteries along the fundus**
   - Splenic artery gives many short gastric arteries.
   - It is the largest branch of coeliac trunk.

10. **b. Splenic artery**

11. **c. Splenic artery**
    - Posterior gastric artery is an unusual branch of splenic artery arising from mid third of splenic artery.

12. **a. Right colic artery**
    - Right colic artery is a small vessel that is highly variable in its anatomy and may be absent.

High Yield Points

- Ovarian artery is a branch of abdominal aorta (and not iliac artery)
- Superior pancreaticoduodenal artery is a branch of gastroduodenal artery
- Gastroduodenal artery is derived from hepatic artery

- Hepatic veins drain directly into IVC (and not superior mesenteric vein , inferior mesenteric vein, splenic vein)
- **Posterior gastric artery** is a branch of **splenic artery**
- Right ovarian artery is a branch of abdominal aorta
- **Cystic artery** is usually a branch of *right hepatic artery*
- **Celiac trunk** is a *vertical* branch of aorta, surrounded by *celiac plexus* and gives *three* terminal branches**.**
- **Spiral valve** is seen in the *cystic duct*
- **Left colic artery** is a branch of *inferior mesenteric artery*
- **Appendicular artery** is a branch of *ileocolic artery*
- Blood supply to liver is 20% by hepatic artery and 80% by portal vein
- **Caudate process** of liver lies to the **right side of celiac trunk**
- **Most** common aberration in renal vessel development is **supernumerary arteries**
- **Approximately** 25 % of adult kidneys present with 2 - 4 renal arteries (more common on left side)
- Branches of splenic artery are **short gastric, hilar, arteria pancreatica magna**, but not right gastroepiploic artery

Portal vein

- The superior mesenteric vein joins splenic vein to form portal vein **behind the neck of the pancreas** at the level of the L1/2 intervertebral disc (at the **transpyloric plane**).
- It is approximately **8 cm long** in the adult and ascends obliquely to the right behind the **first part of the duodenum**, the common bile duct and gastroduodenal artery; at this point, it is directly anterior to the inferior vena cava.
- It enters the right border of the lesser omentum and ascends anterior to the epiploic foramen to reach the right end of the porta hepatis, where it divides into right and left main branches, which accompany the corresponding branches of the hepatic artery into the liver.
- In the lesser omentum, the portal vein lies posterior to both the common bile duct and the hepatic artery.
- The main extrahepatic tributaries of the portal vein are the left gastric (coronary) vein and the posterior superior pancreaticoduodenal vein. Within the liver, the left branch receives the obliterated umbilical vein via the ligamentum teres, which connects to its vertical portion.

Venous Drainage of Abdomen

B. Inferior Vena Cava (IVC)

- The IVC is formed by the union of the **right and left common iliac veins** at vertebral level L5.
- The IVC drains all the blood from below the diaphragm (even portal blood from the GI tract after it percolates through the liver) to the right atrium.
- The IVC is in jeopardy during surgical repair of a herniated intervertebral disc.
- The IVC above the kidneys (suprarenal) should never be ligated (there is a 100% mortality rate).
- The IVC below the kidneys (infrarenal) may be ligated (there is a 50% mortality rate).
- The **right gonadal vein** drains directly into the IVC, whereas the **left gonadal vein** drains into the left renal vein.
  - This is important in females where the appearance of a **right-side hydronephrosis** may indicate thrombosis of the right ovarian vein that constricts the ureter since the right ovarian vein crossed the ureter to drain into the IVC.
  - This is also important in males where the appearance of a **left-side testicular varicocele** may indicate occlusion of the **left testicular vein** and/or **left renal vein** due to a malignant tumor of the kidney.

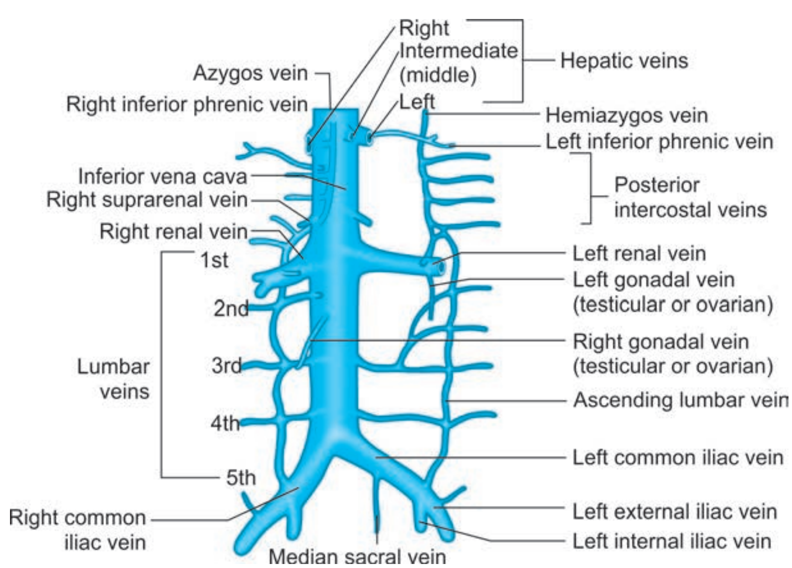


Fig. 32: Inferior vena cava (IVC). This figure shows The IVC and its tributaries. In addition, the azygos vein and the hemiazygos vein are shown. Note the differences in drainage of the right and left gonadal veins.

- **Routes of collateral venous return** exist in case the IVC is blocked by either a malignant retroperitoneal tumor or a large blood clot (thrombus). These include the following.
  - Azygos vein → SVC → right atrium
  - Lumbar veins → external and internal vertebral venous plexuses → cranial dural sinuses → internal jugular vein → right atrium

Hepatic Portal System

- In general, the term "portal" refers to a vein interposed between two capillary beds, i.e., capillary bed → vein → capillary bed.
- The hepatic portal system consists specifically of the following vascular structures: Capillaries of GI tract → portal vein → hepatic sinusoids.
- The **portal vein** is formed posterior to the neck of pancreas by the union of the **splenic vein** and **superior mesenteric vein**. The **inferior mesenteric vein** usually ends by joining the splenic vein.
- The blood within the portal vein carries high levels of nutrients from the GI tract and products of red blood cell destruction from the spleen.
- **Collateral circulation.** The hepatic portal system has a fairly robust collateral circulation. When blood flow through the liver is severely reduced (e.g., **portal hypertension** due to liver cirrhosis), portal blood will be diverted along three routes of collateral circulation.
  - The first route at the esophagus uses the left gastric vein (portal system) which anastomoses with the esophageal vein (IVC system) forming **esophageal varices**.
  - The second route at the umbilicus uses the paraumbilical vein (portal system) which anastomoses with the superficial and inferior epigastric veins (IVC system) forming a **caput medusae**.
  - The third route at the rectum uses the superior rectal vein (portal system) which anastomoses with middle and inferior rectal veins (IVC system) forming **anorectal varices**.
- **Clinical consideration: Portal hypertension.** Portal IVC (caval) anastomosis becomes clinically relevant when **portal hypertension** occurs. Portal hypertension will cause blood within the portal vein to reverse its flow and enter the IVC in order to return to the heart. There are three main sites of portal IVC anastomosis.
- **Esophagus, umbilicus,** and **rectum**. Clinical signs of portal hypertension include vomiting copious amounts of blood, enlarged abdomen due to ascites fluid, and splenomegaly. Portal hypertension may be caused by alcoholism, liver cirrhosis, and schistosomiasis. The photograph shows an elderly man with portal hypertension demonstrating caput medusae.

IVC

1. Two anterior visceral tributaries—the hepatic veins
2. Three lateral visceral tributaries
   - a. Right suprarenal vein (the left drains into the left renal vein)
   - b. Renal veins
   - c. Right testicular or ovarian vein (the left drains into the left renal vein)
3. Five lateral abdominal wall tributaries
   - a. Inferior phrenic vein
   - a. Four lumbar veins
4. Three tributaries of origin
   - a. Two common iliac veins
     - External iliac vein
     - Internal iliac vein
   - b. Median sacral vein

Fig. 33: Tributaries of inferior vena cava

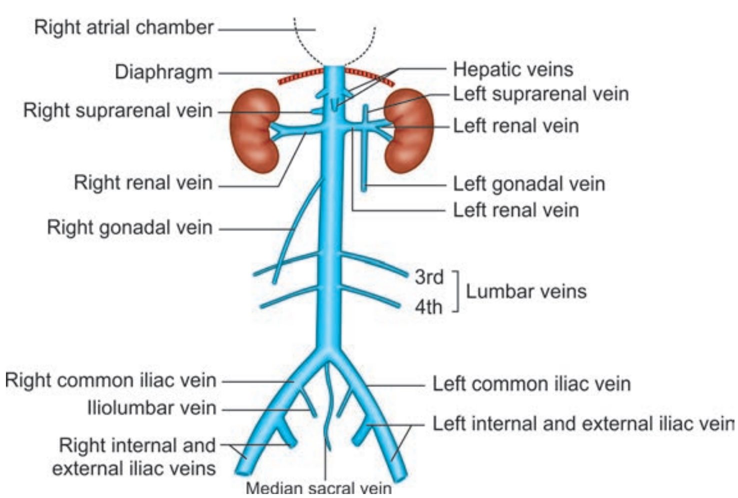


Fig. 34: Extent and tributaries of the inferior vena cava

Left inferior phrenic, suprarenal and gonadal veins do not drain into inferior vena cava[Q].

Relations of IVC (from below upwards)

Anterior	Posterior
Root of mesentery • Right gonadal vessels • Third part of duodenum **Head of pancreas with bile duct** • First part of duodenum and portal vein **(epiploic foramen)** • Liver	• Right psoas major muscle • Right renal artery • Right coeliac ganglion and sympathetic chain • Right suprarenal gland • Right middle suprarenal vein. • Right inferior phrenic artery

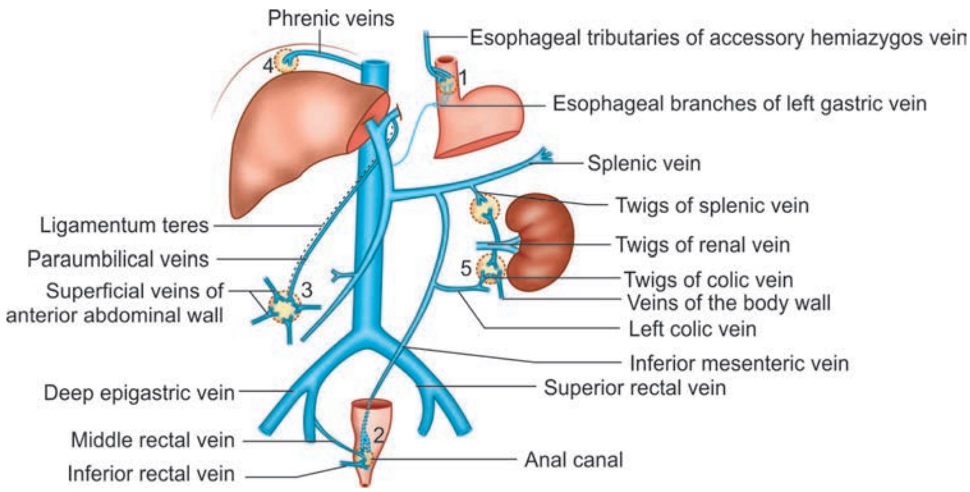


Fig. 35: Site of portocaval anastomosis: 1 = lower end of esophagus; 2 = anal canal; 3 = in the region of umbIlicus; 4 = at the bare area of liver; 5 = between the colic veins and the renal veins

Table 14: Anastomoses between the portal and systemic venous systems

Site of anastomosis	Veins forming portocaval anastomosis	Clinical signs
Lower third of the esophagus	Left gastric vein ↑↓ Esophageal veins draining into azygos vein	Esophageal varices
Umbilicus	Paraumbilical veins ↑↓ Superficial veins of anterior abdominal wall	Caput medusae
Mid-anal canal	Superficial rectal vein ↑↓ Middle and inferior rectal veins	Hemorrhoids

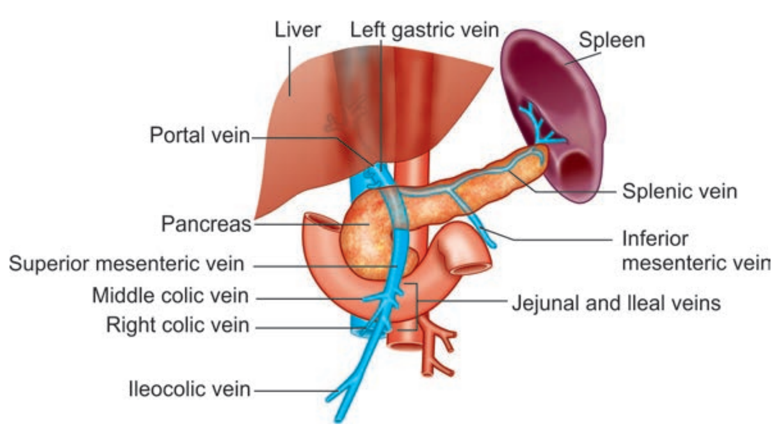


Fig. 36: Portal vein formation

ASSESSMENT QUESTIONS

1. TRUE about inferior vena cava: *(PGIC 2003)*
a. Passes through diaphragm at D10 vertebra
b. Right suprarenal vein drains directly into it
c. It lies anterior to renal artery
d. It forms the posterior boundary of epiploic foramen
e. It is related to psoas muscle

2. Tributaries of left renal vein are all EXCEPT: *(NBEP 2014)*
a. Left adrenal vein
b. Left lumbar vein
c. Left testicular vein
d. Diaphragmatic vein

3. Vein that doesn't cross the midline is: *(AI 2007)*
a. Left brachiocephalic vein
b. Hemiazygous vein
c. Left renal vein
d. Left gonadal vein

4. Portal vein is formed by the union of: *(NEET Pattern 2013)*
a. Splenic and inferior mesenteric veins
b. Splenic and superior mesenteric veins
c. Right and left hepatic veins
d. Hepatic and splenic veins

5. Which of the following vein(s) is/are part of portal circulation: *(PGIC 2015)*
a. Splenic vein
b. Paraumbilical vein
c. Superior rectal vein
d. Left gastric vein
e. Inferior rectal vein

6. Which of the following is false about portal vein?
a. Formed behind the neck of pancreas
b. Bile duct lies anterior and right to it
c. Gastroduodenal artery lies to the left and anterior to it
d. Ascends behind the 2nd part of duodenum

7. True about valves in portal venous system: *(AIIMS May 08)*
a. Present at the junction of superior mesenteric artery with the splenic artery
b. Within the portal vein only
c. The whole system is valveless
d. In the intrahepatic portion of portal vein

8. Portocaval anastomosis is seen between: *(AI 96)*
a. In the rectum: superior rectal vein and inferior rectal vein
b. At the umbilicus: portal vein and accessory hemiazygos vein
c. At the esophagus: Left gastric vein and paraumbilical vein
d. At the liver: portal vein and renal azygos vein

9. Porto systemic shunt is not seen in: *(AI 07)*
a. Liver
b. Spleen
c. Anorectum
d. Gastro esophageal

10. In portal hypertension lower end of the esophagus may show dilatation of veins. Which of the following veins drains into the portal vein from the lower end of the esophagus: *(Karn 11)*
a. Right gastric
b. Left gastric
c. Hemiazygos
d. Inferior phrenic

ANSWERS WITH EXPLANATIONS

1. b. Right suprarenal vein drains directly into it; c. It lies anterior to renal artery; d. It forms the posterior boundary of epiploic foramen; e. It is related to psoas muscle
- **Explanation:** Inferior vena cava passes through the central tendon of diaphragm at D8 (and not D10) vertebra level. (Table)

2. b. Left lumbar vein
- **Explanation:** Left inferior phrenic (**diaphragmatic)** vein, **left adrenal** vein and **left gonadal** vein are tributaries of left renal vein and not the **left lumbar** vein.
- On the right side the corresponding veins drain directly into IVC (and not into the right renal vein).

3. d. Left gonadal vein
- **Explanation: Left gonadal vein** drains into left renal vein and remains on the left side of midline (doesn't cross it).
- Veins crossing the midline are:
  - **Left brachiocephalic vein** crosses the midline to join right counterpart and form SVC**.**
  - **Hemiazygous vein** crosses the midline at T8 vertebra level to drain into azygous vein.
  - **Left renal vein** crosses the midline to enter the IVC.

Note: Left suprarenal, and left inferior phrenic vein enter the left renal vein (do not cross the midline).

4. b. Splenic and superior mesenteric veins
- Portal vein is formed by the union of splenic and superior mesenteric veins, posterior to the neck of pancreas, at transpyloric plane.
- **Portal vein** formation occurs *behind the neck of the pancreas***.** (**NBE 2012**)
- **Portal vein** is formed by the union of *splenic vein* and *superior mesenteric* vein**.** (**NBE 2012**)
- Structure immediately posterior to pancreatic head is **right renal vein.** (**NBE 2012**)

5. a. Splenic vein; b. Paraumbilical vein; c. Superior rectal vein; d. Left gastric vein
- The final common pathway for transport of venous blood from spleen, pancreas, gallbladder and the abdominal portion of the gastrointestinal tract (with the exception of the inferior part of the anal canal and sigmoid) is through the hepatic portal vein.
- Inferior rectal vein belongs to systemic circulation as it drains eventually into the inferior vena cava.

6. d. Ascends behind the 2nd part of duodenum
- Portal vein ascends behind first part of duodenum
- Other options are correct.

7. c. The whole system is valveless
- Although demonstrable during fetal and early neonatal period, there are no valves in portal vein and its tributaries in postnatal period.

8. a. In the rectum : Superior rectal vein and inferior rectal vein

9. b. Spleen
- Portocaval anastomosis (protosystemic shunt) is seen at lower end of esophagus (gstroensophegeal),umblicus, bare area of liver, lower end of rectum (anorectal) ,posterior abdominal wall ,faciform ligament,ligamentum venosum and posterior vaginal wall.

10. b. Left gastric
- At lower end of esophagus,porto-caval anastomosis in between:
  (i) Tributary of portal vein -------------> Left gastric
  (ii) Systemic vein -----------> esophageal veins

Lymphatics

- Aortic lymph nodes are present on the posterior abdominal wall and divided into – pre, lateral and retro aortic.
- Preaortic lymph nodes lie anterior to abdominal aorta and is divided into – coeliac, superior mesenteric and inferior mesenteric.
- They receive afferents from the intermediate nodes. And their efferents are the intestinal trunks which enter the cisterna chyli.
- Lateral aortic lymph nodes lie on each side of abdominal aorta and receive afferents mainly from the common iliac lymph nodes.
- The efferents form the lumbar trunks, which enter the cisterna chyli.
- Few efferents pass to pre-aortic/retroaortic lymph nodes.
- Retroaortic lymph nodes are considered as an extension of lateral aortic lymph nodes only.
- Lymph flow from the pelvic region: Sacral/External/Internal iliac → Common iliac → Lateral aortic → Lumbar trunks → Cisterna chyli. Lateral sacral lymph nodes drain into the common iliac group. Para-colic lymph nodes (midgut &hindgut) drain into the superior/inferior mesenteric lymph nodes—preaortic lymph nodes. The efferents are the intestinal trunks towards the cisterna chyli.

Thoracic duct - Refer

Inguinal Region and External Genitalia

Inguinal Region. The inguinal region is an area of weakness of the anterior abdominal wall due to the penetration of the testes and spermatic cord (in males) or the round ligament of the uterus (in females) during embryologic development. **Deep inguinal ring** is an opening in the transversalis fascia, which continues into the inguinal canal as the internal fascia of the structures passing through the inguinal canal. **Superficial inguinal ring** is a defect in the aponeurosis of the **external oblique muscle** located lateral to the pubic tubercle. **Inguinal canal** is an obliquely oriented passageway that begins at the deep inguinal ring (i.e. the entrance) and ends at the superficial inguinal ring (i.e. the exit). The inguinal canal transmits the **spermatic cord** (in males) or **round ligament of the uterus** (in females). The inguinal canal also transmits blood vessels, lymphatic vessels, and the genital branch of the genitofemoral nerve in both sexes.

Deep Inguinal Ring

- It is an oval opening in the transversalis fascia, approximately midway between the anterior superior iliac spine and the pubic symphysis, and about 1 cm above the inguinal ligament.
- It is related above to the arched lower margin of transversus abdominis and medially to the interfoveolar ligament.
- The inferior epigastric vessels are important medial relations of the deep inguinal ring. They lie on the transversalis fascia as they ascend obliquely behind the conjoint tendon to enter the rectus sheath.

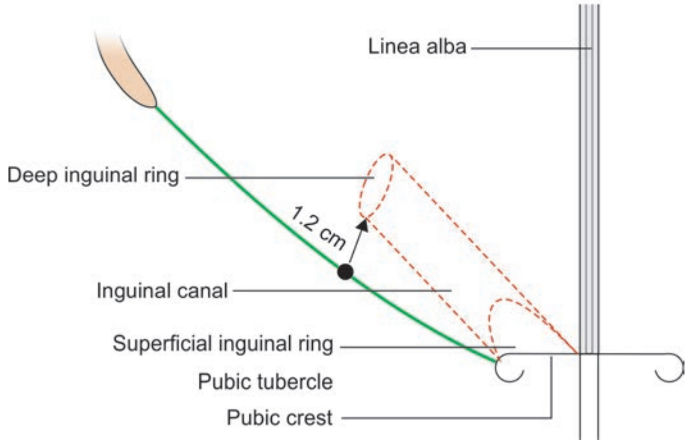


Fig. 37: Surface marking of the inguinal canal

The length of inguinal canal is 4 cm (NBEP 2013)

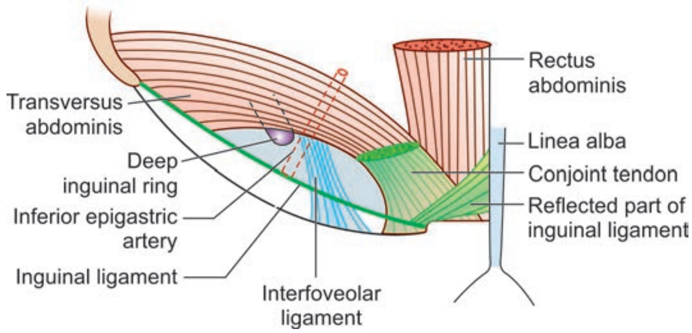


Fig. 38: Interfoveolar ligament

Inguinal Ligament (Poupart Ligament)

- Is the coiled lower border of the aponeurosis of the external oblique muscle, extending between the anterior superior iliac spine and the pubic tubercle.
- Forms the floor (inferior wall) of the inguinal canal.

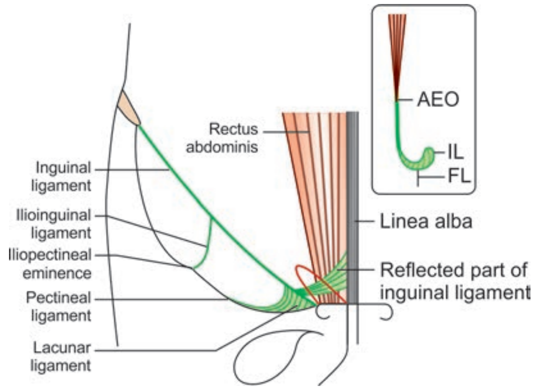


Fig. 39: Inguinal ligament and its extensions. Figure in the inset shows formation of inguinal ligament and its attachment to the fascia lata (AEO = aponeurosis of external bolique, IL = inguinal ligament, FL = fascia lata)

- Modifications of external oblique muscle:
  - Inguinal ligament, Lacunar ligament, Pectineal (Cooper's) ligament, External spermatic fascia.

Reflected Inguinal Ligament

- Is formed by fibers derived from the medial portion of the inguinal ligament and lacunar ligament and runs upward over the conjoint tendon to end at the linea alba.

Falx Inguinalis (Conjoint Tendon)

- Is formed by the aponeuroses of the internal oblique and transverse muscles of the abdomen and is inserted into the pubic tubercle and crest.
- It descends behind the superficial inguinal ring and strengthens the posterior wall of the medial half of the inguinal canal.

Lacunar Ligament (Gimbernat Ligament)

- Represents the medial triangular expansion of the inguinal ligament to the pectineal line of the pubis.
- Forms the medial border of the femoral ring and the floor of the inguinal canal.

Pectineal (Cooper) Ligament

- Is a strong fibrous band that extends laterally from the lacunar ligament along the pectineal line of the pubis.

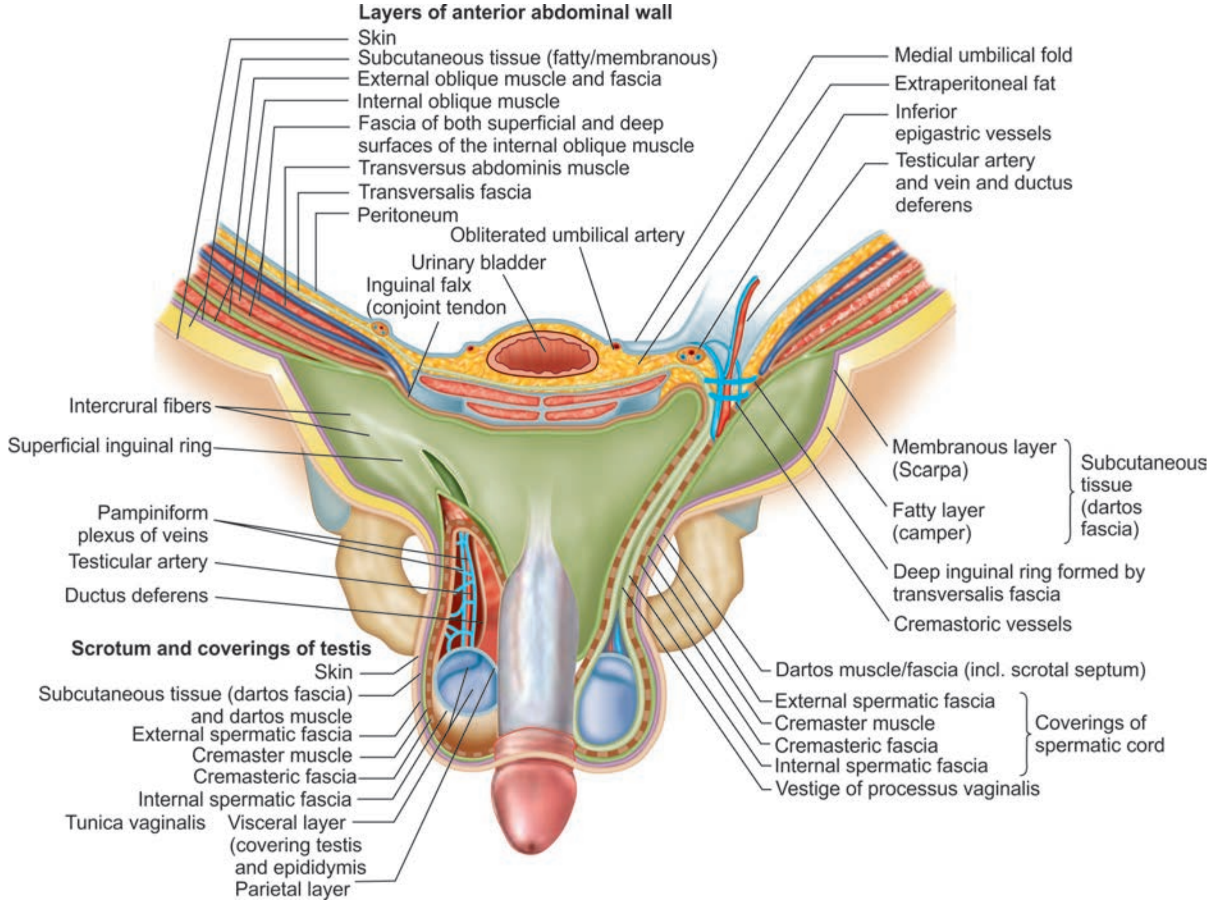


Fig. 40: Corresponding layers of anterior abdominal wall, scrotum, and spermatic cord

The Scrotum

A. General Features. The scrotum is an outpouching of the lower abdominal wall, whereby layers of the abdominal wall continue into the scrotal area to cover the spermatic cord and testes.

Table 15: Comparison between the layers of the anterior abdominal wall and the scrotum

Layer of anterior abdominal wall	Layer of scrotum
Skin	Skin
Superficial fascia	Dartos muscle
External oblique muscles	External spermatic fascia
Internal oblique muscle	Cremasteric muscle and fascia
Transversus abdominis muscle	No corresponding layer (Note: The transversus abdominis muscle does not continue into the scrotum)
Fascia transversalis	Internal spermatic fascia

Inguinal canal is an oblique passage in the lower part of the anterior abdominal wall, situated just above the medial half of the inguinal ligament. It is about 3.75 cm (1.5 inches) long, and is directed downwards, forwards and medially extending from the deep inguinal ring to the superficial inguinal ring. The deep inguinal ring is an oval opening in the fascia transversalis, situated 1.2 cm above the mid-inguinal point, and immediately lateral to the stem of the inferior epigastric artery. The superficial inguinal ring is a triangular gap in the external oblique aponeurosis. It is shaped like an obtuse angled triangle.

Anterior wall (in its whole extent) is formed by (table) skin; superficial fascia; and external oblique aponeurosis. In its lateral one- third the fleshy fibers of the internal oblique muscle are also present. The posterior wall (in its whole extent) is formed by the fascia transversalis, extraperitoneal tissue, and parietal peritoneum. Additionally in its medial two-thirds is present the conjoint tendon; at its medial end the reflected part of the inguinal ligament, and over its lateral one-third the interfoveolar ligament. The roof is formed by the arched fibres of the internal oblique and transversus abdominis muscles and at the floor is the grooved upper surface or the inguinal ligament; and at the medial end by the lacunar ligament.

Table 16: Features of the inguinal canal

Features		Formed by
Boundaries	• Anterior wall • Posterior wall • Roof • Floor	External oblique aponeurosis (supplemented by internal oblique) Fascia transversalis (supplemented by conjoint tendon in the medial 2/3rd) Internal oblique and transversus abdominis muscles (arched fibers) Inguinal ligament (supplemented by lacunar ligament medially)
Openings	• Superficial inguinal ring • Deep inguinal ring	Triangular aperture in external oblique aponeurosis above and lateral to the pubic crest Oval aperture in fascia transversalis 1.25 cm above the midinguinal point

Contents of inguinal canal :

- Spermatic cord in male or round ligament of uterus in female.
- Ilioinguinal nerve: It enters through the interval between external and internal oblique muscles.
- Genital branch of genitofemoral nerve is a constituent of spermatic cord.

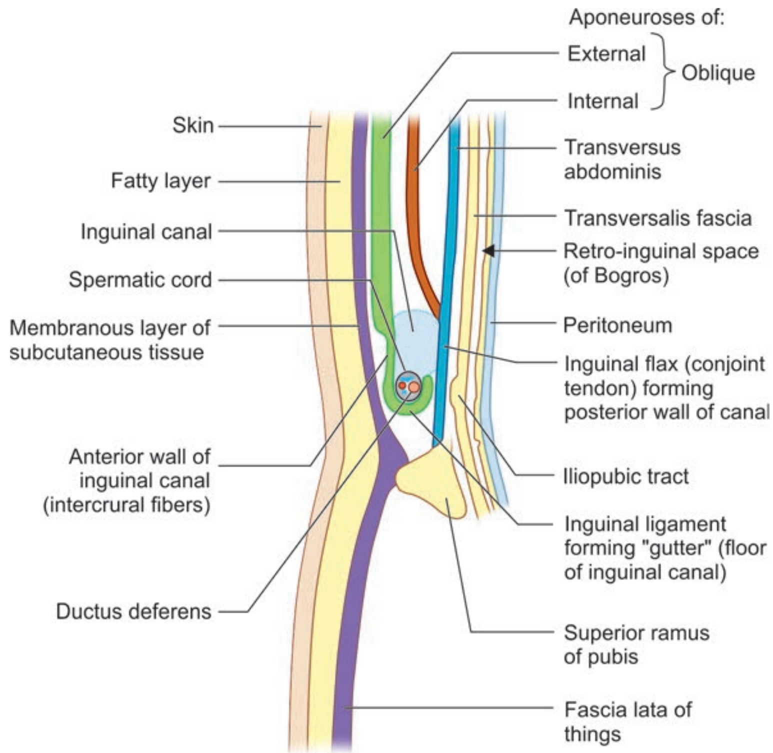
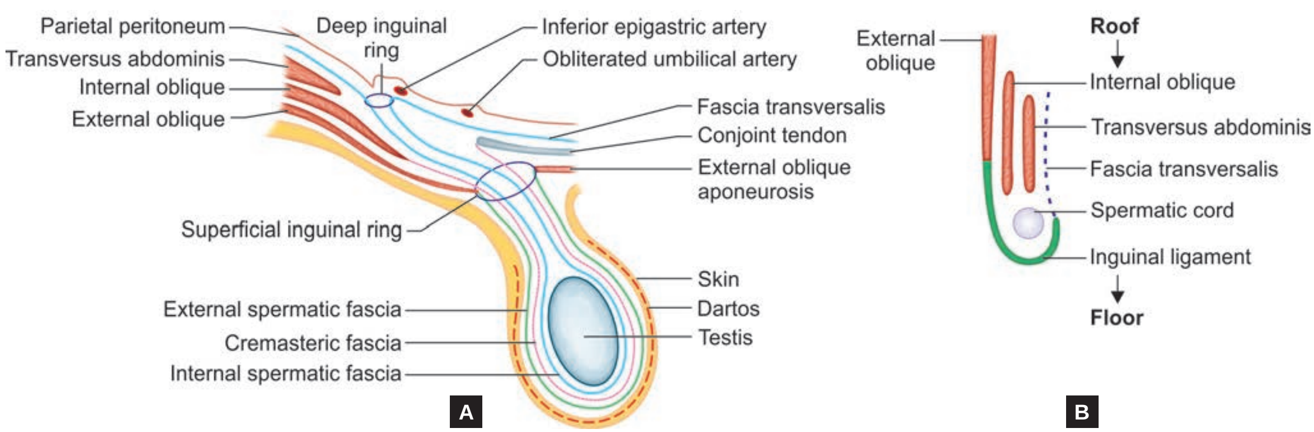


Fig. 41: Schematic sagittal section of inguinal canal



Figs. 42A and B: Boundaries of the inguinal canal: A. Anterior and posterior walls as seen in coronal section; B. roof and floor as seen in sagittal section.

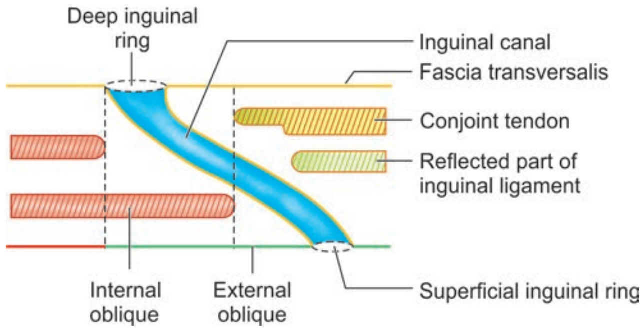
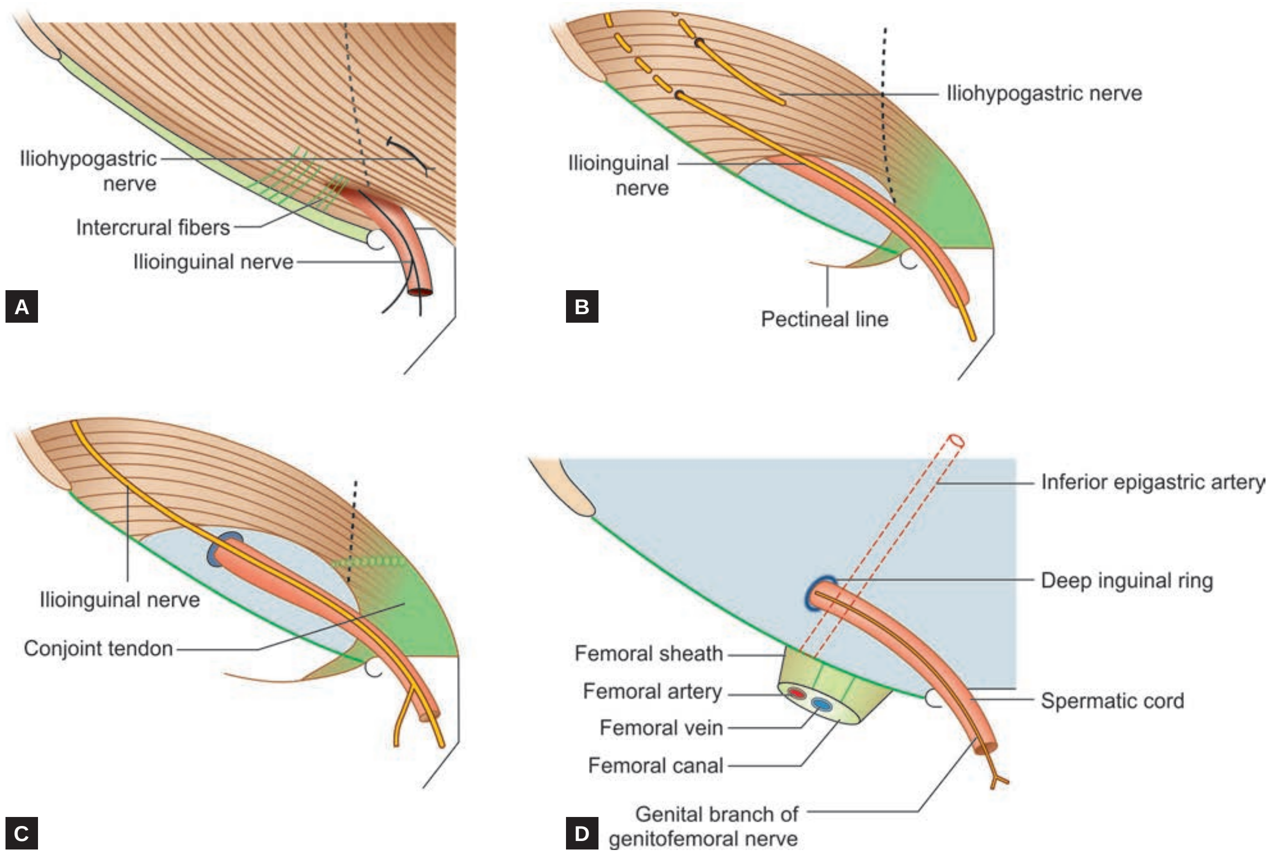


Fig. 43: Structures protecting the anterior and posterior walls of the inguinal canal



Figs. 44A to D: Schematic diagrams to show the formation of the walls of inguinal canal from outside inwards: A. external oblique; B. Internal oblique; C. transversus abdominis; D. fascia transversalis. The formation of anterior and posterior walls and location of inguinal rings can easily be deduced from these figures.

ASSESSMENT QUESTIONS

1. **TRUE about inguinal canal:** *(PGIC 2003)*
   a. It is an intermuscular canal
   b. In male vas deferens passes through it
   c. Superficial inguinal ring is situated superior and lateral to pubic tubercle
   d. Deep inguinal ring is supero-medial to attachment of rectus abdominis
   e. Transmits blood vessels and nerves through it

2. **All of the following are true about inguinal canal EXCEPT:** *(UP 2000 AI 2001)*
   a. Conjoint tendon forms part of the posterior wall
   b. Superficial ring is present in external oblique aponeurosis
   c. Deep ring is an opening in transversalis abdominis
   d. Internal oblique forms both roof and anterior wall

3. **TRUE about deep inguinal ring is:** *(UP 2000; AIIMS 2005)*
   a. A defect in fascia transversalis
   b. Lies an inch above the mid-inguinal point
   c. Present medial to inferior epigastric artery
   d. Commonest site of direct hernia

4. **Structures passing through the inguinal canal are all EXCEPT:** *(AIPG 2012; NBEP 2014)*
   a. Genital branch of genitofemoral nerve
   b. Ilio-inguinal nerve
   c. Inferior epigastric artery
   d. Lymphatics from uterus

5. **Which of the following are associated with external oblique muscles:** *(PGIC 2014)*
   a. Poupart's ligament
   b. Lacunar ligament
   c. Superficial inguinal ring
   d. Conjoint tendon
   e. Cremaster muscle

6. **Internal spermatic fascia is derived from:**
   a. External oblique muscle(NEET Pattern 2013)
   b. Internal oblique muscle
   c. Fascia transversalis
   d. Colle's fascia

7. **Accessory obturator artery is a branch of:**
   a. Inferior epigastric(NEET Pattern 2016)
   b. External iliac
   c. Internal iliac
   d. Obturator

8. **Deep inguinal ring is a deficiency in the:** *(AIIMS 2005)*
   a. Internal oblique muscle
   b. Transversus abdominis muscle
   c. Internal spermatic fascia
   d. Transversalis fascia

9. **Roof of inguinal canal is /are formed by:** *(PGIC 2013)*
   a. Internal oblique muscle
   b. Fascia transversalis
   c. Transversus abdominis muscles
   d. External oblique muscle
   e. Conjoint tendon

10. **All of the following are true about inguinal canal EXCEPT:***(A I 01, UP 2K)*
    a. Conjoint tendon forms part of the posterior wall.
    b. Superficial ring is formed in external oblique aponeurosis
    c. Deep ring is an opening in transverse abdominis
    d. Internal oblique forms both roof and anterior wall

11. **The inguinal canal is NOT bounded posteriorly by:** *(AI 95)*
    a. Transversalis fascia
    b. Internal oblique tendon
    c. Conjoint tendon
    d. Lacunar ligament

12. **True about deep inguinal ring is:** *(UP 2K, AIIMS Nov 05)*
    a. Defect in fascia transversalis
    b. Commonest site of direct hernia
    c. Present medial to inferior epigastric artery
    d. Lies and inch above the mid-inguinal point

13. **Which structure(s) passes behind the inguinal ligament:**
    a. Femoral branch of genitofemoral nerve (PGI Nov 15)
    b. Superficial epigastric artery
    c. Psoas major
    d. Femoral vein
    e. Saphenous vein

14. **Inguinal ligament forms the boundries of:**
    a. Femoral triangle(NEET Dec. 12 Pattern)
    b. Hesselbach's triangle
    c. Both
    d. None

15. **A common structure in the Hesselbach's triangle and femoral triangle is:** *(UP 02)*
    a. Conjoint tendon
    b. Inguinal ligament
    c. Inferior epigastric artery
    d. Rectus femoris

16. **Inferior epigastric artery forms the boundary of:**
    a. Femoral triangle(All India Dec 13 Pattern)
    b. Hesselbach's triangle
    c. Adductor canal
    d. Popliteal triangle

17. **True statement about lower 1/4th anterior abdominal wall:** *(PGI June 06, Dec 07)*
    a. Linea Alba is poorly formed
    b. Two layers of rectus sheath present
    c. External oblique poorly formed
    d. External oblique muscle well formed and strong
    e. Rectus abdominis is divided

18. **True about the anatomy of inguinal hernia which is/are true:** *(PGI June 05)*
    a. Superior inguinal ring is an opening in external oblique aponeurosis
    b. Indirect hernia lies just medial to inferior epigastric artery
    c. Posterior wall is formed by transversalis fascia and conjoined tendon
    d. Cremasteric artery is a branch of external iliac artery
    e. Indirect hernia lies anteromedial to spermatic cord

19. **Which of following are associated with external oblique muscle**: *(PGI May 14)*
    a. Poupart's ligament
    b. Lacunar ligament
    c. Superficial inguinal ring
    d. Conjoint tendon
    e. Cremaster muscle

ANSWERS WITH EXPLANATIONS

1. **a. It is an intermuscular canal; b) In male vas deferens passes through it; c) Superficial inguinal ring is situated superior and lateral to pubic tubercle; e) Transmits blood vessels and nerves through it**
   - Inguinal canal is an **intermuscular canal** surrounded by anterior abdominal wall muscles.
   - It transmits the **vas deferens** (inside **spermatic cord),** in males and round ligament of the uterus, in females.
   - **Superficial inguinal ring** is an aponeurotic opening in the external oblique muscle, lying supero-lateral to pubic tubercle.
   - **Deep inguinal ring** is a deficiency in the fascia transversalis.
   - Inguinal canal **transmits blood vessels**, lymphatic vessels, and the genital branch of the genitofemoral **nerve** in both sexes.

2. **c. Deep ring is an opening in transversalis abdominis**
   - Deep inguinal ring is an opening in the transversalis fascia (and not the muscle).
   - **Internal oblique muscle** and transversalis muscles arch over inguinal canal as **roof** and reach **posterior wall**, where together they form **conjoint tendon**.

3. a. A defect in fascia transversalis
- Deep inguinal ring is present 1/2 inch (1.25cm) above the mid-inguinal point.
- The ring is present lateral (**not medial**) to Inferior epigastric artery (and vein).
- Indirect (**not direct) inguinal hernia** comes through the deep inguinal ring.

4. c. Inferior epigastric artery
- **Inferior epigastric artery** is a branch given by external iliac artery, which ascends supero-medially, becomes medial relation of deep inguinal ring, and subsequently enters rectus sheath.
- It is not a content of inguinal canal.
- **Lymphatics from uterus** follow the round ligament of uterus through the inguinal canal.

5. a. Poupart's ligament; b) Lacunar ligament; c) Superficial inguinal ring.
- **Poupart's** (Inguinal) ligament is the lower in-turned modification of external oblique muscle, It further sends **lacunar** ligament posteriorly to attach to pectineal line.
- **Conjoint tendon** is formed by the converging fibres of internal oblique and transversus abdominis muscle on the posterior wall of inguinal canal.
- **Cremaster** muscle is an extension of internal oblique muscle into the scrotum.

6. c. Fascia transversalis
- Internal spermatic fascia (infundibuliform fascia) is a downward continuation of the transverse fascia, which invests the spermatic cord and scrotum.

7. a. Inferior epigastric
- The pubic branch of inferior epigastric artery contributes to accessory obturator artery
- Usually internal iliac (anterior division) gives the obturator artery.
- Inferior epigastric artery is a branch of external iliac artery. It gives a pubic branch, which sometimes takes place of obturator artery (replaced obturator artery)
- In other cases the pubic branch of inferior epigastric artery joins the obturator artery, and is then called as the **accessory obturator artery**.
- Accessory obturator artery sometimes lies over the lacunar ligament (medial boundary of femoral ring). The surgeon should be careful while performing endoscopic repair of femoral hernia, where he needs to cut the lacunar ligament to reduce the hernia.

8. d. Transversalis fascia
- Deep inguinal ring is an opening in the transversalis fascia through which the abdominal contents like genitofemoral nerve, testicular artery etc. can enter the inguinal canal.
- Internal oblique muscle contributes to the anterior wall of inguinal canal in its lateral 1/3. The muscle then arches over the canal to form its roof and goes deep to form the posterior wall of the inguinal canal (conjoint tendon) in its medial 2/3.
- Transversus abdominis muscle arches over the roof of the inguinal canal and then forms the posterior wall (conjoint tendon) in its medial 2/3.
- Internal spermatic fascia is derived from the fascia transversalis and forms the coverings of spermatic cord and scrotum.
- External oblique muscle forms the anterior wall of inguinal canal in its entire extent and shows a triangular aperture called as the external inguinal ring for the exit of spermatic cord from the inguinal canal.

9. a. Internal oblique muscle and C. Transversus abdominis muscles
- The roof is formed by the arched fibres of the internal oblique and transversus abdominis muscles.

High Yield Points

- Femoral vein lies lateral to femoral ring. *(JIPMER'2016).*
- In femoral hernia, the intestine may enter the femoral ring, and the femoral canal to reach thigh region, and lie inferolateral to pubic tubercle.
- The most medial content of femoral triangle is the inguinal lymphatics. The arrangement of structures (medial to lateral) are: Inguinal lymphatics — Femoral vein, femoral artery, femoral nerve.
- Femoral nerve lies outside the femoral sheath.
- Inferior epigastric artery enters the rectus sheath, and is a landmark to differentiate between direct and indirect inguinal hernia.
- Indirect inguinal hernia: In young adults, intestine may pass through the deep inguinal ring (lateral to inferior epigastric artery), enter the inguinal canal and reach the scrotum.
- Direct inguinal hernia: In elderly patients, intestine may pass medial to inferior epigastric artery and enter the scrotum.

Note: Inguinal hernia (direct or indirect) lies supero-medial to pubic tubercle, and enters the scrotum. Whereas, femoral hernia lies inferolateral to pubic tubercle and enters the thigh region.
- **Superficial inguinal ring** is a defect in the *external oblique* muscle.
- **Superficial inguinal ring** is a hiatus in the aponeurosis of external oblique, just above and lateral to the crest of the pubis.
- **Conjoint tendon** is formed by *internal oblique* muscle and *transversus abdominis*
- Deep inguinal ring is a deficiency in transversalis fascia.
- Lacunar ligament forms the floor of inguinal canal (and not the posterior wall).

Triangles

Iliopubic tract

It is the thickened inferior margin of the fascia transversalis which appears as a fibrous band running parallel and deep (posterior) to the inguinal ligament. When the inguinal region is viewed from its posterior aspect, the iliopubic tract is seen running posterior to inguinal ligament.

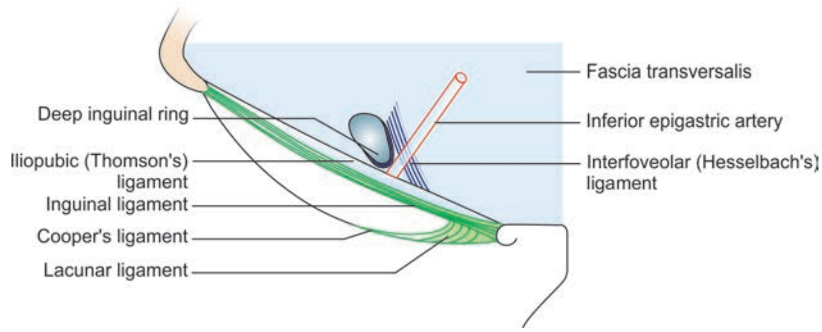


Fig. 45: Iliopubic tract

Iliopectineal arcus or ligament in the pelvi-femoral space

- Is a fascial partition that separates the muscular (lateral) and vascular (medial) lacunae deep to the inguinal ligament.
  - The muscular lacuna transmits the iliopsoas muscle.
  - The vascular lacuna transmits the femoral sheath and its contents, including the femoral vessels, a femoral branch of the genitofemoral nerve, and the femoral canal.

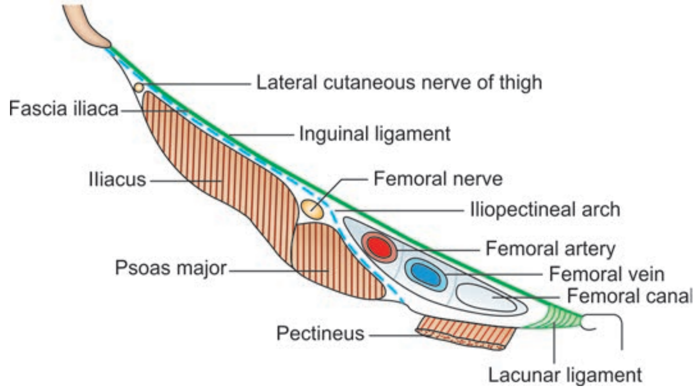


Fig. 46: Subinguinal space and structures passing through it

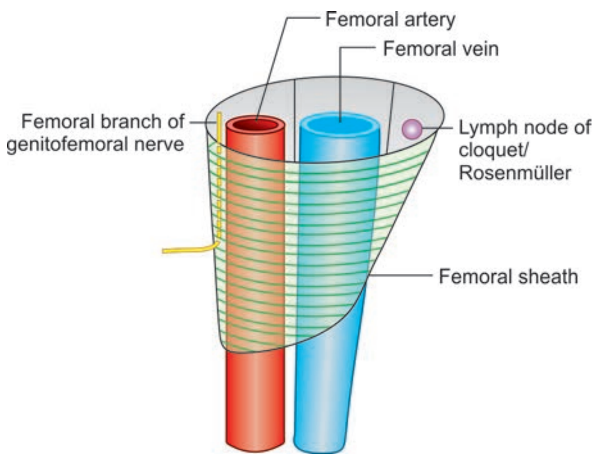


Fig. 47: Walls and contents of the femoral sheath (anterior view)

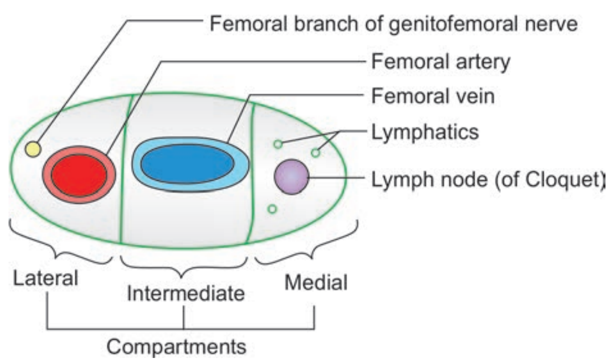


Fig. 48: Compartment of the femoral sheath

- Triangle of doom and pain

Triangle of Doom is bounded by

Vas deferens medially

Testicular vessels laterally

- External iliac vessels covered by **peritoneal fold** posteriorly/inferiorly (base)
- The apex is directed towards the deep inguinal ring.
- Contents: External iliac vessels
- Applied anatomy: During laparoscopic repair of inguinal hernia, application of staples is avoided in this triangle so as to prevent injury to the contents–external iliac vessels.

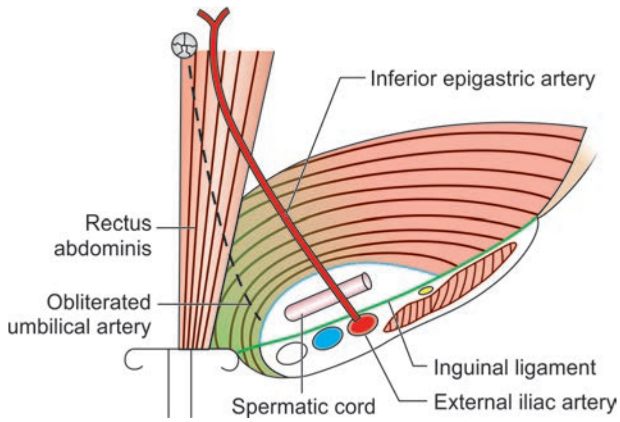


Fig. 49: Boundaries of the inguinal (Hesselbach's) triangle

Inguinal triangle (of Hesselbach)

- It is bounded inferiorly by the medial third of the inguinal ligament, medially by the lower lateral border of rectus abdominis, and laterally by the inferior epigastric vessels.
- It is related to the posterior wall of inguinal canal.

Inguinal Triangle (Hesselbach's Triangle)

The inguinal triangle is situated deep to the posterior wall of the inguinal canal; hence, it is seen on the inner aspect of the lower part of the anterior abdominal wall.

Boundaries

- The boundaries of the inguinal triangle are as follows:
- Medial: Lower 5 cm of the lateral border of the rectus abdominis muscle.
- Lateral: Inferior epigastric artery.
- Inferior: Medial half of the inguinal ligament.
- The floor of the triangle is covered by the peritoneum, Extra-peritoneal tissue, and fascia transversalis.

Note: The medial umbilical ligament (obliterated umbilical artery) crosses the triangle and divides it into medial and lateral parts. The medial part of the floor of the triangle is strengthened by the conjoint tendon.

- The lateral part of the floor of the triangle is weak, hence direct inguinal hernia usually occurs through this part.

Triangle of Pain: A triangular area in the inguinal region, encountered during surgery for inguinal hernias, bounded inferomedially by **gonadal vessels** and superolaterally by the **iliopubic tract**; the lateral femoral cutaneous nerve and the femoral branch of the genitofemoral nerve pass through this area and could be entrapped by staples during surgical procedures.

- During laparoscopic inguinal hernia repair, if a tacker is placed below and lateral to the iliopubic tract, the nerve involved is—lateral cutaneous nerve of thigh. It gives features like Meralgia paraesthetica.

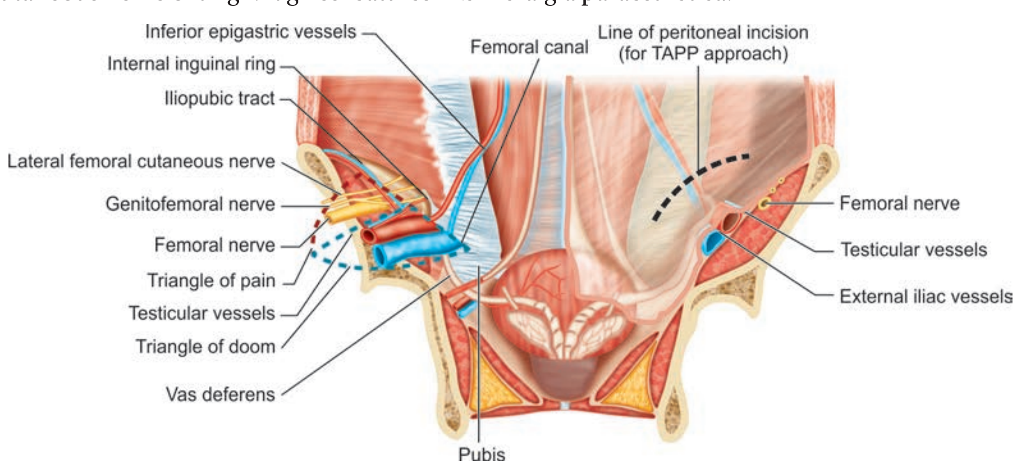


Fig. 50: Antevior abdominal wall (interior view)

ASSESSMENT QUESTIONS

1. Triangle of Doom bounded by all EXCEPT: *(AIIMS 2008)*
a. Vas deferens
b. Testicular vessels
c. Cooper ligament
d. Reflected peritoneal fold

2. Which structure(s) passes behind the inguinal ligament:
a. Femoral branch of genitofemoral nerve (PGIC 2010)
b. Saphenous vein
c. Superficial epigastric artery
d. Psoas major
e. Femoral vein

3. Inferior epigastric artery forms the boundary of:
a. Femoral triangle(NEET Pattern 2013)
b. Hesselbach's triangle
c. Adductor canal
d. Popliteal triangle

4. Which of the following statements is TRUE about conjoint tendon: *(NEET Pattern 2014)*
a. Formed by internal oblique and transversus abdominis
b. Forms the posterior wall of inguinal canal
c. It is pushed anteriorly by direct inguinal hernia
d. All of the above

5. Inguinal ligament forms the boundaries of:
a. Femoral triangle(NEET Pattern 2012)
b. Hesselbach's triangle
c. Both
d. None

6. All are boundaries of inguinal triangle EXCEPT:
a. Inguinal ligament
b. Medial border of pyramidalis
c. Inferior epigastric vein
d. Lateral border of rectus abdominis

ANSWERS WITH EXPLANATIONS

1. c. Cooper's ligament
- Cooper's ligament lies more superior to the triangle of doom (not in the boundary).
- Triangle is bounded by: Vas deferens medially, Testicular vessels laterally and external iliac vessels covered by peritoneal fold posteriorly/inferiorly.
- The apex is directed towards the deep inguinal ring.

2. a. Femoral branch of genitofemoral nerve; d. Psoas major; e. Femoral vein
- The muscles (psoas major and iliacus) and neurovascular structures of posterior abdominal wall/pelvis pass into the femoral region of the thigh through this space.
- This space is called as pelvi-femoral space, ilio-pectineal arcus lies here.
- **Saphenous vein** joins femoral vein below inguinal ligament.
- **Superficial epigastric artery** passes anterior to inguinal ligament.

3. a. Right upper part of body
- Hesselbach's triangle is bounded inferiorly by the medial third of the inguinal ligament, medially by the lower lateral border of rectus abdominis, and laterally by the inferior epigastric vessels.

4 d. All of the above
- Conjoint tendon is present in the posterior wall of inguinal canal (medial 2/3).
- It is formed by the merging fibres of internal oblique and transversus abdominis muscles.
- It becomes one of the covering of the medial direct hernia, coming through the medial part of the Hesselbach's triangle

5. c. Both
- Inguinal ligament is at the base of the femoral triangle and inferior boundary of Hesselbach's triangle.

6. b. Medial border of pyramidalis
- Hesselbach's inguinal triangle is present on the anteroinferior abdominal wall bounded by the rectus abdominis muscle, the inguinal ligament, and the inferior epigastric vessels.
- Medial border: lateral margin of the rectus sheath (linea semilunaris); superolateral border: inferior epigastric vessels; inferior border: inguinal ligament (Poupart's ligament).
- It is the site in which a direct inguinal hernia begins.

High Yield Point
- A common structure in the boundaries of both femoral triangle and Hesselbach's triangle is Inguinal ligament.

Inguinal Hernia

Inguinal Hernia
- Although the inguinal canal is arranged such that the weaknesses in the anterior abdominal wall caused by the deep and superficial inguinal rings are supported, the region is a common site of herniation, particularly in males.
- An inguinal hernia involves the protrusion of a viscus through the tissues of the inguinal region of the abdominal wall.

Indirect Inguinal Hernia
- An indirect inguinal hernia arises through the deep inguinal ring lateral to the inferior epigastric vessels.
- Many indirect hernias are related to the abnormal persistence of a patent processus vaginalis, a tube-like extension of peritoneum through the inguinal canal that is present during normal development and normally becomes occluded after birth (p. 1215).

- Others are acquired as a result of progressive weakening of the posterior wall of the inguinal canal in the region of the deep inguinal ring.
- The hernia may pass through the deep ring or may expand the deep ring such that it is no longer a clear entity.
- Small indirect hernias lie below and lateral to the fibres of the conjoint tendon, but larger hernias often distort and thin the tendon superiorly.
- Small indirect hernias that do not protrude beyond the inguinal canal are covered by the same inner layers as the spermatic cord: namely, the internal spermatic fascia and cremaster.
- If the hernia extends through the superficial inguinal ring, it is also covered by external spermatic fascia.
- In hernias related to a persistent fully patent processus vaginalis, the hernia contents may descend as far as the tunica vaginalis anterior to the testis.
- In many individuals with a partial or fully patent processus vaginalis, an indirect hernia will manifest in childhood, but in others, an actual hernia into the potential sac may not develop until adult life, often as a consequence of increased intra-abdominal pressure or sudden muscular strain.

Direct Inguinal Hernia

- A direct inguinal hernia arises medial to the inferior epigastric vessels.
- Direct hernias are always caused by an acquired weakness of the posterior wall of the inguinal canal; as they enlarge, they frequently extend through the anterior wall of the inguinal canal or superficial inguinal ring, becoming covered by external spermatic fascia in the process.
- A direct inguinal hernia may closely resemble an indirect hernia and can be difficult to distinguish on clinical examination.

Clinical Features of Inguinal Hernias

- Indirect inguinal hernias often descend from lateral to medial, following the path of the inguinal canal, whereas direct inguinal hernias tend to protrude more directly anteriorly.
- With the hernia reduced, pressure applied over the region of the deep inguinal ring may prevent the appearance of an indirect hernia on standing or straining, but distinguishing an indirect from a direct inguinal hernia by clinical examination alone is not reliable (Ralphs et al 1980, Tromp et al 2014).
- Direct hernias are more likely to have a wide neck, making strangulation less likely.

Types of Hernias

1. **Direct Inguinal Hernia**
2. **Indirect Inguinal Hernia**
3. **Femoral Hernia**

Note: Surgical hernia repair may damage the **iliohypogastric nerve,** causing anesthesia of the ipsilateral abdominal wall and inguinal region, and/or the **ilioinguinal nerve,** causing anesthesia of the ipsilateral penis, scrotum, and medial thigh.

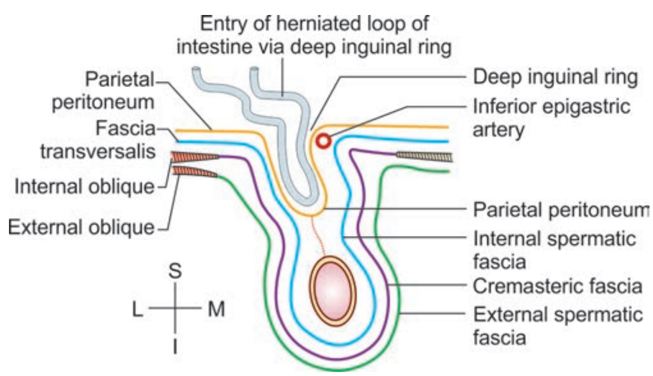


Fig. 51: Coverings of the indirecti inguinal hernia

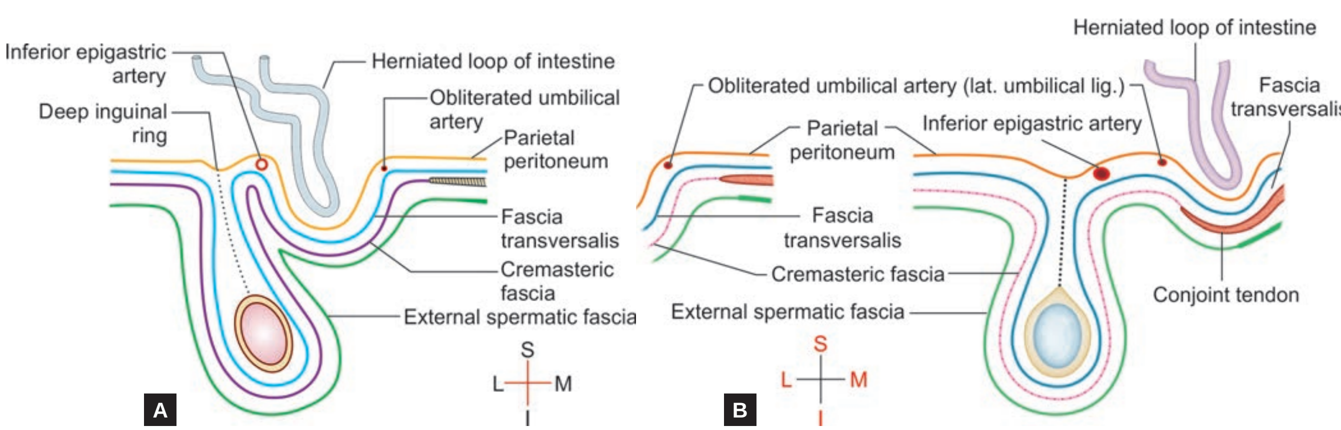


Fig. 52: Coverings of the direct inguinal hernia: A. Lateral direct inguinal hernia; B. Medial direct inguinal hernia

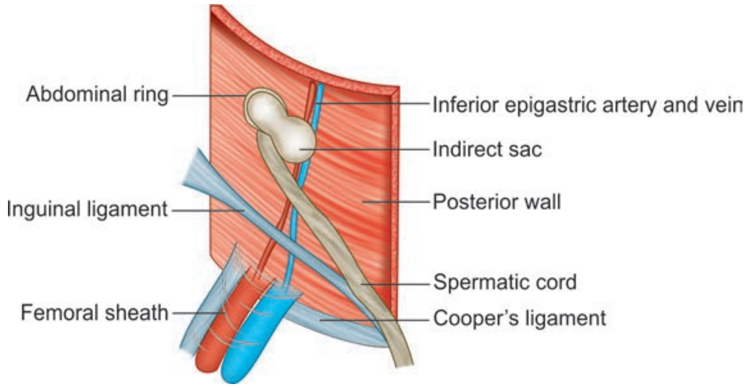


Fig. 53: Indirect inguinal hernia. The posterior inguinal wall is intact. A hernia develops in the patent processus vaginalis (sac) on the anteromedial aspect of the cord.

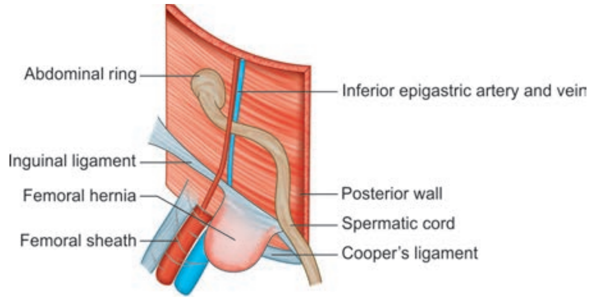


Fig. 54: Direct inguinal hernia. The abdominal ring is intact. A hernia defect is a diffuse bulge in the posterior inguinal wall medial to the inferior epigastric vessels.

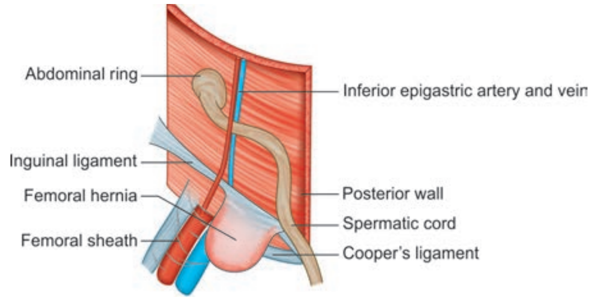


Fig. 55: Femoral hernia. The defect is through the femoral canal, but otherwise involves similar strucutres and insertions as a direct inguinal hernia.

Table 17: Differences between inguinal and femoral hernias

	Inguinal hernia	Femoral hernia
Sex	More common in males	More common in females
Protrusion of hernial sac	Into inguinal canal	Into femoral canal
Neck of protrusion of hernia	Lies above and medial to pubic tubercle	Lies below and lateral to the pubic tubercle

Table 18: Differences between the indirect and direct inguinal hernia

	Indirect inguinal hernia	Direct inguinal hernia
Site of protrusion of hernial sac	Deep inguinal ring	Posterior wall of inguinal canal
Shape	Pear shaped	Globular
Extent	Generally scrotal	Rarely scrotal
Direction	Oblique (directed downward, forward, and medially)	Straight (directed forward)
Neck of hernial sac	Narrow and lies lateral to the inferior epigastric vessels	Wide and lies medial to the inferior epigastric vessels
Reducibility	Sometimes irreducible	Generally always reducible
Age group	Occurs in young age	Occurs in middle and old age
Interanal ring occlusion test*	Positive	Negative

*After reducing the hernia, the pressure is applied over deep inguinal ring and patient is asked to cough. If hernia does not appear, it is indirect (because herniation occurs through the deep inguinal ring), and if hernia appears, it is direct (because herniation occurs through the Hesselbach's triangle).

Femoral hernia

- **Femoral hernia** passes through the femoral ring into the femoral canal, and **femoral vein** lies lateral to it.
- Femoral hernias occur just below the inguinal ligament, when abdominal contents pass through a naturally occurring weakness called the **femoral canal.**
- The femoral canal is located below the inguinal ligament on the lateral aspect of the pubic tubercle.
- The hernia must pass the **femoral ring** to enter the femoral canal.

- The ring is bounded by the inguinal ligament anteriorly, **pectineal ligament** posteriorly, l**acunar ligament** medially, and the femoral vein laterally.
- The three compartments of the femoral sheath (From lateral to medial): **Femoral artery** and its branches, **Femoral vein** and its tributaries, Femoral canal, which contains lymphatic vessels and deep inguinal lymph nodes.

ASSESSMENT QUESTIONS

1. TRUE about anatomy of inguinal hernia: *(PGIC 2005)*
   a. Superficial inguinal ring is an opening in external oblique aponeurosis
   b. Indirect inguinal hernia lies just medial to inferior epigastric artery
   c. Posterior wall is formed by transversalis fascia and conjoint tendon
   d. Cremasteric artery is a branch of external iliac artery
   e. Indirect hernia lies anteromedial to spermatic cord

2. The femoral ring is bounded by the following structures EXCEPT: *(AIPG 2005)*
   a. Femoral vein
   b. Inguinal ligament
   c. Femoral artery
   d. Lacunar ligament

3. Which of the following lies lateral to sheath of femoral hernia: *(AIIMS 2011)*
   a. Femoral artery
   b. Femoral vein
   c. Femoral nerve
   d. Lateral cutaneous nerve of thigh

4. Which of the following does NOT form boundary of femoral ring: *(PGIC 2012)*
   a. Femoral artery
   b. Femoral vein
   c. Femoral nerve
   d. Lacunar ligament
   e. Inguinal ligament

5. A 30-year-old lady presented with swelling below inguinal ligament lateral to pubic tubercle, which structure is lateral to this swelling: *(JIPMER 2016)*
   a. Femoral artery
   b. Femoral vein
   c. Obturator vessels
   d. Internal iliac artery

6. WRONG statement concerning femoral region is:
   a. Medial boundary of femoral ring is lacunar ligament
   b. Femoral hernia lies infero-lateral to the pubic tubercle
   c. Femoral nerve lies inside the femoral sheath
   d. Adductor longus forms the medial boundary of femoral triangle

ANSWERS WITH EXPLANATIONS

1. a. Superficial inguinal ring is an opening in external oblique aponeurosis; c. Posterior wall is formed by transversalis fascia and conjoint tendon; e. Indirect hernia lies anteromedial to spermatic cord
- Indirect inguinal hernia lies just lateral (and **not medial)** to inferior epigastric artery (and vein).
- **Cremasteric artery** is a branch of inferior epigastric artery (which itself is a branch of **external iliac artery**).
- Indirect inguinal hernia protrudes from peritoneal cavity into deep inguinal ring, lies **anteromedial to spermatic cord**, passes through inguinal canal, exit through superficial inguinal ring to enter the scrotum/labia majus.

2. c. Femoral artery
- Femoral vein lies in the lateral wall of femoral ring and not the femoral artery.
- Inguinal ligament forms the anterior boundary of femoral ring and lacunar ligament is at the medial wall.
- Ilio-pectineal ligament of Cooper lies as the posterior boundary of the inguinal ring.

3. b. Femoral vein
- **Femoral hernia** passes through the femoral ring into the femoral canal, and **femoral vein** lies lateral to it.
- Femoral hernias occur just below the inguinal ligament, when abdominal contents pass through a naturally occurring weakness called the **femoral canal.**
- The femoral canal is located below the inguinal ligament on the lateral aspect of the pubic tubercle.
- The hernia must pass the **femoral ring** to enter the femoral canal.
- The ring is bounded by the inguinal ligament anteriorly, **pectineal ligament** posteriorly, l**acunar ligament** medially, and the femoral vein laterally.
- The three compartments of the femoral sheath (From lateral to medial): **Femoral artery** and its branches, **Femoral vein** and its tributaries, Femoral canal, which contains lymphatic vessels and deep inguinal lymph nodes.

4. a. Femoral artery; c. Femoral nerve
- Femoral ring is bounded by the **inguinal ligament** anteriorly, **pectineal ligament** posteriorly, l**acunar ligament** medially, and the **femoral vein** laterally.

5. (b) Femoral vein
- This is a case of femoral hernia, where the sac is inferolateral to the pubic tubercle (below the inguinal ligament).
- The hernia passes through the femoral ring into the femoral canal, lateral to which lies the femoral vein.

6. c. Femoral nerve is inside the femoral sheath.
- Femoral nerve lies outside the femoral sheath.

Male Reproductive System

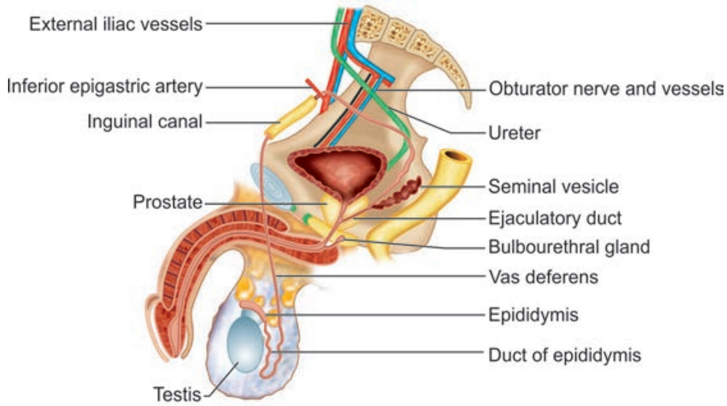


Fig. 56: Male reproductive organs. Note the course and relations of vas deferens, in the four regions (viz., scrotum, spermatic cord, inguinal canal, and pelvis) traversed by it.

Spermatic Cord

- **Spermatic cord** is formed by the vas deferens and surrounding tissue that runs from the deep inguinal ring down to the testis.
- It has a serosal covering (tunica vaginalis), which is an extension of the peritoneum that passes through the transversalis fascia.
- It is ensheathed in three layers of tissue:
  - External spermatic fascia (derived from aponeurosis of the external oblique muscle)
  - Cremasteric muscle and fascia (continuation of the internal oblique muscle and its fascia)
  - Internal spermatic fascia (continuation of transversalis fascia)
- Contents:
  - Ductus deferens
  - Tunica vaginalis (remains of the processus vaginalis)
  - Arteries: testicular artery, artery to ductus deferens, cremasteric artery
  - Nerves: Nerve to cremaster (genital branch of the genitofemoral nerve), sympathetic and parasympathetic nerves (testicular plexus of nerves).

Note: Ilio-inguinal nerve is 'not' located inside the spermatic cord, but runs along the outside of it (in the inguinal canal) on the superficial surface of the external spermatic fascia.

  - Pampiniform venous plexus
  - Lymphatic vessels

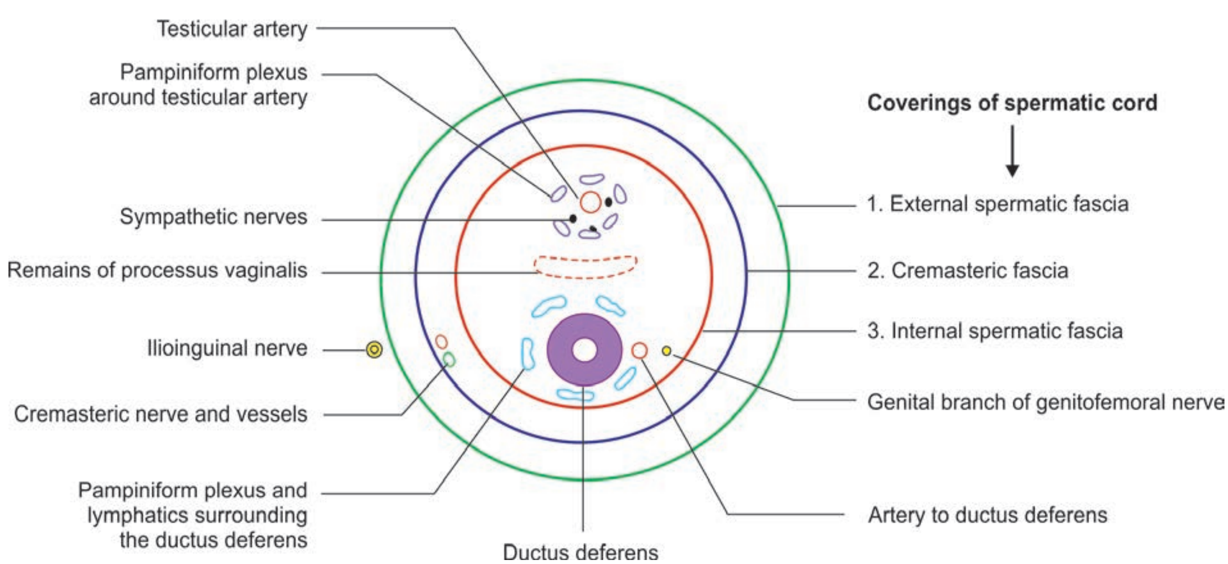


Fig. 57A: Transverse section of the spermatic cord showing its covering content.

Testis, Epididymis and Scrotum

- **Testis** develops retroperitoneally in the abdomen and descends into the pelvis and eventually reach scrotum.
- It is surrounded incompletely (medially, laterally, and anteriorly, but not posteriorly) by a sac of peritoneum called the **tunica vaginalis**.
- Beneath the tunica vaginalis, the testis is surrounded by a thick connective tissue capsule **tunica albuginea** (white).
- **Tunica vasculosa** is a highly vascular layer of connective tissue beneath the tunica albuginea.
- Tunica albuginea projects connective tissue septa inward toward the mediastinum and divides the testes into about 250 lobules, each of which contains one to four highly coiled **seminiferous tubules**. These septa converge toward the midline on the posterior surface, where they meet to form a ridge-like thickening known as the **mediastinum**.
- The testes contain the seminiferous tubules with Leydig (interstitial) cells.
- In the seminiferous tubules of the testes spermatogonial stem cells adjacent to the inner tubule wall divide in a centripetal direction, beginning at the walls and proceeding towards lumen, to produce sperm.
- Spermatogenesis takes **74 days** to complete and about 200 to 300 million spermatozoa are produced daily (about half of these become viable sperm).
- Leydig cells secrete **testosterone**, androstenedione and dehydro-epiandrosterone (DHEA), when stimulated by the pituitary hormone luteinizing hormone (LH).
- Sequence of sperm movement in testis: Seminiferous tubules → straight tubules → rete testis → efferent ductules in testis.

Tunica vaginalis is the pouch of serous membrane that covers the testes. It is derived from the process vaginalis of the peritoneum, which in the fetus precedes the descent of the testes from the abdomen into the scrotum.

- It is the serous sac of the peritoneum that covers the front and sides of the testis and epididymis.
- It consists of a parietal layer that forms the innermost layer of the scrotum and a visceral layer adherent to the testis and epididymis.
- **Processus Vaginalis** is the embryonic diverticulum of the peritoneum that traverses the inguinal canal, accompanying the testis in its descent into the scrotum (or round ligament in the female) and closes forming the tunica vaginalis in the male. Persistent processus vaginalis leads to development of a congenital indirect inguinal hernia, but if its middle portion persists, it develops a congenital hydrocele.

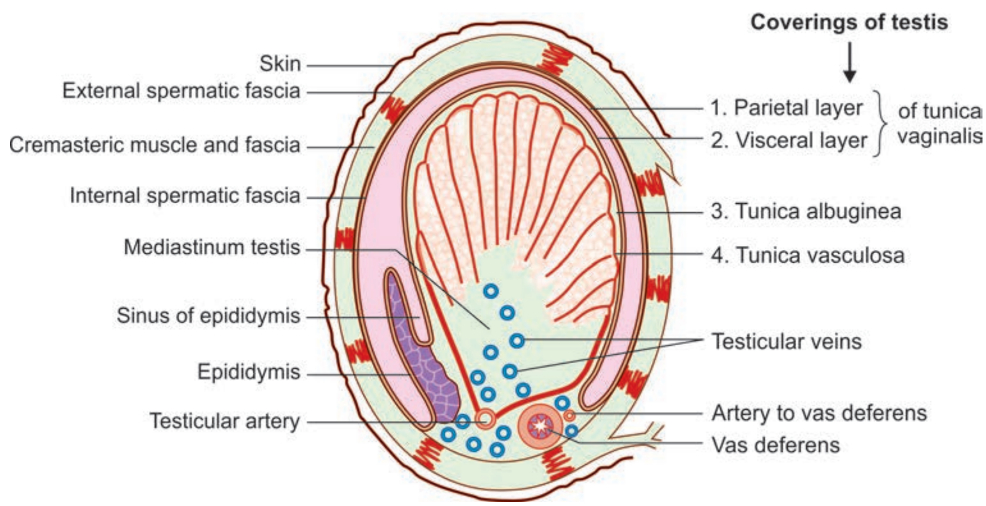


Fig. 57B: Transverse section of the left testis and its surrounding structures to show the coverings of the testis.

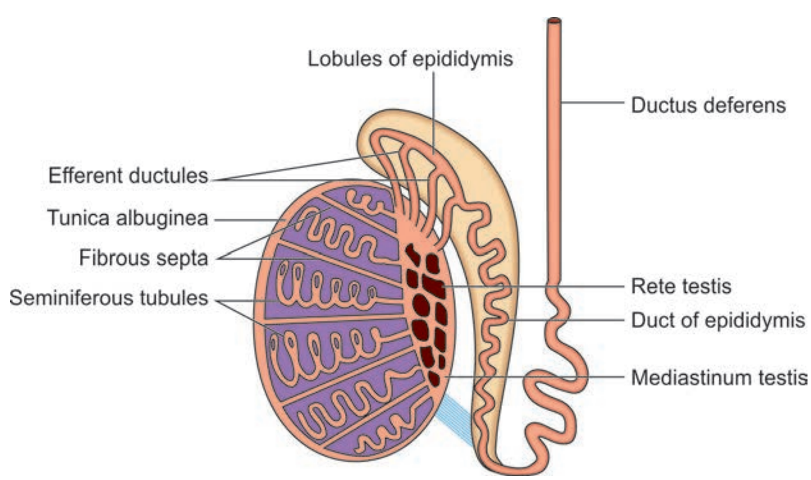


Fig. 57C: Longitudinal section of the testis and epididymis showing their structures.

Arterial Supply:

- **Testicular arteries** (branches of abdominal aorta, just inferior to the renal arteries).
- A rich collateral arterial supply comes from the internal iliac artery (via the artery of the ductus deferens), inferior epigastric artery (via the cremasteric artery), and femoral artery (via the external pudendal artery).
- The collateral circulation is sufficient to allow ligation of the testicular artery during surgery.

Venous Drainage

- **Pampiniform plexus** of spermatic veins is present on the surface of the epididymis and run parallel to the spermatic arteries. This provides a countercurrent exchange of heat and testosterone between the two vessels.
- **Testicular veins** are formed by the union of the veins of the pampiniform plexus around testis.
- Right testicular vein empties into the inferior vena cava and the left testicular vein empties into the left renal vein.

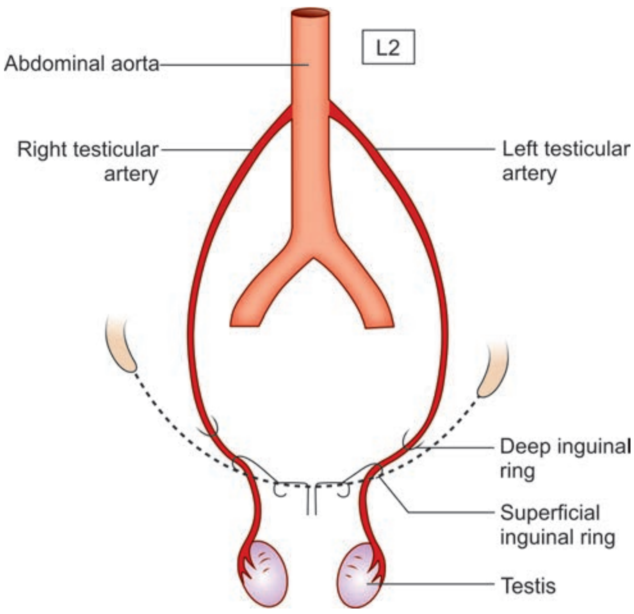


Fig. 58: Testicular arteries

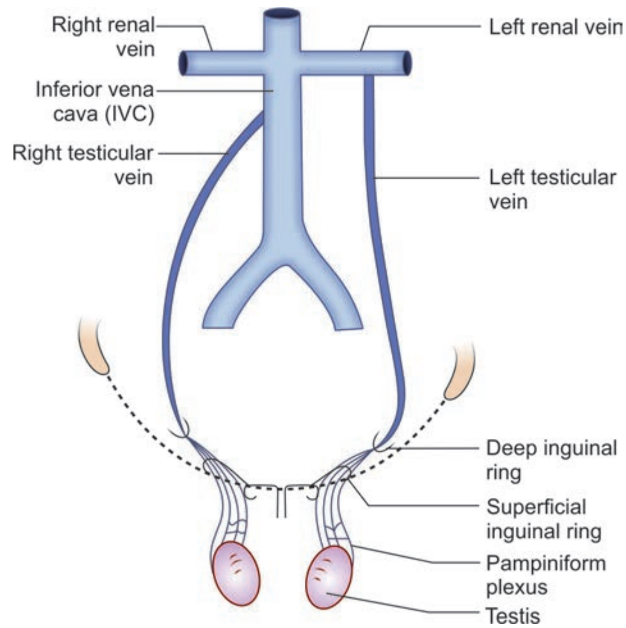


Fig. 59: Venous drainage of the testis

Lymphatic Drainage

- Testicular lymphatics drain into the to the para (lateral) and pre (anterior) **aortic lymph nodes**.

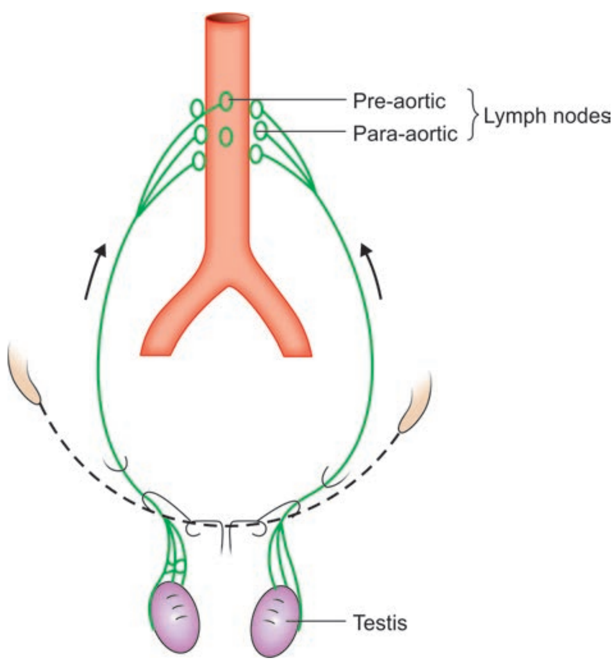
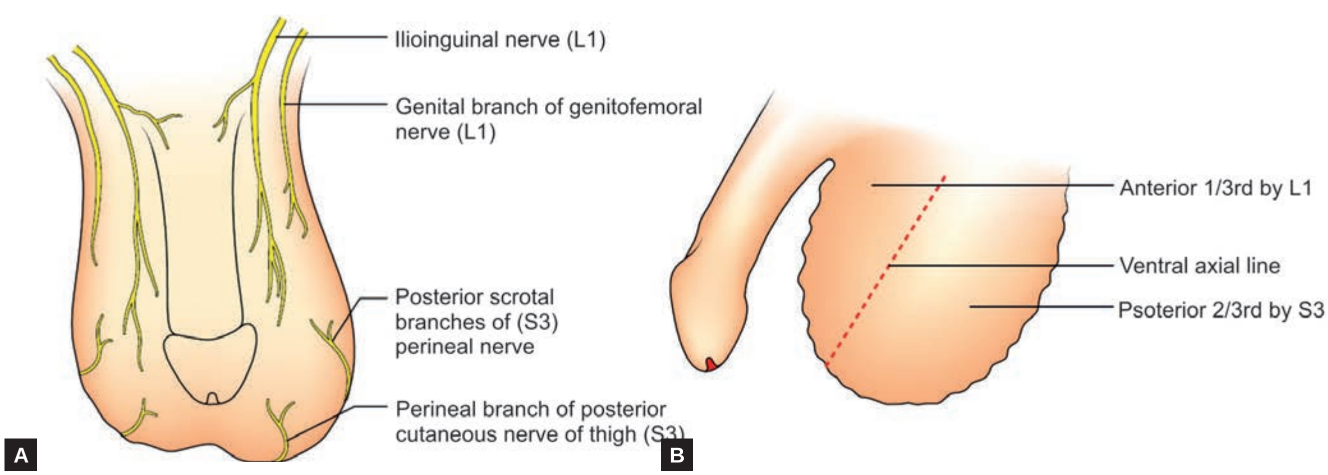


Fig. 60: Lymphatic drainage of the testis

Epididymis is a long (6 m) and highly coiled duct for propulsion of the spermatozoa into the ductus deferens.

- It has a head, body, and tail (which is continuous with the ductus deferens).
- Sperms undergo **maturation**, gain **progressive motility** in epididymis and are **stored there until ejaculation**.

- The principal cells lining the epididymis have the following functions:
  - Continued resorption of testicular fluid that began in the efferent ductules.
  - Phagocytosis of degenerating sperm or spermatid residual bodies not phagocytosed by the Sertoli cells
  - Secretion of glycoproteins, which bind to the surface of the cell membrane of the sperm, sialic acid, and glycero-phospho-choline (which inhibits capacitation, thus preventing sperm from fertilizing a secondary oocyte until the sperm enters the female reproductive tract).
- In the tail region of the epididymis, the muscular coat consists of three layers: Inner longitudinal, middle circular and outer longitudinal layer of smooth muscle. These layers contract to force sperm from the tail of the epididymis to the ductus deferens (sperm emission).
- After the sperm have been in the epididymis for 18 to 24 hours, they develop the capability of motility, even though several inhibitory proteins in the epididymal fluid still prevent final motility until after ejaculation.
- The transit time of sperm through the epididymis is thought to take up to 12 days, though sperms may be stored in the epididymis for several weeks.
- Once ejaculated into the female, the spermatozoa move up the uterus to the isthmus of the uterine tubes, to undergo **capacitation**.
  - This further maturation process involves two components: increasing the motility of the spermatozoa and facilitating their preparation for the acrosome reaction.
  - Capacitation normally lasts for 1 to 10 hours (average 7), during the process sperms gradually lose much of their other **excess cholesterol** and the acrosome membrane becomes much weaker. The membrane of the sperm also becomes much **more permeable to calcium ions**.
  - From the isthmus, the capacitated spermatozoa move rapidly to the tubal **ampulla**, where **fertilization** takes place.
- After ovulation has occurred, the oocyte (ovum) remains fertilizable for 48 hours, although the chance is mostly lost by **18–24 hours**.
- Spermatozoa have a life span of 24–48 hours within the female reproductive tract, if hostile mucus is absent.
  - When there is proper estrogenic cervical mucus, the fertilizing capacity of sperm can last 3–7 days in the periovulatory period (Pallone and Bergus, 2009).
  - Sperms **usually** do not retain their power of fertilization after **24—48 hours** of coitus.
- **Scrotum** contains the testis and the epididymis.
  - It regulates the temperature of the testes and maintains it at 35 degrees Celsius (95 degrees Fahrenheit), i.e. two degrees below the body temperature of 37 degrees Celsius (98.6 degrees Fahrenheit), which is an essential requirement for spermatogenesis.
  - It has thin skin covered with sparse hairs and no fat.
  - **Dartos** muscle is subcutaneous (which wrinkles the skin), and is continuous with the superficial penile fascia and superficial perineal fascia.
  - The **cremaster** muscle covers scrotum and upon contraction elevates the testis.
  - **Arterial supply**: External pudendal arteries and the posterior scrotal branches of the internal pudendal arteries.
  - **Nerve supply**: Anterior scrotal branch of the **ilioinguinal nerve**, the genital branch of **genitofemoral nerve**, the posterior scrotal branch of the perineal branch of the **pudendal nerve**, and the perineal branch of the posterior femoral cutaneous nerve.



Figs. 61A and B: Nerve supply of the scrotum: A. Cutaneous nerves of the scrotum anterior view; B. Lateral view showing segmental innervation

ASSESSMENT QUESTIONS

1. Sperm acquires motility in: *(NEET Pattern 2014)*
a. Seminal vesicle
b. Testes
c. Epididymis
d. Ejaculatory duct

2. Sperm maturation takes place in: *(NEET Pattern 2012)*
a. Vas deferens
b. Seminiferous tubules
c. Epididymis
d. Female genital tract

3. After formation, the sperms are stored in:
a. Rete testis
b. Epididymis
c. Ductus deferens
d. Seminal vesicles

4. Capacitance of sperm takes place in:
a. Seminiferous tubules
b. Epididymis
c. Vas deferens
d. Uterine tube

5. The intricately and prodigiously looped system of veins and arteries that lie on the surface of the epididymis is known as: *(AIPG 2004)*
a. Choroid plexus
b. Tuberal plexus
c. Pampiniform plexus
d. Pectiniform septum

6. Location of testis is higher on: *(NEET Pattern 2013)*
a. Right side
b. Left side
c. May be on right or left side
d. Same level on both sides

7. CORRECT sequence of sperm movements: *(AIPG 2008)*
a. Rete testis → straight tubules → efferent ductules
b. Straight tubules → efferent ductules → epididymis
c. Efferent ductules → rete testis → straight tubules
d. Straight tubules → rete testis → efferent ductules

9. A patient presented with pain in right testes. Examination reveals bag of worms suggestive of varicocele. Right testicular vein drains into: *(JIPMER 2016)*
a. Hemiazygos vein
b. IVC
c. Inferior mesenteric vein
d. Renal vein

9. Left testicular vein drains into: *(NEET Pattern 2015)*
a. Left renal vein
b. IVC
c. SVC
d. Hepatic vein

10. The lymphatic drainage of testes is: *(NEET Pattern 2012)*
a. Inguinal lymph nodes
b. Mesenteric lymph nodes
c. Para-aortic lymph nodes
d. Obturator lymph nodes

11. All of the following are true statements regarding Penis EXCEPT: *(JIPMER 2016)*
a. Corpus spongiosum get terminally expanded to form glans penis
b. Arterial blood supply from internal pudendal artery
c. Skin of penis is supplied by superficial external pudendal artery
d. Penile urethra runs in corpus spongiosum

12. Which of the following structure in the spermatic cord is not at risk of injury during vasectomy: *(AIIMS 2012)*
a. Testicular artery
b. Cremasteric artery
c. Genital branch of genitofemoral nerve
d. Ilioinguinal nerve

13. Injury to which nerve during a herniorrhaphy may cause paresthesia at the root of scrotum and base of penis *(AIIMS 2001)*
a. Ilioinguinal
b. Pudendal
c. Genitofemoral
d. Iliohypogastric

ANSWERS WITH EXPLANATIONS

1. c. Epididymis
- Sperms undergo maturation, gain progressive motility in epididymis and are stored there until ejaculation.

2. c. Epididymis
- Spermatozoa undergo a maturation process and acquire motility and fertility as they migrate from the proximal to the distal end of epididymis.
- The process of maturation continues in the female genital tract as well.

3. b. Epididymis
- Most of the sperms are stored in the **epididymis**, although a small quantity is stored in the **vas deferens**.

4. d. Uterine tube
- Once ejaculated into the female, the spermatozoa reach the uterus and in the **isthmus of the uterine tubes**, they undergo **capacitation**.

5. c. Pampiniform plexus
- Pampiniform plexus of spermatic veins is present on the surface of the epididymis and run parallel to the spermatic arteries.
- Choroid plexus is a capillary plexus lined by the pia mater and secretory ependyma and is involved in CSF formation.
- Tuberal plexus is present on the pars tuberalis of pituitary and is a part of hypothalamo-hypophyseal portal circulation.

6. a. Right side
- Left testis descent begins early and it lies slightly at the lower level than the right.

7. d. Straight tubules → rete testis → efferent ductules
- The sperms form in the seminiferous tubules and pass on to the straight tubules (tubuli recti).
- Next they enter a network of tubules (rete testis) and then reach the efferent ductules.
- Efferent ductules lead them to the epididymis where storage takes place before ejaculation.

8. b. IVC
- Right testicular vein drains into the inferior vena cava; the left testicular vein joins the left renal vein.

9. a. Left renal vein
- Left testicular vein empties into the left renal vein and right testicular vein empties into the inferior vena cava.

10. c. Para-aortic lymph nodes
- Testis drains into the pre-aortic and paraa-ortic lymph nodes.

11. c. Skin of penis is supplied by superficial external pudendal artery
- Penis consists of 2 corpora cavernosa and 1 corpus spongiosum.
- Penile urethra runs in corpus spongiosum, which terminally get expanded to form glans penis.
- Arterial blood supply from branches of internal (not external) pudendal artery.

12. d. Ilioinguinal nerve
- Ilioinguinal nerve is not a content of spermatic cord.

13. a. Ilioinguinal
- During herniorrhaphy ilio-inguinal nerve is damaged, while working in the inguinal canal, whereas, ilio-hypogastric nerve may be damaged while putting the incision for herniorrhaphy at the inguinal region
- Ilioinguinal nerve pierces the obliquus internus, distributing filaments to it, and, accompanying the spermatic cord through the superficial inguinal ring, is distributed to the skin of the upper and medial part of the thigh, and to the following locations in the male and female:
  - In the male (anterior scrotal nerve) to the skin over the root of the penis and anterior part of the scrotum
  - In the female (anterior labial nerve) to the skin covering the mons pubis and labium majus
- The nerve does not pass through the deep inguinal ring, and therefore it only travels through part of the inguinal canal.
- Ilio-hypogastric nerve supplies skin over the iliac crest, upper inguinal and hypogastric areas. (and not the scrotum or penis).

Prostate Gland

- Prostate gland is located between the base of the urinary bladder and the urogenital diaphragm.
- It consists of glandular tissue in fibromuscular stroma.
- It has **three surfaces**:
  - Muscular anterior surface related to the retropubic space
  - Inferior lateral surfaces related to the levator ani
  - Posterior surface related to the seminal vesicles and the ampulla of the rectum.
- It has **five lobes** developmentally and are well observed in fetal prostate:
  - Anterior lobe (or isthmus) lies in front of the urethra and is devoid of glandular substance.
  - Middle (median) lobe, which lies between the urethra and the ejaculatory ducts and is prone to BPH (benign prostatic hypertrophy) obstructing the internal urethral orifice.
  - Posterior lobe, which lies behind the urethra and below the ejaculatory ducts., contains glandular tissue, and is prone to carcinomatous transformation.
  - Lateral lobes (a pair), which are situated on either side of the urethra and form the main mass of the gland.
- Cut surface of an adult prostate do not resemble to lobes and is described in **four zones**:

Name	Fraction of gland	Description
Peripheral zone	~70%	The sub-capsular portion of the posterior aspect of the prostate gland that surrounds the distal urethra and is prone to cancer.
Central zone	~25%	It lies posterior to urethra and surrounds the ejaculatory ducts, accounts for ~2.5% of prostate cancers.
Transition zone	~5%	It surrounds the proximal urethra (periurethral zone) and grows throughout life and is responsible for the benign prostatic hypertrophy. ~10–20% of prostate cancers originate in this zone.
Anterior fibromuscular zone	~5%	It has fibromuscular components only (glandular components absent)

- **Anterior** lobe roughly corresponds to part of **transitional** zone; **posterior** lobe to **peripheral** zone; lateral lobes span all zones and **median** lobe roughly corresponds to part of **central** zone.

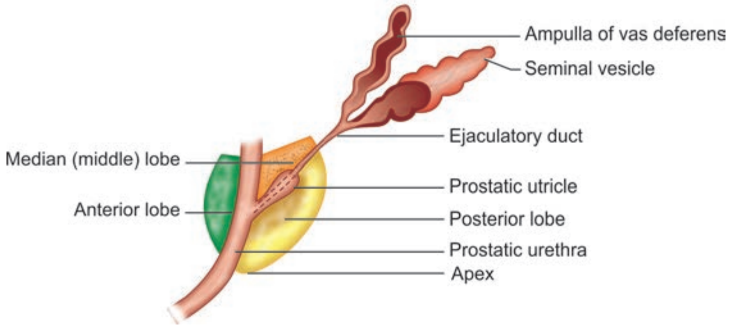
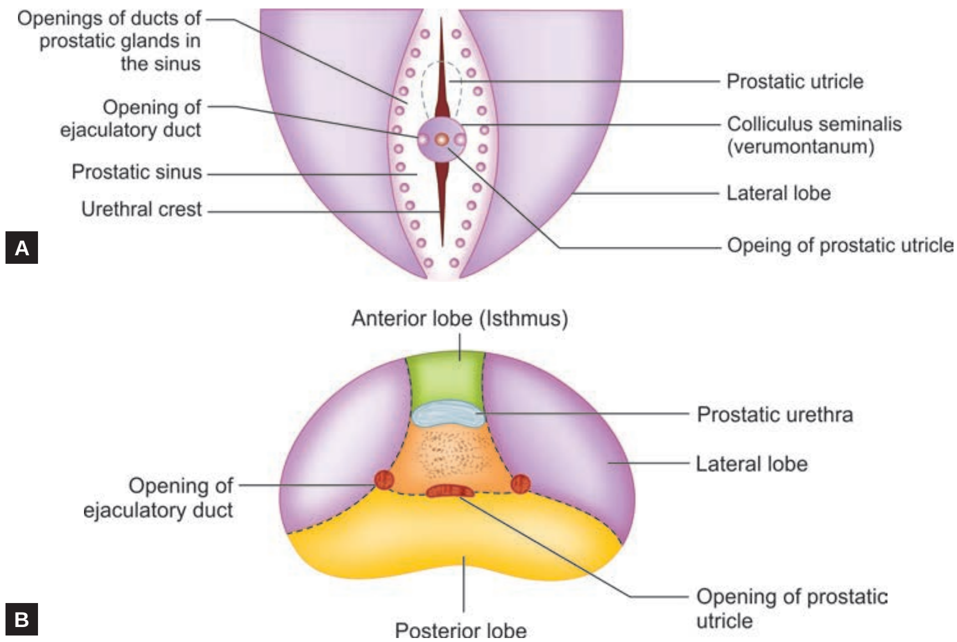


Fig. 62: Prostate gland



Figs. 63A to C: Lobes of the prostate gland as seen in sections through Different planes: A. Left view of a sagittal section; B. coronal section through the posterior half of the gland; C. horizontal section (M = median lobe)

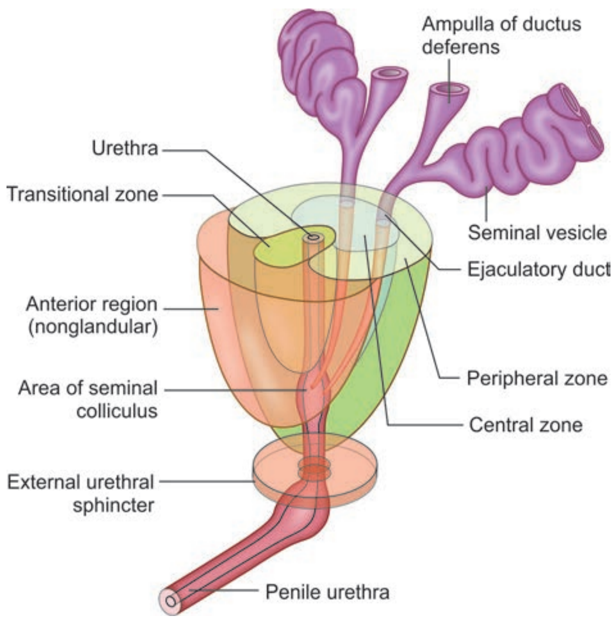


Fig. 64: Surgical zones in prostate

- Prostate has the **urethral crest** located on the posterior wall of the prostatic urethra.
  - There are numerous openings for the prostatic ducts on either side in **prostatic sinus** — a groove between the urethral crest and the wall of the prostatic urethra.
  - The crest has a rounded elevation called the **seminal colliculus** (verumontanum), on which the two ejaculatory ducts and the prostatic utricle open.
  - **Prostatic utricle** is a blind pouch (5 mm deep); it is considered as an analogue to the uterus and vagina in the female.
- Prostate secretes a fluid that produces the characteristic odor of semen.
- In the secretions are prostate-specific antigen (PSA), prostaglandins, citric acid and acid phosphatase, and proteolytic enzymes.

Arterial Supply

Prostate gland is supplied by the branches of inferior vesical, middle rectal, and internal pudendal arteries (branches of internal iliac artery).

Venous Drainage

Prostate drains by two pathways:

- Prostatic venous plexus → internal iliac veins → IVC.
  - Prostatic cancer may metastasize to the heart and lungs, through this channel.
- Prostatic venous plexus → vertebral venous plexus → cranial dural venous sinuses.
  - Prostatic cancer may metastasize to the vertebral column and brain, through this channel.

Clinical Correlations

Benign prostatic hyperplasia (BPH) is seen in the periurethral (transitional) zone, and involves the median lobe.

- It leads to compression of the prostatic urethra and causes BOO (bladder outlet obstruction) to the urine flow.
- The uvula vesicae is a small rounded elevation just behind the urethral orifice at the apex of the trigone. It is raised by the median lobe of prostate gland, and becomes more prominent in BPH, leading to stagnancy of urine.
- TURP (Transurethral resection of the prostate) is the surgical removal of the prostate by means of a cystoscope passed through the urethra. Approximately > 75 % patients develop retrograde ejaculation of semen post TURP, due to injury to internal urethral sphincter during the procedure.

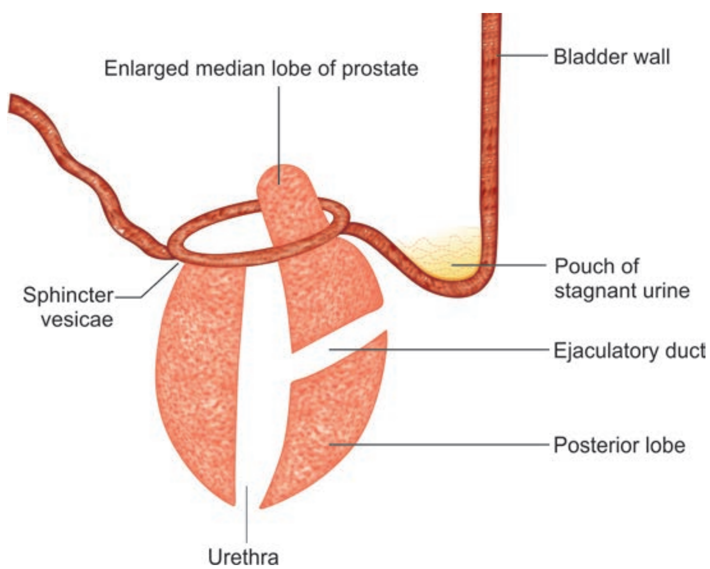


Fig. 65: Bladder outlet obstruction due to median lobe hypertrophy

Corpora amylacea, are small hyaline masses (detected microscopically) found in the **prostate gland**, **neuroglia**, and **pulmonary alveoli**. They are derived from degenerate cells or thickened secretions and occur more frequently with advancing age.

ASSESSMENT QUESTIONS

1. Which lobe of prostate gland raises uvula vesicae:
a. Anterior lobe
b. Posterior lobe
c. Median lobe
d. Lateral lobe

2. Benign Prostatic hypertrophy results in obstruction of the urinary tract. The specific condition is associated with enlargement of the: *(AIPG 2005)*
a. Entire prostate gland
b. Lateral lobes
c. Median lobe
d. Posterior lobes

3. **UNTRUE about prostate is:**
   a. Behind the urethra and between the two ejaculatory ducts lie the median lobe
   b. Colliculus seminalis is an elevation on urethral crest showing three openings
   c. Its urethra is convex anteriorly
   d. Its urethra appears crescentic in transverse section

4. **Which of the following zones is prone to benign prostatic hypertrophy:**
   a. Anterior muscular
   b. Transitional zone
   c. Peripheral zone
   d. Central zone

5. **Prostatic artery is a branch of:** *(NEET Pattern 2015)*
   a. Superior vesical artery
   b. Middle vesical artery
   c. Inferior vesical artery
   d. Superior rectal artery

6. **Most common site of prostatic carcinoma:**
   a. Anterior lobe(All India Dec 15 Pattern)
   b. Median lobe
   c. Posterior lobe
   d. Central zone

7. **A 50-year-old man suffering from carcinoma of prostate showed areas of sclerosis and collapse of T10 and T11 vertebrae in X-ray. The spread of this cancer to the above vertebrae was must probably through:** *(AIIMS 03)*
   a. Sacral canal
   b. Lymphatic vessels
   c. Internal vertebral plexus of veins
   d. Superior rectal veins

8. **Cremasteric artery is a branch of:** *(All India Dec 15 Pattern)*
   a. Internal pudendal artery
   b. External pudendal artery
   c. Inferior epigastric artery
   d. Superior epigastric artery

ANSWERS WITH EXPLANATIONS

1. **c. Median lobe**
   - The trigone of the urinary bladder is bounded by the two orifices of the ureters (base) and the internal urethral orifice (apex).
   - The uvula vesicae is a small rounded elevation just behind the urethral orifice at the apex of the trigone. It is raised by the median lobe of prostate gland, and becomes more prominent in BPH, leading to stagnancy of urine.
2. **c. Median lobe**
   - Benign prostatic hypertrophy involves mainly the transitional zone of the prostate, and is mainly due to the glandular hyperplasia of the median lobe.
   - Median lobe is a common site for adenoma prostate.
   - Adenoma never occurs in the posterior lobe, but primary prostatic carcinoma begins in this region. Lateral lobes may develop adenoma in older age.
   - Entire prostate gland is removed in prostatectomy, leaving behind both of its capsules and the venous plexus between them.
3. **c. Its urethra is convex anteriorly**
   - Male urethra is concave anteriorly.
4. **b. Transitional zone**
   - Peri-urethral transitional zone is prone to BPH (Benign Prostatic Hypertrophy).
   - Peripheral zone is prone to cancer.
5. **c. Inferior vesical artery**
   - The prostate gland is supplied by the branches of inferior vesical, middle rectal, and internal pudendal arteries.
6. **c. Posterior lobe**
7. **c. Internal vertebral plexus of veins**
8. **c. Inferior epigastric artery**

Cowper's Gland

Bulbourethral (BU) Glands of Cowper

A. The BU glands are located in the deep perineal space embedded in the skeletal muscles of the urogenital diaphragm (i.e., deep transverse perineal muscle and sphincter urethrae muscle) and adjacent to the membranous urethrae.
B. The ducts of the BU glands open into the penile urethra.
C. The BU fluid is a clear, mucus-like, slippery fluid that contains galactose, galactosamine, galacturonic acid, sialic acid, and methylpentose.
D. This fluid makes up a major portion of the preseminal fluid (or pre-ejaculate fluid) and probably serves to lubricate the penile urethra.

Seminal Vesicle

Seminal Vesicles

- Are enclosed by dense endopelvic fascia and are lobulated glandular structures that are diverticula of the ductus deferens.
- Seminal vesicles produce the alkaline constituent of the seminal fluid, which contains fructose and choline

Seminal Vesicles

A. The seminal vesicles are highly coiled tubular diverticula that originate as evaginations of the ductus deferens distal to the ampulla.
B. Contraction of the smooth muscle of the seminal vesicle during emission will discharge seminal fluid into the ejaculatory duct.
C. The seminal fluid is a whitish yellow viscous material that contains **fructose** (the principal metabolic substrate for sperm) and **other sugars, choline, proteins, amino acids, ascorbic acid, citric acid,** and **prostaglandins**.
D. Seminal fluid accounts for 70% of the volume of the ejaculated semen.
E. In **forensic medicine,** the presence of fructose (which is not produced elsewhere in the body) and choline crystals are used to determine the presence of semen.

Ductus Deferens and Ejaculatory Ducts

The vas deferens is supplied by the artery to vas deferens. It may be a branch of superior vesical artery, inferior vesical artery or middle rectal artery.

Ductus Deferens

- Is a thick-walled tube that enters the pelvis at the deep inguinal ring at the lateral side of the inferior epigastric artery.
- Crosses the medial side of the umbilical artery and obturator nerve and vessels, passes superior to the ureter near the wall of the bladder, and is dilated to become the ampulla at its terminal part.
- Contains fructose, which is nutritive to spermatozoa, and receives innervation primarily from sympathetic nerves of the hypogastric plexus and parasympathetic nerves of the pelvic plexus.

Ejaculatory Ducts

- Are formed by the union of the ductus deferens with the ducts of the seminal vesicles. Peristaltic contractions
- of the muscular layer of the ductus deferens and the ejaculatory ducts propel spermatozoa with seminal fluid into the urethra.
- Open into the prostatic urethra on the seminal colliculus just lateral to the blind prostatic utricle (see the section
- on urethral crest).

Ductus Deferens

General Features

- The ductus deferens begins at the inferior pole of the testes, ascends to enter the spermatic cord, transits the inguinal canal, enters the abdominal cavity by passing through the deep inguinal ring, crosses the external iliac artery and vein, and enters the pelvis.
- The distal end of the ductus deferens enlarges to form the **ampulla,** where it is joined by a short duct from the seminal vesicle to form the **ejaculatory duct**.
- The smooth muscular coat of the ductus deferens is similar to the tail region of the epididymis (i.e., **inner longitudinal layer, middle circular layer,** and **outer longitudinal layer of smooth muscle**) and contributes to the force of emission.
- **Arterial Supply.** The arterial supply of the ductus deferens is from the **artery of the ductus deferens,** which arises from the internal iliac artery and anastomoses with the testicular artery.
- **Venous Drainage.** The venous drainage of the ductus deferens is to the **testicular vein** and the **distal pampiniform plexus**.
- **Clinical Consideration: Vasectomy.** The scalpel will cut through the following layers in succession to gain access to the ductus deferens: Skin → Colles' fascia and dartos muscle → external spermatic fascia → cremasteric fascia and muscle → internal spermatic fascia → extraperitoneal fat. The tunica vaginalis is not cut.

Ejaculatory Duct

- The distal end of the ductus deferens enlarges to form the **ampulla,** where it is joined by a short duct from the seminal vesicle to form the **ejaculatory duct**.
- The ejaculatory duct passes through the prostate gland and opens into the prostatic urethra at the **seminal colliculus** of the urethral crest.
- The ejaculatory duct has no smooth muscular coat, so it does not contribute to the force for emission.

ASSESSMENT QUESTION

1. **All of the following statements regarding vas deference are true EXCEPT:** *(AIPG 2005)*
   a. The terminal part is dilated to form ampulla
   b. It crosses ureter in the region of ischial spine
   c. It passes lateral to inferior epigastric artery at deep inguinal ring
   d. It is separated from the base of bladder by the peritoneum

ANSWER WITH EXPLANATION

1. **Ans. d. It is separated from the base of bladder by the peritoneum**
   - Vas deferens lies on the posterior wall (base) of the bladder and there is no peritoneum between them. So, there is no separation of vas deferens from the base of bladder by the peritoneum.
   - Peritoneum actually lies more posterior to the vas deferens and forms the recto-vesical pouch.
   - Below the pouch lies the fascia of Denonvillier's–a pelvic fascia condensation to support the pelvic viscera.
   - Vas deferens hooks around the inferior epigastric artery (laterally) at deep inguinal ring and crosses to the ureter (superiorly) in the region of ischial spines. It shows a terminal dilatation called as ampulla, before it joins the duct of seminal vesicle to form common ejaculatory duct.

Penis

Penis has three masses of vascular erectile tissue: **corpora cavernosa** (paired) and the midline **corpus spo giosum**, which are individually bounded by tunica albuginea.

- Penis has a root, which includes two crura and the bulb of the penis, and the body, which contains the three erectile corpora.
- **Glans penis** is the terminal part of the corpus spongiosum, covered by a fold of skin (**prepuce**). **Frenulum** is a median ventral fold passing from the deep surface of the prepuce.
  - The prominent margin of the glans penis is the **corona**, the median slit near the tip of the glans is the external urethral orifice, and the terminal dilated part of the urethra in the glans is the **fossa navicularis**.
- **Smegma** is secreted by the preputial sebaceous glands of the corona, at the inner surface of the prepuce and neck of the glans penis.
- Deep fascia of the penis (**Buck Fascia**) is a continuation of the deep perineal fascia.
  - It is continuous with the fascia covering the external oblique muscle and the rectus sheath.
- **Tunica Albuginea** is a dense fibrous layer that envelops both the corpora cavernosa and the corpus spongiosum.
  - It is more dense around the corpora cavernosa and more elastic around the corpus spongiosum.

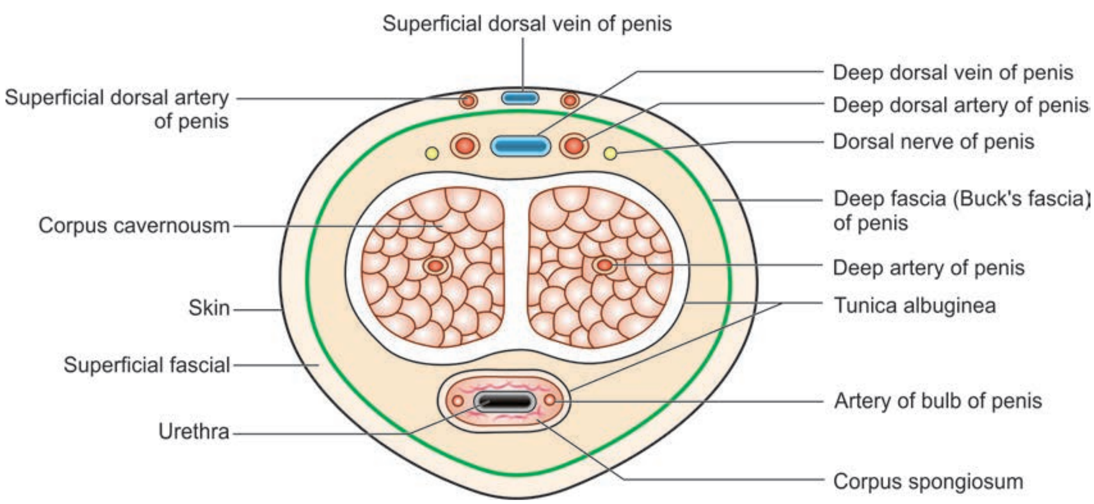


Fig. 66: Transverse section through the body of the penis.

Artery Supply

- Three arteries arise from internal pudendal arteries, branches of anterior divisions of internal iliac arteries.
  - Arteries to crura of the penis (deep artery of penis).
  - Artery to the bulb of penis (supplies proximal half of corpus spongiosum
  - Dorsal artery of penis which supplies distal part of corpus spongiosum and the glans penis
  - Superficial dorsal arteries of penis.

Note: Deep arteries fill the lacunae of erectile tissue in corpus cavernosum. In the flaccid state of the penis, these vessels appear spiral hence termed **helicine arteries**.

Venous Drainage

- Deep dorsal vein of the penis is a midline vein lying deep to the deep (Buck) fascia and superficial to the tunica albuginea.
  - It leaves the perineum through the gap between the arcuate pubic ligament and the transverse perineal ligament and drains into the prostatic and pelvic venous plexuses.
- Superficial dorsal vein of the penis runs toward the pubic symphysis between the superficial and deep fasciae and terminates in the external (superficial) pudendal veins, which drain into the greater saphenous vein.

Lymphatic Drainage

- The lymphatics from the glans penis drain into the deep inguinal lymph nodes (of Cloquet & Rosenmuller). Rest of penis drain into superficial inguinal lymph nodes.

ASSESSMENT QUESTIONS

1. **Crura of penis is supplied by:** *(NEET Pattern)*
   a. Dorsal artery of penis
   b. Deep artery of penis
   c. External pudendal artery
   d. Obturator artery

2. **Lymph from glans penis drains into:** *(NEET Pattern 2012)*
   a. Superficial inguinal canal
   b. Deep inguinal lymph nodes
   c. Obturator nodes
   d. Internal iliac nodes

3. Helicine artery are branch of: *(NEET Pattern 2013)*
a. Deep artery of penis
b. Femoral artery
c. External pudendal artery
d. None of the above

ANSWERS WITH EXPLANATIONS

1. b. Deep artery of penis
- Deep arteries are the principal vessels for filling the lacunae of erectile tissue during erection of the penis.

2. b. Deep inguinal lymph nodes
- Glans penis lymphatics drain into the deep inguinal lymph nodes (of Cloquet & Rosenmuller)

3. a. Deep artery of penis
- Deep arteries fill the lacunae of erectile tissue in corpus cavernosum. In the flaccid state of the penis, these vessels appear spiral hence termed **helicine arteries**.

Cremaster Reflex

Cremasteric Reflex

- Stroking of the skin on the front and inner side of the thigh evokes a reflex contraction of cremaster, which retracts the ipsilateral testis.
- The afferent limb for cremaster reflex is **femoral branch of genitofemoral nerve** (and by **ilio-inguinal nerve** additionally) and efferent limb is carried by **genital branch of genitofemoral nerve**.
- The reflex is usually absent if there is torsion of the testicle.

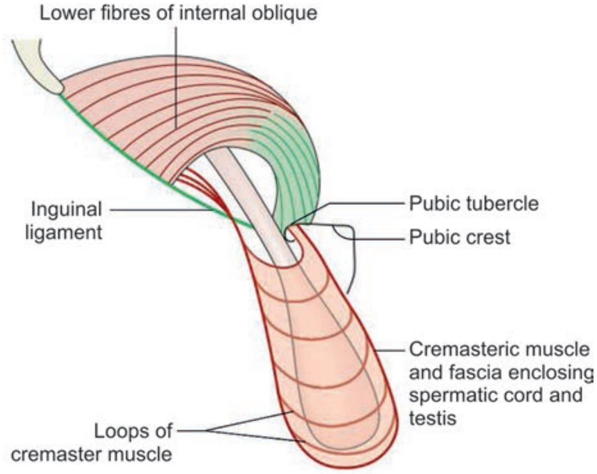


Fig. 67: Schematic diagram to show cremaster muscle

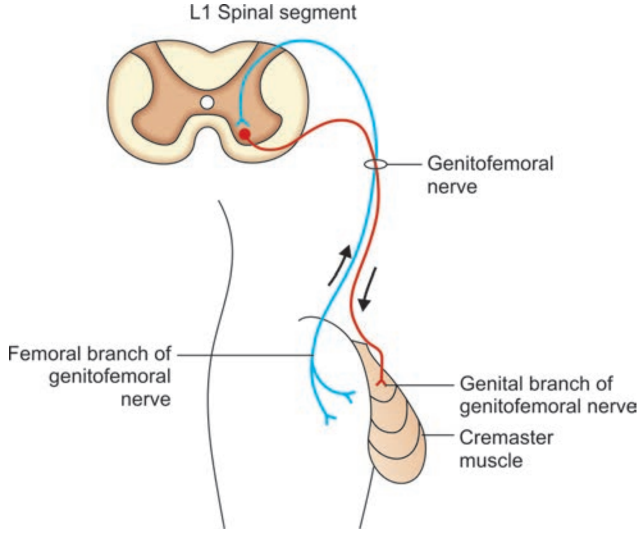


Fig. 68: Neural pathway for cremasteric reflex.

Erection and Ejaculation

Erection is under parasympathetic system — carried out by pelvic splanchnic nerves.

- There occurs dilatation of the arteries supplying the erectile tissue, and thus causes engorgement of the corpora cavernosa and corpus spongiosum, compressing the veins and thus impeding venous return and causing erection.
- Erection is maintained by contraction of the bulbospongiosus and ischiocavernosus muscles, which compresses the erectile tissues of the bulb and the crus.

Ejaculation is under sympathetic system

- Friction to the glans penis and other sexual stimuli result in excitation of sympathetic fibers.
- There occurs contraction of the smooth muscle of the epididymal ducts, the ductus deferens, the seminal vesicles, and the prostate.
- The contraction of the smooth muscles push spermatozoa and the secretions of both the seminal vesicles and prostate into the prostatic urethra, where they join secretions from the bulbourethral and penile urethral glands.
- Rhythmic contractions of the bulbospongiosus compresses the urethra and pushes and ejects the secretions from the penile urethra.
- Ejaculation is accompanied by contraction of the internal urethral sphincter (of the bladder), which prevents retrograde ejaculation of the semen into the bladder.

ASSESSMENT QUESTIONS

1. **The efferent limb of cremaster reflex is carried by:** *(NEET Pattern 2014)*
   a. Femoral branch of genitofemoral nerve
   b. Genital branch of genitofemoral nerve
   c. Ilio-inguinal nerve
   d. Pudendal nerve

ANSWER WITH EXPLANATION

1. **Ans. b. Femoral branch of genitofemoral nerve > c.Ilio-inguinal nerve**
   - The afferent limb for cremaster reflex is **femoral branch of genitofemoral nerve** (and also by **ilio-inguinal nerve** additionally) and efferent limb is carried by **genital branch of genitofemoral nerve**.
   - Cremasteric reflex involves sensory and motor fibers of the genitofemoral nerve, formed by fibers from both the L1 and L2 spinal nerves.
   - When the inner thigh is stroked, sensory fibers of the femoral branch of the genitofemoral nerve (and the ilioinguinal nerve) are stimulated.
   - These synapses in the spinal cord and activate the motor fibers of the genital branch of the genitofemoral nerve which causes the cremaster muscle to contract and elevate the testis.

Abdominal Cavity and Peritoneum

Phrenocolic ligament	Support anterior end of spleen and prevents its downwards displacement.
Lienorenal ligament	Contains splenic vessels and tail of pancreas.
Gastrosplenic ligament	Contains short gastric vessels.

Lesser/Greater Omentum

A. Lesser Omentum

- A fold of peritoneum that extends from the porta hepatis of the liver to the lesser curvature of the stomach.
- It consists of the hepatoduodenal ligament and hepatogastric ligament.

Contents:

- Along the lesser curvature of the stomach the lesser omentum contains: Right and left gastric vessels and associated gastric lymph nodes and branches of the left gastric nerve.
- The portal triad lies in the free margin of the hepatoduodenal ligament and consists of the following:
  - Common bile duct (anterior and to the right)
  - Hepatic artery (anterior and to the left)
  - Portal vein (lies posterior)

B. Greater Omentum

- A fold of peritoneum that hangs down from the greater curvature of the stomach. It is known as the **abdominal policeman** because it adheres to areas of inflammation.

High Yield Points

- The vessel traversing mesocolon is middle colic artery.
- **Left ureter** crossing the bifurcation of left common iliac artery lies behind **intersigmoid recess**, which is a surgical guide for locating left ureter.
- **Intersigmoid recess** is constantly present in the fetus and in early infancy, but **may disappear with age.**
- **Inferior mesenteric vein** is a content of **para-duodenal fossa.**
- **Denonvillier's fascia** separates posterior surface of **prostate from rectum**. It represents the obliterated rectovesical pouch of peritoneum in male.

ASSESSMENT QUESTIONS

1. **Structures injured while resecting the free edge of lesser omentum:** *(PGIC 2012)*
   a. Hepatic artery proper
   b. Portal vein
   c. Cystic duct
   d. Hepatic vein
   e. Common bile duct

2. **Lesser omentum has following contents EXCEPT:**
   a. Hepatic vein(NEET Pattern 2015)
   b. Hepatic artery
   c. Portal vein
   d. Bile duct

ANSWERS WITH EXPLANATIONS

1. **a. Hepatic artery proper; b. Portal vein; e. Common bile duct.**
   a. Free edge of lesser omentum contains the structures that enter the porta hepatis (DAV). D – Duct (Common bile), A- Artery (proper hepatic), V – Vein (portal).
   b. Cystic duct and **hepatic vein** are not the content of lesser omentum.

2. **a. Hepatic vein**
   c. Lesser omentum contains the DAV structure: D - Duct (bile), A - Artery (hepatic) and V - Vein (portal).

Greater/Lesser Sac; Morison Pouch

- Peritoneal cavity is a potential space between the visceral and parietal peritoneum.
- It is divided into the lesser sac and greater sac.

Lesser Peritoneal Sac (Omental Bursa)

- A small space behind the stomach that is also called as left posterior intraperitoneal space (LPIS).
- Lesser sac forms due to the clockwise rotation of the stomach by 90-degree during embryologic development.
- Boundaries
- Anterior wall (from above downwards)
  - Caudate lobe of liver
  - Lesser omentum
  - Stomach (postero-inferior surface)
  - Greater omentum (anterior two layers)
- Posterior wall (from below upward)
  - Greater omentum (posterior two layers)
  - Structures forming the **stomach bed** (except spleen)
    - Transverse colon.
    - Transverse mesocolon.
    - Pancreas.
    - Upper part of the left kidney and left Suprarenal gland
  - Diaphragm.
- Right border: Liver
- Left border: Gastrosplenic and splenorenal ligaments

Applied anatomy: Acute pancreatitis is probably the most common cause of a fluid collection within the lesser sac. Bleeding from trauma or a ruptured splenic artery aneurysm and perforation of a posterior gastric ulcer are other causes of lesser sac collections.

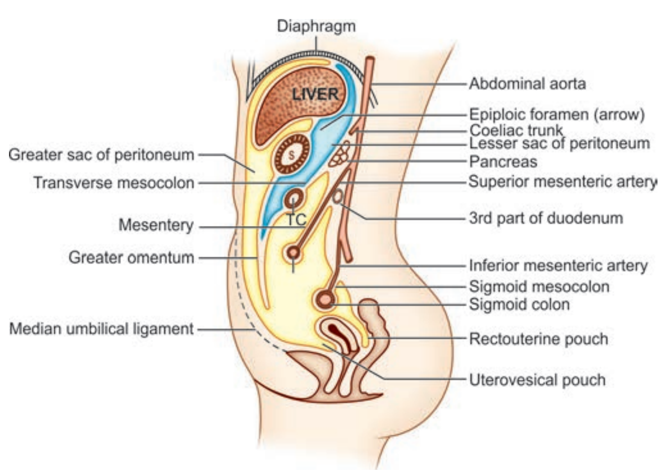


Fig. 69: Peritoneal cavity greater sac and lesser sac

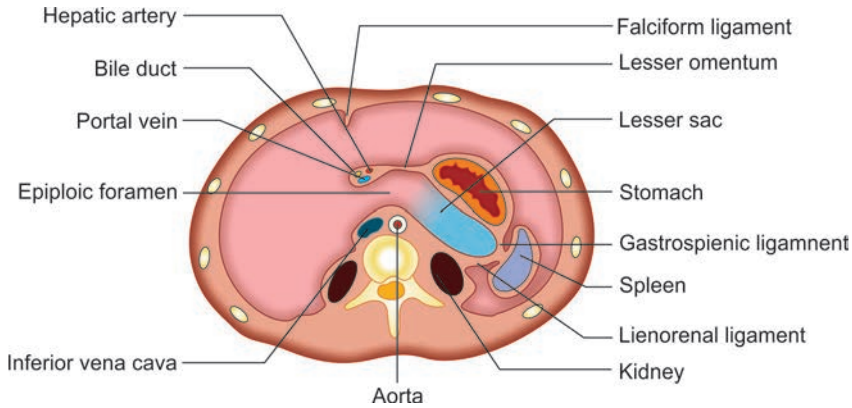


Fig. 70: Peritoneal cavity showing greater and lever sac. Epiploic foramen boundaries are also evident

Greater Peritoneal Sac

- The remainder of the peritoneal cavity and extends from the diaphragm to the pelvis.
- It contains a number of pouches, recesses, and Paracolic gutters through which peritoneal fluid circulates.
- Paracolic gutters are channels that run along the ascending and descending colon. Normally, peritoneal fluid flows upward through the paracolic gutters to the subphrenic recess, where it enters the lymphatics associated with the diaphragm.
- In supine position excess Peritoneal Fluid due to peritonitis or ascites flows upward through the paracolic gutter to the subphrenic recess and the hepatorenal recess (most dependent location).
- In upright (sitting/standing) position excess Peritoneal Fluid due to peritonitis or ascites flows downward through the paracolic gutters to the rectovesical pouch (in males) or the rectouterine pouch (in females).

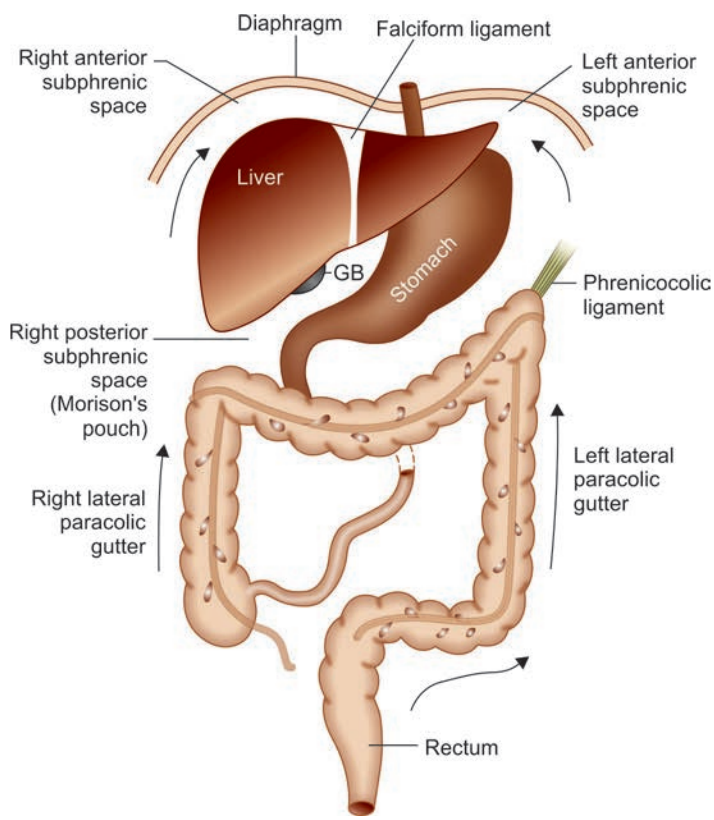


Fig. 71: Schematic diagram showing subphrenic spaces and paracolic gutters (GB = gallbladder).

Note: Rectouterine pouch of Douglas is the peritoneal space between the rectum and uterus. It is the most dependent part of the peritoneal cavity in upright position. In the supine position it is the most dependent part of the pelvic cavity.

Hepatorenal pouch (of Morison)

It is the right subhepatic space, lies between the inferior surface of the right lobe of the liver and the upper pole of the right kidney.

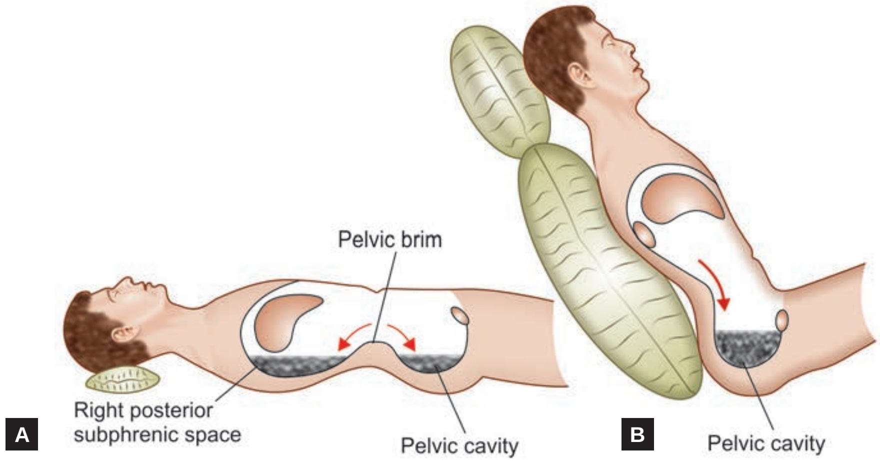


Fig. 72: Most dependent pouches of the peritoneal cavity where the fluid, or blood, or pus collects: (A) when subject is in supine position; (B) when subject is in semi-upright position.

High Yield Points

- Lesser sac (omental bursa) is also called as left posterior intraperitoneal space (LPIS) and left subhepatic space. *(JIPMER 2004)*
- Hepatorenal pouch of Morison is also called as right posterior intraperitoneal space (RPIS) or right subhepatic space. *(JIPMER 2010)*
- The **most dependent** part of abdomen in **standing position** is rectouterine pouch of Douglas. *(NBEP 2014)*
- **Pouch of Douglas** is present between *uterus and rectum*. *(NBE 2006, 2009)*
- Rectouterine pouch of Douglas lies between rectum (posteriorly) and uterus and posterior fornix of vagina (anteriorly). *(DPG 2010)*
- A posteriorly perforating ulcer in the pyloric antrum of the stomach is likely to produce initial localized peritonitis or abscess formation in the lesser sac (omental bursa). *(AI 2003, AIIMS 2004)*

ASSESSMENT QUESTIONS

1. True about boundaries of lesser sac: *(PGIC 2000)*
a. Posteriorly stomach
b. Crus of diaphragm
c. Spleen
d. Greater omentum

2. True about relation of epiploic foramen is:
a. Portal vein posterior **(NEET Pattern 2014)**
b. IVC inferior
c. Hepatic superior
d. Bile duct anterior

3. In Pringle's manoeuvre the structure ligated is:
a. Portal pedicle
b. Hepatic vein
c. Inferior vena cava
d. Cystic duct

4. Following are the boundaries of epiploic foramen EXCEPT:
a. Free margin of lesser omentum
b. Inferior vena cava
c. Quadrate lobe of liver
d. Right adrenal

5. Lesser sac of stomach is bounded by: *(PGI 2000)*
a. Posterior wall of stomach
b. Visceral surface of spleen
c. Under surface of liver
d. Greater omentum

6. Spleen projects into the following space of peritoneal cavity: *(AIIMS 2008, 11)*
a. Greater sac
b. Left subhepatic space
c. Infracolic compartment
d. Paracolic gutter

7. A posteriorly perforating ulcer in the pyloric antrum of the stomach is likely to produce initial localized peritonitis or abscess formation in the: *(AIIMS 2004)*
a. Greater sac
b. Right subhepatic/hepatorenal space (pouch of Morison)
c. Omental bursa
d. Right subphrenic space

8. A 50-year-old female presents with chronic upper GI complaints. Upper GI endoscopy shows proliferating mass in the stomach and she was eventually diagnosed to have gastric carcinoma. During surgery, before approaching the stomach, lesser omentum is seen. Free edge of lesser omentum formed by: *(JIPMER 2016)*
a. Hepatic artery
b. Portal vein
c. Bile duct
d. All of these

9. Most dependent part of abdomen in standing position is: *(NEET Pattern 2014)*
a. Vesicouterine pouch
b. Pouch of Douglas
c. Rectouterine pouch
d. b and c

ANSWERS WITH EXPLANATIONS

1. d. Greater omentum
- **Greater omentum** is present as the anterior as well as posterior boundary of lesser sac.
- Stomach is present **anterior** to lesser sac.
- Spleen and crus of diaphragm are not in relation with lesser sac.

2. d. Bile duct anterior
- Portal vein is anterior, IVC posterior and liver superior.

3.
- In Pringle manoeuvre, a large atraumatic haemostat is used to clamp the hepatoduodenal ligament (free border of the lesser omentum) interrupting the flow of blood through the hepatic artery and the portal vein and thus helping to control bleeding from the liver.
- If bleeding though continue, it is likely that the inferior vena cava or the hepatic vein were also traumatized.
- It is a temporary cross-clamping (intermittent soft vascular clamping) for control of hepatic bleeding during liver surgery or donor hepatectomy for living donor liver transplantation.

4. c. Quadrate lobe of liver
- Caudate (and **not quadrate**) lobe lies as the superior border of the epiploic foramen.

5. a. Posterior wall of stomach; c. Undersurface of liver; d. Greater omentum
- Visceral surface of spleen is not related to lesser sac.

6. d. Greater sac
- Spleen develops in the dorsal mesentery and projects into the greater sac of peritoneal cavity.
- Liver develops in the ventral mesentery and also project into the greater sac.
- Lesser sac is the smaller part of peritoneal cavity lying posterior to the stomach. It is also called as left posterior (sub-hepatic) space.
- Spleen is separated from the lesser sac by the Gastrosplenic and Lienorenal ligaments.
- Left anterior (sub-hepatic) space reaches the spleen, but spleen is not projecting into it.
- Spleen lies above the level of transverse colon and is in the supracolic compartment (and not the infracolic).
- Infracolic compartments lie below the transverse colon and are having the right and left paracolic gutters.
- This compartment extends till true pelvis. Spleen is separated from the left paracolic gutter by the phrenocolic ligament.
- Phrenocolic ligament attaches the splenic flexure of transverse colon to the diaphragm and supports the anterior end of spleen, preventing its projection into the left paracolic gutter.

7. d. Omental bursa
- A posterior perforation of ulcer in the pyloric antrum of the stomach will discharge the contents behind the stomach in the omental bursa.
- The peritonitis or abscess formation in this patient occurs in the lesser sac (Omental bursa) and not the greater sac.
- Right posterior space or right sub-hepatic space is also known as hepatorenal pouch of Morison. This is the most dependent part of the abdominal cavity and may contain pus due to spread from gallbladder/vermiform appendix, etc.
- Right anterior space or right sub-phrenic space lies between the right lobe of the diaphragm and the diaphragm.
- Peritonitis due to gallbladder or vermiform appendix occurs in this space.

8. d. All of these
- Free edge of lesser omentum contains the 'DAV' structures that enter the porta hepatis. D - Duct (bile), A - Artery (hepatic), V - Vein (portal).
- These structures form the anterior boundary of epiploic foramen.

9. d. b and c
- The most dependent part of abdomen in standing position is rectouterine pouch of Douglas.

Morison pouch/ Winslow foramen

Morison Pouch
- It is situated between the posteroinferior surface of the liver and front of the right kidney
- Boundaries
  - Anterior: Posteroinferior (visceral) surface of the liver.
  - Posterior: Peritoneum covering the front of the upper pole of the right kidney and the diaphragm.
  - Above: Posterior (inferior) layer of the coronary ligament.
  - Below: Transverse colon and mesocolon.
- Communications
  - On the left: It communicates through foramen epiploicum with the lesser sac of peritoneum (omental bursa).
  - Along the sharp inferior border of liver: It communicates with the right anterior intraperitoneal compartment.

Omental (Winslow) Foramen
- The opening (or connection) between the greater peritoneal sac and lesser peritoneal sac.
- Boundaries
- Anterior: Free margin of lesser omentum containing DAV (Duct, Artery, Vein)
- Posterior: T12 vertebra, with IVC and right adrenal gland
  - Superior: Liver (1st part, caudate lobe)
  - Inferior: Duodenum (1st part)

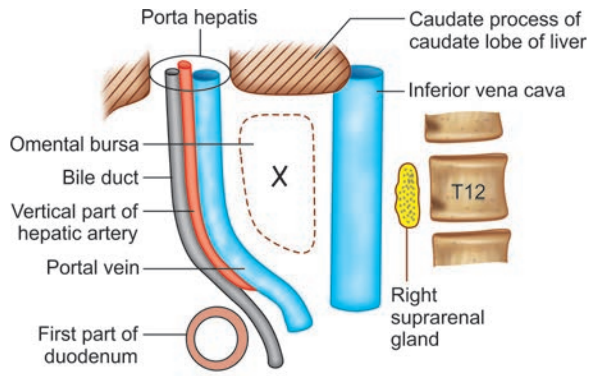


Fig. 73: Boundaries of the foramen epiplocuim

Root of Mesentery

A. Attached border

- It is attached to an oblique line across the posterior abdominal wall, extending from the duodenojejunal junction to the ileocecal junction.
- The duodenojejunal junction lies to the left side of L2 vertebra, whereas the ileocaecal junction lies in right iliac fossa, at the upper part of the right sacroiliac joint.
- The root of mesentery from above downward crosses in front of:
- Horizontal (third) part of duodenum
- Abdominal aorta
- Inferior vena cava
- Right gonadal vessels
- Right ureter
- Right psoas major muscle

Note: The root of mesentery divides the infracolic compartment into two parts: right and left. The right one is small and terminates in the right iliac fossa. The left one is larger and passes without interruption into true pelvis.

B. Free border (intestinal border)

- **It is about 6 m (20 feet) long** and encloses the jejunum and ileum.
- The root of mesentery is 6 inches (15 cm) long whereas its periphery (free border) is 6 m long. This accounts for the formation of folds (pleats) in it (a frill-like arrangement).
- It has fat deposition along its root, which diminishes toward the intestinal border. Near the intestinal border it presents fat-free windows (translucent are of peritoneum. The amount of fat is greater in the distal part of the mesentery.

C. Contents of mesentery:

- Superior mesenteric artery and vein (in the root) and its jejunal, ileal branches.
- Jejunum and ileum (enclosed in the free border)
- Lymph nodes (100–200 in number) and lymphatics
- Autonomic nerve plexuses
- Fat and connective tissue

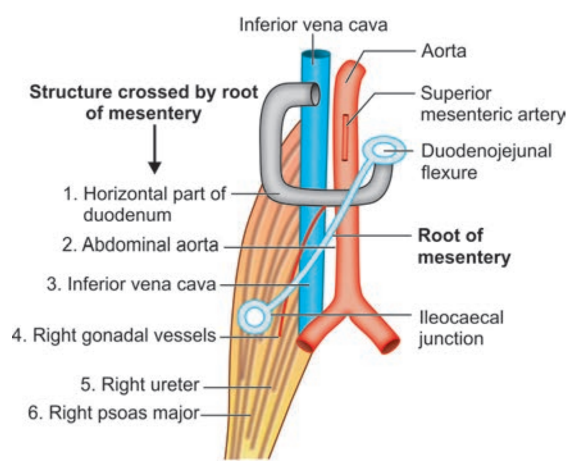


Fig. 74: Structures crossed by the root of the mesentery.

ASSESSMENT QUESTIONS

1. The mesentery of small intestine, along its attachment to the posterior abdominal wall, crosses all or the following structures EXCEPT: *(AIIMS 2004, AIPG 2011)*
   a. Left gonadal vessels
   b. Third part of duodenum
   c. Aorta
   d. Right ureter

ANSWERS WITH EXPLANATIONS

1. a. Left gonadal vessels
   a. The root of mesentery lies on the right side of abdominal cavity and crosses right **gonadal vessels (not left).**
   b. The root of the mesentery lies along a line running diagonally from the duodenojejunal flexure on the left side of the second lumbar vertebral body to the right sacroiliac joint.
   c. It crosses over the third (horizontal) part of the duodenum, aorta, inferior vena cava, right ureter and right psoas major.
   d. It does not cross the **left ureter, left gonadal vessels or superior mesenteric artery.**
   e. Superior mesenteric artery is a **content** of the mesentery**.**

Sigmoid Mesocolon

- The sigmoid mesocolon is a triangular fold of peritoneum, which suspends the sigmoid colon from the pelvic wall. The attachment of the root of sigmoid mesocolon onto the pelvic wall takes the form of an inverted 'V', the apex of which lies at the division of the left common iliac artery. The intersigmoid recess of peritoneum is found at the apex of the V-shaped attachment and the left ureter lies behind the peritoneum of this recess.
- The left limb of V is attached along the upper half of the left external iliac artery and the right limb to the posterior pelvic wall extending downward and medially from the apex to the median plane of sacrum up to the level of S3 vertebra.

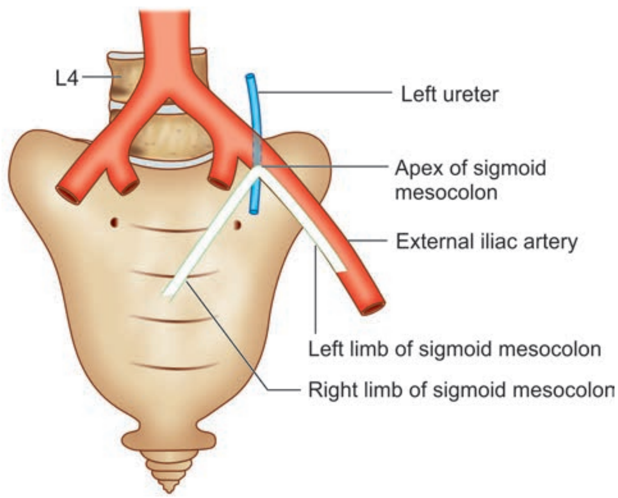


Fig. 75: Attachments of the root of sigmoid mesocolon.

Mesorectum

ASSESSMENT QUESTIONS

1. Contents of mesorectum are of EXCEPT: *(AIIMS 2013,15)*
   a. Inferior rectal vein
   b. Superior rectal vein
   c. Para rectal node
   d. Inferior mesenteric plexus

ANSWERS WITH EXPLANATIONS

1. a. Inferior rectal vein
   - Inferior rectal vein is not a content of mesorectal fascia.
   - The mesorectum (mesentery of the rectum) and its contents are intimately related to the rectum down to the level of levator ani. Mesorectum contains superior rectal artery and its branches, superior rectal vein and its tributaries, lymphatic vessels and nodes that lie along the superior rectal artery. It also contains branches from the inferior mesenteric plexus which descend to innervate the rectum and loose adipose connective tissue.

Spleen: Peritoneal Connections

- **Peritoneal connections of the spleen:** The peritoneal connections of the spleen anchor it in the left upper quadrant of the abdomen; they include the gastrosplenic, splenorenal and phrenicocolic ligaments.
- The gastrosplenic ligament runs between the greater curvature of the stomach and the hilum of the spleen, and is in continuity with the left side of the greater omentum.
- The peritoneal layers of the gastrosplenic ligament separate to enclose the spleen and then rejoin to form the splenorenal and phrenicocolic ligaments.
- The splenorenal ligament extends from the spleen to the posterior abdominal wall, and the phrenicocolic ligament connects the splenic flexure of the colon to the diaphragm.
- The splenorenal ligament is formed from two layers of peritoneum.
- The anterior layer is continuous medially with the peritoneum of the posterior wall of the lesser sac over the left kidney and runs up to the splenic hilum, where it is continuous with the posterior layer of the gastrosplenic ligament.
- The posterior layer of the splenorenal ligament is continuous laterally with the peritoneum over the inferior surface of the diaphragm and runs on to the splenic surface over the renal impression.
- The splenic vessels lie between the layers of the splenorenal ligament, and the tail of the pancreas is usually present in its lower portion.
- The gastrosplenic ligament is also formed from two layers of peritoneum.
- The posterior layer is continuous with the peritoneum of the splenic hilum and the peritoneum over the posterior surface of the stomach.
- The anterior layer is continuous with the peritoneum reflected off the gastric impression of the spleen and with the peritoneum over the anterior surface of the stomach.
- The short gastric and left gastroepiploic branches of the splenic artery, with their corresponding veins, pass between the layers of the gastrosplenic ligament.
- A fan-shaped fold of peritoneum often extends from the anterior aspect of the gastrosplenic ligament below the inferior pole of the spleen and blends with the phrenicocolic ligament. The phrenicocolic ligament

Peritoneal Spaces

- Peritoneal cavity can be divided into several spaces and pathological processes are often contained within these spaces.
- Peritoneal cavity into two main compartments, supramesocolic (supracolic) and inframesocolic (or infracolic), which are partially separated by the transverse colon and its mesentery.
- Supracolic compartment has a number of spaces: 1. Right subphrenic space; 2. Right subhepatic space (Hepato-renal pouch of Morison); 3. Lesser sac; 4. Left subphrenic space; 5. Left subhepatic space. Infracolic compartment spaces: 1. Right para-colic gutter; 2. Left para-colic gutter.
- The right paracolic gutter is continuous with the right supracolic compartment, and hence, bile/pus/blood released from viscera above can reach inferiorly till the pelvic cavity. For example. Tracking of pus in gastric ulcer perforation:
- Pus of gastric antral perforation moves into lesser sac → Epiploic foramen → Hepatorenal pouch of Morison (supra-colic compartment) → Right paracolic gutter (Infracolic compartment) → Pouch of Douglas (pelvic cavity).
- The peritoneal cavity is a single continuous space between the parietal peritoneum lining the abdominal wall and the visceral peritoneum enveloping the abdominal organs.
- It consists of the greater sac, which is the main peritoneal cavity surrounding most of the abdominal and pelvic viscera, and the lesser sac, or omental bursa, which is a small diverticulum situated behind the stomach and lesser omentum and in front of the pancreas.
- These two sacs communicate via the epiploic foramen.

For clinical purposes, the

The pelvic peritoneal spaces are described above.

Supramesocolic Compartment

- This lies between the diaphragm and the transverse mesocolon.
- It can be arbitrarily divided into right and left supramesocolic spaces.
- The right supramesocolic space can be subdivided into the right subphrenic space, the right subhepatic space and the lesser sac.
- The left supramesocolic space can be divided into two subspaces: the left subphrenic space and the left perihepatic space. These 'spaces' usually communicate but may nevertheless be sites of localized fluid collections.

Right subphrenic space

- The right subphrenic space lies between the diaphragm and the anterior, superior and right lateral surfaces of the right lobe of the liver.
- It is bounded on the left by the falciform ligament and posteriorly by the upper layer of the coronary ligament.
- Because of the clockwise flow of peritoneal fluid from the lower abdomen and pelvis, it is a relatively common site for an infected fluid collection after a perforated appendicitis or duodenal ulcer.

Right subhepatic space (Hepatorenal pouch)

- The right subhepatic space lies between the inferior surface of the right lobe of the liver and the upper pole of the right kidney.
- It is bounded superiorly by the inferior layer of the coronary ligament, laterally by the right lateral abdominal wall, posteriorly by the anterior surface of the upper pole of the right kidney, and inferomedially by the hepatic flexure, transverse mesocolon, second part of the duodenum, and part of the head of the pancreas.
- In the supine position, the hepatorenal pouch (of Morison) is more dependent than the right paracolic gutter.
- It is a site where a pathological fluid collection may develop.
- **Lesser sac (omental bursa)** The lesser sac is a cavity lined with peritoneum and connected to the main peritoneal cavity (greater sac) by the epiploic foramen (of Winslow).
- It is considered part of the right supramesocolic compartment because it develops in the embryo on the right side of the ventral mesogastrium (p. 1059).
- It has posterior and anterior walls and superior, inferior, right and left borders.
- The sac varies in size according to the volume of the viscera making up its walls; it may be partially obliterated by natural adhesions between the anterior and posterior walls.
- The anterior wall of the lesser sac consists of the posterior peritoneal layer of the lesser omentum, the peritoneum over the posterior wall of the stomach and first part of the duodenum, and the posterior upper part of the anterior sheet of the greater omentum.
- At its right border, the anterior wall is mostly formed by the lesser omentum but, towards the left, the lesser omentum becomes progressively shorter and more of the anterior wall is formed by the posterior surface of the stomach and greater omentum.
- The lower part of the posterior wall of the lesser sac is formed by the anterior peritoneal layer of the posterior sheet of the greater omentum, which overlies the transverse mesocolon.
- More superiorly, the peritoneum of the posterior wall covers, from below upwards, a small part of the head and the whole neck and body of the pancreas, the medial part of the anterior aspect of the upper pole of the left kidney, most of the left suprarenal gland, the commencement of the abdominal aorta, the coeliac trunk and part of the diaphragm.
- The inferior phrenic, splenic, left gastric and common hepatic arteries lie partly behind the bursa.
- Many of these structures form the ‘bed’ of the stomach and are separated from it only by the linings of the lesser sac.
- The superior border of the lesser sac is narrow and lies between the right side of the oesophagus and the upper end of the fissure for the ligamentum venosum; it is sometimes referred to as the superior recess of the omental bursa.
- Here, the peritoneum of the posterior wall of the lesser sac is reflected anteriorly from the diaphragm to join the posterior layer of the lesser omentum.
- The inferior border runs along the line of fusion of the layers of the greater omentum, which extends from the gastrosplenic ligament on the left to the peritoneal fold behind the first part of the duodenum on the right.
- If the layers of the greater omentum are not completely fused, the lesser sac may extend to the inferior limit of this structure, but this is rarely demonstrable at surgery.
- The right border of the lesser sac is where the peritoneum overlying the head and neck of the pancreas is reflected on to the inferior aspect of the first part of the duodenum.
- The line of this reflection ascends to the left, along the medial side of the gastroduodenal artery.
- Near the upper duodenal border, the right border joins the floor of the epiploic foramen round the hepatic artery proper.
- The epiploic foramen therefore interrupts the right border.
- Above the epiploic foramen, the right border is formed by the peritoneal reflection from the diaphragm to the right margin of the caudate lobe of the liver, which then crosses the inferior vena cava.
- The left border of the lesser sac runs from the left end of the root of the transverse mesocolon and is mostly formed by the inner peritoneal layers of the splenorenal and gastrosplenic ligaments.
- The part of the lesser sac lying between the splenorenal and gastrosplenic ligaments is referred to as the splenic recess.
- Above the spleen, the two ligaments merge to form the short gastrophrenic ligament, which passes forwards from the diaphragm to the posterior aspect of the fundus of the stomach and forms part of the upper left border of the lesser sac.
- The two layers of the gastrophrenic ligament diverge near the abdominal oesophagus, leaving part of the posterior gastric surface devoid of peritoneum. The left gastric artery runs forwards here into the lesser omentum.
- The lesser sac is indented by a crescentic peritoneal fold that runs from the upper border of the neck of the pancreas to the upper part of the lesser curvature of the stomach.
- It is variably described but commonly known as the gastropancreatic fold.
- The upper part of this fold overlies the left gastric artery as it runs from the posterior abdominal wall to the lesser curvature of the stomach.
- The lower part of the fold overlies the common hepatic artery as it runs from the posterior abdominal wall to the lesser omentum.
- When the fold is prominent, it divides the lesser sac into a smaller superior and a larger inferior recess.
- The superior recess lies posterior to the lesser omentum and encloses the caudate lobe of the liver; it extends superiorly into the fissure for the ligamentum venosum and lies adjacent to the right crus of the diaphragm posteriorly.
- The inferior recess of the lesser sac lies between the stomach and pancreas, and is contained within the double sheet of the greater omentum.

- Acute pancreatitis is probably the most common cause of a fluid collection within the lesser sac (or just behind its posterior peritoneal lining) (p. 1182).
- Bleeding from trauma or a ruptured splenic artery aneurysm and perforation of a posterior gastric ulcer are other causes of lesser sac collections.

Epiploic foramen

- The epiploic foramen (foramen of Winslow or aditus to the lesser sac) is a short, vertical slit, about 3 cm in height in adults, behind the free right border of the lesser omentum.
- It is the entrance to the lesser sac from the greater sac.
- The hepatoduodenal ligament, formed by the thickened free right margin of the lesser omentum and extending between the porta hepatis above and the upper border of the first part of the duodenum below, forms the anterior boundary of the foramen. Within this free border lie the bile duct (anteriorly on the right), the hepatic artery (anteriorly on the left) and the portal vein (posteriorly), together with nerves and lymphatics (see above).
- Rapid control of the hepatic artery and portal vein can be obtained by compression of the free edge of the lesser omentum (a 'Pringle' manoeuvre), which is a potentially useful technique in liver trauma and surgery. Superiorly, the peritoneum of the posterior layer of the hepatoduodenal ligament runs over the caudate process of the liver, forming the roof of the epiploic foramen.
- This layer of peritoneum is then reflected on to the inferior vena cava, which forms the posterior border of the foramen.
- The floor of the foramen is formed by the peritoneal reflection overlying the upper border of the first part of the duodenum as it runs forwards above the head of the pancreas.
- A narrow passage, the vestibule of the lesser sac, may be formed to the left of the foramen between the caudate process above and the first part of the duodenum below.
- To the right, the rim of the foramen is continuous with the peritoneum of the greater sac.
- The anterior and posterior walls of the foramen are normally apposed, which partly explains why patients can develop large fluid collections isolated to the greater or lesser sac (Shrestha et al 2010).

Left subphrenic space

- The left subphrenic space lies between the diaphragm, the anterior and superior surfaces of the left lobe of the liver, the anterosuperior surface of the stomach and the diaphragmatic surface of the spleen.
- To the right it is bounded by the falciform ligament.
- It is expanded in the absence of the spleen and is a common site for fluid collection after splenectomy.
- The left subphrenic space is substantially larger than the right and can be divided into a left perihepatic space and anterior and posterior subphrenic spaces; these are in continuity in the absence of disease.
- The definitions of the boundaries of these spaces vary.
- The left anterior subphrenic space is large and lies between the superior and anterolateral surfaces of the spleen and the diaphragm.
- Inferiorly and medially, this space is bounded by the phrenicocolic, splenorenal and gastrosplenic ligaments.
- The phrenicocolic ligament partially obstructs the flow of fluid from the left paracolic gutter (Meyers 1973), which may explain why left subphrenic collections are less frequent than right subphrenic collections after lower abdominal and pelvic surgery.
- Nevertheless, the left subphrenic space is a relatively common site of fluid collection after upper abdominal surgery, particularly surgery involving the spleen or distal pancreas.
- The left posterior subphrenic space is small and lies between the fundus of the stomach and the diaphragm above the origin of the splenorenal ligament.
- The left perihepatic space is sometimes subdivided into anterior and posterior spaces.
- The left anterior perihepatic space lies between the Free tumour cells in the peritoneal cavity, especially from mucinous tumours, may gain access to the lesser sac and settle by gravity into the inferior recess of the lesser sac.
- This is more likely on the right side of the lesser sac in an area recognized surgically as the 'subpyloric space'. Growth of tumour at this site may cause gastric outlet obstruction.
- During surgical exploration of the abdomen, some peritoneal surfaces cannot be visualized without the aid of specific surgical manoeuvres.
- One of these sites is the posterior aspect of the hepatoduodenal ligament.
- The recess created by the posterior aspect of the hepatoduodenal ligament and the caudate process is an important site for mucinous peritoneal metastases.
- It can be visualized during cytoreductive surgery by passing a tape around the structures in the free edge of the lesser omentum and retracting them forwards. anterosuperior surface of the left lobe of the liver and diaphragm.
- The left posterior perihepatic space, also known as the gastrohepatic recess, lies inferior to the left lobe of the liver.
- It extends into the fissure for the ligamentum venosum on the right. Posteriorly, it is separated from the superior recess of the lesser sac by the lesser omentum.

Extraperitoneal subphrenic spaces

- There are two potential subphrenic spaces that actually lie outside the peritoneum but are of clinical relevance because they may be sites of fluid accumulation.
- The right extraperitoneal space is bounded by the two layers of the coronary ligament, the bare area of the liver, and the inferior surface of the right hemidiaphragm.
- The left extraperitoneal space lies anterior to the left suprarenal gland and upper pole of the left kidney.

Paracolic Gutters

- The right and left paracolic gutters are peritoneal depressions on the posterior abdominal wall alongside the ascending and descending colon, respectively.
- The principal paracolic gutter lies lateral to the colon on each side.
- A less obvious medial paracolic gutter may be present, more often on the right side, if the ascending or descending colon possesses a short mesentery for part of its length.
- The right (lateral) paracolic gutter runs from the superolateral aspect of the hepatic flexure of the colon, down the lateral aspect of the ascending colon and caecum.
- It is continuous with the peritoneum of the pelvic cavity below.
- Superiorly, it is continuous with the peritoneum that lines the hepatorenal pouch and with the lesser sac through the epiploic foramen.
- Bile, pus, blood or other fluid may run along the gutter and collect in sites distant to the organ of origin.
- In supine patients, infected fluid from the right iliac fossa may ascend in the gutter to the right subphrenic space.
- In erect or semi-recumbent positions, fluid from the stomach, duodenum or gallbladder may run down the gutter to collectin the right iliac fossa (mimicking acute appendicitis) or pelvis to form an abscess.
- The right paracolic gutter is deeper than the left, which, together with the partial barrier provided by the phrenicocolic ligament, may explain why subphrenic collections are more common on the right.

Recesses of the Peritoneal Cavity

- Peritoneal fossae or recesses within the peritoneal cavity are occasionally sites of internal herniation.
- If a loop of intestine becomes stuck in fossa or recess, the bowel may become obstructed or strangulate from a constriction at the entrance to the recess.
- The contents of the peritoneal fold forming the fossa/recess must be considered when repairing such a hernia.

Lesser sac

- Although not usually classified as a peritoneal recess, the lesser sac may be a site of internal herniation.
- There are reports of the small intestine, caecum, transverse colon or gallbladder migrating through the epiploic foramen into the lesser sac and causing acute abdominal symptoms.
- The distribution of peritoneal metastases via the paracolic gutters is not the same on each side.
- Peritoneal fluid usually tracks freely along the right paracolic gutter, whereas the flow of peritoneal fluid running down the left paracolic gutter from the upper abdomen will be impeded by any attachments of the sigmoid colon to the left abdominal wall.
- Cancer deposits at this site tend to invade the mesentery of the junction between the sigmoid and descending colon, and therefore necessitate sigmoid colectomy for tumour clearance.
- The superior and inferior recesses of the duodenum may be sites of occult peritoneal metastases and must be examined in patients having surgery for peritoneal metastases.

Peritoneal fluid collections

- Fluid collections frequently develop within the peritoneal cavity in response to a wide range of pathological processes.
- In the absence of inflammation, peritoneal adhesions or previous surgery, serous fluid tends to be distributed widely between the peritoneal spaces.
- Simple ascites can therefore be drained freely from any convenient dependent part of the peritoneal cavity; drainage is most commonly performed by blind puncture or ultrasound-guided insertion of a catheter into the lower left or right paracolic gutters.
- The mobility of the small bowel makes it very unlikely to be injured during this procedure.
- Fluid collections caused by inflammatory processes are often much thicker because they contain pus, fibrin or blood.
- Furthermore, they are usually associated with peritoneal adhesions arising from peritoneal inflammation.
- These factors predispose to the formation of localized fluid collections, which may become walled-off as the inflammatory process progresses.
- Any of the peritoneal spaces may develop a localized collection, but the subphrenic, subhepatic and pelvic spaces are the most common sites since they are well defined by peritoneal folds and organs forming their boundaries.
- These spaces are also the most dependent regions within the peritoneal cavity.
- Surgical access to the peritoneal spaces is less often needed today because of advances in radiologically guided percutaneous drainage using fluoroscopy, ultrasound, computed tomography (CT) or magnetic resonance imaging (MRI) guidance.
- These techniques offer reliable and versatile methods of accessing peritoneal spaces, including relatively inaccessible subhepatic, perihepatic or intermesenteric collections.

- Posterolateral translumbar or trans-sciatic approaches can also be used to access the retroperitoneum and pelvis, respectively.
- Occasionally, a surgical approach is necessary; thus, a subcostal or lateral intercostal incision may be required to drain a subphrenic abscess or an inguinal incision to drain a pelvic abscess.

ASSESSMENT QUESTIONS

1. Which of the following is TRUE about location of omental bursa: *(JIPMER-04)*
a. Left subhepatic
b. Left subphrenic
c. Right subhepatic
d. Right subphrenic

2. Lesser omentum has following contents EXCEPT: *(All India Dec 14 Pattern)*
a. Hepatic vein
b. Hepatic artery
c. Portal vein
d. Bile duct

3. Lesser sac of stomach is bounded by: *(PGI 2000)*
a. Posterior wall of stomach
b. Visceral surface of spleen
c. Under surface of liver
d. Greater omentum

4. A posteriorly perforating ulcer in the pyloric antrum of the stomach is likely to produce initial localized peritonitis or abscess formation in the: *(AIIMs Nov 04, AI 03)*
a. Greater sac
b. Left subhepatic and hepatorenal spaces (pouch of Morison)
c. Omental bursa
d. Right subphrenic space

5. All are true about boundaries of epiploic foramen EXCEPT: *(CET July 15 Pattern)*
a. Anterior portal vein and hepatic artery.
b. Posterior : IVC
c. Inferior: liver
d. Inferior: duodenum

6. Which of the following is true about location of Omental Bursa: *(JIPMER 04)*
a. Left sub hepatic
b. Left sub phrenic
c. Right sub hepatic
d. Right sub phrenic

7. Pouch of Douglas is situated between: *(DPG 10)*
a. Bladder and the uterus
b. Bladder and pubic symphysis
c. Bladder and the rectum
d. Uterus and rectum

8. Most dependent part of abdomen in standing position is:
a. Vesicouterine pouch(All India Dec 13 Pattern)
b. Pouch of Douglas
c. Rectouterine pouch
d. b and c

9. Subdiaphragmatic right posterior intraperitoneal space is: *(JIPMER 10)*
a. Lesser sac
b. Morison's pouch
c. Hepatorenal pouch
d. Superior part of supracolic compartment

10. Morison's pouch is: *(CET July 15 Pattern)*
a. Right subphrenic space
b. Right subhepatic space
c. Left subhepatic space
d. Left subphrenic space

11. Which of the following veins is found in relation to the paraduodenal fossa: *(AI 08)*
a. Inferior mesenteric vein
b. Middle colic vein
c. Left colic vein
d. Splenic vein

12. Which of the following peritoneal recesses is constantly present in infants but disappears with age: *(Delhi 06)*
a. Intersigmoid recess
b. Superior ileocecal recess
c. Inferior ileocecal
d. Superior duodenal recess

13. Which structure lies in the intersigmoid recess: *(PGI 95)*
a. Left ureter
b. Left ureter and left common Iliac artery
c. Left ureter and left common iliac vein
d. Left ureter, left common Iliac artery and left common Iliac vein

14. In which of the following vessels transverse mesocolon seen: *(All India Dec 13 Pattern)*
a. Right colic artery
b. Left colic artery
c. Middle colic artery
d. Iliocolic artery

15. Contents of mesorectum are of EXCEPT: *(AIIMS Nov. 13)*
a. Inferior rectal vein
b. Superior rectal vein
c. Pararectal node
d. Inferior mesenteric plexus

16. Fascia of Denon villiers: *(Karn 94)*
a. Membranous layer of fascia of the thigh
b. Perirenal fascia
c. Fascia between the rectal ampulla and the prostate and the seminal

ANSWERS WITH EXPLANATIONS

1. a. Left subhepatic
- Left subhepatic space is the other name for the lesser sac (omental bursa).
- Right subhepatic space is the hepatorenal pouch of Morison.

2. a. Hepatic vein
- Right tree margin of lesser omentum contains:- (i) Hepatic artery proper, (ii) Portal vein, (iii) Bile duct,(iv) Lymph nodes and lymphatics,and (v) Hepatic plexus of nerves.

3. a. Posterior wall of stomach ; 'c' ie., Under surface of liver and 'd' ie., Greater omentum (

- Boundaries of lesser sac are:-
  1. Anterior wall :- Caudate lobe of liver,stomach,lesser omentum,and 2nd layer of greater omentum.
  2. Posterior wall:- 3rd layer of greater omentum, and structures forming stomach bed (transverse colon, transverse mesocolon, diaphragm,left kidney,left suprarenal gland, pancreas and splenic vessels).
  3. Right border:- Right free margin of greater omentum and floor of epiploic foramen
  4. Left border:- Left free margin of greater omentum;gastrosplenic, linorenal and gastrophrenic ligaments.
  5. Upper border:- reflection of peritoneum from esophagus to diaphragm
  6. Lower border:- Continuation of 2nd and 3rd layers of greater omentum.

4. c. Omental bursa

- A posterior gastric ulcer may perforate into the lesser sac (omental bursa).
- The leaking fluid passes out through epiploic foramen to reach the hepatorenal pouch.
- Sometimes in these cases the epiploic foramen is closed by adhesions.
- Then the lesser sac becomes distended,and can be drained by a tube passed through the lesser omentum.

5. c. Inferior liver

- Epiploic foramen (foramen of winslow or aditus to lesser sac) is a slit like opening through which lesser sac communicates with greater sac. It is situated at the level of T12 vertebra.Its boundaries are :-
- Anterior :- Right free margin of lesser omentum (contains portal vein,hepatic artery proper and bile duct).
- Posterior:- IVC,right suprarenal gland and T12 vertebra
- Superior:- Caudate lobe of liver
- Inferior:- 1st part of duodenum and horizontal part of hepatic artery.

6. a. Left subhepatic space

- Lesser sac (Omental bursa) is left posterior intraperitoneal space, also called left subhepatic space.

7. c. Uterus and rectum

- In females rectouterine pouch (pouch of Douglas) lies between rectum (posteriorly) and uterus and posterior fornix of vagina (anteriorly).

8. d. b and c

- The rectovesical pouch (in males) and rectouterine pouch (in females) are the most dependent portions of peritoneal cavity in erect posture.

9. b. Morrison's pouch

- Right posterior intraperitoneal space or right subhepatic space is hepatorenal pouch of Morrison.

10. b. Right subhepatic space

11. a. Inferior mesenteric vein

- Inferior mesenteric vein lies in the free edge of the peritoneal fold of paraduodenal recess.

12. a. Intersigmoid recess

- Intersigmoid recess is constantly present in the foetus and in early infancy, but may disappear with age.

13. a. Left ureter

- Left ureter crossing the bifurcation of left common iliac artery lies behind intersigned recess, which is a surgical guide for locating left ureter.

14. c. Middle colic artery

Mesentery of gut	Vessels contained by mesentery
Mesentery proper (Mesentery of small intestine)	Jejunal and ileal branches of superior mesenteric vessels
Transverse mesocolon	Middle colic vessel
Mesoappendix	Appendicular vessels
Sigmoid mesocolon	Sigmoid vessels

15. a. Inferior rectal vein

- Mesorectum does not contain inferior rectal vein
- Mesorectum contains superior rectal artery ,branches from the inferior mesenteric plexus which descend to innervate the rectum and loose adipose connective tissue.

16. c. Fascia between the rectal ampulla and the prostate and the seminal vesicles

- Posterior surface of prostate is separated from rectum by the fascia of Denonvilliers which is the obliterated rectovesical pouch of peritoneum.

Gut tube

Stomach

Arterial supply

The arterial supply of the stomach is from the following.

- **Right and left gastric arteries** which supply the lesser curvature (abdominal aorta → celiac trunk → common hepatic artery → right gastric artery; abdominal aorta → celiac trunk → left gastric artery).
- **Right and left gastroepiploic arteries** which supply the greater curvature (abdominal aorta → celiac trunk → common hepatic artery → gastroduodenal artery → right gastroepiploic artery; abdominal aorta → celiac trunk → splenic artery → left gastroepiploic artery).
- **Short gastric arteries** which supply the fundus (abdominal aorta → celiac trunk → splenic artery → short gastric arteries).

Venous drainage

- The venous drainage of the stomach is to the following.
- **Right and left gastric veins** (right and left gastric veins → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava).
- **Left gastroepiploic vein** and **short gastric veins** (left gastroepiploic vein and short gastric veins → splenic vein → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava).
- **Right gastroepiploic vein** (right gastroepiploic vein → superior mesenteric vein → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava).

Innervation

- The innervation of the stomach is by the **enteric nervous system** which in the stomach consists of the myenteric plexus of Auerbach only. The enteric nervous system is modulated by the parasympathetic and sympathetic nervous systems.
- **Parasympathetic**
  - Preganglionic neuronal cell bodies are located in the **dorsal nucleus of the vagus**. Preganglionic axons run in CN X and enter the **anterior and posterior vagal trunks**.
  - Postganglionic neuronal cell bodies are located in the enteric nervous system, some of which are the "traditional" postganglionic parasympathetic neurons that release ACh as a neurotransmitter.
  - The postganglionic axons terminate on mucosal glands and smooth muscle.
- **Sympathetic**
  - Preganglionic neuronal cell bodies are located in the **intermediolateral cell column** of the spinal cord (T5 to T9). Preganglionic axons form the **greater splanchnic nerve**.
  - Postganglionic neuronal cell bodies are located in the **celiac ganglion**.
  - Postganglionic axons synapse in the complex circuitry of the enteric nervous system.

Clinical Considerations

- **Gastric ulcers** most often occur within the **body of the stomach** along the **lesser curvature** above the **incisura angularis**.
- **Carcinomas of the stomach** are most commonly found in the **pylorus** of the stomach and may metastasize to **supraclavicular lymph nodes (Virchow nodes)** on the left side which can be palpated within the posterior triangle of the neck. Carcinomas of the stomach may also metastasize to the ovaries where it is called a **Krukenberg tumor**.

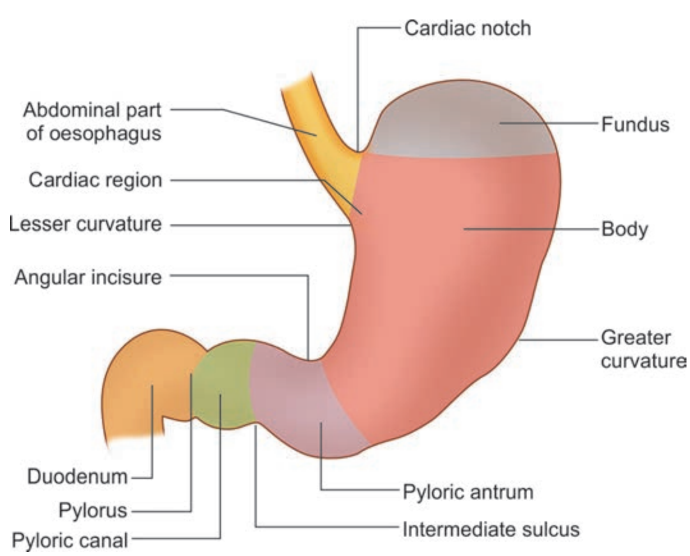


Fig. 76: The parts of the stomach

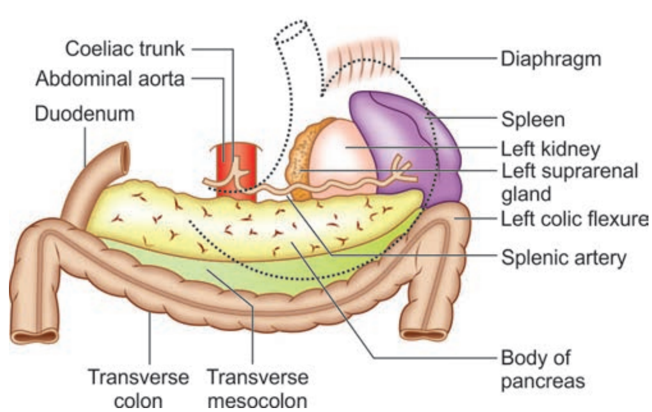


Fig. 77: The "Stomach bed"

Stomach bed:
- Diaphragm.
- Left kidney.
- Left suprarenal gland.
- Pancreas.
- Transverse mesocolon.
- Left colic flexure (splenic flexure of colon).
- Splenic artery.
- Spleen.
- Pancreas (**except tail)** is in the posterior relation of stomach. (Kerala 2001)
- Splenic artery (and not **vein**) is in the posterior relation of stomach.

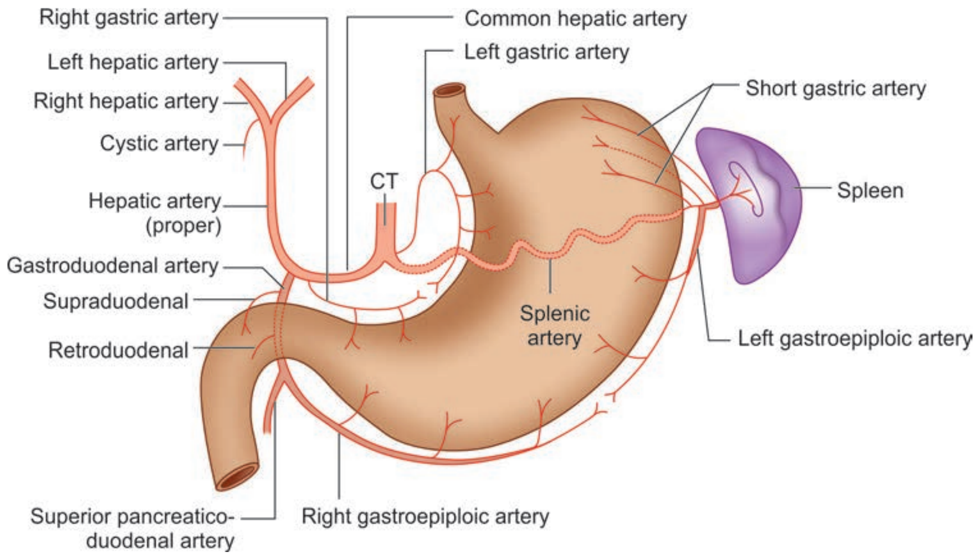


Fig. 78: Arteries of the stomach (CT = coeliac trunk).

- Posterior gastric artery is a branch of splenic artery (JIPMER 2008)
- The left gastric artery usually arises directly from the coeliac trunk. The short gastric arteries, left gastroepiploic artery and, when present, the posterior gastric artery are branches of the splenic artery. The right gastric artery and right gastroepiploic artery arise from the hepatic artery and its gastroduodenal branch, respectively.
- The left gastroepiploic artery is the largest branch of the splenic artery.

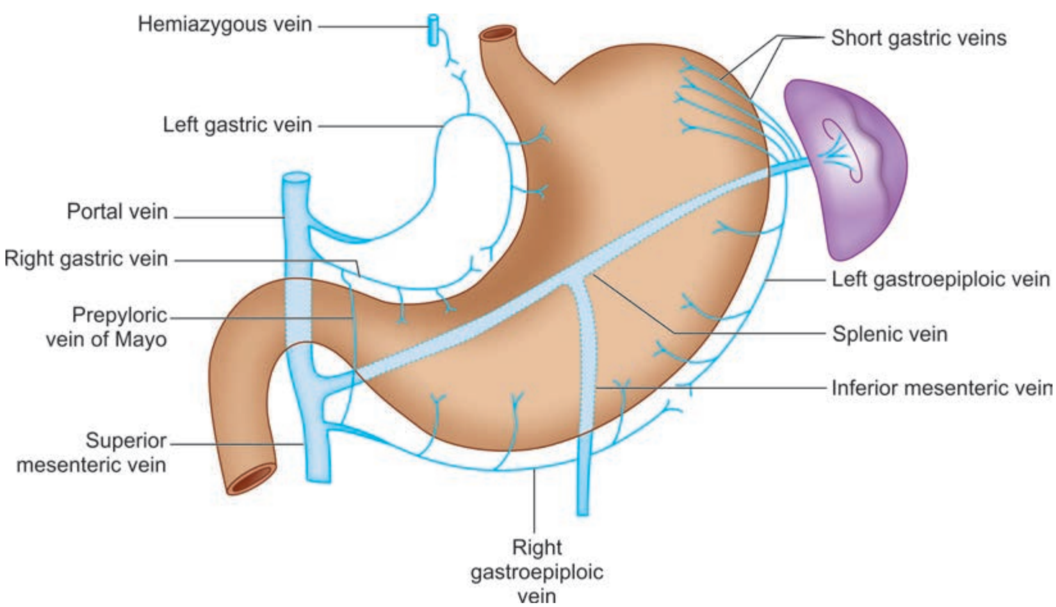
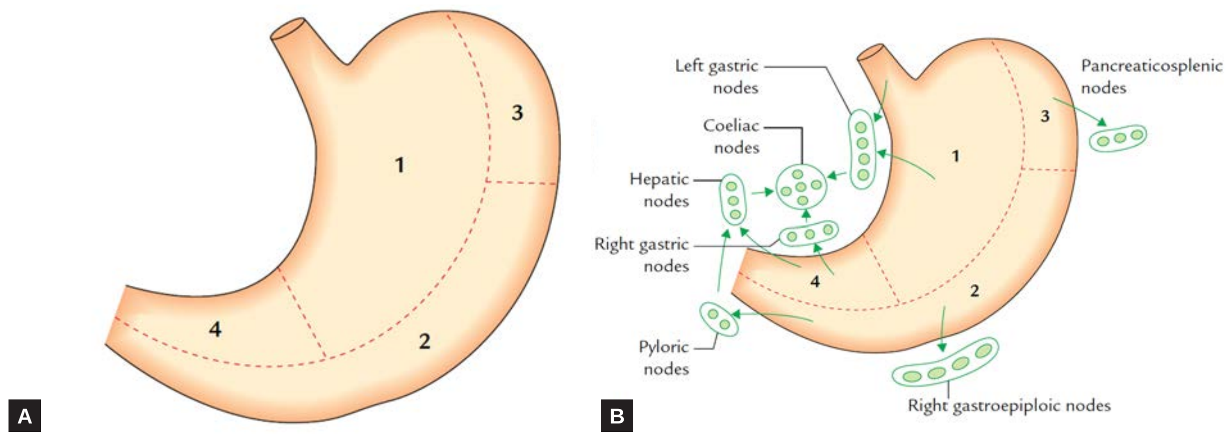
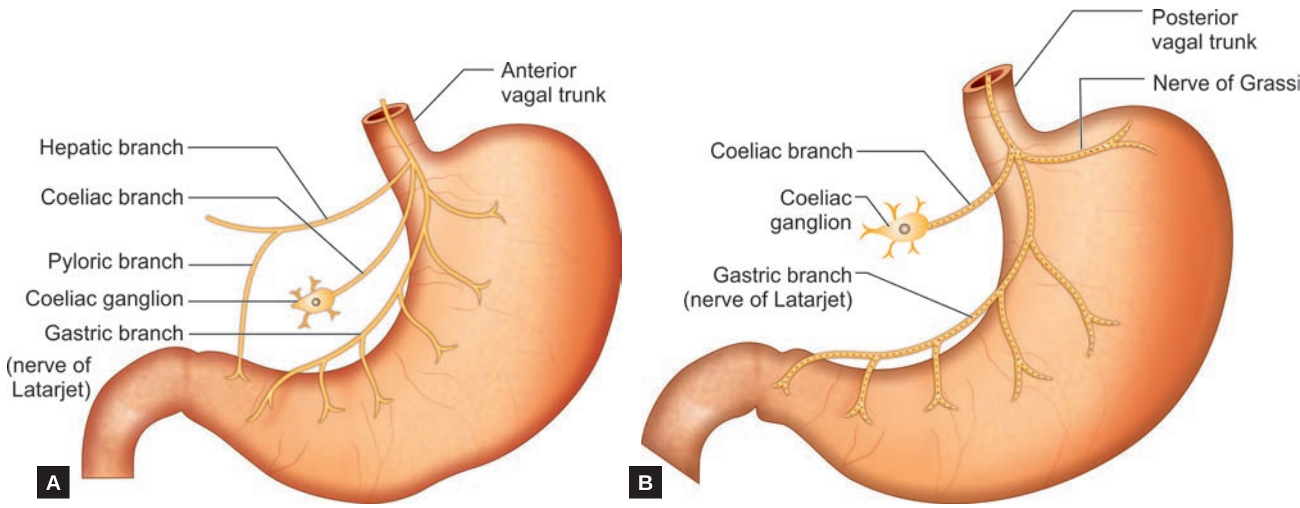


Fig. 79: Venous drainage of the stomach.



Figs. 80A and B: Lymphatic drainage of the stomach: (A) Lymphatic territories; (B) Lymph node groups drawing the lymphatic territories of the stomach

- Stomach do not drain into **pre-aortic lymph nodes** directly. (NBEP 2013)



Figs. 81A and B: Parasympathetic innervation of the stomach: (A) distribution of the anterior vagal trunk; (B) Distribution of the posterior vagal trunk.

- Criminal Nerve of Grassi: A branch of the right posterior vagus which passes to the left behind the oesophagus, ending in the gastric cardia. (NBEP 2014)
- The nerve of Latarjet: The posterior nerve of the lesser curvature is a branch of the anterior vagal trunk which supplies the pylorus. (NBEP 2014)

ASSESSMENT QUESTIONS

1. **Nerve or grassi branch of:** *(CET June 14 Pattern)*
   a. Right vagus
   b. Left vagus
   c. Trigeminal
   d. Hypoglossal

2. **Nerve of laterjet of vagus is seen in:**
   a. Thorax(All India Dec 14 Pattern)
   b. Neck
   c. Stomach
   d. Heart

3. **Stomach is supplied by:** *(All India Dec 15 Pattern)*
   a. Coeliac trunk
   b. Splenic artery
   c. Gastroduodenal artery
   d. All of the above

4. **Stomach derives its blood supply from all these arteries directly or indirectly EXCEPT:** *(CET Nov 14 Pattern)*
   a. Splenic artery
   b. Hepatic artery
   c. Superior mesenteric artery
   d. Celiac axis

5. **Most important blood supply to stomach is:**
   a. Left gastric artery (AIIMS Nov 13)
   b. Short gastric artery
   c. Left gastroepiploic artery
   d. Right gastroepiploic artery

6. **The bed of stomach is not formed by:** *(Kerala 01)*
   a. Left kidney
   b. Left suprarenal vein
   c. Splenic vein
   d. Tail of pancreas

7. Lymphatic drainage of stomach include all EXCEPT: *(NEET Dec 12 pattern)*
a. Right gastroepiploic nodes
b. Pyloric nodes
c. Preaortic nodes
d. Coeliac nodes

ANSWERS WITH EXPLANATIONS

1. a. Right vagus
- Nerve of grassi supplies the fundus of stomach.It is a branch of posterior (right) vagal trunk.

2. c. Stomach
- Main gastric nerve of Latarjet is branch of vagus and supplies the stomach.

3. d. All of the above
- Arterial supply of stomach is as follows -
- Along lesser curvature: Left gastric artery (branch of coeliac trunk) and right gastric artery (branch of proper hepatic artery).
- Along greater curvature: Right gastroepiploic artery (branch of gastroduodenal artery) and left gastroepiploic artery(branch of splenic artery).
- Fundus : 5-7 short gastric arteries (branches of splenic artery).

4. c. Superior mesenteric artery

5. a. Left gastric artery
- he consistently largest artery to the stomach is left gastric artery.

6. c. Splenic vein and 'd' ie., Tail of pancreas
- The posterior surface of stomach is related to structures forming the stomach bed, all of which are separated from stomach by the cavity of the lesser sac. These structures forming stomach bed are (i) Diaphragm,(ii) left kidney, (iii) left suprarenal (adrenal) gland, (iv) pancreas (body), (v) transverse colon, (vi) splenic flexure of colon and (vii) splenic artery. Sometimes spleen is also included in stomach bed, but it is separated from stomach by greater sac(not lesser sac).

7. c. Pre aortic nodes

Lymphatic drainage of stomach
- The stomach can be divided into four lymphatic territories. The drainage of these areas is as follows.
- Upper part of left 1/3rd drains into the pancreaticosplenic nodes lying along the splenic artery,i.e, on the back of the stomach. Lymph vessels from these nodes travel along the splenic artery to reach the coeliac nodes.
- Right 2/3rd drains into the left gastric nodes lying along the artery of the same name. These nodes also drain the abdominal part of the oesophagus .Lymph from these nodes drains into the coeliac nodes.
- Lower part of left 1/3rd drians into the right gastroepiploic nodes that lie along the artery of the same name. Lymph vessels arising in these nodes drain into the first and second parts of the duodenum.From here the lymph is drained further into the hepatic nodes that lie along the hepatic artery ; and finally into the coeliac nodes.
- Lymph from ie., Pyloric part drains in different directions into the pyloric,hepatic, and left gastric nodes, and passes from all these nodes to the coeliac nodes.
- Note that lymph from all areas of the stomach ultimately reaches the coeliac nodes . From here it passes through the intestinal lymph trunk to reach the cisterna chyli.

SI - Duodenum, Jejunum, Ileum

Duodenum

A. General Features. The duodenum pursues a C-shaped course around the head of the pancreas.

The duodenum is divided into four parts.

1. Superior Part (First Part)
- The first 2 cm of the superior part is intraperitoneal and therefore has a mesentery and is mobile; the remaining distal 3 cm of the superior part is retroperitoneal.
- Radiologists refer to the first 2 cm of the superior part of the duodenum as the **duodenal cap** or **bulb**.
- The superior part begins at the pylorus of the stomach (**gastroduodenal junction**) which is marked by the **prepyloric vein**.
- Posterior relationships include the **common bile duct** and **gastroduodenal artery**. The **hepatoduodenal ligament** attaches superiorly and the **greater omentum** attaches inferiorly.
- Abdominal Viscera **109**

2. Descending Part (Second Part)
- The descending part is retroperitoneal and receives the **common bile duct** and **main pancreatic duct** on its posterior/medial wall at the **hepatopancreatic ampulla (ampulla of Vater)**.

3. **Horizontal Part (Third Part)**
   - The horizontal part is retroperitoneal and runs horizontally across the L3 vertebra between the superior mesenteric artery anteriorly and the aorta and inferior vena cava (IVC) posteriorly.
   - In severe abdominal injuries, this part of the duodenum may be crushed against the L3 vertebra.
4. **Ascending Part (Fourth Part)**
   - The ascending part is intraperitoneal and ascends to meet the jejunum at the **duodenojejunal junction** which occurs approximately at the L2 vertebral level about 2 to 3 cm to the left of the midline.
   - This junction usually forms an acute angle which is called the **duodenojejunal flexure** which is supported by the **ligament of Treitz** (represents the cranial end of the dorsal mesentery).
   - The ligament of Treitz serves as the anatomical landmark for the distinction between **upper and lower gastrointestinal (GI) tract bleeds**.

B. **Arterial Supply.** The arterial supply of the duodenum is from the following:
   - **Supraduodenal artery** which supplies the upper portion of the duodenum (abdominal aorta → celiac trunk → common hepatic artery → gastroduodenal artery → supraduodenal artery).
   - **Anterior and posterior superior pancreaticoduodenal arteries** (abdominal aorta → celiac trunk → common hepatic artery → gastroduodenal artery → anterior and posterior superior pancreaticoduodenal arteries).
   - **Anterior and posterior inferior pancreaticoduodenal arteries** (abdominal aorta → superior mesenteric artery → anterior and posterior inferior pancreaticoduodenal arteries).

C. **Venous Drainage.** The venous drainage of the duodenum is to the following:
   - **Anterior and posterior superior pancreaticoduodenal veins** (anterior and posterior superior pancreaticoduodenal veins → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava).
   - **Anterior and posterior inferior pancreaticoduodenal veins** (anterior and posterior inferior pancreaticoduodenal veins → superior mesenteric vein → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava).

D. **Innervation.** See Section VI.

E. **Clinical Considerations**
   - **Duodenal ulcers** most often occur on the anterior wall of the first part of the duodenum (i.e., at the **duodenal cap**) followed by the posterior wall (danger of perforation into the pancreas).
   - **Perforations of the duodenum** occur most often with ulcers on the **anterior wall** of the duodenum. Perforations occur less often with ulcers on the **posterior wall**. However, posterior wall perforations may erode the **gastroduodenal artery** causing severe hemorrhage and extend into the pancreas. Clinical findings: Air under the diaphragm, pain radiates to the left shoulder.

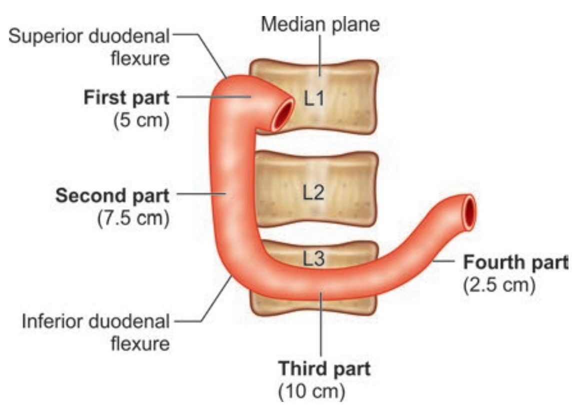


Fig. 82: Parts of the duodenum.

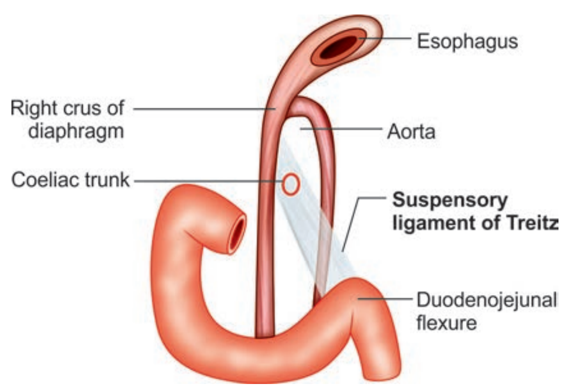


Fig. 83: Suspensory ligament of Treitz.

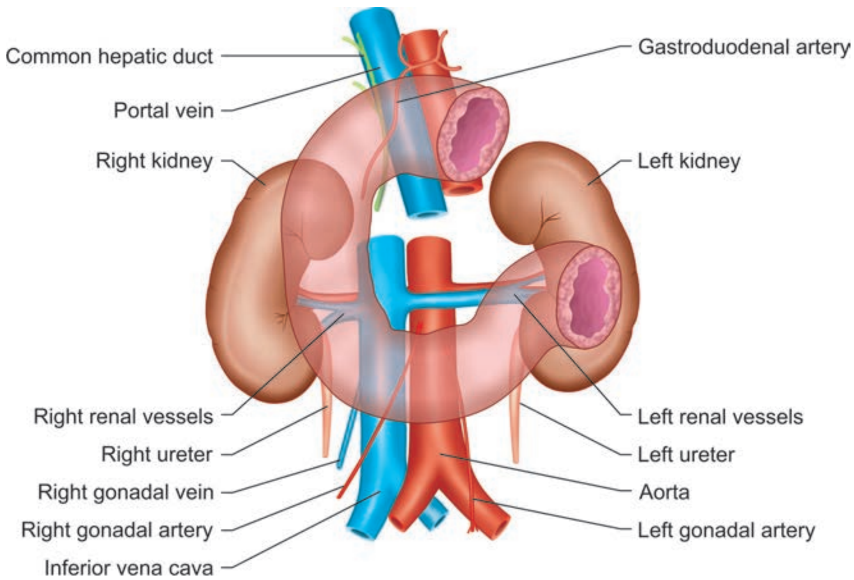


Fig. 84: The four parts of the duodenum. Anterior and posterior)

Table 19: Relationships of duodenum

Part of Duodenum	Anterior	Posterior	Medial	Superior	Inferior	Vertebral Level
Superior (1st part) **(A & B)**	Peritoneum Gallbladder Quadrate lobe of liver	Bile duct Gastroduodenal artery Hepatic portial vein IVC	Pylorus	Neck of gallbladder	Neck of pancreas	Anterolateral to L1 vertebra
Descending (2nd part) **(C)**	Transverse colon Transverse mesocolon Coils of small intestine	Hilum of right kidney Renal vessels Ureter Psoas major	Head of pancreas Pancreatic duct Bile duct	Superior part of duodenum	Inferior part of duodenum	Right of L2-L3 vertebrae
Inferior (horizontal) (3rd part) **(D)**	SMA SMV Coils of small intestine	Right psoas major IVC Aorta Right ureter		Head and uncinate Process of pancreas Superior mesenteric vessels	Coils of small intestine (illum)	Anterior to L3 vertebra
Ascending (4th part) **(E)**	Beginning of root of mesentery Coils of jejunum	Left psoas major Left margin of aorta	SMA, SMV, uncinate process of pancreas	Body of pancreas	Coils of jejunum	Left of L3 vertebra

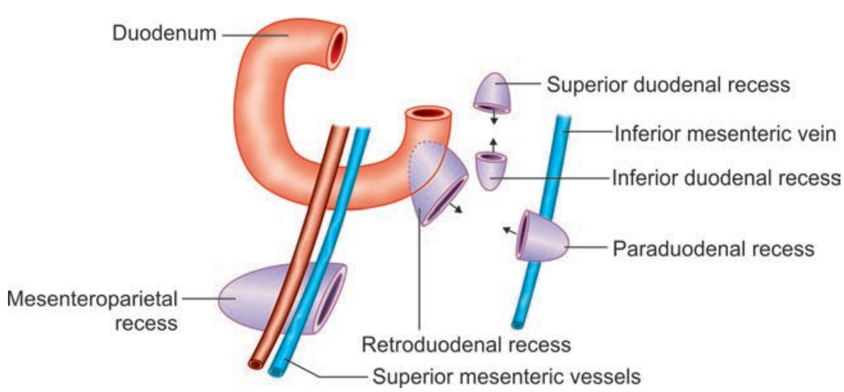
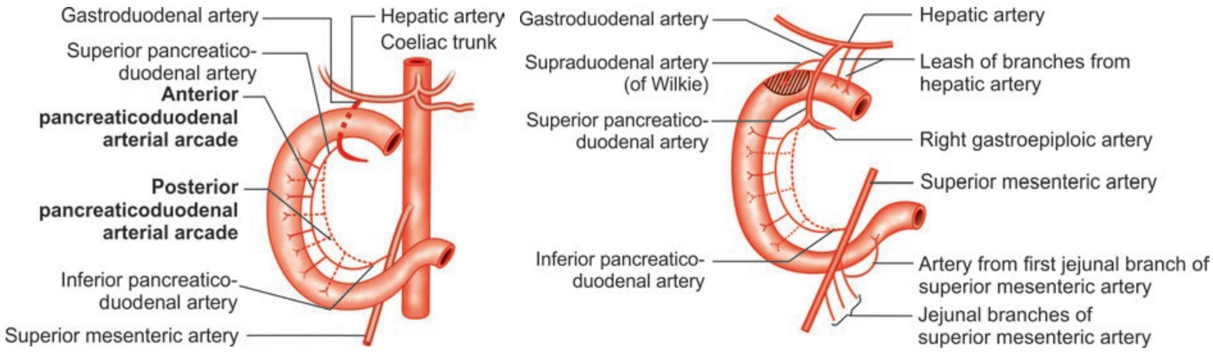


Fig. 85: Duodenal recesses



Figs. 86A and B: Arterial supply of the duodenum: (A) Pancreaticoduodenal arterial arcades; (B) Various arteries supplying the duodenum.

Different arteries of the duodenum derived directly or indirectly from the above two arteries are:

1. Superior pancreaticoduodenal artery, a branch of gastroduodenal artery (a branch of hepatic artery from the coeliac trunk).
2. Inferior pancreaticoduodenal artery, a branch of the superior mesenteric artery.
   - Each of the above two arteries divide into anterior and posterior branches. Respective branches of superior and inferior pancreaticoduodenal arteries anastomose to form anterior and posterior pancreaticoduodenal arterial arcades.
   - Each anastomotic arterial arcade gives off a row of vasa recta. The vasa recta of the anterior arcade supply the anterior surface and those of the posterior arcade supply the posterior surface of the duodenum.
   - Between the two rows of vasa recta lies the head of the pancreas.
3. Supraduodenal artery of "Wilkie": Usually it is a branch of the gastroduodenal artery from the coeliac trunk and supplies the anterosuperior and posterosuperior surfaces of the first part.
4. Retroduodenal branches of the gastroduodenal artery.
5. Leash of branches of the hepatic artery.
6. Branches from the right gastroepiploic artery.
7. Artery from the first jejunal branch of the superior mesenteric artery: It supplies branches to the fourth part of the duodenum.

Note: Arteries 3, 4, 5, and 6 exclusively supply the first part of the duodenum.

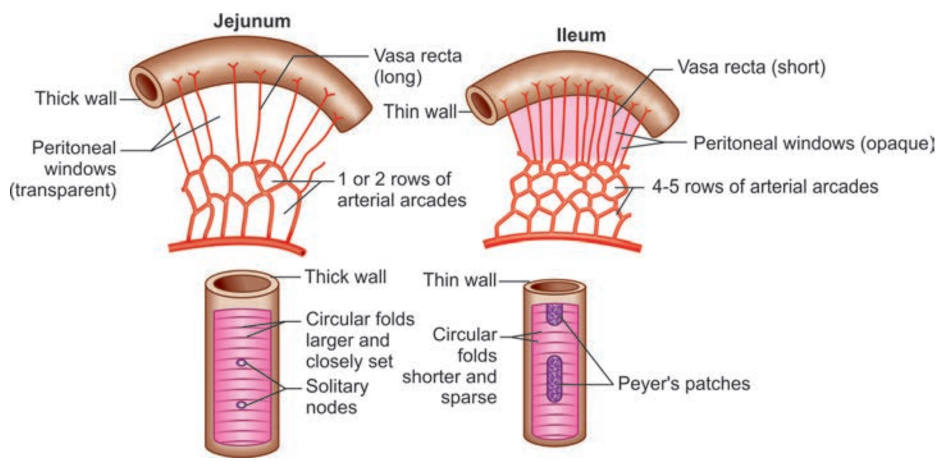


Fig. 87: Differences between the jejunum and ileum.

Table 20: Differences between the jejunum and ileum.

Features	Jejunum	Ileum
Walls	Thicker and more vascular	Thinner and less vascular
Lumen	Wider and often found empty (diameter = 4 cm)	Narrower and often found full (diameter = 3.5 cm)
Ciruclar folds/plicae circulares (valves of Kerckring)	Longer and closely set	Smaller and sparsely set
Villi	More, larger, thicker, and leaf-like	Less, shorter, thinner, and finger-like
Aggregated lymph follicles (Peyer's patches)	Small, circular, and few in number, and found only in the distal part of the jejunum	Large oval and more in number (± 10 cm × 1.5 cm) and found throughout the extent of ileum being maximum in the distal part
Mesentery	Contains less fat and becomes semitranslucent between the vasa recta called peritoneal windows	Contains more fat there are no peritoneal windows between the vasa recta
Arterial arcades	One or two rows with long vasa recta	Four or five rows with short vasa recta

High Yield Points

- Brunner's gland are related to proximal part of duodenum.
- Valvulae conniventes are seen in jejunum.

Note: Valvulae conniventes (also known as plicae circulares, valves of Kerckring) are the **permanent** transverse folds of the luminal surface of the small intestine (less marked in ileum), involving both the mucosa and submucosa.

ASSESSMENT QUESTIONS

1. Brunner's glands are seen in which of the following? *(NEET Dec 12 Pattern)*
a. Stomach:
b. Small intestine
c. Large instestine
d. Duodenum

2. Length of human intestine is about: *(CET July 15 pattern)*
a. 5 meter
b. 8 meter
c. 12 meter
d. 15 meter

3. Which of the following is related to third part of duodenum: *(NEET Dec 12 pattern)*
a. Portal vein
b. Head of pancreas
c. Hepatic artery
d. Superior mesenteric vein

4. Minor duodenal papilla is opening of: *(NEET Dec 12 pattern)*
a. Hepatic duct
b. Hepatopancreatic ampulla
c. Accessory pancreatic duct
d. Bile duct

5. All of these supply the first 2 cm of the duodenum EXCEPT: *(AIIMS 02)*
a. Supraduodenal artery
b. Common hepatic artery
c. Gastroduodenal artery
d. Superior pancreaticoduodenal artery

6. All of these supply the first 2 cm of the duodenum, EXCEPT: *(AIIMS 02)*
a. Supraduodenal artery
b. Common hepatic artery
c. Gastroduodenal artery
d. Superior pancreaticoduodenal artery

7. All of the statements are true about ileum EXCEPT: *(PGI 98)*
a. LN in mesentery
b. 3-6 arcades in continuation
c. Smaller diameter than jejunum
d. Large circular mucosal folds

8. Valvulae conniventes are seen in: *(PGI Nov 14)*
a. Jejunum
b. Ileum
c. Stomach
d. Colon

9. On contrast radiography which among the following is false? *(AIIMS May 11)*
a. Ileum is featureless
b. Colon has haustrations
c. Jejunum is feathery
d. Distal part of duodenum has a cap

ANSWERS WITH EXPLANATIONS

1. b. 8 meter
- Length of human intestine is 7.5 meter to 8.5 meter:
  (i) Small intestine ------> 6 to 7 meter
  (ii) Large intestine --------> 1.5 meter

2. d. Duodenum

Part of gut	Histological features
Stomach	Gastric pits and glands .Gastric glands contain (from above downwards): Mucus neck cells,parietal cells, chief cells.
Duodenum	Brunner's glands in the submucosa
Jejunum	Solitary lymphoid nodules
Ileum	Submucosal aggregated lymphoid tissue, called peyer's patches.
Large intestine	Crypts of lieberkuhn and large number of goblet cells. Paneth (zymogen) cells lie at the deepest part of the crypts.

3. d. Superior mesenteric vein

4. c. Accessory pancreatic duct
- Major duodenal papilla -----> Hepatopancreatic ampulla (opening of biliary pancreatic duct).
- Minor duodenal papilla --------> Accessory pancreatic duct opening.

5. d. Supplied by superior mesenteric artery
- First part of duodenum also called superior part, is 5 cm (2 inches) long.
- It is derived from foregut and therefore is supplied by coeliac trunk.

6. a. Supraduodenal artery
- The part of duodenum before the opening of bile duct (major duodenal papilla) develops from foregut and therefore is supplied by coeliac trunk through superior pancreaticoduodenal artery, a branch of gastroduodenal artery, which in turn is a branch of common hepatic artery.
- Part of duodenum distal to opening of bile duct is developed from midgut and therefore is supplied by superior mesenteric artery through inferior pancreatico- duodenal artery. First part of duodenum receives additional supply from right gastric artery, supraduodenal artery (a branch of common hepatic artery),retroduodenal branch of gastrodudenal artery and right gastroepiploic artery.

Note
- All the given options supply 1st part of duodenum.However among these, supraduodenal artery is inconstant and therefore can be chosen as the answer.

7. d. Large circular mucosal folds
- Circular folds are smaller and fewer
- There are 3 or 6 arterial arcades with no windows.
- Lumen of ileum is narrower and often loaded
- Mesentery of jejunum and ileum (mesentery proper) contains 100-200 lymph nodes

8. a. Jejunum
- The nervous and villous coal of the jejunum are extensive and are thrown into folds,called Valvulae conniventes which give feathery appearance in the jejunum.
- Ileum is tubular featureless
- Volvulae conniventes is radiological feature,ie. Complete band across the bowel gas shadow.

9. d. Distal part of duodenum has a cap
- The first part of the duodenum has the duodenal cap or bulb and not the distal part.
- The first part of the duodenum is visible as a triangular shadow on barium studies and is known as duodenal cap.
- The small intestine contains mucosal folds known as plicae circulares or valvulae conniventes that are visible on barium studies and help in the distinction between small instestine and colon. Colon instead can be identified by presence of haustrations.
- Valvulae conniventes are more prominent in the jejunum giving the 'feathery appearance' on barium. These mucosal folds are generally reduced distally giving a 'featureless' appearance of distal ileum.

Large Intestine

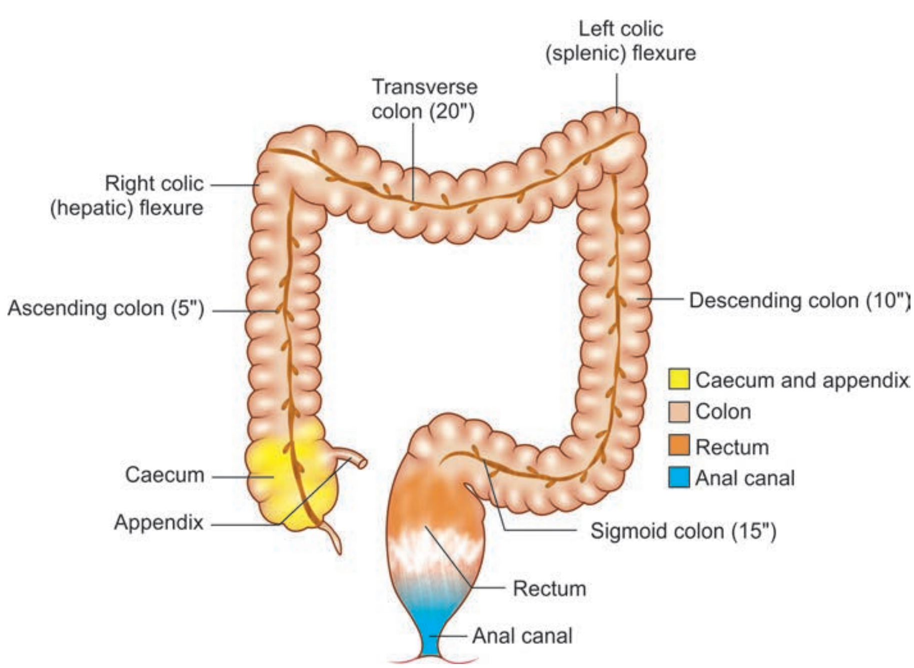
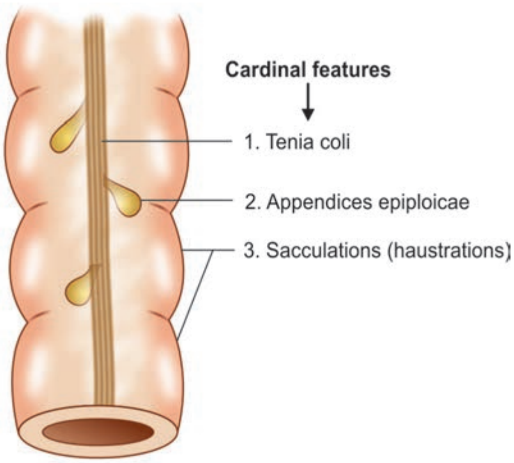


Fig. 88: Parts of the large intestine

- The shortest part of colon is ascending colon. (Delhi 2009, Punjab 2011)



Figs. 89: Cardinal features of the lungs intestine: Surface view

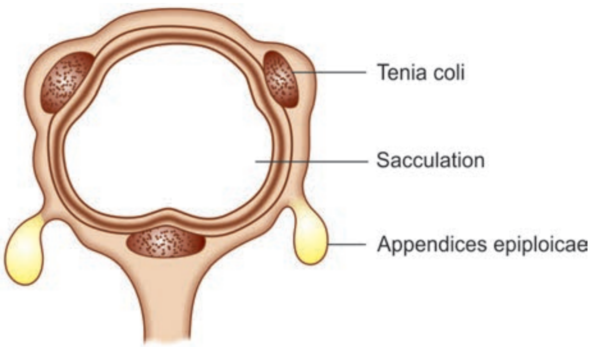


Fig. 90: In corss-sectional view.

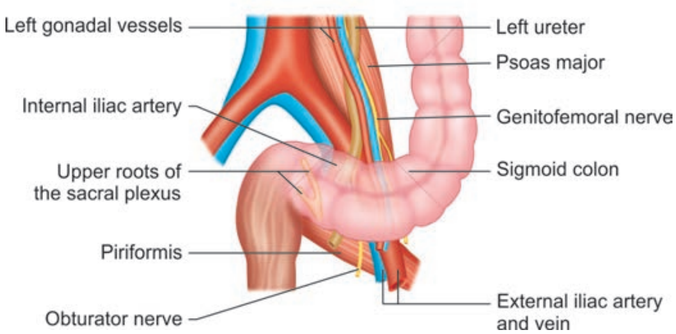


Fig. 91: Posterior relations of the sigmoid colon

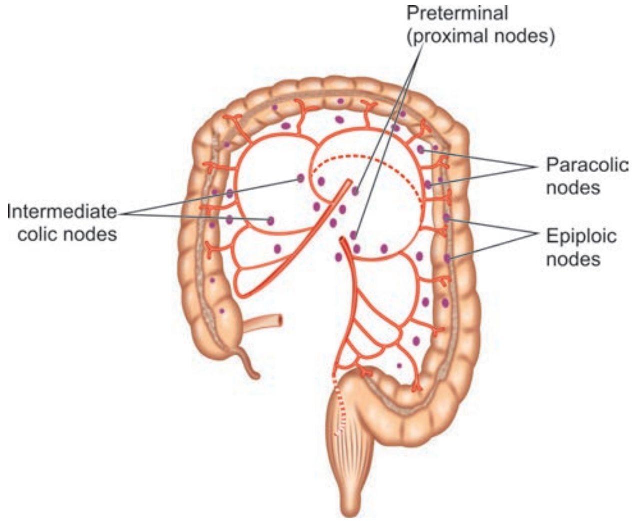


Fig. 92: Lymphatic drainage of the colon

- Lymph nodes related to the colon form four groups: epicolic, paracolic, intermediate colic and preterminal colic nodes. Epicolic nodes are minute whitish nodules on the serosal surface of the colon, sometimes within the appendices epiploicae. Paracolic nodes lie along the medial borders of the ascending and descending colon and along the mesenteric borders of the transverse and sigmoid colon. Intermediate colic nodes lie along the named colic vessels (the ileocolic, right colic, middle colic, left colic, sigmoid and superior rectal arteries). Preterminal colic nodes lie along the main trunks of the superior and inferior mesenteric arteries and drain into pre-aortic nodes at the origin of these vessels.

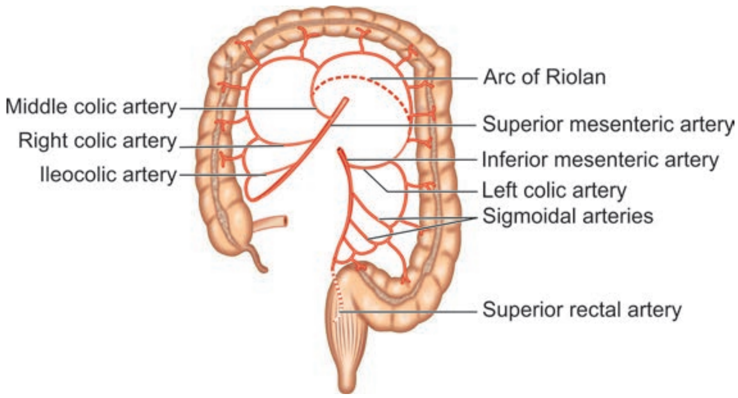


Fig. 93: Arterial supply of the colon. Note the formation of marginal artery of Drummond.

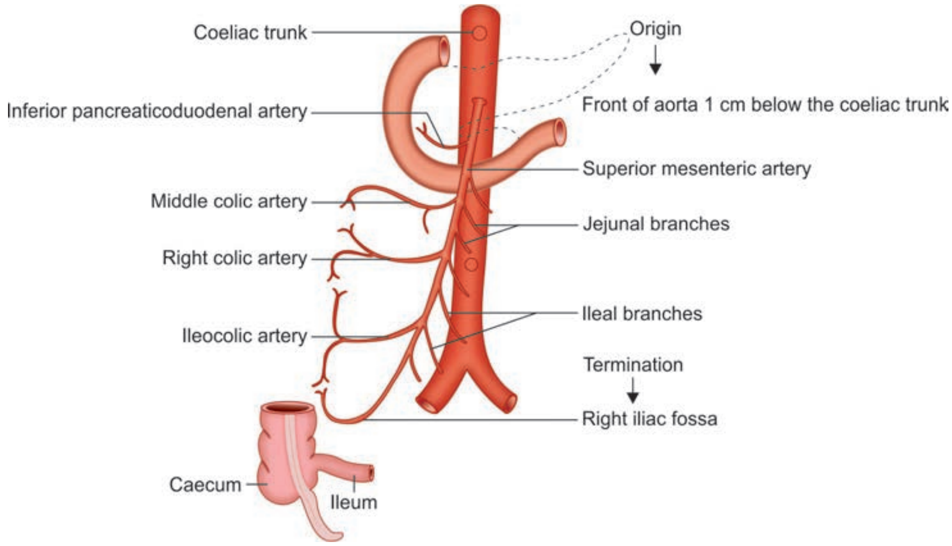


Fig. 94: Superior mesenteric artery and branches

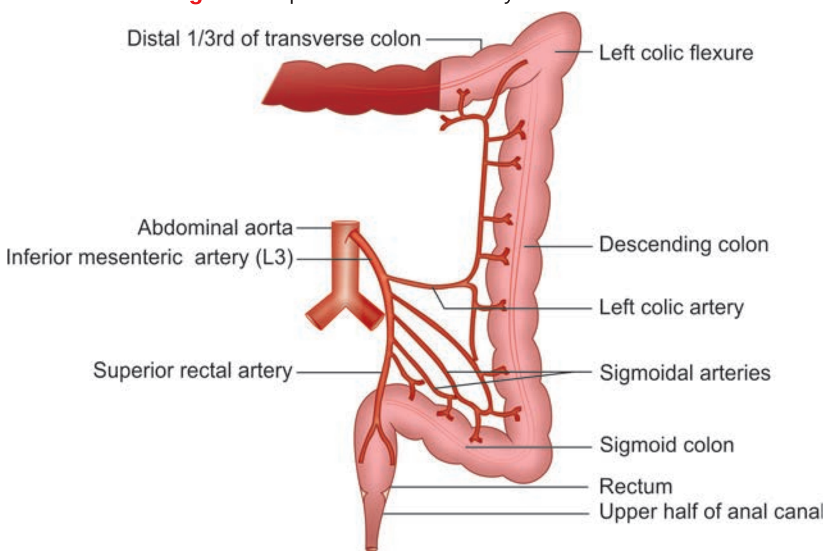


Fig. 95: Inferior mesenteric artery, its branches, and distribution.

- **Watershed area** between superior mesenteric artery and inferior mesenteric artery prone to early ischemia is **splenic flexure**. (AIIMS 2007)
- Colonic ischaemia is usually maximal in the region of the **splenic flexure** and proximal descending colon because this segment is furthest from the collateral arterial supplies.

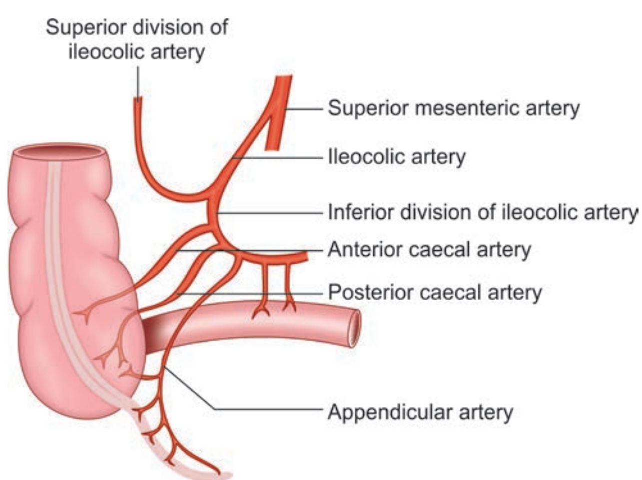


Fig. 96: Arterial supply of the caecum and appendix

Rectum is devoid of sacculations, appendices epiploicae or mesentery

- **Peyer patches** are absent in **colon**. (NBEP 2013)
- **Appendix epiploicae** are present in **sigmoid colon**.

Note: Appendices epiploicae are present only on colon (4 parts). They are **absent** from other parts of intestine like **caecum, appendix, rectum, anal canal**.

V Appendix

Appendix

A. General Features

- The appendix is an intraperitoneal (**mesoappendix**), narrow, muscular tube attached to the posteromedial surface of the cecum.
- The appendix is located ≈2.5 cm below the ileocecal valve.
- The appendix may lie in the following positions: **Retrocecal (65%), pelvis (32%), subcecal (2%), anterior juxta-ileal (1%), and posterior juxta-ileal (0.5%)**.

B. Arterial Supply

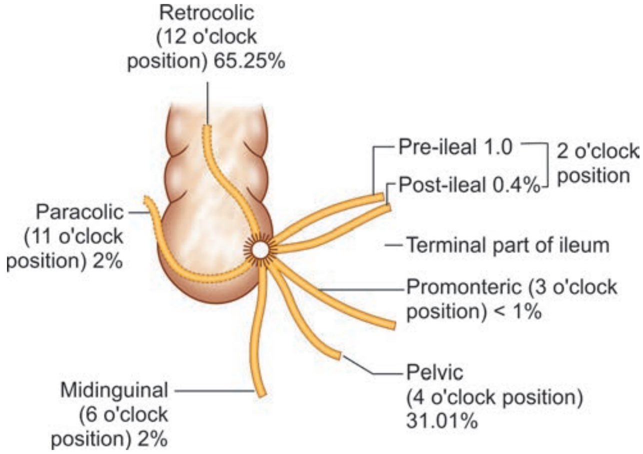
- The arterial supply of the appendix is from the **appendicular artery** (abdominal aorta → superior mesenteric artery → ileocolic artery → posterior cecal artery → appendicular artery).

C. Venous Drainage

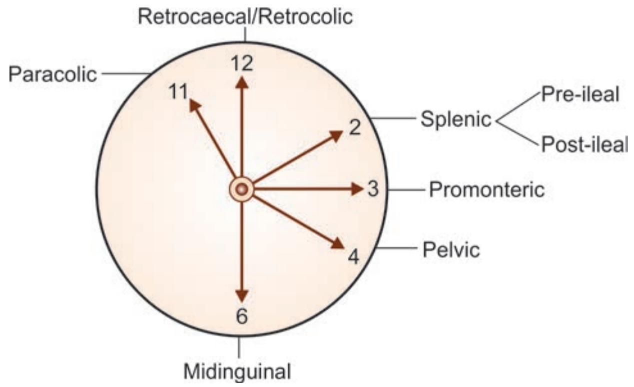
- The venous drainage of the appendix is to the **posterior cecal vein** (posterior cecal vein → superior mesenteric vein → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava).

D. Clinical Consideration

Appendicitis begins with the obstruction of the appendix lumen with a fecal concretion (fecalith) and lymphoid hyperplasia followed by distention of the appendix. Clinical findings include initial pain in the umbilical or epigastric region (later pain localizes to the right lumbar region), nausea, vomiting, anorexia, tenderness to palpation, and percussion in the right lumbar region. Complications may include peritonitis due to rupture of the appendix. **McBurney point** is located by drawing a line from the right anterior superior iliac spine to the umbilicus. The midpoint of this line locates the root of the appendix. The appendix is suspended by the **mesoappendix** (i.e., intraperitoneal) and is generally found in the **retrocecal fossa** (although its position is variable).



Figs. 97: Position of vermiform appendix (after Treves): actual position



Figs. 98: Positions according to the needle of clock.

ASSESSMENT QUESTIONS

1. The shortest part of colon is: *(DPG Mar 09, punjab 11)*
a. Transverse colon
b. Ascending colon
c. Descending colon
d. Sigmoid colon

2. Not seen in colon: *(NEET Dec 12 Pattern)*
a. Taeniae
b. Peyer's patches
c. Sacculations
d. Appendices

3. Which of the following is the terminal group of lymph node for colon? *(AIIMS Nov 08)*
a. Paracolic
b. Epicolic
c. Preaortic
d. Ileocoic

4. Colon is supplied by all EXCEPT: *(CET July 15 pattern)*
a. Inferior mesenteric artery
b. Ileocolic artery
c. Middle colic artery
d. Internal iliac artery

5. Blood supply of sigmoid colon is by: *(PGI 2K)*
a. Middle colic artery
b. Marginal artery
c. Left colic artery
d. Sigmoid artery

6. Watershed area between SMA and IMA which commonly result in ischemia is: *(AIIMS Nov 07)*
a. Hepatic flexure
b. Splenic flexure
c. Rectosigmoid junction
d. Ileocolic junction

7. Structure not forming watershed area: *(CET Nov 15 Pattern)*
a. Splenic flexure
b. Brain
c. Duodenum
d. None

8. Appendix epiploicae present in: *(AIIMS May 10)*
a. Appendix
b. Caeccum
c. Rectum
d. Sigmoid colon

9. All of the following are features of large intestine, EXCEPT: *(AI 02)*
a. Large intestine secretes acidic mucus which helps in formation of stools.
b. It is a site of mucocutaneous junction
c. Its epithelium contains goblets cells in large numbers
d. Absorbs salt and water.

10. The commonest anatomical position of appendix is:
a. Retrocaecal(All India Dec 13 Pattern, AI 10)
b. Pelvic
c. Paracaecal
d. Preileal

11. True statement about appendix: *(PGI June 06)*
a. Does not have mesentery
b. Has taenia coli
c. Develops from midgut
d. Supplied by appendicular branch of ileocolic

ANSWERS WITH EXPLANATIONS

1. b. Ascending colon
- Among given options, ascending colon is shortest.

Coecum ------------> 6 cm	Sigmoid colon --------------> 37.5cm
Ascending colon ------------> 12.5 cm	Rectum ---------------> 12 cm
Transverse colon --------------> 50 cm	Anal canal -------> 3.8 cm
Descending colon ----------> 25 cm	

2. b. Pyer's patches

3. c. Preaortic
- Terminal nodes for colon are superior mesenteric and inferior mesentric nodes (both are preaortic nodes).
- Preaortic lymph nodes are :- coeliac nodes, superior mesenteric nodes and inferior mesenteric nodes.

4. d. Internal iliac artery
- The blood supply of colon is derived from the marginal artery of Drummond.It is a paracolic anastomotic artery formed by anastomosis between colic branches of superior mesenteric artery (ileocolic, right colic, middle colic) and colic branches of inferior mesenteric artery (left colic and sigmoidal arteries). Terminal branches from marginal artery are distributed as long and short vessels vasa longa and vasa bravia.

5. b. Marginal artery and 'd' ie., Sigmoid artery
- Blood supply of sigmoid colon comes from sigmoid artery and marginal artery of sudeck.
- Marginal artery is an arterial coscade formed by anastomosis of ileocolic,rt. Colic, middle colic, left colic, and sigmoid arteries. And blood supply of colon (Large intestine) is derived from marginal artery.

6. b. Splenic flexure
- There are areas of colon with poor blood supply resulting from incomplete anastomosis of marginal arteries. These are watershed areas of colon and include:
  1. Splenic flexure (Griffith point) : Water shed area between superior mesenteric artery and inferior mesenteric artery.
  2. Rectosigmoid junction (Sudeck's point): Water shed zone between inferior mesenteric artery and internal iliac artery.

7. c. Duodenum
- Watershed area is a region of the body which is supplied by terminal part of two or more arteries.
- These areas are particularly vulnerable to ischemia because they are supplied by most distal part of arteries.
- Watershed areas -
  (i) Splenic flexure of colon
  (ii) Rectosigmoid junction
  (iii) Brain
  (iv) Spinal cord

8. d. Sigmoid colon
- Small bags of peritoneum filled with fat, called appendices epiploicae are present over the surface of large intestine , except for appendix, coecum and rectum.

9. a. Large intestine secretes acidic mucus which helps in formation of stools.
- Secretions of large intestine are alkali nor acidic.
- Large intestine extends from ileocaecal junction to the anus (site for mucocutaneous junction).
- Although epithelium of large intestine is absorptive villi are absent
- Adequate lubrication for passage of contents is provided by mucin secreting goblet cells.
- Large intestine absorbs salt and water.

10. a. Retrocaecal
- Most common position of appendix is retrocaecal (12 o' clock).

11. c. Develops from midgut and 'd' ie., Supplied by appendicular branch of ileocolic
- Appendix develops from midgut and therefore is supplied by superior mesenteric artery through appendicular branch of ileocolic artery.
- Appendix is suspended by a peritoneal fold called as mesoappendix.

ASSESSMENT QUESTIONS

1. The bed of the stomach is not formed by: *(Kerala 2001)*
a. Left kidney
b. Left suprarenal gland
c. Splenic vein
d. Tall of pancreas

2. Which of the following is present in the peritoneal reflection which forms one of the borders of the paraduodenal fossa: *(AIPG 2008)*
a. Inferior mesenteric vein
b. Middle colic vein
c. Left colic vein
d. Splenic vein

3. Major artery supply to stomach is by which branch of celiac trunk:
a. Left gastric artery
b. Short gastric artery
c. Right gastro-epiploic artery
d. Left gastro-epiploic artery

4. Which of the following is the terminal group of lymph node for colon: *(AIIMS 2008)*
a. Preaortic
b. Lateral aortic
c. Para aortic
d. Intermediate aortic

5. Appendices epiploicae are present in: *(AIIMS 2010)*
a. Caecum
b. Appendix
c. Sigmoid colon
d. Rectum

6. Maximum mucosa associated lymphoid tissue is seen in:
a. Stomach
b. Duodenum
c. Jejunum
d. Ileum

7. Which fold of GIT is NOT permanent: *(AIIMS 2008)*
a. Rugae
b. Plicae semilunaris
c. Spiral Valve of Heister
d. Transverse rectal

8. A patient has a penetrating ulcer of the posterior wall of the first part of the duodenum. Which blood vessel is subject to erosion:
a. Common hepatic artery
b. Gastroduodenal artery
c. Proper hepatic artery
d. Anterior superior pancreatico-duodenal artery

9. Wrong about ileum, as compared with jejunum is:
a. Short club shaped villi
b. Long vasa recta
c. More lymphoid nodules
d. More fat in mesentery

10. Which of the following is present in the peritoneal reflection which forms one of the borders of the paraduodenal fossa:
a. Inferior mesenteric vein
b. Middle colic vein
c. Left colic vein
d. Splenic vein

ANSWERS WITH EXPLANATIONS

1. c. Splenic vein > d. Tail of pancreas
- Splenic artery (and not **vein**) is in the posterior relation of stomach.
- Pancreas (**except tail)** is in the posterior relation of stomach.

2. a. Inferior mesenteric vein
- Inferior mesenteric vein is present in the paraduodenal fossa (a peritoneal recess in the vicinity of duodenum). The surgeon should be careful while operating in this region for cases like internal herniation.

3. a. Left gastric artery
- According to the surgery books by Sabiston and Schwartz, the largest artery to the stomach is left gastric artery.

4. a. Preaortic
- The terminal lymph node group for colon is pre-aortic.
- The flow of the lymph is epicolic → paracolic → intermediate colic → preterminal colic nodes → pre-aortic lymph nodes.

5. c. Sigmoid colon
- Appendices epiploicae are pouches of peritoneum containing fat present in in all the four parts of the colon (ascending, transverse, descending and sigmoid).
- They are absent in the beginning (caecum and appendix) and ending (rectum and anal canal) of large intestine.
- These appendages can become inflamed, a benign but painful process known as epiploic appendagitis which can mimic acute appendicitis and other conditions.

6. **d. Ileum**
   - The amount of lymphoid tissue increases towards the ileum.
   - Peyer patches are aggregations of lymphoid tissue (MALT) seen in the terminal ileum.
7. **a. Rugae**
   - Rugae are the mucosal folds present in the stomach, which disappear on distension, hence are not permanent.
   - Plicae semilunaris/circulares are circular folds of mucous membrane and are permanent (not obliterated by distension).
   - They are also called as Valves of Kerkring.
   - Spiral valve of Heister is formed by the mucosal folds at the terminal opening of cystic duct into the common hepatic duct to form the common bile duct.
   - It is not a true valve but is permanent and narrows down the lumen of cystic duct at the terminal end.
   - When the duct is distended, the spaces between the folds get dilated, making the folds more obvious.
   - Transverse rectal folds are permanent mucosal folds and are more marked during rectal distension. They are also called as Houston's valves or plicae transversalis.
8. **b. Gastroduodenal artery**
   - Gastroduodenal artery passes behind the first part of duodenum and is prone to bleeding in posterior perforation of duodenal ulcer.
   - Splenic artery may be eroded by penetrating ulcer of the posterior wall of the stomach into the lesser sac.
   - Left gastric artery may be subjected to erosion by a penetrating ulcer of the lesser curvature of the stomach.
9. **b. Long vasa recta.**
   - Ileum has short vasa recta with relatively more arcades.
10. **a. Inferior mesenteric vein**
    - **Paraduodenal fossa** is an occasional recess in the peritoneum to the left of the terminal portion of the duodenum located posterior to a fold containing the **inferior mesenteric vein**.

Intestine: Vasculature

Table 21: Arterial supply to Intestines

Artery	Origin	Course	Distribution
Superior mesenteric	Abdominal aorta	Runs in root of mesentery to ileocecal junction	Part of gastrointestinal tract derived from midgut
Intestinal (jejunal and ileal) (n = 15–18)	Superior mesenteric artery	Passes between two layers of mesentery	Jejunum and ileum
Middle colic		Ascends restroperitoneally and passes between layers of transverse mesocolon	Transverse colon
Right colic		Passes retroperitoneally to reach ascending colon	Ascending colon
Ileocolic	Terminal branch of superior mesenteric artery	Runs along root of mesentery and divides into ileal and colic branches	Ileum, cecum, and ascending colon
Appendicular	Ileocolic artery	Passes between layers of mesco-appendix	Appendix
Inferior mesenteric	Abdominal aorta	Descends retroperitoneally to left of abdominal aorta	Supplies part of gastrointestinal tract derived from hindgut
Left colic	Inferior mesenteric artery	Passes retroperitoneally towards left to descending colon	Descending colon
Sigmoid (n = 3 – 4)		Passes retroperitoneally towards left to decending colon	Descending and sigmoid colon
Superior rectal	Terminal branch of inferior mesenteric artery	Descends retroperitoneally to rectum	Proximal part of rectum
Middle rectal	Internal iliac	Passes retroperitoneally to rectum	Midparts of rectum
Inferior rectal	Internal pudendal artery	Crosses ischioanal fossa to reach rectum	Distal part of rectum and anal canal

Table 22: Collateral Arterial Intestinal Blood Flow

Involved circulation	Mesenteric artery	Adjoining artery	Collateral artery
Systemic	Celiac	Descending aorta	Phrenic
Systemic	IMA	Hypogastric	Middle haemorrhoidal
Mesenteric	Celiac	SMA	Superior/inferrior pancreaticoduodenal
Mesenteric	SMA	IMA	Arch of Riolan
Mesenteric	SMA	Celiac/IMA	Intra mesenteric
Mesenteric	SMA	IMA	Marginal

Note: IMA, inferior mesenteric artery; SMA, superior mesenteric artery

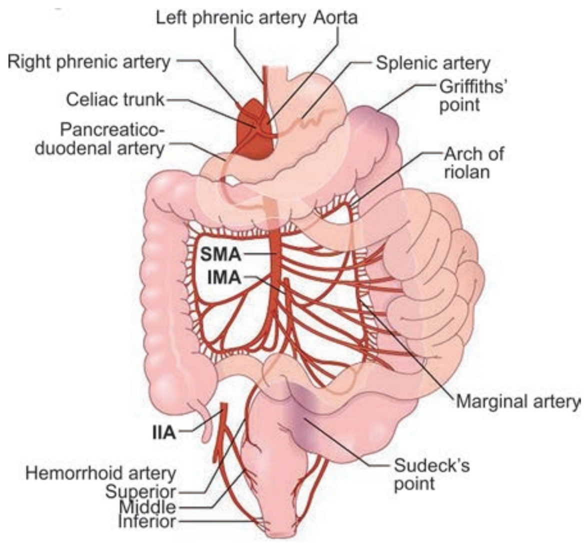


Fig. 99: Watershed areas (Griffith and sudeck's point).

ASSESSMENT QUESTIONS

1. Ligation of the coeliac artery mostly affects all EXCEPT: *(Kerala 2001)*
a. Stomach
c. Jejunum
b. Pancreas
d. Spleen

2. Right gastroepiploic artery is a branch of: *(AI 2001; AIIMS 2009)*
a. Right hepatic artery
b. Hepatic artery
c. Gastroduodenal artery
d. Superior mesenteric artery

3. All are true about coeliac trunk EXCEPT: *(NBEP 2013)*
a. Ventral branch of aorta
b. Surrounded by a plexus of nerves
c. Lies at lower border of pancreas
d. Left gastric artery is a branch

4. All are branches of inferior mesenteric artery EXCEPT: *(NBEP 2013)*
a. Left colic
b. Superior rectal
c. Middle rectal
d. Sigmoidal artery

5. Arterial supply of the duodenum is by:
a. Celiac artery
b. Superior mesenteric artery
c. Inferior mesenteric artery
d. Both superior mesenteric and celiac arteries

6. Which of the following is TRUE about splenic artery:
a. Smaller than left gastric artery
b. Gives short gastric arteries along the fundus
c. Curves around the fundus
d. Arises from abdominal aorta

7. Which veins drain directly into inferior vena cava: *(NEET Pattern 2012)*
a. Superior mesenteric vein
b. Inferior mesenteric vein
c. Hepatic vein
d. Splenic vein

8. One of the following is the watershed area of the colon between the superior and inferior mesenteric arteries: *(AIIMS 2007)*
a. Ascending colon
b. Hepatic flexure
c. Splenic flexure
d. Descending colon

9. Blood supply of stomach: *(PGI 2003, 2001)*
a. Right gastric artery
b. Left gastric artery
c. Splenic artery
d. Inferior phrenic artery
e. Superior mesenteric artery

10. Stomach derives its blood supply from all these arteries directly or indirectly EXCEPT: *(NBEP 2014)*
a. Splenic artery
b. Hepatic artery
c. Superior mesenteric artery
d. Celiac artery

11. Most important blood supply to stomach is: *(AIIMS 2013)*
a. Left gastric artery
b. Short gastric arteries
c. Left gastroepiploic artery
d. Right gastroepiploic artery

12. Lymphatic drainage of stomach include all EXCEPT: *(NEET 2013)*
a. Right gastroepiploic
b. Pyloric nodes
c. Pre-aortic nodes
d. Celiac nodes

13. Which of the following is related to the third part of duodenum: *(NBE 2013)*
a. Portal vein
b. Hepatic artery
c. Head of pancreas
d. Superior mesenteric vein

14. All of these supply the first 2 cm of the duodenum EXCEPT: *(AIIMS 2002)*
a. Supraduodenal artery
b. Common hepatic artery
c. Gastroduodenal artery
d. Superior pancreaticoduodenal artery

15. On Contrast radiography which among the following is FALSE: *(AIIMS 2011)*
a. Ileum is featureless
b. Colon has haustrations
c. Jejunum is feathery
d. Distal part of duodenum has a cap

16. Appendicular artery is a branch of: *(NEET Pattern 2012)*
a. Ileocolic
b. Right colic
c. Inferior mesenteric
d. Marginal artery

ANSWERS WITH EXPLANATIONS

1. c. Jejunum
- **Jejunum** is a part of midgut supplied by branches of superior mesenteric artery (and not celiac artery).
- Coeliac artery supplies derivatives of foregut like **stomach**, **pancreas**.
- It also gives branch to **spleen**.

2. c. Gastroduodenal artery
- Right gastroepiploic artery is a branch of **gastroduodenal artery**.
- Left gastroepiploic artery is a branch of splenic artery.

3. c. Lies at lower border of pancreas
- Celiac trunk lies at the upper aspect of **pancreas** (**and not lower**)
- Celiac trunk is a **ventral** branch of abdominal aorta, is surrounded by the **nerve plexus** called celiac plexus.
- It gives three branches, **left gastric artery** being one.

4. c. Middle rectal
- **Middle rectal artery** is a branch of the anterior division of internal iliac artery.
- Inferior mesenteric artery supplies hindgut derivatives by giving branches like **left colic, sigmoidal, superior rectal** arteries.

5. c. Both superior mesenteric and celiac arteries
- Proximal duodenum (foregut) is supplied by branches of **celiac artery** and the distal duodenum is supplied by branches of **superior mesenteric artery**.

6. b. Gives short gastric arteries along the fundus
- Splenic artery is the largest branch of celiac trunk.
- It is not a direct branch of **abdominal aorta**.
- It runs posterior to stomach (in stomach bed) and send **short gastric arteries** in gastrosplenic ligament to reach the fundus of stomach.

7. c. Hepatic vein
- **Hepatic veins** drain the liver into inferior vena cava.
- **Superior mesenteric vein** is joined by **splenic vein** to form the portal vein, which itself drains into the liver.
- **Inferior mesenteric vein** drain into the *splenic vein*, before it drains into portal vein.

8. c. Splenic flexure
- 'Watershed area' is the term referring to regions of the body that receive dual blood supply from the most distal branches of two large arteries, such as the **splenic flexure** of the large intestine.
- The weakest link in the marginal chain of vessels (of Drummond) is near the left colic (splenic) flexure, between the middle colic artery (mid-gut) & the left colic artery (hind-gut).
- An inner arterial circle (of Riolan) between the ascending branch of left colic artery and the trunk of middle colic artery may supplement the blood supply to this region of colon.
- During times of blockage of one of the arteries that supply of the watershed area, such as in atherosclerosis, these regions are spared from ischemia by virtue of their dual supply. However, during times of systemic hypoperfusion, such as in DIC or Heart failure, these regions are particularly vulnerable to ischemia by virtue of the fact that they are supplied by the most distal branches of their arteries, and thus the least likely to receive sufficient blood.

9. a. Right gastric artery; b. Left gastric artery; c. Splenic artery
- **Inferior phrenic artery** supplies diaphragm. **Superior mesenteric artery** supplies mid-gut derivatives.

10. c. Superior mesenteric artery
- **Superior mesenteric artery** supplies mid-gut derivatives.

11. a. Left gastric artery
- The largest artery supply to stomach is left gastric artery.

12. c. Pre-aortic nodes
- Stomach does not drain into **pre-aortic lymph nodes**.

13. d. Superior mesenteric vein
- **Superior mesenteric vein** (and artery) cross the anterior to the **third part of the duodenum** to enter the mesentery of small intestine.

14. a. Supraduodenal artery
- Though **supraduodenal artery** also supplies the first 2 cm of duodenum, but is an inconstant branch, missing in a proportion of population (hence could be taken as answer).

15. d. Distal part of duodenum has a cap

- Duodenal cap is present in the first(proximal and **not distal**) part of duodenum, visible as a triangular shadow on barium studies.
- Plicae circulares (valvulae conniventes) are present in the small intestine. In **jejunum** they give **feathery** appearance and are minimal in **ileum (featureless)**.
- Large intestine (**Colon**) has the presence of **haustrations**.

16. a. Ileocolic

- Appendicular artery is given by ileocolic artery, which itself is terminal branch of superior mesenteric artery.

Liver and Hepatobiliary Apparatus

Functional anatomy of the liver is based on Couinaud's division of the liver into eight (subsequently nine, then later revised back to eight) functional segments, based on the distribution of portal venous branches in the parenchyma. Further understanding of the intrahepatic biliary anatomy is used as the main guide for division of the liver by few investigators. The liver is divided into four portal sectors by the four main branches of the portal vein. These are right lateral, right medial, left medial and left lateral. The three main hepatic veins lie between these sectors as intersectoral veins. These intersectoral planes are also called portal fissures (or scissures). Each sector is subdivided into segments (usually two), based on their supply by tertiary divisions of the vascular biliary (Glissonian) sheaths.

Liver

A. General Features

- The liver stroma begins as a thin connective tissue capsule called **Glisson capsule** that extends into the liver around the portal triads, around the periphery of a hepatic lobule, extends into the perisinusoidal space of Disse to surround hepatocytes, and then terminates around the central vein.
- The components of the **porta hepatis** are the following.
- **Bile duct**
- **Portal vein**
- **Hepatic artery**
- **Lymphatic vessels**
- **Hepatic nerves**

B. Lobes of the Liver

- The liver is classically divided into the **right lobe** and **left lobe** by the **interlobar fissure** (an invisible line running from the gallbladder to the IVC), **quadrate lobe**, and **caudate lobe**.
- The left lobe contains the **falciform ligament** (a derivative of the ventral mesentery) with the **ligamentum teres** (a remnant of the left umbilical vein) along its inferior border.
- The **bare area** of the liver is located on the diaphragmatic surface and is devoid of peritoneum.
- **Liver segmentation**. The right portal fissure, the main portal fissure, and the umbilical fissure divide the liver into four vertical divisions. Three of the four vertical divisions are further divided by the transverse portal plane into eight liver segments (I to VIII) each supplied by a tertiary branch of the portal triad. Liver segments I to VIII each has its own intrasegmental blood supply and biliary drainage.
- Liver is divided into lobes following two classifications:
  - Anatomical lobes
  - Physiological (functional) lobes

Note: Recently these two classification have become more and more overlapping.

Anatomical Lobes

- **Falciform ligament** (diaphragmatic surface) divides liver into right and left anatomical lobes. On the visceral surface falciform ligament is followed to **fissure for ligamentum venosum** and **fissure for ligamentum teres**, hence demarcating left anatomical lobe from right.
- Anatomical right lobe is approximately six times larger than the left lobe.
- Some authors mention four lobes of liver:

Note: Two fissures and two fossae form a H-shaped figure dividing liver into 4 lobes.

- Right lobe to right of groove for IVC and the fossa for gallbladder.
- Left lobe to the left of the fissures for ligamentum teres and ligamentum venosum.
- **Caudate lobe** lying between the groove for ligamentum venosum (on left) and groove for the inferior vena cava (on the right), located above porta hepatis.
- **Quadrate lobe** bounded by fissure for ligamentum teres (on left) and gallbladder fossa (on right), lying below porta hepatis.

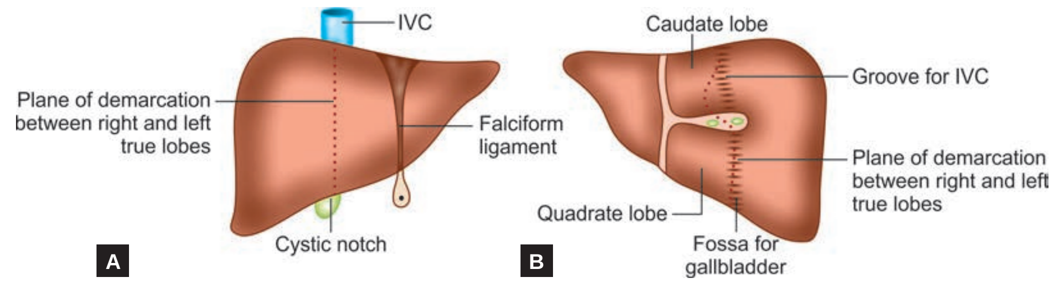


Fig. 100A and B: True/physiological lobes of the liver: (A) Plane of demarcation on anterosuperior surface; (B) Visceral surface is shown by the interrupted redline.

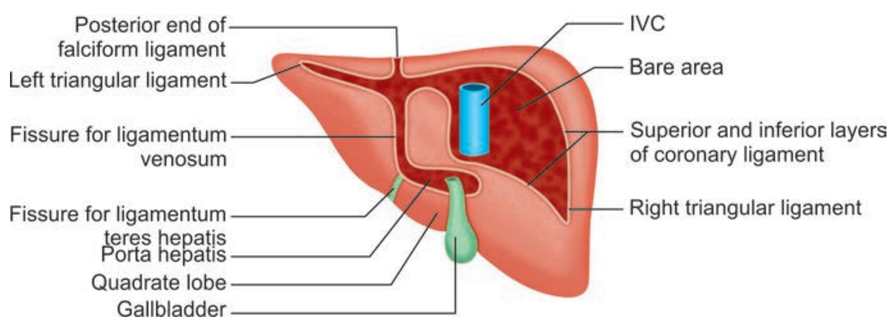


Fig. 101: Liver—vieved from behind

Functional (physiological) lobes

- This division of the liver into **lobes** is based on the intrahepatic distribution of branches of the **bile ducts, hepatic artery, and portal vein**.
- It is further subdivided into four **sectors** (divisions)and then into eight **segments**, each served independently by a secondary or tertiary branch of the portal triad, respectively.

Note: **Cantlie's line** divides liver into right and left hemi-livers and passes through the fossa for gallbladder, to the groove for IVC. On the posterior surface it runs from fossa for IVC to the cystic notch.

- Each physiological lobe of the liver has its own primary branch of the hepatic artery and portal vein and is drained by its own hepatic duct.

According to Gray's Anatomy (Edition 41) the **functional anatomy** of the liver is based upon

1. **Portal vein** branches
2. **Biliary duct** distribution
3. **Vascular biliary** (Glissonian) sheath

Note: There is a mention of **hepatic veins** being in the portal **fissures** (scissures) as well.

- **Couinaud's division** of the liver into eight (subsequently nine, then later revised back to eight) functional segments, based on the distribution of **portal venous branches** in the parenchyma.
- The liver is divided into **four portal sectors** by the four main branches of the portal vein. These are right lateral, right medial, left medial and left lateral (sometimes, the term posterior is used in place of lateral, and anterior in place of medial).
- The three main hepatic veins lie between these sectors as intersectoral veins.
- These intersectoral planes are also called portal fissures (or scissures).
- Each sector is subdivided into segments (usually two), based on their supply by tertiary divisions of the **vascular biliary (Glissonian) sheaths.**

Note: Glisson's capsule of the liver becomes condensed as Glissonian sheaths around the branches of the portal triad structures as they enter the liver parenchyma and subdivide into segmental branches. Thus, each bile duct, hepatic artery and portal vein is surrounded by a single fibrous sheath, which Couinaud called the 'Valoean sheath'.

Couinaud's Classification:

- Hepatic segments are numbered I to VIII in a clockwise direction.
- Segments I to IV belong to left hemiliver and V to VIII are present in the right hemiliver.
- Segment I to IV (left lobe) are supplied by the left branch of hepatic artery, left branch of portal vein and drained by left hepatic duct.
- Segments V to VIII of right lobe are supplied by right hepatic artery, right branch of portal vein and drained by right hepatic duct.

Caudate Lobe

- **Segment I** corresponds to the anatomical **caudate lobe** and is a boundary line structure (belongs to both right and left hemi-liver). It has dual artery, venous and biliary supply.

- It lies posterior to segment IV and is subdivided into three parts (caudate process, Spiegel lobe and paracaval portion).
- The Glissonian sheaths to segment I arise from both right and left main sheaths; the segment therefore receives vessels from both the left and right branches of the portal vein and hepatic arteries.
- Caudate lobe drains bile into both the hepatic ducts and venous drainage is directly into IVC (and not the major hepatic veins).

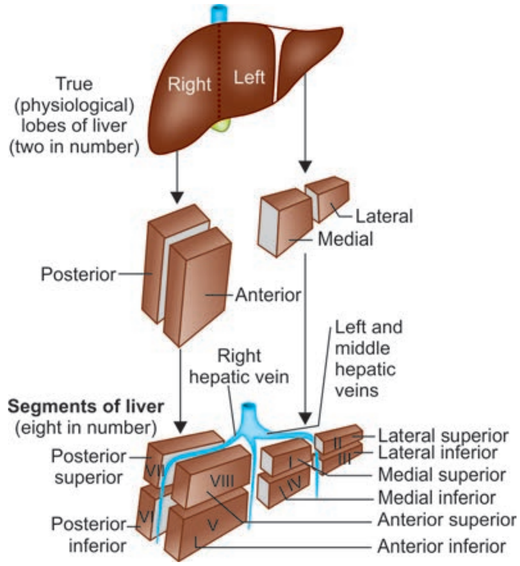


Fig. 102: Segment of the liver

The liver has two lobes, which can be further subdivided into four sectors/divisions and then into eight surgically resectable hepatic segments, each served independently by a secondary or tertiary branch of the portal triad, respectively.

Liver Lobes, Sectors and Segments

- Right lobe:
  - The anterior sector of the right lobe contains superior (VIII) and inferior (V) segments.
  - The posterior sector of the right lobe has superior (VII) and inferior (VI) segments.
- Left lobe:
  - The medial sector of the left lobe (quadrate lobe, segment IV) is part of the left lobe from a surgical perspective but lies to the right of the midline; it is further divided into a superior subsegment (A) and an inferior subsegment (B).
  - The lateral sector of the left lobe contains segments II and III.

Table 23: Terminology for subdivision of liver

Anatomical term	Right lobe			Left Lobe	Caudate Lobe	
Function/ Surgical term	Right (part of liver [Right portal lobe*])		Left (part of) Liver [Left portal lobe^{+}]		Posterior (part of) liver	
	Right lateral division	Right medial division	Left medial division	Left lateral division	[Right caudate lobe^{+}]	[Left caudate lobe*]
	Posterior lateral segment **Segment VII** [Posterior superior area]	Posterior lateral segment **Segment VIII** [Anterior superior area]	[Medial superior area] Left medial segment **Segment IV** [Medial inferior area = quadrate lobe]	Lateral segment **Segment II** [Lateral superior area]	Posterior segment **Segment I**	
	Right anterior lateral segment **Segment VI** [Posterior inferior area]	Anterior medial segment **Segment V** [Anterior inferior area]		Left lateral anterior segment **Segment III** [Lateral inferior area]		

The labels in the table and figures above reflect the new **Terminologia Antaomica: International antomical Terminology (1998). Previous terminology is in brackets.
Under the schema of the previous terminology, the caudate lobe was divided into right and left halves, and
*The right half of the caudate lobe was considered a subdivision of the right portal lobe
$^{+}$The left half of the caudate lobe was considered a subdivision of the left portal lobe.
$^{++}$Cantile line and the right sagittal fissure are surface markings defining the main portal fissure.

Liver: Lobes, division and segments

Note: The caudate lobe may in fact be considered a third liver; its vascularization is independent of the bifurcation of the portal triad (it receives vessels from both bundles) and is drained by small hepatic veins, which enter directly into the IVC (Pg. 272; K L Moore - 7th Edition)

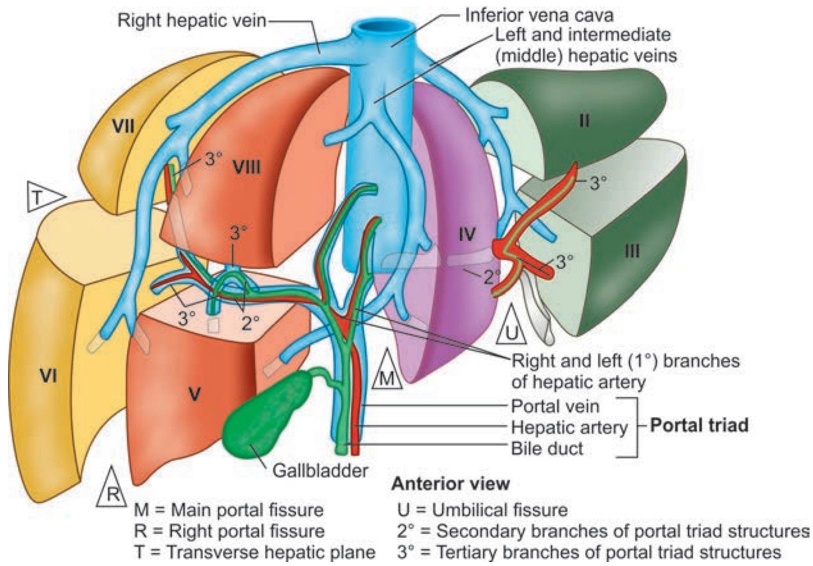


Fig. 103: Liver Segments (Couinaud's classification)

Figure Hepatic segmentation

- The right, intermediate, and left hepatic veins course within three planes or fissures [right portal (R), main portal (M), and umbilical (U)] that divide the liver into four vertical divisions, each served by a secondary (2°) branch of the portal triad.
- Three divisions are further subdivided at the transverse portal plane (T) into hepatic segments, each supplied by tertiary (3°) branches of the triad.
- The left medial division and caudate lobe are also considered hepatic segments, bringing the total to eight surgically resectable hepatic segments.
- Each segment has its own intra segmental blood supply and biliary drainage. The hepatic veins are intersegmental, draining the portions of multiple segments adjacent to them.
- Takasaki described a different basis for subdividing the gross architecture of the liver, in which the portal vein had three branches (right, middle and left) and there were just two hepatic veins (right and middle, the left hepatic vein being a tributary of the middle hepatic vein. Takasaki had divided the liver into three parts of almost equal volume, based on the three branches of the portal vein and the two hepatic veins.

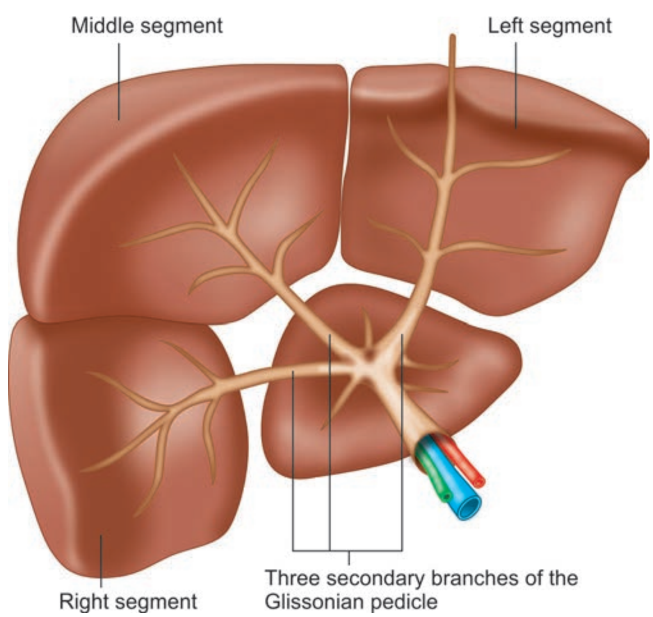


Fig. 104: The liver is divided into three segments and a caudate area, according to the ramification of the Glissonian pedicles.

Fissures of Liver

Three major fissures (main, left and right portal fissures), not visible on the surface, run through the liver parenchyma and contain the three main hepatic veins.

Three minor fissures (umbilical, venous and fissure of Gans) are visible as physical clefts of the liver surface. The fissure of Gans is also known as Rouvière's sulcus or the incisura hepatis dextra.

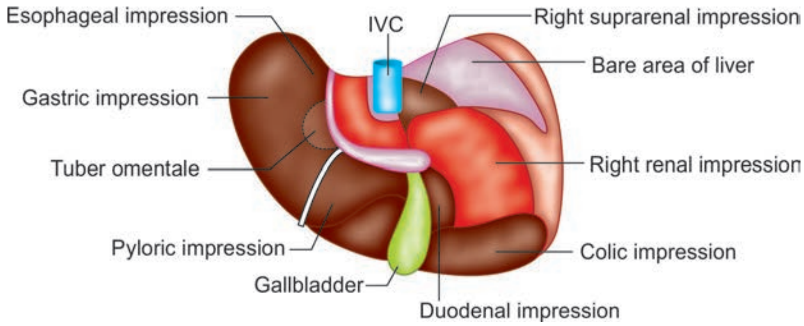


Fig. 105: Visceral relations of the liver (relations of the inferior/visceral surface of the liver)

Table 24: Relations of diaphragmatic and visceral surfaces of the liver

Surface		Relations
Diaphragmatic surface (parietal surface)	Superior surface with diaphragm intervening	• Corresponding lung and pleura on either side • Pericardium and heart in the centre
	Anterior surface	• Xiphoid process • Anterior abdominal wall
	Right lateral surface with diaphragm intervening	• Lung and pleura in the upper one-third • Costodiaphragmatic recess in the middle one-third • 10th and 11th ribs in the lower one-third
	Posterior surface: a. With peritoneum intervening b. With peritoneum not intervening	• Abdominal part of the esophagus • Right suprarenal gland • Inferior vena cava
Visceral surface (inferior surface)	a. With peritoneum intervening b. With peritoneum not intervening	• Stomach • Duodenum • Right colic flexure • Right kidney • Gallbladder

Most of the liver is covered by the peritoneum. The areas which are not covered by the peritoneum are:

1. Bare area of the liver: It is a triangular area on the posterior aspect of the right lobe (details on p. 115).
2. Fossa for gallbladder, on the inferior surface of the liver between right and quadrate lobes.
3. Groove for IVC, on the posterior surface of the right lobe of the liver.
4. Groove for ligamentum venosum.
5. Porta hepatis.

- **Arterial Supply**
  - The arterial supply of the liver is from the **right hepatic artery** and **left hepatic artery** (abdominal aorta → celiac trunk → common hepatic artery → proper hepatic artery → right hepatic artery and left hepatic artery → hepatic sinusoids).
- **Portal Supply**
  - The portal supply of the liver is from the **portal vein** (superior mesenteric vein, inferior mesenteric vein, and splenic vein → portal vein → hepatic sinusoids).
  - The portal vein is formed by the union of the splenic vein and superior mesenteric vein.
  - The inferior mesenteric vein joins the splenic vein.
  - The arterial blood and portal blood mix in the hepatic sinusoids.
- **Venous Drainage**
  - The venous drainage of the liver is to the **central veins** located at the center of a classic liver lobule (central veins → hepatic veins → inferior vena cava).
- **Innervation**
  - The exact function of both the parasympathetic and sympathetic innervations is unclear, except that sympathetics play a role in vasoconstriction.
  - Pathology involving the diaphragmatic surface of the liver may be referred via the phrenic nerve to the right shoulder region (C3, 4, 5 dermatomes).

Gallbladder

A. General Features

- The gallbladder is divided into the **fundus** (anterior portion), **body,** and the **neck** (posterior portion).
- A small pouch **(Hartmann pouch)** may extend from the neck as a sequela to pathologic changes and is a common site for gallstones to lodge.
- **Rokitansky-Aschoff sinuses** occur when the mucosa of the gallbladder penetrates deep into the muscularis externa. They are an early indicator of pathologic changes (e.g., acute cholecystitis or gangrene).

B. Arterial Supply

- The arterial supply of the gallbladder is from the **cystic artery** (abdominal aorta → celiac trunk → common hepatic artery → proper hepatic artery → right hepatic artery → cystic artery).

C. Venous Drainage

- The venous drainage of the gallbladder is to the **cystic vein** (cystic vein → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava).

Extrahepatic Biliary Ducts

A. General Features

- The **right and left hepatic ducts** join together after leaving the liver to form the **common hepatic duct**.
- The common hepatic duct is joined at an acute angle by the **cystic duct** to form the **bile duct**.
- The cystic duct drains bile from the gallbladder. The mucosa of the cystic duct is arranged in a spiral fold with a core of smooth muscle known as the **spiral valve (valve of Heister)**. The spiral valve keeps the cystic duct constantly open so that bile can flow freely in either direction.

- The bile duct passes posterior to the pancreas and ends at the **hepatopancreatic ampulla (ampulla of Vater)** where it joins the **pancreatic duct**.

The **sphincter of Oddi** is an area of thickened smooth muscle that surrounds the bile duct as it traverses the ampulla. The sphincter of Oddi **controls bile flow** (sympathetic innervation causes contraction of the sphincter).

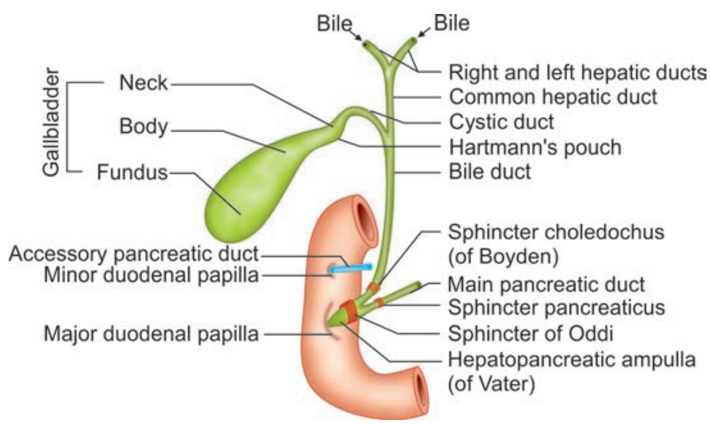
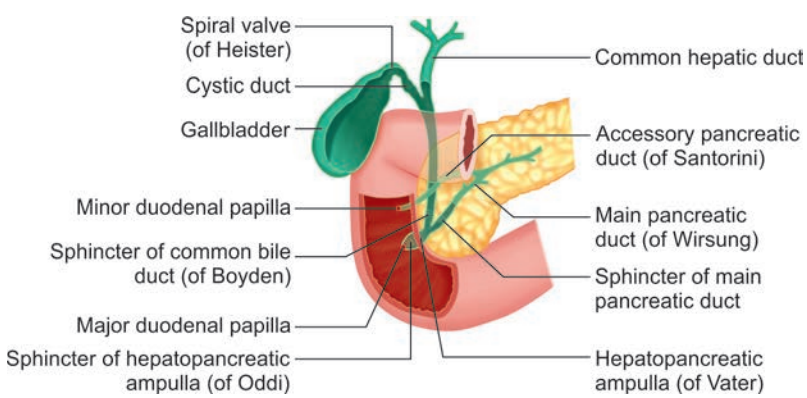


Fig. 106: Components of the extrahepatic biliary apparatus. Note the sphincters around hepatopancreatic ampulla and terminal parts of the bile, and main pancreatic duct.



Figs. 107: Relationship of hepatic, pancreatic, and gallbladder duct. The gallbladder is a blind pouch joined to a single cystic duct in which numerous mucosal folds form the spiral valve (of Heister). The cystic duct joins with the common hepatic duct, and together they form the common bile duct that leads into the duodenum. At the entry to the duodenum, the common bile duct is joined by the main pancreatic duct to form the hepatopancreatic ampulla (of Vater), and together they enter the second part of the duodenum. Sphincters of the common bile duct (of Boyden), the main pancreatic duct, and the hepatopancreatic ampulla (of Oddi) control the flow of bile and pancreatic secretion into the duodenum. When the common bile duct sphincter contracts, bile cannot enter the duodenum; it backs up and flows into the gallbladder, where it is concentrated and stored.

- Minor duodenal papilla is the opening of accessory pancreatic duct *(NBEP 2013)*

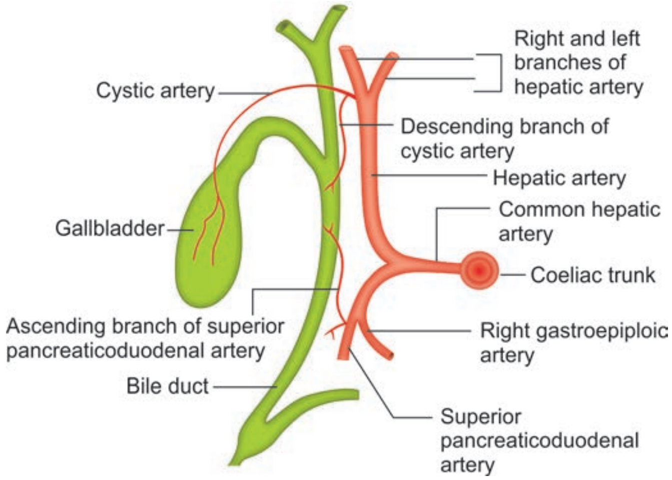


Fig. 108: Blood supply of the gallbladder and bile duct.

Calot's Triangle

- Hepatobiliary triangle is a region formed between the cystic duct, the common hepatic duct and the inferior surface of the liver is the. It is often mistakenly referred to as Calot's triangle, which is an isosceles triangle based on the common hepatic duct, with the cystic artery and cystic duct forming its sides.

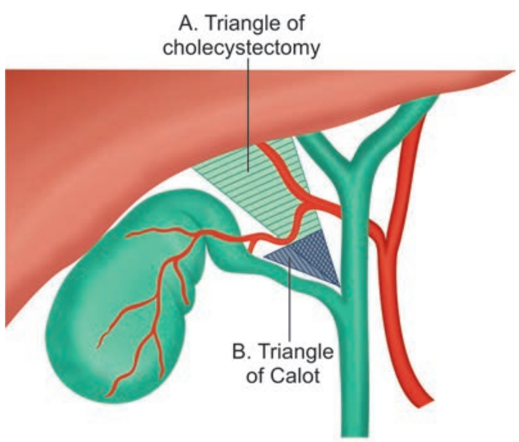


Fig. 109: Blood supply of the gallbladder and bile duct.

ASSESSMENT QUESTIONS

1. **TRUE statement regarding bare area of liver:**
   a. Covered by visceral peritoneum *(JIPMER 2008)*
   b. Supplied by phrenic nerve
   c. Present In the left lobe of liver
   d. Attached to the diaphragm

2. **According to Couinaud's classification, the 4th segment of the liver is:** *(AIIMS 2007)*
   a. Caudate lobe
   b. Quadrate lobe
   c. Left lobe
   d. Right lobe

3. **Blood supply of liver is:** *(NEET Pattern 2013)*
   a. 80% hepatic artery, 20% portal vein
   b. 20% hepatic artery, 80% portal vein
   c. 50% hepatic artery, 50% portal vein
   d. 100% hepatic artery

4. **A hemangioma was found on the left of the falciform ligament of the liver. Surgeon dissecting Couinaud's segments of liver to the left of attachment of falciform ligament resects which lobes:** *(AIPG 2008)*
   a. 2,3
   b. 1,4b
   c. 2,4a
   d. 1,4a

5. **A segmental resection was performed removing part of liver lying left of the falciform ligament. The segments still retained in the left surgical liver are:**
   a. 2,3
   b. 1,4
   c. 2,4
   d. 1,4,5

6. **Which is NOT true:** *(AIIMS 2009,11)*
   a. Caudate lobe drains only left hepatic duct
   b. Right anterior hepatic duct formed by V and VIII segment
   c. Left hepatic duct formed in umbilical fissure
   d. Left hepatic duct crosses IV segment

7. All of the following segments of liver drains into right hepatic duct EXCEPT: *(AIIMS 2009)*
a. I
b. III
c. V
d. VIII

8. The right lobe liver consists of which of the following segments: *(AIIMS 2004)*
a. V, VI, VII, VIII
b. IV, V, VI, VII, VIII
c. I, V, VI, VII, VIII
d. I, IV, V, VI, VII, VIII

9. Sphincter of Oddi consists of: *(AIIMS 2009,11)*
a. 2 sphincters
b. 3 sphincters
c. 4 sphincters
d. 5 sphincters

10. All of the following are present in the liver capsular plate EXCEPT: *(AIIMS 2011)*
a. Ductal plate
b. Hilar plate
c. Umbilical plate
d. Cystic plate

11. All are true about functional divisions of liver EXCEPT:
a. Based upon portal vein & hepatic vein *(AIIMS 2015)*
b. Divided into 8 segments
c. Three major & three minor fissures
d. 4 sectors

12. Which of the following statement about portal triad is CORRECT: *(JIPMER 2016)*
a. Hepatic artery is medial to portal vein
b. Common bile duct is medial to hepatic artery
c. Portal vein is posterior to both common bile duct and hepatic duct
d. Portal vein is anterior to common bile duct but posterior to portal vein

13. Liver is divided into two surgical halves by all EXCEPT:
a. Cantlie's line
b. Right hepatic vein
c. Portal vein at porta hepatis
d. Biliary duct at porta hepatis

14. Liver is divided in 2 halves by all EXCEPT:
a. Hepatic vein(NEET Pattern 2013)
b. Portal vein
c. Hepatic artery
d. Hepatic duct

15. Cystic artery is usually a branch of which of the following: *(NEET Pattern 2012)*
a. Right gastric artery
b. Right hepatic artery
c. Splenic artery
d. Celiac artery

16. Calot's triangle is bounded by all EXCEPT:
a. Inferior surface of liver
b. Common hepatic duct
c. Cystic duct
d. Cystic artery

17. Spiral valve of Heister is seen in: *(NEET Pattern 2013)*
a. Neck of gallbladder
b. Cystic duct
c. Pancreatic duct
d. Pylorus

18. Weight of liver: *(All India Dec 13 Pattern)*
a. 600–800 gm
b. 1000–1200 gm
c. 1400–1600 gm
d. 1800–2000 gm

19. Space of Disse is seen in: *(NEET Dec 12 Pattern)*
a. Spleen
b. Liver
c. Lung
d. Heart

20. The Couinaud's segmental nomenclature is based on the position of the: *(AI 04)*
a. Hepatic veins and portal vein
b. Hepatic veins and biliary ducts
c. Portal vein and biliary ducts
d. Portal vein and hepatic artery

21. A surgeon excises a portion of liver of he left of the attachment of the falciform ligament. The segments that have been resected are: *(All India Dec 13 Pattern, AI 08)*
a. Segment 1a and 4
b. Segment 1 and 4b
c. Segment 2 and 3
d. Segment 1 and 3

22. The right lobe of liver consists of which of the following segments: *(AIIMS 04)*
a. V,Vi,VII and VIII
b. IV,V,VI,VII and VIII
c. I,V,VI,VII and VIII
d. I,IV,V,VI, VII and VIII

23. Caudate lobe of liver is: *(All India Dec 13 Pattern)*
a. 1
b. III
c. IV
d. VI

24. False about hepatic duct: *(AIIMS May 09)*
a. Left hepatic duct formed in umbilical fissure
b. Caudate lobe drains only left hepatic duct
c. Right anterior hepatic duct is formed by V and VIII segments
d. Left hepatic duct crosses IV segments

25. Right hepatic duct drains all, EXCEPT: *(AIIMS May 09)*
a. Segment I
b. Segment III
c. Segment V
d. Segment VI

26. Liver is divided in 2 halves by all, EXCEPT: *(AIIMS 94)*
a. Right hepatic vein
b. Portal vein
c. Hepatic artery
d. Hepatic duct

27. Liver segment which is physiologically independent:
a. Segment I(CET July 15 Pattern)
b. Segment Ii
c. Segment III
d. Segment IV

28. Relation of caudate lobe of liver is: *(PGI 98)*
a. Posterior to portal vein
b. Anterior to right inferior phrenic artery
c. Posterior to ligamentum teres
d. Posterior to ligamentum venosum

29. Venous blood of liver is drained by: *(SGPGI AI 01)*
a. Portal vein
b. Hepatic artery
c. Sinusoids
d. Hepatic veins

30. Ligamentum teres of the liver is remnant of: *(SGPGI 05,PGI May 10)*
a. Umbilical arteries
b. Left umbilical vein
c. Ductus venosus
d. Ductus arteriosus

31. Blood supply of liver: *(NEET Dec 12 Pattern)*
a. 80% hepatic artery, 20% portal vein
b. 20% hepatic artery, 80% portal vein
c. 50% hepatic artery, 50% portal vein
d. 100% hepatic artery

32. Bare area of liver is related to: *(All India Dec 15 Pattern)*
a. Aorta
b. Hepatic vein
c. Portal vein
d. Gallbladder

33. Which is not a boundary of Calot's triangle: *(CET July 15 Pattern)*
a. Common hepatic duct
b. Cystic duct
c. Right lobe of liver
d. Gallbladder

34. What lies between cystic duct and common hepatic duct:
a. Lymph node (NEET Dec 12 Pattern)
b. Portal vein
c. Hepatic vein
d. Cystic artery

35. Spiral valve is seen in: *(NEET Dec 12 Pattern)*
a. Neck of gallbladder
b. Cystic duct
c. Colon
d. Pylorus

36. Valve of Heister is seen in: *(All India Dec 13 Pattern)*
a. Cystic duct
b. Common bile duct
c. Common hepatic duct
d. Pancreatic duct

37. Hartman's pouch is seen in: *(CET July 15 Pattern)*
a. Liver
b. Bile duct
c. Pancreas
d. Gallbladder

38. Fibromuscular wall is seen in: *(NEET Dec 12 pattern)*
a. Gallbladder
b. Duodenum
c. Jejunum
d. ileum

39. Which of the following statements is true regarding the relation of bile duct: *(PGI Dec.05)*
a. Posteriorly related to 1st part of duodenum
b. Related posteriorly to the tunnel of pancreatic head
c. Anteriorly related to 1st part of duodenum
d. Related to IVC posteriorly
e. It lies left to hepatic artery in the free border of lesser omentum.

40. True regarding common bile duct is all EXCEPT: *(AI 2000)*
a. Opens 10 cm distal to the pylorus
b. Lies anterior to IVC
c. Portal vein lies posterior to it
d. Usually opens into duodenum separate from the main pancreatic duct

41. Sphincter of Oddi consists of: *(AIIMS May 09,11)*
a. 2 sphincters
b. 3 sphincters
c. 4 sphincters
d. 5 sphincters

42. Pancreatic and bile ducts open into duodenum at :
a. Ampulla (All India Dec 13 Pattern)
b. Minor duodenal papilla
c. Duodenal cap
d. None

43. Predominant blood supply to the supraduodenal bile duct is derived from: *(AI 12)*
a. Vessels that run upward along the bile duct from the duodenal end of the duct such as the retroduodenal and the gastroduodenal arteries.
b. Vessels that run downward along the bile duct from the hepatic and of the duct such as the right hepatic artery.
c. Vessels that arise from the hepatic artery proper as it rungs up along the common bile duct and supplies it with twigs in a non-axial distribution.
d. Vessels that arise from the cystic artery.

ANSWERS WITH EXPLANATIONS

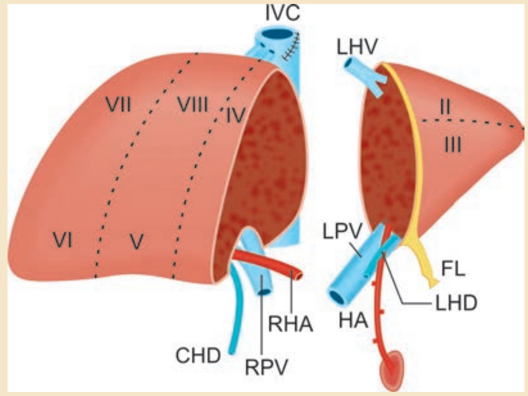
1. d. Attached to the diaphragm
- Bare area of liver is present in right (and not **left) lobe of liver, in contact with diaphragm** and **not covered by visceral peritoneum**, is supplied by autonomic nervous system (and **not phrenic nerve).**
- **Areas not covered by peritoneum:**
  - **Fossa for gallbladder**
  - **Fissure for ligamentum venosum**
  - **Groove for IVC**

2. b. Quadrate lobe
- Quadrate lobe (4b) of liver is inferior part of segment 4, better visualized from the posterior aspect of liver.
- Caudate (comma-shaped) lobe is the beginning of the segmental nomenclature as is taken as segment-I (posterior segment).
- Segments are numbered in a clockwise direction when liver is visualized in anterior view.
- Except for the caudate lobe (third liver), the liver is divided into right & left livers based on the primary (1 degree) division of the portal triad into right and left branches.
- The plane between the right and left livers being the main portal fissure in which the middle hepatic vein lies.

3. b. 20% hepatic artery, 80% portal vein
- Liver receives a dual blood supply from the hepatic portal vein and hepatic arteries.
- Portal vein delivers approximately 75-80% of the liver's blood supply, and carries venous blood drained from the spleen, gastrointestinal tract, and its associated organs.
- Hepatic artery supply arterial blood to the liver, accounting for the remaining quarter of its blood flow. Oxygen is provided from both sources; approximately half of the liver's oxygen demand is met by the portal vein, and half is met by the hepatic artery.
- Blood flows through the liver sinusoids and empties into the central vein of each lobule. The central veins coalesce into hepatic veins, which leave the liver and drain into the inferior vena cava

4. a. 2, 3

- Segments 2 & 3 lie to the left of the falciform ligament and will be resected in this patient.
- Couinaud's classification divides liver into various segments based upon the distribution of portal & hepatic veins.
- Major removal of liver segments follows the Couinaud's classification for putting the lines of resection.
- The hepatic veins provide surgical planes to dissect the liver, but the surgeon has to bear with the hemorrhage, as they are followed and are a major source of bleeding during dissection.



5. b. 1,4

- During hepatic resection, segments 2 and 3 (lying left to the falciform ligament) have been removed, and segments 1 and 4 are retained in the left surgical liver.

6. a. Caudate lobe drains only left hepatic duct

- Caudate lobe is a boundary line structure (belongs to both right and left liver) and drains bile into both the hepatic ducts.

7. b. III

- Segment III belongs to left liver and drains bile into left hepatic duct.
- Right liver has segment V, VI, VII and VIII, which drain into right hepatic duct.
- Caudate lobe (segment I) drains into both right and left hepatic duct.

8. a. V, VI, VII, VIII

- According to Couinaud's hepatic segmentation the functional right lobe of liver consists of V, VI, VII and VIII segments (A).
- Segment I and IV belongs to left surgical liver.

9. b. 3 sphincters > c. 4 sphincters > d. 5 sphincters

- The entire sphincter mechanism is actually composed of numerous muscle fibre sphincters and the answer stands controversial.
- The latest information points to a total number of three (Gray's Anatomy, Ed 41), though there have been mention of four, five and still more higher number in the past.
- The portal for entry of bile and pancreatic juice in humans has been divided into three parts: (i) biliary (choledochus), (ii) pancreaticus, and (iii) ampulla.

10. a. Ductal plate

- Liver plate has 3 parts, which does not include ductal plate.
- Cystic plate separates the gallbladder from the liver. Hilar plate is at the confluence of the hepatic ducts at the hilum.
- Umbilical plate lodges the left portal triad, starting from the hilum of liver (porta hepatis).
- The plate system consists of bile ducts and blood vessels surrounded by a sheath that is continuous with Glisson's capsule, intrahepatically, and the hepatoduodenal ligament, extrahepatically.
- This system also contains a large number of lymphatics, nerves, and a small vascular network.
- Couinaud classification states that the bile ducts and hepatic artery are located within the plate system, but that the portal vein is covered with a separate sheath of loose connective tissue, and that is why the plate containing the extrahepatic bile duct and hepatic artery can be easily separated from the portal vein.

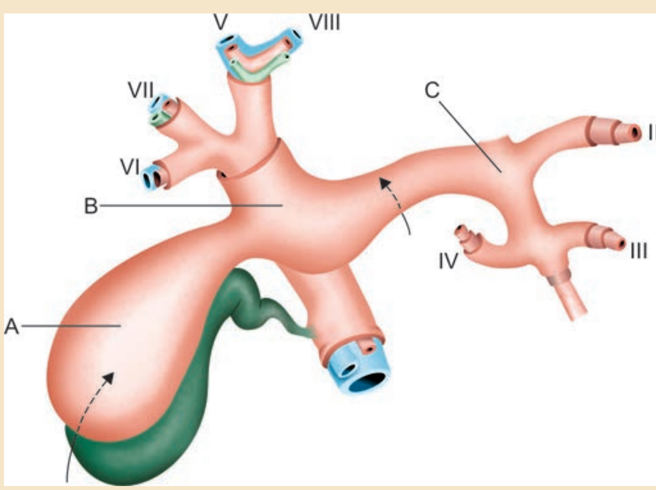


Fig. 110: The plate system. A. The cystic plate between the gallbladder and liver. B. The hilar plate at the biliary confluence at the base of segment IV. C. The umbilical plates above the umbilical portion of the Prtal vein. Shown are the plane of dissection of the cystic plate for cholecystectomy and the hilar plate for exposure of the hepatic duct cofluence and main left hepatic duct (orrows). (From Blumgart LH, Hann LE: Surgical and radiologic anatomy of the liver and biliary tract. In Blungart LH, Fong Y (eds): Surgery of the liver and biliary tract, London, 2000, WB Saunders, pp3–44)

11. Ans. c. Three major & three minor fissures
- Gray's Anatomy mentions three major fissures (not minor) in the functional division of liver.
- Functional anatomy of the liver is based on Couinaud's division of the liver into eight functional segments, based on the distribution of portal venous branches in the parenchyma.
- The liver is divided into four portal sectors by the four main branches of the portal vein. These are right lateral, right medial, left medial and left lateral.
- The three main hepatic veins lie between these sectors as intersectoral veins. These intersectoral planes are also called portal fissures (or scissures) namely: Main, left and right portal fissures.

12. Ans. c. Portal vein is posterior to both common bile duct and hepatic duct
- The arrangement of structures at the porta hepatis is DAV (in anterior to posterior order): Duct (bile duct) → Artery (hepatic) → Vein (portal). Hepatic artery lies medial to the bile duct, both being anterior to portal vein.

13. Ans. b. Right hepatic vein
- Liver is divided into two surgical halves by following middle hepatic vein (and not the right hepatic vein).

14. a. Hepatic vein
- Liver is divided into two halves (right & left) and each receives its own primary branch of the hepatic artery and hepatic portal vein and is drained by its own hepatic duct.
- From a surgical point of view, the liver is divided into right and left lobes of almost equal (60:40) size by a major fissure (Cantlie's line) running from the gallbladder fossa in front to the IVC fossa behind. This division is based on the right and left branches of the hepatic artery, portal vein, and tributaries of hepatic ducts. The middle hepatic vein (MHV) lies in Cantlie's line.
- Previously hepatic veins were mentioned as the basis of liver segmentation, but recently they have been removed from Gray's anatomy (Ed 41).

15. b. Right hepatic artery
- The gallbladder is supplied by the cystic artery (a branch of right hepatic artery).
- It may arise from the main trunk of the hepatic artery, from the left hepatic artery, or from the gastroduodenal artery.

16. a. Inferior surface of liver
- Calot's triangle lies between three Cs—Common hepatic duct, Cystic duct, and Cystic artery.
- Inferior surface of liver forms the boundary for the triangle of cholecystectomy.
- The cystic artery commonly arises from the right hepatic artery is the boundary for the Calot's triangle.
- In the angle between common hepatic duct and cystic duct lies the Calot's lymph node of Lund, which gets inflamed in cholecystitis.

17. b. Cystic duct
- Spiral valve of Heister is formed by the mucosal folds at the terminal opening of cystic duct into the common hepatic duct to form the common bile duct.
- It is not a true valve but is permanent and narrows down the lumen of cystic duct at the terminal end.
- When the duct is distended, the spaces between the folds get dilated, making the folds more obvious.

18. c. 1400-1600 gm
- Liver weights about 1500-1600 gm in males and 1200 gm-1300 gm in females.

19. b. Liver

Histology of the liver
- Liver is covered by Glisson's capsule.
- Liver is divided into hexagonal lobules oriented around the terminal tributaries of the hepatic vein. (Terminal hepatic veins),i.e., Terminal hepatic vein is in the centre of the lobule and area around the hepatic vein is called centrilobular zone.
- At periphery of lobule, lies the portal tract containing hepatic artery,bile duct and portal vein.Area around portal tract is called periportal zone.
- Area between periportal zone and centrilobular zone is called midzonal area.
- All around the central vein are the major parenchymal cells, ie., hepatocytes.
- Lobule contains sinusoid (sinusoidal capillaries) which have fenestrated endothelium covering the subendothelial space of Dissc. This space contains stellate cell processes and hepatocellular microvilli.
- Other important cells of liver are Kupffer cells, which belong to monocytic- macrophage system and function as phagocytic cells.

20. a. Hepatic vein and portal

Based on the distribution of the portal vein and hepatic vein, couinaud divided functional lobes of liver into eight segments.

21. c. Segment 2 and 3
- The portion of liver on the left side of falciform ligament is left (anatomical) lobe of liver. And in Couinaud's functional segmentation of liver, the segment number 2,3,4a and 4b form the left liver lobe.

22. a. V,VI,VII and VIII
- Right lobe------> Segment V,VI, VII and VIII
- Left lobe -----> Segment I,II,III,IV.

23. a. I
- Caudate lobe is segment I.

24. b. Caudate lobe drains only left hepatic duct
- Caudate lobe (anatomical part of right lobe) belongs physiologically to both right and left lobes because it receives blood from right and left hepatic arteries,right and left branches of portal vein ; and drains blood into both right and left hepatic duct.
- Right anterior segments are V and VIII,thus their duct is right anterior hepatic duct.
- Right anterior hepatic (or segmental) duct (RASD) is formed by segments 5 and 8 and right posterior hepatic (segmental) duct (RPSD) is formed by Y segment 6 and 7. Both of these ducts join to form the right hepatic duct. Left anterior (medial) hepatic or segmental duct drains segment 3 and 4, whereas left posterior (lateral) hepatic duct drains segment 2. Both of these ducts join to form left hepatic duct in umbilical fissure.

25. b. Segment III
- Segments V,and VI are part of right hepatic lobe and are therefore drain into right hepatic duct.
- Segments III is a part of left hepatic lobe and is therefore drains into left hepatic duct.
- Segment I (Caudate lobe),through anatomically is a part of left lobe, is functionally is part of both right and left lobes because it receives blood from right and left hepatic arteries,and right and left branches of portal vein and drains bile into both right and left hepatic duct.

26. a. Hepatic vein
- Physiologically right and left lobes are supplied respectively by right and left branches of portal vein and hepatic artery and drain bile into corresponding hepatic ducts (bile duct).

27. a. Segment I
- Caudate lobe (segment I) is a physiological independent part of liver, supplied by both right and left hepatic arteries; right and left branches of portal vein and drains bile into both right and left hepatic duct.

28. b. Anterior to right inferior phrenic artery
- Caudate lobe lies anterior to crura of diaphragm,right inferior phrenic artery and coeliac trunk.
- Caudate lobe is superior to portal vein (lies in porta hepatis) and to right of ligament venosum.

29. d. Hepatic veins
- Venous drainage is through hepatic veins into IVC.

30. b. Left umbilical vein (Ref: BDC Vol. II 6th /e.p. 307)
- The ligament teres represents the obliterated left umblical vein.

31. b. 20% hepatic artery,80% portal
- The liver has dual blood supply :-
  (i) 20% of blood supply is through the hepatic artery.
  (ii) 80% of blood supply is through the portal vein.

32. b. Hepatic vein
- Between two layers of coronary ligaments, there is a large triangular area in daphrgmatic surface of liver which is not covered by peritoneum.
- It is called ‘bare area of liver.’
- It is related to inferior vena cava (IVC).
- The hepatic veins (usually three) leave the liver in bare area.
- This area is clinically important as it is a site where infection can spread from abdominal cavity to thoracic cavity.

33. d. Gall bladder

Boundaries of cystohepatic (Calot’s) triangle are :
(i) Inferiorly : Cystic duct
(ii) Superiorly : Right lobe of liver
(iii) Medially : Common hepatic duct.

34. a. Lymph node

The cystic lymph node lies in the angle between the cystic and common hepatic ducts.
- Cystic artery passes behind the cystic duct and common hepatic duct. The spiral valve of the cystic duct

35. b. Cystic duct
- The mucous membrane of the cystic duct forms a series of 5-12 crescentic folds, arranged spirally to form the so called spiral valve of Heister. This is not a true valve.

36. a. Cystic duct

37. d. Gall bladder
- Hartman’s pouch is a small diverticulum in the neck of gall bladder.

38. a. Gall
- The extrahepatic biliary tree and gall bladder share a similar microscopic anatomy,consisting of a fibromuscular wall lined by mucin producing columnar epithelium similar to that seen in intrahepatic bile ducts.

39. c. Anteriorly related to 1st part of duodenum and 'd' ie., Related to IVC posteriorly

- Relations of bile duct are:

(i) Supraduodenal part(above first part of duodenum):- This part lies in the free margin of lesser omentum.Its relations are
- Anterior ------> Liver
- Posterior -------> Portal vein and epiploic formen
- Left side ---------> Hepatic rtery

(ii) Retro-duodenal part (Behind first part of duodenum):- Its relations are :
- Anterior --------> 1st part of duodenum
- Posterior --------> IVC
- Left side ----------> Gastroduodenal artery

(iii) Infraduodenal part (Below first part of duodenum) :- Its relation are :
- Anterior------> Head of pancreas
- Posterior -------> IVC

40. d. Usually opens into duodenum separate from the main pancreatic duct

- Bile duct opens into 2nd part of duodenum after joining pancreatic duct. It opens into major duodenal papilla , 8-10 cm distal to pylorus.
- For option b nad c, see above explanation.

41. b. 3 sphincters

- Sphincter of Oddi consists of three sets of sphincters:-

(i) Sphincter choledochus (Sphincters of Boyden).
(ii) Sphincter pancreaticus
(iii) Sphincter of Oddi (proper).

42. a. Ampulla of vater

- Within the wall of second part of duodenum bile duct and pancreatic duct unite to form hepatopancreatic ampulla (ampulla of vertex),which opens at major duodenal papilla.

43. a. Vessels that run upward along the bile duct from the duodenal end of the duct such as the retroduodenal and the gastroduodenal arteries

Blood supply of supraduodenal bile duct

1. Axial blood supply
- The blood supply to the supraduodenal bile duct is essentially axial (98%)
- The most important of these vessels run along the lateral borders of the bile duct and are called the '3 o clock' and '9 o' clock arteries.
- These,together with other smaller branches and retorportal vessels from a free anastomosis within the wall of the bile duct.
- 60% of the blood supply occurs from the duodenal (caudal) end of the duct primarily from branches of the retreduodenal artery (Posterior superior pancreaticoduodenal Artery).
- 38% of the blood supply occurs from the hepatic (cephalic) end of the Right Hepatic Artery.

Non -axial blood supply
- Non axial blood supply accounts for only 2% of blood supply to the supraduodenal bile duct.
- This non axial blood supply is derived from branches of the hepatic artery proper as it runs along the common bile duct.

High Yield Points

- Calot's triangle: an isosceles triangle based on the common hepatic duct with the cystic artery and cystic duct forming its sides.
- Minor duodenal papilla is opening of accessory pancreatic duct.

Spleen and Pancreas

Spleen

General Features

- The spleen is located in the left hypochondriac region anterior to the 9th, 10th, and 11th ribs which puts the spleen in jeopardy in the case of rib fractures.
- The spleen does not extend below the costal margin and, therefore, is not palpable unless splenomegaly is present.
- The spleen is attached to the stomach by the gastrosplenic ligament which contains the short gastric arteries and veins and the left gastroepiploic artery and vein.
- The spleen is attached to the kidney by the splenorenal ligament which contains the five terminal branches of the splenic artery, tributaries of the splenic vein, and the tail of the pancreas.
- Accessory spleens occur in 20% of the population and are commonly located near the hilum, tail of the pancreas, or within the gastrosplenic ligament.

- The functions of the spleen include removal of old or abnormal red blood cells (RBCs), removal of inclusion bodies from RBCs [e.g. Howell-Jolly bodies (nuclear remnants), Pappenheimer bodies (iron granules), Heinz bodies (denatured hemoglobin)], removal of poorly opsonized pathogens, IgM production by plasma cells, storage of platelets, and protection from infection.

Arterial Supply

- The arterial supply is from the splenic artery (the largest branch of the celiac trunk) which gives off the following branches: Dorsal pancreatic artery, great pancreatic artery, caudal pancreatic arteries, short gastric arteries, left gastroepiploic artery, and ends with about five terminal branches.
- The five terminal branches of the splenic artery supply individual segments of the spleen with no anastomosis between them (i.e. end arteries) so that obstruction or ligation of any terminal branch will result in splenic infarction (i.e. the spleen is very prone to infarction).
- Splenic artery aneurysms show a particularly high incidence of rupture in pregnant women such that these aneurysms should be resected in women of childbearing age.

Venous Drainage

- The venous drainage is to the splenic vein via tributaries.
- The splenic vein joins the superior mesenteric vein to form the portal vein.
- The inferior mesenteric vein usually joins the splenic vein.
- Splenic vein thrombosis is most commonly associated with pancreatitis and shows the following clinical signs: Gastric varices and upper gastrointestinal bleeding.
- The spleen (mesodermal) appears about the sixth week as a localized thickening of the coelomic epithelium of the dorsal mesogastrium.

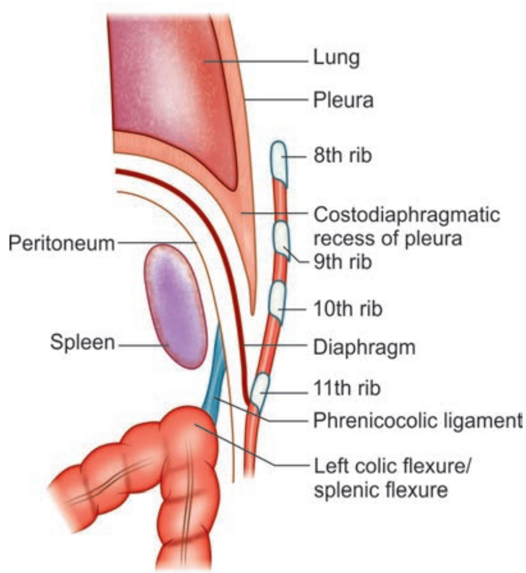


Fig. 111: Longitudinal section through the midaxillary line to show the relations of diaphragmatic surface of the spleen.

- Anterior end of the spleen is held up by phrenocolic ligament *(NBEP 2013)*
- N.B. The Harris' dictum of odd numbers 1, 3, 5, 7, 9, 11 summarizes some splenic statistics, viz., it measures 1 inch in thickness, 3 inches in breadth, 5 inches in length, weighs 7 oz, and lies deep to 9, 10, and 11 ribs.

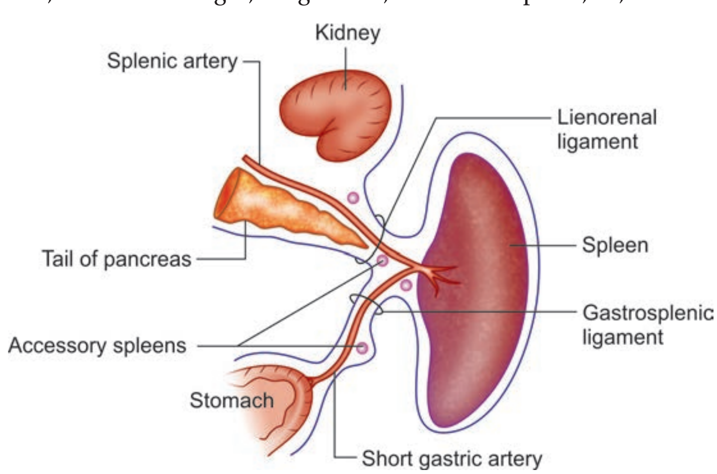


Fig. 112: Peritoneal relations of the spleen.

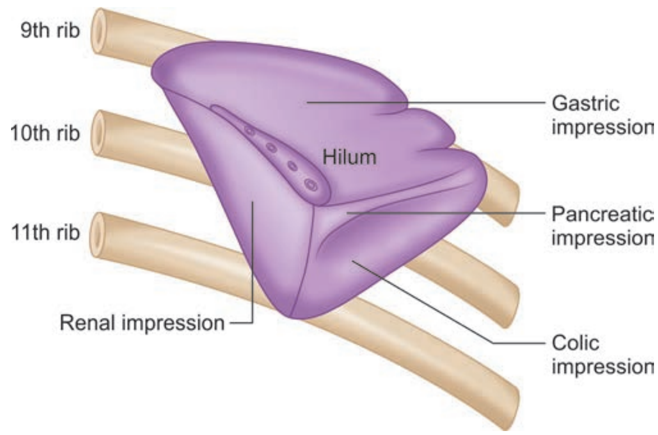


Fig. 113: Visceral surface of the spleen showing different impressions.

- Visceral Relations
- The visceral surface of the spleen is related to the following viscera:
  1. Fundus of the stomach.
  2. Anterior surface of the left kidney.
  3. Left colic flexure.
  4. Tail of pancreas.
- These viscera produce impressions on this surface (for details see visceral surface on page 104).
- The diaphragmatic surface of the spleen is related to the diaphragm, which separates it from the costophrenic recess of the pleura, lung, and 9 to 11 ribs.
- Accessory Spleens
- The failure of fusion of splenunculi results in the formation of accessory spleens (splenunculi). These are usually found in the derivatives of the dorsal mesogastrium, viz.
- (a) in the gastrosplenic ligament, (b) in the lienorenal ligament, and (c) in the greater omentum. Rarely they are formed in the left spermatic cord and in the broad ligament of the uterus (left side).
- Rupture of spleen: Although well protected by 9th, 10th, and 11th ribs, the spleen is the most frequently ruptured organ in the abdomen following severe external blow.
  The pain is referred to the left shoulder due to irritation of the left dome of diaphragm by the splenic blood.It is called 'Kehr's sign'.

ASSESSMENT QUESTIONS

1. Right isomerism is: *(AIPG 2011)*
a. Asplenia
b. Two spleens
c. One spleen
d. Polysplenia

2. All of the following statements about the splenic artery are true EXCEPT that it: *(AIIMS 2005)*
A. Has a tortuous course
b. Is a branch of the coeliac trunk
c. Has branches that anastomose freely within the spleen
d. Supplies the greater curvature of stomach

3. All of the following form visceral relations of spleen EXCEPT:
a. Stomach
b. Splenic flexure of colon
c. Kidney
d. Adrenal gland

4. Spleen extends from: *(NEET Pattern 2012)*
a. 5th to 9th rib
b. 9th to 11th rib
c. 2nd to 5th rib
d. 11th to 12th rib

5. Downward displacement of enlarged spleen is prevented by:
a. Lienorenal ligament
b. Phrenocolic ligament
c. Upper pole of right kidney
d. Sigmoid colon

6. Most common location of accessory spleen:
a. Hilum of spleen (NEET Pattern 2015)
b. Greater omentum
c. Lesser omentum
d. None

ANSWERS WITH EXPLANATIONS

1. a. Asplenia
- Rights sided bilateralism (isomerism) is characterized by asplenia (or hypoplastic spleen) and lefts sided bilateralism (isomerism) is characterized by polysplenia.

2. c. Has branches that anastomose freely within the spleen
- Branches of splenic artery are end-arteries since they do not anastomose any further in the substance of spleen.
- Splenic artery is the largest branch of coeliac trunk and has a tortuous course.
- Splenic artery supplies the greater curvature of stomach by giving short gastric arteries and left gastroepiploic artery.

3. d. Adrenal gland
- Visceral surface of spleen has gastric, renal and colic impressions, but not adrenal.

4. b. 9th to 11th rib
- Spleen lies along the 9th and 11th ribs.

5. b. Phrenico-colic ligament
- Phrenicocolic (Hensing's) ligament is a double fold of peritoneum, that continues from the left colic flexure to the thoracic diaphragm opposite the tenth and eleventh ribs.
- It passes below and serves to support the spleen (hence named sustentaculum lienis).

6. a. Hilum of spleen
- Most common site of accessory spleen is hilum of spleen.

Pancreas

Pancreas

A. General Features
- In the adult, the pancreas is a retroperitoneal organ that measures 15 to 20 cm in length and weighs about 85 to 120 g.
- The pancreas is both an exocrine gland and an endocrine gland.

The pancreas consists of four parts as follows:

1. Head of the Pancreas
- The head is the expanded part of the pancreas that lies in the concavity of the C-shaped curve of the duodenum and is firmly attached to the descending and horizontal parts of the duodenum.
- The uncinate process is a projection from the inferior portion of the pancreatic head.
- The structures that lie posterior to the head of the pancreas are the IVC, right renal artery, right renal vein, and the left renal vein.

2. Neck of the Pancreas
- The structures that lie posterior to the neck of the pancreas are the confluence of the superior mesenteric vein and splenic vein to form the portal vein.

3. Body of the Pancreas
- The structures that lie posterior to the body of the pancreas are the aorta, superior mesenteric artery, left suprarenal gland, left kidney, renal artery, and renal vein.

4. Tail of the Pancreas
- The tail of the pancreas is related to the splenic hilum and the left colic flexure.

B. Arterial Supply. The arterial supply of the pancreas is from the following.
- Anterior and posterior superior pancreaticoduodenal arteries which supply the head and neck of the pancreas (abdominal aorta → celiac trunk → common hepatic artery → gastroduodenal artery → anterior and posterior superior pancreaticoduodenal arteries).
- Anterior and posterior inferior pancreaticoduodenal arteries which supply the head and neck of the pancreas (abdominal aorta → superior mesenteric artery → anterior and posterior inferior pancreaticoduodenal arteries).
- Dorsal pancreatic artery which supplies the body and tail of the pancreas (abdominal aorta → celiac trunk → splenic artery → dorsal pancreatic artery).
- Great pancreatic artery which supplies the body and tail of the pancreas (abdominal aorta → celiac trunk → splenic artery → great pancreatic artery).
- Caudal pancreatic arteries which supply the body and tail of the pancreas (abdominal aorta → celiac trunk → splenic artery → caudal pancreatic arteries).

C. Venous Drainage. The venous drainage of the pancreas is to the following:
- Splenic vein (splenic vein → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava).
- Superior mesenteric vein (superior mesenteric vein → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava).

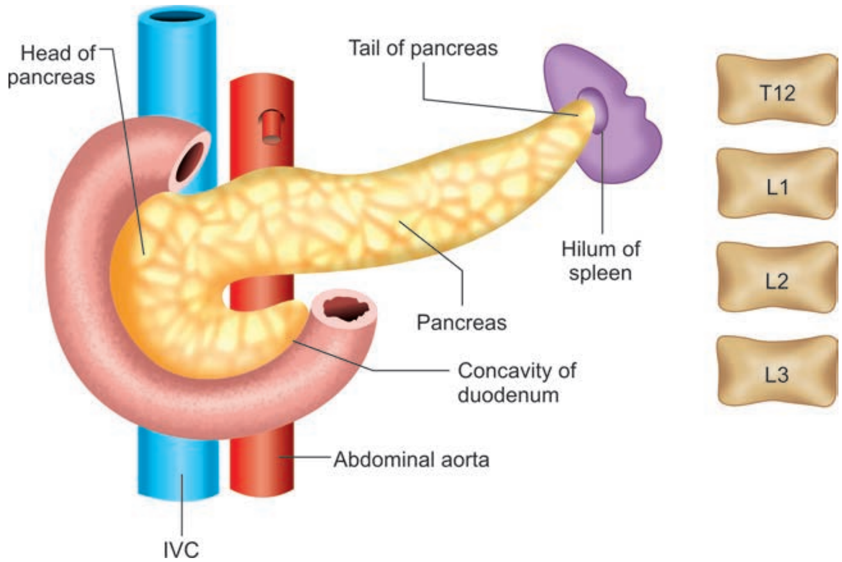


Fig. 114: Visceral relations of the different parts of the pancreas

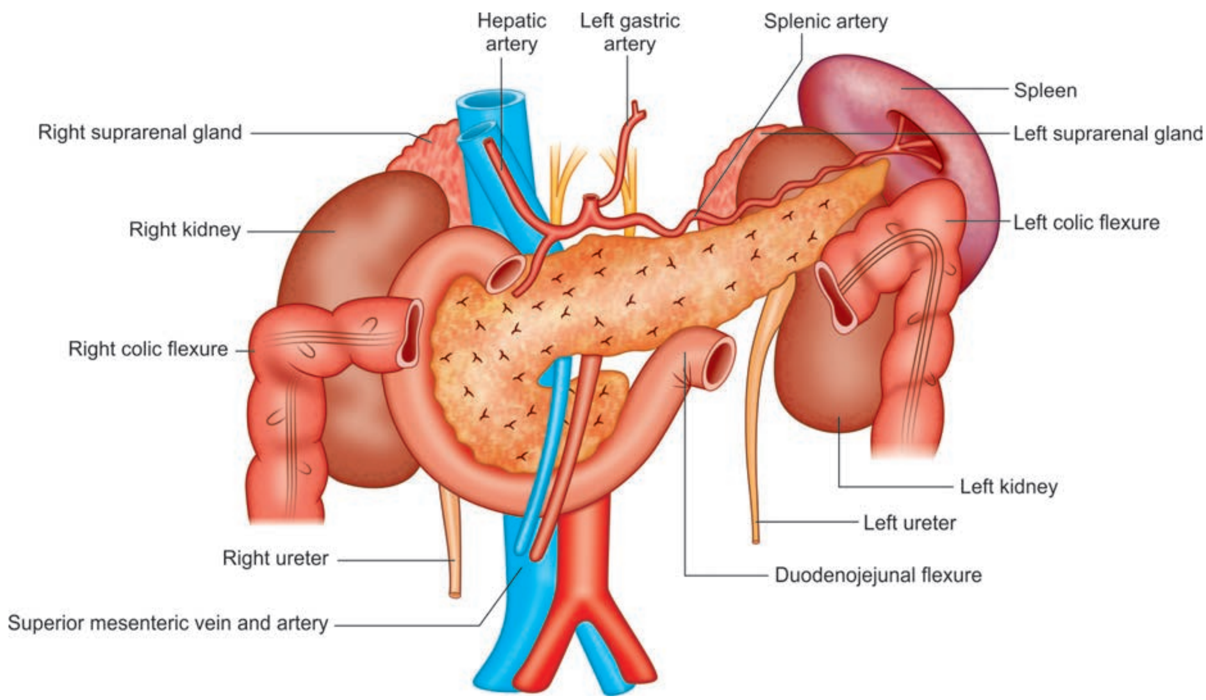
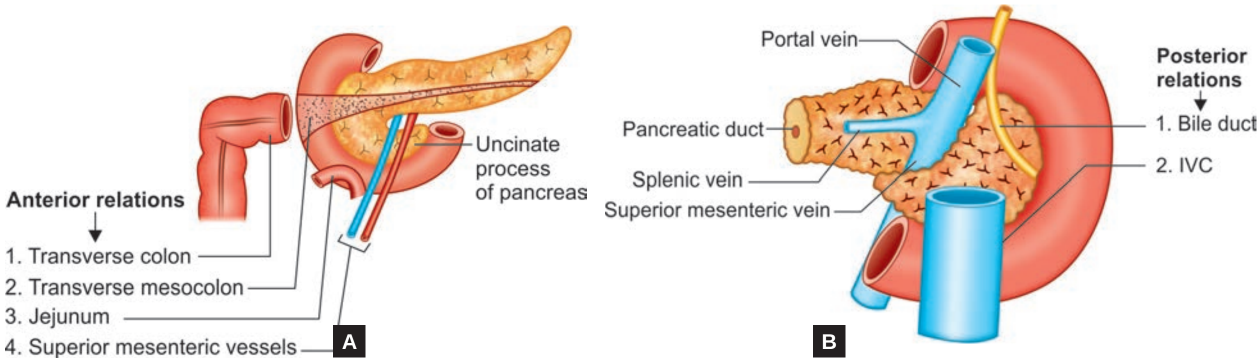


Fig. 115: Visceral relations of the different parts of the pancreas

- Superior mesenteric vein and artery are anterior relations of uncinate process (pancreas)
- Abdominal aorta lies posterior to uncinate process (pancreas)



Figs. 116A and B: Relations of the head of pancreas: (A) Anterior relations; (B) Posterior relations

- Structure immediately posterior to head of pancreas is right renal vein. *(NBEP 2013)*
- Posterior relations of pancreatic head are IVC, terminal parts of right and left renal veins, common bile duct.
- Behind the neck of pancreas, superior mesenteric vein joins splenic vein to form portal vein: *(AIIMS 2005)*

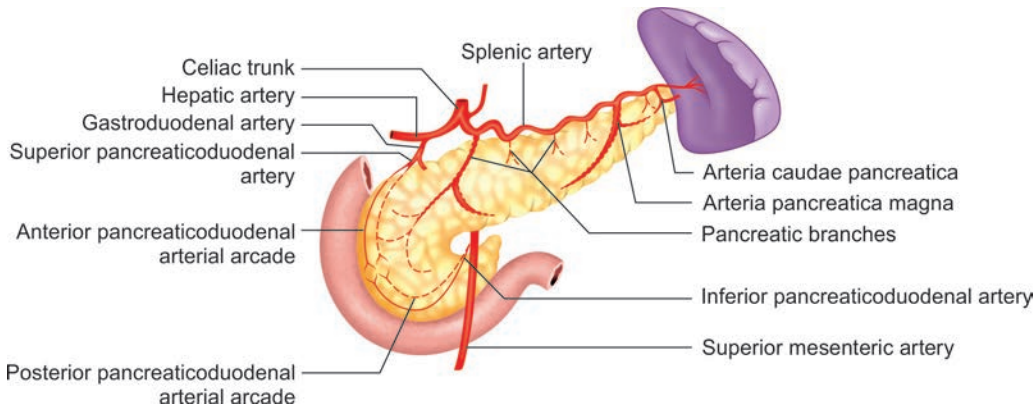


Fig. 117: Arterial supply of the pancreas

ASSESSMENT QUESTIONS

1. Posterior relations of head of pancreas are all EXCEPT:
   a. Common bile duct (AIPG 2011)
   b. Inferior vena cava
   c. First part of duodenum
   d. Aorta

2. Structure immediately posterior to pancreatic head:
   a. Right renal vein *(NEET Pattern 2012)*
   b. Splenic artery
   c. Inferior mesenteric vein
   d. Coeliac trunk

3. The neck of pancreas is related on its posterior surface to: *(AIIMS 2005)*
   A. Gastroduodenal artery
   b. Superior mesenteric vein
   c. Inferior vena cava
   d. Bile duct

4. All of the following statements regarding relations of pancreas are true EXCEPT:
   a. Right renal vein is immediately posterior to the head
   b. Superior mesenteric vein lies anterior to the uncinate process
   c. First part of duodenum is posterior to the head
   d. Superior mesenteric vein lies posterior to the neck

5. Regarding artery supply of pancreas, which of the following is/are CORRECT: *(PGIC)*
   a. Both superior and inferior pancreaticoduodenal arteries are branches of gastroduodenal artery
   b. Posterior superior pancreaticoduodenal artery is a branch of superior mesenteric artery
   c. Anterior inferior pancreaticoduodenal artery is a branch of superior mesenteric artery
   d. Posterior inferior pancreaticoduodenal artery is a branch of gastroduodenal artery
   e. Body and tail are supplied by splenic artery

ANSWERS WITH EXPLANATIONS

1. c. First part of duodenum > d. Aorta
- First part of duodenum is anterior to the head of pancreas.
- Aorta is posterior to the uncinate process of pancreas (and not the head)
- Right and left renal veins drain into IVC behind the head of pancreas.
- Bile duct passes behind the head of pancreas and is joined by pancreatic duct, before opening into second part of duodenum.

2. a. Right renal vein
- Right and left renal veins drain into IVC behind the head of pancreas.

3. Ans. b. Superior mesenteric vein
- Superior mesenteric vein joins the splenic vein behind the neck of pancreas to form the portal vein.
  - Gastroduodenal artery lies behind the first part of duodenum and the head of pancreas. It might produce severe haemorrhage in posterior perforation of duodenal ulcer.
  - Inferior vena cava and bile duct lie behind the head of pancreas. Carcinoma of head of pancreas can compress these structures and lead to obstructive jaundice.

4. c. First part of duodenum is posterior to the head
- First part of duodenum lies anterior to the head of pancreas.

5. c. Anterior inferior pancreaticoduodenal artery is a branch of superior mesenteric artery; e. Body and tail are supplied by splenic artery.
- Gastroduodenal artery gives superior pancreaticoduodenal arteries (anterior and posterior both).
- Superior mesenteric artery gives inferior pancreaticoduodenal arteries (anterior and posterior both).
- Splenic artery runs on the superior border of pancreas and give multiple branches to body and tail of pancreas.

Kidney

Structure

Kidney

- Is a retroperitoneal organ lying on posterior abdominal wall at the level of T12 –L3.

Note: Right kidney lies a little lower than the left because of the large size of the right lobe of the liver.

- 11 cm long, 6 cm wide, and 3 cm thick, and weighs 150 g in men and 135 g in women.
- Location:

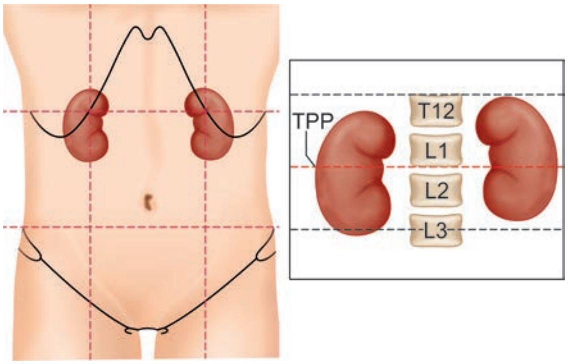


Fig. 118: Surface marking for kidneys

- Kidney occupies epigastric, hypochondriac, lumbar and umbilical regions.
- Transpyloric plane (TPP) passes through the upper part of the hilum of the right kidney and the lower part of the hilum of the left kidney.

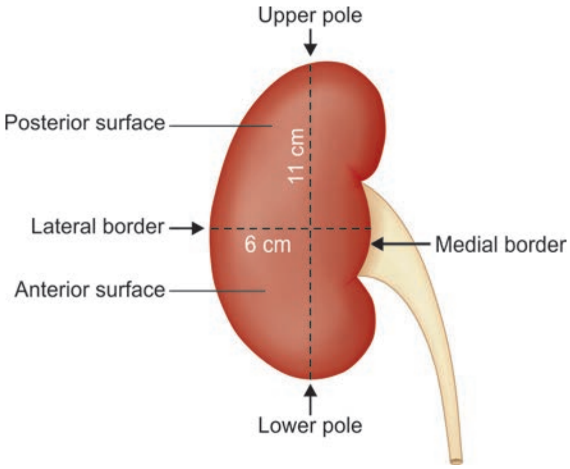


Fig. 119: External features and measurements of the kidney

- Hilus is an indentation on its medial border, through which the ureter, renal vessels, and nerves enter or leave the kidney (Anterior to posterior arrangement of structures is VAP[Q] (vein artery pelvis).

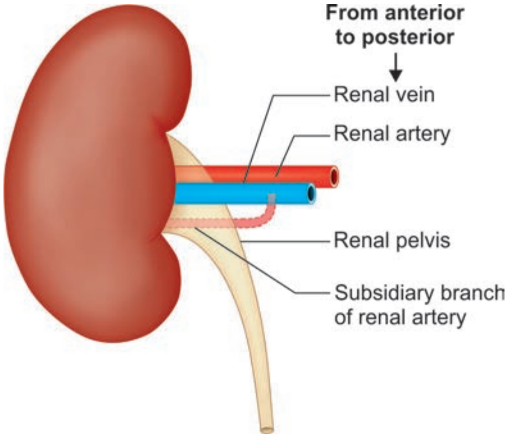


Fig. 120: Structures at the hilum of kidney (also shown are the relations)

Coverings of Kidney

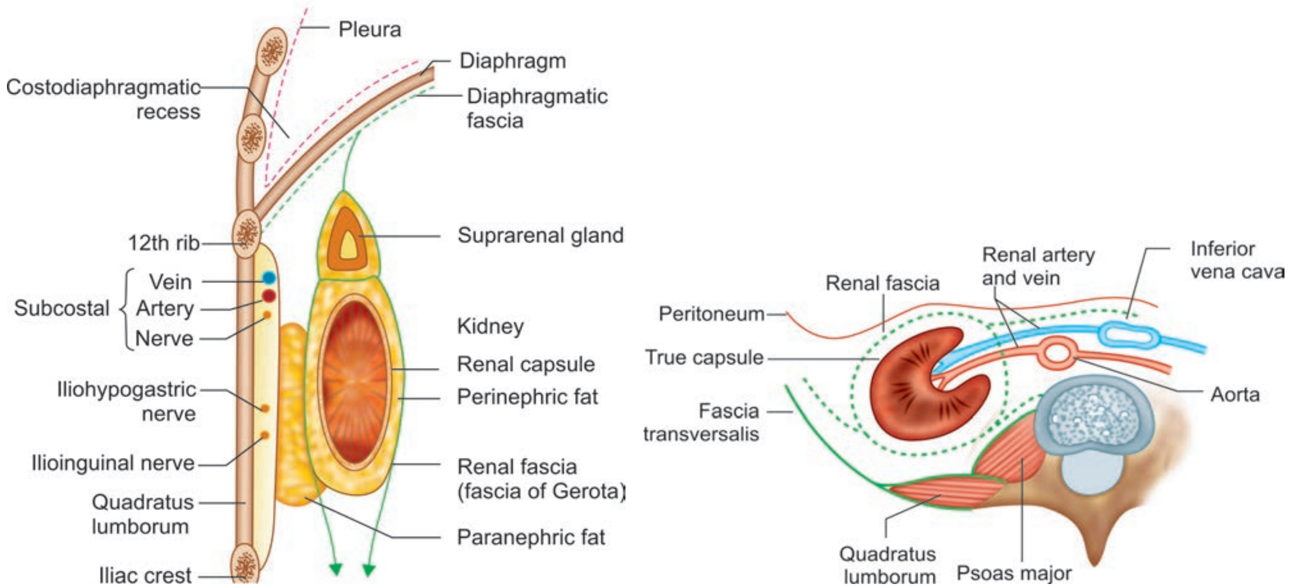
- Kidney is invested by a firm, fibrous renal capsule (true capsule) and is surrounded by the renal fascia (false capsule), which divides the fat into two regions.
- The perirenal (perinephric) fat lies in the perinephric space between the renal capsule and renal fascia, and the pararenal (paranephric) fat lies external to the renal fascia.

Renal Fascia (of Gerota)

It is the false capsule, which surrounds the kidney and perirenal fat and has two layers:

1. Anterior layer (fascia of Toldt).
2. Posterior layer (fascia of Zuckerkandl).

- The two layers enclose the suprarenal gland and then fuse with each other to continue superiorly with the diaphragmatic fascia.
- Inferiorly, the two layers remain separate and enclose the ureter.
- Laterally, the two layers unite and are continuous with the fascia transversalis.



Figs. 121A and B: Capsules (coverings) of the kidney: (A) Seen in vertical section through posterior abdominal wall in the lumbar region; (B) as seen in cross section through posterior abdominal wall in the lumbar region

Structure

Kidney consists of the medulla and cortex, containing 1 to 2 million nephrons (in each kidney), which are the anatomic and functional units of the kidney. Each nephron consists of a renal corpuscle (found only in the cortex), a proximal convoluted tubule, Henle loop, and a distal convoluted tubule.

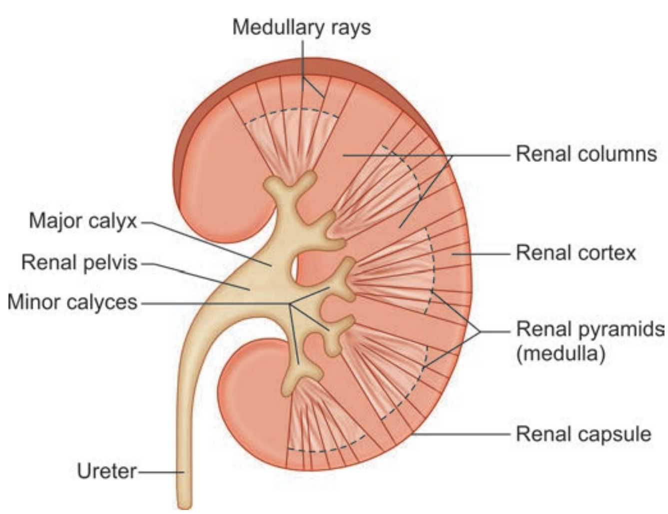


Fig. 122: Location of the uriniferous tubule within the kidney

- Renal papilla opens into minor calyx

Cortex

- Forms the outer part of the kidney and also projects into the medullary region between the renal pyramids as renal columns (of Bertini).
- Contains renal corpuscles and proximal and distal convoluted tubules. The renal corpuscle consists of the glomerulus (a tuft of capillaries) surrounded by a glomerular (Bowman) capsule, which is the invaginated blind end of the nephron.

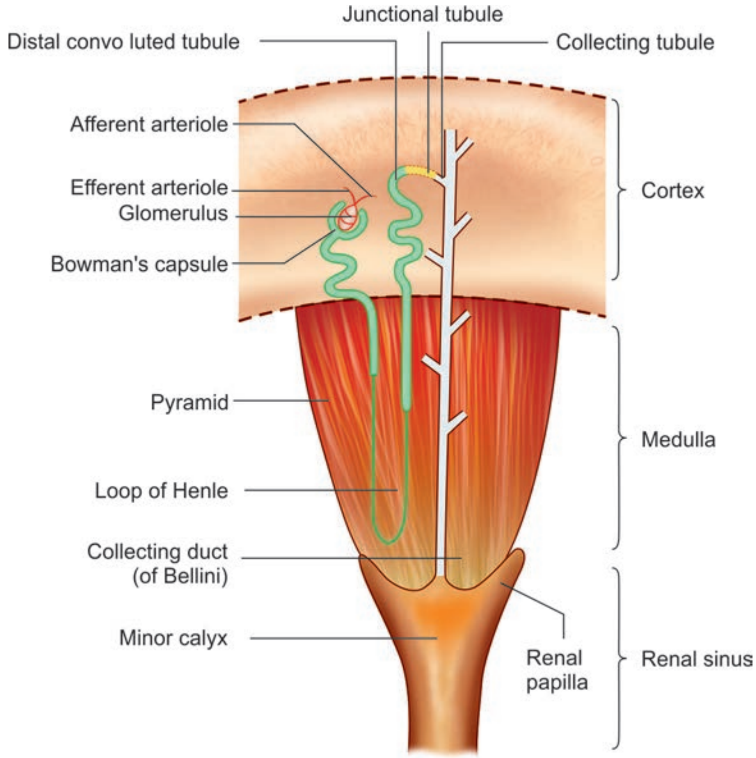


Fig. 123: Location of the uriniferous tubule within the kidney

Medulla

- Forms the inner part of the kidney and consists of 8 to 12 renal pyramids (of Malpighi), which contain straight tubules (Henle loops) and collecting tubules.
- **An apex of the renal pyramid, the renal papilla, fits into the cup-shaped minor calyx** Q on which the collecting tubules open (10 to 25 openings).

Note:

- A renal pyramid along with its covering cortical tissue forms a **lobe of the kidney.**
- **Minor calyces** receive urine from the collecting tubules and empty into two or three **major calyces,** which in turn empty into an upper dilated portion of the ureter, the **renal pelvis.**

Neurovascular Supply

Renal Arteries

- Arise from the abdominal aorta (at L1 vertebra level) inferior to the origin of the superior mesenteric artery.
- The right artery is longer and a little lower than the left and passes posterior to the IVC; the left artery passes posterior to the left renal vein.
- Give rise to the inferior suprarenal and ureteric arteries.
- At or near the hilum of the kidney, each renal artery divides into anterior and posterior divisions.

Anterior and Posterior Divisions

- The anterior division branches into four **anterior segmental arteries** which supply anterior segments of the kidney called the **apical segmental artery, anterosuperior segmental artery, anteroinferior segmental artery,** and **inferior segmental artery.**
- The posterior division continues as the posterior segmental artery which supplies the posterior segment of the kidney.

Segmental Arteries

- The segmental arteries are end arteries (i.e. they do not anastomose) and are distributed to various segments of the kidney. Segmental arteries have the following clinical importance:

- Since there is very little collateral circulation between segmental arteries (i.e., end arteries), an **avascular line (Brodel white line)** is created between anterior and posterior segments such that a longitudinal incision through the kidney will produce minimal bleeding. This approach is useful for surgical removal of renal (staghorn) calculi.
- Ligation of a segmental artery results in necrosis of the entire segment of the kidney.

Note: Supernumerary renal arteries - In about 30% individuals accessory renal arteries are also found. They commonly arise from the aorta and enter the kidney at the hilus or at one of its poles, usually the lower pole.

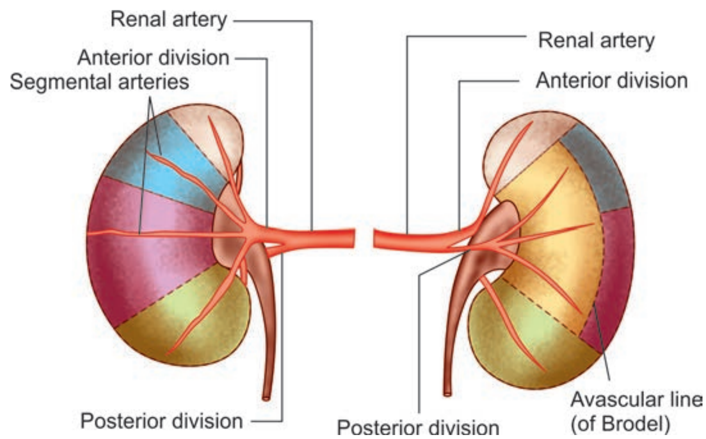


Fig. 124: Renal arteries.

Vasculature:
- The segmental arteries branch into 5 to 11 **interlobar arteries** (run between pyramids) which turn along the base of the pyramid **(arcuate arteries)** and further branch into smaller **interlobular arteries** that supply the cortex.
- In the cortex, the **interlobular artery** gives off the afferent arterioles (one to each glomerulus), which give rise to the capillaries that form the glomerulus. The **glomerular capillaries** reunite to form a single **efferent arteriole** that, in turn, gives rise to a second network of capillaries, the **peritubular capillaries.**
- Some of the peritubular capillaries form long loops called the **vasa recta,** which accompany the thin segments of the nephrons.

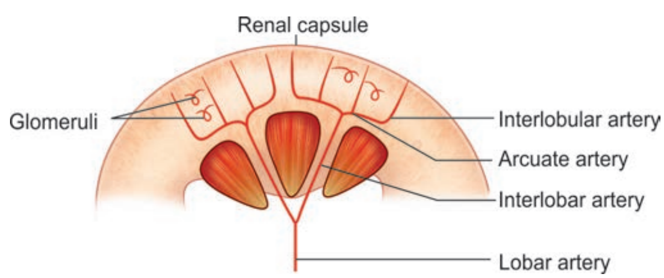


Fig. 125: Arrangement of arteries within the kidney

The subdivisions of the renal arteries are described sequentially as segmental, lobar, interlobar, arcuate and interlobular arteries, and afferent and efferent glomerular arterioles

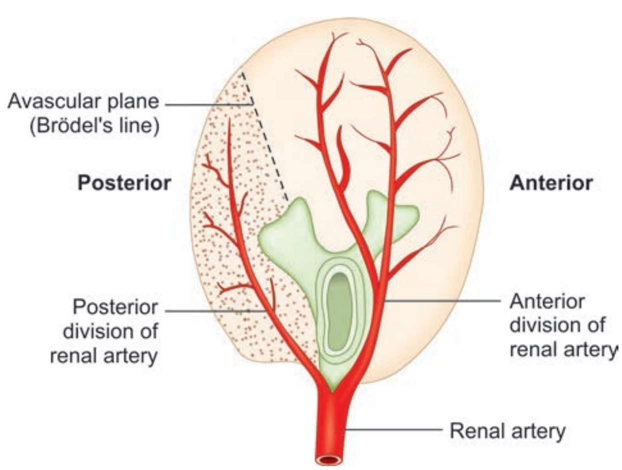


Fig. 126: Schematic diagram showing avascular plane of the kidney (Brödel's line)

Venous Drainage

- Peritubular capillaries drain into the interlobular veins → arcuate veins → interlobar veins → renal vein → IVC.
- The left is three times longer[Q] than the right (7.5 cm and 2.5 cm, respectively), and for this reason, **the left kidney is the preferred side for live donor nephrectomy[Q].**
- The left renal vein runs from its origin in the renal hilum, posterior to the splenic vein and the body of pancreas, and then across the **anterior aspect of the aorta, just below the origin of the superior mesenteric artery[Q]. Nutcracker syndrome,** characterized by left renal vein hypertension secondary to compression of the vein between the aorta and the superior mesenteric artery, has been associated with haematuria and varicocele in children. The left gonadal vein enters the left renal vein from below, and the left suprarenal vein, usually receiving one of the left inferior phrenic veins, enters it above but nearer the midline.

Lymphatic Drainage

- The lymphatics from the kidney drain into the **para-aortic** lymph nodes at the level of origin of the renal arteries.

ASSESSMENT QUESTIONS

1. **All of the following are true regarding blood supply to the kidney EXCEPT:** *(AI 2002)*
   a. Stellate veins drain the superficial zone
   b. It is a type of portal circulation
   c. Renal artery divides into five segmental arteries before entering the hilum
   d. Its segmental arteries are end arteries

ANSWERS WITH EXPLANATIONS

1. **b. It is a type of portal circulation.**
   - In the renal glomeruli the glomerular capillary bed lies between afferent and efferent arterioles and may be considered as a portal circulation, but most of the authors do not mention so, including Gray's anatomy.
   - In essence, a portal system is a capillary network that lies between two veins. Blood supplying the organ thus passes through two sets of capillaries before it returns to the heart.
   - In **hepatic portal system** blood supplying the abdominal organs passes through two sets of capillaries before it returns to the heart.
   - A venous portal circulation also connects the median eminence and infundibulum of the **hypothalamus with the adenohypophysis.**

Nerve Supply (Renal Plexus)

- Rami from the **coeliac ganglion and plexus[Q]**, aorticorenal ganglion, lowest thoracic splanchnic nerve, first lumbar splanchnic nerve and aortic plexus form a dense plexus of autonomic nerves around the renal artery.
- The **sympathetic** fibres are derived from T10-L2 spinal segments, and the **parasympathetic** fibres are derived from vagus nerves.

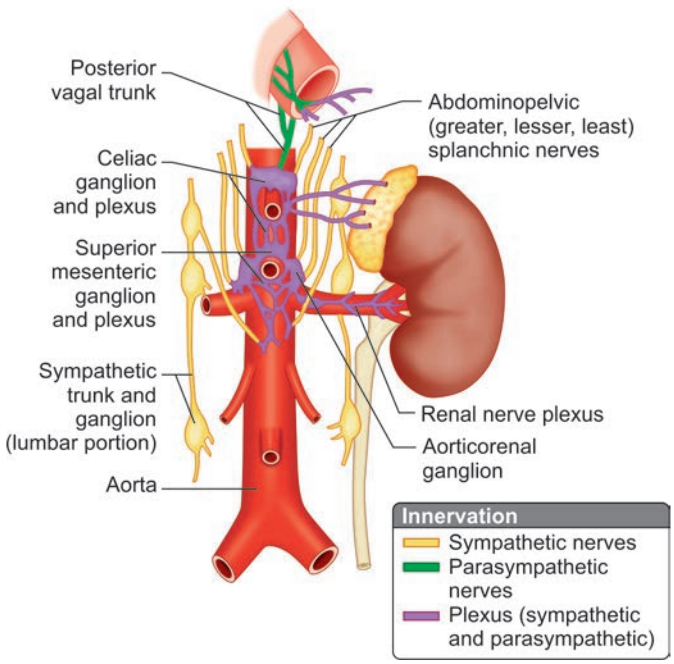


Fig. 127: Location of the uriniferous tubule within the kidney

Renal Pain

- Radiates downward and forward from loin into the groin along the T12 (±2) dermatome.
- It occurs due to stretching of the renal capsule and spasm of the smooth muscle in the renal pelvis.

- The afferent fibres pass successively through the renal plexus, lowest splanchnic nerve, sympathetic trunk, and enter the T12 spinal segment.
- The pain is felt in the renal angle and gets referred along the subcostal nerve to the flank and anterior abdominal wall and along the **ilioinguinal nerve (L1)** into the groin.

Note: **Renal angle** lies between the lower border of the 12th rib and the lateral border of sacrospinalis (erector spinae) muscle.

ASSESSMENT QUESTIONS

1. **Nerve supply to kidney is from:** *(NBEP 2012)*
   a. Lumbar plexus
   b. Coeliac plexus
   c. Inferior mesenteric nerve
   d. None

ANSWERS WITH EXPLANATIONS

1. **b. Coeliac plexus.**
   - Kidney is supplied by branches around the renal artery, carried from various sources, including **coeliac plexus**
   - The nerves to the kidneys arise from the renal nerve plexus and consist of sympathetic and parasympathetic fibers**.** The **renal nerve plexus** is supplied by fibers from the abdominopelvic (especially the least) splanchnic nerves.
   - Visceral afferent fibers conveying pain sensation (e.g., resulting from obstruction and consequent distension) follow the sympathetic fibers retrograde to spinal ganglia and cord segments T10–L2.

Relations

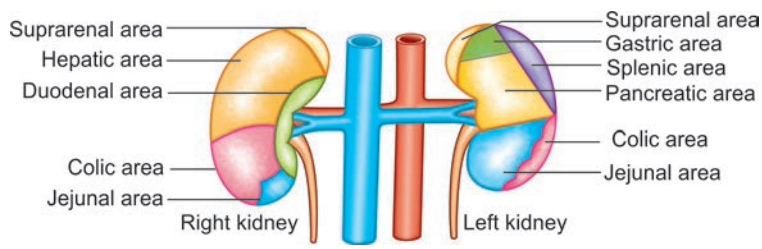


Fig. 128: Anterior relations of the kidneys

Relations of Kidney

Anterior Relations

Right	Left
• Right suprarenal gland • Right lobe of the liver • Second part of the duodenum • Hepatic (right) colic flexure • Jejunum	• Left suprarenal gland • Spleen • Stomach • Pancreas and splenic vessels • Splenic (left) colic flexure • Jejunum

Note: Tail of pancreas is not related to left kidney.

Posterior Relations (both kidneys)

- Muscles: Diaphragm, quadratus lumborum, psoas major, and transversus abdominis.
- Nerves: Subcostal (T12), iliohypogastric (L1), and ilioinguinal (L1).
- Vessels: Subcostal vessels.
- Ribs: 12th Rib (Left kidney is related to the 11th rib as well)
- Ligaments: Medial and lateral arcuate ligament

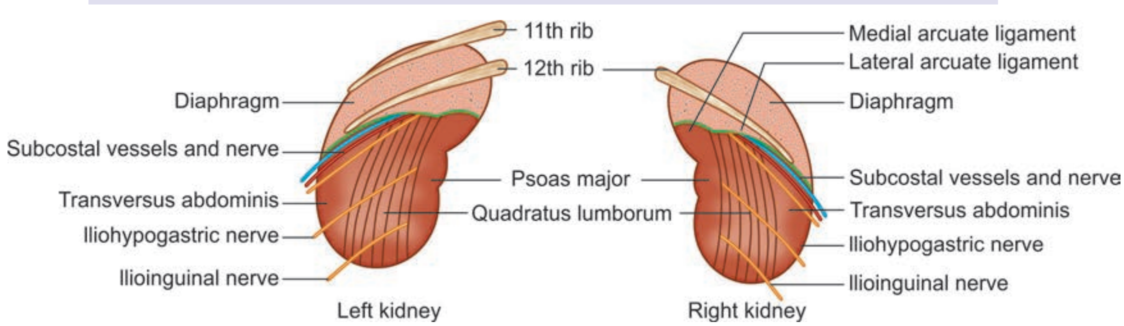


Fig. 129: Posterior relations of the kidneys

ASSESSMENT QUESTIONS

1. While exposing the kidney from behind, all of the following nerves are liable to injury EXCEPT: *(AI 2004)*
- a. Lateral cutaneous nerve of thigh
- b. Ilio-inguinal nerve
- c. Subcostal nerve
- d. Ilio-hypogastric nerve

2. Anterior relations of the right kidneys are all EXCEPT:
- a. 4th part of duodenum(NBEP 2013)
- b. Liver
- c. Hepatic flexure
- d. Adrenal gland

3. In the relation of right kidney, all are devoid of peritoneum EXCEPT:
- a. Supra renal gland
- b. Liver
- c. Duodenum
- d. Colon

4. All of the following are the posterior relations of the kidney EXCEPT: *(NEET Pattern 2014)*
- a. Psoas major
- b. Quadratus lumborum
- c. Sympathetic chain
- d. Ilioinguinal nerve

ANSWERS WITH EXPLANATIONS

1. a. Lateral cutaneous nerve of thigh
- **Lateral cutaneous nerve of thigh** is not related to the posterior aspect of kidney.
- Refer Fig. Picture on page "Relations"

2. a. 4th part of duodenum
- Right kidney is related to the 2nd part of duodenum (and not 4th part).
- Refer Fig. Picture on page "Relations"

3. b. Liver
- **Liver** is covered by peritoneum as it gets related anteriorly to right kidney.
- Suprarenal gland, duodenum, colon are retroperitoneal organs, as they come in relation to kidney and kidney itself is retroperitoneal as well.
- Posterior relations of kidney are psoas major, Quadratus lumborum, ilio-inguinal nerve **but not the sympathetic chain. (NBEP 2014)**

4. c. Sympathetic chain
- The nerves related to kidney's posteriorly are: Subcostal (T12), iliohypogastric (L1), and ilioinguinal (L1).
- **Left renal vein** crosses **in front of aorta, below and behind SMA (superior mesenteric artery).** (**AIIMS 2007; NBE 2012**)
- Left renal vein is longer, as it has to cross the midline of the body to drain into IVC.
- **Nut cracker syndrome:** Compression of the left renal vein between the aorta and the superior mesenteric artery, causing hypertension in the kidney with flank pain and sometimes fever and gross hematuria

Applied Anatomy

Nephroptosis is a downward displacement of the kidney, dropped kidney, or floating kidney caused by loss of supporting perirenal fascia. It may cause intermittent ureteric obstruction or kinking of a renal artery, resulting in hydronephrosis.

Renal transplantation: Left kidney transplantation is preferred (due to longer renal vein). The donor kidney is placed retroperitoneally in the iliac fossa with hilum parallel to the external iliac vessels. The renal artery is anastomosed end to end to the internal iliac artery and renal vein is anastomosed end to side to the external iliac vein. The ureter is implanted into the urinary bladder (ureterocystostomy).

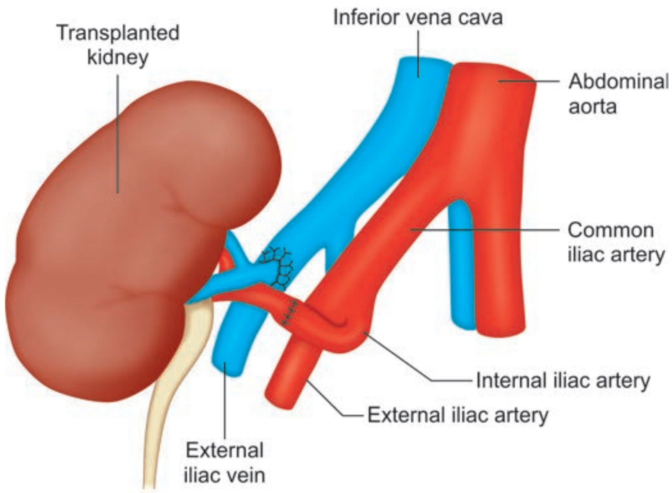


Fig. 130: The transplanted kidney

ASSESSMENT QUESTIONS

1. All are TRUE about right kidney EXCEPT: *(AIIMS 2001)*
a. Right renal vein is shorter than left
b. Related to duodenum
c. Right kidney is preferred over left for transplantation
d. Right kidney is placed at the lower level than left

ANSWERS WITH EXPLANATIONS

1. c. Right kidney is preferred over left for transplantation
- The left kidney from a living, related donor is preferred for kidney transplantation because it has a **longer renal vein** and thus is easier to implant in the recipient.
- Because of the presence of liver, **right kidney is at a lower level than lef**t. Left kidney relates with 11th rib as well, whereas, right is related to 12th rib only (dig)

High Yield Points

- **Renal angle** lies between 12th rib and lateral border of **sacrospinalis (erector spinae)** muscle. **(AIIMS 2007; NBEP 2013)**

ASSESSMENT QUESTIONS

1. Most medially located renal structure is:
a. Major calyx
b. Minor calyx
c. Renal cortex
d. Renal pelvis

2. Renal papilla opens into: *(NEET Pattern 2012)*
a. Cortex
b. Pyramid
c. Minor calyx
d. Major calyx

3. While exposing the kidney from behind, all of the following nerves are liable to injury EXCEPT: *(AIPG 2004)*
a. Lateral cutaneous nerve of thigh
b. Ilioinguinal nerve
c. Subcostal nerve
d. Iliohypogastric nerve

4. Left renal vein crosses the Aorta: *(AIIMS 2007)*
a. Anteriorly, above the superior mesenteric artery
b. Anteriorly, below the superior mesenteric artery
c. Posteriorly, at the level of superior mesenteric artery
d. Anteriorly, below the inferior mesenteric artery

5. While exposing the kidney from behind,all of the following nerves are liable to injury EXCEPT: *(AI 04)*
a. Lateral cutaneous nerve of thigh
b. Ilioinguinal nerve
c. Subcostal nerve
d. Iliohypogastric nerve

6. True about relations of renal artery and vein:
a. Left renal vein passes behind aorta *(CET July 15 Pattern)*
b. Renal artery passes in front of IVC
c. Right renal vein shorter than left renal vein.
d. Renal artery is a branch of internal iliac artery.

7. All of the following are true regarding blood supply to the kidney EXCEPT: *(AI 2002)*
a. Stellate veins drain the superficial zone
b. It is a type of portal circulation
c. Renal artery divides into five segmental arteries before entering the hilum
d. Its segmental arteries are end arteries

8. Nerve supply of kidney is from: *(NEET Dec 12 Pattern)*
a. Lumbar plexus
b. Coeliac plexus
c. Inferior mesenteric nerve
d. None

9. Correct relationship of structures at hilum of kidney from anterior to posterior is: *(AIIMS 99)*
a. Renal artery, renal vein, renal pelvis
b. Renal vein, renal artery, renal pelvis
c. Renal vein, renal artery, renal pelvis

10. Tributaries of left renal vein are all except:
a. Left adrenal vein (CET Nov 14 Pattern)
b. Left testicular vein
c. Diaphragmatic vein
d. Left lumbar vein

11. Sturcture that does not cross the midline is: *(AI 07)*
a. Left gonadal vein
b. Left renal vein
c. Left branchiocephalic vein
d. Hemiazygos vein

12. Renal angle lies between: *(AIIMS May 07)*
a. 12th rib and lateral border of sacrospinalis
b. 11th rib and lateral border of sacrospinalis
c. 12th rib and lateral border of quadratus lumborum
d. 11th rib and lateral border of quadratus lumborum

13. Which of these best describes the renal angle: *(NEET Dec 12 Pattern)*
a. Angle between the lattissimus dorsi and the 12th rib
b. Angle between the erector spinae and the iliac crest
c. Angle between the 12th rib and the erector spinae
d. Angle between the 12th rib and the rectus abdominis

14. True about left renal vein: *(AIIMS Nov 07)*
a. Posterior and inferior to superior mesenteric artery
b. Posterior and superior to superior mesenteric artery
c. Anterior and inferior to superior mesenteric artery
d. Anterior and superior to superior mesenteric artery

ANSWERS WITH EXPLANATIONS

1. d. Renal pelvis
- Among the given choices renal pelvis is the most medial structure.
- Arranged medial to lateral: Renal pelvis → Major calyx → minor calyx → renal medulla → renal cortex.

2. c. Minor calyx
- An apex of the renal pyramid, the renal papilla, fits into the cup-shaped minor calyx.

3. Ans. a. Lateral cutaneous nerve of thigh
- Lateral cutaneous nerve of thigh is a branch from the lumbar plexus but is not the posterior relation of kidneys.
- Hence, it is not liable to get injured in posterior exposure of kidneys.
- Sub-costal, ilio-inguinal, and iliohypogastric nerves are the branches of lumbar plexus and form the posterior relations of kidney.
- They might be damaged in exposing kidney from posterior approach.

4. b. Anteriorly, below the superior mesenteric artery
- Left renal vein crosses in front of the aorta from right to left towards the left kidney.
- It lies below the superior mesenteric artery (L-1 vertebral level) and above the renal artery (between L-1 and L-2 vertebra).
- Inferior vena cava lies on the right side of the midline, hence the left renal vein is the longer, as it crosses the midline to enter the IVC .
- The left renal vein may be compressed by an aneurysm of the superior mesenteric artery as the vein crosses anterior to the aorta. Patients with compression of the left renal vein may result in renal (and adrenal) hypertension on the left. A varicocele may also be found on the left side.
- Since inferior vena cava is not laterally symmetrical, the left renal vein often receives the following veins: left inferior phrenic vein, left suprarenal vein, left gonadal vein (left testicular vein in males, left ovarian vein in females) and left 2nd lumbar vein. This is in contrast to the right side of the body, where these veins drain directly into the IVC.
- The suprarenal and gonadal veins drain into the IVC on the right and the renal vein on the left.
- The azygos vein is connected to the IVC, while the hemiazygos vein is connected to the left renal vein.

5. a. Lateral cutaneous nerve of thigh*Subcostal, ilioinguinal and iliohypogastric nerves are related to the posterior surface of kidney and hence are liable to injury while exposing the kidney from behind.

6. c. Right renal vein shorter than left renal vein
- Right renal vein is shorter than left renal vein
- Left renal vein passes in front of aorta and renal artery (right) passes behind IVC.
- Renal artery is a branch of abdominal aorta.

7. b. It is a type of portal circulation.
- In the renal glomeruli the glomerular capillary bed lies between afferent and efferent arterioles and may be considered as a portal circulation, but most of the authors do not mention so (including Gray's anatomy).
- In essence, portal circulation is a capillary network that lies between two veins. Blood supplying the organ thus passes through two sets of capillaries before it returns to the heart.
- Renal artery divides close to the hilum into five segmental arteries that are end arteries (i.e., they do not anastomose significantly with other segmental arteries, so that the area supplied by each segmental artery is an independent, surgically resectable unit or renal segment).

8. b. Coeliac plexus

Kidney is supplied by renal plexus, an offshoot of coeliac plexus.

9. b. Renal vein, renal artery, renal pelvis

*Kidney hilum contains following structures (anterior to posterior): renal vein, renal artery, and pelvis.

10. d. Left lumbar vein
- Left inferior phrenic vein, left suprarenal vein and left gonadal veins are tributaries to the left renal vein which drain into IVC and right counter part or these veins drain directly into the inferior vena cava.

11. a. Left gonadal vein
- Left gonadal vein, left suprarenal vein and right renal vein do not cross mid line.
- Hemiazygous vein cross midline at T8 vertebral level to join azygous vein.
- Left renal vein is longer than right renal vein and cross midline anterior to aorta to drain into IVC.
- However, left gonadal and supra renal vein drain into left renal vein (almost vertically) without crossing midline.

12. c. Angle between the 12th rib and the erector spinae

13. a. 12th rib and lateral border of sacrospinalis

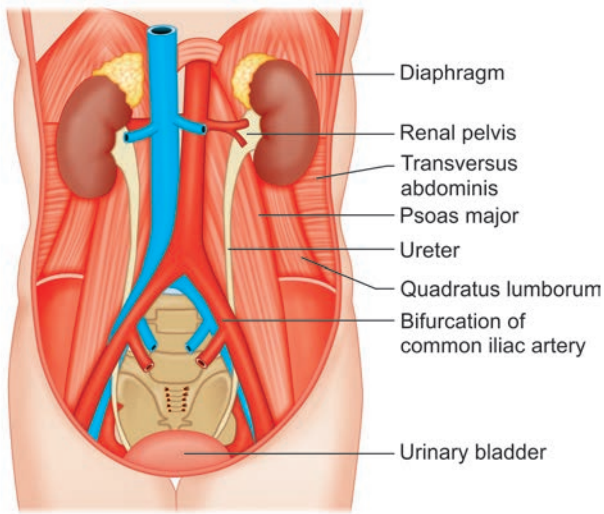
Renal angle lies between the lower border of 12th rib and the outer border of erector spinae (sacrospinalis).

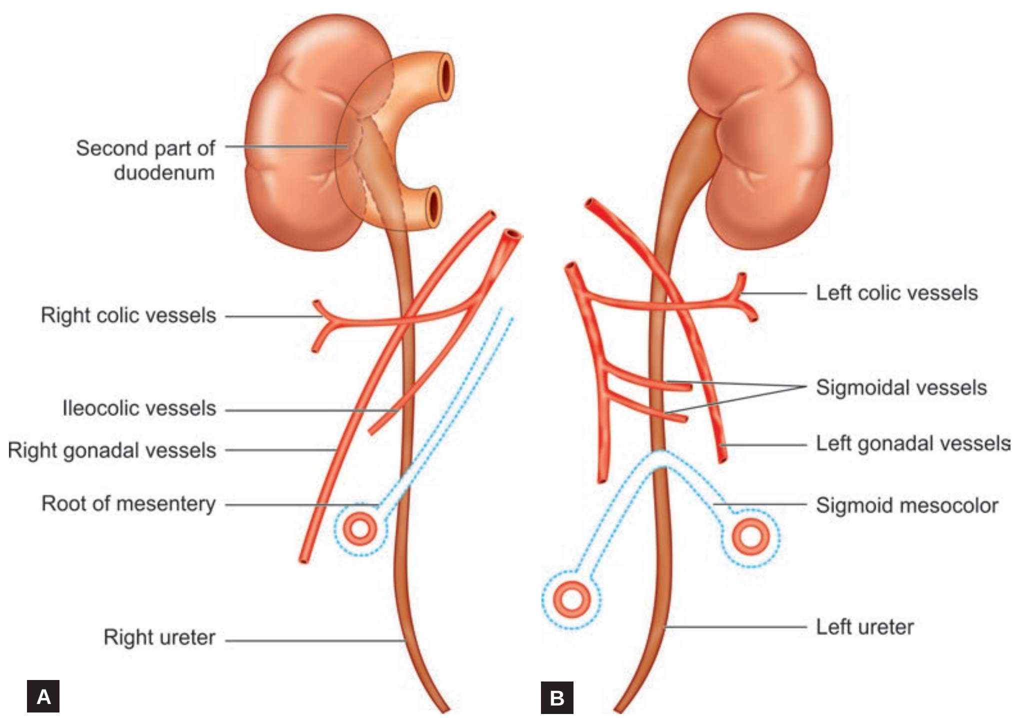
14. c. Anterior and inferior to superior mesenteric artery.* Left renal vein crosses aorta anteriorly. *It lies below the superior mesenteric artery.

Ureter

Embryology:
- Develops from the **ureteric bud**, given by the **mesonephric duct**.

Ureter
- A muscular tube that begins as a continuation of renal pelvis, extending from the kidney to the urinary bladder.
- Length 25-30 cm (proximal half lies in abdomen and distal half lies in pelvic cavity). Lumen = 3 mm.
  - It begins at the **ureteropelvic junction** where the renal pelvis joins the ureter (at the lower end of kidney).
  - Within the abdomen, the ureters descend **retroperitoneal** and anterior to the **psoas major** muscle where they cross the pelvic inlet to enter the minor (or true) pelvis.
  - Within the minor (or true) pelvis, the ureters descend **retroperitoneal** and anterior to the **common iliac artery and vein** where they may be compromised by an aneurysm of the common iliac artery.
  - The ureters end at the **ureterovesical junction** surrounded by the **vesical venous plexus**.
  - The ureters end by traveling obliquely through the wall of the urinary bladder (i.e., the **intramural portion of the ureter**) and define the upper limit of the **urinary bladder trigone**.
  - Ureter is valveless though the intramural portion of the ureter functions as a check valve (**ureterovesical valve of Sampson**) to prevent urine reflux.





Figs. 131A and B: Anterior relations of the abdominal parts of the ureters: A. Right ureter; B. Left ureter

Note: Medially the right ureter is related to inferior vena cava and left ureter is related to left gonadal vein and inferior mesenteric vein.

Anterior relations	
Right ureter	• Duodenum (2nd part) • Right colic vessels • Ileocolic vessels • Right gonadal vessels • Root of mesentery
Left ureter	• Left colic vessels • Sigmoidal vessels • Left testicular or ovarian vessels • Sigmoid mesocolon

Posterior relations: Both the ureters run anterior to psoas major muscle and bifurcation of common iliac artery

Note: Respective colic and gonadal vessels run anterior to ureters.

Relations (in pelvis)

- **In the male,** the ureters pass posterior to the **ductus deferens**.
- **In the female,** the ureters pass posterior and inferior to the **uterine artery** which lies in the **transverse cervical ligament** (or **cardinal ligament of Mackenrodt**) and lie 1 to 2 cm lateral to the **cervix of the uterus**. During gynecologic operations (e.g., hysterectomy), the ureters may be inadvertently injured. The most common sites of injury are at the pelvic brim where the ureter is close to the ovarian blood vessels and where the uterine artery crosses the ureter along the side of the cervix.

Normal Constrictions in Ureter

- Ureter may be obstructed by renal calculi (kidney stones) where it joins the renal pelvis (ureteropelvic junction), where it crosses the pelvic brim over the distal end of the common iliac artery, or where it enters the wall of the urinary bladder (ureterovesicular junction).
- The vesico-ureteric junction is the narrowest of these areas and can be responsible for arresting the passage of stones of as little as 2–3 mm.

Note: Surgery books also mention sites of constrictions at juxtaposition of the vas deferens/broad ligament and other at trigonal opening.

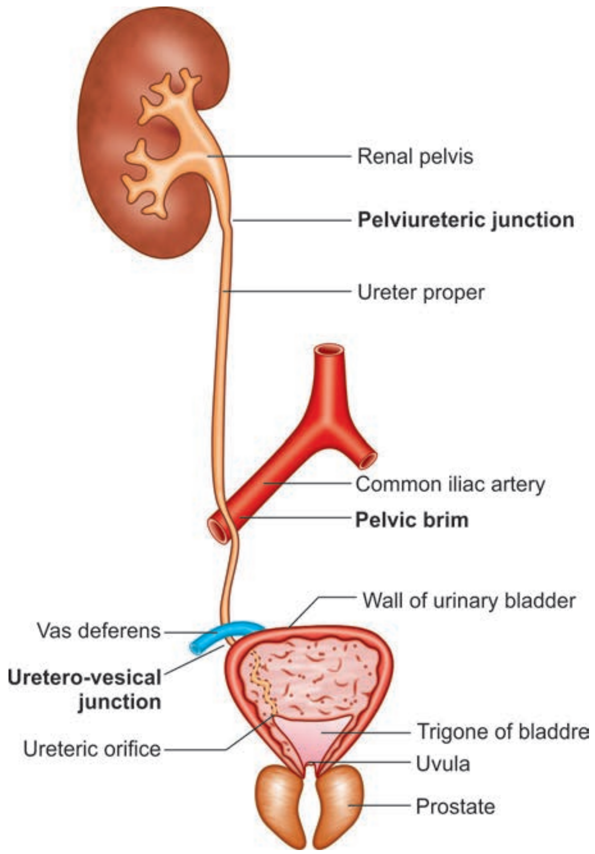


Fig. 132: Normal sites of anatomical constrictions in the ureter (arrows)

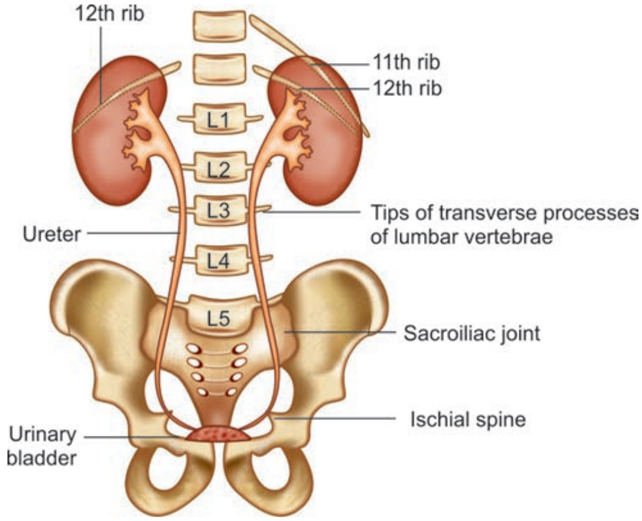


Fig. 133: Drawing from an intravenous pyelogram to show the relationship of the ureters to the bony landmarks

- Radiopaque shadow of ureteric calculus are seen at the following sites:
  a. Near the tips of the transverse processes of lumbar vertebrae.
  b. Overlying the sacroiliac joint.
  c. Overlying or slightly medial to the ischial spine.

Vascular Supply:

- Receives arterial supply from
  1. Renal
  2. Gonadal (Testicular/ovarian)
  3. Direct branches from abdominal aorta.
  4. Common and Internal iliac (but not external iliac)
  5. Vesical (superior and inferior).
  6. Middle rectal.
  7. Uterine.

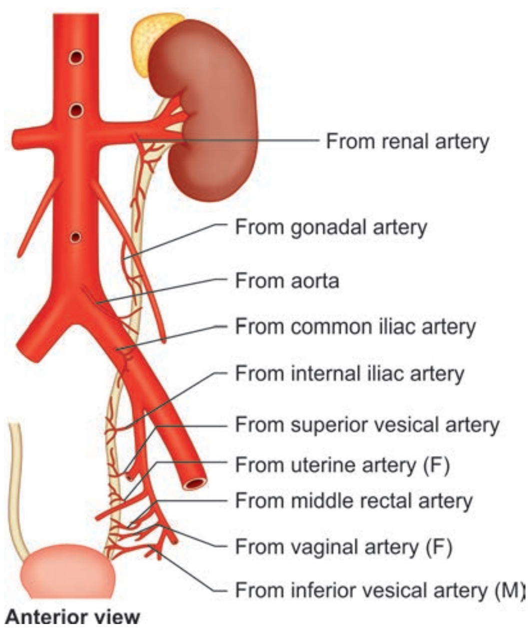


Fig. 134: Normal sites of anatomincal constrictions in the ureter (arrows)

- **Venous drainage:** Veins follow the arteries supplying ureter.
- **Lymphatic drainage:** The lymph from the ureter is drained into lateral aortic and iliac nodes.

Nerve Supply

- T10 - L2 (sympathetic) and S2-4 (parasympathetic) fibres reach ureter by branches from the renal and aortic plexuses, and the superior and inferior hypogastric plexuses.

- The nerves are not essential for the initiation and propagation of ureteric contraction waves, they are just modulatory in function.
- Peristalsis wave is generated in smooth muscle cells of the minor calyces (**pacemaker**).
- Impulse propagation is myogenic conduction mediated by the electrotonic coupling of one muscle cell to its immediate neighbours by means of intercellular 'gap' junctions.

Referred Pain

- Excessive distension of the ureter or spasm of its muscle may be caused by a stone (calculus) and provokes severe pain (ureteric colic, which is commonly, but mistakenly, called renal colic).
- The spasmodic pain is referred to cutaneous areas innervated from spinal segments that supply the ureter, shoots down and forwards from the loin to the groin and scrotum or labium majus.
- Pain from upper ureteral obstruction is referred to the lumbar region (T12 and L1) and from middle ureteral obstruction is referred to the inguinal, scrotal or mons pubis, and upper medial aspect of the thigh **genitofemoral nerve** (L1, L2). The cremaster, which has the same innervation, may reflexly retract the testis.
- Calculus at the lower portion of ureter send pain via the **nervi erigentes** (S-2, 3, 4) and felt at the posterior thigh converging on to the midline openings of in the perineum (pudendal nerve territory).

ASSESSMENT QUESTIONS

1. Ureter derives its blood supply from: *(PGIC 2003, 2010)*
a. Renal artery
b. Gonadal artery
c. Common iliac artery
d. Inferior vesical artery
e. Superior mesenteric artery

2. Artery supply to ureter is by all EXCEPT:
a. Gonadal artery
b. Common iliac artery
c. External iliac artery
d. Vesical artery

3. About ureter TRUE is: *(PGIC 2005, 2008)*
a. Begins at hilum
b. 25 cm
c. Enters true pelvis after crossing iliac vessels
d. Totally retroperitoneal
e. Changes its direction at ischial spine

4. TRUE about ureter's entry into bladder: *(PGIC 2009)*
a. At medial angle of trigone
b. At lateral angle of trigone
c. Make an angle
d. Is straight
e. Valveless

5. Ureteric constrictions are at all sites EXCEPT:
a. Pelvi-ureteric junction(NEET Pattern 2013)
b. Lesser pelvis
c. Ischial spine
d. Urinary bladder wall

6. The narrowest part of the ureter is at: *(AIIMS 2005)*
a. Uretero-pelvic junction
b. Iliac vessel crossing
c. Pelvic ureter
d. Uretero-vesicle junction

7. Left ureter is related to: *(PGIC 2003)*
a. Quadratus lumborum
b. Left gonadal vessels
c. Superior mesenteric vein
d. Sigmoid mesocolon
e. Internal iliac artery

8. All of the following structures cross the right ureter anteriorly EXCEPT: *(AI 2012)*
a. Terminal ileum
b. Vas deferens
c. Genitofemoral nerve
d. Right colic and ileocolic vessels

9. Ureteric peristalsis is due to: *(AIIMS 2007)*
a. Sympathetic innervation
b. Parasympathetic innervation
c. Both sympathetic and parasympathetic innervation
d. Pacemaker activity of the smooth muscle cells in the renal pelvis

10. Anterior relations of right ureter are all EXCEPT: *(JIPMER 2016)*
a. Gonadal vessels
b. Root of mesentery
c. Ileocolic vessels
d. Bifurcation of right common iliac artery

11. All are relations of left ureter EXCEPT: *(AIIMS 2016)*
a. Sigmoid mesentery
b. Bifurcation of common iliac artery
c. Quadratus lumborum
d. Gonadal vessels

ANSWERS WITH EXPLANATIONS

1. a. Renal artery; b. Gonadal artery; c. Common iliac artery; d. Inferior vesical artery
- Ureter has multiple arteries supplying it, but is not supplied by **inferior mesenteric artery**.

2. c. External iliac artery
- Ureter has numerous arteries supplying as shown in the diagram (but not external iliac).

3. b. 25 cm; c. Enters true pelvis after crossing iliac vessels; d. Totally retroperitoneal; e. Changes its direction at ischial spine
- Ureter has a total length of **25 cm** (12.5 cm abdominal and 12.5 cm pelvic).
- Ureter begins as a downward continuation of renal pelvis at the medial margin of the lower end of the kidney (**it does not begin at hilum**)
- It is a **retroperitoneal** structure and enters true pelvis passing pelvic brim at the bifurcation of common **iliac artery**. (It is also the level of beginning of external iliac artery at sacro-iliac joint)
- In its downward course, **opposite the ischial spine**, ureter turns antero-medial and runs towards the base of bladder.

4. b. At lateral angle of trigone; c. Make an angle; e. Valveless
- Ureter enters the urinary bladder **at the lateral angle**, has an **oblique course** through it and is **valveless**.
- The intramural portion of the ureter **functions as** a check valve (**ureterovesical valve of Sampson**) to prevent urine reflux.

5. b. Lesser pelvis
- **Lesser pelvis** is a vague option and does not specify a precise location.
- Ureter has five constrictions in its course:
  - **Pelvi-ureteric junction** (tip of transverse process, radiologically)
  - Pelvic brim (sacro-iliac joint radiologically)
  - Juxtaposition of vas deferens/broad ligament
  - Uretero-vesical junction (**ischial spine**, radiologically)
  - Opening at trigone

6. d. Uretero-vesicle junction
- The narrowest lumen is where the ureter enters the bladder wall (**uretero-vesicle** junction) and may be responsible for arresting the passage of stones of as little as 2–3 mm.
- Note: Sometime the question may not have the option of uretero-vesical junction, in that case the intramural ureter (the part inside detrusor), may be taken as the answer.

7. b. Left gonadal vessels; d) Sigmoid mesocolon ; e) Internal iliac artery
- **Left gonadal vessels** and **sigmoid meso-colon** are present anterior to ureter in the abdomen.
- **Internal iliac artery** is present posterior to ureter in the pelvic cavity.
- Inferior mesenteric artery (not **superior mesenteric vein**) is present on medial aspect of ureter.

8. c. Genitofemoral nerve
- **Genitofemoral nerve** is posterior (not anterior) relation of ureter.

9. d. Pacemaker activity of the smooth muscle cells in the renal pelvis
- The functional significance of sympathetic & para-sympathetic nerve supply to ureter is not clear.
- Intact innervation of renal pelvis or ureter is not necessary for the initiation or propagation of peristalsis from the calyceal pacemakers.

10. d. Bifurcation of right common iliac artery
- Bifurcation of right common iliac artery is posterior to the ureter (table).

11. c. Quadratus lumborum
- Left ureter is related posteriorly to psoas major muscle (not quadratus lumborum).
- Posterior relations: Both the ureters run anterior to psoas major muscle and bifurcation of common iliac artery.
- Gonadal vessels cross the ureters anteriorly (medial to lateral) and descend down along with them.
- Medially the right ureter is related to inferior vena cava and left ureter is related to inferior mesenteric vein.

High Yield Point
- During surgeries ureter can identified by the **peristalsis** .

Adrenal Gland

Suprarenal (Adrenal) Gland
- Retroperitoneal organ lying on the superomedial aspect of the kidney. It is surrounded by a capsule and renal fascia.
- Is pyramidal on the right and semilunar on the left.
- **Cortex** secretes three types of steroid hormones. The outer zona **glomerulosa** produces mineralocorticoids (aldosterone); the middle zona **fasciculata** produces glucocorticoids (cortisol) and the inner zona **reticularis** produces androgens.
- **Medulla** receives preganglionic sympathetic nerve fibers directly, and secretes epinephrine and norepinephrine.

Vascular Supply
- Receives arteries from **three** sources: **inferior phrenic** artery, **abdominal aorta**, and the **renal artery** Q.
- Is drained via the suprarenal vein, which empties into the IVC on the right and the renal vein on the left .

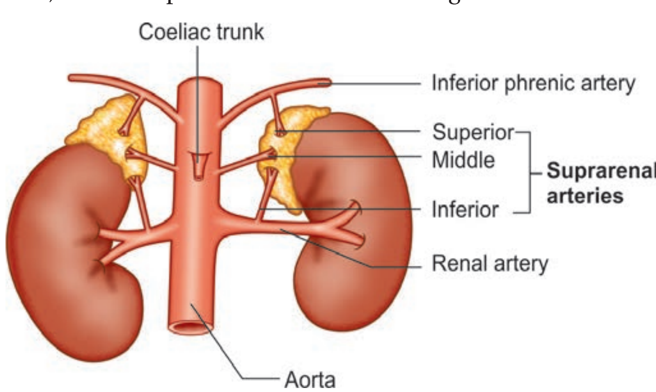


Fig. 135: Arterial supply of the suprarenal gland.

Nerve Supply

- Sympathetic preganglionic neuronal cell bodies are located in the intermediolateral cell column of the spinal cord (T10-L1). Preganglionic axons run with the splanchnic nerves.
- Modified postganglionic neuronal cell bodies called **chromaffin cells** are located in the adrenal medulla.

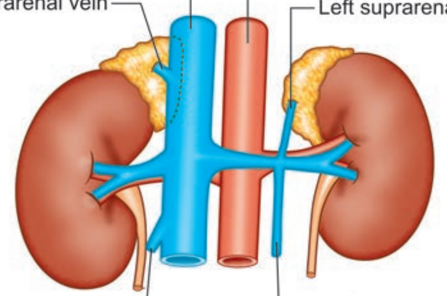


Fig. 136: Venous drainage of the suprarenal gland

ASSESSMENT QUESTIONS

1. **Right adrenal vein drains into:** *(NEET Pattern 2014)*
   a. Right renal vein
   b. Inferior vena cava
   c. Second right lumbar vein
   d. Third lumbar vein

ANSWERS WITH EXPLANATIONS

1. **b. Inferior vena cava**
   - Right adrenal vein drains into **inferior venae cava** and left adrenal vein into left renal vein.

High Yield Points

- Adrenal gland weighs approximately **5 g** (the medulla contributes about one-tenth of the total weight) Q.
- Adrenal gland drains into **lateral aortic** (para-aortic) lymph nodes Q.

ASSESSMENT QUESTIONS

1. **Suprarenal gland gets its blood supply from all of the following arteries EXCEPT:** *(AIIMS 96)*
   a. Aorta
   b. Renal artery
   c. Inferior phrenic vein
   d. Superior mesenteric artery
2. **Lymphatics of suprarenal gland drain into lymph nodes:** *(MH 10)*
   a. Internal iliac
   b. Para-aortic
   c. Superficial inguinal
   d. Coeliac
3. **The right adrenal vein drains into:** *(All India Dec 14 Pattern)*
   a. Right renal vein
   b. Inferior vena cava
   c. Second right lumbar vein
   d. Third right lumbar vein
4. **All of the following statements of Adrenal gland are true EXCEPT:** *(AI 97)*
   a. Both are supplied by three arteries
   b. Both adrenal glands drain directly into inferior vena cava
   c. Right gland is pyramidal in shape
   d. Average weight is about 5 gms.

ANSWERS WITH EXPLANATIONS

1. **d. Superior mesenteric artery Arterial supply of adrenal gland is by three arteries :-**
   (i) Superior suprarenal artery (branch of inferior phrenic artery)
   (ii) Middle suprarenal artery (branch of abdominal aorta)
   (iii) Inferior suprarenal artery (branch of renal artery).
2. **b. Para-aortic *Lymphatics from suprarenal glands drain into pre and para aortic lymph nodes.**
3. **b. Inferior vena cava**
   *Right suprarenal (adrenal) vein drains into IVC and left one into left renal vein.
4. **b. Both adrenal glands drain directly into inferior vena cava**
   *Venous drainage is through suprarenal vein.
   *Right suprarenal (adrenal) vein drains into IVC, and left suprarenal vein drains into IVC via the left renal vein.

Miscellaneous Questions

ASSESSMENT QUESTIONS

1. Structure that does NOT cross the midline is: *(AIPG 2007)*
a. Left gonadal vein
b. Left renal vein
c. Left brachiocephalic vein
d. Hemiazygos vein

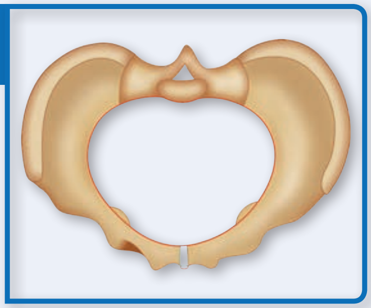
2. Porto systemic shunt is NOT seen in: *(AIPG 2007)*
a. Liver
b. Spleen
c. Anorectum
d. Gastro Esophageal junction

ANSWERS WITH EXPLANATIONS

1. a. Left gonadal vein
- Left gonadal vein drains into the left renal vein at right angles, and does not cross the midline.
- Left renal vein cross the midline since it has to drain into the inferior vena cava, which lies slightly to the right side of the midline.
- Left brachio-cephalic vein cross the midline to reach the superior vena cava, which also lies towards the right side of the midline.
- Hemiazygos vein crosses the midline at the level of T-8 vertebra to drain into the azygos vein lying on the right posterior thoracic wall.

2. b. Spleen
- Porto-systemic shunts form the important route of collateral circulation in case of portal hypertension.
- Spleen does not have any of such porto-systemic shunts.
- Hepatic venules of portal circulation anastomose with the phrenic veins (systemic) at the bare area of liver.
- In the ano-rectum, superior rectal vein of portal system anastomose with the middle and inferior rectal veins (systemic circulation).
- There lies an anastomosis at gastro-oesophageal junction between the oesophageal tributaries of left gastric veins (portal) and the azygos system of veins (systemic).
- A patient of portal hypertension develops varicose veins (varices) at these sites, e.g. oesophageal varices, anorectal varices

CHAPTER 10



Pelvis

Pelvis and Perineum

- **Pelvis** is the lower part of the trunk between the abdomen and the thighs.
- The pelvic region of the trunk includes the bony pelvis, the pelvic cavity, the pelvic floor (below the pelvic cavity), and the perineum (below the pelvic floor).
- **Pelvic diaphragm** separates the pelvic cavity above from the perineal region (including perineum) below.
- **Perineum** is a part of the pelvic outlet located inferior to the pelvic diaphragm.
- The pelvic cavity of the true pelvis has the pelvic floor as its inferior border (and the pelvic brim/inlet as its superior border).

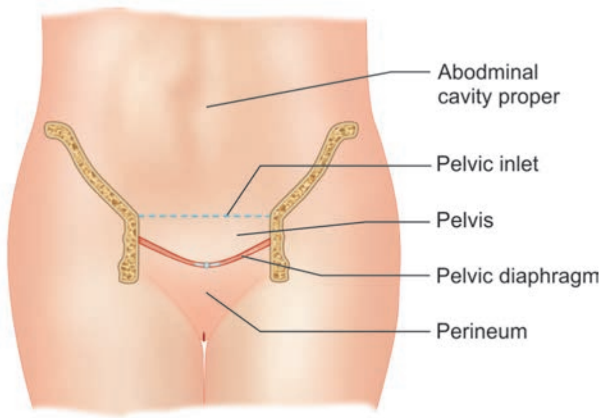


Fig. 1: Relationship between abdomen, pelvis and perineum

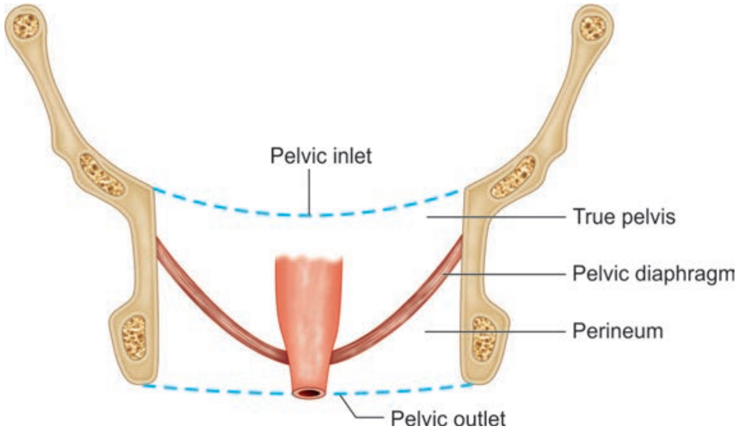


Fig. 2: Relationship between pelvis and perineum

- The pelvic skeleton is formed by the pair of hip bones (anterolaterally) and sacrum and the coccyx (posteriorly).
- The two hip bones connect the spine with the lower limbs. They are attached to the sacrum posteriorly, connected to each other anteriorly (pubis symphysis), and joined with the two femurs at the hip joints.

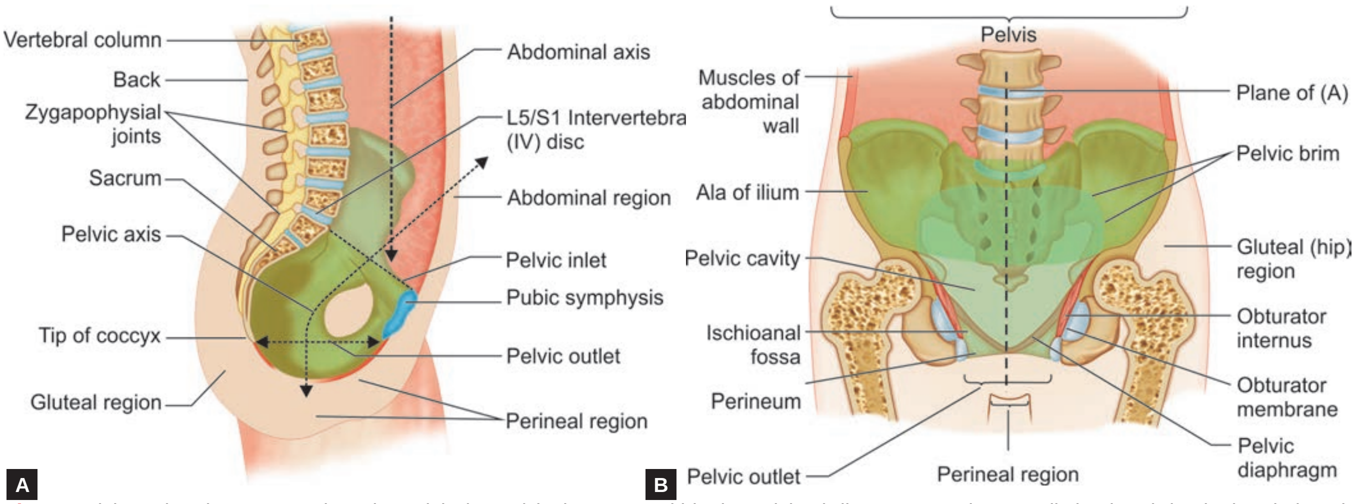


Fig. 3: Pelvis and perineum. A and B: The pelvis (green) is the space within the pelvic girdle, overapped externally by the abdominal and gluteal regions, perineum, and lower back. The greater pelvis is pelvic by virtue of its bony boundaries, but is abdominal in terms of its contents. The lesser pelvis provides the bony framework (skeleton) for the pelvic cavity and deep perineum

- Pelvic cavity is enclosed by the bony pelvis and contains the pelvic viscera (urinary bladder, uterus, rectum and the related structures), the pelvic floor at the base of the cavity assists in supporting the viscera.

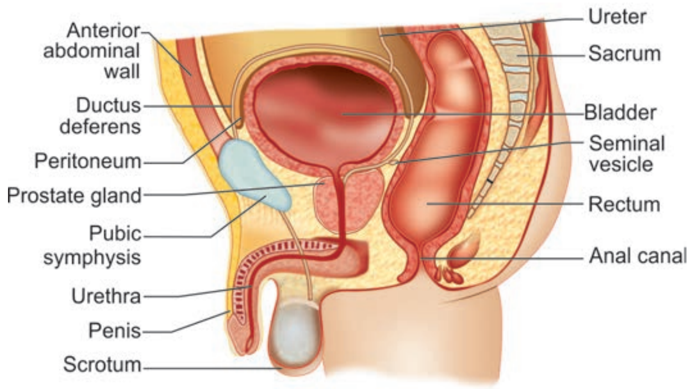


Fig. 4: Sagittal section of male pelvis, showing the pelvic viscera

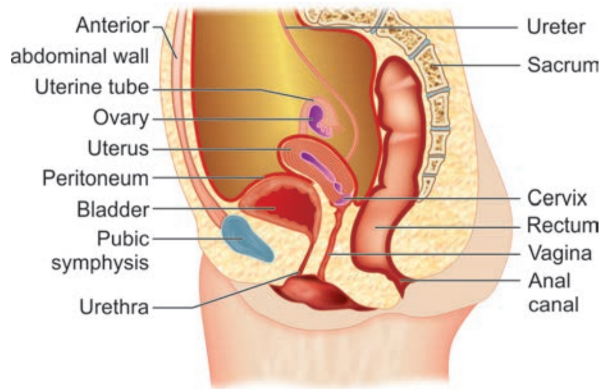


Fig. 5: Sagittal section of female pelvis, showing the pelvic viscera

Bones

- Pelvis is the ring of bones formed by the two hip bones, the sacrum, and the coccyx.
- Bony pelvis is subdivided into:
  - Pelvic girdle i.e., the two hip bones (appendicular skeleton), which connects the spine to the lower limbs
  - Pelvic region of the spine i.e., sacrum, and coccyx (axial skeleton)
- Pelvic cavity is divided by the pelvic brim or iliopectineal line into:
  - Greater (or false) pelvis, above the pelvic brim
  - Lesser (or true) pelvis, below the pelvic brim

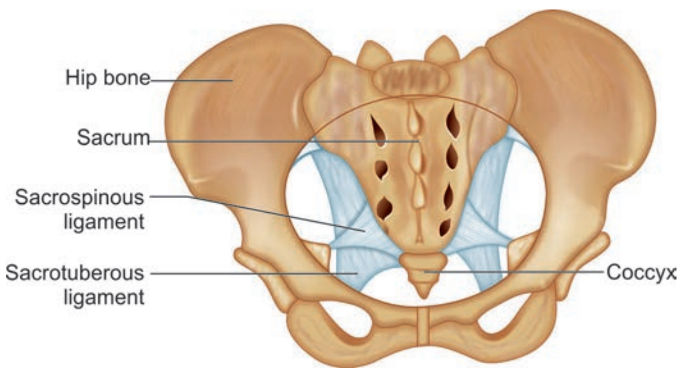


Fig. 6: Bony pelvis (anterior view)

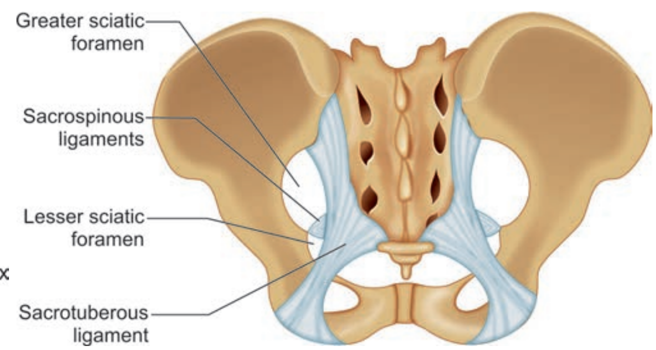


Fig. 7: Bony pelvis (posterior view)

Pelvic Inlet/Brim leads into the lesser pelvis and is the superior rim of the pelvic cavity and is bounded posteriorly by the promontory of the sacrum and the anterior border of the ala of the sacrum (sacral part), laterally by the arcuate or iliopectineal line of the ilium (iliac part) and anteriorly by the pectineal line, the pubic crest, and the superior margin of the pubic symphysis (pubic part).

- The linea terminalis includes the pubic crest, iliopectineal line, and arcuate line.
- It is crossed by the ureter, gonadal vessels, middle sacral vessels, iliolumbar vessels, lumbosacral trunk, obturator nerve, spermatic cord, round ligament of the uterus, sympathetic trunk, suspensory ligament of the ovary, and so forth.

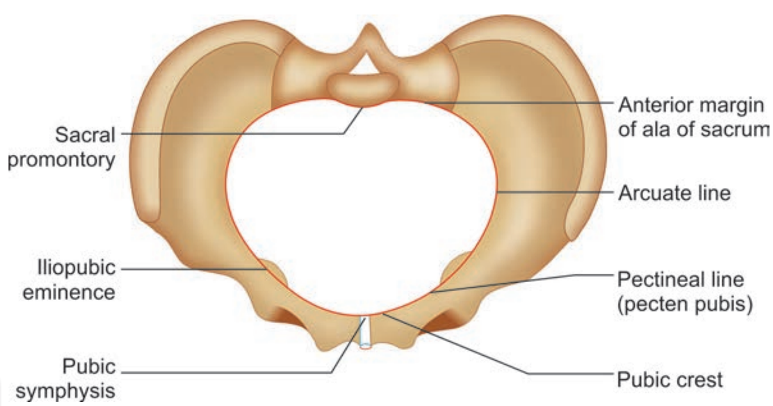


Fig. 8: Pelvic inlet

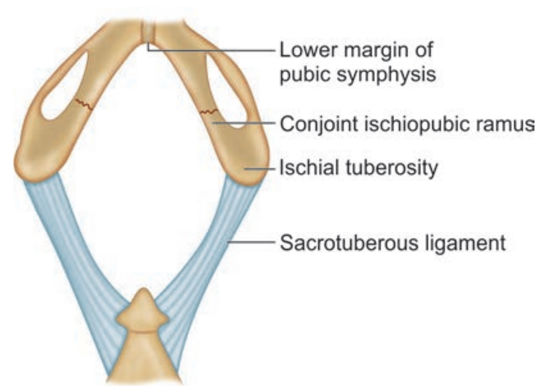


Fig. 9: Pelvic outlet

- **Pelvic Outlet** is the diamond-shaped aperture bounded posteriorly by the sacrum and coccyx; laterally by the ischial tuberosities and sacrotuberous ligaments; and anteriorly by the pubic symphysis, arcuate pubic ligament, and rami of the pubis and ischium.
  - It is closed by the pelvic and urogenital diaphragms.
- The axis of the pelvic cavity running through the central point of the inlet and the outlet almost parallels the curvature of the sacrum.

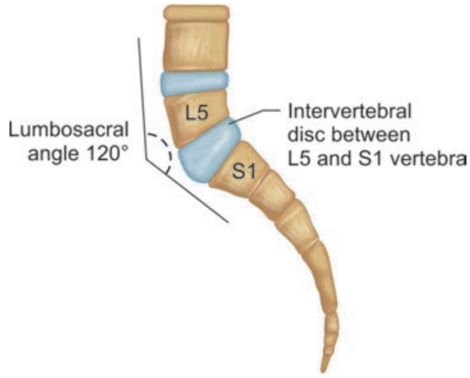


Fig. 10: Lumbosacral angle

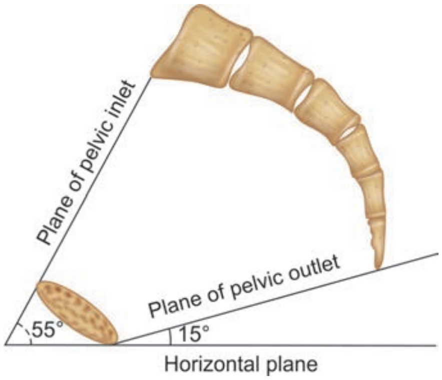


Fig. 11: Pelvic inclination

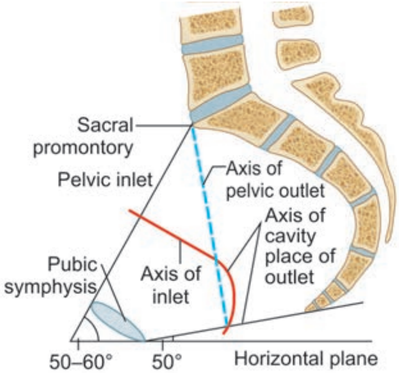


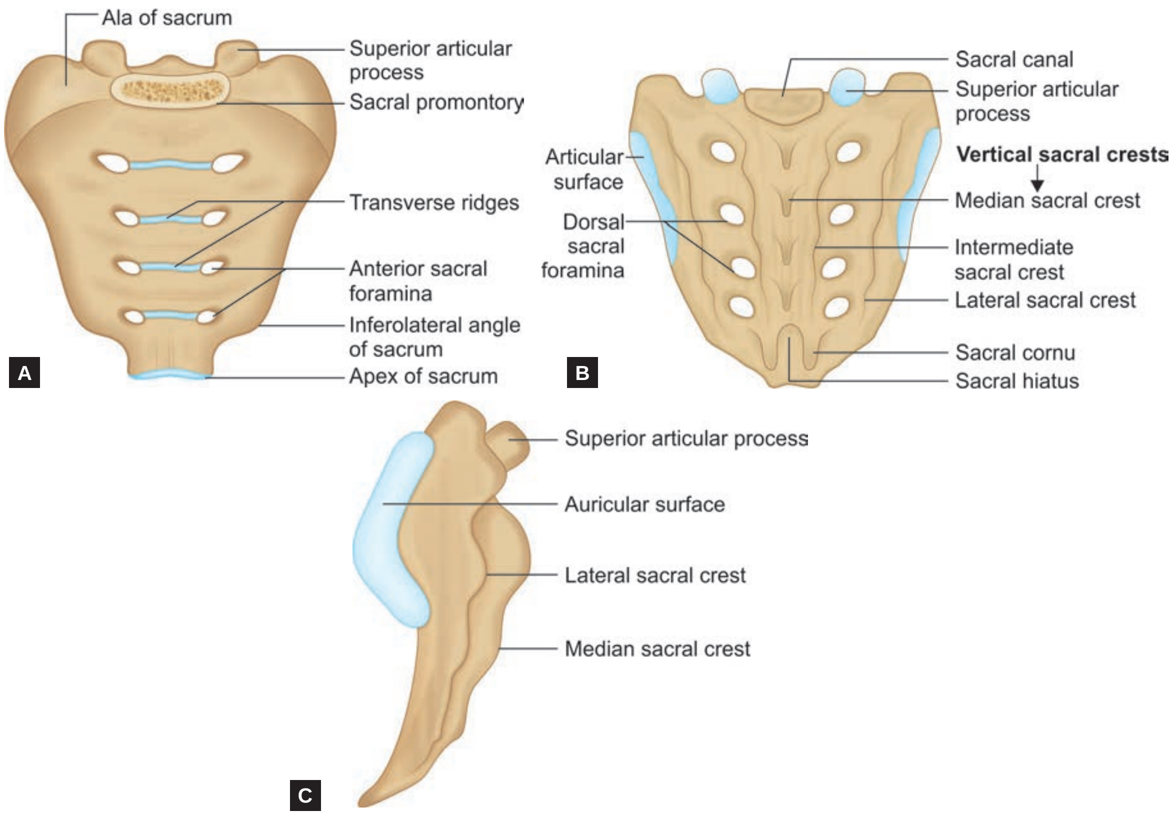
Fig. 12: A median sagittal section through the female pelvis. Showing the planes of the inlet and outlet and the axis of the pelvic cavity

High Yield Point

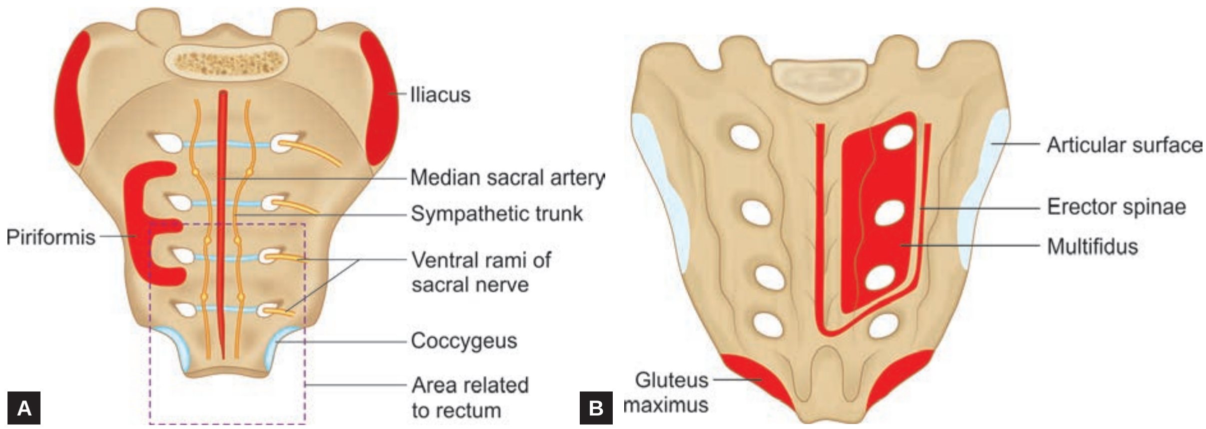
- **Upper border** of pubic ramus forms a part of **arcuate line**.

Sacrum

- Sacrum bone is formed by the fusion of the S1 to S5 vertebrae and lies in the posterior aspect of the bony pelvis.
- Sacrum contains the **dorsal sacral foramina**, which transmit dorsal primary rami of sacral spinal nerves; **ventral sacral foramina**, which transmit ventral primary rami of sacral spinal nerves.
- **Sacral hiatus** is formed due to the failure of the laminae of the S5 vertebrae to fuse.
- The pedicles form the **sacral cornua**, which serve as landmarks in locating the sacral hiatus for administration of caudal anesthesia.



Figs. 13A to C: General features of the sacrum: A. Pelvic surface; B. Dorsal surface; C. Lateral surface



Figs. 14A and B: Special features of the sacrum: A. Pelvic surface; B. Dorsal surface

Table 1: Differences between the male and female sacrum

Features	Male	Female
Base of sacrum	Width of articular area (body of S1 vertebra) is more than the length of ala of one side, i.e. body is broad and alae are narrow	Width of articular area (body of S1 vertebra) is either equal or less than the length of ala of one side, i.e. body is narrow and alae are broad
Sacral index	Less (sacrum is relatively longer and narrower)	More (sacrum is relatively shorter and broader)
Pelvic surface	• Smoothly curved, "C" shaped (curvature of the pelvic surface is gradual from above downward) • Concavity of sacrum is shallower	• Abruptly curved, "J" shaped (Lower part of the pelvic surface abruptly curves forward, curvature being most marked between S1 and S2 segments and between S3 and S5 segments) • Concavity of sacrum is deeper
Auricular surface	• Extends on the upper 3 or 3½ of sacral vertebrae • Relatively larger and less obliquely set • Concavity of dorsal border of the auricular surface is less marked	• Extends on to the upper 2 or 2½ of the sacral vertebrae • Relatively smaller and more obliquely set • Concavity of dorsal border of the auricular surface is more marked

Coccyx

- Coccyx is formed by the fusion of the Co1 to Co4 vertebrae.

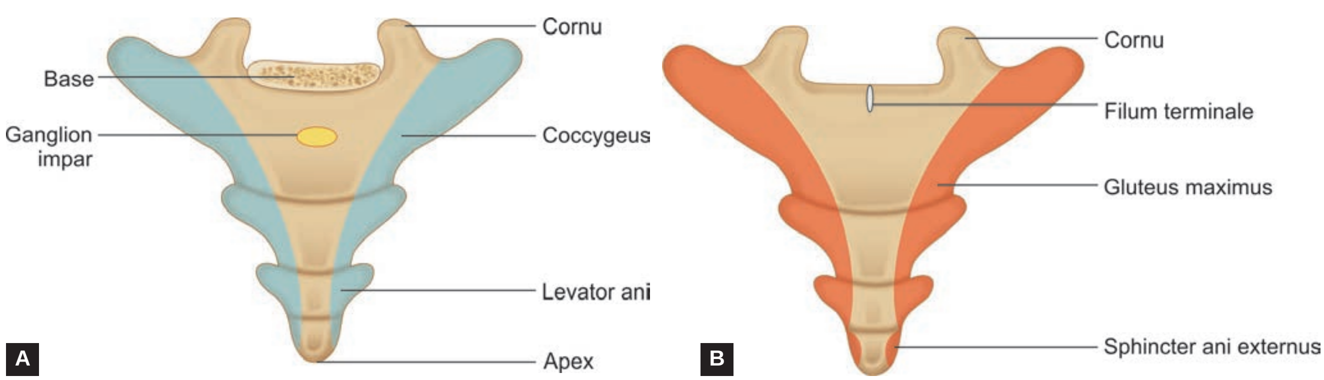
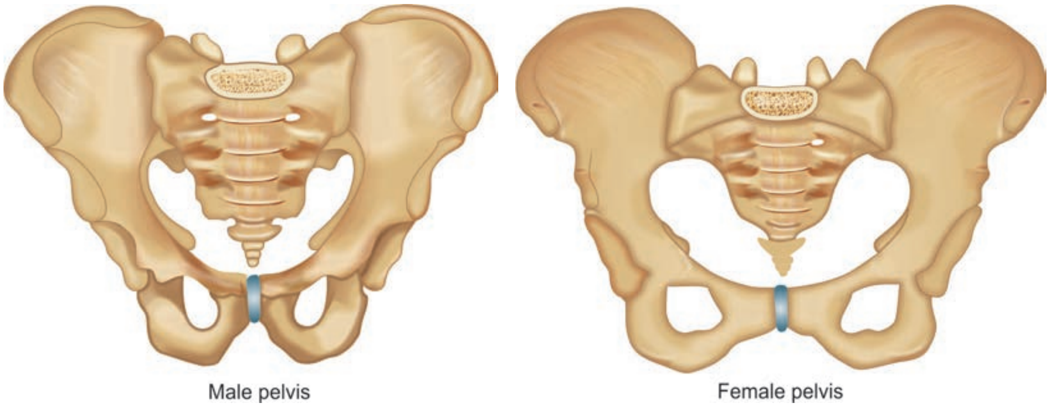


Fig. 15: Coccyx: A. Pelvic surface; B. Dorsal surface

Table 2: Differences between the male and female pelvis

	Male	Female
General structure	Heavy and thick	Light and thin
Articular surfaces	Large	Small
Muscle attachments	Well marked	Indistinct
False pelvis	Deep	Shallow
Pelvic inlet	Heart shaped	Oval

	Male	Female
Pelvic canal/cavity	"Long segment of a short cone," i.e., long and tapered	"Short segment of a long cone," i.e., short with almost parallel sides
Pelvic outlet	Comparatively small	Comparatively large
First piece of sacrum	Superior surface of the body occupies nearly half the width of base of sacrum	Superior surface of the body occupies about one third the width of base of sacrum
Sacrum	Long, narrow, with smooth forward concavity	Short, wide, flat, curving forward in the lower part
Sacroiliac articular facet (auricular surface)	Extends down up to the lower border of third piece of sacrum	Extends down only up to the upper border of third piece of sacrum
Subpubic angle (angle between inferior pubic rami)	< 90° (angle between the middle and index fingers)	90° or more (angle between the thumb and the index finger)
Inferior pubic ramus	Presents a strong everted surface for attachment of the crus of the penis	This marking is not present
Acetabulum	Large	Small
Ischial tuberosities	Inturned	Everted
Obturator foramen	Larger and oval	Smaller and triangular



Figs. 16: Male and female pelvis

Table 3: Differences between the male and female hip bones

Features	Female	Male
Greater sciatic notch	Wider (75°)	Narrower (<50°)
Ischial spine	Not inverted	Inverted
Ischiopubic ramus	Thin and not everted	Thick and everted
Obturator foramen	Triangular	Oval
Acetabular diameter	Less than 5 cm	More than 5 cm
Distance between the pubic tubercle and anterior acetabular margin	Less than transverse diameter of acetabulum	Equal to the transverse diameter of acetabulum
Pre-auricular sulcus	More conspicuous	Less conspicuous
Iliac fossa	Shallower	Deeper

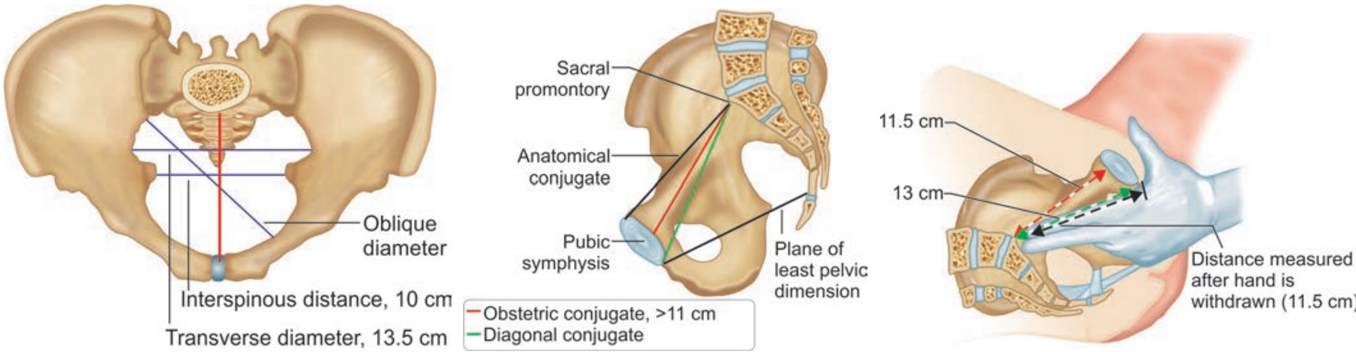
Female Pelvis

- Pelvic inlet is measured by using transverse, oblique, and anteroposterior (conjugate) diameters.
- Pelvic outlet is measured by the transverse diameter and interspinous diameters.

Table 4: Pelvic dimensions in female pelvis

Diameter	At inlet	At mid-pelvis	At outlet
Anteroposterior	11	12	13
Oblique	12	12	12
Transverse	13	12	11

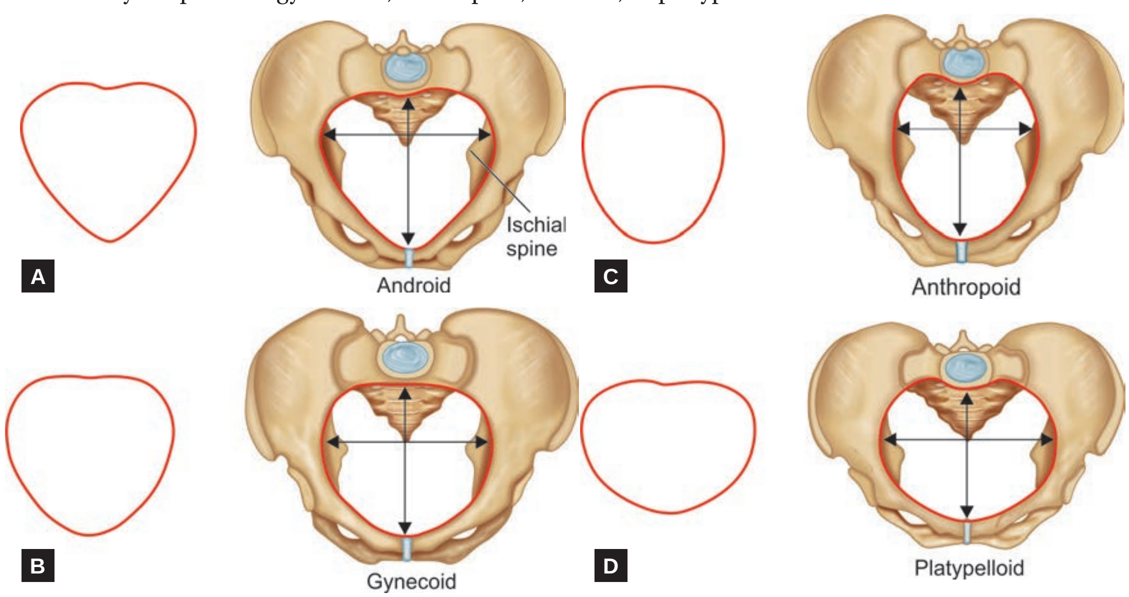
- **Diagonal conjugate** is the distance from the sacral promontory to the inferior margin of the pubic symphysis.
  - This diameter is measured during an obstetric examination (~13 cm).
- **Obstetric conjugate** is the least (shortest) anteroposterior diameter of the pelvic inlet from the sacral promontory to a point a few millimeters below the superior margin of the pubic symphysis (>10 cm).
  - It is estimated indirectly by subtracting 1.5 to 2 cm from the diagonal conjugate.
- **True conjugate** is the distance from the sacral promontory to the superior margin of the pubic symphysis.
  - This diameter is measured radiographically on a lateral projection.
- **Transverse diameter** is the distance between the ischial tuberosities (~13 cm).
- **Interspinous diameter** is the distance between the ischial spines (~10 cm). The ischial spines may present a barrier to the fetus during childbirth if the interspinous diameter is less than 9.5 cm.



(A) Superior view **(B) Mediel view (from left)** **(C) medial view (from right)**

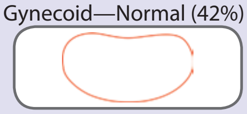
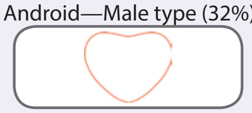
Figs. 17A to C: Pelvic diameters in female pelvis

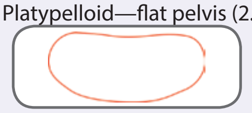
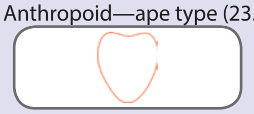
- Types of female pelvis: The greatest transverse diameter of the inlet and its division into anterior and posterior segments are used to classify the pelvis as gynaecoid, anthropoid, android, or platypelloid.



Figs. 18A to D: Types of female pelvis

Table 5: Types of the female pelvis (normal and its variants) and their features

Type	Features
Gynecoid—Normal (42%) 	• Inlet is transversely oval (transverse diameter is more than anteroposterior diameter) • Spacious roomy pelvic cavity • Suitable for easy passage of the baby during delivery
Android—Male type (32%) 	Inlet is heart-shaped (anteroposterior diameter is more than transverse diameter) Pelvic cavity is funnel-shaped Outlet reduced in all diameters May result in obstructed labor

Type	Features
Platypelloid—flat pelvis (2.5%) 	Inlet is anteroposteriorly compressed (transverse diameter is much greater than the anteroposterior diameter) Poses difficulty in delivery
Anthropoid—ape type (23.5%) 	Inlet is compressed from side-to-side (anteroposteiro diameter is much greater than the transverse diameter) Poses difficulty in smooth delivery

ASSESSMENT QUESTIONS

1. **Upper border of pubic ramus forms:** *(NEET Pattern 2014)*
   a. Pubic tubercle
   b. Pubic symphysis
   c. Arcuate line
   d. Upper margin of obturator foramen

2. **The type of joint between the sacrum and the coccyx is a:** *(AIPG 2005)*
   a. Symphysis
   b. Synostosis
   c. Synchondrosis
   d. Syndesmosis

3. **Sacral promontory is the landmark for:** *(NEET Pattern 2013)*
   a. Origin of superior mesenteric artery
   b. Termination of presacral nerve
   c. Origin of inferior mesenteric artery
   d. None of the above

4. **Articular surface of the sacrum extends up to how many vertebrae in males?** *(NEET Pattern 2015)*
   a. 1 to 1 1/2
   b. 2 to 2 1/2
   c. 3 to 3 1/2
   d. 4 to 4 1/2

5. **Lower limit of sacroiliac joint lies up to which level in females?** *(NEET Pattern 2015)*
   a. 1 to 1 1/2
   b. 2 to 1 1/2
   c. 3 to 3 1/2
   d. 4 to 4 1/2

6. **Untrue about female pelvis is:**
   a. Subpubic angle is wide (>80 degrees)
   b. Obturator foramen in triangular
   c. Greater sciatic notch is wide (~90 degrees)
   d. Long and narrow sacrum

7. **Almost half of the females have which of the following type of pelvis?**
   a. Anthropoid
   b. Android
   c. Platypelloid
   d. Gynaecoid

ANSWERS WITH EXPLANATIONS

1. **c. Arcuate line**
   - Upper border of superior pubic ramus is called pectineal line (or pecten pubis). It contributes to arcuate line.
   - Upper border of inferior pubic ramus forms lower margin of obturator foramen.

2. **a. Symphysis**
   - Sacro-coccygeal joint is a secondary cartilaginous joint – symphysis, which always lie in the midline.
   - Symphysis may turn into synostosis with advancing age. For example, symphysis menti becomes a synostosis after the age of one year.
   - Synchondrosis is a primary cartilaginous joint as seen at the costo-chondral junctions of thoracis wall.
   - Syndesmosis is a fibrous joint seen at some limited locations, e.g. inferior tibio-fibular joint.

3. **b. Termination of presacral nerve**
   - Superior hypogastric plexus (presacral nerve) lies in front of the bifurcation of the abdominal aorta and body of the fifth lumbar vertebra between the two common iliac arteries.
   - Origin of superior mesenteric artery lies at L1 and inferior mesenteric artery at L3 vertebral level.

4. **c. 3 to 3 1/2**
   - Articular surface of the sacrum extends on to the upper three or three and a half sacral vertebrae in adult male.
   - In females it extends on to the upper 2 or 2½ of the sacral vertebrae.

5. **b. 2 to 1 1/2**
   - Articular surface of the sacrum (lower limit of sacro iliac joint) extends on to upper 2 or 2 1/2 of the sacral vertebrae in females. .
   - In males it extends on to the upper 3 or 3 1/2 of the sacral vertebrae.

6. **d. Long and narrow sacrum**
   - Female pelvis has short and wide sacrum

7. **d. Gynaecoid**
   - The gynaecoid pelvis is the normal female type; its pelvic inlet typically has a rounded oval shape and a wide transverse diameter.
   - A platypelloid or markedly android (masculine or funnel-shaped) pelvis in a woman may present with difficult vaginal delivery of a fetus

Joints

Lumbosacral Joint is present between vertebra L5 and the base of the sacrum, joined by an intervertebral disk and supported by the iliolumbar ligaments.

Sacroiliac Joint is a plane synovial joint between the auricular surfaces of the sacrum and ilium.

- It is covered by cartilage and is supported by the anterior, posterior, and interosseous sacroiliac ligaments.
- It transmits the weight of the body to the hip bone.

Sacrococcygeal Joint is a symphysis (secondary cartilaginous) joint between the sacrum and coccyx, reinforced by the anterior, posterior, and lateral sacrococcygeal ligaments.

Pubic Symphysis is also a fibrocartilaginous joint between the two hip bones, joined anteriorly by a fibrous cartilage covered by a hyaline cartilage in the median plane.

Nerve Supply

- **Nerve supply** to **pelvic viscera** (like urinary bladder, uterus, rectum etc.):
- **Sympathetic** fibers arising from intermedio-lateral horn cells of lower thoracic and upper lumbar spinal segments (T10-12; L1-2) and carried by the **lumbar splanchnic nerves**.
- **Parasympathetic** innervation to the pelvic viscera derives from **vagus** nerve and **pelvic splanchnic nerves** (also termed nervi erigentes).
  - Neurone bodies of vagus nerve are present in the **dorsal nucleus of vagus** (medulla oblongata)
  - Preganglionic neuronal cell bodies are located in the gray matter (intermedio-lateral horn cells) of the S2 to S4 spinal cord and form the pelvic splanchnic nerves.
  - Postganglionic neuronal cell bodies are located near or within the respective viscera.
- **Superior hypogastric plexus** (also termed the presacral nerve).
  - It is the downward continuation of the aortic plexus (intermesenteric plexus) from the inferior mesenteric ganglion. It receives the L3 and L4 lumbar splanchnic nerves.
  - Beginning below the aortic bifurcation and extending downward retroperitoneally, this plexus is formed by sympathetic fibers arising from spinal levels (T10-12; L1-2).
  - It descends anterior to the L5 vertebra and at the level of the sacral promontory, this superior hypogastric plexus divides into a right and a left **hypogastric nerve**, which run downward along the pelvis side walls and lies in the extraperitoneal connective tissue lateral to the rectum.
    - Hypogastric nerves provides branches to the sigmoid colon and the descending colon and is joined by the pelvic splanchnic nerves to form the **inferior hypogastric** (or pelvic plexus).
  - Superior hypogastric plexus contains preganglionic and postganglionic **sympathetic** fibers, **visceral afferent** fibers, and few, if any, **parasympathetic** fibers, which may run a **recurrent** course through the **inferior** hypogastric plexus.
- **Inferior Hypogastric Plexus** (also termed the pelvic plexus) is formed by the union of **two hypogastric nerves** (sympathetic), **two pelvic splanchnic nerves** (parasympathetic), and **sacral splanchnic nerves** (L5 and S1 to S3).
  - It is **retroperitoneal** collection of nerves lying at the S4 and S5 level, against the posterolateral pelvic wall, lateral to the rectum, vagina, and base of the bladder.
  - It contains pelvic ganglia, in which both sympathetic and parasympathetic preganglionic fibers synapse.
  - Fibers of this plexus accompany internal iliac artery branches to their respective pelvic viscera.
  - It gives rise to rectal plexus, utero-vaginal plexus, vesical plexus, and prostatic plexus.
  - Vesical plexus innervates the bladder and the middle rectal travels to the rectum.
  - Uterovaginal plexus (Frankenhauser plexus), reaches the proximal fallopian tubes, uterus, and upper vagina.
  - Extensions of the inferior hypogastric plexus also reach the perineum along the vagina and urethra to innervate the clitoris and vestibular bulbs.
- **Sacral Splanchnic Nerves** consist of preganglionic sympathetic fibers that come off the sympathetic chain and synapse in the inferior hypogastric (pelvic) plexus.
- **Pelvic Splanchnic Nerves (Nervi Erigentes)** arise from the sacral segment of the spinal cord (S2–S4) and are the only splanchnic nerves that carry parasympathetic fibers. (All other splanchnic nerves are sympathetic).
  - They contribute to the formation of the pelvic (or inferior hypogastric) plexus, and supply the descending colon, sigmoid colon, and other viscera in the pelvis and perineum.
- **Sacral sympathetic trunk** is a continuation of the paravertebral sympathetic chain ganglia in the pelvis. The sacral trunks descend on the inner surface of the sacrum medial to the sacral foramina and converge to form the small median ganglion impar anterior to the coccyx.

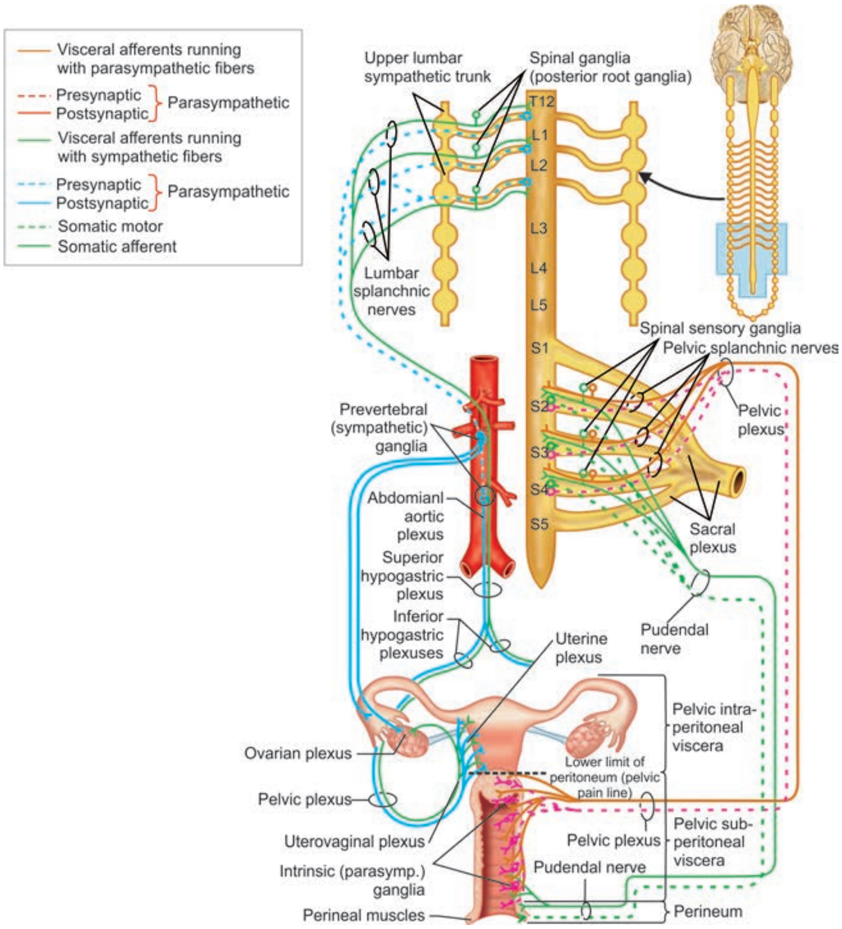


Fig. 19: Autonomic and somatic innervation of the female reproductive organs. Pelvic splanchnic nerves, originate from the S2-S4 anterior rami, supply parasympathetic motor fibers to the uterus and vagina (and vasodilator fibers to the erectile tissue of the clitoris and bulb of the vestibule). Presynaptic sympathetic fibers traverse the sympathetic trunk and pass through the lumbar splanchnic nerves to synapse in prevertebral ganglia with postsynaptic fibers; the latter fibers travel through the superior and inferior hypogastric plexuses to reach the pelvic viscera. Visceral afferent fibers conducting pain from intraperitoneal structures (such as the uterine body) travel with the sympathetic fibers to the T12-L2 spinal ganglia. Visceral afferent fibers conducting pain from subperitoneal structures such as the cervix and vagina (i.e., the birth canal), travel with parasympathetic fibers to the S2-S4 spinal ganglia. Somatic sensation from the opening of the vagina also passes to the S2-S4 spinal ganglia via the pudendal nerve. In addition, muscular contractions of the uterus are hormonally induced.

Table 6: Innervation of the female genitalia

	Origin	Proximal course	Distal course	Organ	Function
Parasympathetic	S2–S4	Pelvic splanchnic nerves	Pelvic ganglia	Uterine tube Uterus	Vasodiation
		Cavernous (deep, cavernosal) nerves of clitoris		Vagina Clitoris	Transudation Erection
Sympathetic	T12, L1–L2	Superior mesenteric and renal plexus Superior hypogastric plexus	Ovarian plexus Hypogastric nerve ↓ Inferior hypogastric plexus ↓ Uterovaginal plexus (Frankenhauser's ganglion)	Ovary Uterine tube, uterus, upper vagina	Vasoconstriction Contraction
Somatic	S2, 3, 4	Pudendal nerve Pudendal nerve	Dorsal nerve of clitoris Posterior labial nerves	Clitoris Lower vagina Labia majora Ischiocavernosus Bulbospongiosus	 Contraction

(With permission from shoja MM, Sharma A. Mirzaya N, Groat C, Watanabe K, Loukas M and Tubbs RS. Neuroanatomy of the Female Abdominoplevic Region: A Review with Application to Pelvic Pain Syndrome, Clinical Anatomy 26.66–76, 2013)

Sacral Plexus Components:

- **Anterior primary rami** of L4 to L5 (lumbosacral trunk) and S1 to S4 spinal nerves.
- **Divisions** are formed by the rami dividing into anterior and posterior divisions.
- **Branches**

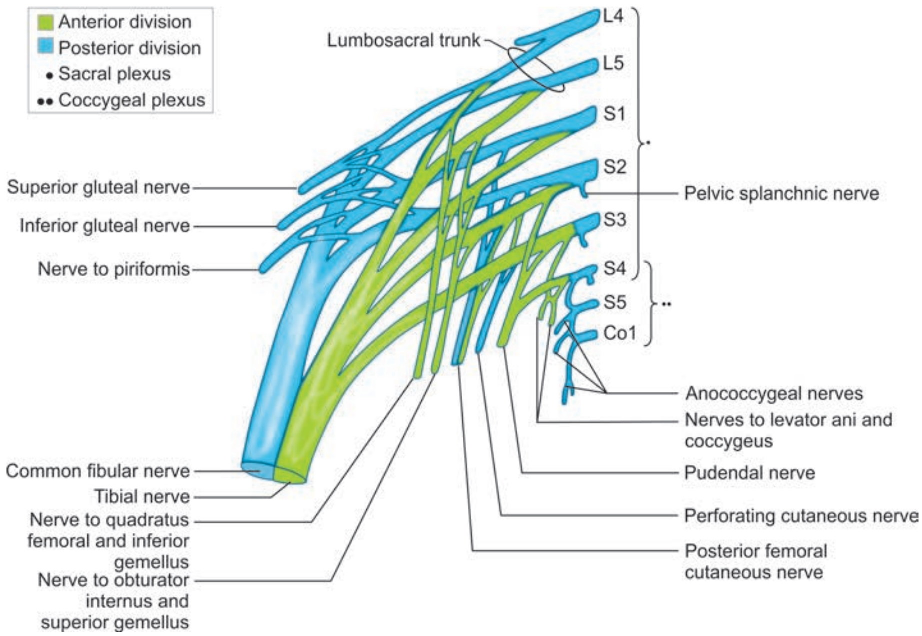


Fig. 20: Sacral plexus, branches and the coccygeal nerve plexus

Table 7: Somatic nerve of pelvis

Nerve	Origin	Distribution
Sciatic	L4, L5, S1, S3	Articular branches to hip joint and muscular branches to flexors of knee in thigh and all muscles in leg and foot
Superior gluteal	L4, L5, S1	Gluteus medius and gluteus minimus muscles
Nerve to quadratus femoris (and interior gemellus)	L4, L5 S1	Quadratus femoris and inferior gemellus muscles
Nerve to piriformis	S1, S2	Piriformis muscle
Posterior cutaneous nerve of thigh	S2, S3	Cutaneous branches to buttocks and uppermost medial and posterior surfaces of thigh
Perforating cutaneous	S2, S3	Cutaneous branches to medial part of buttocks
Pudendal	S2, S3, S4	Structures in perineum: Sensory to genitalia; muscular branches to perineal muscles, external urethral sphincter, and external anal sphincter
Pelvic splanchnic	S2, S3, S4	Pelvic viscera via inferior hypogastric and pelvic plexuses
Nerves to levator ani and coccygeus	S3, S4	Levator ani and coccygeus muscles

Table 8: Nerves of perineum

Nerve	Origin	Course	Distribution
Anterior labial nerves (♀); Anterior scrotal nerves (♂)	Terminal part of ilioinguinal nerve (L1)	Arise as ilio-inguinal exits superficial inguinal ring; pass anteriorly and inferiorly	*In females*, sensory to mons pubis and anterior part of labium jajus; *in males*, sensory to pubic region, skin of proximal penis, and anterior aspect of scrotum, and adjacent thigh
Genital branch of genitofemoral nerve	Genitofemoral nerve (L1 and L2)	Emerges through or near superficial inguinal ring	*In females* sensory to anterior labia majora; *in males*, motor to cremaster muscle, sensory to anterior aspect of scrotum and adjacent thigh
Perineal branch of posterior cutaneous nerve of thigh	Posterior cutaneous nerve of thigh (S1–S3)	Arises deep to interior border of gluteus maximus; passes medially over sacrotuberous ligament to parallel ischiopubic ramus	Sensory to lateral perineum (labia majora in ♀, scrotum in ♂), genitofemoral sulcus, and superior most medial thigh; may overlap lateral parts of perineum supplied by pudendal nerve
Inferior clunial nerves	Posterior cutaneous nerve of thigh (S1–S3)	Arises deep to and emerge from inferior border of gluteus maximus, ascending in subcutaneous tissue	Skin of inferior gluteal region (buttocks)—gluteal fold and area superior to it

Nerve	Origin	Course	Distribution
Pudendal nerve (S2–S4)	Sacral plexus (anterior rami of S2–S4)	Exits pelvis via infrapiriform part of greater sciatic foramen; passes posterior to sacrospinous ligament; enters perineum via lesser sciatic foramen, immediately dividing into branches as it enters pudendal canal	Motor to muscles of perineum and sensory to majority of perineal region via its branches, the inferior rectal and perineal nerves, and the dorsal nerve of clitoris or penis
Inferior anal (rectal) nerve	Pudendal nerve (S3–4)	Passes medially from area of ischial spine (entrance to pudendal canal), traversing ischio-anal fat body	External and sphincter; participates in innervation of inferior and medial-most part of levator ani (puborectalis); sensory to anal canal inferior to pectinate line and circumanal skin
Perineal nerve	Pudendal nerve	Arises near entrance to pudendal canal, paralleling parent nerve to and of canal, then passes medially	Divides into superficial and deep branches, the posterior labial or scrotal nerve and the deep perineal nerve
Posterior labial nerve (♀), posterior scrotal nerves (♂)	Superficial terminal branch of perineal nerve	Arise in anterior (terminal) end of pudendal canal, passing medially and superficially	Motor to muscles of superficial perineal pouch (ischiocavernosus, bulbospongiosus, and superficial perineal muscles); in females, sensory to vestibule of vagina and inferior part of vagina
Deep perineal nerve	Deep terminal branch of perineal nerve	Arise in anterior (terminal) end of pudendal canal, passing medially and superficialy	Motor to muscles of superficial perineal pouch (ischiocavernosus, bulbospongiosus, and superficial perineal muscles); in females, sensory to vestibule of vagina and inferior part of vagina

- **Coccygeal Plexus** is formed by the anterior primary rami of S4 and S5 spinal nerves and the coccygeal nerve.
- Coccygeal nerve innervates the coccygeus muscle, part of the levator ani muscles, and the sacrococcygeal joint.
- Anococcygeal nerves arise from coccygeal plexus and innervate the skin between the tip of the coccyx and the anus.
- Cutaneous innervation of the perineal region.

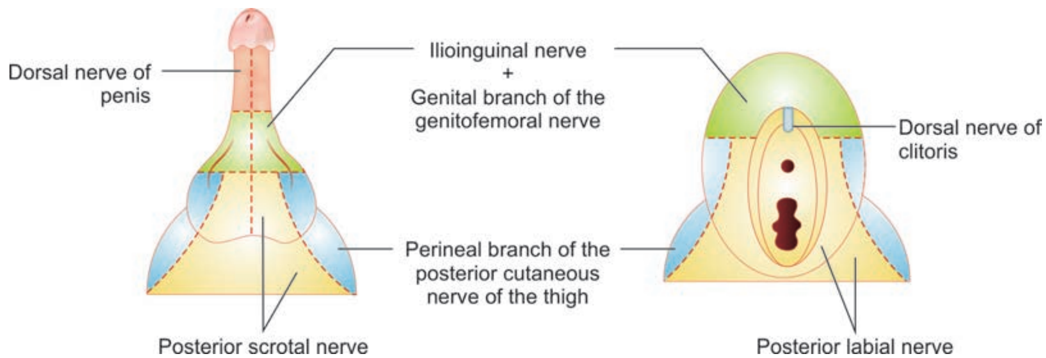


Fig. 21: Cutaneous innervation of the urogenital region

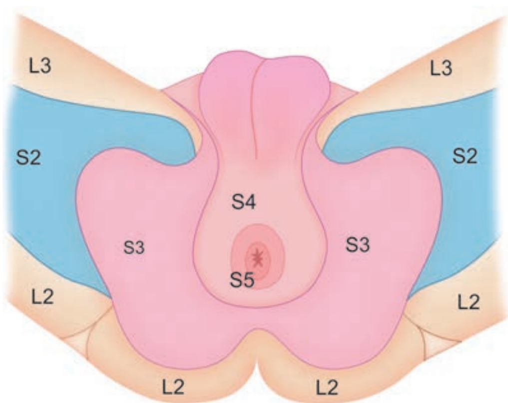


Fig. 22: Dermatomes of the perineum region

Pudendal Nerve

Pudendal nerve is formed by the anterior primary rami of S2–4 in the pelvic cavity.

- It leaves the pelvic cavity by passing through the greater sciatic foramen (between the piriformis and coccygeus muscles).
- It crosses the ischial spine posteriorly and enters the perineum with the internal pudendal artery through the lesser sciatic foramen.

- Next it enters the pudendal canal, gives rise to the inferior rectal nerve and the perineal nerve, and terminates as the dorsal nerve of the penis (or clitoris).
  - **Inferior rectal nerve** is a branch of pudendal nerve, given within the pudendal canal, divides into several branches, crosses the ischiorectal fossa, and innervates the sphincter ani externus and the skin around the anus.
  - **Perineal nerve** divides into a deep branch, which supplies all of the perineal muscles, and a superficial (posterior scrotal or labial) branch, which supplies the scrotum or labia majora.
  - **Dorsal Nerve** of the penis (or clitoris) is the terminal branch, pierces the perineal membrane, runs between the two layers of the suspensory ligament of the penis (or clitoris), and runs deep to the deep fascia on the dorsum of the penis (or clitoris) to innervate the skin, prepuce, and glans.
- **Alcock's pudendal canal** is present in the lateral wall of ischiorectal fossa, within layers of obturator fascia.
- It has a length of 2.5 cm and lies above the ischial tuberosity.
- It extends from the lesser sciatic foramen to the posterior limit of the deep perineal pouch.
- It contains pudendal nerve, internal pudendal artery and vein and send inferior rectal nerve and vessels medially through the fossa towards the anal canal.

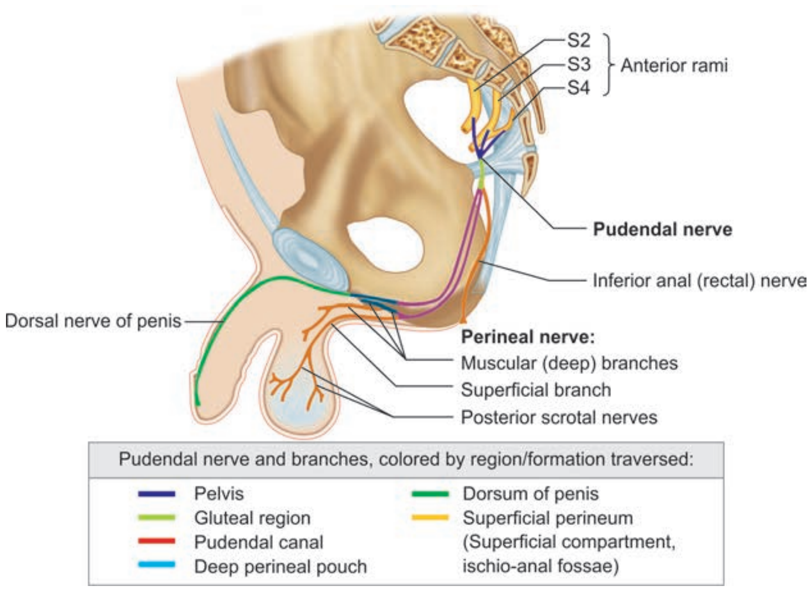


Fig. 23: Pudendal nerve: Formation, course and branches

Pudendal nerve block: Local anaesthetic agent is injected near the pudendal nerve in the region of ischial spine.

- Ischial spine is the landmark and is palpated through the vagina.
- A needle is guided by the finger to the ischial spine. A 1% lignocaine solution is injected transvaginally or just lateral to the labia majora around the tip of the ischial spine and through the sacrospinous ligament.
- Pudendal block paralyses the skeletal muscles of perineum and anaesthetizes the skin of perineum. It also leads to loss of sensation at the openings of urethra, vagina and anal canal.
- Pudendal block leads to urinary and faecal incontinence, hence urine and faecal matter needs to be evacuated prior to the procedure (Rectal enema and Foley's catheterization).
- For a complete anesthesia of the perineal region, the ilioinguinal nerve (which branches into the anterior labial nerves), genitofemoral nerve, and perineal branch of the posterior femoral cutaneous nerve are also anesthetized.

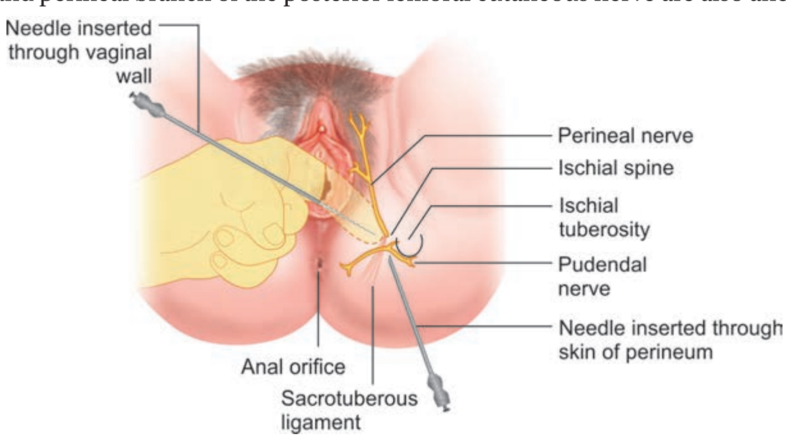


Fig. 24: Pudendal nerve block

ASSESSMENT QUESTIONS

1. Pelvic splanchnic nerves supply all EXCEPT: *(AIIMS 2010)*
- a. Vermiform appendix
- b. Urinary bladder
- c. Uterus
- d. Rectum

2. Pudendal nerve supplying motor part to external sphincter is derived from: *(NEET Pattern 2013)*
- a. L5-S1 roots
- b. S1- S2 roots
- c. L2-L3 roots
- d. S2-S3 roots

3. All of the following are true regarding the pudendal nerve EXCEPT: *(AIPG)*
- a. Both sensory and motor
- b. Derived from S2, 3, 4 spinal nerve roots
- c. Leaves pelvis through the lesser sciatic foramen
- d. Only somatic nerve to innervate the pelvic organ

4. Pelvic pain is mediated by: *(NEET Pattern 2013)*
- a. Pudendal nerve
- b. Sciatic nerve
- c. Autonomic nerves
- d. None of the above

5. True about nervi erigentes are all EXCEPT: *(NEET Pattern 2015)*
- a. An autonomic nerve
- b. Parasympathetic outflow
- c. Arise from ventral rami of S2, 3, 4
- d. Joins superior hypogastric plexus

6. Preganglionic parasympathetic nerve fibers which supply pelvic viscera is/are: *(PGIC 2003)*
- a. Ventral rami of S2,3,4
- b. Hypogastric plexus
- c. Pudendal nerve
- d. Pelvic Splanchnic nerve
- e. Inferior mesenteric plexus

7. Which is NOT supplied by pelvic splanchnic nerves? *(AIIMS 2009,10)*
- a. Rectum
- b. Urinary bladder
- c. Appendix
- d. Uterus

8. Pudendal nerve block abolishes pain from: *(JIPMER 2016)*
- a. Upper cervix
- b. Superior part of vagina
- c. Lower cervix
- d. Inferior part of vagina

9. Root value of inferior rectal nerve supplying external anal sphincter is:
- a. L–3, 4, 5
- b. L–5; S-1
- c. S–2, 3, 4
- d. S–4, 5

ANSWERS WITH EXPLANATIONS

1. a. Vermiform appendix
- Pelvic splanchnic nerves are the parasympathetic nerves to supply the pelvic viscera like urinary bladder, uterus and rectum. Appendix is a part of Mid-gut and is supplied by the Vagus nerve.

2. d. S2-S3 roots
- Pudendal nerve is contributed by the anterior primary ramus of S-2, 3, 4 in the sacral plexus and supply external sphincters of urethra, vagina and anal canal.

3. c. Leaves pelvis through the lesser sciatic foramen
- Pudendal nerve (S2–S4) passes out of the pelvic cavity through the greater sciatic foramen (below the piriformis muscle) and enters the gluteal region.
- It travels around the posterior surface of the ischial spine, and re-enters the pelvic cavity through the lesser sciatic foramen.
- Next the pudendal nerve travels within the fascia of the obturator internus muscle (called the pudendal canal of Alcock) and gives rise to the inferior rectal and perineal nerves, and terminates as the dorsal nerve of the penis (or clitoris).
- It is a somatic and mixed (sensory and motor) nerve supplying skin and skeletal muscles of perineum.
- It is the only somatic nerve that supplies the terminal portions of the pelvic organs (urethra, vagina and anal canal).

4. c. Autonomic nerves
- Pelvic pain is carried by the autonomic nervous system: Sympathetic component is carried by lumbar splanchnic nerves (T-12, L1,2) and parasympathetic component is nervi erigentes (S-2,3,4).

5. d. Joins superior hypogastric plexus
- There is no answer in this question, because all the statements are true.
- Nervi erigentes belong to the parasympathetic component of autonomic nervous system. They arise from the ventral primary ramus of S2,3,4 and ascend from the inferior hypogastric plexus via the right and left hypogastric nerves to reach the superior hypogastric plexus.
- Some authors are of the opinion that they do not join the superior hypogastric plexus.

6. a. Ventral rami of S2,3,4; d. Pelvic Splanchnic nerve
- Pelvic viscera are supplied by the inferior hypogastric plexus situated by the sides of rectum.
- Each plexus is composed of both sympathetic and parasympathetic fibres.
- The nerve cells in it are postganglionic parasympathetic neurons. It receives postganglionic sympathetic fibres from the superior hypogastric plexus (presacral nerve) and preganglionic parasympathetic fibres from the pelvic splanchnic nerve (S2, S3, and S4).

7. c. Appendix
- Vermiform appendix is a part of mid-gut under the supply of vagus nerve (not pelvic splanchnic nerves).

8. d. Inferior part of vagina
- Pudendal nerve supplies the structures in the perineum, including the opening of vagina.
- Pelvic viscera (including cervix and major portion of vagina) are supplied by the autonomic nervous system: Lumbar splanchnic nerves (sympathetic) and nervi erigentes (parasympathetic).

9. c. S – 2, 3, 4
- External anal sphincter is supplied by inferior rectal nerve branch of pudendal nerve.

Muscles

- **Pelvic floor** is composed of several overlapping sheets of muscles and connective tissues.
  - It closes the pelvic and abdominal cavities and bear the load of the visceral organs.
  - It control the openings of the gastrointestinal and urogenital tubes that pierce through it.
  - It has two hiatuses: Anteriorly urogenital hiatus through which urethra and vagina pass through and posteriorly anal hiatus through which anal canal passes.
- **Pelvic diaphragm** separates the pelvic cavity above from the perineal region below.
  - It lies posterior and deep to the urogenital diaphragm and medial and deep to the ischiorectal fossa.
  - It forms the pelvic floor and supports all of the pelvic viscera. On contraction, raises the entire pelvic floor.
  - It flexes the anorectal canal during defecation and helps the voluntary control of micturition.
  - It helps direct the fetal head toward the birth canal at parturition.
  - It is composed of muscle fibers of the **levator ani** and the **coccygeus** muscle (covered by the parietal pelvic fascia on their upper and lower aspects), and associated connective tissue which span the area underneath the pelvis.
  - These muscles arise between the symphysis and the ischial spine and converge on the coccyx and the anococcygeal ligament which spans between the tip of the coccyx and the anal hiatus.
  - Right and left levator ani lie almost horizontally in the floor of the pelvis, separated by a narrow gap that transmits the urethra, vagina, and anal canal.
  - The levator ani muscle has two parts: pubococcygeus (anterior) and iliococcygeus (posterior).
    - Pubococcygeus runs backward from the body of the pubis toward the coccyx. Some fibers are inserted into the prostate, urethra, vagina & anorectal junction and named accordingly: puboprostaticus, pubourethralis, pubovaginalis, puborectalis respectively.
    - Iliococcygeus attaches to the ilium part of hip bone and coccyx bone lies posteriorly and is not well developed.
  - Ischio-coccygeus (simply called coccygeus) is situated behind the levator ani and frequently tendinous as much as muscular, extends from the ischial spine to the lateral margin of the sacrum and coccyx.

Note: Some sources do not consider 'pelvic floor' and 'pelvic diaphragm' to be identical. It is mentioned that diaphragm consists of only the levator ani and coccygeus, while the 'floor' should also include the perineal membrane and deep perineal pouch.

Functions of pelvic diaphragm:
- Excellent support of pelvic viscera (urinary bladder, uterus, rectum etc.).
- Help in maintenance of continence as part of the urinary, vaginal and anal sphincters.
- Facilitates birth by resisting the descent of the presenting part, causing the foetus to rotate forwards to navigate through the pelvic girdle.
- Helps maintain optimal intra-abdominal pressure.

Clinical Correlations

- Damaged pelvic diaphragm leads to prolapse of pelvic viscera and incontinence.
- Pelvic floor muscles can be strengthened with Kegel exercises.

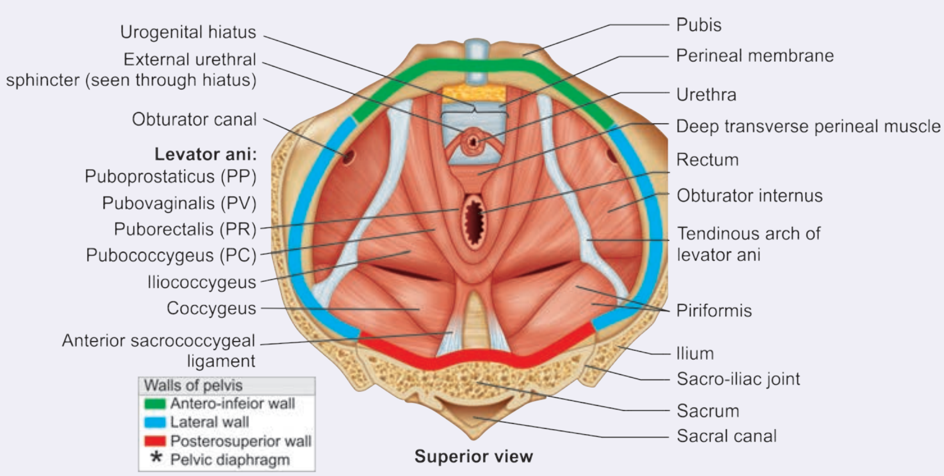


Fig. 25: Pelvic diaphragm and the related muscles

- **Perineal body** (central perineal tendon) is the fibromuscular tissue located in the midline at the junction between the anal and urogenital triangles, just anterior to the anal sphincter.
  - In males, it is found between the bulb of penis and the anus and in females, it is present between the vagina and anal canal, and about 1.25 cm in front of the anus.
  - Structures attaching to perineal body: External anal sphincter; Bulbospongiosus muscle; Superficial and deep transverse perineal muscle; Anterior fibers of the levator ani (including puborectalis or pubovaginalis etc.); Fibers from external urinary sphincter; Conjoint longitudinal coat (of rectum).
  - Perineal body is an important support of pelvic viscera and is essential for the integrity of the pelvic floor.
  - Perineal body tear during vaginal delivery leads to widening of the gap between the anterior free borders of levator ani muscle of both sides, thus predisposing the woman to prolapse of pelvic viscera (urinary bladder, uterus, rectum etc.)

Table 9: Muscles of pelvic walls and floor

Boundary	Muscle	Proximal Attachment	Distal Attachment	Innervation	Main Action
Lateral wall	Obturator internus	Pelvic surfaces of ilium and ischium; obturator membrane	Greater trochanter of femur	Nerve to obturator internus (L5, S1, S2)	Rotates thigh laterally; assits in holding head of femur in acetabulum
Posterosuperior wall	Piriformis	Pelvic surface of S2–S4 segments; superior margin of greater sciatic notch and sacrotuberous ligament	Greater trochanter of femur	Anterior rami of S1 and S2	Rotates thigh laterally; abducts thigh; assists in holding head of femur in acetabulum
Floor	Coccygeus (ischiococcygeus)	Ischial spine	Inferior end of sacrum and coccyx	Branches of S4 and S5 spinal nerves	Forms small part of pelvic diaphragm that supports pelvic viscera; flexes coccyx
	Levator ani (puborectalis, pubococcygeus, and iliococcygeus	Body of pubis; tendinous arch of obturator fascia; ischial spine	Perineal body; coccyx; anococygeal ligament; walls of prostate or vagina, rectum, and canal	Nerve to levator ani (branches of S4), inferior and (rectal) nerve, and coccygeal plexus	Forms most of pelvic diaphragm that helps support pelvic viscera and resists increases in intra-abdominal pressure

Muscles of the Superficial Perineal Pouch.

Table 10: Muscles of perineum

Muscle	Origin	Course and distribution	Innervation	Main action
External sphincter	Skin and fascia surrounding anus; coccyx via anococcygeal ligament	Passes around lateral aspects of anal canal, insertion into perineal body	Inferior anal (rectal) nerve, a branch of pudendal nerve (S2–S4)	Constricts anal canal during peristalsis, resisting defecation; supports and flexes perineal body and pelvic floor
Bulbospongiosus	*Male:* median rapheon ventral surface of bulb of penis; perineal body	*Male:* surrounds lateral aspects of bulb of penis and most proximal part of body of penis, inserting into perineal membrane, dorsal aspect of corpus spongiosum and corpora cavernosa, and fascia of bulb of penis	Muscular (deep) branch of perineal nerve, a branch of pudendal nerve (S2–S4)	*Male:* supports and fixes perineal body/pelvic floor; compresses bulb of penis to expel last drops of urine/semen; assists erection by compressing outflow via deep perineal vein and by pushing blood from bulb into body of penis
	Female: perineal body	*Female:* passes on each side of lower vagina, enclosing bulb and greater vestibular gland; inserts into pubic arch and fascia of corpora cavernosa of clitoris		*Female:* supports and flexes perineal body/pelvic floor; "sphincter" of vagina; assists in erection of clitoris (and perhaps bulb of vestibule); compresses greater vestibular gland
Ischiocavernosus	Internal surface of ischiopubic ramus and ischial tuberosity	Embraces crus of penis of clitoris, inserting onto inferior and medial aspects of crus and to perineal membrane medial to crus	Muscular (deep) branch of perineal nerve, a branch of pudendal nerve (S2–S4)	Maintains erection of penis or clitoris by compressing outflow veins and pushing blood from the root of penis or clitoris into the body of penis or clitoris

Muscle	Origin	Course and distribution	Innervation	Main action
Superficial transverse perineal muscle		Passes along inferior aspect of posterior border of perineal membrane to perineal body		Supports and flex perineal body/pelvic floor to support abdominopelvic viscera and resist increased intra abdominal pressure
Deep transverse perineal muscle		Passes along superior aspect of posterior border of perineal membrane to perineal body and external anal sphincter		
External urethral sphincter	(Compressor urethra portion only)	Surrounds urethra superior to perineal membrane; in males, it also ascends anterior aspect of prostate; in females, some fibers also enclose vagina (urethrovaginal sphincter)	Dorsal nerve of penis or clitoris, the terminal branch of the pudendal nerve (S2–S4)	Compresses urethra to maintain urinary continence; in females, urethrovaginal sphincter portion also compresses vagina

- Bulbospongiosus muscle compress the bulb in the male, impeding venous return from the penis and thereby maintaining erection.
- Contraction (along with contraction of the ischiocavernosus) constricts the corpus spongiosum, thereby expelling the last drops of urine (or semen in ejaculation).
- Compress the erectile tissue of the vestibular bulbs in the female and constrict the vaginal orifice (vaginal sphincter).

High Yield Points

- **Pelvic diaphragm** is contributed by levator ani (pubococcygeus and Iliococcygeus) and ischiococcygeus muscles. Parts of pubococcygeus: pubourethralis, puboprostaticus, pubovaginalis, puborectalis are components of the diaphragm. Ischiococcygeus (coccygeus) lies immediately cranial to levator ani and is contiguous with it, but is not a part of levator ani muscle.
- The right and left puborectalis unite behind the anorectal junction to form a muscular sling. Some regard them as a part of the sphincter ani externus.
- **Sacrospinous ligament** may represent either a degenerate part or an aponeurosis of the muscle *Ischiococcygeus*.

ASSESSMENT QUESTIONS

1. **Name the muscle forming pelvic diaphragm:**
   a. Deep transverse perinei
   b. Sphincter urethrae
   c. Levator ani
   d. None of the above

2. **Levator ani muscle include all EXCEPT:** *(NEET Pattern 2016)*
   a. Puborectalis
   b. Pubococcygeus
   c. Iliococcygeus
   d. Ischiococcygeus

3. **All are content of sphincter of vagina EXCEPT:**
   a. Pubovaginalis
   b. External urethral sphincter
   c. Internal urethral sphincter
   d. Bulbospongiosus

ANSWERS WITH EXPLANATIONS

1. **c. Levator ani**
   - **Pelvic diaphragm** is contributed by levator ani (pubococcygeus and Iliococcygeus) and ischiococcygeus muscles.
   - Parts of pubococcygeus: pubourethralis, puboprostaticus, pubovaginalis, puborectalis are components of the diaphragm.
   - Ischiococcygeus (coccygeus) lies immediately cranial to levator ani and is contiguous with it, but is not a part of levator ani muscle.

2. **d. Ischiococcygeus**
   - Ischiococcygeus muscle is a component of pelvic diaphragm, but is not included under levator ani muscle.
     - Levator ani muscle is subdivided into named portions according to their attachments and the pelvic viscera to which they are related (pubococcygeus, iliococcygeus and puborectalis).
     - Pubococcygeus is often subdivided into separate parts according to the pelvic viscera to which each part relates (puboperinealis, puboprostaticus or pubovaginalis, puboanalis, puborectalis).
   - Note: Ischiococcygeus (coccygeus) is not a part of levator ani muscle, lies immediately cranial and contiguous with it. Together with levator ani muscle it forms the pelvic diaphragm.

3. **c. Internal urethral sphincter**
   - Internal urethral sphincter is present in males to prevent retrograde ejaculation of semen into urinary bladder, it is absent in females.

Arterial Supply

Internal Pudendal Artery is a branch from the anterior division of internal iliac artery.

- It leaves the pelvis by way of the greater sciatic foramen between the piriformis and coccygeus and immediately enters the perineum through the lesser sciatic foramen by hooking around the ischial spine, accompanied by the pudendal nerve during its course.
- It passes along the lateral wall of the ischiorectal fossa in the pudendal canal.
- Branches

Table 11: Arteries of Pelvis

Artery	Origin	Course	Distribution	Anastomoses
Gonadal	Abdominal aorta	Descends retroperitoneally;		
Testicular (♂)		Traverses inguinal canal and enter scrotum	Abdominal and/or pelvic ureter, ovary, and ampullary end of uterine tube	Cremasteric artery, artery of ductus deferens
Ovarian (♀)		Crosses pelvic brim, descends in suspensory ligament of ovary	Abdominal and/or pelvic ureter, ovary, and ampulary end of uterine tube	Uterine artery via tubal and ovarian branches
Superior rectal	Continuation of inferior mesenteric artery	Crosses left common iliac vessels and descends into pelvis between layers of sigmoid mesocolon	Superior part of rectum	Middle rectal artery; inferior rectal (internal pudendal) artery
Median sacral	Posterior aspect of abdominal aorta	Descends close to midline over L4 and L5 vertebrae, sacrum, and coccyx	Inferior lumbar vertebrae, sacrum, and coccyx	Lateral sacral artery (via medial sacral branches)
Internal iliac	Common iliac artery	Passes medially over pelvic brim and descends into pelvic cavity; often forms anterior and posterior divisions	Main blood supply to pelvic organs, gluteal muscles, and perineum	
Anterior division of internal iliac	Internal iliac artery	Passes medially over pelvic brim and descends into pelvic cavity; often forms anterior and posterior divisions	Main blood supply to pelvic organs, gluteal muscles, and perineum	
Umbilical	Anterior division of internal iliac artery	Runs a short pelvic course, gives off superior vesical arteries, then obliterates, becoming medial umbilical ligament	Superior aspect of urinary bladder and, in some males, ductus deferens (via superior vesical arteries and artery to ductus deferens)	(Occasionally the patent part of the umbilical artery)
Superior vesical	(Patent proximal umbilical artery)	Usually multiple; pass to superior aspect of urinary bladder	Superior aspect of urinary bladder; in some males, ductus deferens (via artery to ductus deferens)	Inferior vesical (♂); Vaginal artery (♀)
Obturator		Runs anterio-inferiorly on obturator fascia of lateral pelvic wall, exiting pelvis via obturator canal	Pelvic muscles, nutrient artery to ilium, head of femur, and muscles of medial compartment of thigh	Inferior epigastric (via pubic branch); umbilical artery
Inferior vesical (♂)		Passes subperitoneally in lateral ligament of bladder, giving rise to prostatic artery (♂) and occasionally the artery to the ductus deferens	Inferior aspect of male urinary bladder, pelvic part of urete; prostate, and seminal glands; occasionally ductus deferens	Superior vesical artery
Artery to ductus deferens (♂)	(Superior or inferior vesical artery)	Runs subperitoneally to ductus deferens	Ductus deferens	Testicular artery; cremasteric artery
Prostatic branches (♂)	(Inferior vesical artery)	Descends on posterolateral aspects of prostate	Prostate and prostatic urethra	Deep perineal (internal pudendal)
Uterine (♀)		Runs anatomically in base of broad ligament/superior cardinal ligament, gives rise to vaginal branch, then crosses ureter superiorly to reach lateral aspect of uterine cervix	Uterus, ligaments of uterus, medial parts of uterine tube and ovary, and superior vagina	Ovarian artery (via tubal and ovarian branches); vaginal artery

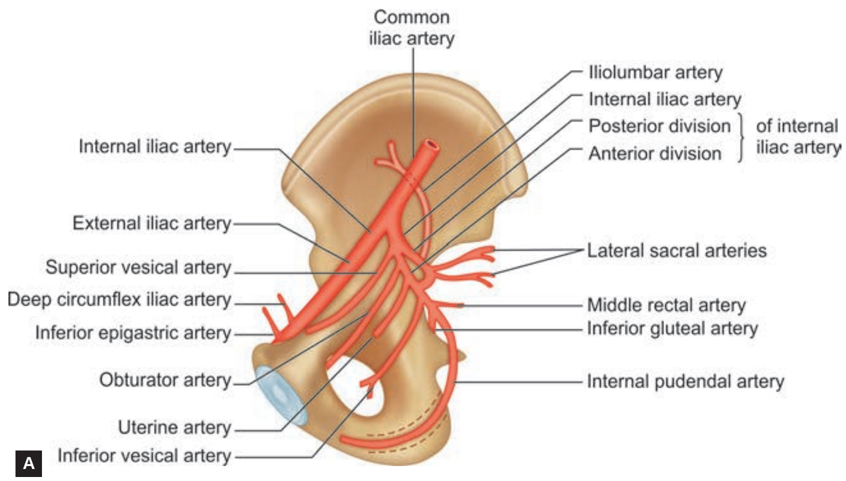
Contd...

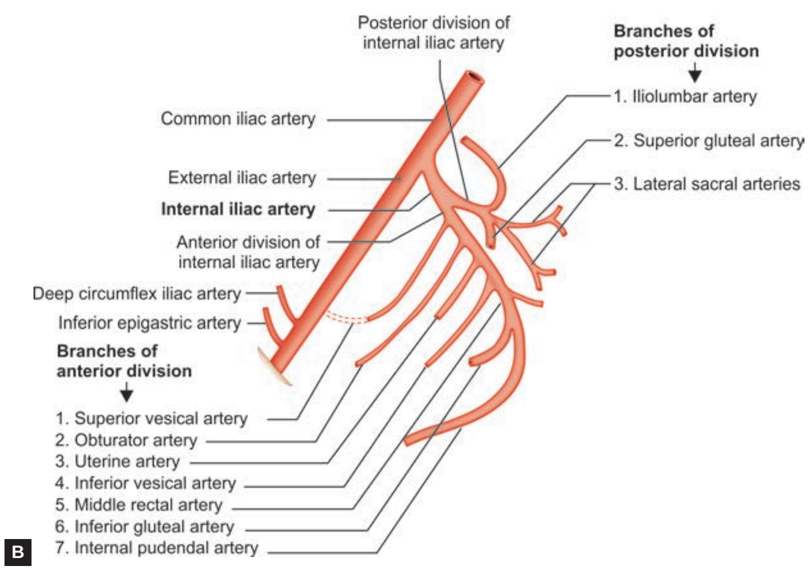
Artery	Origin	Course	Distribution	Anastomoses
Vaginal (♀)	(Uterine artery)	Divides into vaginal and inferior vesical branches, the former descending on the vagina, the latter passing to the urinary bladder	Vaginal branch: lower vagina, vestibular bulb, and adjacent rectum; inferior vesical branch: fundus of urinary bladder	Vaginal branch of uterine artery, superior vesical artery
Internal pudendal	Anterior division of internal iliac artery	Exits pelvis via infrapiriform part of greater sciatic foramen, enters perineum (ischio-anal fossa) via lesser sciatic foramen, passes via pudendal canal to UG triangle	Main artery of perineum, including muscles and skin of anal and urogenital triangles, erectile bodies	(Umbilical artery; prostatic branches of inferior vesical artery in males)
Middle rectal		Descends in pelvis to inferior part of rectum	Inferior part of rectum, seminal glands, prostate (vagina)	Superior and inferior rectal arteries
Inferior gluteala		Exits pelvis via infrapiriform part of greater sciatic foramen	Pelvic diaphragm (coccygeus and levator ani), piriformis, quadratus femoris, superiormost hamstrings, gluteus maximus, and sciatic nerve	Profunda femoris artery (via medial and lateral circumflex femoral arteries)
Posterior division of internal iliac	Internal iliac artery	Passes posteriorly and gives rise to parietal branches	Pelvic wall and gluteal region	
Iliolumbarb		Ascends anterior to sacro-iliac joint and posterior to common iliac vessels and psoas major, dividing into iliac and lumbar branches	Psoas major, iliacus, and quadratus lumborum muscles; cauda equina in vertebral canal	Circumflex iliac artery and 4th (and lowest) lumbar artery
Lateral sacral (superior and inferior)	Posterior division of internal iliac artery	Runs on anteromedial aspect of piriformis to send branches into pelvic sacral foramina	Piriformis, structures in sacral canal, erector spinae, and overlying skin	Medial sacral arteries (from median sacral artery)
Superior gluteal		Passes between lumbosacral trunk and anterior ramus of S1 spinal nerve to exit pelvis via suprapiriform portion of greater sciatic foramen	Piriformis, all three gluteal muscles, and tensor fasciae latae	Lateral sacral, inferior gluteal, internal pudendal, deep circumflex, femoral, lateral circumflex femoral

Table 12: Arteries of Perineum

Artery	Origin	Course	Distribution in perineum
Internal pudendal	Anterior division of internal iliac artery	Leaves pelvis through greater sciatic foramen; hooks around ischial spine to enter perineum via lesser sciatic foramen; enters pudendal canal	Primary artery of perineum and external genital organs
Inferior rectal	Internal pudendal artery	Arises at entrance to pudendal canal; traverses ischio-anal fossa to anal canal	Anal canal inferior to pectinate line; anal sphincters; peri-anal skin
Perineal		Arises within pudendal canal; passes to superficial pouch (space) on exit	Supplies superficial perineal muscles and scrotum of male/ vestibule of female
Posterior scrotal (♂) or labial (♀)	Terminal branch of perineal artery	Runs in superficial fascia of posterior scrotum or labia majora	Skin of scrotum or labia majora and minora
Artery of bulb of penis (♂) or vestibule (♀)		Pierces perineal membrane to reach bulb of penis or vestibule of vagina	Supplies bulb of penis (including bulbar urethra) and bulbo-urethral gland (male) or bulb of vestibule and greater vestibular gland (female)

Artery	Origin	Course	Distribution in perineum
Deep artery of penis (♂) or clitoris (♀)		Pierces perineal membrane to enter crura of corpora cavernosa of penis or clitoris; branches run proximally and distally	Supplies most erectile tissue of corpora cavernosa of penis or clitoris via helicine arteries
Dorsal artery of penis (♂) or clitoris (♀)	Terminal branch of internal pudendal artery	Passes to deep pouch; pierces perineal membrane and traverses suspensory ligament of penis or clitoris to run on dorsum of penis or clitoris to glans	Deep perineal pouch; skin of penis; fascia of penis or clitoris; distal corpus spongiosum of penis, including spongy urethra; glans penis or clitoris
External pudendal, superficial, and deep branches	Femoral artery	Pass medially from thigh to reach anterior aspect of the urogenital triangle or perineum	Anterior aspect of scrotum and skin at root of penis of male; mons pubis and anterior aspect of labia of female





Figs. 26A and B: Arterial supply of pelvis and perineum

ASSESSMENT QUESTIONS

1. **Branch of internal iliac artery is/are:** *(PGIC 2014)*
   a. Inferior vesical artery
   b. Inferior epigastric artery
   c. Iliolumbar artery
   d. Internal pudendal artery
   e. Obturator artery

2. **Internal pudendal artery is a branch of:** *(NEET Pattern 2015)*
   a. Anterior division of internal iliac
   b. Posterior division of internal iliac
   c. Anterior division of external iliac
   d. Posterior division of external iliac

3. All are branches of the internal iliac artery except: *(NEET Pattern 2012)*
a. Ovarian artery
b. Superior vesical artery
c. Middle rectal artery
d. Inferior vesical artery

4. Artery to ductus deferens is a branch of: *(NEET Pattern 2016)*
a. Superior vesical artery
b. Inferior vesical artery
c. Internal pudendal artery
d. Middle rectal artery

5. Accessory obturator artery is a branch of: *(NEET Pattern 2016)*
a. Inferior epigastric
b. External iliac
c. Internal iliac
d. Obturator

ANSWERS WITH EXPLANATIONS

1. a. Inferior vesical artery; c. Iliolumbar artery; d. Internal pudendal artery; e. Obturator artery
- Inferior epigastric artery is a branch of external (not internal) iliac artery.

2. a. Anterior division of internal iliac
- Anterior division of internal iliac artery gives the internal pudendal artery which accompanies pudendal nerve in the pudendal canal and supply the perineum region.

3. a. Ovarian artery
- Ovarian artery is a branch of the abdominal aorta.
- Gonads develop in the abdomen region and gonadal arteries are branches of abdominal aorta.
- As the gonads descend down to pelvic cavity, gonadal arteries become longer (Testicular > Ovarian).

4. a. Superior vesical artery > b. Inferior vesical artery > d. Middle rectal artery
- Vas deferens is usually derived from the **superior vesical artery**, and occasionally from the **inferior vesical artery**, both branches of the internal iliac artery.

Note: It may also arise from **middle rectal artery**.

5. a. Inferior epigastric
- Accessory obturator artery is the pubic branch of inferior epigastric artery, which itself is given by external iliac artery.
- Lacunar ligament is medial boundary of femoral ring and accessory obturator artery may lie on that in some percentage of population.
- In reduction of femoral hernia, we must be careful of accessory obturator artery, while the lacunar ligament is cut to enlarge the femoral ring to reduce the hernia.

Venous Drainage

Pelvic Venous Plexus

It lies within the minor (true) pelvic cavity and is formed by intercommunicating veins surrounding the pelvic viscera and include the rectal venous plexus, vesical venous plexus, prostatic venous plexus, uterine venous plexus, and vaginal venous plexus.

Components

- Pelvic venous plexuses → internal iliac veins, which join the external iliac veins to form the common iliac veins → common iliac veins, which join to form the inferior vena cava (IVC). This is the major pathway.
- Pelvic venous plexuses → median sacral vein → common iliac vein → IVC
- Pelvic venous plexuses → ovarian veins → IVC
- Pelvic venous plexuses → superior rectal vein → inferior mesenteric vein → portal vein
- Pelvic venous plexuses → lateral sacral veins → internal vertebral venous plexus → cranial dural sinuses

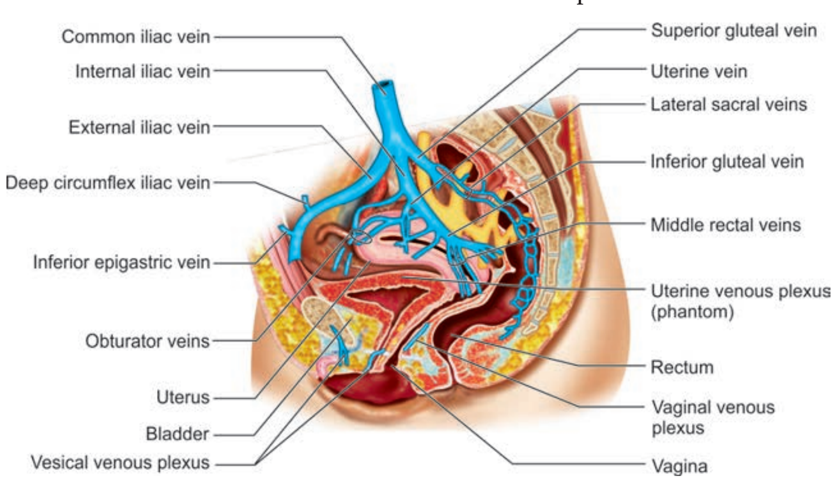


Fig. 27: Venous drainage of pelvis and perineum

Lymphatics

- Lymphatic Drainage of the **Perineum**.
- Lymphatics drain via the superficial inguinal lymph nodes, which receive lymph from the lower abdominal wall, buttocks, penis, scrotum, labium majus, and lower parts of the vagina and anal canal.
- These lymph nodes have efferent vessels that drain primarily into the external iliac nodes and ultimately to the lumbar (aortic) nodes.
- Lymphatics from the glans penis (or clitoris) and labium minus pass to the deep inguinal and external iliac nodes.
  Lymphatic Drainage of the **Pelvis**
- The lymphatics follow the internal iliac vessels to the internal iliac nodes to the common iliac nodes and subsequently to the lumbar (aortic) nodes.
- Internal iliac nodes receive lymph from the upper part of vagina and other pelvic organs, and they drain into the common iliac and then to the lumbar (aortic) nodes.
- Lymph from the uppermost part of the rectum drains along the superior rectal vessels, inferior mesenteric nodes, and then aortic nodes.
- Lymph from the testis and epididymis or ovary drains along the gonadal vessels directly into the aortic nodes.
- Lymph vessels from the prostate drain into the internal iliac nodes.
- Lymph vessels from the ovary, uterine tube, and fundus follow the ovarian artery and drain into the para-aortic nodes. Lymph vessels from the uterine body and cervix and bladder drain into the internal and external iliac nodes.

Lymphatic Drainage of structures of pelvis and perineum

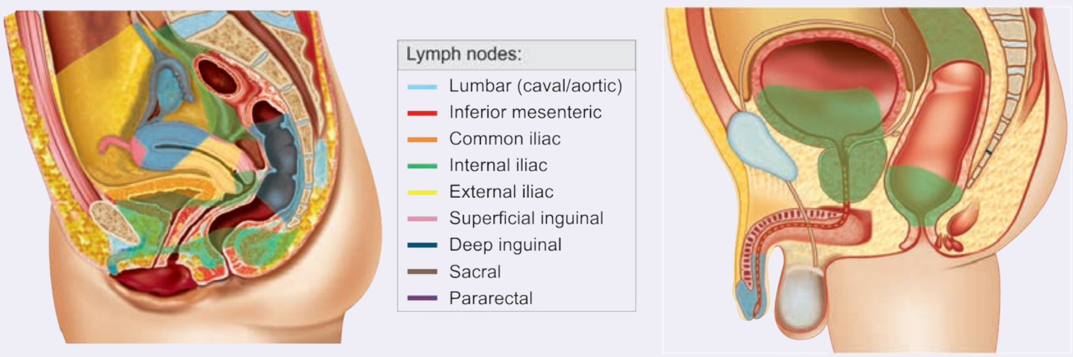


Fig. 28: Lymphatic drainage of pelvis and perineum

Table 13: Lymphatic drainage of the pelvis and perineum region

Lymph node group		Structures typically drainage to lymph node group	
Lumbar	*Female:* along ovarian vessels	Gonads and associated structures; common iliac nodes	*Female:* ovary; uterine tube (except isthmus and intra-uterine parts); fundus of uterus
	Male: along Testicular vessels		*Male urethra:* testis; epididymis
Inferior mesenteric		Superiormost rectum; sigmoid colon; descending colon; pararectal nodes	
Common iliac		External and internal iliac lymph nodes	
Internal iliac		Inferior pelvic structures; deep perineal structures; sacral nodes	*Female:* base of bladder; inferior pelvic ureter; anal canal (above pectinate line); inferior rectum; middle and upper vagina; cervix; body of uterus
			Male: prostatic urethra; prostate; base of bladder; inferior pelvic ureter; inferior seminal glands; cavernous bodies; anal canal (above pectinate line); inferior rectum
External iliac		Anterosuperior pelvic structures; deep inguinal nodes	*Female:* superior bladder: superior pelvic ureter; upper vagina; cervix; lower body of uterus
			Male: superior bladder; superior pelvic ureter; upper seminal gland; pelvic part of ductus deferens; intermediate and spongy urethra (secondary)
Superficial inguinal		Lower limb: superficial drainage of inferolateral quadrant of trunk, including anterior abdominal wall inferior to umbilicus, gluteal region, and superficial perineal structures	*Female:* superolateral uterus (near attachment of round ligament); skin of perineum including vulva; ostium of vagina (inferior to hymen); prepuce of clitoris; peri-anal skin; anal canal inferior to pectinate line
			Male: skin of perineum including skin and prepuce of penis; scrotum; peri-anal skin; anal canal inferior to pectinate line

Lymph node group	Structures typically drainage to lymph node group	
Deep inguinal	Glans clitoris or penis; superficial inguinal nodes	*Female:* glans clitoris
Sacral	Postero-inferior pelvic strucutres; inferior rectum; inferior vagina	
Pararectal	Superior rectum	

ASSESSMENT QUESTIONS

1. Superficial inguinal lymphatics drain all of the following EXCEPT: *(NRET Pattern 2005)*
   a. Anal canal below pectinate line
   b. Glans penis
   c. Urethra
   d. Perineum

2. Infection/inflammation of all of the following causes enlarged superficial inguinal lymph nodes EXCEPT: *(AIPG 2004)*
   a. Isthmus of uterine tube
   b. Inferior part of anal canal
   c. Big toe
   d. Penile urethra

3. Distal part of spongy male urethra drains via which lymph nodes? *(AIPG 2009)*
   a. Superficial inguinal
   b. External Iliac
   c. Deep inguinal
   d. Aortic

ANSWERS WITH EXPLANATIONS

1. b. Glans penis
- **Glans penis** drains into **deep inguinal lymph nodes (Cloquet)**.
- Anal canal **below** pectinate line drains into **superficial inguinal** lymph nodes, and above the pectinate line into internal iliac lymph nodes.
- Proximal urethra drains into iliac and distal urethra into inguinal lymph nodes
- Perineum majorly drains into superficial inguinal lymph nodes.

2. d. Penile urethra
- Lymphatics from the penile urethra (and glans penis) mainly run towards deep inguinal lymph nodes.
- Though few lymphatics may end up in the superficial inguinal lymph nodes.
- Isthmus of uterine tube, inferior part of anal canal and big toe all drain towards the superficial group of lymph nodes.
- Lymphatics from the isthmus follow the round ligament of uterus and lymphatics from the great toe follow the great saphenous vein, both reaching the superficial inguinal lymph nodes.

3. c. Deep inguinal
- Distal spongy urethra and the glans penis drain into the deep inguinal lymph nodes of **Cloquet and Rosenmuller.**
- Spongy part of male urethra mainly drains into the deep inguinal lymph nodes. Some lymphatics may end in the superficial inguinal/ external iliac lymph nodes as well.
- Lymphatics from the prostatic and membranous urethra pass mainly to the internal iliac lymph nodes. Some lymphatics from these areas may end in the external iliac lymph nodes also.
- Eventually all the lymphatics reach the aortic lymph nodes → Thoracic duct → Left sided neck veins.
- Female urethra drains into both the internal and external iliac lymph nodes.
- Lymph drainage of penis: Penile skin → Superficial lymph nodes; Glans → Deep inguinal and External iliac lymph nodes.

Lymphatic Drainage - Females

Table 14: Lymphatic drainage of the female genitalia

Structure	Nodes
Vulva	
Labia, clitoris, and perineum Perineum and lower labia majora Clitoris	Superficial inguinal nodes Rectal lymphatic plexus Superficial inguinal nodes Direct to deep inguinal nodes Direct to internal iliac nodes
Vagina Upper vagina Mid-vagina Lower vagina	Internal and external iliac nodes Internal iliac nodes Superficial inguinal nodes
Uterus Fundus Isthmus of tube and round ligament Body of uterus, including cervix	Para-aortic nodes Superficial inguinal nodes External iliac nodes Internal iliac nodes Obturator nodes
Uterine (Fallopian) tubes	Para-aortic nodes Internal iliac nodes Superficial inguinal nodes
Ovaries	Para-aortic nodes

Male Reproductive System

Male reproductive system is described in chapter 9-Abdomen.

Female Reproductive System

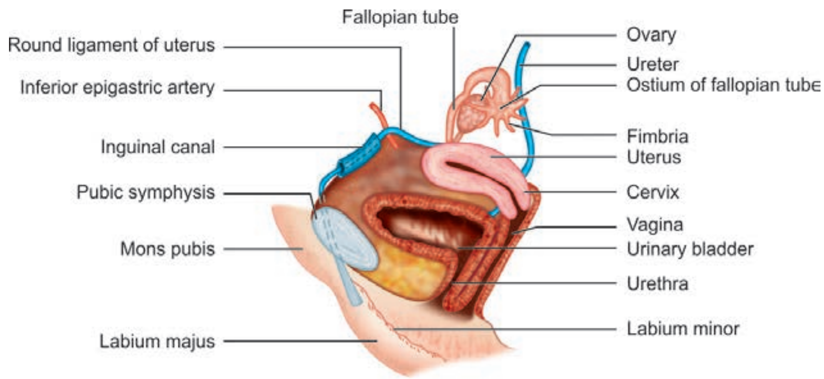


Fig. 29: Female genital organs

Ovary

Ovaries are the female gonads located in the pelvic cavity, posterior to the broad ligament, in the **ovarian fossa of Waldeyer**, between the divergent external and internal iliac vessels.

- They are attached to the lateral pelvic wall by the **suspensory ligament of the ovary** (a region of the broad ligament), which contains the ovarian artery, vein, and nerve.
- The blood vessels, lymphatics, and nerves pass over the pelvic inlet, cross the external iliac vessels, and then enter the suspensory ligament of the ovary (lateral end of broad ligament) and finally enter the hilum of ovary via the **mesovarium**.
- The ovary consists of a **cortex** and **medulla**. In young women, the outermost portion of the cortex is smooth, has a dull white surface (**tunica albuginea**).
- The surface of the ovaries is not covered by mesothelium, but instead by a simple cuboidal epithelium called the **germinal epithelium of Waldeyer**.
- Beneath this epithelium, the **cortex** contains oocytes and developing follicles. The **medulla** is the central portion, which is composed of loose connective tissue.
- There are a large number of arteries and veins in the medulla and a small number of smooth muscle fibers.

Ovarian fossa of Waldeyer is a shallow depression wherein the ovary lies.

- It lies on the lateral pelvic wall below the pelvic brim.
- Behind the ovarian fossa are retroperitoneal structures, including the ureter, internal iliac vessels, obturator vessels and nerve, and the origin of the uterine artery.
- Posterior border of ovary is free and faces the peritoneum, which overlies the upper part of the internal iliac artery and vein, and the ureter.
- Ovarian fossa is bounded **anteriorly** by the external iliac vessels and inferiorly by the uterine tubes (in the free margin of broad ligament).
- The obturator nerve and vessels cross the **floor** of the fossa.

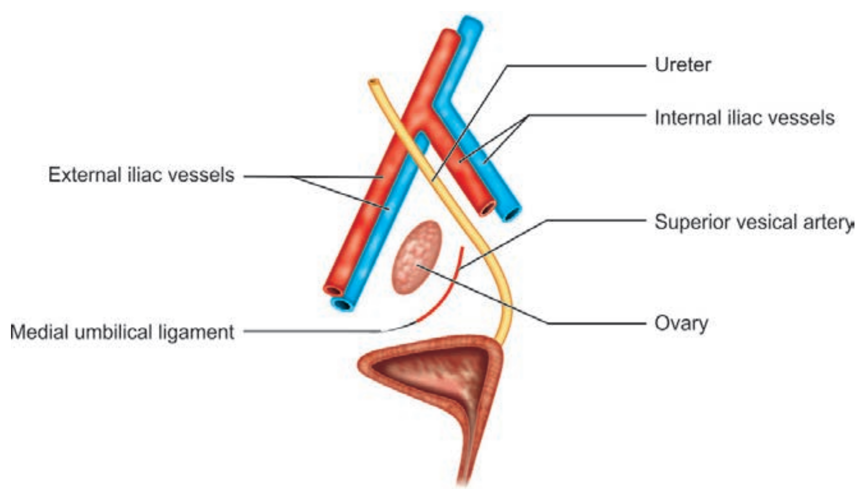


Fig. 30: Boundaries and relation of ovary (in ovarian fossa)

Peritoneal Relations

- **Ovarian Ligament** is a fibromuscular cord that extends from the ovary to the uterus below the uterine tube, running within the layers of the broad ligament.
- **Suspensory Ligament of the Ovary** is a band of peritoneum that extends upward from the ovary to the pelvic wall and transmits the ovarian vessels, nerves, and lymphatics.

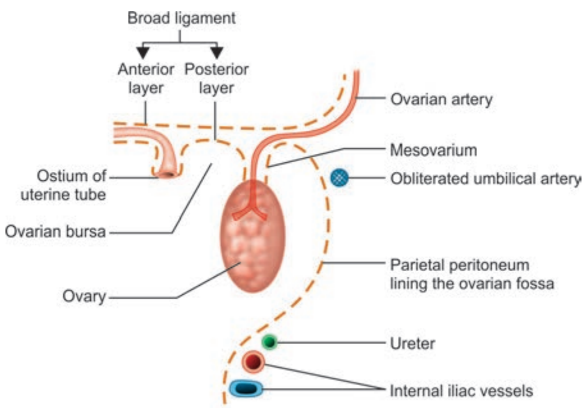


Fig. 31: Peritoneal relations of the ovary

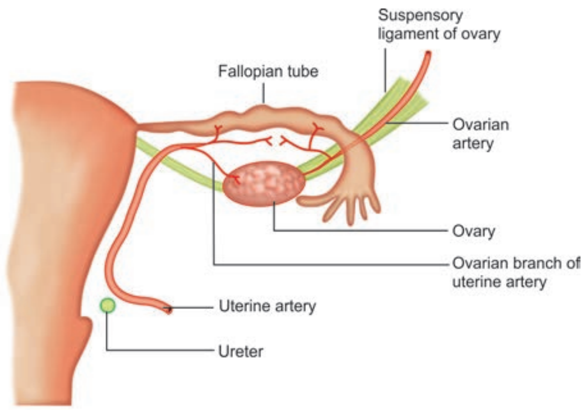


Fig. 32: Arterial supply of the ovary

Arterial Supply

- **Ovarian arteries** (branch of abdominal aorta) and ascending branches of the **uterine arteries** (branch of internal iliac artery).

Venous Drainage

- Ovaries drain into **ovarian veins**, right empties into the inferior vena cava and the left ovarian vein empties into the left renal vein.

Lymphatic Drainage

- Lymphatics drain into the para (lateral) and pre (anterior) **aortic lymph nodes**.

Nerve Supply

- Sympathetic nerves are derived from spinal segment T10, 11.
- Parasympathetic nerves are vagus (laterally) and nervi erigentes (medially) nerve.
- Sensory (general visceral afferent) fibres follow the ovarian artery and enter at T10,11 spinal cord level.
  - Ovarian pain is referred in the umbilical region (T10).
  - The intractable ovarian pain can be alleviated by transecting the suspensory ligament, which contain the afferent fibres.

ASSESSMENT QUESTIONS

1. **Ureter is present in which wall of ovarian fossa?** *(DNB Pattern- 2016)*
   a. Anterior
   b. Posterior
   c. Medial
   d. Lateral

2. **Ovarian fossa is formed by all EXCEPT:** *(NEET Pattern 2015)*
   a. Obliterated umbilical artery
   b. Internal iliac artery
   c. Ureter
   d. Round ligament of ovary

ANSWERS WITH EXPLANATIONS

1. **b. Posterior**
   - Behind the ovarian fossa are retroperitoneal structures, including the ureter, internal iliac vessels, obturator vessels and nerve, and the origin of the uterine artery.

2. **d. Round ligament of ovary**
   - Round ligament of ovary is infero-medial to the ovary.

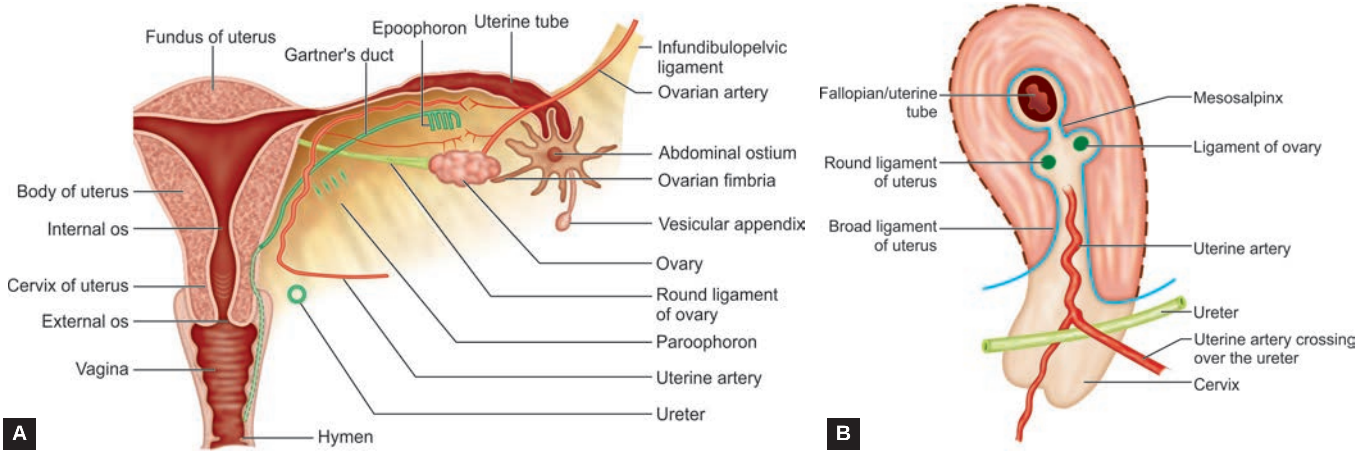
Uterus

Uterus is the female where development of fetus occurs during gestation.

- It is located within the pelvic region immediately behind and almost overlying the bladder, and in front of the rectum.
- The upper end fundus, is connected to the fallopian tubes and the lower end cervix, opens into the vagina.
- It is divided into **four** regions:
  - **Fundus** is located superior to the cornua and contributes largely to the upper segment of the uterus during pregnancy. At term, the fundus may extend as high as the xiphoid process (vertebral level T9).
  - **Cornu** is located near the entry of the uterine tubes.

- ➢ **Body** is located between the cornu and cervix. The **isthmus** is part of the body and is the dividing line between the body of the uterus and the cervix. The isthmus is the preferred site for a surgical incision during a delivery by cesarean section.
- ➢ **Cervix** is located inferior to the body of the uterus and protrudes into the vagina. The cervix contains the internal os, cervical canal, and external os.
- ➢ The external os in a nulliparous woman is **round** and **transverse** in a parous woman.

- Uterus has three layers (innermost to outermost):
  - ➢ **Endometrium** is the inner epithelial layer along with its mucosal membrane and has two layers:
    - Basal layer
    - Functional layer which thickens and is sloughed during the menstrual cycle.
    - During pregnancy, the uterine glands and blood vessels in the endometrium increase in size and number and vascular spaces fuse, become interconnected, forming the placenta.
  - ➢ **Myometrium** contains the smooth muscle.
  - ➢ **Perimetrium** is the serous layer of visceral peritoneum covering the outer surface of uterus.
- **Cervix** is the lower part of the uterus that measures about 2.5 to 3 cm in length.
  - ➢ The junction between the cervix and uterus is at the **internal os. Endocervical canal** connects the uterine cavity with the vaginal cavity and extends from the internal os to the **external os**.
  - ➢ Cervix is divided into a supravaginal portion (**endocervix**) and a vaginal portion (**ectocervix**) which protrudes into the vagina.
  - ➢ At puberty the **simple columnar epithelium** of the endocervical canal extends onto the ectocervix and its exposure to the acidic (pH = 3) of the vagina induces a transformation from columnar to stratified **squamous epithelium** (i.e., squamous metaplasia) and the formation of a transformation zone.

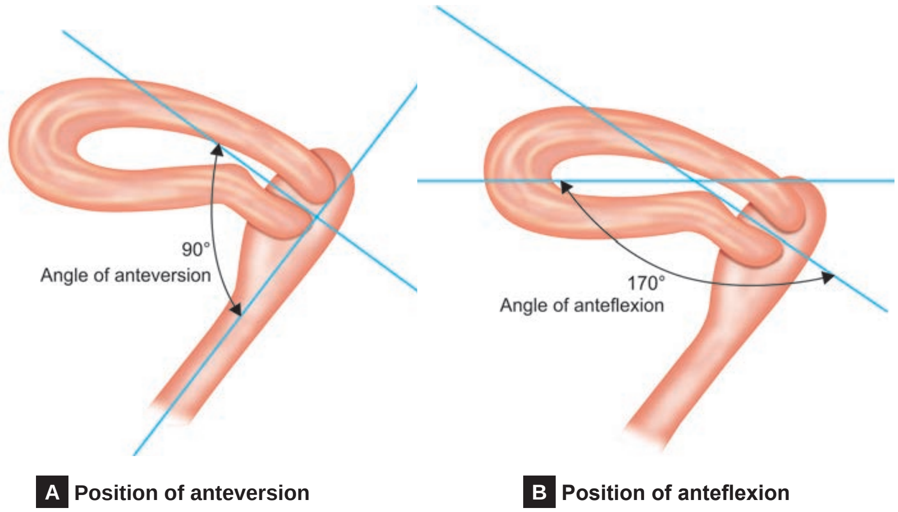


Figs 33A and B: Contents of the broad ligament (A) posterior aspect of the right broad ligament of the uterus (B) sagittal section through the broad ligament of the uterus showing structures that lie within the broad ligament

- **Broad ligament** consists of double layer of parietal peritoneum ,extending from the uterus to the lateral pelvic wall and functions to hold the uterus in position.
  - ➢ It does not contain the ovary but is attached to the ovary through the mesovarium.
  - ➢ It has a posterior layer that curves from the isthmus of the uterus (the rectouterine fold) to the posterior wall of the pelvis alongside the rectum.
  - ➢ It has four regions:
    - Mesovarium connects the posterior layer of the broad ligament with anterior surface of the ovary.
    - Mesosalpinx is the fold of the broad ligament that suspends the uterine tube.
    - Mesometrium is the part of the broad ligament below the Mesosalpinx and mesovarium.
    - Suspensory ligament of the ovary
- **Contents**: Ovarian NVB (artery, vein, and nerves), ovarian ligament of the uterus (which is a remnant of the gubernaculum in the embryo), Uterine tubes and NVB (Uterine artery, vein, and nerves - which lie at the base of the broad ligament within the transverse cervical ligament), Round ligament of the uterus (which is a remnant of the gubernaculum in the embryo), Epoophoron and paroophoron (which are remnants of the mesonephric tubules in the embryo), Gartner duct (which is a remnant of the mesonephric duct in the embryo), Ureter (which lies at the base of the broad ligament posterior and inferior to the uterine artery), nerve plexus, and lymphatic vessels.

Position of the Uterus

Uterus is normally in an anteverted and anteflexed position, which places the uterus in a nearly horizontal position lying on the superior wall of the urinary bladder.



Figs 34A and B: A. Position of anteversion B. Position of anteflexion

- **Anteversion**: The long axis of the uterus is bent forward on the long axis of the vagina, against the urinary bladder.
  - It is the anterior bend of the uterus at the angle between the cervix and the vagina.
- **Anteflexion**: It refers to the anterior bend of the uterus at the angle between the cervix and the body of the uterus.

Arterial supply: The uterus is supplied by uterine arteries and partly by the ovarian arteries.

- Uterine artery is a branch of anterior division of internal iliac artery, runs medially across the pelvic floor in the base of the broad ligament, towards the uterine cervix.
- It passes superior to the ureter, superolateral to the fornix of the vagina.
- Then it ascends along the side of the uterus. At the superolateral angle of uterus it turns laterally, runs along the uterine tube and anastomose with the ovarian artery.
- Uterine artery supplies vagina, uterus, medial two-third of uterine tube, ovary, ureter, and structures within the broad ligament.
- **Branches:**
  - Near the cervix after crossing the ureter, it gives ureteric, vaginal, and cervical branches. The cervical branches form circular anastomosis around the isthmus.
  - Along the side of body of the uterus it gives off arcuate branches which run transversely on the anterior and posterior surfaces of the body of uterus and anastomoses with their counter parts along the midline.
  - Along the fallopian tube it gives off tubal and ovarian branches.

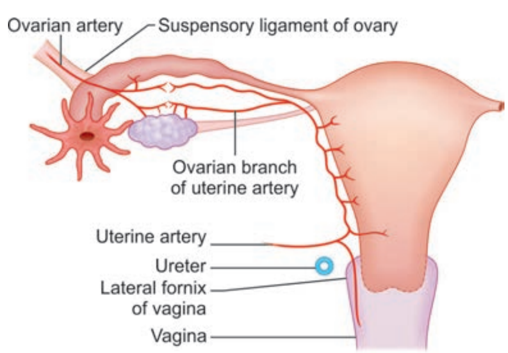


Fig. 35: Uterus: arterial supply

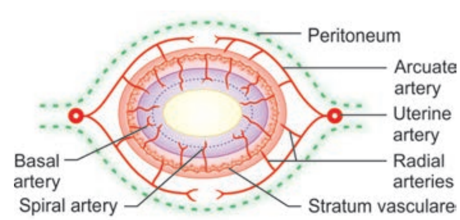


Fig. 36: Intrinsic arterial circulation of the uterus

Intrinsic uterine circulation:

- Uterine artery gives **arcuate** (coronary) arteries which anastomose on the anterior and posterior surfaces of the body of the uterus in the midline.
  - **Radial** arteries arise from the arcuate arteries and pierce the myometrium centripetally, anastomose with each other and form stratum vasculare in the middle layer of myometrium.
  - From stratum vasculare **basal** and **spiral** are given to supply the endometrium.
  - Spiral arteries supply the functional zone of the endometrium (which is cast off during menstruation) and basal arteries supply the basal zone of the endometrium (which helps in the regeneration of the denuded endometrium).

Venous Drainage of the uterus is to the internal iliac veins (which empties into the IVC).

Lymphatic drainage:

- Fundus and upper part of the body: Pre and para-aortic lymph nodes along the ovarian vessels (few lymphatics from the lateral angles of the uterus travel along the round ligaments of the uterus and drain into superficial inguinal lymph nodes .
- Middle part of the body : External iliac nodes via broad ligament.
- From cervix, on each side the lymph vessels drain in three directions:
  - Laterally: External iliac and obturator nodes.
  - Posterolaterally: Internal iliac nodes (major drainage)
  - Posteriorly: Sacral nodes

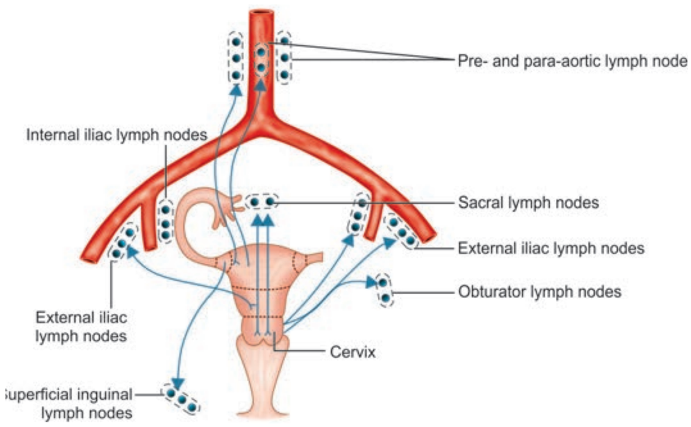


Fig. 37: Lymphatic drainage of uterus

Nerve supply

The nerve supply to the uterus is predominantly from the **inferior hypogastric plexus** and branches are carried by arteries (**uterine** and **ovarian**).

- Nerves ascend with uterine arteries in the broad ligament and connect with tubal nerves with the ovarian plexus.
- Nerves to the cervix form a plexus that contains small paracervical ganglia.
- Sympathetic preganglionic efferent fibres are derived from neurones in the last thoracic and first lumbar spinal segments (T10-12; L1-2) which synapse on the postganglionic neurones in the superior and inferior hypogastric plexuses. These fibres produce uterine contraction (in non-pregnant uterus) and vasoconstriction. Uterine contraction in pregnant uterus is under oxytocin hormone.
- Parasympathetic preganglionic fibres arise from neurones in the second to fourth sacral spinal segments (S-2,3,4) and relay in the paracervical ganglia, and cause uterine inhibition and vasodilation, but these activities are complicated by hormonal control of uterine functions.
- Most afferent sensory fibers from the **uterus** ascend through the **inferior hypogastric plexus** and enter the spinal cord via **lumbar splanchnic** (T10-12; L1-2) and corresponding spinal nerves.
  - The sensory nerves from the **cervix** and upper part of the **birth canal** pass through the pelvic splanchnic nerves (**nervi erigentes**) to the S-2,3,4 nerves.
  - Those from the **lower portion** of the birth canal pass primarily through the **pudendal nerve**.

Labour pain

- Pain during **first stage of labour** is initially confined to T11 – T12 dermatomes (latent phase), but eventually labour enters active phase and much of the pain is due to dilatation of cervix and lower uterine segment and pain passes through hypogastric plexus and aortic plexus before entering the spinal cord at T10 – L1 nerve roots.
- Stretching and compression of the pelvic and perineal structures involves pudendal nerve (S2-4), so pain during **second stage of labour** involves T10 – S4 dermatomes.

Clinical Correlations

- **Spinal anesthesia** up to spinal nerve T10 is necessary to block pain for vaginal delivery and up to spinal nerve T4 for cesarean section (due to the sympathetic fibre levels being at higher level than motor or sensory blockade).
- **Lumbar spinal anaesthesia** (spinal block), in which the anesthetic agent is introduced with a needle into the spinal subarachnoid space and it anaesthetizes the intraperitoneal, subperitoneal and somatic structures.
  - It produces complete anesthesia inferior to approximately the waist level.
  - The perineum, pelvic floor, and birth canal are anesthetized, and motor and sensory functions of the entire lower limbs, as well as sensation of uterine contractions, are temporarily eliminated.
- **Caudal epidural block**, in which the anesthetic agent is administered using an in-dwelling catheter in the sacral canal, and it anaesthetizes the subperitoneal and somatic structures.
  - The entire birth canal, pelvic floor, and most of the perineum are anesthetized, but the lower limbs are not usually affected and the mother is aware of uterine contractions.

- **Pudendal nerve block** is provides local anesthesia over the perineum (S2–S4 dermatomes) and the inferior quarter of the vagina.
  - It does not block pain from the superior birth canal (uterine cervix and superior vagina), so the mother is able to feel uterine contractions.

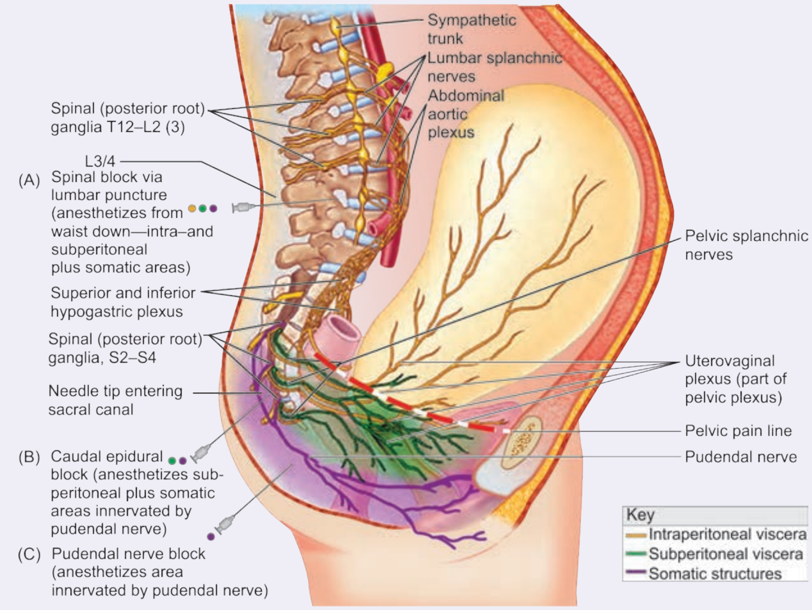


Fig. 38: Obstetric blocks: (A) Spinal block; (B) Caudal epidural block; (C) Pudendal block.

ASSESSMENT QUESTIONS

1. The following group of lymph nodes receives lymphatics from the uterus EXCEPT: *(AIPG 2005)*
- a. External iliac
- b. Internal iliac
- c. Superficial inguinal
- d. Deep inguinal

2. Ovarian pathology is referred to: *(AIIMS 2010)*
- a. Gluteal region
- b. Anterior thigh
- c. Medial part of thigh
- d. Back of thigh

3. All are true regarding uterus EXCEPT: *(PGIC 2014)*
- a. Lymph vessels from fundus drain to para-aortic lymph nodes
- b. Broad ligament provides primary support to uterus
- c. Mainly supplied by uterine artery
- d. Supplied by ovarian artery
- e. Posterior surface is related to intestine

4. Lymphatic drainage of uterine cervix is all EXCEPT:
- a. Obturator
- b. Sacral
- c. External iliac
- d. Internal iliac

5. Lymphatic drainage of the cervix occurs by all of the following lymph nodes EXCEPT: *(AIPG 2006)*
- a. Parametrial lymph nodes
- b. Deep inguinal lymph nodes
- c. Obturator lymph nodes
- d. External iliac lymph nodes

6. All the following pairs are correct concerning the lymphatics of uterus EXCEPT:
- a. Fundus: Para-aortic
- b. Mid-uterus: External iliac
- c. Cervix: Superficial inguinal lymph nodes
- d. Cervix: Sacral

ANSWERS WITH EXPLANATIONS

1. d. Deep inguinal
- Lymphatics from the uterus reach the superficial inguinal lymph nodes but not the deep inguinal.
- The lymphatics follow the round ligament of uterus to reach the superficial inguinal lymph nodes.
- Upper part of the uterus like fundus, drain mainly into the para-aortic lymph nodes.
- Lymphatics from cervix region spread towards external iliac as well as internal iliac group of lymph nodes.

2. c. Medial part of thigh
- Ovarian pathology may irritate the obturator nerve lying in the vicinity, which leads to a referred pain in the medial thigh (Dermatome: L-2).
- Obturator nerve (L-2, 3 & 4) is the nerve of medial thigh and supplies the skin on the medial thigh. This type of pain is a somatic referred pain.
- Another example is the pain felt in the knee joint in a case of Perthes' disease, which is pathology of hip joint but referred somatic pain is felt in the knee joint, since, both the joints are supplied by a common nerve – the obturator nerve.
- The visceral pain of the ovary is carried by the visceral nerves having root value T – 10, 11. Hence, visceral referred pain from the ovarian pathology will be felt in the skin bearing dermatome T: 10, 11.
- Pain in the medial thigh could be a referred pain from viscera like ureter, hind gut, uterus, urinary bladder. Or it could be a somatic referred pain irritating obturator nerve as in a case of appendicitis, pelvic abscess or ovarian pathology as in the present case.

3. b. Broad ligament provides primary support to uterus
- Lymphatics from the uterine fundus drain towards the para-aortic lymph nodes.
- Broad ligament is a fold of peritoneum and poor support of uterus. Primary supports of uterus are muscular supports.
- Uterus is supplied by uterine (mainly) and ovarian arteries.
- Posterior surface of uterus is related to coils of the terminal ileum and to the sigmoid colon. It is covered with peritoneum and forms the anterior wall of the rectouterine pouch.

4. a. Obturator
- Uterus drains into all the lymphatic destinations mentioned in the choices, hence this appears to be a wrong question, though some standard textbooks do not mention obturator lymph nodes in the lymphatic drainage.

5. b. Deep inguinal lymph nodes
- Lymphatic drainage from the cervix does not drain into the deep inguinal lymph nodes.
- Obturator lymph nodes receive a minor component of lymphatic drainage from the cervix.
- The lymphatics of cervix mainly move towards the internal iliac lymph nodes. Additionally it drain towards external iliac; rectal and the sacral lymph nodes as well.
- Parametrial lymph nodes receive the lymphatics of cervix and direct them towards their further destination.

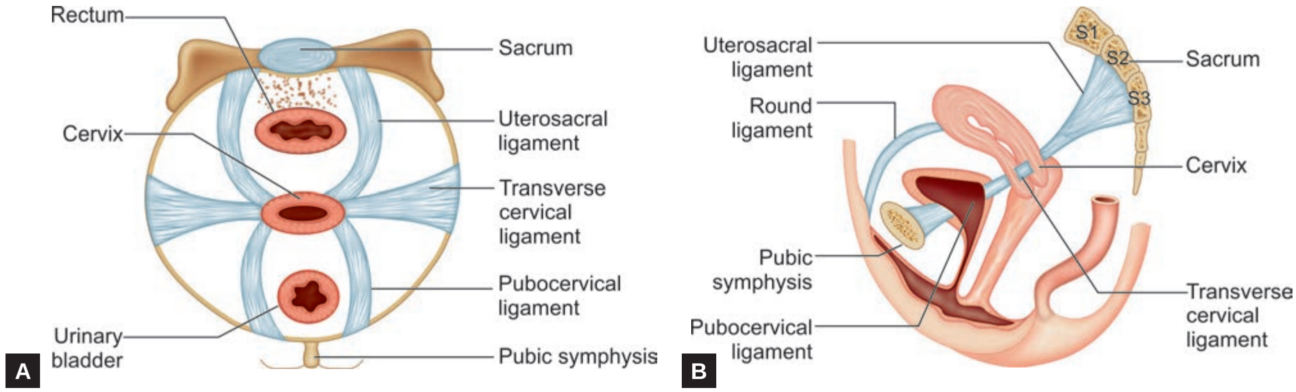
6. c. Cervix: Superficial inguinal lymph nodes
- Uterine cervix do not drain into the inguinal lymph nodes (superficial or deep).
- Fundus and upper part of the body: Pre- and para-aortic lymph nodes along the ovarian vessels (few lymphatics from the lateral angles of the uterus travel along the round ligaments of the uterus and drain into superficial inguinal lymph nodes .
- Middle part of the body : External iliac nodes via broad ligament.
- From cervix, on each side the lymph vessels drain in three directions:
  - Laterally: External iliac and obturator nodes.
  - Posterolaterally: Internal iliac nodes
  - Posteriorly: Sacral nodes

Supports of Pelvic Viscera

Pelvic viscera (like urinary bladder, uterus, rectum, etc.) are supported by numerous structures. Supports of uterus has been discussed in great detail.

Supports of uterus

- Muscular (dynamic supports) - provide excellent support
  - Pelvic diaphragm (levator ani and coccygeus)
  - Urogenital diaphragm (urethral sphincter & deep transverse perinei)
  - Perineal body (common perineal tendon for attachment of numerous perineal muscles)
- Pelvic fascia condensations (passive supports) – provide good support
  - Transverse cervical ligaments (of Mackenrodt).
  - Pubo-cervical ligaments.
  - Uterosacral (sacro-cervical) ligaments
- Peritoneal folds - provide poor support
  - Broad ligaments
  - Round ligament of uterus (remnant of the gubernaculum in the embryo)
  - Utero-vesical fold of peritoneum
  - Recto-vaginal fold of peritoneum
- Uterine position and axis (anteflexed and anteverted)



Figs 39A and B: Ligamentous (fibromuscular) supports of the uterus: A. Superior view; B. lateral view. All these ligaments (except round ligaments) are formed by the pelvic fascia condensations (visceral layer)

- **Transverse Cervical Ligaments** of Mackenrodt's are the most important ligaments of the uterus, hence often called cardinal ligaments.
  - They are the fibromuscular condensation of pelvic fascia around the uterine vessels, at the base of broad ligament.
  - They are fan-shaped fibromuscular bands extending from the lateral aspect of cervix and upper vaginal wall to the lateral pelvic wall.
  - They form a hammock which supports the uterus and prevent its downward displacement.
- **Pubocervical Ligaments** are a pair of fibrous bands which extend from the cervix to the posterior aspects of the pubic bones.
- **Uterosacral Ligaments** are a pair of fibrous bands which extend from the cervix to the second and third sacral vertebrae, and pass on each side of the rectum.
  - These ligaments pull the cervix backward against the forward pull of the round ligaments and help in the maintenance of anteflexed and anteverted positions of the uterus.
- **Round Ligaments** of the Uterus are a pair of fibromuscular bands which lie between the two layers of broad ligament.
  - It begins at the lateral angle of the uterus, passes forward and laterally between the two layers of broad ligament, enters the deep inguinal ring after winding around the lateral side of the inferior epigastric artery.
  - It traverses the inguinal canal, emerges through the superficial inguinal ring, and splits into numerous thread-like fibrous bands which merge with the fibroareolar tissue of the labium majus.
  - These ligaments pull the fundus forward and help to maintain the anteversion and anteflexion of the uterus.
- **Sacro-cervical** ligaments extend from the lower end of the sacrum to the cervix and the upper end of the vagina.
- **Rectouterine** (Sacro-uterine) Ligaments hold the cervix back and upward and sometimes elevate a shelf-like fold of peritoneum (rectouterine fold), which passes from the isthmus of the uterus to the posterior wall of the pelvis lateral to the rectum. It corresponds to the sacro-genital (recto-prostatic) fold in the male.

Clinical Correlations

- **Prolapse of uterus** may occur if the supports are weakened.
- During parturition the muscular supports undergo lot of stretching and may give up, leading to uterus being pushed inside vagina and come out into the perineum.
- Surgical support: The cardinal ligaments have enough fibrous content to provide anchor for the wide loops of sutures during several surgical procedures.

Pelvic fascia

Parietal pelvic fascia covering the obturator internus and levator ani muscles and the visceral pelvic fascia surrounding the pelvic organs are continuous where the organs penetrate the pelvic floor, forming a tendinous arch of pelvic fascia bilaterally.

- The endopelvic fascia lies between, and is continuous with, both visceral and parietal layers of pelvic fascia.
- **Hypogastric sheath** is a condensation of pelvic fascia, which lies along the postero-lateral pelvic walls and carries the neuro-vascular bundles towards the pelvic viscera. It also provides pelvic viscera support and has three lamina:
  - **Anterolateral** ligament of urinary bladder which carries superior vesical arteries and veins.
  - **Posterolateral** ligaments of rectum which carries middle rectal arteries and veins.
  - **Middle** lamina which in male forms recto-vesical septum (between urinary bladder and rectum) and in female forms cardinal ligament of uterus which carries uterine artery in its superior-most portion at the base of broad ligament of uterus.

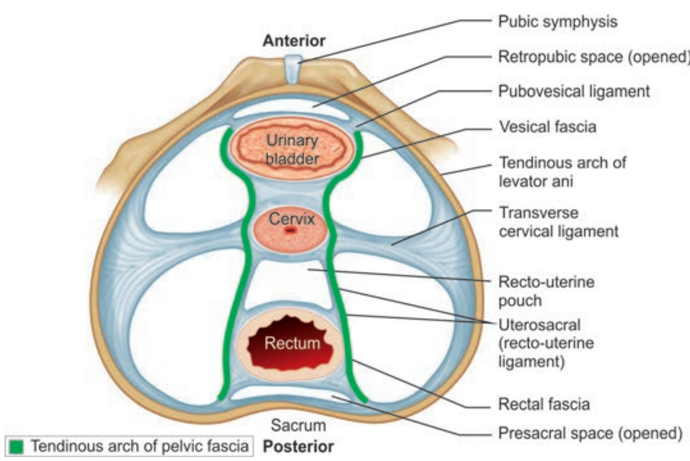


Fig. 40: Ligamentous supports of pelvic viscera

Additional ligaments:

- Pubovesical (Female) or Puboprostatic (Male) Ligaments are condensations of the pelvic fascia that extend from the neck of the bladder (or the prostate gland in the male) to the pelvic bone.

- Inferior Pubic (Arcuate Pubic) Ligament arches across the inferior aspect of the pubic symphysis and attaches to the medial borders of the inferior pubic rami.

ASSESSMENT QUESTIONS

1. **Hypogastric Sheath is a condensation of:** *(AIPG 2010,11)*
   a. Scarpa's fascia
   b. Colle's fascia
   c. Pelvic fascia
   d. Inferior layer of Urogenital diaphragm

2. **Which is NOT a part of the hypogastric sheath:**
   a. Transverse cervical ligament
   b. Broad ligament
   c. Lateral ligament of bladder
   d. Uterosacral ligament

3. **Support of prostate is:** *(NEET Pattern 2013)*
   a. Pubococcygeus
   b. Ischiococcygeus
   c. Iliococcygeus
   d. None of the above

4. **Supports of the uterus are all EXCEPT:** *(AIIMS 2006)*
   a. Uterosacral ligament
   b. Broad ligament
   c. Mackenrodt's' ligament
   d. Levator ani

5. **Which of the following doesnot prevent prolapse of uterus?**
   a. Perineal body
   b. Pubocervical ligament
   c. Broad ligament
   d. Transverse cervical ligament

ANSWERS WITH EXPLANATIONS

1. **c. Pelvic fascia**
   - Hypogastric sheath is a condensation of pelvic fascia.
   - It lies along the postero-lateral pelvic walls and carries the neuro-vascular bundles towards the pelvic viscera.
   - It also provides pelvic viscera support.

2. **b. Broad ligament.**
   - Hypogastric sheath is a condensation of the pelvic fascia which transmits vessels and nerves along the lateral pelvic wall towards the pelvic viscera.
   - Broad ligament of uterus is not a part of the hypogastric sheath. It is a peritoneal fold.
   - Parts of the hypogastric sheath:
     - Anterior lamina – Lateral ligament of bladder.
     - Middle lamina – Transverse cervical ligament, rectovesical septum in males.
     - Posterior lamina – Presacral fascia, uterosacral ligament (containing middle rectal vessels).

   Note: The endopelvic fascia lies between, and is continuous with, both visceral and parietal layers of pelvic fascia.

3. **a. Pubococcygeus**
   - Anterior fibers of pubococcygeus surround the prostate to form levator prostatae muscle, which supports the prostate.
   - Pubovaginalis in the female is the equivalent of levator prostate in the male.
   - Both originate from the posterior pelvic surface of the body of the pubis bone. Fibres pass inferiorly, medially and posteriorly to insert into a midline raphe, the central perineal tendon.

4. **b. Broad ligament**
   - Broad ligament is a double fold of peritoneum and is a weak support of uterus, its function as uterine support is comparatively insignificant.
   - The best supports of pelvic viscera are the muscular supports like Levator ani.
   - The pelvic fascia condensations like utero-sacral and Mackenrodt's ligaments are considered as good supports of uterus.

5. **c. Broad ligament**
   - Broad ligament is a peritoneal fold and poor support of uterus.
   - Perineal body is a central perineal tendon, which receives attachment of perineal muscles, which support the pelvic viscera.
   - Pubocervical and Transverse cervical ligaments are the pelvic fascia condensations, which are good supports of pelvic viscera.

Uterine Tube

Uterine tubes (oviducts) extend 8 to 14 cm from the uterine cornua and are anatomically classified along their length as an **interstitial** (1 cm) portion, **isthmus** (3 cm), **ampulla** (5 cm), and **infundibulum** (1 cm).

- Interstitial (intramural) portion is embodied within the uterine muscular wall.
- Isthmus has narrow lumen (2- 3 mm) and widens gradually into the (5- 8-mm) more laterally.
- Ampulla is the longest and has the widest lumen, and fertilization takes place here.
- Infundibulum is the funnel-shaped fimbriated distal extremity, which opens into the peritoneal cavity.

In cross section, the extrauterine fallopian tube contains a mesosalpinx, myosalpinx, and endosalpinx.

- **Mesosalpinx**, which is a region of the broad ligament, has a single-cell mesothelial layer functioning as visceral peritoneum.
- **Myosalpinx** has smooth muscle arranged in an inner circular and an outer longitudinal layer.
- **Endosalpinx** is the tubal mucosa having columnar epithelium composed of ciliated and secretory (peg) cells resting on a sparse lamina propria. The ciliated cells are most abundant at the fimbriated end.

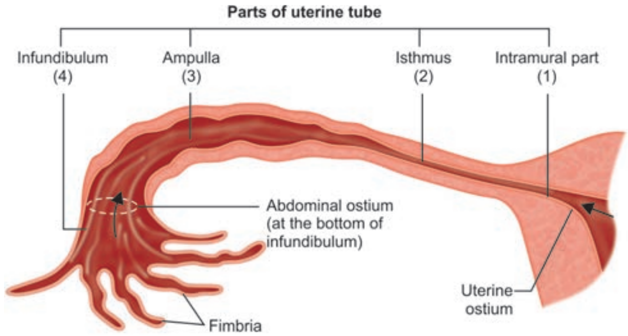


Fig. 41: Parts of the uterine tube

Arterial Supply

- **Ovarian** arteries (branches of abdominal aorta) and the ascending branches of the **uterine** arteries (branches of internal iliac artery).

Venous Drainage

- Uterine tubes drain into ovarian veins and the uterine veins.

Nerve Supply

- Preganglionic parasympathetic fibres are derived from the vagus for the lateral half of the tube, and pelvic splanchnic nerves for the medial half.
- Preganglionic sympathetic supply is derived from neurones in the intermediolateral column of the T10 - L2 spinal segments; postganglionic sympathetic fibres are most likely derived from the superior hypogastric plexus, via the superior hypogastric and hypogastric nerves.
- Visceral afferent fibres travel with the sympathetic nerves and enter the cord through corresponding dorsal roots to reach spinal segment T 10; they may also travel with parasympathetic fibres.

ASSESSMENT QUESTIONS

1. **Maximum number of mucosal folds are found in which part of fallopian tube?** *(NEET Pattern 2015)*
   a. Infundibulum
   b. Ampulla
   c. Isthmus
   d. Interstitial portion

2. **Which part of the uterine tube acts as anatomical sphincter?**
   a. Intramural part
   b. Isthmus
   c. Ampulla
   d. Infundibulum

3. **The sensory supply of the fallopian tube and ovary is from:**
   a. T6 to T8
   b. T8 to T10
   c. T10 to T12
   d. L2 to L4

ANSWERS WITH EXPLANATIONS

1. **a. Infundibulum**
   - The mucosa is thrown into longitudinal folds, which are most pronounced distally at the infundibulum and decrease to shallow bulges in the intrauterine (intramural) portion.

2. **b. Isthmus > a. Intramural part**
   - The arrangement of the muscles at the **isthmus** is such that it can work like a sphincter, preventing the oocyte from entering the uterine cavity.
   - Some authors mention the location of sphincter at the junction of uterus and uterine tube (**intramural part**).

3. **c. T10 to T12**
   - Visceral afferent fibres travel with the sympathetic nerves and enter the cord through corresponding dorsal roots (T12 ±2).

Vagina

Vagina is a fibromuscular tube that extends from the cervix to the vestibule of the vagina.

- It is the longest part of the birth canal.
- **Vaginal** fornix is the recess between the cervix and the wall of the vagina and is divided into three regions.
  - Anterior fornix is located anterior to the cervix and is related to the vesicouterine pouch. The urinary bladder is palpable through the anterior fornix during a digital examination.
  - Lateral fornices are located lateral to the cervix.
  - Posterior fornix is located posterior to the cervix and is related to the rectouterine pouch (of Douglas). The rectum, sacral promontory (S1 vertebral body), and coccyx are palpable through the posterior fornix during digital examination. It is also a site for culdocentesis.

- In the standing position, the vagina ascends posteriorly and superiorly, forming an angle of 60–70° with the horizontal plane. It forms an angle of over 90° to the uterine axis.
- The vaginal mucosa is attached to the uterine cervix higher on the posterior cervical wall than on the anterior; the anterior wall is approximately 7.5 cm long and the posterior wall is approximately 9 cm long.
- The upper quarter of the posterior vagina is separated from the rectum by the peritoneum of the recto-uterine pouch, and by moderately dense fibromuscular tissue (Denonvillier's fascia) in its middle half and in its lower quarter, it is separated from the anal canal by the fibromuscular perineal body.
- It opens into the vestibule and is partially closed by a membranous crescentic fold, the hymen.
- It is supported by the levator ani; the transverse cervical, pubocervical, and sacrocervical ligaments (upper part); the urogenital diaphragm (middle part); and the perineal body (lower part).

Epithelium

- The epithelium of vagina is non-keratinized, stratified, squamous similar to, and continuous with, that of the ectocervix.

Arterial Supply

- Superior portion of the vagina is supplied by the vaginal branches of uterine artery (branch of internal iliac artery).
- Middle and lower portions of the vagina are supplied by the internal pudendal artery, which arises from the internal iliac artery.

Venous Drainage

- Vaginal venous plexus (which is continuous with the uterine venous plexus), which empties into the internal iliac veins → IVC.

Lymphatic Drainage

- Upper three-fourths drain into the internal iliac nodes.
- Lower one-fourth (below the hymen) belong to perineal region and drains into the superficial inguinal nodes.

Nerve Supply

- Upper three-fourths of vagina is supplied by the pelvic splanchnic nerves (S2, S3 and, sometimes, S4).
- Lower one-fourth is supplied by the deep perineal branch of the pudendal nerve (S2, S3 and S4).

External Genitalia

Female external genitalia (or vulva/pudendum) consists of a vestibule of vagina and its surrounding structures such as mons pubis, labia majora, labia minora, clitoris, vestibular bulb and pair of greater vestibular glands.

Labia Majora are two folds of hairy skin with underlying fat pads.

- These longitudinal folds run downward and backward from the mons pubis and are joined anteriorly by the anterior labial commissure.
- Labia majora are embryologic homologue of scrotum (male).
- Round ligaments of the uterus terminations in the labia majora.

Labia Minora are two folds of hairless skin (with no fat) located medial to the labia majora that enclose the vestibule of the vagina.

- Labia minora are divided into upper (lateral) parts, which, above the clitoris, fuse to form the prepuce of the clitoris, and lower (medial) parts, which fuse below the clitoris to form the frenulum of the clitoris.
- Posteriorly each labium minus is continuous with the **fourchette**, which connects the labia with the vaginal introitus.

Clitoris is homologous with the penis, but with no corpus spongiosum, and does not transmit the urethra.

- The body of the clitoris is formed by two corpora cavernosa, which are continuous with the crura of the clitoris.
- Glans of the clitoris is derived from the corpora cavernosa.

Vestibule of the Vagina represents the embryologic urogenital sinus**.**

- It is the space between the labia minora, which contains the urethral orifice, paraurethral glands (of Skene), vaginal introitus (incompletely covered by the hymen), greater vestibular glands (of Bartholin), and lesser vestibular glands.

Bulbs of the Vestibule are a paired mass of erectile tissue on each side of the vaginal orifice and are the homologues of the bulb of the penis of the corpus spongiosum.

- They are covered by the bulbospongiosus muscle.
- Each bulb is joined to one another and to the undersurface of the glans clitoris by a narrow band of erectile tissue.

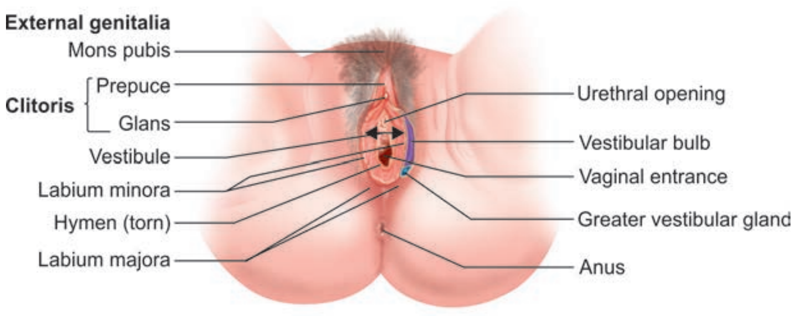


Fig. 42: An inferior view of the female perineum

Greater Vestibular (Bartholin) Glands lie in the superficial perineal pouch deep to the vestibular bulbs in the female.

- They are homologous to the bulbourethral glands in the male.
- They consist of two small oval bodies that flank the vaginal orifice, in contact with, and often overlapped by, the posterior end of the vestibular bulb.
- They are compressed during coitus and secrete mucus that lubricates the vagina.
- They are located slightly posterior and on each side of the opening of the vagina.
- Each opens into the vestibule by a 2 cm duct, situated in the groove between the hymen and the labium minora.
- The glands are composed of tubulo-acinar type with columnar cells. The epithelium of the Bartholin duct is cuboidal near the gland, but becomes transitional and finally stratified squamous near the opening of the duct.

ASSESSMENT QUESTIONS

1. All are parts of vulva EXCEPT: *(NEET Pattern 2012)*
a. Labia minora
b. Labia majora
c. Perineal body
d. Clitoris

2. All is true about Bartholin gland EXCEPT:
a. Homologous of male bulbo-urethral gland
b. Present in the superficial perineal pouch
c. Located at the junction of anterior 1/3 and middle 1/3 of labia majora
d. Opens into the vestibule between hymen and labia minora

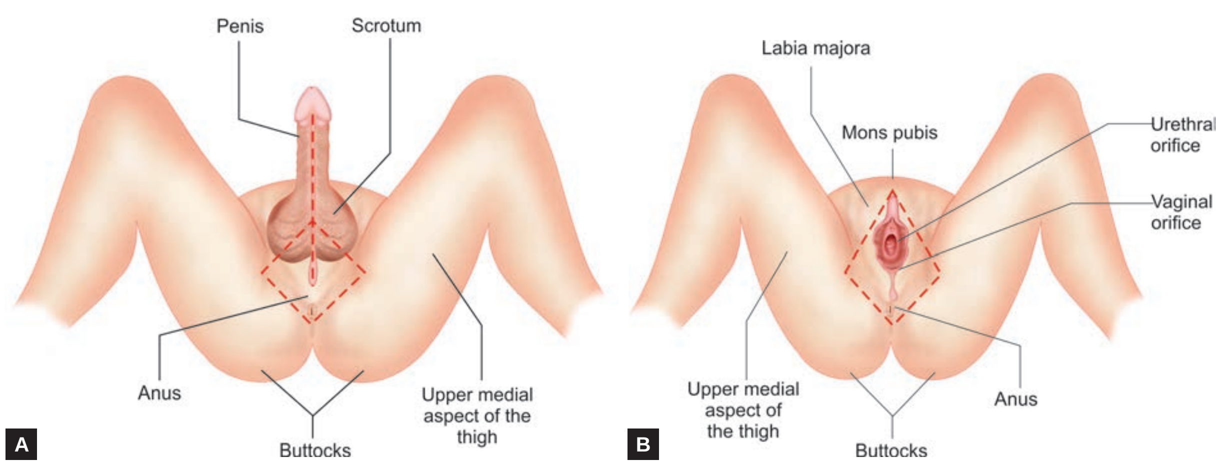
ANSWERS WITH EXPLANATIONS

1. c. Perineal body
- The female external genitalia (or vulva/pudendum) consists of a vestibule of vagina and its surrounding structures such as mons pubis, labia majora, labia minora, clitoris, vestibular bulb and pair of greater vestibular glands.

2. c. Located at the junction of anterior 1/3 and middle 1/3 of labia majora
- Bartholin gland is located at the junction of middle 1/3 and posterior 1/3 of labia majora.
- The duct opens in the postero-lateral wall of vagina (vestibule).
- The epithelium of the Bartholin duct is cuboidal near the gland, but becomes transitional and finally stratified squamous near the opening of the duct.

Perineum

- **Perineum** is the diamond-shaped region between the thighs, which corresponds to the outlet of the pelvis and presents with openings of urethra, vagina and anal canal.
- It includes **perineal pouches** (superficial and deep); **ischiorectal fossa**; pudendal canal and anal canal.
- **Boundaries**:
  - Anterior: Pubic symphysis, arch and the arcuate ligament
  - Anterolateral : Ischiopubic rami
  - Lateral: Ischial tuberosities
  - Postero-lateral: Sacrotuberous ligaments
  - Posterior: Tip of the coccyx
  - Floor: Skin and fascia
  - Roof: Pelvic diaphragm and associated fascia
- It is divided into an anterior **urogenital triangle** and a posterior **anal triangle** by a line drawn across the surface connecting the ischial tuberosities.



Figs 43A and B: Perineum as seen in lithotomy position (The red broke lines mark the boundaries of pelvic outlet): A. male perineum; B. female perineum. Interrupted red lines indicate the position of pelvic outlet.

Perineal Pouches

Urogenital triangle contains the superficial and deep perineal pouches (spaces):

Superficial Perineal Pouch

- It lies between the perineal membrane (inferior fascia of the urogenital diaphragm) and the Colles fascia (membranous layer of superficial perineal fascia).
- It is an open compartment, due to the fact that anteriorly, the space communicates freely with the potential space lying between the superficial fascia of the anterior abdominal wall and the anterior abdominal muscles.
- Contents

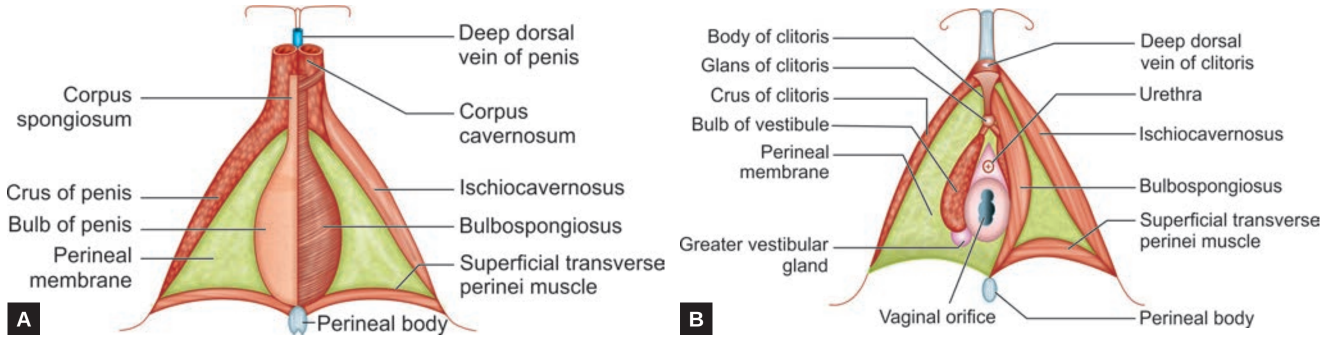
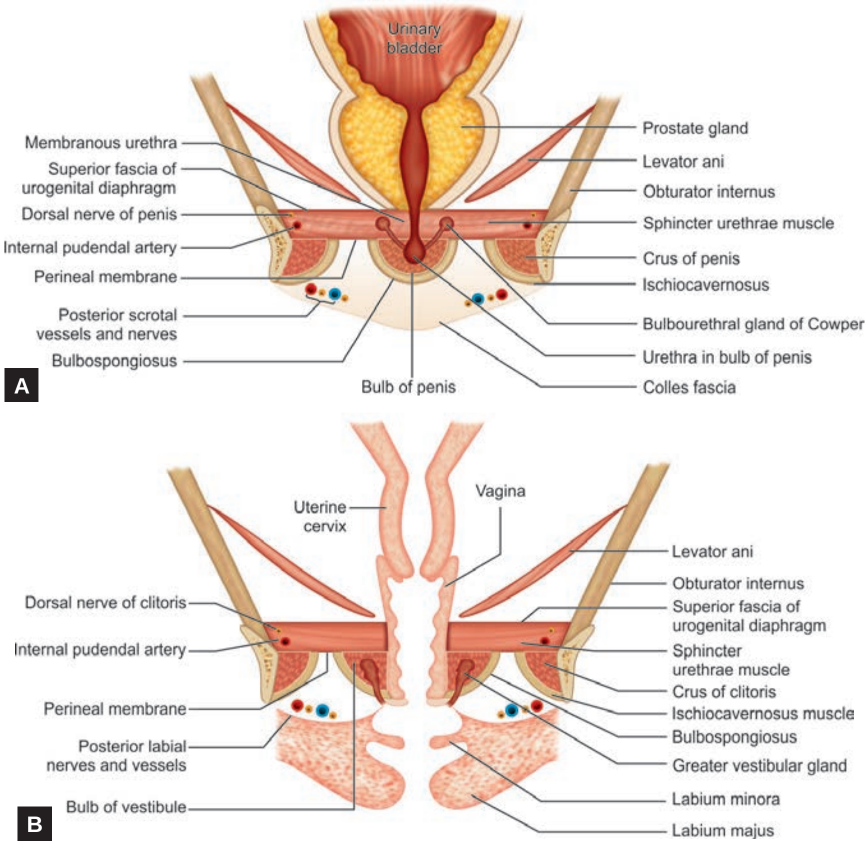


Fig. 44A: Root of the penis and superficial perineal muscles. The superficial perineal muscles are removed in the left of the diagram to show crus and bulb of the penis.

Fig. 44B: Root of clitoris and superficial perineal muscles. The superficial perneal muscles have been removed in the left half of the diagram to show bulb of the vestibule and greater vestibular gland.

- **Deep perineal pouch** is enclosed in part by the perineum, and located superior to the perineal membrane (inferior fascia of urogenital diaphragm).
- It lies between the superior and inferior fasciae of the urogenital diaphragm.
- Recently the deep pouch is being described as the region between the perineal membrane and pelvic diaphragm.
- Contents



Figs 45 A and B: Coronal section of the urogenital region showing contents of the superficial and deep perineal pouches: (A) male, (B) female

Table 15: Structure within the deep and superficial perineal spaces

Male	Female
Structures Within the Deep perineal Space	
Membranous urethra	Urethra Vagina
Urogenital (UG) diaphragm Deep transverse perineal muscle Sphincter urethrae muscle	UG diaphragm Deep Transverse perineal muscle Sphincter urethrae muscle
Branches of internal pudendal artery Artery of the Penis	Branches of internal pudendal artery Artery of the clitoris
Branches of pudendal nerve Dorsal nerve of the penis	Branches of pudendal nerve Dorsal nerve of the clitoris
Bulbourethral glands (of Cowper)	No glands
Structures Within the Superficial Perineal Space	
Penile (spongly) urethra	Urethra Vestibule of the vagina
Bulbospongiosus muscle Ischiocavernosus muscle Superficial transverse perineal muscle	Bulbospongiosus muscle Ischiocavernosus muscle Superficial transverse perineal muscle
Branches of internal pudendal artery Perineal artery → posterior scrotal arteries Dorsal artery of the penis Deep artery of the penis	Branches of internal pudendal artery Perineal artery → posterior labial arteries Dorsal artery of the clitoris Deep artery of the clitoris
Branches of pudendal nerve Perineal nerve → posterior scrotal nerves Dorsal nerve of the penis	Branches of pudendal nerve Perineal nerve → posterior labial nerves Dorsal nerve of the clitoris
Bulb of the penis Crura of the penis	Vestibular bulb Crura of the clitoris
Perineal body	Perineal body Round ligament of the uterus
Duct of the bulbourethral gland	Greater vestibular glands (of Bartholin)

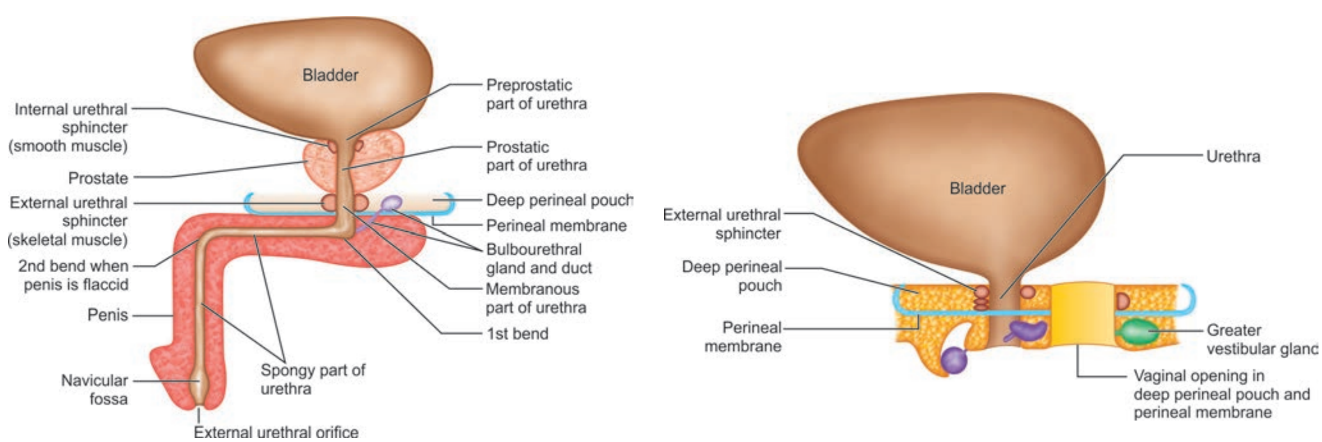


Fig. 46: Perineal pouches (superficial and deep) in male and female

- **Urogenital diaphragm** (triangular ligament) is term is used **occasionally** to describe the muscular components of the deep perineal pouch
  - It is described as a layer of the pelvis that separates the deep perineal pouch from the upper pelvis, lying between the perineal membrane (inferior fascia of the urogenital diaphragm) and superior fascia of the urogenital diaphragm.
  - It contains muscles like external urethral sphincter and deep transverse perinei, attaching to the perineal body.
  - The urethra and the vagina pass through the urogenital diaphragm.
  - The term urogenital diaphragm should not be confused with the pelvic diaphragm (pelvic floor), which is a true diaphragm supporting the pelvic viscera.

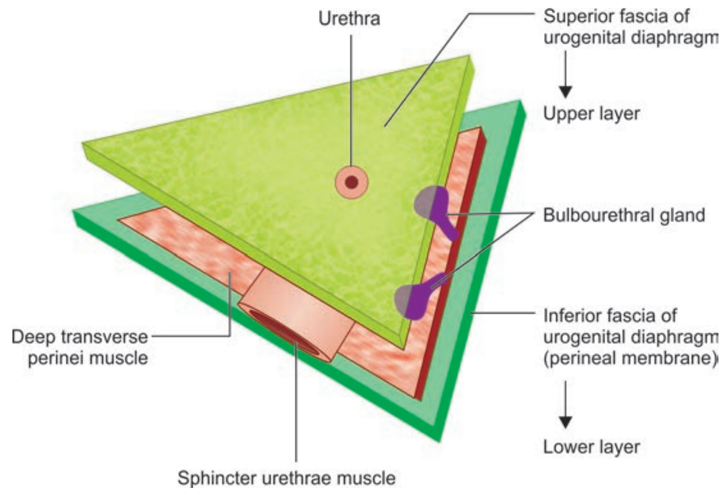


Fig. 47: Urogenital diaphragm (in male)

- **Bulbourethral** (Cowper) Glands lie among the fibers of the sphincter urethrae in the deep perineal pouch in the male, on the posterolateral sides of the membranous urethra.
  - The ducts pass through the perineal membrane to reach superficial perineal pouch and open into the bulbous portion of the spongy (penile) urethra.

Clinical Correlations

- Episiotomy is a surgical incision of the perineum (and the posterior vaginal wall) to enlarge the vaginal opening during childbirth.
- It is done during second stage of labour to quickly enlarge the opening for the baby to pass through.
- There are two types of episiotomies.
  - Median Episiotomy starts at the frenulum of the labia minora and proceeds directly downward cutting through the skin → vaginal wall → perineal body → superficial transverse perineal muscle.
  - Mediolateral Episiotomy starts at the frenulum of the labia minora and proceeds at a 45-degree angle cutting through the skin → vaginal wall → bulbospongiosus muscle.

Perineal Fascia

- Perineal fascia has two parts (superficial and deep) and each of these can be subdivided into superficial and deep parts.
  - Superficial perineal fascia
    - Fatty layer
    - Deeper membranous layer (Colles' fascia)
  - Deep perineal fascia
    - Perineal membrane (inferior fascia of urogenital diaphragm)
    - Superior fascia of urogenital diaphragm (Considered hypothetical)
- During dissection in the perineum, the arrangement of layers (from superficial to deep) is:

Skin → superficial perineal fascia (fatty layer) → superficial perineal fascia (deeper membranous layer - Colles' fascia) → Superficial perineal pouch → Perineal membrane (inferior fascia of urogenital diaphragm) → Deep perineal pouch → superior fascia of urogenital diaphragm (hypothetical) → fascia and muscles of pelvic floor (levator ani, coccygeus) → pelvic viscera.

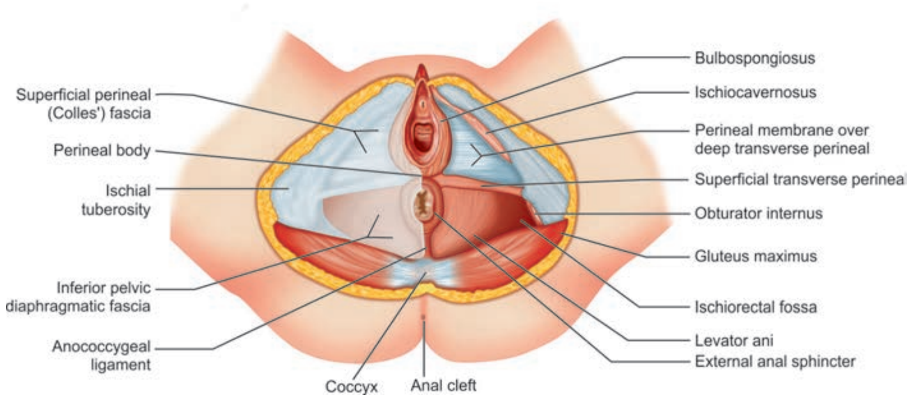


Fig. 48: Dissection in the female pelvis, showing relations of superficial and deep perineal pouches. Note the location of perineal body and ischiorectal fossa

- **Colles' fascia** is the deep membranous layer (of the superficial perineal fascia) and forms the floor (inferior boundary) of the superficial perineal pouch.
  - On either side it is firmly attached to the margins of the rami of the pubis and ischium, lateral to the crus penis and as far back as the tuberosity of the ischium.
  - Posteriorly, it curves around the superficial transverse perineal muscle to join the lower margin of the perineal membrane.
  - It emerges from the inferior side of the perineal membrane and continues along the ventral (inferior) penis without covering the scrotum.
  - It separates the skin and subcutaneous fat from the superficial perineal pouch and covers the muscles in the pouch.
  - It becomes continuous with the dartos tunic of the scrotum, with the superficial fascia of the penis, and with the Scarpa fascia of the anterior abdominal wall.
  - Straddle injuries may rupture of the bulbous spongy urethra below the perineal membrane, leading to extravasation of urine into the superficial perineal pouch, which may spread inferiorly into the scrotum, anteriorly around the penis, and superiorly into the lower part of the abdominal wall.

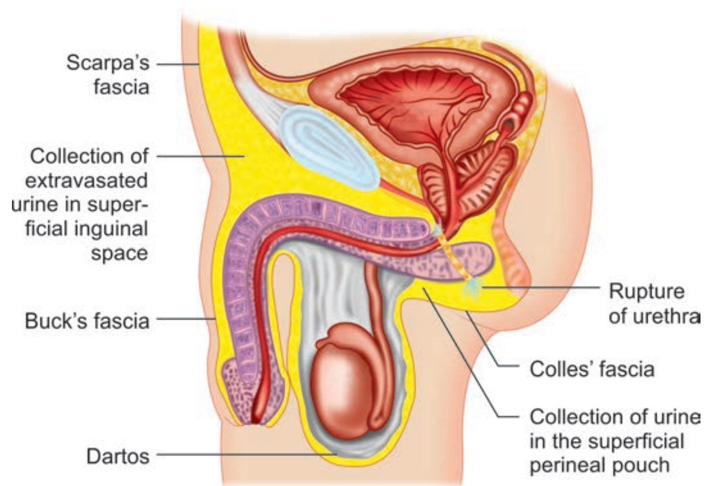
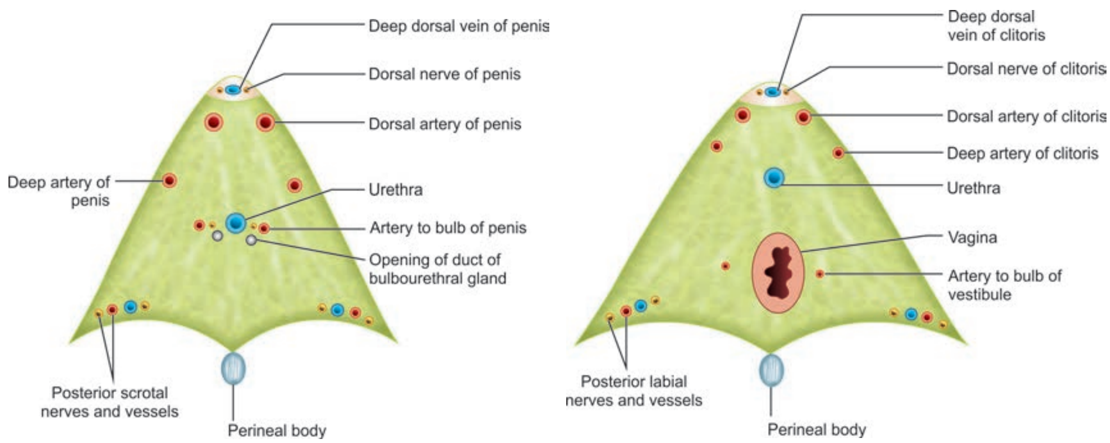


Fig. 49: Rupture of urethra in perineum and collection of extravasated urine in superficial perineal pouch and superficial inguinal space

- **Perineal membrane** is the inferior fascia of urogenital diaphragm.
- Location:
  - It is the roof (superior boundary) of the superficial perineal pouch, and the floor (inferior boundary) of the deep perineal pouch.
  - It is thickened anteriorly to form the **transverse ligament of the perineum**, which spans the subpubic angle just behind the deep dorsal vein of the penis (or clitoris).
- Shape:
  - It is triangular in shape, and about 4 cm. in depth.
  - Apex is directed forward, and is separated from the arcuate pubic ligament by an oval opening for the transmission of the deep dorsal vein of the penis (or clitoris).
  - Lateral margins are attached on either side to the inferior rami of the pubis and ischium, above the crus penis.
  - Base is directed toward the rectum, and connected to the perineal body, posteriorly. The base is fused with both the pelvic fascia and Colle's fascia.
- Relations:
  - It is continuous with the deep layer of the superficial fascia behind the superficial transverse perineal muscle, and with the inferior layer of the diaphragmatic part of the pelvic fascia.
- Perforations:
  - It lies between the urogenital diaphragm and the external genitalia and is perforated by the urethra (and vagina).
  - Arteries to the bulb, and the ducts of the bulbourethral glands pierce pass through it.
  - It is also pierced by the deep arteries of the penis (or clitoris), one on either side close to the pubic arch and by the dorsal arteries and nerves of the penis (or clitoris) near the apex of the fascia.
  - Its base is perforated by the perineal vessels and nerves, while between its apex and the arcuate pubic ligament the deep dorsal vein of the penis (or clitoris) passes upward into the pelvis.



Figs 50A and B: Structures piercing the perineal membrane: A. In male: B. in female

ASSESSMENT QUESTIONS

1. Superficial perineal space contains all EXCEPT: *(NEET Pattern 2012)*
   a. Root of penis
   b. Urethral artery
   c. Great vestibular glands (Bartholin glands)
   d. Membranous urethra

2. Superficial muscles of perineum: *(NEET pattern 2014)*
   a. Ischiocavernosus
   b. Bulbocavernosus
   c. Levator ani
   d. Ischio-coccygeus

3. Urogenital diaphragm is contributed by all EXCEPT: *(NEET Pattern 2012)*
   a. Sphincter urethra
   b. Perineal body
   c. Colles' fascia
   d. Perineal membrane

4. All are the contents of deep perineal pouch EXCEPT: *(AIIMS 2008; AIPG 2009)*
   a. Bulb/Root of penis
   b. Dorsal nerve of penis
   c. Sphincter urethra
   d. Bulbo urethral glands

5. NOT a part of superficial perineal pouch: *(AIIMS 2011)*
   a. Posterior scrotal nerves
   b. Sphincter urethrae
   c. Ducts of bulbourethral glands
   d. Bulbospongiosus muscle

6. Nerve supply to the perineum is: *(NEET Pattern 2012)*
   a. Pudendal nerve
   b. Inferior rectal nerve
   c. Pelvic splanchnic nerves
   d. Hypogastric plexus

7. All of the following are attached to perineal body EXCEPT: *(NBE 2013)*
   a. Superficial transverse perinei
   b. Iliococcygeus
   c. Bulbospongiosus
   d. Ischio-cavernosus

8. The deep perineal space:
   a. Is formed superiorly by the perineal membrane
   b. Contains a segment of the dorsal nerve of the penis
   c. Is formed inferiorly by Colles' fascia
   d. Contains the greater vestibular glands

ANSWERS WITH EXPLANATIONS

1. d. Membranous urethra
- Membranous urethra is a content of deep perineal pouch, which continues as spongy urethra in superficial perineal pouch.

2. a. Ischiocavernosus
- Muscles in the superficial perineal pouch are ischiocavernosus, bulbospongiosus and superficial transverse perinei.

3. c. Colles' fascia
- Urogenital diaphragm contains the deep perineal pouch and is lined inferiorly by the perineal membrane and not Colles' fascia.
- Colles' fascia lies at the floor (inferior lining) of superficial perineal pouch.
- Urogenital diaphragm is a triangular musculo-fascial diaphragm in the anterior part of perineum. It is contributed by mainly two muscles: sphincter urethrae and deep transverse perinei. These muscles are enclosed within a superior and inferior fascia. The inferior fascia is also called as perineal membrane.
- Perineal body is a fibromuscular body attached at the posterior border of perineal membrane in the midline. Both the fascia of urogenital diaphragm are attached to the perineal body. Perineal body is a good support of pelvic viscera and is attached by numerous muscles of the perineum including the muscles of urogenital diaphragm – deep transverse perinei and sphincter urethrae.

4. a. Bulb/Root of penis
- Bulb/Root of penis lies in the superficial perineal pouch and not the deep perineal pouch.
- Bulb of vagina/ root of clitoris also lie in the superficial perineal pouch.
- Contents of deep perineal space in males: Membranous part of urethra, Muscles of urogenital diaphragm (Sphincter urethra and Deep transverse perinei), Bulbo-urethral glands of Cowper, Internal pudendal vessels and branches, Dorsal nerve of penis and muscular branches of perineal nerve.
- Contents of deep perineal space in females: Part of urethra (same as in males), Part of vagina, Muscles of urogenital diaphragm (same as males), Internal pudendal vessels and branches (same), Dorsal nerve of clitoris and muscular branches of perineal nerve.

5. b. Sphincter urethrae
- Sphincter urethrae (external urethral sphincter) is present in the wall of membranous urethra, in the deep perineal pouch, it also extends vertically, around the anterior aspect of the prostatic urethra.
- Posterior scrotal nerves are the branches of pudendal nerve, and do pass the superficial perineal pouch.
- Cowper's bulbourethral gland is present in the deep perineal pouch, but it's duct pierces the perineal membrane and opens into the bulbous urethra in the superficial perineal pouch.
- Bulbospongiosus muscle is a content of superficial perineal pouch, functions as a vaginal sphincter in a female; and for a male it help to empty the urethra of the urine/semen.
- The superficial perineal pouch is a fully enclosed compartment, Its inferior border (floor) is the perineal fascia (Colles' fascia and superior border (roof) is the perineal membrane.
- The contents are muscles : ischiocavernosus, bulbospongiosus muscle, superficial transverse perineal muscle. Other contents are: Crura of penis (males) / Crura of clitoris (females), bulb of penis (males) / Vestibular bulbs (females), Greater vestibular glands (female).

6. a. Pudendal nerve
- Pudendal nerve is the nerve of perineum. It is a mixed (sensory and motor) nerve to supply skin and skeletal muscles of perineum.

7. d. Ischio-cavernosus
- **Ischio-cavernosus** is not a midline muscle and is not attached to the central perineal tendon (perineal body).
- Superficial and deep transverse perineal muscles, both attach to the perineal body.
- Iliococcygeus (pelvic diaphragm) has attachment to the perineal body
- Bulbospongiosus is a muscle in the superficial perineal pouch which covers bulb of penis (or vagina) and attaches to perineal body.

8. b. Contains a segment of the dorsal nerve of penis.
- Dorsal nerve of penis is a content of both superficial and deep perineal pouch. Other choices are applicable to superficial perineal pouch.

Anal Triangle and Ischiorectal Fossa

- **Anal Triangle** has two components: Muscles and Ischiorectal fossa
- Muscles of the Anal Triangle: External anal sphincter, Obturator internus, levator ani and coccygeus muscles.
- Ischiorectal Fossa (IRF) is present on either side of the anorectum and is separated from the pelvic cavity by the levator ani muscle (and fascia).
  - **Boundaries**:
    - Anterior: Urogenital diaphragm (with perineal membrane)
    - Posterior: Gluteus maximus (and sacrotuberous ligament)
    - Superomedial: Sphincter ani externus and levator ani
    - Lateral: Obturator internus muscle (with obturator fascia) on ischial tuberosity
    - Floor: Skin
    - Roof: Meeting point of obturator fascia (covering obturator internus) and inferior fascia of the pelvic diaphragm (covering levator ani muscle).
  - **Contents**: Inferior rectal neurovascular bundle (nerve, artery and vein); fat; perineal branches of the posterior femoral cutaneous nerve, and the pudendal canal (with pudendal nerve, internal pudendal artery and vein).

Note: Pudendal canal is formed either by the splitting of the obturator fascia (or by separation between the fascia lunata and the obturator fascia).

- A communication (horse shoe shaped) is present between the two IRF passing behind the anal canal.

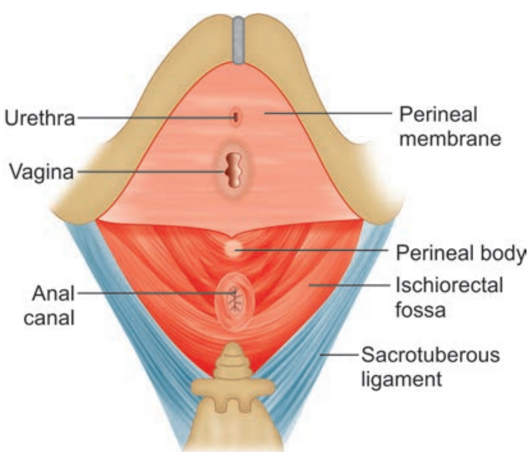


Fig. 51: Surface view of the ischiorectal fossa and perineal membrane

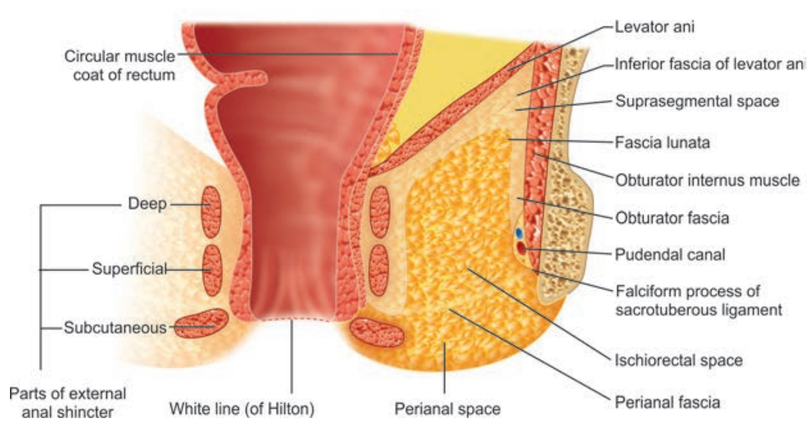


Fig. 52: Boundaries of the ishiorectal fossa as seen in coronal section through the anal triangle

ASSESSMENT QUESTIONS

1. **Boundaries of ischiorectal fossa are:** *(NEET Pattern 2014)*
   a. Posterior : Perineal membrane
   b. Anterior : Sacrotuberous ligament
   c. Lateral : Obturator internus
   d. Medial : Gluteus maximus

2. **During incision and drainage of ischiorectal abscess, which nerve is/are injured?** *(PGIC 2012)*
   a. Superior rectal nerve
   b. Inferior rectal nerve
   c. Superior gluteal nerve
   d. Inferior gluteal nerve
   e. Posterior labial nerve

3. **Pudendal canal is a part of:** *(NEET Pattern 2014)*
   a. Colles fascia
   b. Obturator fascia
   c. Scarpa's fascia
   d. None

4. **All of the following pairs about the boundaries of ischiorectal fossa are correct EXCEPT:**
   a. Anterior: Perineal membrane
   b. Posterior: Gluteus maximus
   c. Medial: Levator ani
   d. Lateral: Obturator externus

5. **UNTRUE about ischiorectal fossa:**
   a. Obturator fascia meets anal fascia at the apex
   b. A communication is present between the two IRF in front of anal canal
   c. Alcock's canal is located at the lateral wall
   d. Inferior rectal nerve and vessels pass through it

ANSWERS WITH EXPLANATIONS

1. **c. Lateral : Obturator internus**
   - Lateral boundaries of ischiorectal fossa is the ischial bone with obturator internus muscle covered by obturator fascia.
   - Perineal membrane lies anterior and sacrotuberous ligament and gluteus maximus are posterior.
2. **b. Inferior rectal nerve; e. Posterior labial nerve**
   - Dissection of ischiorectal fossa, may involve injury to inferior rectal, pudendal, posterior scrotal (or labial) nerve and vessels along with perforating branches of S2-S3 and perineal branches of S4 nerve.
3. **b. Obturator fascia**
   - Pudendal canal is formed in the obturator fascia in the lateral wall of the ischiorectal fossa.
4. **d. Lateral: Obturator externus**
   - Obturator internus is present at the lateral wall of ischiorectal fossa. It is covered by obturator fascia, which has pudendal canal in it.
5. **b. A communication is present between the two IRF in front of anal canal**
   - A communication is present between the two IRF in **behind** the anal canal.
   - Apex (roof): Meeting point of obturator fascia (covering obturator internus) and inferior fascia of the pelvic diaphragm (covering levator ani muscle)
   - **Alcock's pudendal canal** is present in the lateral wall of ischiorectal fossa and send **inferior rectal nerve** and vessels medially *through the fossa* towards the anal canal.

Urinary Bladder and Urethra

Urinary Bladder

- Urinary Bladder is the hollow viscus with prominent smooth muscle (detrusor) walls which is a temporary reservoir for urine with a capacity of 120 to 320 mL.
- It is situated below the peritoneum and extends upward above the pelvic brim as it fills; may reach as high as the umbilicus if fully distended.
- The empty bladder is tetrahedral-shaped and consists of a posterior surface, anterior surface, superior surface, apex, and neck. Relations:
  - **Posterior surface** (Fundus or Base)
    - Upper part is separated from rectum by the rectovesical pouch containing coils of the small intestine.
    - Lower part is separated from rectum by the terminal parts of vas deferens and seminal vesicles.
    - The triangular area between the vas deferens is separated from the rectum by rectovesical fascia (of Denonvillier's).
    - In females the base of bladder is separated from the cervix of uterus and by the vesicouterine pouch.
  - **Anterior surface** is related to the pubic symphysis and retropubic space of Retzius.
  - **Superior surface** is related to the peritoneal cavity (covered by peritoneum), sigmoid colon, and terminal coils of the ileum. In the female, the peritoneum is reflected posteriorly to the uterus forming the vesicouterine pouch.
  - **Apex** is located posterior to the upper part of the pubic symphysis and is related to the one median umbilical ligament or urachus (a remnant of the allantois in the fetus).
  - **Neck** is the lowest region of the bladder and is located posterior to the lower part of the pubic symphysis. It is pierced by the internal urethral orifice. In the male, the neck is related to the prostate gland and prostatic urethra and in the female, the neck is related to the urogenital diaphragm.

- **Trigone** of the bladder is located on the posterior surface of the bladder (fundus or base).
  - Its limits are defined superiorly by the openings of the ureters and inferiorly by the internal urethral orifice, around which is a thick circular layer called the internal urethral sphincter (sphincter vesicae).
  - It is always **smooth-surfaced** because the mucosa is tightly adherent to the detrusor muscle.
  - **Uvula vesicae**, which is a small eminence at the apex of its trigone, projecting into the orifice of the urethra.

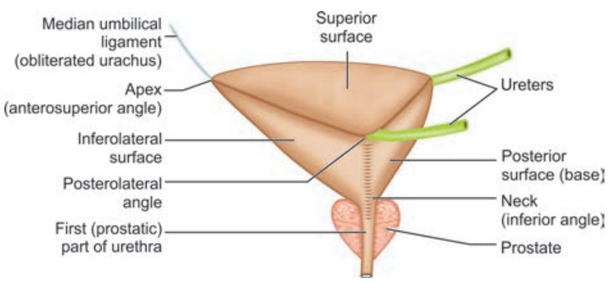


Fig. 53: External features of empty bladder (left lateral view)

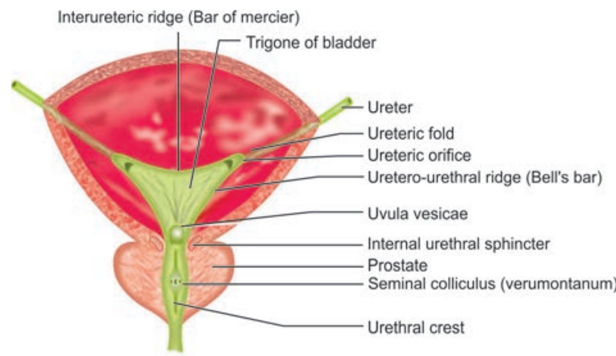


Fig. 54: Interior of the urinary bladder as seen in the coronal section

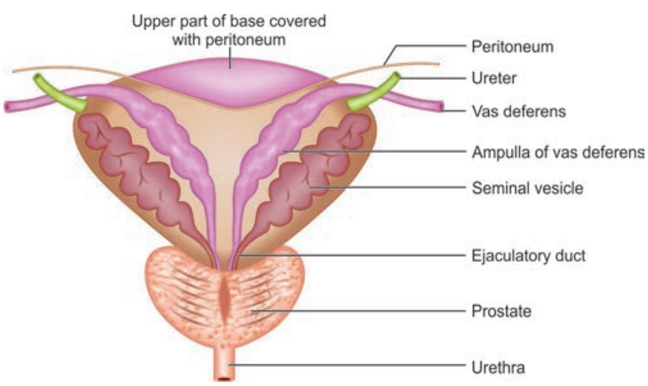


Fig. 55: Relation of the base of urinary bladder in the male

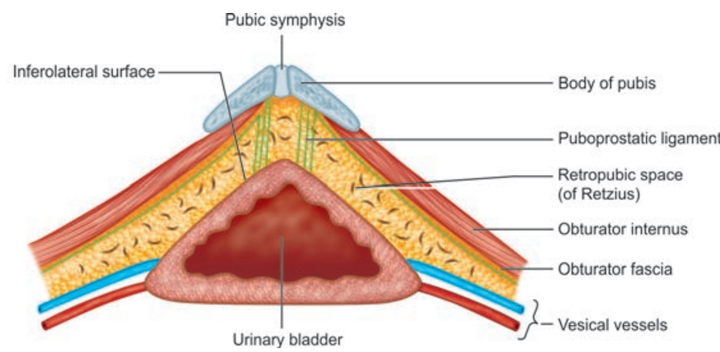


Fig. 56: Relations of the inferolateral surfaces of the urinary bladder

Arterial Supply

- Superior and inferior vesical arteries (branches of internal iliac artery), obturator artery, and inferior gluteal artery.
- In females branches of the uterine artery and vaginal artery additionally supply the bladder.
- **Venous drainage**
- Urinary bladder drains into the prostatic (or vesical) plexus of veins, which empties into the internal iliac vein.

Nerve Supply:

Urinary bladder is innervated by the **vesical plexus** which receives input from the **inferior hypogastric plexus**.

- The vesical plexus contains both parasympathetic and sympathetic components.
  - Parasympathetic (for urine evacuation)
    - Preganglionic neuronal cell bodies are located in the intermediolateral cell column of the S2 to S4 spinal cord segments and the axons travel to the vesical plexus as the pelvic splanchnic nerves.
    - Postganglionic neuronal cell bodies are located in the vesical plexus and the bladder wall and axons are distributed to the detrusor muscle of the bladder where they cause contraction of the detrusor muscle and relaxation of the internal urethral sphincter.
  - Sympathetic (for storage of urine)
    - Preganglionic neuronal cell bodies are located in the intermediolateral cell column of T10-L2 spinal cord segments.
    - Preganglionic axons pass through the paravertebral ganglia (do not synapse) to become the lesser thoracic splanchnic nerve, least thoracic splanchnic nerve, first lumbar splanchnic nerve, and second lumbar splanchnic nerve and travel to the inferior hypogastric plexus by way of the superior hypogastric plexus.
    - Postganglionic neuronal cell bodies are located in the inferior hypogastric plexus and the axons enter the vesical plexus and are distributed to the detrusor muscle of the bladder.
    - They lead to relaxation of the detrusor muscle and contraction of the internal urethral sphincter (although some investigators claim their action is strictly on the smooth muscle of blood vessels).

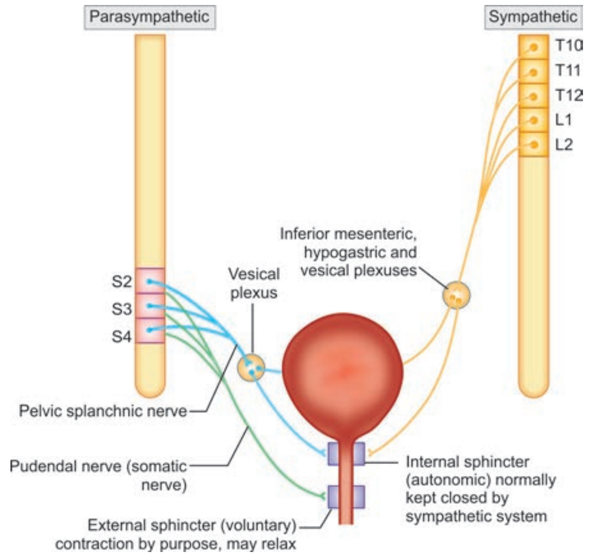


Fig. 57: Autonomic innervation of the urinary bladder (inferior hypogastric plexus)

- Sensory Innervation: Sensory information from the bladder is carried by both parasympathetic (mainly) and sympathetic fibres.
  - Parasympathetic afferent (sensory) neurons whose cell bodies are located in the dorsal root ganglion run with the pelvic splanchnic nerves and relay pain and stretch information from the bladder to S2 to S4 spinal segments within the CNS.
    - The pain associated with bladder pathology may be referred over the S2 to S4 dermatomes (i.e., perineum and posterior thigh).
    - The stretch information associated with bladder fullness from stretch receptors in the bladder wall runs with the pelvic splanchnic nerves and serves as the afferent limb in the micturition reflex.
  - Sympathetic afferent (sensory) neurons whose cell bodies are located in the dorsal root ganglion run with the lesser thoracic splanchnic nerve, least thoracic splanchnic nerve, first lumbar splanchnic nerve, and second lumbar splanchnic nerve, and relay pain information from the bladder to the T10-L2 spinal cord segments with the CNS.
    - The pain associated with bladder pathology may be referred over the T10-L2 dermatomes (i.e., lumbar region, inguinal region, and anterosuperior thigh).

Micturition (Urination) is the release of urine from the urinary bladder through the urethra to the exterior.

- It is initiated by stimulating **stretch receptors** in the detrusor muscle in the bladder wall due to increasing volume (approximately 300 mL for adults) of urine.
- It is assisted by contraction of the abdominal muscles, which increases the intra-abdominal and pelvic pressures.
- It involves the following processes:
  - The **sympathetic** nervous system (general visceral efferent) works for **storage** of urine in urinary bladder.
  - It relaxes the detrusor muscle and constrict the internal sphincter, inhibiting emptying.
  - General visceral afferent impulses arise from stretch receptors in the bladder wall and enter the spinal cord (S2–S4) via the nervi erigentes.
  - **Parasympathetic** preganglionic (GVE) fibers help in urine **evacuation** by contraction of the detrusor muscle and relaxation of the internal urethral sphincter. It is brought about by nervi erigentes which synapse in the pelvic (inferior hypogastric) plexus.
  - General somatic efferent fibers in the pudendal nerve can contract the external urethral sphincter (skeletal muscle) to hold the urine at our own will.
  - At the end of micturition, the external urethral sphincter contracts, and bulbospongiosus muscles in the male expel the last few drops of urine from the urethra.

Rectovesical Pouch

- Is a peritoneal recess between the bladder and the rectum in males, and the vesicouterine pouch is a peritoneal sac between the bladder and the uterus in females.

ASSESSMENT QUESTIONS

1. **All are true about the trigone of the urinary bladder EXCEPT:** *(AIIMS 2006)*
   a. Mucosa is loosely associated to the underlying musculature
   b. Mucosa is smooth
   c. It is lined by transitional epithelium
   d. It is derived from the absorbed part of the mesonephric duct

2. **Urethral crest is due to:** *(AIIMS 2013)*
   a. Opening of prostatic glands
   b. Puboprostatic spread
   c. Insertion of detrusor
   d. Insertion of trigone

3. **Where is the cave of Retzius present?** *(NEET Pattern 2012)*
   a. Between urinary bladder and rectum
   b. Between urinary bladder and cervix
   c. In front of the bladder
   d. Between the cervix and the rectum

4. **All are related to posterior surface of urinary bladder EXCEPT:** *(JIPMER 2001)*
   a. Ureter
   b. Rectum through rectovesical pouch
   c. Seminal vesicles
   d. Vas deferens

5. **FALSE regarding trigone of bladder:** *(NEET Pattern 2015)*
   a. Lined by transitional epithelium
   b. Mucosa smooth and firmly adherent
   c. Internal urethral orifice lies at lateral angle of base
   d. Developed from mesonephric duct

6. **In bladder injury pain is referred to all EXCEPT:** *(NEET Pattern 2012)*
   a. Upper part of thigh
   b. Lower abdominal wall
   c. Flank
   d. Penis

7. **If a missile enters the body just above the pubic ramus through the anterior abdominal wall it will most likely pierce which of the following structures?** *(AIIMS 2000)*
   a. Abdominal aorta
   b. Left renal vein
   c. Urinary bladder
   d. Spinal cord

ANSWERS WITH EXPLANATIONS

1. **a. Mucosa is loosely associated to the underlying musculature**
   - Mucosa is tightly adherent to the underlying musculature in the trigone of urinary bladder.
   - The mucosa appears smooth at the trigone because of this tight adherence, since folding is not possible in the mucosa.
   - In other places the mucosa is highly folded or stretched according to the state of distension.
   - Trigone of bladder is derived by the absorption of the mesonephric duct in to the bladder wall.
   - Transitional epithelium lines the urinary bladder throughout its extent, including the trigone.

2. **d. Insertion of trigone**
   - The superficial trigone muscle becomes continuous with the smooth muscle of the proximal urethra, and extends in the male along the **urethral crest** as far as the openings of the ejaculatory ducts.

3. **c. In front of the bladder**
   - Cave of Retzius (retropubic space) is the extraperitoneal space between the pubic symphysis and urinary bladder.
   - It is basically a preperitoneal space, behind the transversalis fascia and in front of peritoneum.

4. **a. Ureter**
   - Ureters join the superolateral angles of urinary bladder (not related to the posterior surface).
   - Relations of posterior surface of urinary bladder:
     - Upper part is separated from rectum by the rectovesical pouch containing coils of the small intestine.
     - Lower part is separated from rectum by the terminal parts of vas deferens and seminal vesicles.
     - The triangular area between the vas deferens is separated from the rectum by rectovesical fascia (of Denonvillier's).

5. **c. Internal urethral orifice lies at lateral angle of base**
   - Internal urethral orifice lies at the apex (no the lateral angle of base) of urinary bladder.
   - It's the ureters that open at lateral angles.

6. **c. Flank**
   - This is a wrong question with no appropriate answer. The best possible option is flank region, as little is known about the functional significance of thoracolumbar afferents.
   - Pain fibres of urinary bladder are carried by both sympathetic and parasympathetic fibres.
   - Parasympathetic fibres (nervi erigentes) are derived from S2, S3, S4 segments of the spinal cord and the referred pain is felt in the corresponding dermatomes in perineum and posterior thigh.
   - Sympathetic fibres are derived from T11, 12 and L1, 2 segments of the spinal cord and the pain is referred to the lumbar region, inguinal region, and anterosuperior thigh.

7. **c. Urinary bladder**
   - A distended urinary bladder may be ruptured by injuries of lower abdominal wall, as mentioned in the question.
   - Spinal cord terminates at L1 vertebral level; left renal vein is given at L1-2 level and abdominal aorta bifurcates at L4. None of the mentioned structures reach the level of pubic ramus.

Urethra

Male urethra serves as a passage for urine (and semen) to the exterior and has a length of about 20 cm.

- It begins at the internal urethral orifice of the bladder where the detrusor muscle extends longitudinally into the prostatic urethra and forms a complete collar around the neck of the bladder called the **internal urethral sphincter**.
- Male urethra consists of three parts: prostatic, membranous, and spongy
  - **Prostatic** urethra courses through and is surrounded by the prostate gland.
  - **Membranous** urethra courses through the urogenital diaphragm (deep perineal pouch) where it becomes related to the deep transverse perineal muscle and sphincter urethrae muscle (external urethral sphincter), both of which are skeletal muscles innervated by the pudendal nerve.
  - **Spongy** urethra has two parts; Bulbous and penile

- ➢ Bulbous spongy urethra courses through the bulb of the penis and develops endodermal outgrowths into the surrounding mesoderm to form the bulbourethral glands of Cowper.

  Note: The glands are present in males in relation with membranous urethra (in the deep perineal pouch), whereas the duct opens into the bulbous spongy urethra (in superficial perineal pouch).
- ➢ Penile spongy (cavernous) urethra courses through and is surrounded by the corpus spongiosum. Distal part of the penile urethra courses through the glans penis and terminates as the navicular fossa at the external urethral orifice.

- Prostatic urethra and the membranous urethra together are considered as the **posterior urethra** and bulbous urethra plus the penile urethra are called the **anterior urethra**.
- The narrowest lumen is present at the external urethral meatus and the second narrowest is in the membranous urethra.
- The widest lumen is present in the bulbous part of penile urethra, second widest is the prostatic urethra.

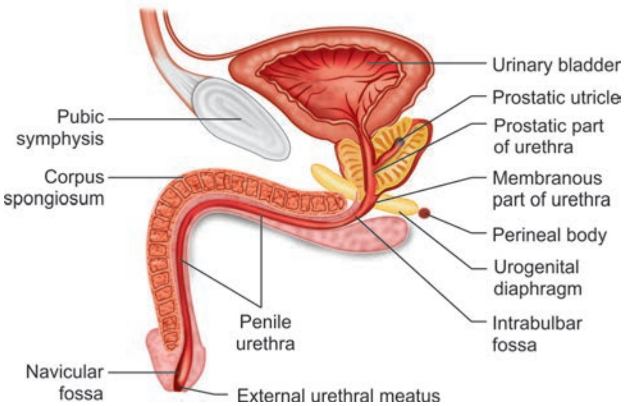


Fig. 58: Parts of male urethra

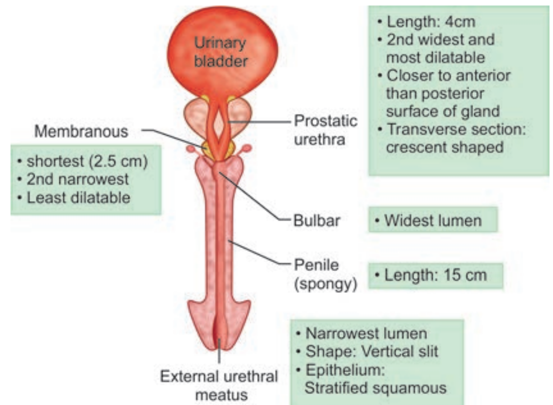


Fig. 59: Parts and features of male urethra

Table 16: Parts of Male urethra

Part	Length*	Location/Disposition	Features
Intramural (preprostatic) part	0.5–1.5 cm	Extends almost vertically through neck of bladder	Surrounded by internal urethral sphincter: diameter and length vary, depending on whether bladder is filling or emptying
Prostatic urethra	3.0–4.0 cm	Descends through anterior prostate, forming a gentle, anteriorly concave curve; is bounded anteriorly by a vertical trough-like part (rhabdosphincter) of external urethral sphincter	Widest and most dilatable part; features urethral crest with seminal colliculus, flanked by prostatic sinuses into which prostatic ducts open; ejaculatory ducts open onto colliculus, hence urinary and reproductive tracts merge in this part
Intermediate (membranous) part	1.0–1.5 cm	Passes through deep perineal pouch, surrounded by circular fibers of external urethral sphincter; penetrates perineal membrane	Narrowest and least distensible part (except for external urethral orifice)
Spongy urethra	~15 cm	Courses through corpus spongiosum; initial widening occurs in blub of penis; widens again distally as navicular fossa (in glans penis)	Longest and most mobile part; bulbo-urethral glands open into bulbous part; distally, urethral glands open into small urethral lacunae entering lumen of this part

*Lengths are provided for purposes of comparison—students should not memorize these lengths

Table 17: Urethra (Lymphatics)

Region	Lymph nodes
Posterior urethra	Internal iliac, external iliac (few)
Membranous urethra	Internal iliac
Anterior urethra (with glans penis)	Deep inguinal, superficial inguinal (few), external iliac

Table 18: Urethra (Epithelium)

Region	Epithelium
Proximal part of prostatic urethra	Transitional (urothelium)
Distal part of prostatic urethra, membranous urethra, major part of penile urethra	Pseudo stratified or stratified columnar
Distal penile urethra	Stratified squamous

- Female urethra is approximately **4 cm long**, begins at the internal urethral orifice of the bladder where the detrusor muscle extends longitudinally into the urethra but does **not** form a significant **internal urethral sphincter**.
  - ➢ It courses through the **urogenital diaphragm** (deep perineal pouch) where it becomes related to the deep transverse perineal muscle and sphincter urethrae muscle.

- Posterior surface of the female urethra fuses with the anterior wall of the vagina such that the external urethral sphincter **does not completely surround** the female urethra.
- It terminates as the **navicular fossa** at the external urethral orifice which is situated between the labia minora, in front of the vaginal opening and behind the glans clitoris.

ASSESSMENT QUESTIONS

1. The Prostatic urethra is characterized by all of the following features, EXCEPT: *(AIPG)*
   a. Is the widest and most dilatable part
   b. Presents a concavity posteriorly
   c. Lies closer to anterior surface of prostate
   d. Receives Prostatic ductules along its posterior wall

2. NOT true about prostatic urethra: *(AIIMS 2009,10)*
   a. Trapezoid shape in cross section
   b. Presence of veru montanum
   c. Opening of prostatic ducts
   d. Urethral crest on posterior wall

3. Bulbourethral glands open into which part of the urethra? *(NEET Pattern 2012)*
   a. Membranous
   b. Spongy
   c. Prostatic
   d. Intramural

4. WRONG statement about male urethra is:
   a. Length of male urethra is 20 cm
   b. Membranous urethra has shortest length
   c. Narrowest lumen is at the external urethral meatus
   d. Prostatic urethra has the widest lumen

ANSWERS WITH EXPLANATIONS

1. b. Presents a concavity posteriorly
- Prostatic urethra presents an **anterior** (and not posterior) concavity, which becomes more prominent in the membranous part. It runs downwards and forwards to exit prostate slightly anterior to its apex.
- Though the lumen of the prostatic urethra does show a posterior concavity, as observed in a cut section of prostate.
- Prostatic urethra is considered as the widest and most dilatable part, though recent literature mentions that bulbous part of spongy urethra has the widest lumen.
- Prostatic urethra passes more anteriorly through the prostate and is at the junction of anterior 1/3 and posterior 2/3 rd of prostate. Hence, it lies closer to the anterior surface of the prostate.
- It receives multiple openings of prostatic ductules at its posterior wall.

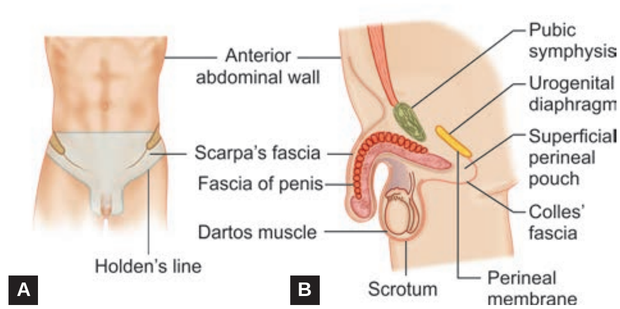
2. a. Trapezoid shape in cross section
- Transverse section of prostate shows crescent (semilunar) shaped lumen of urethra (and not **trapezoid)**.
- **Veru montanum** (seminal colliculus) is a rounded elevation on the posterior wall of prostatic urethra showing three openings.
- Prostatic urethra has a midline elevation on the posterior wall of prostatic urethra called **urethral crest**.
- There are multiple openings found on the sides of urethral crest for the glandular secretions of prostate

3. b. Spongy
- Bulbourethral glands are present in males in relation with membranous urethra (in the deep perineal pouch), whereas the duct opens into the bulbous spongy urethra (in superficial perineal pouch).

4. d. Prostatic urethra has the widest lumen
- Male urethra has a total length of 20 cm and is divided mainly into 4 parts.
- Membranous urethra has the shortest length - 1.5 cm.
- The narrowest lumen is present at the external urethral meatus and the second narrowest is in the membranous urethra.
- The widest lumen is present in the bulbous part of penile urethra, second widest is the prostatic urethra.

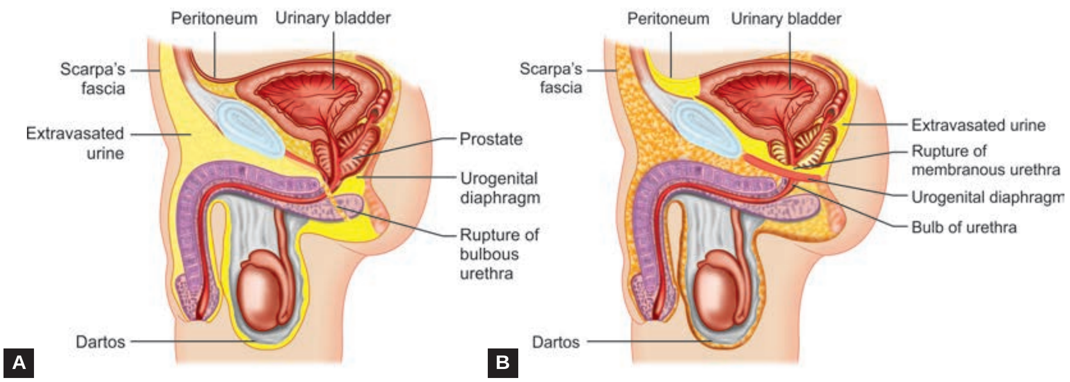
Extravasation of Urine

- The attachments of Scarpa's and Colles' fasciae are such that they prevent the passage of extravasated urine due to urethral rupture backward into the ischiorectal fossae and downward into the thighs.
- The line of fusion of Scarpa's fascia passes over Holden's line, body of pubis, margins of pubic arch, and posterior border of the perineal membrane/posterior edge of the urogenital diaphragm.
- Therefore, if male urethra is ruptured in the perineum, the extravasated urine collects first in the superficial pouch of perineum and then on to the anterior abdominal wall inferior to the umbilicus in the superficial inguinal space.



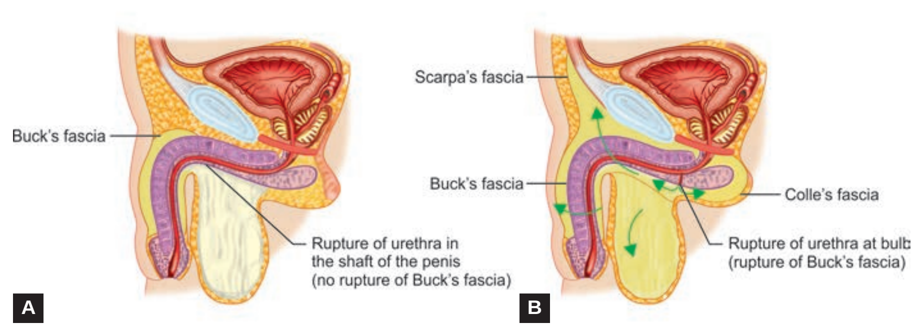
Figs. 60A and B: Extent of the membranous layer of superficial fascia of the abdomen (Scarpa's fascia): (A) Anterior view; (B) Sagittal section

- In a case of **fundal rupture of urinary bladder** (as may occur in bomb explosions), the peritoneum covering the fundus is also ruptured, leading to extravasation of urine into the peritoneal cavity (**ascites**).
- Pelvic fractures may result in pulling of pubo-prostatic ligaments and rupture of the **membranous part of the urethra**. In this case urine escapes into the deep perineal pouch and can extravasate upward into the peri-vesical space (around the prostate and bladder) or downward into the superficial perineal space (if there is associated rupture of perineal membrane).
- In a case of straddle injury, there is rupture of the **bulbous portion of the spongy urethra** below the urogenital diaphragm and the extravasated urine may pass into the **superficial perineal space** and spread inferiorly into the **scrotum**, anteriorly around the **penis**, and superiorly into the lower part of the **abdominal wall**.
- The urine cannot spread laterally into the thigh because the inferior fascia of the urogenital diaphragm (the perineal membrane) and the superficial fascia of the perineum are firmly attached to the ischiopubic rami and are connected with the deep fascia of the thigh (fascia lata).
- It cannot spread posteriorly into the anal region (ischiorectal fossa) because the perineal membrane and Colles fascia are continuous with each other around the superficial transverse perineal muscles.
- It cannot enter the deep perineal pouch, because perineal membrane prevents that.



Figs 61A and B: Rupture of urethra: (A) Rupture of the bulbous urethra leading to superficial extravasation; (B) Rupture of the urethra above the urogenital diaphragm leading to deep extravasation. The yellow coloured areas represent the extra-vasated urine

- **Penile fracture:** Diagnosis of albugineal rupture is usually made from a characteristic history of severe pain with a cracking or popping sound during acute bending of the erect penis, followed by immediate detumescence, penile swelling, and deformity.
- **Albugineal rupture** is associated with urethral injury in 10–20% of cases.
- **Penile hematoma is confined to the shaft when the Buck's fascia is intact**.
- If the Buck fascia has been violated, the swelling and ecchymosis are contained within the Colles fascia. In this instance, a "butterfly-pattern" ecchymosis may be observed over the perineum, scrotum, and lower abdominal wall.



Figs 62A and B: Extravasation of urine (A) Urine is confined to penile shaft, (if Buck's fascia is intact), (B) Urine extravasation is into the penile & scrotal layers and along the anterior abdominal wall (if Buck's fascia is ruptured).

ASSESSMENT QUESTIONS

1. **Scarpa's fascia gets attached to:** *(JIPMER 2010)*
   a. Inguinal ligament
   b. Fascia lata of thigh
   c. Conjoint tendon
   d. Pubic crest

2. **A 16-year-old boy presents to the emergency department with straddle injury and rupture of the bulbous urethra. Extravasated urine from this injury can spread into which of the following structures?**
   a. Scrotum
   b. Ischiorectal fossa
   c. Deep perineal space
   d. Thigh

3. **Injury to the male urethra above the perineal membrane due to a pelvic fracture, causes urine to accumulate in all of the following EXCEPT:**
   a. Space of Retzius
   b. Deep perineal pouch
   c. Superficial perineal pouch
   d. Peritoneal cavity

4. **Injury to the male urethra below the perineal membrane causes urine to accumulate in:** *(AIPG 2007)*
   a. Superficial perineal pouch
   b. Deep perineal pouch
   c. Space of Retzius
   d. Pouch of Douglas

5. **A patient exposed to bomb explosion injury presents with rupture of the fundus of urinary bladder. The extravasated urine reaches:**
   a. Space of Retzius
   b. Deep perineal pouch
   c. Superficial perineal pouch
   d. Peritoneal cavity

6. **After fracture of the penis (injury to the tunica albuginea) with intact Buck's fascia, there occurs hematoma:**
   a. The penis and scrotum
   b. At the perineum in a butterfly shape
   c. Penis, scrotum, perineum and lower part of anterior abdominal wall
   d. Shaft of the penis only.

7. **In penile injury, Colle's fascia prevents extravasation of urine in:** *(NEET pattern 2013)*
   a. Ischiorectal fossa
   b. Perineum
   c. Abdomen
   d. Thigh

ANSWERS WITH EXPLANATIONS

1. b. Fascia lata of thigh
- Scarpa's fascia is the deep membranous layer of superficial fascia of anterior abdominal wall.
- It crosses the **inguinal ligament** and gets attached to the **fascia lata of thigh** along Holden's line, below and parallel to inguinal ligament.

2. a. Scrotum
- Extravasation of urine may result from rupture of the bulbous spongy urethra below the perineal membrane; the urine may pass into the superficial perineal pouch and spread inferiorly into the scrotum, anteriorly around the penis, and superiorly into the lower part of the abdominal wall.
- The urine cannot spread laterally into the thigh because the perineal membrane and the superficial fascia of the perineum are firmly attached to the ischiopubic rami and are connected with the deep fascia of the thigh (fascia lata).
- It cannot spread posteriorly into the anal region (ischiorectal fossa) because the perineal membrane and Colles's fascia are continuous with each other around the superficial transverse perineal muscles.

3. d. Peritoneal cavity
- Rupture of membranous part of the urethra may lead to urine escaping into the space around the prostate and bladder and extraperitoneal space **(but not the peritoneal cavity)**.
- If the urogenital diaphragm is also disrupted urine leaks into deep perineal space and into the superficial perineal space (as the perineal membrane is also ruptured).
- The most common type of urethral injury is at the junction of posterior and anterior (bulbous) urethra. Radiologists consider a type III urethral injury as a combined anterior/posterior urethral injury.

4. a. Superficial perineal pouch
- **Superficial perineal pouch** lies below the perineal membrane and has the spongy part of urethra lying in it.
- Any injury to the spongy urethra like the bulbous rupture of urethra leads to the extravasation of urine into the superficial perineal pouch.
- The urine can track from the superficial pouch towards the anterior abdominal wall and reach just anterior to the external oblique aponeurosis.
- Perineal membrane separates the **deep perineal pouch** from the superficial and prevents urine from entering the deep perineal pouch from superficial.
- **Space of Retzius** is an extra-peritoneal space lying between the pubic bones and the urinary bladder.
- Membranous rupture of urethra (above the perineal membrane) may cause accumulation of blood and urine in this space.
- **Pouch of Douglas** is the recto-vesical (or recto-uterine) pouch of peritoneum. Douglas pouch is intra-peritoneal and also well separated from the superficial pouch. Neither of the two varieties of urethral rupture the urine can reach into this space.

5. d. Peritoneal cavity
- Rupture of the dome (superior wall) of the urinary bladder, leads to rupture of peritoneum and results in an intraperitoneal extravasation of urine within the peritoneal cavity (ascites).
- It is caused by a compressive force on a full bladder.

6. d. Shaft of the penis only
- **Penile Fracture -** Diagnosis of albugineal rupture is usually made from a characteristic history of severe pain with a cracking or popping sound during acute bending of the erect penis, followed by immediate detumescence, penile swelling, and deformity.
- **Albugineal rupture** is associated with urethral injury in 10–20% of cases.
- **Penile hematoma is confined to the shaft when the Buck's fascia is intact**.
- If the Buck fascia has been violated, the swelling and ecchymosis are contained within the Colles fascia. In this instance, a "butterfly-pattern" ecchymosis may be observed over the perineum, scrotum, and lower abdominal wall.

7. a. Ischiorectal fossa
- Colle's fascia attachments prevents extravasation of urine into the **ischiorectal fossa**.
- Penile injuries may lead to extravasation of urine into penile and scrotal layers, **perineum**, anterior **abdominal** wall.
- Urine is prevented from entering the thigh by fascia lata attachments.

Urethra Sphincter System

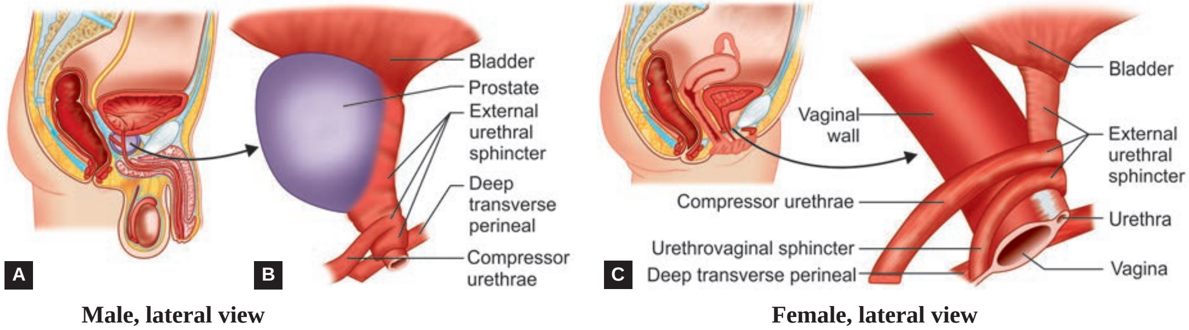
Sphincter urethrae is the external sphincter muscle of urethra which surrounds the whole length of the membranous portion of the urethra, and is enclosed in the fascia of the urogenital diaphragm.

- Its external fibers arise from the junction of the inferior rami of the pubis and ischium and from the neighboring fasciae.
- They arch across the front of the urethra and bulbourethral glands, pass around the urethra, and behind it unite with the muscle of the opposite side, by means of a tendinous raphe. It is also inserted into the perineal body.
- Its innermost fibers form a continuous circular investment for the membranous urethra.
- Has an inferior part that is attached to the anterolateral wall of the vagina in the female, forming a urethrovaginal sphincter that compresses both the urethra and vagina.
- Male external urethral sphincter is formed by two muscles: sphincter urethra and compressor urethrae muscles, both in the deep perineal space.
- Female external urethral sphincter is formed by three muscles: sphincter urethra, compressor urethrae, and urethro-vaginalis muscles.

Table 19: Differences between the internal and external sphincters of the urethra

Internal urethral sphincter	External urethral sphincter
Surrounds the internal urethral orifice	Surrounds the membranous part of urethra
Derived from the bladder musculature of trigonal region	Derived from the sphincter urethrae muscle
Innervated by the sympathetic fibres (T11–12 segments)	Innervated by the somatic fibres (S2, S3, S4 segments)
Involuntary	Voluntary

External urethral sphincter is supplied by neurones in Onuf's nucleus (S2, 3 4) and by perineal branches of the pudendal nerve lying on the perineal aspect of the pelvic floor.



Figs 63A to C: Deep perineal pouch and male and female external urethral sphincters. (A) The deep perineal pouch is seen through (left side) and after removal of the perineal membrane (right side) (B) The trough like fibers of the superior male external urethral sphincter ascend to the neck of the bladder as part of the isthmus of the prostate. The inferior sphincter includes cylindrical and loop-like portions (compressor urethrae) (C) Female urethral sphincter complex.

ASSESSMENT QUESTIONS

1. **All of the following statements are true about sphincter urethra EXCEPT:** *(AIIMS 2014)*
   a. Located at the bladder neck
   b. Originate from ischiopubic ramus
   c. Is a voluntary muscle
   d. Supplied by pudendal nerve

2. **Sphincter urethrae is present in:** *(NEET Pattern 2012)*
   a. Prostatic urethra
   b. Spongy urethra
   c. Membranous urethra
   d. Penile urethra

3. **Vaginal sphincter is formed by all EXCEPT:** *(AIIMS 2009, 10)*
   a. Internal urethral sphincter
   b. External urethral sphincter
   c. Pubovaginalis
   d. Bulbospongiosus

ANSWERS WITH EXPLANATIONS

1. **a. Located at the bladder neck**
   - Sphincter urethra (external urethral sphincter) is a content of deep perineal pouch (not the bladder neck).
   - It is a skeletal (voluntary) muscle, supplied by somatic pudendal nerve (S2,3,4) and works for urinary continence.
   - It takes its origin from the ischiopubic ramus on each side and unite with the muscle of the opposite side by means of a tendinous raphe.
   - Internal urethral sphincter (sphincter vesicae) is located at the bladder neck, is a smooth (involuntary) muscle engaged in preventing retrograde ejaculation of semen, supplied by L1 sympathetic fibres.

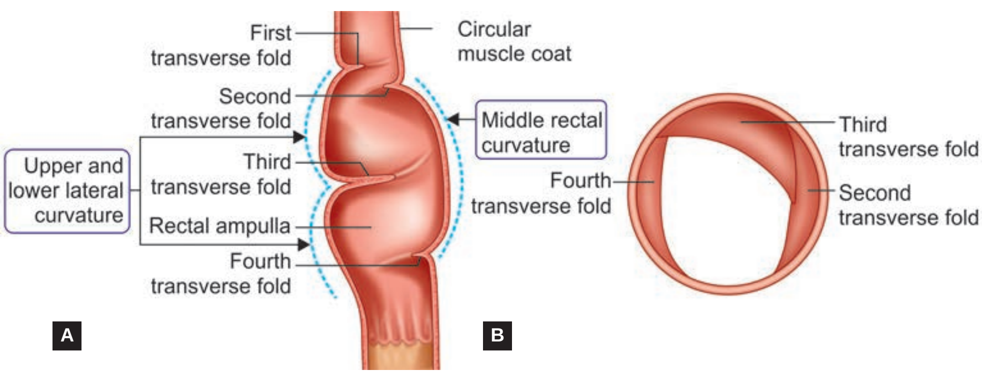
2. c. Membranous urethra
- External urethral sphincter (sphincter urethrae) is present in relation to the membranous urethra, in the deep perineal pouch.

3. a. Internal urethral sphincter
- **Internal urethral sphincter** do not function as vaginal sphincter. In some textbook it is mentioned internal urethral sphincter is **absent** in females.
- Muscles that compress the vagina and act as sphincters include the pubovaginalis, external urethral sphincter (especially its urethrovaginal sphincter part), and bulbospongiosus.
- The External urethral sphincter surrounds the vagina also and works as urethro-vaginal sphincter. It is innervated by the nerve fibres of Onuf's nucleus (S-2, 3, 4) via the pudendal nerve.
- Pubo-vaginalis is a part of pubo-coccygeus (Levator ani) and functions as genital tract sphincter. Levator ani muscle forms the Pelvic diaphragm.
- Bulbo-spongiosus is a muscle of superficial perineal pouch and is a constrictor of genital tract.
- Internal urethral sphincter: Females lack the internal urethral sphincter. It is actually the anatomical bladder neck (pre-prostatic) sphincter observed in males. The internal urethral sphincter prevents retrograde passage of semen into the urinary bladder during ejaculation. It is innervated by the L-1 sympathetic fibres. L-1 fibres should not be cut while performing lumbar sympathectomy otherwise, would result in retrograde ejaculation of semen.
- Urinary continence in females is maintained by the following muscles: Sphincter urethrae, Compressor urethra, Sphincter urethro-vaginalis, Pubo-urethralis (part of Levator ani muscle).

Rectum and Anal Canal

Rectum

- **Rectum** is the part of the large intestine which lies between the sigmoid colon and the anal canal.
- It begins at vertebral level S3 and ends at the tip of the coccyx (i.e., the **anorectal junction**) where the **puborectalis muscle** forms a U-shaped sling causing an 80-degree **perineal flexure**.
- **Ampulla of the rectum** is a dilated portion of the rectum that lies just above the pelvic diaphragm.
- Rectum is normally empty of fecal matter.
- Unlike the sigmoid colon, rectum has no sacculations, appendices epiploicae or taeniae coli.
- Rectum has three **lateral curvatures**: the upper and lower are convex to the right, and the middle (most prominent) is convex to the left. On the luminal aspect, these three curves are marked by semicircular folds (Houston's valves).



Figs 64A and B: Rectum in (A) Coronal view (B) Transverse view

- There are two types of **mucosal folds** in rectum: temporary and permanent.
- When the rectum is empty, the mucosa has several longitudinal folds in its lower part, which are temporary and disappear during distension.
- **Permanent folds**, also called Houston's valves are crescentic (semilunar) **transverse** folds situated against the concavities of the lateral curvatures of the rectum.
  - They are formed by the mucosa, submucosa and inner circular layer of smooth muscle that permanently extend into the lumen of the rectum to support the fecal mass.
  - They are **permanent** and become more prominent when the rectum is distended.
  - They are usually three in number; sometimes a fourth is found, and occasionally only two are present, and numbered from above downward as follows:
    - First fold (or superior fold) is at the commencement of the rectum, distal to the rectosigmoid junction. It projects from the right (or left wall) and may occasionally encircles the rectal lumen (Not mentioned in most of the books).
    - Second fold projects from the left rectal wall along the concavity of upper lateral curvature. It lies opposite the middle of rectum.
    - Third fold is the **largest and most constant**, lies immediately above the rectal ampulla. It projects from the anterior and right wall just below the level of the anterior peritoneal reflection, along the concavity of middle lateral curvature. It has prominent circular muscle.
    - Fourth (inferior) fold is the most variable and projects from the left wall of the rectum along the concavity of lower lateral curvature. It lies about 2.5 cm above the anus.
  - These transverse folds of the rectum (rectal valves) provide support to hold the faeces and prevent its urging toward the anus, which would produce a strong urge to defecate. They are visible per anum with the aid of a speculum.

Relations

Table 20: Anterior relations of the rectum in male and female

Portion of rectum	Relations: In male	Relations: In female
Upper two-third of rectum (peritoneal)	Rectovesical pouch and coils of the small intestine and sigmoid colon with it	Rectouterine pouch and coils of the small intestine and sigmoid colon with it
Lower one-third of rectum/ampulla (non-peritoneal)	• Base of the urinary bladder • Ureters (terminal parts) • Seminal vesicles • Ampullae of vas deferens • Prostate (All these structures are separated from the rectum by the well-defined rectovesical fascia of Denonvilliers)	Vagina (lower part) (It is separated from rectum by an ill-defined rectovaginal fascia)

Table 21: Posterior relations of the rectum in male and female

In the midline	On each side of midline
• Loswer three pieces of sacrum • Coccyx • Anococcygeal raphe • Ganglion impar • Median sacral vessels • Superior rectal artery (opposite S3 vertebra only) • Fascia of Waldeyer*	• Piriformis } Mostly of the left side • Coccygeus • Levator ani • Sympathetic chains • Anterior primary rami of S3, S4, S5, and coccygeal nerve (Col) • Pelvic splanchnic nerves • Lateral sacral vessels

*The fascia of Waldeyer is a connective tissue by which rectum (ampulla) is attached to the sacrum and coccyx.

- Lower third of rectum is below the peritoneum, which is reflected anteriorly on to the urinary bladder in males to form the rectovesical pouch, or on to the posterior vaginal fornix in females to form the recto-uterine pouch (of Douglas).
  - It contains peritoneal fluid and some of the small intestine.
  - The level of this reflection is higher in males; the rectovesical pouch is approximately 7.5 cm above the anorectal junction in males, while the recto-uterine pouch is approximately 5.5 cm above the anorectal junction in females.
- **Waldeyer's fascia** is the presacral fascia present between rectum and sacrum.
  - It lines the anterior aspect of the sacrum, enclosing the sacral vessels and nerves.
  - It continues anteriorly as the pelvic parietal fascia, covering the entire pelvic cavity.
  - It is limited postero-inferiorly, as it fuses with the mesorectal fascia, lying above the levator ani muscle, at the level of the anorectal junction.
  - It has been mistakenly described as the posterior aspect of the mesorectal fascia. These two fascias are separate entities. During rectal surgery and mesorectum excision, dissection along the avascular alveolar plane between these two fascias, facilitates a straightforward dissection and preserves the sacral vessels and hypogastric nerves.
- Rectal or digital (finger) examination is performed for palpating enlargements, tissue hardening, hemorrhoids, rectal carcinoma, prostate cancer, seminal vesicle, ampulla of the ductus deferens, bladder, uterus, cervix, ovaries, anorectal abscesses, perineal body etc.

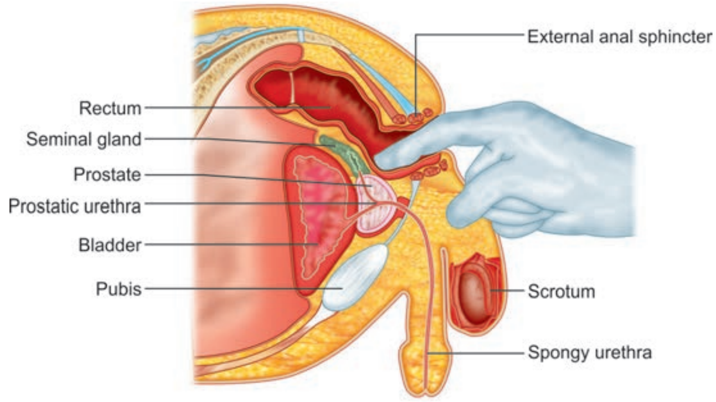


Fig. 65: Rectal digital examination-Medial view (from left)

ASSESSMENT QUESTION

1. **Pelvic fascia between rectum and sacrum is:**
   a. Denonvillier's fascia
   b. Colle's fascia
   c. Waldeyer's fascia
   d. Scarpa's fascia

ANSWERS WITH EXPLANATIONS

1. c. Waldeyer's fascia

- Waldeyer's fascia (presacral fascia) lines the anterior aspect of the sacrum, enclosing the sacral vessels and nerves.
- It is limited postero-inferiorly, as it fuses with the mesorectal fascia, lying above the levator ani muscle.
- Identification and preservation of the Waldeyer's fascia is of fundamental importance in preventing complications and reducing local recurrences of rectal cancer.
- Denonvillier's fascia is a membranous partition separating the rectum from the prostate and urinary bladder; this structure in the male corresponds to the fascia rectovaginalis in the female.

Anal Canal

Anal canal is the terminal portion of the large intestine having a length of ~ 4 cm long and extends from the rectum at the anorectal junction to the surface of the body at the anus.

- It divides into an upper two-thirds (visceral portion), which belongs to the intestine, and a lower one-third (somatic portion), which belongs to the perineum.
- A point of demarcation between visceral and somatic portions is called the **pectinate** (dentate) line, which is a serrated line following the anal valves.

Upper Anal Canal

- Mucosa of the upper anal canal is thrown into longitudinal folds called the **anal columns** (of Morgagni). The base of the anal columns marks the **pectinate line**.
- At the base of the anal columns are folds of tissue called the **anal valves**. Behind the anal valves are small, blind pouches called the **anal sinuses** into which anal glands open.
- Upper anal canal is surrounded by the internal anal sphincter which is a continuation of smooth muscle from the rectum with involuntary control via autonomic innervation.
- It is lined by **simple columnar epithelium**.

Lower Anal Canal

- It extends from the pectinate line to the anal verge (the point at which perianal skin begins).
- It is surrounded by external anal sphincter which is a skeletal muscle under voluntary control via the pudendal nerve.
- It is lined by **stratified squamous epithelium** (non-keratinized) till Hilton's line. Below that it becomes keratinized.
- **Hilton white line** is the intermuscular (inter-sphincteric) groove between the lower border of the internal anal sphincter and the subcutaneous part of the external anal sphincter. It indicates the junction between keratinized stratified squamous epithelium and non-keratinized stratified squamous epithelium.
- **Anal transition zone** (ATZ) is interposed between uninterrupted colo-rectal type mucosa above and uninterrupted squamous epithelium below, irrespective of the type of epithelium present in the zone itself.
  - It lies above the dentate (pectinate line) and reaches up to 2 cm.
  - It is composed of 5-9 cells layers. The surface cells can be columnar, cuboidal or somewhat more flattened
- **Pecten** is the zone in the lower half of the anal canal between the pectinate line and the anal verge.
- **Anal verge** is the distal end of the anal canal, forming a transitional zone between the epithelium of the anal canal and the perianal skin.

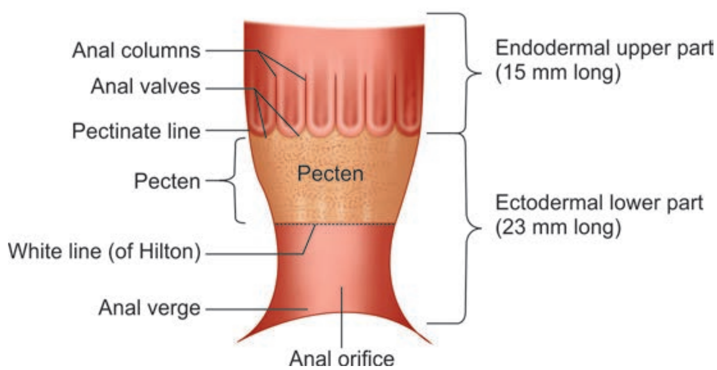


Fig. 66: Interior of the anal canal

Neurovascular Bundle

Arterial supply

- Rectum
  - **Superior rectal artery** (continuation of the inferior mesentery artery) is the chief supply.
  - **Middle rectal artery** (branch of anterior division of the internal iliac artery).
  - **Inferior rectal artery** (branch of internal pudendal artery)
  - **Median sacral artery** (branch of the abdominal aorta)

- **Anal canal**
  - It is supplied by terminal branches of the **superior rectal artery** and the **inferior rectal artery**, together with a small contribution from the **median sacral artery**.
  - Middle rectal artery do not supply the anal canal.

Venous drainage

- Venous drainage of the rectum and anal canal parallels the arterial supply.
- Upper portions are drained predominantly by the **superior rectal veins**, tributaries portal mesenteric venous system; some blood returns to the systemic circulation via the **middle rectal veins**.
  - **Superior rectal vein** → inferior mesenteric vein → portal vein → hepatic sinusoids → central veins → hepatic veins → inferior vena cava
  - **Middle rectal vein** → internal iliac vein → common iliac vein → inferior vena cava
- Lower portions drain via the **inferior rectal** branches of the internal pudendal vein into systemic circulation.
  - **Inferior rectal vein** → internal pudendal vein → internal iliac vein → common iliac vein → inferior vena cava

Note: Porto-systemic anastomosis: Superior rectal vein (tributary of **portal vein**) forms anastomosis with middle and inferior rectal veins (tributaries of **inferior vena cava**).

Clinical Correlations

- **Internal hemorrhoids** are varicosities of the superior rectal veins. They are located above the pectinate line and are covered by rectal mucosa. These present with painless bleeding.
- **External hemorrhoids** are varicosities of the inferior rectal veins. They are located below the pectinate line near the anal verge and are covered by skin. These present with painful bleeding.

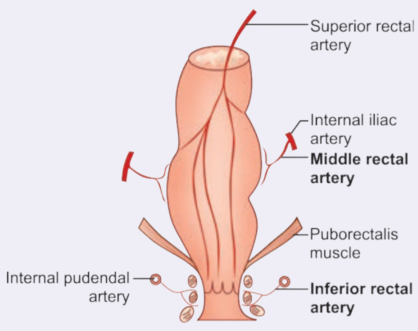


Fig. 67: Arterial supply of the rectum and anal canal

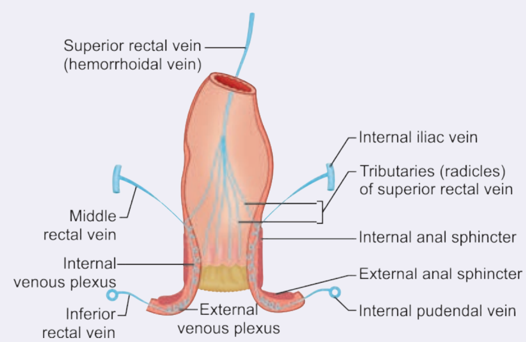


Fig. 68: Venous drainage of the rectum and anal canal

Lymphatic Drainage

- **Rectum**
  - Upper half lymphatics accompany the superior rectal vessels and drain into the inferior mesenteric nodes.
    - Few of these vessels drain into the pararectal lymph nodes (on each side of the rectosigmoid junction).
  - Lower half lymphatics accompany the middle rectal vessels and drain into the internal iliac nodes.
- **Anal canal**
  - Pectinate line forms the "water shed line" of the anal canal.
    - **Upper** half lymphatics drain into the **internal iliac lymph nodes**
    - **Lower** half lymphatics drain into the **superficial inguinal** lymph nodes (horizontal group)

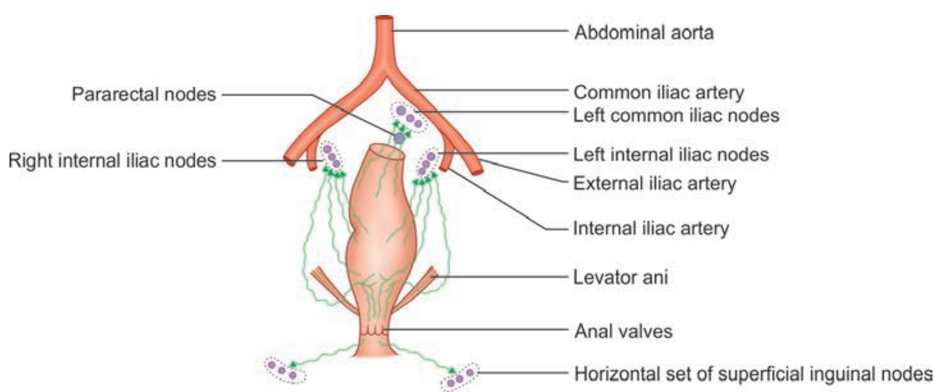


Fig. 69: Lymphatic drainage of the rectum and anal canal

Nerve Supply

- **Rectum**
  - Lumbar splanchnic nerves are the sympathetic component derived from L1, L2 segments of the spinal cord.
  - Nervi erigentes are the parasympathetic nerves from S2, S3, S4 segments of the spinal cord.
- **Anal canal**
  - Upper anal canal is supplied by autonomic nervous system (parasympathetic and sympathetic nerves)
    - Internal anal sphincter is a smooth muscle under involuntary control
    - Sensations are limited to stretch and ischaemia .
  - Lower anal canal is supplied by the somatic pudendal nerve.
    - External anal sphincter is a skeletal muscle under voluntary control
    - It is sensitive to somatic sensations like touch, pain, temperature etc.

Table 22: Comparison between upper and lower anal canal

Features	Upper Anal Canal	Lower Anal Canal
Arterial supply	Superior rectal artery (branch of inferior mesenteric artery)	Inferior rectal artery (branch of internal pudendal artery)
Venous drainage	Superior rectal vein → inferior mesenteric vein → hepatic portal system	Inferior rectal vein → internal pudendal vein → internal iliac vein → IVC
Lymphatic drainage	Deep nodes	Superficial inguinal nodes
Innervation	Motor: Autonomic innervation of internal anal sphincter (smooth muscle) Sensory: Stretch sensation; no pain sensation	Motor: Somatic innervation (pudendal nerve) of external anal sphincter (striated muscle sensory: Pain, temperature, touch sensation)
Embryologic derivation	Endoderm (hindgut)	Ectoderm (proctodeum)
Epithelium	Simple columnar	Stratified squamous non-keratinized
Tumors	Palphable enlarged superficial nodes will NOT be found Patients do NOT complain of pain	Palpable enlarged superficial nodes will be found Patients do complain of pain
Hemorrhoids	Internal hemorrhoids (varicosities of superior rectal veins) Covered by rectal mucosa Patients do NOT complain of pain	External hemorrhoids (varicosities of inferior rectal veins) Covered by skin Patients do complain of pain

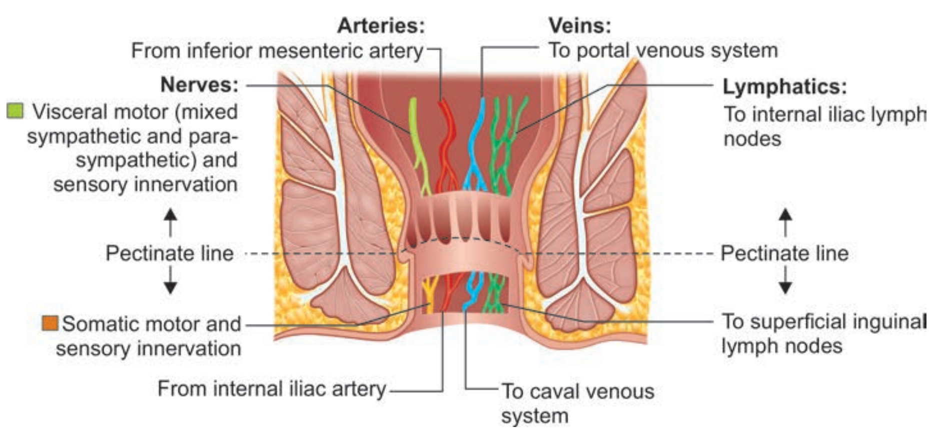


Fig. 70: Transitions occurring at pectinate line. Vessels and nerves superior to the pectinate line are visceral; those inferior to the pectinate line are parietal or somatic. This orientation reflects the embryological development of the anorectum.

- **Waldeyer's fascia**: Presacral fascia at the floor of the retro-rectal space.

Anorectal Junction

- **Anorectal ring** (or flexure) is the demarcation between the rectum and the anal canal, where the puborectalis muscle forms a sling around the posterior aspect of the anorectal junction, kinking it anteriorly.
- It is formed by fusion of fibres of:
  - Puborectalis
  - Uppermost fibres of external anal sphincter
  - Internal anal sphincter

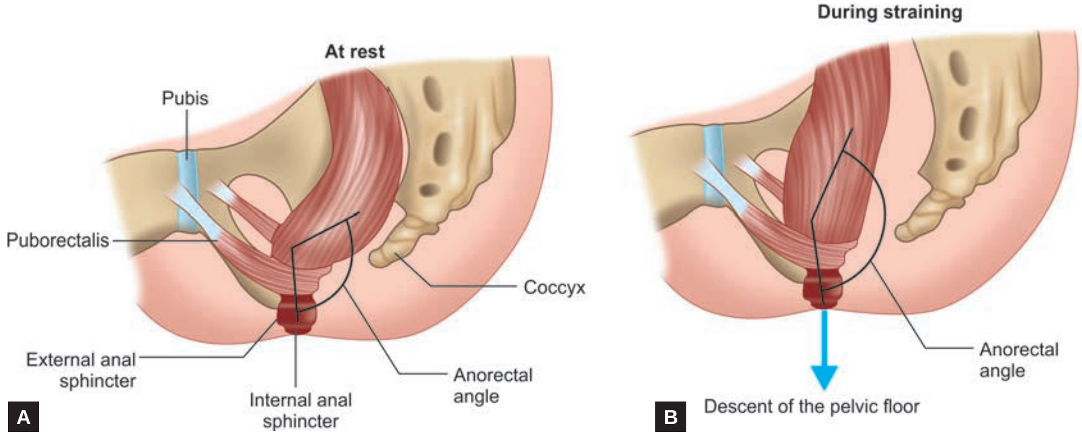


Fig. 71A and B: Anorectal ring and angle

Anorectal Angle

- Faecal continence is maintained by normal rectal sensation and tonic contraction of the internal anal sphincter and the puborectalis muscle, which wraps around the anorectum, maintaining an anorectal angle between 80° and 110°.
- The angle is 2–3 cm anterior to and slightly below the tip of the coccyx, level with the apex of the prostate in males.

Clinical Correlations

- Damage to the anorectal ring results in rectal incontinence.
- **Defecation** is initiated by distention of the rectum, the afferent impulses carried by the pelvic splanchnic nerves.
- The motor component of parasympathetic pelvic splanchnic nerve increases peristalsis (contracts smooth muscles in the rectum) for bowel evacuation.
- Sympathetic lumbar splanchnic nerve causes storage by a decrease in peristalsis and maintaining tone in the internal sphincter.
- The feces are stored in the ampulla, which is the lower dilated part of the rectum that lies above the pelvic diaphragm.
- During defaecation the intra-abdominal pressure is increased by holding the breath and contracting the diaphragm, the abdominal muscles, and the levator ani, thus facilitating the expulsion of faeces.
- During defecation, the pelvic floor muscles (including the puborectalis) relax, allowing the anorectal angle to straighten by at least 15°, and the perineum descends by 1-3.5 cm.
- The smooth muscle in the wall of the rectum contracts, the internal anal sphincter relaxes, and the external anal sphincter relaxes to pass the faeces.
- After evacuation, the contraction of the puborectalis and the anal sphincters closes the anal canal.

ASSESSMENT QUESTIONS

1. **Anal canal NOT supplied by:** *(AIIMS 2015)*
   a. Superior rectal artery
   b. Inferior rectal artery
   c. Median sacral artery
   d. Middle rectal artery

2. **All form anorectal ring EXCEPT:** *(AIIMS 2013)*
   a. External anal sphincter
   b. Internal anal sphincter
   c. Puborectalis
   d. Anococcygeal raphe

ANSWERS WITH EXPLANATIONS

1. **d. Middle rectal artery**
   - Middle rectal artery supplies the rectum, but '**not**' the anal canal.
   - The anal canal is supplied by terminal branches of the **superior rectal artery** and the **inferior rectal artery** branch of the internal pudendal artery, together with a small contribution from the **median sacral artery**.
   - The arterial supply to the epithelium of the lower anal canal in the midline, particularly posteriorly, is relatively deficient and is thought to predispose to the occurrence of acute and chronic **anal fissures**, which are most commonly found in the midline, especially posteriorly.

2. **d. Anococcygeal raphe**
   - **Anorectal ring** is a muscular present at the junction of rectum and anus. it is formed by fusion of fibres of **puborectalis**, uppermost fibres of **external anal sphincter** and **internal anal sphincter.**
   - **Anococcygeal raphe** a fibrous median raphe in the floor of the pelvis, which extends between the coccyx and the margin of the anus and is not a component of anorectal ring.
   - Damage to the anorectal ring results in rectal incontinence.

CHAPTER 11

Lower Limb

Table 1: Parts of the lower limb		
Parts	**Bones**	**Joints**
Gluteal region (on side and back of pelvis)	Hip bone	Sacroiliac joint
Thigh (from hip to knee)	Femur	• Hip joint • Knee joint
Leg (from knee to ankle)	• Tibia • Fibula	• Tibiofibular joints • Ankle joint
Foot (from heel to toes)	• Tarsals (7) • Metatarsals (5) • Phalanges (14)	• Intertarsal joints (e.g. subtalar talocalcaneonavicular, transverse tarsal, etc.) • Intermetatarsal joints • Metatarsophalangeal joints • Interphalangeal joints

Homologous parts of the upper and lower limb	
Upper limb	**Lower limb**
Shoulder/pectoral girdle	Hip girdle/pelvic girdle
Shoulder joint	Hip joint
Arm	Thigh
Elbow joint	Knee joint
Forearm	Leg
Wrist joint	Ankle joint
Hand • Carpus • Metacarpus • Fingers*	For • Tarsusot • Metatarsus • Toes*

Embryology

- The lower limb is first recognizable as a laterally projecting thickening in the body wall opposite somites 24–29 at **day 28**. The core of mesenchymal cells is derived from both somatopleuric and paraxial mesenchyme.
- The lower limb rotates in utero **medially 90 degrees**, while the upper limb rotates laterally 90 degrees.

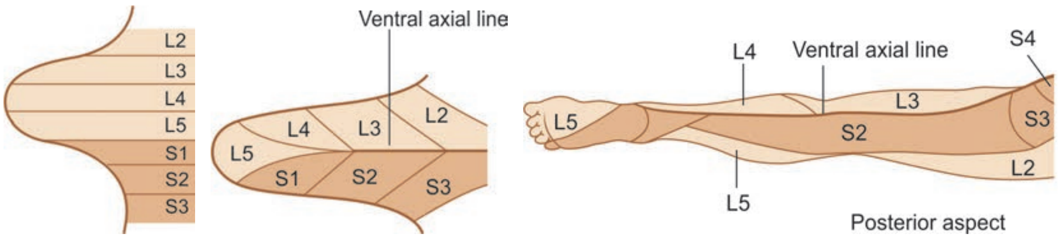


Fig. 1: Dermatomes of lower limb.

- Thus, the limbs are **180 degree out of phase** with one another (knee anterior and big toe medial versus elbow posterior and thumb lateral).
- The **extensor** compartment in lower limb comes **anterior** and the flexor compartment becomes posterior.
- The dorsal and ventral **axial lines** both reach the **ankle joint**, ventral reaches the medial aspect.
- The blood supply to the lower limb is derived from the lateral branch of the **fifth lumbar intersegmental artery**, which continues into the limb bud as the axial artery.
- The preaxial vein becomes the long saphenous vein, which drains into the femoral vein at the saphenous opening.
- The **postaxial vein** becomes the short saphenous vein, which passes deep and joins the popliteal vein.

Surface Marking

- The inguinal or groin skin crease marks the junction of the anterior thigh with the anterior abdominal wall and lies distal to the inguinal Ligament.
- **Tuffier's line:** It is drawn by joining the most superior aspects of the iliac crests almost always crosses the L4 body or L4/L5 intervertebral disc.
- This line is used as a landmark when performing a lumbar puncture; localization via palpation, especially in females and patients with a greater body mass index (BMI), often places it at a higher vertebral level, up to the L2–L3 interspace.
- In neonates, Tuffier's line sits at the L4/L5 interlaminar space level whilst prone, moving to the upper third of L5 during vertebral column flexion.

- The iliac crest terminates posteriorly as the posterior superior iliac spine, which is marked superficially by the gluteal dimples (dimples of Venus).
- Palpation places the posterior superior iliac spines in the range of the L5–S1 vertebral junction to the S2 spinous process level, whereas radiographic assessment shows their inferior margin to mark vertebral level S2 almost always.
- The caudal limit of the dura mater ranges from the L5–S1 junction to S4, with the majority sitting at the lower S1 to the S2 level and the mean position being lower in males versus females.
- The termination of the dural sac is located at mean of 31.6 ± 11.8 mm from the sacral hiatus apex, a point relevant to caudal anesthetic administration.
- The inguinal or groin skin crease marks the junction of the anterior thigh with the anterior abdominal wall and lies distal to the inguinal ligament.
- The inguinal ligament can be felt running between the anterior superior iliac spine and the pubic tubercle.
- The groin/inguinal crease (Holden's line), where the deep layer of the subcutaneous tissue of the anterior abdominal wall meets the fascia lata of the thigh, is distal to the inguinal ligament and runs obliquely.
- **Buttock and hip:**
  - The intergluteal cleft, which separates the buttocks inferiorly, begins superiorly at the S3 or S4 vertebrae.
- **Thigh:**
  - The inguinal ligament can be felt running between the anterior superior iliac spine and the pubic tubercle.
  - The groin/inguinal crease (Holden's line), where the deep layer of the subcutaneous tissue of the anterior abdominal wall meets the fascia lata of the thigh, is distal to the inguinal ligament and runs obliquely.

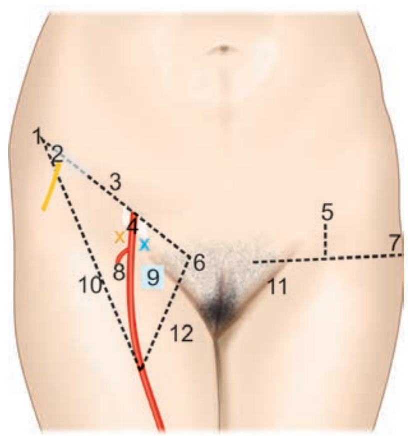


Fig. 2: Surface marking femoral triangle region

Fig. 2: 1—anterior superior iliac spine; 2—lateral femoral cutaneous nerve and its zone of emergence into femoral triangle (white); 3—inguinal ligament; 4—femoral artery and zone of emergence into femoral triangle (white): mid-inguinal point ± 1 cm either side, femoral nerve (yellow cross) and vein (blue cross) sit lateral and medial, respectively, to the femoral artery; 5—femoral head: located 2- 4 cm above the midpoint of the greater trochanter to pubic tubercle line; 6—pubic tubercle; 7—greater trochanter to pubic tubercle line; 8—profunda femoris artery; 9- zone of saphenofemoral junction location: almost always sits within a 3 cm × 3 cm zone situated 1- 4 cm lateral and 0-3 cm inferior to the pubic tubercle; 10—sartorius; 11—inguinal/groin crease; 12—adductor longus.

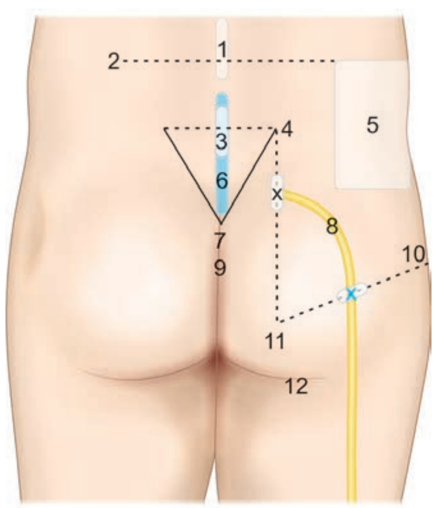


Fig. 3: Surface marking: gluteal and lower back region.

Fig. 3: 1—zone of supracristal plane intersection with vertebrae (white): ranges from the L2-L3 to the L4-L5 junction/interspinous space; 2—highest point of iliac crests (supracristal plane or Tuffier's line): most commonly intersects the L4 vertebra to the L4/5 junction; 3—zone of intersection between the vertebrae and a horizontal plane between the posterior superior iliac spines (white): ranges from the L5-SI junction/interspinous space to S2; 4—posterior superior iliac spine and interspinous plane: marked by a skin indentation (dimple of Venus); 5—safe zone (white) for gluteal region junction (upper lateral quadrant), determined via a vertical line from the highest point of the iliac crest to ischial tuberosity level, and a horizontal line passing through its midpoint; 6, zone of termination of dural sac (blue): ranges from L5—S1 to S4, most commonly sitting from the lower pan of S1 to the S2 level; 7—sacral hiatus bordered by sacral cornua, located at the apex of an approximately equilateral triangle with baseline measurement taken between the posterior superior iliac spines; 8—course of sciatic nerve: from approximately one-third of the way down a line joining the posterior superior iliac spine to the ischial tuberosity (superior X and white zone) to the midpoint or middle third of a line joining the ischial tuberosity to the upper greater trochanter (inferior X and white zone); 9— tip of coccyx within intergluteal cleft; 10—greater trochanter; 11—ischial tuberosity, 12—gluteal fold.

Femoral Pulse

Femoral artery pulse can be taken at mid-inguinal point (± 1 cm either side).

Note: The midinguinal point is halfway between the anterior superior iliac spine and the pubic symphysis.

The artery normally passes directly anterior to the hip joint and can be compressed against either the superior pubic ramus or the hip joint (Femoral pulse).

It is represented by the upper two third of a line joining the mid inguinal point to adductor tubercle.

Note: Femoral vein has same markings as femoral artery except that the upper point is taken 1 cm medial to mid inguinal point and lower point 1 cm lateral to adductor tubercle.

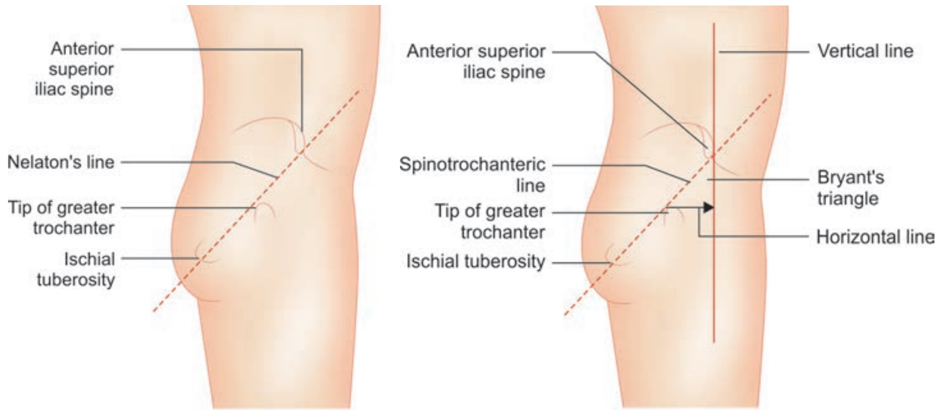


Fig. 4: Nelaton's line and Byryant's triangle

- **Nelaton's line**: It is drawn by joining the anterior superior iliac spine and the most prominent point of ischial tuberosity. It crosses the tip of greater trochanter
- **Bryant's triangle**: With the patient in supine position, a vertical line is drawn passing downwards from the anterior superior iliac spine; another line is drawn extending from ASIS to the tip of greater trochanter. The third is a horizontal line from the tip of greater trochanter to the first line.

ASSESSMENT QUESTIONS

1. **Which structure lies midway between the anterior superior iliac spine and pubic symphysis:** *(NEET Pattern 2012)*
   a. Femoral artery
   b. Deep inguinal ring
   c. Superior epigastric artery
   d. Inguinal ligament

2. **Line from midinguinal point to adductor tubercle represents:** *(NEET Pattern 2013)*
   a. Inferior epigastric artery
   b. Femoral artery
   c. Superior epigastric artery
   d. Obturator artery

ANSWERS WITH EXPLANATIONS

1. **a. Femoral artery**
   - Halfway between the anterior superior iliac spine and the pubic symphysis lies the midinguinal point.
   - Femoral artery pulse is felt at the midinguinal point ± 1 cm either side (medial to lateral).
   - Deep inguinal ring lies about 1 cm above the inguinal ligament at the mid-inguinal point.
   - ***Note:*** It is mid-inguinal point and not the mid-point of inguinal ligament.

2. **b. Femoral artery**
   - In slight flexion, abduction and lateral rotation of hip joint, a line drawn from the midinguinal point to the adductor tubercle represents the femoral artery.

Bones

Bones of the lower limb include

- Hip (coxal/innominate) bone formed by the fusion of the ilium, ischium, and pubis.
- Thigh and leg region: Femur, patella, tibia and fibula.
- Foot region: Tarsal bones (talus, calcaneus, navicular, cuboid, and three cuneiform bones); metatarsals and phalanges (proximal, middle, and distal).

Hip Bone

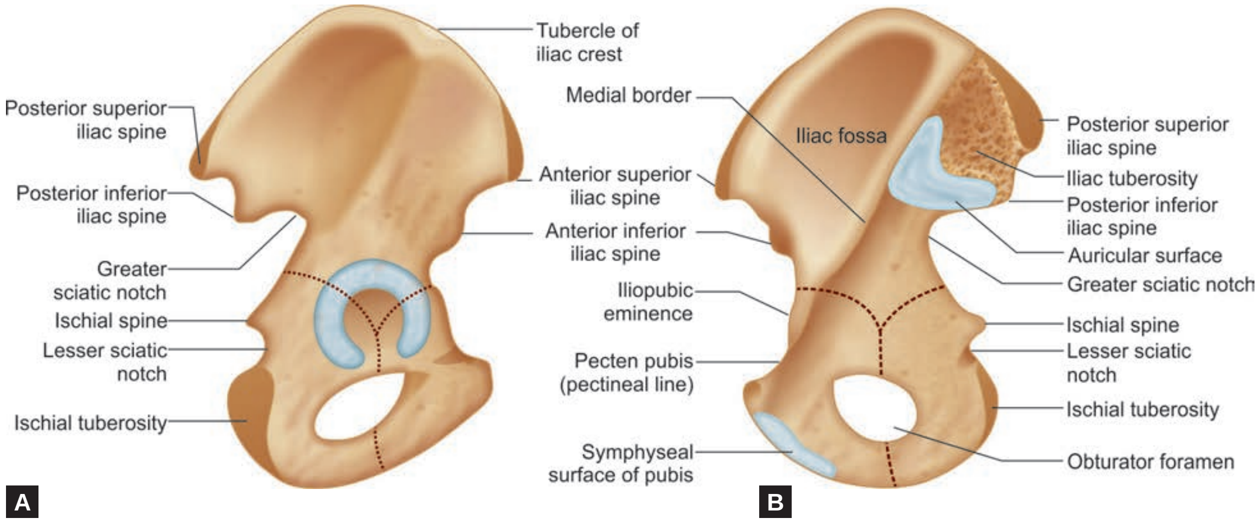
Hip bone Is formed by the fusion of the **ilium, pubis**, and **ischiumin** the acetabulum.

- It articulates with the sacrum at the sacroiliac joint to form the pelvic girdle.
- **Ilium** forms the lateral part of the hip bone and consists of the body, which joins the pubis and ischium to form the acetabulum, and the ala or wing, which forms the iliac crest.
  - It comprises also the anterior superior iliac spine, anterior inferior iliac spine, posterior iliac spine, greater sciatic notch, iliac fossa, and gluteal lines.

- **Pubis** forms the anterior part of the acetabulum and the anteromedial part of the hip bone. It comprises of the
  - Body which articulates at the symphysis pubis.
  - Superior ramus which enters the formation of the acetabulum
  - Inferior ramus which joins the ramus of the ischium, a part of the obturator foramen (formed by fusion of the ischium and pubis).
- **Ischium** forms the posteroinferior part of the acetabulum and the lower posterior part of the hip bone. It consists of the
  - Body which joins the ilium and superior ramus of the pubis to form the acetabulum
  - Ramus which joins the inferior pubic ramus to form the ischiopubic ramus.
  - Ischial spine, ischial tuberosity, and lesser sciatic notch.

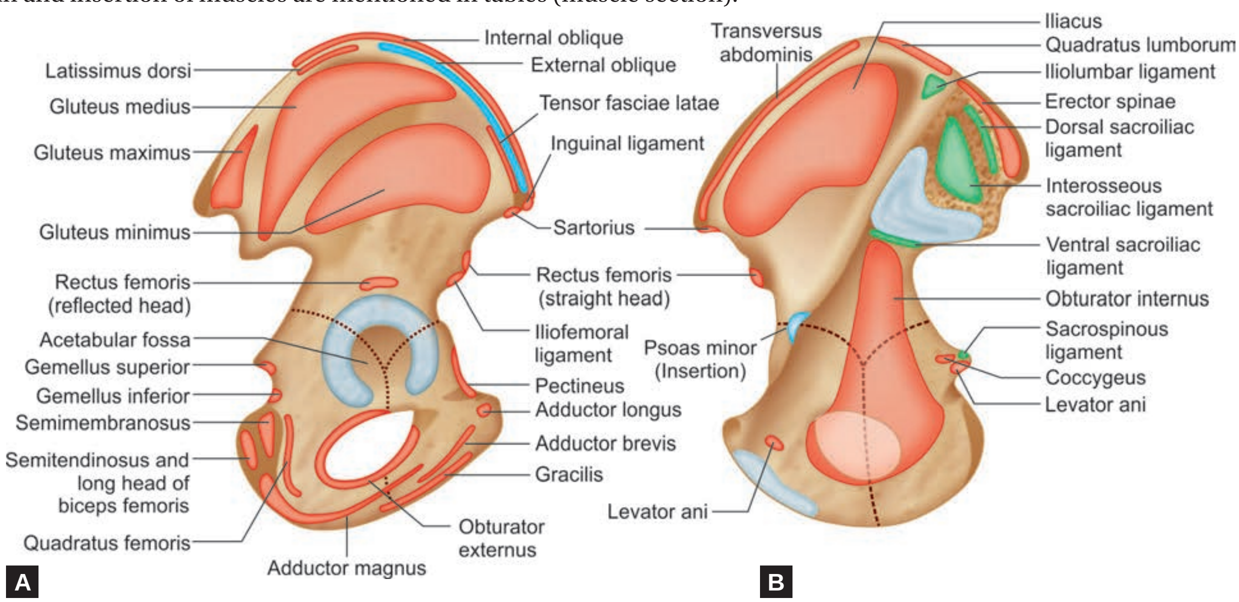
Acetabulum is an incomplete cup-shaped cavity on the lateral side of the hip bone in which the head of the femur articulates.

- It is formed by the ilium superiorly, the ischium posteroinferiorly, and the pubis anteromedially.
- It includes the acetabular notch, which is bridged by the transverse acetabular ligament.



Figs. 5A and B: General features of the ilium: (A) Outer surface; (B) Inner surface

Origin and insertion of muscles are mentioned in tables (muscle section).



Figs. 6A and B: Special features (attachments) of the ilium: (A) Outer surface; (B) Inner surface

Ischial tuberosity is broadly divided into upper and lower area.

- The upper area of the tuberosity is further subdivided by an oblique line into a superolateral part for semimembranosus and an inferomedial part for the long head of biceps femoris and semitendinosus.
- The lower area is subdivided by an irregular vertical ridge into lateral and medial areas. The larger lateral area is for part of adductor magnus.
- The medial area is covered by fibroadipose tissue that usually contains the sciatic bursa of gluteus maximus, which supports the body in sitting.

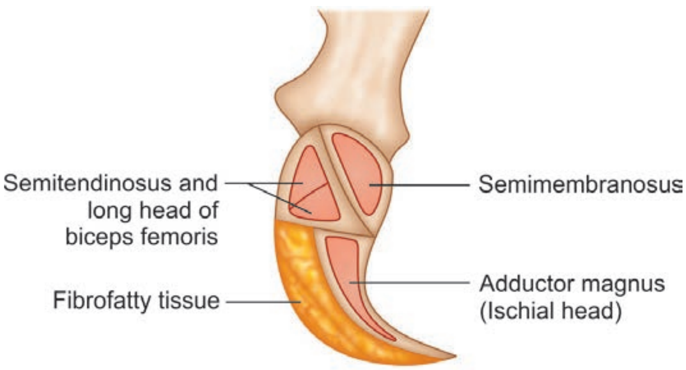


Fig. 7: Attachments on the left ischial tuberosity (posterior aspect)

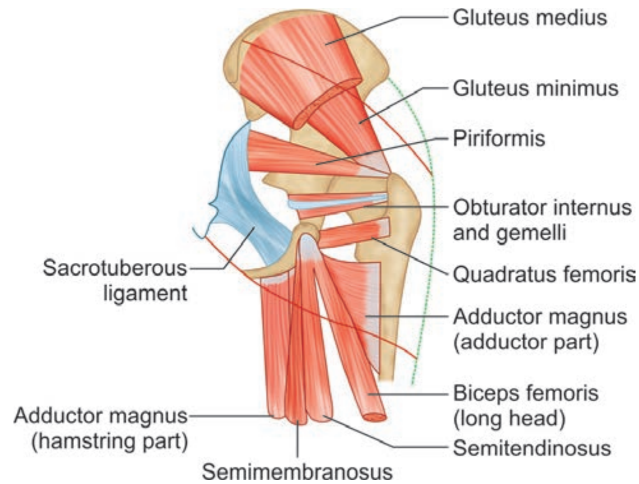


Fig. 8: Muscles under cover of the gluteus maximus. The upper and lower borders of gluteus maximus muscle are indicated by thick red lines

Sacrotuberous ligament (runs from the sacrum to the ischial tuberosity) and **sacrospinous ligaments** (runs from the sacrum to the ischial spine) convert the **greater** and **lesser sciatic notches** of the hip bone into greater and lesser sciatic foramina, the two important exits from the pelvis.

Sacrotuberous ligament is a broad band of fibrous tissue which extends from sides of the sacrum and coccyx to the medial side of the ischial tuberosity.

- The lowest fibres of gluteus maximus are attached to it and the lower part of the ligament continue into the tendon of biceps femoris.
- The coccygeal branches of the inferior gluteal artery, the perforating cutaneous nerve and filaments of the coccygeal plexus pierce the ligament.

Sacrospinous ligament extends from the ischial spine to the lateral margins of the sacrum and coccyx anterior to the sacrotuberous ligament. It is regarded as a degenerate part of coccygeus muscle.

Greater sciatic foramen is bounded anterosuperiorly by the greater sciatic notch, posteriorly by the sacrotuberous ligament and inferiorly by the sacrospinous ligament and ischial spine.

- Piriformis muscle pass through it, above which the superior gluteal vessels and nerve leave the pelvis.
- Below piriformis, the inferior gluteal vessels and nerve, sciatic and posterior femoral cutaneous nerves, nerve to quadratus femoris and **PIN** structures (**P**udendal nerve, **I**nternal pudendal vessels and **N**erve to obturator internus) leave the pelvis.

Other important structures as they exit the pelvic cavity to enter the gluteal and thigh regions: Superior gluteal vein, artery, and nerve; inferior gluteal vein, artery, and nerve; sciatic nerve.

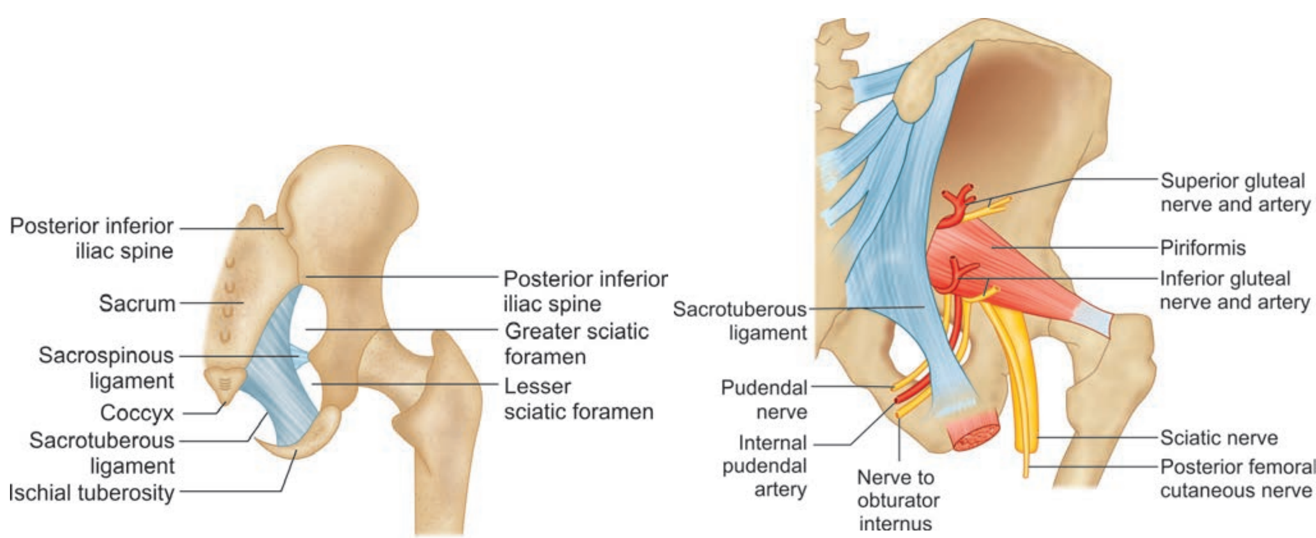


Fig. 9: PIN (Pudendal nerve, Internal pudendal vessels and Nerve to obturator internus) structures come from pelvic cavity, pass through the greater sciatic notch, hook behind the ischial spine (in gluteal region) and move into the lesser sciatic notch, to enter the perineum. The tendon (and not muscle) of obturator internus passes through the lesser sciatic notch

Ossification of hip bone

Table 2: Ossification of the hip bone		
Centres	**Age of appearance**	**Age of fusion**
Primary centres • 1 for ilium • 1 for ischium • 1 for pubis	2nd month of IUL 3rd month of IUL 4th month of IUL	18th year
Secondary centres • 2 for iliac crest • 2 for Y-shaped acetabular cartilage • 1 for ischial tuberosity	Puberty	20–25 years*
*Except acetabular cartilage which ossifies at the age of 17 years		

ASSESSMENT QUESTIONS

1. **The ischial tuberosity provides attachment to:** *(NEET Pattern 2015)*
   a. Obturator internus
   b. Quadratus femoris
   c. Gluteus maximum
   d. Adductor magnus

2. **TRUE about attachment at ischial tuberosity:** *(NEET Pattern 2015)*
   a. Origin of semitendinosus from superolateral area
   b. Origin of semimembranosus from superolateral area
   c. Origin of long head of biceps from inferolateral area
   d. Origin of adductor magnus from inferomedial area

3. **All of the following structures pass through lesser sciatic foramen except:** *(NEET Pattern 2013)*
   a. Pudendal nerve
   b. Obturator internus muscle
   c. Internal pudendal vessels
   d. Nerve to obturator internus

4. **Structure passing through both greater and lesser sciatic foramen are all except:** *(NEET Pattern 2015)*
   a. Pudendal nerve
   b. Internal pudendal vein
   c. Nerve to obturator internus
   d. Tendon of obturator internus

5. **Structures passing through lesser sciatic foramen:** *(PGIC)*
   a. Internal pudendal vessels
   b. Obturator internus muscle
   c. Pudendal nerve
   d. Nerve to obturator internus
   e. Pyriformis muscle

6. **Sacrotuberous ligament is pierced by:** *(NBEP Pattern 2015)*
   a. S1 Nerve
   b. L5 Nerve
   c. Coccygeal nerve
   d. None

ANSWERS WITH EXPLANATIONS

1. **d. Adductor magnus**
   - Posterior (hamstring) part of adductor magnus takes origin from the ischial tuberosity.
2. **b. Origin of semimembranosus from superolateral area**
   - Semi-membranosus arises by a long, flat tendon from a superolateral impression on the ischial tuberosity.
   - Semitendinosus and biceps femoris (long head) arises from an inferomedial impression on the upper area of the ischial tuberosity.
   - Hamstring part of adductor magnus originates from the inferolateral aspect of the ischial tuberosity.
   - Infero-medial aspect of gluteal tuberosity has no muscle attachment and is covered by fibrofatty tissue and is in contact with the surface we sit upon.
3. **b. Obturator internus muscle**
   - It is the tendon (not muscle) of obturator internus, which passes through lesser sciatic notch.
4. **d. Tendon of obturator internus**
   - PIN (Pudendal nerve, Internal pudendal vessels and Nerve to obturator internus) structures come from pelvic cavity, pass through the greater sciatic notch, hook behind the ischial spine (in gluteal region) and move into the lesser sciatic notch.
   - The tendon (and not muscle) of obturator internus passes through the lesser sciatic notch.
5. **a. Internal pudendal vessels, c. Pudendal nerve, d. Nerve to obturator internus**
   - Pyriformis muscle pass through greater sciatic notch.
6. **c. Coccygeal nerve**
   - The sacrotuberous ligament is pierced by the coccygeal branches of the inferior gluteal artery, the perforating cutaneous nerve and filaments of the coccygeal plexus.

Femur

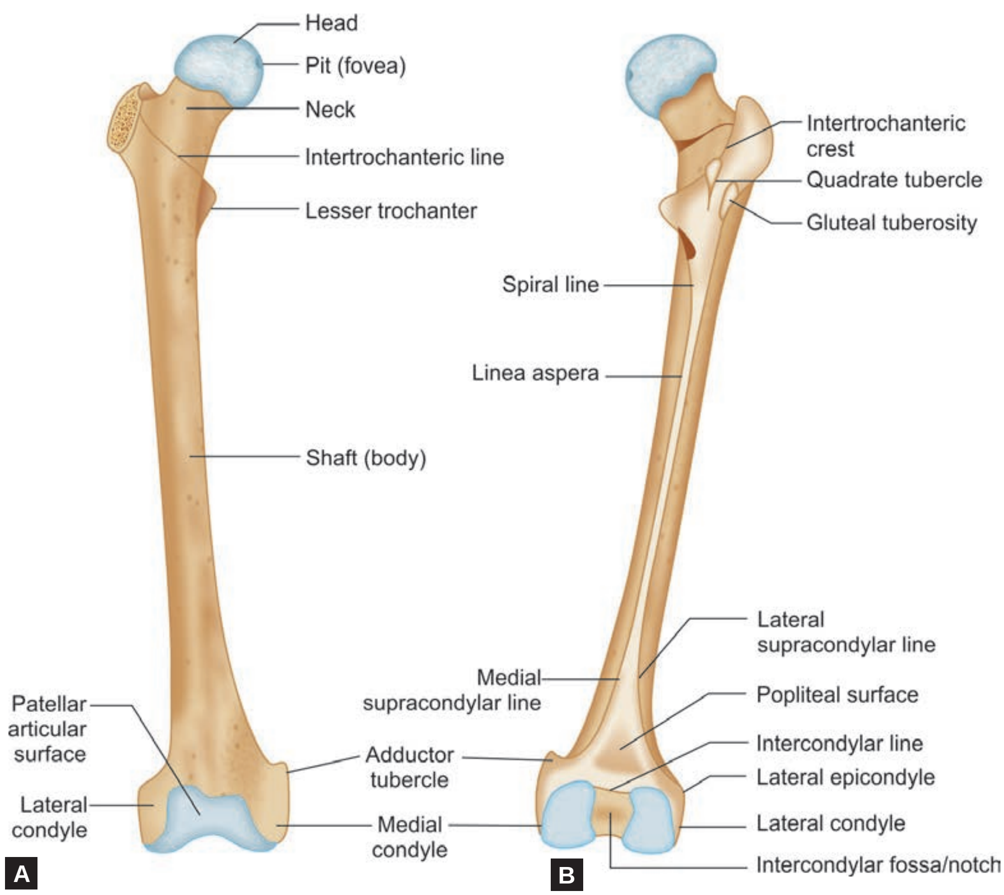
Femur is the longest and strongest bone of the body. It shows the following features:

- **Head** forms about two-thirds of a sphere and is directed medially, upward, and slightly forward to fit into the acetabulum.
  - It has a depression in its articular surface, the fovea capitis femoris, to which the ligamentum capitis femoris is attached.

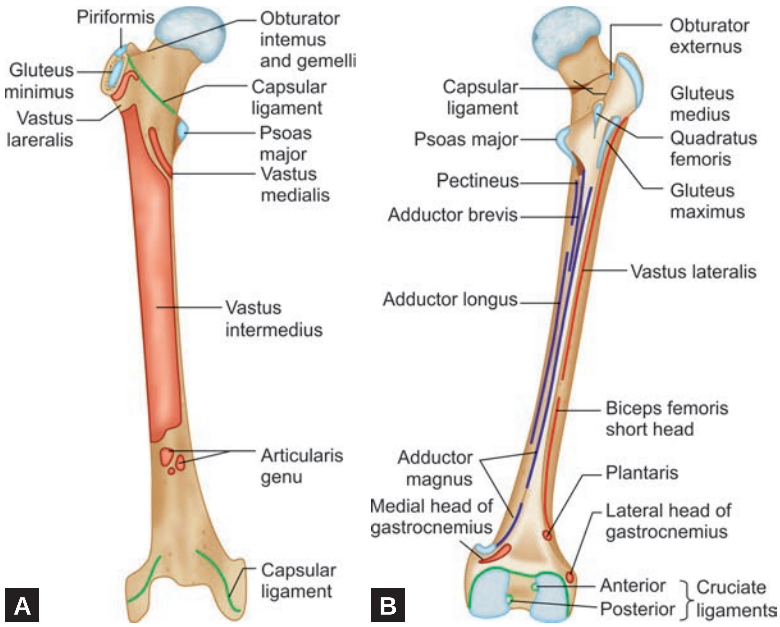
- **Neck** connects the head to the body (shaft), forms an angle of about 125 degrees with the shaft.
  - It is separated from the shaft in front by the intertrochanteric line, to which the iliofemoral ligament is attached.
- **Greater Trochanter** projects upward from the junction of the neck with the shaft.
  - It provides an insertion for the gluteus medius and minimus, piriformis, and obturator internus muscles.
  - It receives the obturator externus tendon on the medial aspect of the trochanteric fossa.
- **Lesser Trochanter** is located in the angle between the neck and the shaft.
  - It projects at the inferior end of the intertrochanteric crest.
  - It receives an insertion for the iliopsoas tendon.
- **Linea Aspera** is the rough line or ridge on the shaft of the femur.
  - It exhibits lateral and medial lips that provide attachments for many muscles and the three intermuscular septa.
  - It is perforated a little below its center by the nutrient canal, which is directed obliquely upward.
- **Pectineal Line** runs from the lesser trochanter to the medial lip of the linea aspera.
  - It provides an insertion for the pectineus muscle.
- **Adductor Tubercle** is a small prominence at the uppermost part of the medial femoral condyle.
  - It receives an insertion for the adductor magnus muscle.

Nutrient foramina are located in the region of in the linea aspera (are **directed proximally**) one is usually near its proximal end and a second usually near its distal end.

- The main **nutrient artery** to femur is usually derived from the second perforating artery (branch of **profunda femoris artery**).
- If two nutrient arteries occur, they may branch from the first and third **perforators**.
- **Linea aspera** is a prominent longitudinal ridge or crest, on the middle third of the bone, presenting a medial and a lateral lip. It is an important insertion point for the adductors and the intermuscular septa that divides the thigh into three compartments.
- Superiorly the medial lip becomes continuous with the spiral line and the outer (lateral) lip becomes continuous with the gluteal tuberosity, which extends up to the root of greater trochanter.
- When the lower end of linea aspera is traced downward, its inner and outer lips, diverge below, and enclose a triangular popliteal surface in the lower one-third of the shaft. The medial lip becomes continuous with the medial supracondylar line, which ends at the adductor tubercle. The lateral lip becomes continuous with lateral supra condylar line.



Figs. 10A and B: General features of the femur: (A) Anterior view; (B) Posterior view



Figs. 11A and B: Special features (attachments) of the femur: A, anterior view; B, posterior view

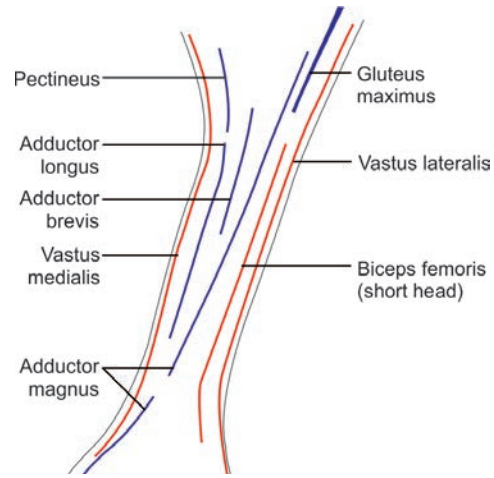


Fig. 12: Structures attached to the lines aspera (magnified view)

Attachments on linea aspera:

- From the **medial lip** of the linea aspera vastus medialis originates.
- From the **lateral lip** the vastus lateralis and short head of biceps femoris takes origin.
- The adductor magnus is inserted into the linea aspera, and to its lateral prolongation above, and its medial prolongation below.
- Between the vastus lateralis and the adductor magnus two muscles are attached: the gluteus maximus inserted above, and the short head of the biceps femoris originating below.
- Between the adductor magnus and the vastus medialis muscles inserted are : the adductor brevis and adductor longus.

Table 3: Ossification of the femur

Centres	Time of appearance	Time of fusion
Primary centre In mid-shaft	7th to 8th week of IUL	
Secondary centre • 1 for head • 1 for greater trochanter • 1 for lesser trochanter	• 1 year • 3 years • 13 years	Three separate epiphysis 18th year
For lower end 1	• 9 months (at the time of birth)	• 20 years

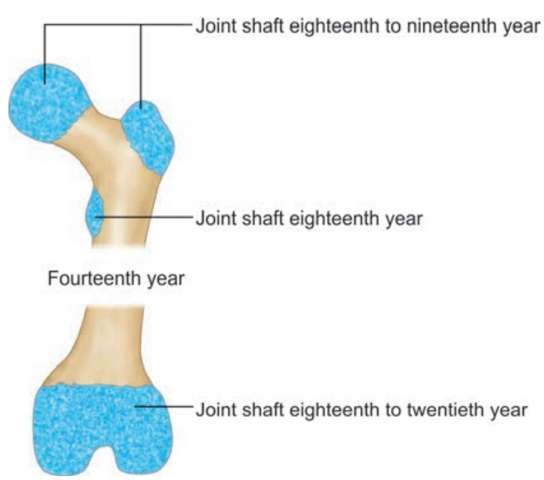


Fig. 13: Ossification of femur

- **Angle** formed between the neck and the shaft of femur is 125-140°. It keeps reducing with age.
  - Children (age 3 years) — 135°
  - Adults — 125°
  - Older age — 120°
- **Coxa valga** is an alteration of the angle made by the axis of the femoral neck to the axis of the femoral shaft so that the angle exceeds 135 degrees and, thus, the femoral neck becomes straighter.
- **In coxa vara** the angle is less than 120 degrees and, thus, the femoral neck becomes more horizontal.
- **Angle of torsion** is between the axes of head and neck of the femur and transverse axis of femoral condyles.

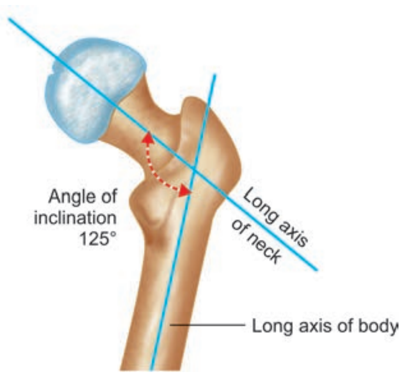


Fig. 14: Angle of inclination of the femur

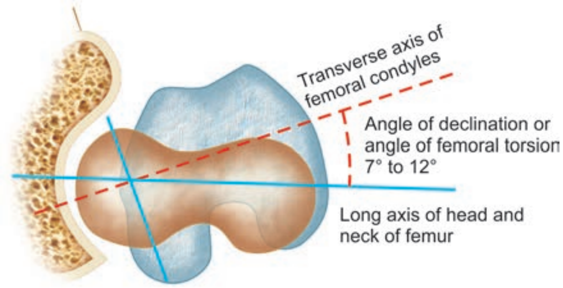


Fig. 15: Angle of the femoral torsion (angle of declination of the femur)

ASSESSMENT QUESTIONS

1. **True about linea aspera:** *(NEET Pattern 2013)*
   a. Forms lateral border of femur
   b. Forms medial border of femur
   c. Continues as gluteal tuberosity
   d. Present on the posterior surface of femur

2. **Muscle attached to medial lip of linea aspera of femur:** *(NEET Pattern 2015)*
   a. Short lead of biceps femoris
   b. Vastus lateralis
   c. Vastus intermedius
   d. Vastus medial

3. **Lower end of femur is ossified from how many ossification centers:** *(NEET Pattern 2013)*
   a. 1
   b. 2
   c. 3
   d. 4

4. **Angle of the neck of femur to shaft is:** *(JIPMER 2007; NBEP 2013)*
   a 110°
   b 125°
   c 135°
   d 100°

ANSWERS WITH EXPLANATIONS

1. **c. Continues as gluteal tuberosity**
   - Linea aspera is present on the middle third of the posterior border of femur.
   - Superiorly the medial lip becomes continuous with the spiral line and the outer (lateral) lip becomes continuous with the gluteal tuberosity.
2. **a, d. Short lead of biceps femoris, Vastus medial**
   - From the **medial lip** of the linea aspera vastus medialis originates.
3. **a. 1**
   - Lower end of femur has one secondary centre of ossification, which appears near the birth (9 months of intrauterine life) and fuses by 20th year.
4. **b. 125°**
   - The femoral neck is located between head and trochanters.
   - The femoral neck and the femoral diaphysis form the femoral neck angle that normally is about 125–140°.
   - In normal adult it is about 125° and 135° in a child at age 3 years.

Tibia

Tibia is the weight-bearing medial bone of the leg.

- It has the **tibial tuberosity** into which the patellar ligament inserts.
- The medial and lateral **condyles** articulate with the condyles of the femur.
- The lower end has a projection **medial malleolus** with a malleolar groove for the tendons of the tibialis posterior and flexor digitorum longus muscles and another groove (posterolateral to the malleolus groove) for the tendon of the flexor hallucis longus muscle. It also provides attachment for the deltoid ligament.

- The shaft shows a **nutrient foramen** directed away from the upper growing end.
- **Nutrient artery** to tibia is a branch of the **posterior tibial artery**; it may also arise at the level of the popliteal bifurcation or as a branch from the anterior tibial artery.
- On entering the bone, the nutrient artery divides into ascending and descending branches.
- It is one of the largest of the nutrient arteries.

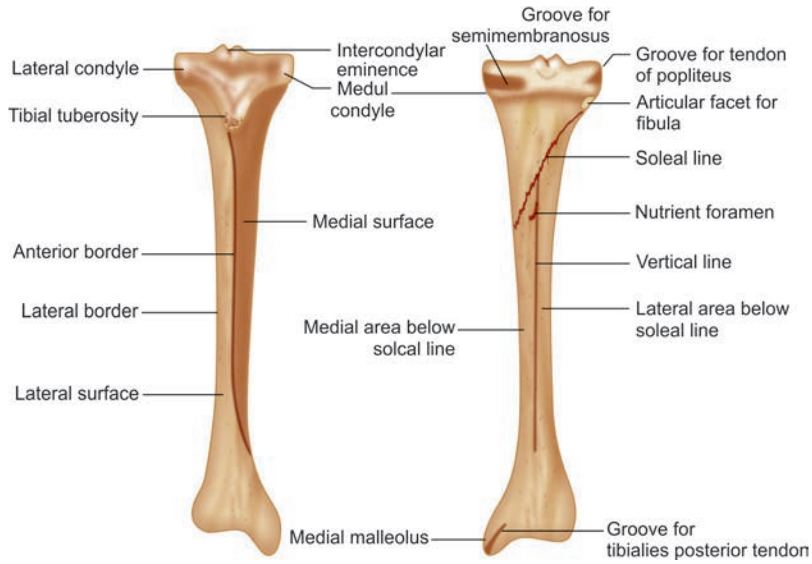
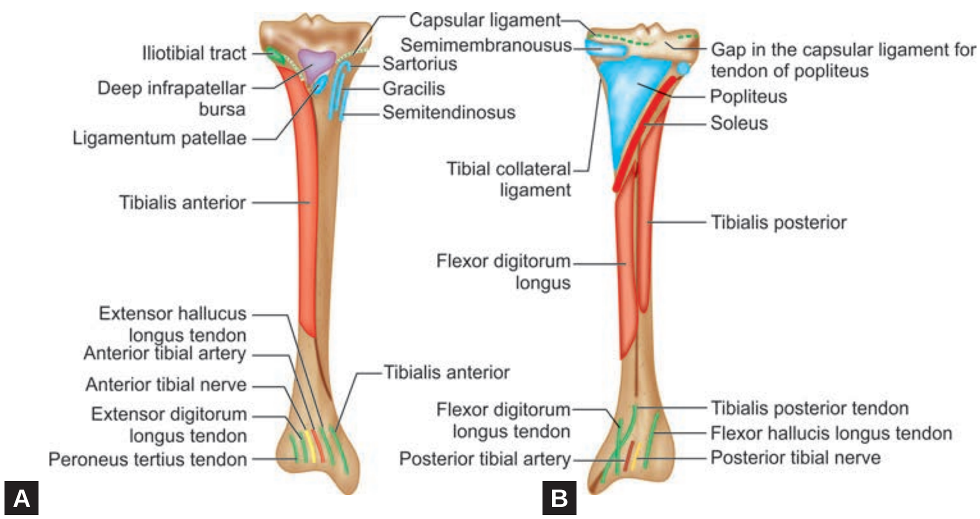
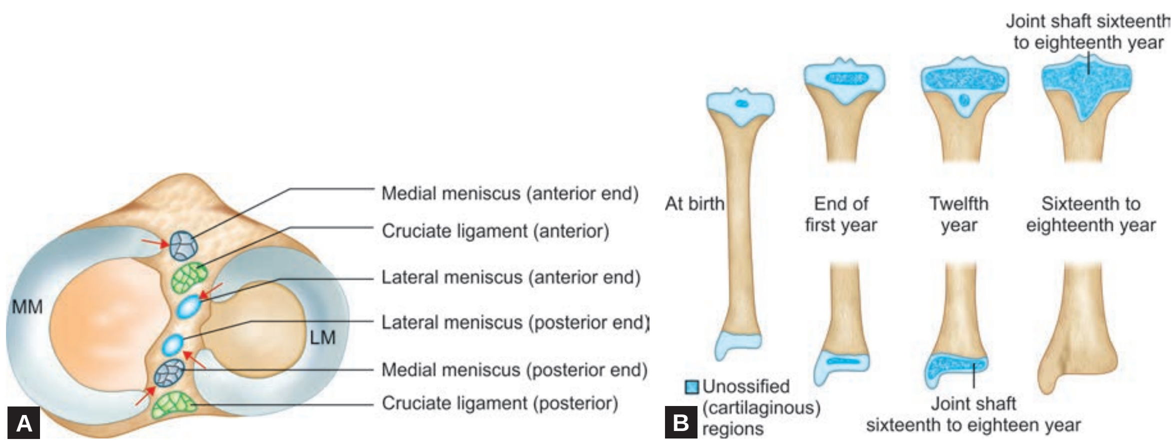


Fig. 16: Angle of the femoral torsion (angle of declination of the femur)



Figs. 17A and B: Speical features (attachment) of the tibia: A, anterior aspect; B, posterior aspect



Figs. 18A and B: Speical features (attachment) of the tibia: (A) anterior aspect; (B) Posterior aspect

Ossification of tibia: It has three centres: one primary and two secondary.

- **Primary** centre appears in the middle of shaft at the age of seventh week of IUL.
- **Secondary** centres:
  - For the **upper end** appears at birth or shortly after birth and fuses with the shaft: 20 years.
  - For the **lower end** appears at 2 years and fuses with the shaft: 18 years.

Fusion with the Shaft: 18 years

ASSESSMENT QUESTIONS

1. **All of the following are true about upper end of tibia except:** *(AI 2000)*
   a. Ossification centre for the upper end fuses by 18 years
   b. Meniscal cartilage is attached to the intercondylar area
   c. Gives attachment to semimembranosus
   d. Posterior aspect of patella articulates with upper end of tibia laterally

2. **Nutrient artery to tibia arises from which of the following arteries:** *(JIPMER 2008)*
   a. Popliteal artery
   b. Anterior tibial artery
   c. Posterior tibial artery
   d. Peroneal artery

ANSWERS WITH EXPLANATIONS

1. **d. Posterior aspect of patella articulates with upper end of tibia laterally**
   - Patella has no articulation with tibia; it is articulated to femur only.
   - **Upper end of tibia** fuses with the shaft by **18 years**.
   - Both medial and lateral **menisci** are attached to the **intercondylar area** on tibia.
   - **Semi-membranosus** muscle is attached to the medial condyle of tibia, posteriorly.
2. **c. Posterior tibial artery**
   - Nutrient artery is a branch of the posterior tibial artery; it may also arise at the level of the popliteal bifurcation or as a branch from the anterior tibial artery.

Fibula

- **Fibula** bone has little or no function in weight-bearing but provides attachment for muscles.
  - It has a head (apex) that provides attachment for the fibular collateral ligament of the knee joint.
  - Lateral malleolus is a projection that articulates with the trochlea of the talus; lies more inferior and posterior than the medial malleolus,
    - It provides attachment for the anterior talofibular, posterior talofibular, and calcaneofibular ligaments.
    - It also has the sulcus for the peroneus longus and brevis muscle tendons.
- **Ossification** of fibula: The fibula ossifies from three centres: one primary and two secondary.
  - Primary centre appears in the middle of the shaft: at the age of eighth week of IUL.
  - Secondary centres:
    - For the upper end: Appearance: 3–4 years. Fusion with the shaft: 20 years.
    - For the lower end: Appearance: 1–2 years. Fusion with the shaft: 18 years.

  Note: In fibula, law of union of epiphysis is **not** followed.
- Law of ossification: Epiphyseal (secondary) centre which **appears first** unites last with the diaphysis.
- In fibula, epiphyseal centre for lower end **appears first and also unites first**.
- The explanation to this violation is that epiphyseal centre in the lower end of fibula appears earlier because it is pressure epiphysis and in the upper end later because it is traction epiphysis.
- Since the growing end fibula is its upper end (as evidenced by the direction of nutrient foramen) it unites with the diaphysis last although its epiphyseal centre also appears last.
- **Nutrient artery** branches from the fibular (peroneal) artery to enter 14–19 cm from the apex of the head of the fibula.

High Yield Point

- Styloid process of fibula bone gives attachment to fibular collateral ligament (knee joint) and biceps femoris.

Patella

Patella bone is the largest sesamoid bone and is located within the tendon of the quadriceps femoris, which articulates with the femur but not with the tibia.

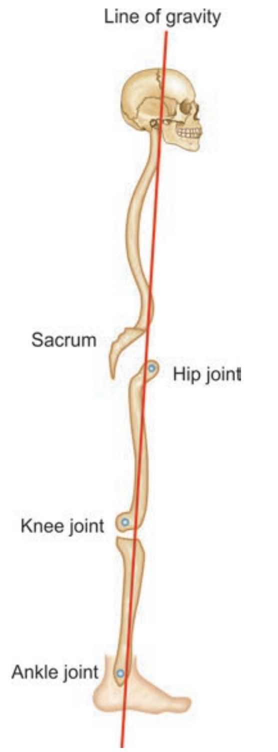
- It attaches to the tibial tuberosity by a continuation of the quadriceps tendon called the patellar ligament.
- It functions to obviate wear and attrition on the quadriceps tendon as it passes across the trochlear groove and to increase the angle of pull of the quadriceps femoris, thereby magnifying its power.

Ossification: Several centres appear during the third to sixth years and these coalesce rapidly.

- Accessory marginal centres appear later and fuse with the central mass.

Weight Distribution

- Line of gravity of the body passes through the cervical vertebrae, anterior to the thoracic vertebrae, through the lumbar vertebrae, anterior to the sacrum, posterior to the hip joints, and anterior to the knee and ankle joints.
- Body weight is transferred from the vertebral column through sacroiliac joints to the pelvic girdle and from pelvic girdle through the hip joints to the femurs.
- Pelvic girdle connects the lower limb to the axial skeleton via the sacroiliac joint, a plane synovial type of joint, allows effective weight transmission from the trunk to the lower limb.
  - Anteriorly, the pelvic girdle articulates with the contralateral girdle at the pubic symphysis, a secondary cartilaginous joint that may display a slight degree of mobility during hip and sacroiliac movement, and during
- Body weight is transferred from the knee joint to the ankle joint by the tibia.
  - Fibula does not articulate with the femur, hence does not transfer any weight.
  - At the ankle, the weight born by the tibia is transformed to the talus- the keystone of the longitudinal arch of the foot.
  - The longitudinal arch formed by the tarsals and metatarsals, evenly distribute the weight between the heel and foot when standing.
- Both the knee and ankle are commonly subject to closed injuries, and the relatively superficial location of the knee renders it susceptible to open injury
- Although the ankle is frequently injured and is a major load-bearing joint, the incidence of clinically significant degenerative arthritis is surprisingly low when compared with that found in the hip and knee joints.



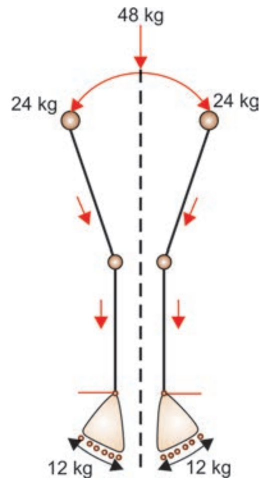


Fig. 19: Distribution of weight to the feet

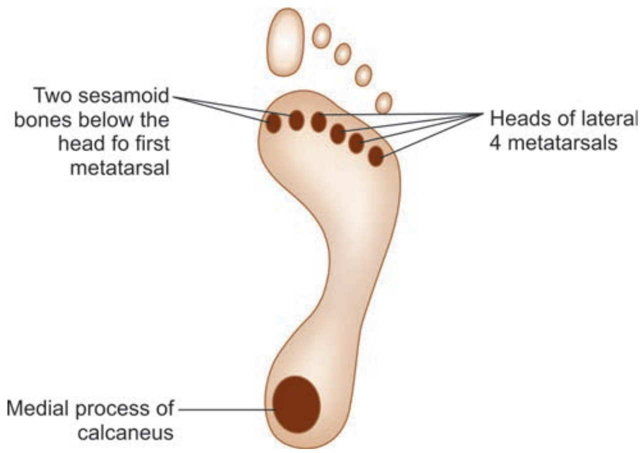


Fig. 20: Weight-bearing points of the foot

Bones

ASSESSMENT QUESTION

1. **FALSE about tibia fibula is:** *(NEET Pattern 2015)*
   a. Nutrient artery of tibia is from posterior tibial artery
   b. Nutrient artery of fibula is from peroneal artery
   c. Proximal end of tibia is related to common peroneal nerve
   d. Tibia is the most common site of osteomyelitis

ANSWER WITH EXPLANATION

1. **c. Proximal end of tibia is related to common peroneal nerve**
   - There is no detail of common peroneal nerve relation to the proximal end of tibia in literature.
   - Primary hematogenous osteomyelitis is more common in infants and children, usually occurring in the long bone metaphysis, upper end of tibia being the commonest site of acute osteomyelitis.

High Yield Points

- Tibio-femoral condyles are involved in weight transmission (pressure epiphysis) and are intracapsular.
- Lower end of femur ossifies from one centre of ossification.
- Lateral lip of linea aspera continues as gluteal tuberosity.

Joints

- **Pelvic girdle** connects the lower limb to the axial skeleton via the sacroiliac joint, in which mobility has been sacrificed for stability and strength, which allows effective weight transmission from the trunk to the lower limb.
  - Anteriorly, the pelvic girdle articulates with the contralateral girdle at the pubic symphysis, has slight degree of mobility during hip and sacroiliac movement, especially during childbirth.
  - The hip has balanced stability and mobility and allows movement in all three orthogonal planes.
  - The more distal joints have gained mobility at the cost of stability.
  - The knee joint is a compound joint mainly between the femur and the tibia, and allows flexion, extension and some medial and lateral rotation of the leg.
    - It is not a true hinge joint because its axes of flexion and extension are variable and there is coupled rotation.
    - It also includes the articulation between the patella and femur.
  - The tibia and fibula articulate with each other at the superior and inferior tibiofibular joints.
    - The superior joint allows slight gliding movement only, whereas the inferior joint allows a degree of fibular rotation linked to ankle motion.
  - The ankle (talocrural) joint is formed by the distal ends of the tibia and fibula gripping the talus, and allows dorsiflexion and plantar flexion.
  - The multiple joints in the foot allow the complex movements as required for working as a platform for standing and for shock absorption and propulsion in gait.
  - The various movements, alongwith muscles and their innervation.

Joint	Movement	Muscle	Innervation	L1	L2	L3	L4	L5	S1	S2	S3
HIP	Flexion	Psoas major	Spinal nn. L1- 3								
		Iliacus	Femoral n.								
		Pectineus	Femoral n. or accessory obturator n.								
		Rectus femoris	Femoral n.								
		Adductor longus	Obturator n.								
		Sartorius	Femoral n.								
	Extension	Gluteus maximus	Inferior gluteal n.								
		Adductor magnus	Obturator and tibial nn.								
		Semitendinosus, semimem-branosus, biceps femoris	Tibial and common fibular nn.								
	Medial rotation	Iliacus	Femoral n.								
		Gluteus medius and minimus	Superior gluteal n.								
		Tensor fasciae latae	Superior gluteal n.								
	Lateral rotation	Superior and inferior gemelli	Nerve to obturator internus and nerve to quadratus femori, srespectively								
		Quadratus femoris	Nerve to quadratus femoris								
		Piriformis	Nerve to piriformis								
		Obturator internus	Nerve to obturator internus								
		Obturator externus	Obturator n.								
		Sartorius	Femoral n.								
	Adduction	Gracilis	Obturator n.								
		Adductor longus	Obturator n.								
		Adductor magnus	Obturator and tibial nn.								
		Adductor brevis	Obturator n.								
		Pectineus	Femoral n. or accessory obturator n.								
	Abduction	Tensor fasciae latae	Superior gluteal n.								
		Gluteus medius and minimus	Superior gluteal n.								
		Piriformis	Nerve to piriformis								

Joint	Movement	Muscle	Innervation	L1	L2	L3	L4	L5	S1	S2	S3
Knee	Flexion	Semimembranosus	Tibial n.								
		Semitendinosus	Tibial n.								
		Biceps femoris	Tibial and common fibular nn								
		Gastrocnemius	Tibial n.								
	Extension	Quadriceps femoris									
		Rectus femoris	Femoral n.								
		Vastus lateralis	Femoral n.								
		Vastus intermedius	Femoral n.								
		Vastus medals	Femoral n.								
Ankle	Dorsiflexion	Tibialls anterior	Deep fibular n.								
		Extensor digitorum longus	Deep fibular n.								
		Extensor hallucis longus	Deep fibular n.								
		Fibularis tertius	Deep fibular n.								
	Plantar Flexion	Gastrocnemius	Tibial n.								
		Soleus	Tibial n.								
		Flexor digitorum longus	Tibial n.								
		Flexor hallucis longus	Tibial n.								
		Fibularis longus	Superficial fibular n.								
		Tibialis posterior	Tibial n.								
	Inversion	Tibialis anterior	Deep fibular n.								
		Tibialis posterior	Tibial n.								
	Eversion	Fibularis longus	Superficial fibular n.								
		Fibularis tertus	Deep fibular n.								
		Fibularis brevis	Superficial fibular n.								
Toes	Flexion	Flexor digitorum longus	Tibial n.								
		Flexor hallucis longus	Tibial n.								
		Flexor hallucis brevis	Medial plantar n.								
		Flexor digitorum brevis	Medial plantar n.								
		Flexor accessorius (quadratus plantae)	Lateral planter n.								
		Flexor digiti minimi brevis	Lateral planter n.								
		Abductor hallucis	Medial plantar n.								
		Abductor digiti minimi	Lateral plantar n.								
		Lumbricals	Medial and lateral plantar nn.								
	Extension	Extensor digitorum longus	Deep fibular n.								
		Extensor hallucis longus	Deep fibular n.								
		Extensor digitorum brevis	Deep fibular n.								
	Abduction	Abductor hallucis	Medial plantar n.								
		Abductor digiti minimi	Lateral plantar n.								
		Dorsal interossei	Lateral plantar n.								
	Adduction	Plantar interossei	Lateral plantar n.								
		Adductor hallucis	Lateral plantar n.								

Note: Blue shading denotes nerve roots from which there is a known dominant contribution. green shading denotes nerve roots from which the contribution is of similar degree.

Joint	Type
Sacroiliac joint	Plane synovial
Pubis symphysis	Symphysis (secondary cartilaginous)
Hip	Ball and socket synovial
Knee	Bicondylar (>Modified hinge) synovial
Superior tibiofibular joint	Plane synovial
Middle radioulnar	Fibrous (Syndesmosis)
Inferior tibiofibular	Fibrous (Syndesmosis)
Ankle	Hinge synovial
Talocalcaneonavicular	Ball and socket synovial
Subtalar (talocalcaneal)	Plane synovial
Calcaneocuboid	Saddle synovial
Other Intercarpal and midcarpal	Plane synovial
Metatarsophalangeal	Ellipsoid (> Condylar) synovial
Interphalangeal	Hinge

Hip Joint

Hip joint is a synovial ball-and-socket joint and exhibits a very effective compromise between mobility and stability that allows movement in all three orthogonal planes.

Ligaments of hip joint

- **Capsule** attaches to acetabular margin of hip bone, labrum and transverse acetabular ligament.
  - On the femur, it is attached anteriorly to the intertrochanteric line and posteriorly 1 cm in front of (medial to) the intertrochanteric crest).
  - It has two types of fibres—inner circular (zona orbicularis) fibres and outer longitudinal fibres (which are reflected along the neck toward the head to form the retinacula).
  - Note: The synovial membrane lines inner aspect of the fibrous capsule, the intracapsular portion of the femoral neck, glenoid labrum (both surfaces), transverse acetabular ligament, ligamentum teres, and fat in the acetabular fossa.
- **Iliofemoral** ligament (of Bigelow) lies anteriorly and blends with the capsule.
  - It has inverted Y-shaped , whose apex is attached to the lower half of the anterior inferior iliac spine and acetabular margin and the base to the intertrochanteric line.
  - It has three parts: A lateral thick band of oblique fibres, a medial thick band of vertical fibres, and a large central thin portion.
  - It is the strongest ligament of body and prevents the trunk from falling backward in the standing posture.
  - It also prevents hyperextension of hip joint during standing.
- **Pubofemoral ligament** reinforces the fibrous capsule inferiorly, extends from the pubis bone to the femoral neck, and **limits abduction** and extension.
- **Ischiofemoral ligament** supports the capsule posteriorly. its fibres attach to ischium bone, spiral behind the femoral neck to be attached into the greater trochanter deep to the iliofemoral ligament.
- **Ligamentum teres** (round) of the head of femur is actually a flat triangular ligament with apex attached to the fovea of the head, and its base to the transverse acetabular ligament.
  - It carries acetabular branches of the obturator and medial circumflex femoral arteries.
- **Acetabular labrum** is a fibrocartilaginous rim attached to the acetabular margin to deepen it. It's transverse acetabular part bridges the acetabular notch.

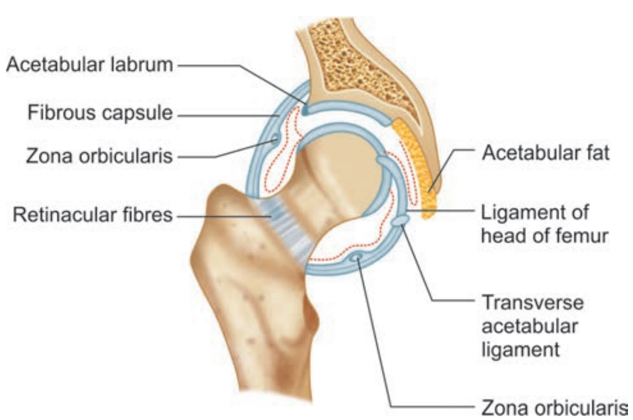


Fig. 21: Coronal section of the right hip joint showing the fibrous capsule and the lining of synovial member

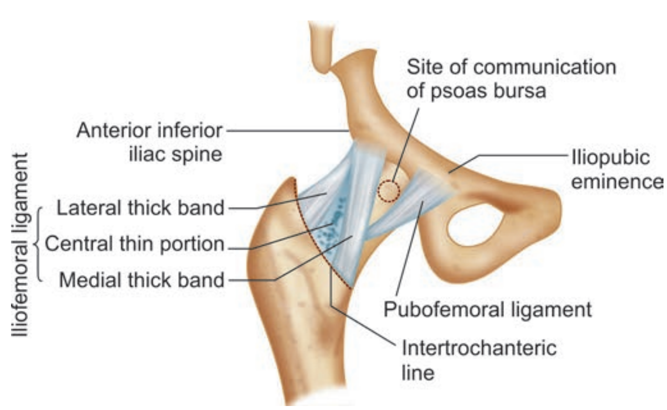


Fig. 22: Iliofemoral and pubofemoral ligaments

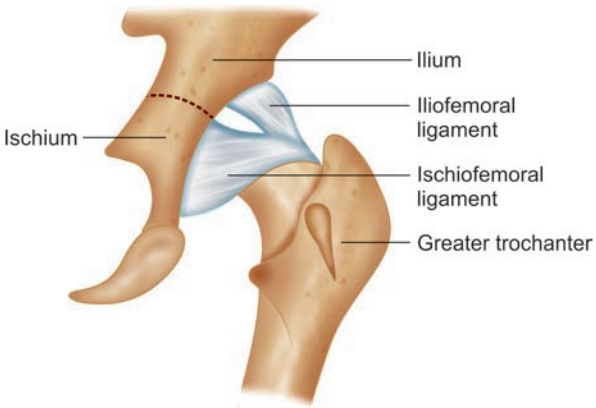


Fig. 23: Ischiofemoral and iliofemoral ligaments

Neurovascular Bundle (Hip Joint)

Arterial Supply

- Medial and lateral circumflex femoral arteries, obturator artery, superior and inferior gluteal arteries.
- They also supply the **head of femur**, but arterial supply of the head and neck of the femur is chiefly derived from the **medial circumflex artery**.
- These are **retinacular** arteries, which run along the neck of the femur through the retinaculum of the capsule.
- **Note:** Nutrient artery of the femur gives few branches to the neck and head of femur

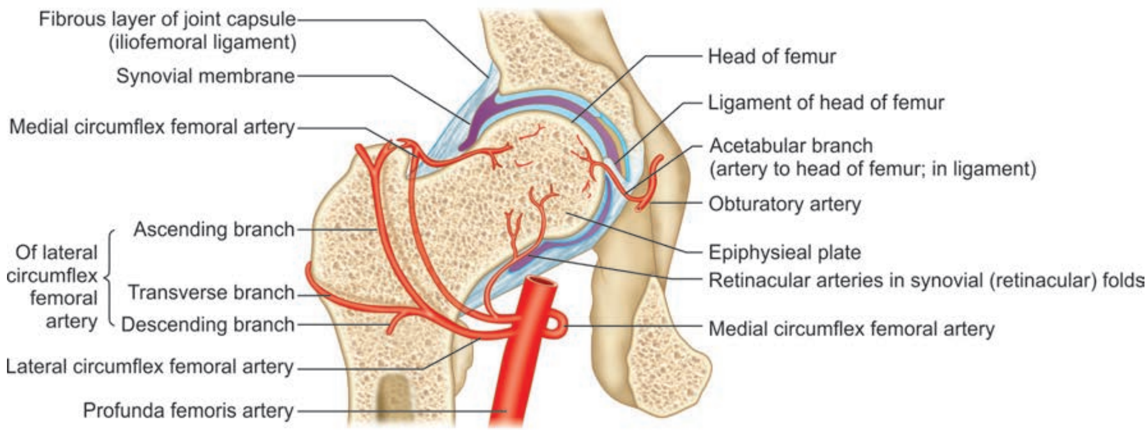
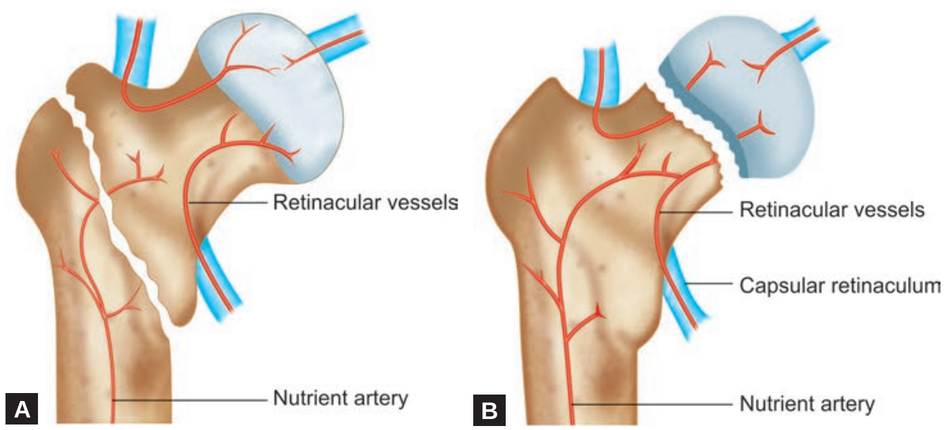


Fig. 24: Blood supply of head and neck of femur. Branches of the medial and lateral circumflex femoral arteries, branches of the profunda femoris artery, and the artery to the femoral head (a branch of the obturator artery) supply the head and neck of the femur. In the adult, the medial circumflex femoral artery is the most important source of blood to the femoral head and adjacent (proximal) neck



Figs. 25A and B: Involvement of arteries supplying the head of femur: (A) Non-involvement of retinacular vessels in extracapsular pretrochanteric fracture of the neck of femur; (B**)** Involvement of retinacular vessels in intracapsular subcapital fracture of the neck of femur

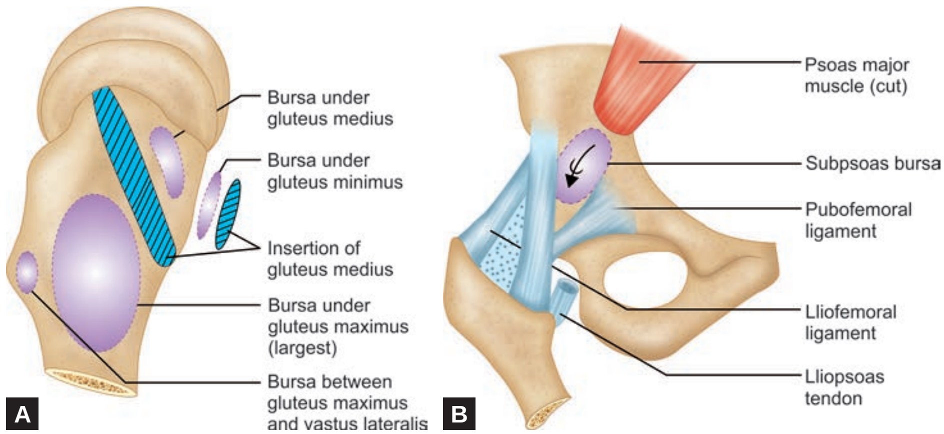
Nerve supply: Femoral nerve (via nerve to rectus femoris), anterior division of obturator nerve, nerve to quadratus femoris, superior gluteal nerve, sciatic nerve (occasional).

Bursa (Around Hip Joint)

There are seven bursa related to hip joint: four under glutens maximus, one under gluteus medius, one under gluteus minimus, and one under psoas tendon.

Few of them are discussed here:

- Trochanteric bursa : Between gluteus maximus and greater trochanter.
- Ischial bursa : Between gluteus maximus and ischial tuberosity.
- Gluteofemoral bursa: Between gluteus maximus and vastus lateralis .
- Subpsoas bursa : Between the iliopubic eminence and the psoas tendon.
    - It communicates with the synovial cavity through a gap between the iliofemoral and pubofemoral ligaments.



Figs. 26A and B: Bursae around the hip joint: (A) bursae on greater trochanter; (B) Subpsoas bursa communicating with the cavity of hip joint (arrow)

ASSESSMENT QUESTION

1. Gluteofemoral bursa is in between gluteus maximus and: *(NEET Pattern 2014)*

a. Greater trochanter
b. Lesser trochanter
c. Ischial tuberosity
d. Vastus lateralis

ANSWER WITH EXPLANATION

1. d. Vastus lateralis

Gluteofemoral bursa is present between gluteus maximus and vastus lateralis.

Radiology

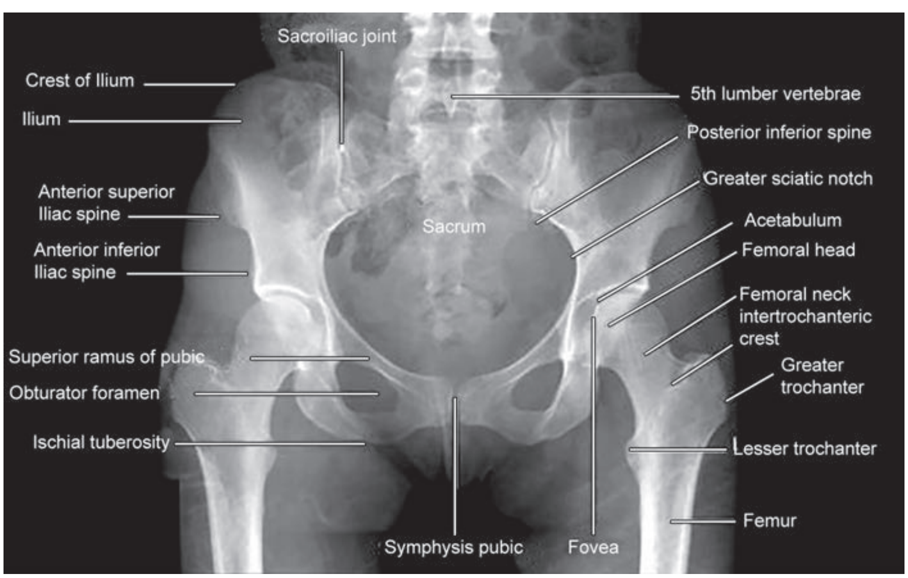


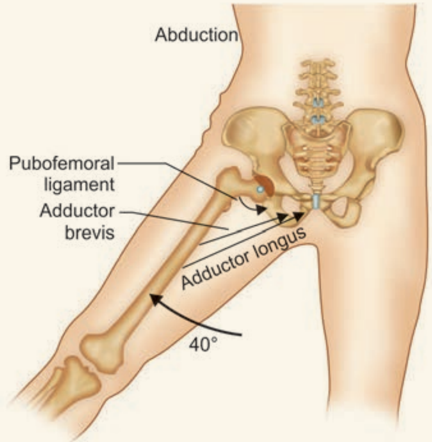
Fig. 27: X-ray—Hip joint

ASSESSMENT QUESTIONS

1. Regarding hip joint, which of the following statements is true: *(NEET pattern 2014)*
   a. Retinaculum attaches femur to hip bone
   b. Inferior gluteal nerve supplies the hip abductors
   c. Capsule is attached to the intertrochanteric line
   d. Ilio-psoas causes hip abduction

2. Iliofemoral ligament arise from: *(PGIC 2014)*
   a. Ischial tuberosity
   b. Anterior superior iliac spine
   c. Iliopubic rami
   d. Anterior inferior iliac spine
   e. Iliac crest

3. Abduction of the thigh is limited by:
   a. Tension in the adductors
   b. Tension in the adductors and iliofemoral ligament
   c. Tension in the adductors and pubofemoral ligament
   d. Tension in the adductors and ischiofemoral ligament



4. Hip flexion is done by all EXCEPT:
   a. Ilio-psoas
   b. Pectineus
   c. Sartorius
   d. Semitendinosus

5. Gluteofemoral bursa is in between gluteus maximus and: *(NEET pattern 2014)*
   a. Greater trochanter
   b. Lesser trochanter
   c. Ischial tuberosity
   d. Vastus lateralis

ANSWERS WITH EXPLANATIONS

1. c. Capsule is attached to the intertrochanteric line
- **Capsule of the hip joint is attached to the intertrochanteric line.**
- **Retinacular fibres** are reflected capsular fibres running on the neck of femur and carry arterial supply to neck and head of femur. They are not attached to hip bone.
- **Inferior gluteal nerve** supplies gluteus maximus muscle, which is the chief extensor at hip joint. Hip abductors are supplied by superior gluteal nerve.
- **Ilio-psoas** muscle is the chief muscle for hip flexion.

2. d. Anterior inferior iliac spine
- Iliofemoral ligament attaches to the anterior inferior iliac spine and the rim of the acetabulum, spreads obliquely downwards and lateral to attach to the intertrochanteric line on the anterior side of the femoral head.

3. c. Tension in the adductors and pubofemoral ligament
- Pubofemoral (adductor) muscles and pubofemoral ligaments pull the femur back towards pubis bone (midline), hence limiting abduction.

4. d. Semitendinosus
- **Hip flexion** is chiefly carried out by **ilio-psoas** muscle and assisted by muscles like **pectineus, sartorius** etc.
- **Semitendinosus** is a hamstring muscle for **hip extension** along with the gluteus maximus.

5. d. Vastus lateralis
Gluteofemoral bursa is present between gluteus maximus and vastus lateralis.

High Yield Points

- The strongest flexor of hip joint is ilio-psoas muscle.
- Hip flexion is done by sartorius, pectineus, rectus femoris (but not gluteus maximus).
- Trendelenberg test is positive in paralysis of gluteus medius, gluteus minimus, tensor fascia lata (but not gluteus maximus).
- The iliofemoral ligament of Bigelow (that forms an inverted Y shape) is the strongest ligament of the hip joint and limits hyperextension.
- Langenbeck triangle has its apex at the anterior superior spine of the ilium, its base along the anatomical neck of the femur, and its external side by the external face of the greater trochanter of the femur (JIPMER 2015).

Knee Joint

Knee joint is a bicondylar synovial joint, between the femur and the tibia, allows flexion, extension and some medial and lateral rotation of the leg.

- It is not a true hinge joint because its axes of flexion and extension **are variable and there is coupled rotation.**
- It also includes the articulation between the patella and femur; hence consists of three **functional compartments (a compound joint).**

Table 4: Muscles producing movement

		Muscles Producing Movement			
Movement	**Degrees possible**	**Primary**	**Secondary**	**Factors limiting (checking) movement**	**Comments**
Extension	Normal knees extend to 0° (straight alignment of axes of tibia and femur)[a]	Quadriceps femoris	Weakly: tensor fasciae latae	Anterior edge of lateral meniscus contacts shallow groove between tibial and patellar surfaces of femora condyles; anterior cruciate ligament contacts groove in intercondylar fossa	Ability of quadriceps to produce extension is most effective when hip joint is extended, flexion diminishes its efficiency
Flexion	120° (hip extended); 140° (hip flexed); 160° passively	Hamstrings (semitendinosus, semimembranosus, long head of biceps); short head of biceps	Gracilis, sartorius, gastrocnemius, popliteus	Calf of leg contacts thigh; length of hamstrings is also a factor—more knee flexion is possible when hip joint is flexed; cannot fully flex knee when hip is extended	Normally, role of gastrocnemius is minimal, but in presence of a supracondylar fracture, it rotates (flexes) distal fragment of femur
Medial rotation	10° with knee flexed; 5° with knee extended	Semitendinosus and semimembranosus when knee is flexed; popliteus when non-bearing knee is extended	Gracilis, sartorius	Collateral ligaments, loose during flexion without rotation, become taut at limits of rotation	When extended knee is bearing weight, action of popliteus laterally rotates femur; when not bearing weight, popliteus medially rotates patella
Lateral rotation	30°	Biceps femoris when knee is flexed		Collateral ligaments become taut; anterior cruciate ligament becomes wound around posterior cruciate ligament	At end of rotation, with no opposition, tensor fasciae latae can assist in maintaining position

[a]Straight alignment of axis of tibia with axis of femur is 0°; normal range extends to –3° (3° of hyperextension).

- The range of extension is 5–10° beyond the 'straight position.'
- Active flexion is approximately 120° with the hip extended, 140° when it is flexed, and 160° when aided by a passive element, e.g. sitting on the heels.
- Voluntary rotation is 60–70° but conjunct rotation only 20°.
- **Menisci**:
  - The menisci (semilunar cartilages) are crescentic, intracapsular, fibrocartilaginous laminae dividing knee joint into two compartments.
  - Flexion and extension of the knee take place in the upper compartment, whereas the rotation of the knee occurs in the lower compartment.
  - Their peripheral attached borders are thick and convex, and their free, inner borders are thin and concave.
  - Their peripheries are vascularized by capillary loops from the fibrous capsule and synovial membrane, while their inner regions are less vascular.
  - Peripheral tears have the potential to heal satisfactorily on surgical reconstruction.
  - Central meniscal tears seldom heal spontaneously (poor blood supply); and are often resected.
  - The meniscal horns are richly innervated compared with the remainder of the meniscus. The central one-third is devoid of innervation.
  - Only the outer portion is covered by synovium.
  - The tibial attachment of the meniscus is known as the coronary (meniscotibial) ligament.
- **Medial meniscus** (C-shaped)
  - Anterior horn is attached to the anterior tibial intercondylar area in front of the anterior cruciate ligament.
  - The posterior horn is fixed to the posterior tibial intercondylar area, between the attachments of the lateral meniscus and posterior cruciate ligament.
  - Its peripheral border is attached to the fibrous capsule and the deep surface of the tibial collateral ligament. Medial meniscus is relatively fixed and moves much less than the lateral meniscus (more prone to injury due to fixed nature).
- **Lateral meniscus** (O-shaped)
  - The lateral meniscus covers a larger area than the medial meniscus.
  - Its anterior horn is attached in front of the intercondylar eminence, posterolateral to the anterior cruciate ligament, posterior horn gets attached behind this eminence, in front of the posterior horn of the medial meniscus.

- Near its posterior attachment, it sends an anterior (Humphrey) and posterior (Wrisberg) meniscofemoral ligament attaching to the medial femoral condyle, which controls the mobility of posterior horn alongwith popliteus muscle. Lateral meniscus It is grooved posterolaterally by the tendon of popliteus, which separates it from the fibular collateral ligament. Popliteus muscle has a protective function by pulling the posterior horn of meniscus backward, so that it is not crushed between the articular surfaces.
- ***Note:*** Pain on the medial rotation of tibia on the femur indicates injury of the medial meniscus while pain on the lateral rotation of tibia on the femur indicates injury of the lateral meniscus.

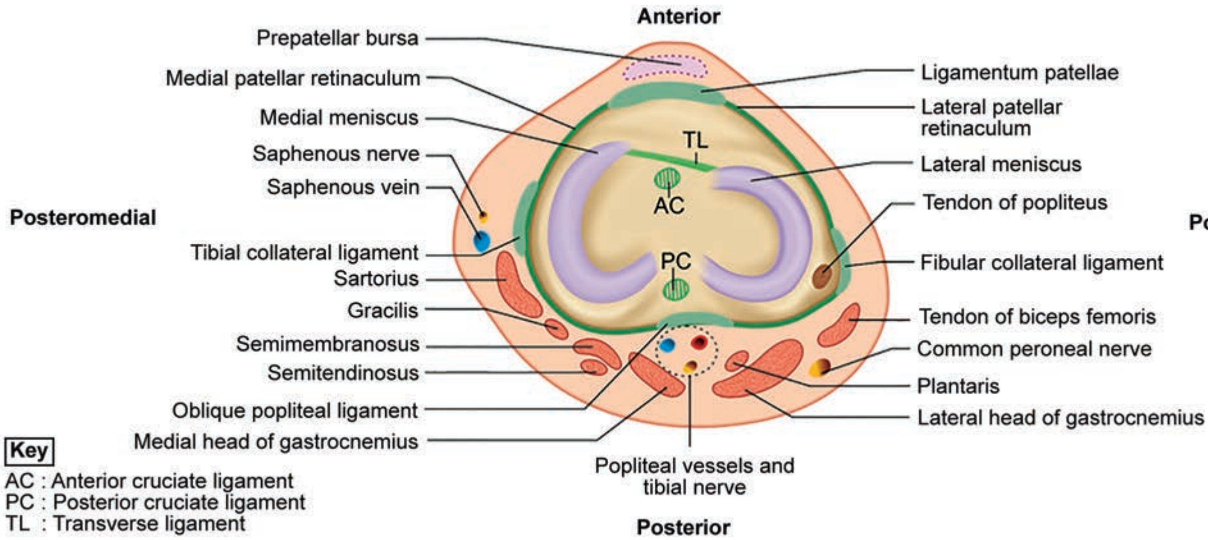


Fig. 28: Relations of the knee joint (transverse section of right knee joint)

- **Cruciate Ligaments**
  - The cruciate ligaments cross each other (hence named) and attach tibia bone with femur and maintain anteroposterior stability of the knee joint.
  - Further naming as anterior and posterior is with reference to their tibial attachments.
  - These ligaments invaginate the synovial membrane from posterior side in the knee joint and synovial membrane almost surrounds the ligaments but is reflected posteriorly from the posterior cruciate ligament to adjoining parts of the capsule. Hence, cruciate ligaments are intracapsular but extrasynovial structures still lined by synovial membrane all around (except the posterior portion of PCL, which is devoid of synovial membrane).
- **Anterior cruciate ligament** is attached to the anterior intercondylar area of the tibia and runs backward, upward, and laterally (BUL) to get attached to the posteromedial aspect of the lateral femoral condyle.
  - It prevents forward sliding of the tibia on the femur (or posterior displacement of the femur on the tibia) and prevents hyperextension of the knee joint.
  - It is **taut during extension of the knee** and is lax during flexion. It may be injured in hyperextension injuries.
- Posterior cruciate ligament is attached below to the posterior part of the intercondylar area of the tibia.
  - It runs forward, upward, and medially to attach anterior part of the lateral surface of the medial femoral condyle.
  - It prevents **posterior translation** of the tibia (and posterior dislocation of tibia on femur) to **limit hyperflexion** of the knee.
  - It is taut during flexion of the knee and is lax during extension.
- In posterior attachment of PCL anterolateral and posteromedial bundles have been defined. They are named (against convention) according to their femoral attachments.
  - The anterolateral bundle tightens in flexion while the posteromedial bundle is tight in extension of the knee.
  - Each bundle slackens as the other tightens. Unlike the anterior cruciate ligament, it is not isometric during knee motion, i.e. the distance between attachments varies with knee position.
- M**edial (tibial) collateral ligament** is one of the four major ligaments of the knee.
  - It resists forces pushing the knee medially (towards the body), which would otherwise produce valgus deformity.
  - It is attached proximally to the medial condyle of femur immediately below the adductor tubercle; below to the medial condyle of the tibia and medial surface of its body.
  - It is intimately adherent to the medial meniscus and a damaged MCL is usually accompanied by injury to medial meniscus also.
  - Morphologically, the medial collateral ligament represents the degenerated tendon of insertion of the ischial head of the adductor magnus, & fibular ligament represents the degenerated tendon of the peroneus longus.
- **Oblique popliteal ligament** is an expansion from the tendon of semimembranosus muscle, runs upward and laterally superficial to the capsule to be attached to the intercondylar line of the femur.
  - It blends with capsule of knee joint and is pierced by: middle genicular vessels, middle genicular nerve, posterior division of the obturator nerve.

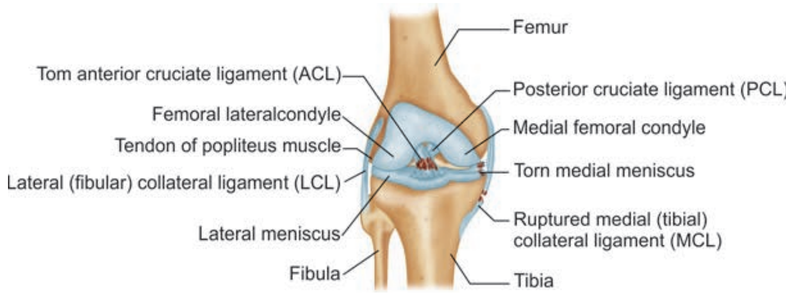


Fig. 29: Knee joint ligaments, showing a case of terrible triad (injured three ligaments: ACL, medial meniscus and tibial collateral ligament)

- **Locking of the knee:**
  - When the foot is fixed on the ground conjunct **medial rotation of the femur** on the tibia in the later stages of extension is part of a 'locking' mechanism, the so-called 'screw-home movement', which is an asset when the fully extended knees are subjected to strain.
  - Full extension results in the close-packed position, with maximal spiralization and tightening of the ligaments.
  - Locking of knee joint involves lateral rotation of tibia, if the foot is not fixed to the ground and
  - is free in the air.

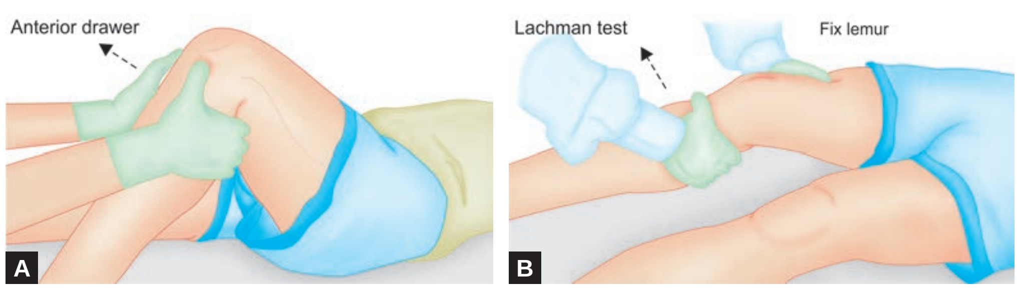
Fig. 30: Locking of knee joint: It may involve medial rotation of femur or lateral rotation of tibia, at the last stages of knee extension. Tibial tuberosity moves towards the lateral border of patella

Locking of the knee joint	Unlocking of the knee joint
Medial rotation of the femur on tibia during terminal phase of extension	Lateral rotation of the femur on tibia during initial phase of flexion
It is brought about by quadriceps femoris	It is brought about by the popliteus muscle
Locked knee becomes absolutely rigid	Unlocked knee can be further flexed
All ligaments are taut	All ligaments are relaxed

- **Unlocking of the knee**
  - At the beginning of flexion from full extension (with the foot fixed), lateral femoral rotation occurs, which 'unlocks' the join.
  - The unlocking is carried out by the popliteus.
  - When the knee is unlocked, it can be further flexed by the hamstring muscles.
- Locking of knee is essential for bearing load during erect posture. The locked joint must be unlocked to facilitate progress of locomotion. During walking locking and unlocking of the knee takes place alternatively and rhythmically.

Clinical Correlations

- Drawer test
  - Anterior drawer test is a forward sliding of the tibia on the femur due to a rupture of the anterior cruciate ligament, whereas posterior drawer sign is a backward sliding of the tibia on the femur caused by a rupture of the posterior cruciate ligament.
  - The anterior cruciate ligament is injured more than the posterior cruciate ligament (thicker & stronger).
  - Lachman test is carried out at 20-30° of knee flexion and is less painful. It has high sensitivity and specificity as compared with the original anterior drawer test (done at 90° knee flexion).



Figs. 31A and B: (A) Anterior drawer test in ACL injury. (B) Lachman test

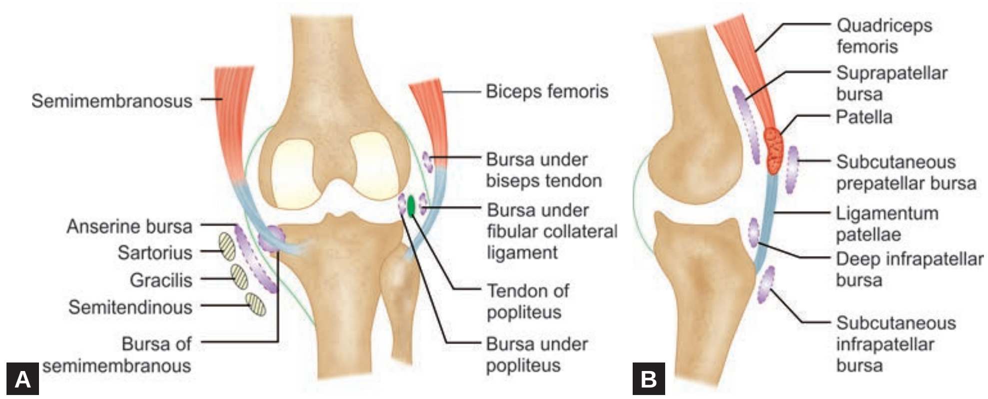
Clinical Correlations

- Knock-knee (genu valgum) is a condition in which the tibia is bent or twisted laterally and the knees are abnormally close together.
  - Genu valgum is normal in early childhood, but can occur with damage to the medial collateral ligament in adults.
- Bowleg (genu varum) is a condition in which the tibia is bent medially, resulting from collapse of lateral collateral ligament.

Bursae

Table 5: Bursae around knee joint

Bursae	Locations	Comments
Suprapatellar	Between femur and tendon of quadriceps femoris	Held in position by articular muscle of knee; communicationts freely with superior extension of synovial cavity of knee joint
Popliteus	Between tendon of popliteus and lateral condyle of tibia	Opens into synovial cavity of knee joint inferior to lateral meniscus
Anserine	Separates tendons of sartorius, gracilis, and semitendinosus from tibia and tibial collateral ligament	Area where tendons of these muscles attach to tibia; resembles a goose's foot (L. pes anserinus)
Gastrocnemius	Deep to proximal attachment of tendon of medial head of gastrochnemius	An extension of synovial cavity of knee joint
Semimembranosus	Between medial hoad of gastrocnemius and semimembranosus tendon	Related to distal attachment of semimembranosus
Subcutaneous prepatellar	Between skin and anterior surface of patella	Allows free movement of skin over patella during movements of leg
Subcutaneous infrapatellar	Between skin and tibial tuberosity	Helps knee withstand pressure when kneeling
Deep infrapatellar	Between patellar ligament and anterior surface of tibia	Separated from knee joint by infrapatellar fat pad



Figs. 32A and B: Bursae around the knee joint: (A) Bursae on the medial and lateral aspects of the knee; (B) Bursae on the front of the knee

Anserine Bursa

- Tendons of one muscle from each of the three compartments of the thigh: sartorius (anterior), gracilis (medial), and semitendinosus (posterior) are inserted into the upper part of the medial surface of the tibia.
- These muscles work like guy ropes to stabilize the bony pelvis on the femur.
- There is an anserine bursa at their tibial attachment separating each other near their insertion and also from the tibial collateral ligament.

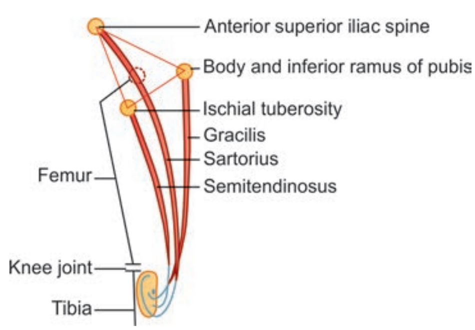


Fig. 33: Guy ropes

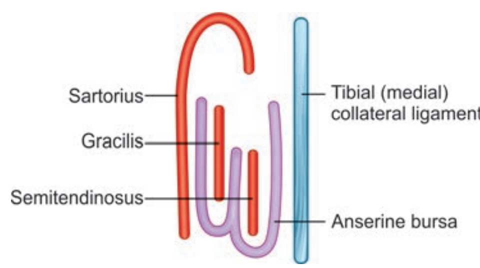


Fig. 34: Bursa anserinus

Clinical Correlations

- Inflammation of the subcutaneous prepatellar bursa and infrapatellar bursa are referred to popularly as 'housemaid's knee' and 'clergyman's knee', respectively.
- **Clergyman's knee,** indicates that it is due to a position where the patient kneels down in church while praying, may develop bursitis after repeated friction between the skin and the patella.
- **Housemaid knee** presents with infrapatellar bursitis, a swelling that is superficial to the patellar ligament, but distal to the patella. This occurs due to a repetitive posture of kneeling down and bending forward in activities like mopping up the floor.

Fig. 35: Housemaid knee: Pre-patellar bursitis

ASSESSMENT QUESTIONS

1. **Pes anserinus includes following three muscles EXCEPT:** *(NEET Pattern 2015)*
   a. Semitendinosus
   b. Semimembranosus
   c. Gracilis
   d. Sartorius

2. **Clergyman's knee is an inflammation of:**
   a. Anserine bursa
   b. Pre-patellar bursa
   c. Suprapatellar bursa
   d. Infrapatellar bursa

ANSWERS WITH EXPLANATIONS

1. **b. Semimembranosus**
   - Tendons of one muscle from each of the three compartments of the thigh: sartorius (anterior), gracilis (medial), and semitendinosus (posterior) are inserted into the upper part of the medial surface of the tibia. Anserine bursa is at their tibial attachment separating each other near their insertion and also from the tibial collateral ligament.
2. **d. Infrapatellar bursa**
   - The popular name, clergyman›s knee, indicates that it is due to a position where the patient kneels down in church while praying, may develop bursitis after repeated friction between the skin and the patella.

Neurovascular Supply

Arterial Supply

- Arterial anastomosis around the knee contributed by: Five genicular branches of popliteal artery, descending genicular branch of femoral artery, descending branch of the lateral circumflex femoral artery, two recurrent branches of the anterior tibial artery, and circumflex fibular branch of the posterior tibial artery.

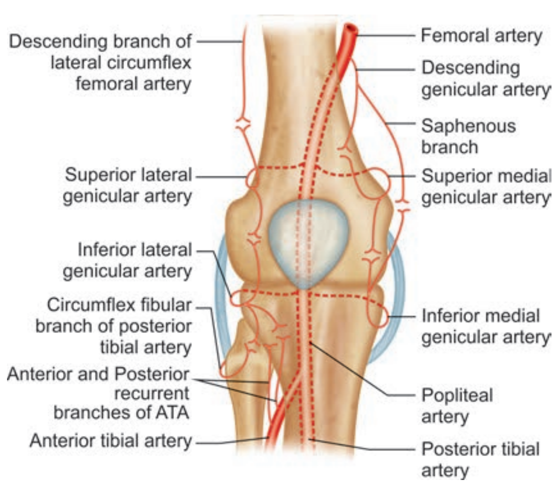


Fig. 36: Arterial anastomosis (genicular anastomosis) around the knee joint (ATA = anterior tibial artery)

- Superior medial genicular artery anastomosis with the descending genicular branch of the femoral artery and inferior medial genicular artery
- Inferior medial genicular artery anastomosis with the superior medial genicular artery and saphenous artery- a branch of the descending genicular artery (a branch of femoral artery).
- Superior lateral genicular artery anastomosis with the descending branch of the lateral circumflex femoral artery and inferior lateral genicular artery.
- Inferior lateral genicular artery anastomosis with the superior lateral genicular artery, anterior and posterior recurrent branches of the anterior tibial artery, and circumflex fibular branch of posterior tibial artery.

Nerve Supply

- Femoral nerve (through branches to vasti)
- Tibial and common peroneal nerves (through genicular branches)
- Obturator nerve (through posterior division)

Injuries

- **Unhappy triad** or O'Donoghue triad of the knee joint may occur when a football player's cleated shoe is planted firmly in the turf and the knee is struck from the lateral side.
  - Mechanism of Injury: Foot fixed, knee flexed, twisting fall.
  - It is characterized by the (a) rupture of the tibial collateral ligament, as a result of excessive abduction; (b) tearing of the anterior cruciate ligament, as a result of forward displacement of the tibia; and (c) injury to the medial meniscus, as a result of the tibial collateral ligament attachment.

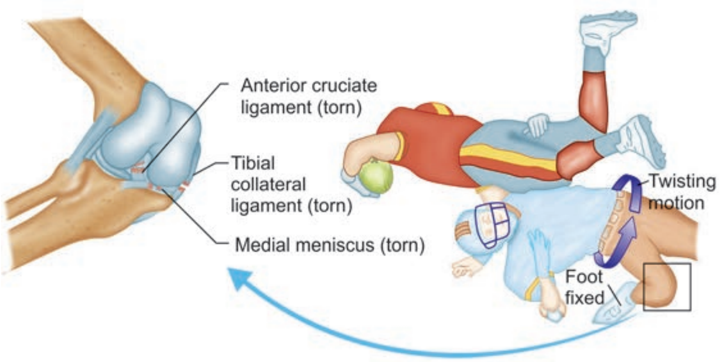


Fig. 37: Terrible triad in football player

High Yield Points

- Rectus femoris and vastus muscles are for knee extension, Knee flexion is carried out by hamstring muscles.
- A torn portion of meniscus may sometimes displace and become jammed between the femur and tibia in the centre of the joint - a 'bucket handle tear'. This may cause a blocking of extension - 'locking of the knee'.
- The knee is the largest synovial joint in the body.
- ACL and PCL are intracapsular but extrasynovial ligaments (lie inside the knee joint capsule but outside the synovial cavity of the joint), still covered by synovial membrane.

Radiology

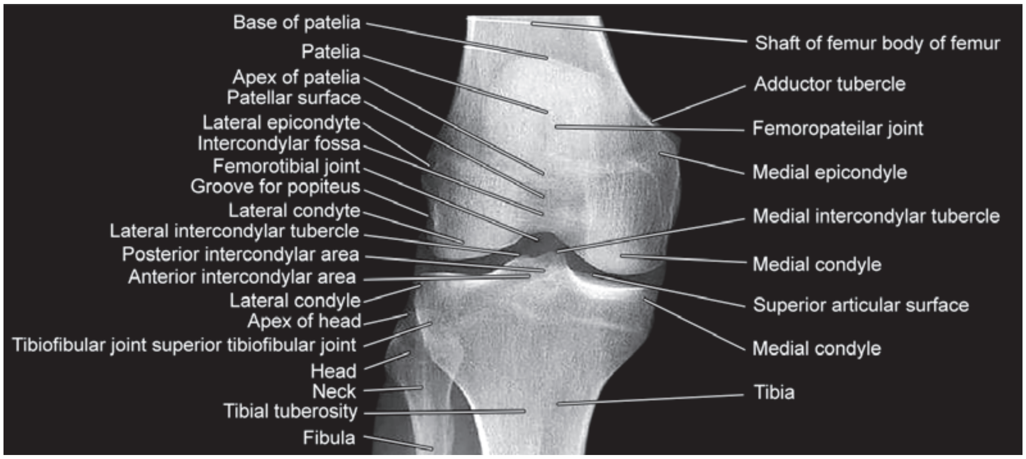


Fig. 38: X-ray–Knee joint

ASSESSMENT QUESTIONS

1. ACL originates from: *(NEET Pattern 2015)*
   a. Posterior part of intercondylar area of tibia
   b. Anterior part of intercondylar area of tibia
   c. Medial part of medial femoral condyle
   d. Lateral part of lateral femoral condyle

2. Coronary ligament of knee is situated between: *(AIPG 2008, AIIMS 2012)*
   a. Menisci and synovium
   b. Two posterior horns of menisci
   c. Meniscus and tibial condyle
   d. Meniscus and femoral condyle

3. A healthy young athlete sitting at table with knee at 90-degree flexion. What will happen when he fully extends the knee? *(AIIMS 2010)*
   a. Movement of tibial tuberosity towards medial border of patella
   b. Movement of tibial tuberosity towards lateral border of patella
   c. Movement of tibial tuberosity towards centre of patella
   d. No change in relationship

4. Physiological locking involves: *(AIPG 2008; NBEP 2012)*
   a. Internal rotation of femur over stabilized tibia
   b. Internal rotation of tibia over stabilized femur
   c. External rotation of tibia over stabilized femur
   d. External rotation of femur over stabilized tibia

5. ACL prevents: *(NBEP 2014; JIPMER 2016)*
   a. Anterior dislocation of tibia
   b. Posterior dislocation of tibia
   c. Anterior dislocation of femur
   d. Posterior dislocation of femur

6. About posterior cruciate ligament, TRUE statement is: *(AIPG 2007)*
   a. Prevent posterior displacement of tibia
   b. Attaches to lateral femoral condyle
   c. Intrasynovial
   d. Inserted on medial side of medial femoral condyle

7. The blood supply of anterior cruciate ligament is primarily derived from: *(AIPG 2008)*
   a. Superior medial genicular artery
   b. Descending genicular artery
   c. Middle genicular artery
   d. Circumflex fibular artery

8. Oblique popliteal ligament is pierced by: *(NEET Pattern 2013)*
   a. Anterior branch of popliteal artery
   b. Medial inferior genicular branch of popliteal artery
   c. Medial superior genicular branch of popliteal artery
   d. Middle genicular branch of popliteal artery

9. Medial rotation of tibia in flexed leg is brought about by: *(JIPMER 2000)*
   a. Popliteus
   b. Vastus medialis
   c. Quadriceps femoris
   d. Adductor magnus

10. Physiological locking involves: *(UPPG; NBEP 2013)*
   a. Internal rotation of femur over stabilized tibia
   b. Internal rotation of tibia over stabilized femur
   c. External rotation of tibia over stabilized femur
   d. External rotation of femur over stabilized tibia

11. A healthy young athlete sitting at table with knee at 90-degree flexion. What will happen when he fully extends the knee? *(AIIMS)*
   a. Movement of tibial tuberosity towards lateral border of patella
   b. Movement of tibial tuberosity towards medial border of patella
   c. Movement of tibial tuberosity towards centre of patella
   d. No change in relationship

12. Anterior cruciate ligament prevents: *(NEET Pattern 2015)*
   a. Anterior dislocation of tibia
   b. Posterior dislocation of tibia
   c. Anterior dislocation of femur
   d. Posterior dislocation of femur

13. A boy playing football received a blow to the lateral aspect of the knee and suffered a twisting fall. His medial meniscus is damaged; which other structure is most likely to be injured?
   a. Deltoid ligament
   b. Posterior cruciate ligament
   c. Anterior cruciate ligament
   d. Patellar-ligament

14. All of the following movements are possible due to contraction of tensor fascia lata except: *(AIPG)*
   a. Medial rotation of hip joint
   b. Abduction of hip joint
   c. Flexion of hip joint
   d. Extension of hip joint

15. In polio contracture of the iliotibial tract leads to all EXCEPT:
   a. Hip flexion and abduction
   b. Lateral rotation of tibia
   c. Knee flexion
   d. Varus deformity at knee

16. Oblique popliteal ligament attaches to: *(JIPMER 2006)*
   a. Semimembranosus
   b. Semitendinosus
   c. Adductor magnus
   d. Sartorius

17. TRUE statement about posterior cruciate ligament is: *(AIPG 2007; AIIMS 2007)*
   a. Attached to the lateral femoral condyle
   b. Intrasynovial
   c. Prevents posterior dislocation of tibia
   d. Relaxed in full flexion

18. Patellar anastomosis is formed by which artery: *(NEET Pattern 2014)*
   a. Descending genicular
   b. Anterior tibial recurrent
   c. Posterior tibial recurrent
   d. All of the above

19. TRUE about medial meniscus: *(PGIC 2014)*
   a. Made up of hyaline cartilage
   b. Injury of lateral meniscus is more frequent then medial meniscus
   c. C-shaped
   d. Fixed to medial collateral ligament
   e. Inner part is more avascular

20. O'Donoghue's triad comprises of: *(PGIC 2015)*
   a. Anterior cruciate ligament tear
   b. Posterior cruciate ligament tear
   c. Medial meniscus
   d. Lateral meniscus
   e. Medial collateral ligament

21. Posterior dislocation of tibia on femur is prevented by: *(PGIC 2011)*
   a. Posterior cruciate ligament
   b Anterior cruciate ligament
   c. Medial meniscus
   d. Lateral meniscus
   e. Medial collateral ligament

ANSWERS WITH EXPLANATIONS

1. b. Anterior part of intercondylar area of tibia
- Anterior cruciate ligament is attached to the anterior intercondylar area of the tibia and posterior cruciate ligament posteriorly.

Note: Naming as anterior and posterior is with reference to their tibial attachments.

2. c. Menisci and tibial condyle
- Coronary ligament is that part of the capsule which lies between the periphery of menisci and the tibial condyle. It attaches the lower border of both the menisci to the tibia (also called as tibio-meniscal ligament).

3. b. Movement of tibial tuberosity towards lateral border of patella
- In full extension the knee gets locked, which involves lateral rotation of tibia (since foot is off the ground). Hence, tibial tuberosity moves laterally **towards the lateral border of patella**.
- Physiological Knee locking happens in the last 30° of knee extension and involves the rotation of either bone femur or tibia.
- It involves medial rotation of femur on tibia if the foot is fixed to the ground (weight bearing leg). If the foot is off the ground (as sitting on a table) then tibia has to rotate opposite (laterally) to lock the knee joint. In either cases, tibial tuberosity moves laterally towards the lateral border of patella.
- **Pathological knee locking:** It is an orthopedic problem where patient has some meniscal injury and he finds difficulty in carrying out knee extension fully.

4. a. Internal rotation of femur over stabilized tibia > c. External rotation of tibia over stabilized femur
- When the foot is fixed to the ground and tibia stabilized, during the last stages of knee extension, **femur rotates internally** (medially) to lock the knee joint.
- If the foot is off the ground (as sitting on a table) then tibia rotates opposite (**externally**/laterally) to lock the knee joint.

5. a. Anterior dislocation of tibia > d. Posterior dislocation of femur
- Anterior cruciate ligament (ACL) prevents the anterior displacement of tibia on the bone femurs, and posterior displacement of femur on tibia as well.
- In ACL injury **anterior drawer test** becomes positive, i.e., tibia becomes loose and can pulled anteriorly on the bone femur.

6. a. Prevent posterior displacement of tibia
- Posterior cruciate ligament (PCL) prevents posterior displacement of tibia on femur.
- PCL attaches to the lateral surface of the medial femoral condyle.
- It is intracapsular but extrasynovial, still lined by synovial membrane almost entirely.

7. c. Middle genicular artery
- Middle genicular artery is a branch of popliteal artery and supplies the cruciate ligaments and the synovial membrane of knee joint.
- It reaches the interior of knee by piercing the oblique popliteal ligament of the knee.
- Fibular head artery is the circumflex fibular branch given by the posterior tibial artery, which contributes towards the anastomosis around the knee joint.
- Descending genicular artery is a branch of femoral artery and also contributes to the knee joint anastomosis.
- Superior genicular artery is a branch of popliteal artery and is an important branch in the anastomosis around the knee joint

8. d. Middle genicular branch of popliteal artery
- Oblique popliteal ligament is an expansion from the tendon of semimembranosus muscle, running upward and laterally superficial to the capsule to be attached to the intercondylar line of the femur, strengthens the capsule of knee joint posteriorly.
- It is intimately related to the popliteal artery and pierced by: Middle genicular nerve, middle genicular vessels, and posterior division of the obturator nerve.

9. a. Popliteus
- Medial rotation of the flexed leg is produced by popliteus, semimembranosus and semitendinosus, assisted by sartorius and gracilis.

10. a. Internal rotation of femur over stabilized tibia > c. External rotation of tibia over stabilized femur
- When the foot is fixed on the ground conjunct **medial rotation of the femur** on the tibia in the later stages of extension is part of a 'locking' mechanism.
- Locking of knee joint involves **lateral rotation of tibia**, if the foot is not fixed to the ground and is free in the air. This statement is mentioned by few authors, hence answer of second preference.

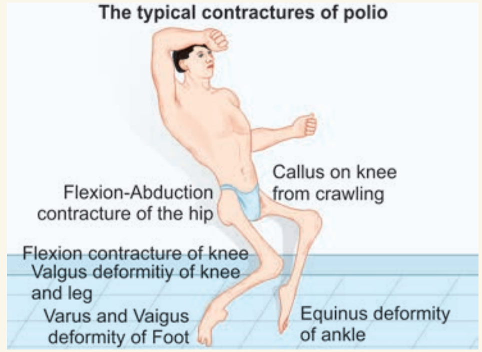
11. a. Movement of tibial tuberosity towards lateral border of patella
- This manoeuvre leads to locking of knee joint, with lateral rotation of tibia, and the tibial tuberosity moving towards lateral border of patella.

12. a. Anterior dislocation of tibia > d. Posterior dislocation of femur
- Anterior cruciate ligament prevents anterior dislocation of tibia is mentioned by most of the authors.
- Few other mention ACL prevents posterior dislocation of femur on fixed tibia.

13. c. Anterior cruciate ligament
- This is a case of terrible (triple) triad and leads to damage of three ligaments: TCL (Tibial Collateral Ligament), medial meniscus and ACL (Anterior Cruciate Ligament). Lachman test becomes positive.

14. d. Extension of hip joint
- Tensor fasciae latae is one of the anterior thigh muscles. It originates from the external lip of the iliac crest & descends to insert into the iliotibial tract.
- The iliotibial tract inserts into the anterolateral surface of the lateral tibial condyle.
- Innervation is provided by the superior gluteal nerve (L4, L5)
  - Its actions are varied:
  - Abduction, flexion and medial rotation at hip
  - Weak extension of knee joint
  - Stabilize the pelvis during walking
  - Counters the pull of gluteus maximus on the iliotibial tract

15. d. Varus deformity at knee
- Ilio-tibial tract is the insertion of 2 muscles into the lateral tibial condyle.
- The muscles are: gluteus maximus & tensor fascia lata.
- In polio contracture it leads to flexion, abduction & lateral rotation at both the hip & knee joint.
- It leads to genu valgus & not varus at knee, since it is attached on the lateral tibial condyle).



16. a. Semimembranosus
- Oblique popliteal ligament is an expansion from the tendon of semimembranosus muscle, runs upward and laterally superficial to the capsule to be attached to the intercondylar line of the femur.

17. c. Prevents posterior dislocation of tibia
- Posterior cruciate ligament is attached to the posterior most impression on the intercondylar area on the tibia.
- It runs in the forward and upward direction to reach the medial condyle of femur.
- When the knee is flexed, it resists the forces pushing tibia posteriorly in relation to femur. Therefore it is important while going downstairs or downhill.
- It restricts anterior femoral dislocation on fixed tibia.
- Cruciate ligaments lie within the capsule but are not inside the synovial cavity i.e., they are intracapsular and extrasynovial.
- It is well relaxed in mid-flexion.

18. d. All of the above
- A network of vessels is present around and above the patella and on the contiguous ends of the femur and tibia, forming a superficial and a deep plexus.

19. c. C-shaped; d. Fixed to medial collateral ligament
- Menisci are crescentic C shape fibrocartilaginous structures.
- The peripheries are vascularized by capillary loops from the fibrous capsule and synovial membrane, while their inner regions are avascular.
- Meniscal tears mostly occur in inner zone and seldom heal spontaneously (poor vascularity).
- Peripheral zone have the potential to heal spontaneously, due to good vascular supply.
- Medial meniscus is more vulnerable to injury than lateral because of its fixity to the tibial collateral ligament and greater excursion during rotatory movement.
- Lateral meniscus is pulled and protected by popliteus muscle.

20. a. Anterior cruciate ligament tear; c. Medial meniscus; e. Medial collateral ligament
- O'Donoghue's triad may occur when a football player's cleated shoe is planted firmly in the turf and the knee is struck from the lateral side.
- It is characterized by the (a) rupture of the tibial collateral ligament, as a result of excessive abduction; (b) tearing of the anterior cruciate ligament, as a result of forward displacement of the tibia; and (c) injury to the medial meniscus, as a result of the tibial collateral ligament attachment.

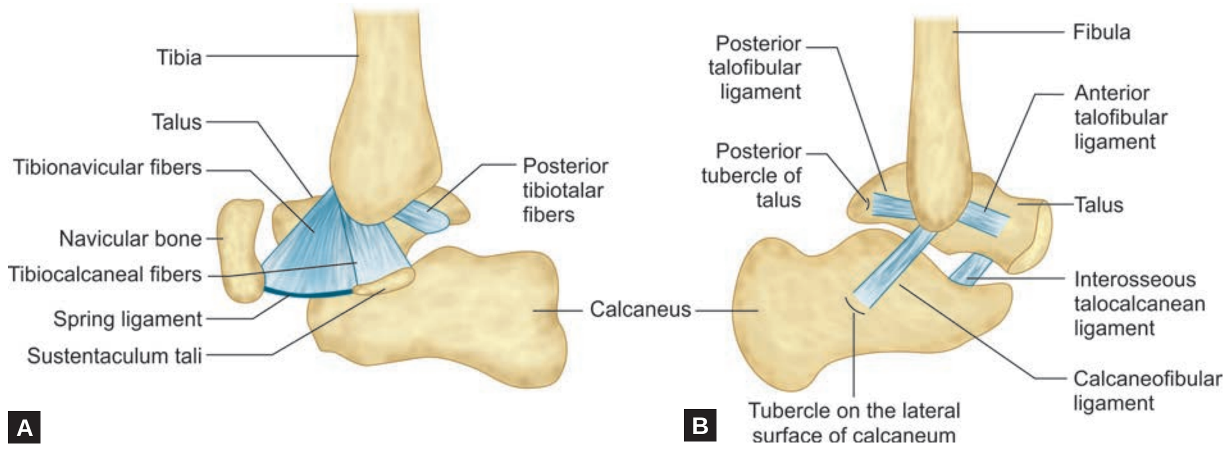
21. b. Anterior cruciate ligament
- PCL prevents posterior translation of the tibia (and **posterior dislocation** of tibia on femur) to **limit hyperflexion** of the knee.

Tibia-fibula Joints

- Tibia and fibula articulate with each other at the superior and inferior tibiofibular joints.
  - The superior joint, a plane synovial joint, allows slight gliding movement only.
  - The inferior joint, a fibrous joint (syndesmosis), lies just above the ankle and allows a degree of fibular rotation linked to ankle motion.
  - Middle tibio-fibular joint is also fibrous syndesmosis, with slight possibility of movement.

Ankle Joint

- Ankle (talocrural) joint is formed by the distal ends of the tibia and fibula 'gripping' the talus, and allows dorsiflexion and plantar flexion.
- Ankle joint is stabilized by the following factors:
- **Passive:**
  - Medial and lateral ligament complexes—e.g. deltoid ligament
  - Distal tibiofibular ligaments—e.g. deepening of tibiofibular socket posteriorly by inferior tibiofibular ligament
  - Tendons crossing the joint (4 anteriorly and 5 posteriorly)
  - Bony contours and the capsular attachments—e.g. trochlear surface on the superior aspect of the body of talus is wider in front than behind. During dorsiflexion, ankle joint of the anterior wider part of the trochlea moves posteriorly and fits properly into the tibiofibular mortise (pincer), hence joint is more stable in dorsiflexion (than plantarflexion).
- **Dynamic:**
  - Gravity
  - Muscle action—e.g. calf muscle (like soleus and gastrocnemius) help to increase stability when leaning forward
  - Ground reaction
- Failure of the fibular muscles: varus instability
- Failure of the tendon of tibialis posterior: valgus instability—acquired flat-foot (planovalgus) deformity.



Figs. 39A and B: Collateral ligaments of the ankle joint: A, deltoid ligament; B, lateral ligament.

- **Medial (Deltoid) Ligament** of ankle joint is attached to the **medial malleolus** on tibia. It has **four** parts: the tibionavicular, tibiocalcaneal, anterior tibiotalar, and posterior tibiotalar ligaments
- Tibio-calcaneal ligament attaches to the Sustentaculum tali (of calcaneum).
- Tibio-navicular part of deltoid ligament attaches to the Spring (plantar calcaneo-navicular) ligament.
- It prevents overeversion of the foot and helps maintain the **medial longitudinal arch**.
- The lateral ligament (specifically its anterior talofibular ligament component) is the most frequently injured ligament of the body. Injury occurs primarily by inadvertent inversion of the plantarflexed, weight-bearing foot.

Clinical Correlation

- Pott's (Dupuytren's) fracture is caused by forced eversion of foot and involves the lower end of the fibula, often accompanied by fracture of the medial malleolus (or rupture of the deltoid ligament).

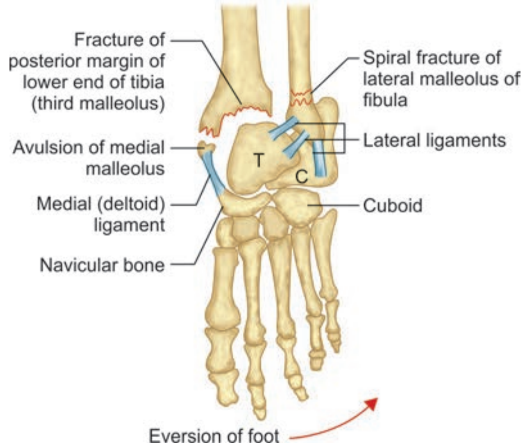


Fig. 40: Pott's fracture (T = talus, C = Calcaneus)

ASSESSMENT QUESTIONS

1. The stability of the ankle joint is maintained by all of the following except: *(AIIMS 2003)*
a. Plantar calcaneonavicular (spring) ligament
b. Deltoid ligament
c. Lateral ligament
d. Shape of the superior talar articular surface

2. Deltoid ligament is not attached to: *(AIIMS 2009)*
a. Medial cuneiform
b. Medial malleolus
c. Sustentaculum tali
d. Spring ligament

3. Stability of ankle joint is maintained by all except: *(AIIMS 2009)*
a. Collateral ligaments
b. Cruciate ligaments
c. Tendons of muscles crossing the joint
d. Close apposition of articular surfaces of bones

4. Deltoid ligament has all the following components except:
a. Anterior tibiotalar
b. Tibionavicular
c. Tibiocalcaneal
d. Calcaneonavicular

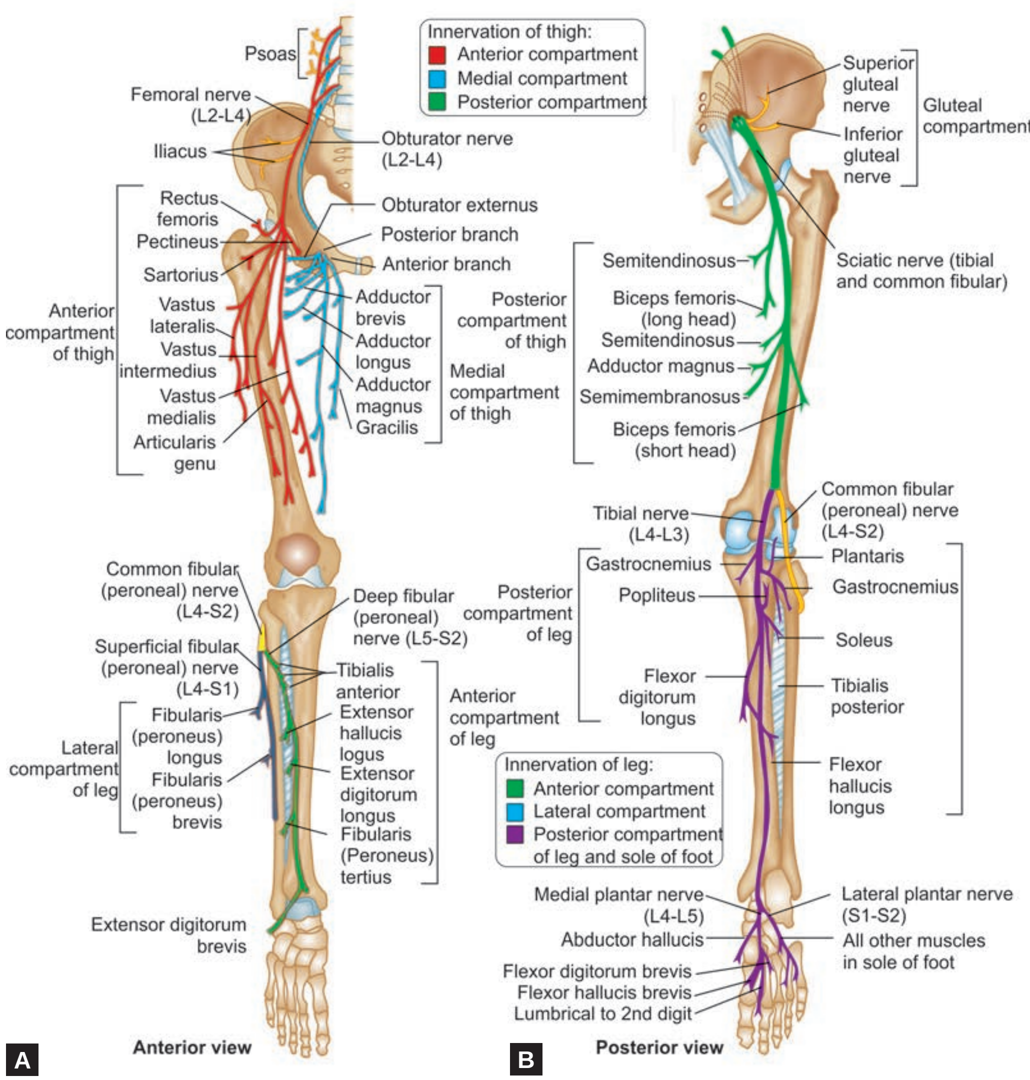
5. Plantar flexion is brought about by which of these muscles: *(PGI 2002)*
a. Plantaris
b. FHL
c. Tibialis anterior
d. Peroneus brevis
e. Soleus

ANSWERS WITH EXPLANATIONS

1. **a. Plantar calcaneonavicular (spring) ligament**
   - Spring ligament works for the maintenance of medial longitudinal arch.
2. **a. Medial cuneiform**
   - **Deltoid ligament** is a triangular (delta shaped) ligament on the medial side of the ankle attached to tibia (Medial malleolus).
   - No part is attached to **medial cuneiform** bone.
3. **b. Cruciate ligaments**
   - **Cruciate ligaments** are present in the knee (and not ankle) joint.
4. **d. Calcaneonavicular**
   - Deltoid ligament attaches to medial malleolus of tibia and calcaneonavicular (spring) ligament has no such attachment.
5. **Ans. a. Plantaris, b. FHL, e. Soleus**
   - Calf muscles carry out the movement of plantar flexion.

Nerve Supply

- Nerves of the lower limb are derived from the ventral primary rami of the lumbar and sacral nerves forming the lumbar plexus (L1-L4) in the posterior abdominal wall and the sacral plexus (L4–S4) in the pelvis.
  - The lumbar plexus lies deep within psoas major, anterior to the transverse processes of the first three lumbar vertebrae.
  - The sacral plexus lies in the pelvis on the anterior surface of piriformis, external to the pelvic fascia, which separates it from the inferior gluteal and internal pudendal vessels.
  - The lumbosacral trunk (L4 and L5) emerges medial to psoas major on the posterior abdominal wall and lies on the ala of the sacrum before crossing the pelvic brim to join the ventral ramus of S1.
  - The main nerves of the lower limb are as follows: Femoral nerve, Obturator nerve, Sciatic nerve, Tibial nerve, Common peroneal nerve, Superficial peroneal nerve, Deep peroneal nerve, plantar nerves.



Figs. 41A and B: Innervation of the lower limb muscle. (A) Anterior view. (B) Posterior view

Lumbar Plexus

- Components:
  - Rami are the L1 to L4 ventral primary rami of spinal nerves
  - Divisions (Anterior and Posterior) are formed by rami dividing into anterior and posterior divisions.
  - Branches:

Table 6: Branches of the lumbar plexus

Muscular	T12, L1–4
Iliohypogastric	L1
Ilioinguinal	L1
Genitofemoral	L1, L2
Lateral femoral cutaneous	L2, L3
Femoral	L2–4 dorsal divisions
Obturator	L2-4 ventral divisions
Accessory obturator	L3, L4

- Lumbosacral trunk (L4 and L5) arises from lumbar plexus and emerge medial to psoas major (posterior abdominal wall), lies on the ala of the sacrum before crossing the pelvic brim to join the ventral ramus of S1. L3 may also contribute, occasionally.

Sacral Plexus

Table 7: The branches of the sacral plexus

	Ventral divisions	Dorsal divisions
Nerve to quadratus femoris and gemellus inferior	L4, 5, S1	
Nerve to obturator internus and gemellus superior	L5, S1, 2	
Nerve to piriformis		(L5), S1, 2
Superior gluteal		L4, 5, S1
Inferior gluteal		L5, S1, 2
Posterior femoral cutaneous	S2, 3	S1, 2
Tibial (sciatic)	L4, 5, S1, 2, 3	
Common fibular (sciatic)		L4, 5, S1, 2
Perforating cutaneous		S2, 3
Pudendal	S2, 3, 4	
Branches to levator ani, coccygeus and external anal sphincter	S4	

ASSESSMENT QUESTIONS

1. **All are branches of lumbar plexus except:** *(NEET Pattern 2015)*
   a. Iliohypogastric nerve
   b. Ilioinguinal nerve
   c. Obturator nerve
   d. Subcostal nerve

2. **What is the root value of sciatic nerve:** **(NEET Pattern 2012)**
   a. S1,S2,S3
   b. L4,L5; S1,S2,S3
   c. L1,L2,L3
   d. L2,L3,L4

3. **Root value of the posterior cutaneous nerve of the thigh:** *(NEET Pattern 2012)*
   a. S1,S2
   b. S2,S3
   c. S1,S2,S3
   d. S2,S3,S4

4. **Nerve root of pudendal nerve is:** *(NEET Pattern 2014)*
   a. S1,S2,S3
   b. S2,S3,S4
   c. S3,S4
   d. S2,S3

ANSWERS WITH EXPLANATIONS

1. **d. Subcostal nerve**
   - Subcostal nerve arises from the anterior division of the twelfth thoracic nerve, is larger than the others; runs along the lower border of the twelfth rib, often gives a communicating branch to the first lumbar nerve, and passes under the lateral lumbocostal arch.
   - It innervates the Transversus, and passes forward between it and the Obliquus internus to be distributed in the same manner as the lower intercostal nerves.
   - It communicates with the iliohypogastric nerve of the lumbar plexus, and gives a branch to the Pyramidalis. It also gives off a lateral cutaneous branch that supplies sensory innervation to the skin over the hip.

2. **b. L4,L5; S1,S2,S3**
   - **Sciatic nerve** arises from the ventral divisions of L-4,5 and S-1,2,3.

2. **c. S1,S2,S3**
   - Posterior cutaneous nerve of thigh arises from the sacral plexus with root value S-1,2,3.

4. **b. S2,S3,S4**
   - Pudendal nerve arises from the ventral primary rami of S-2,3,4.

Cutaneous Nerves

- **Cutaneous nerves** supplying the lower limb are derived from the branches of nerves of lumbar and sacral plexuses.
  - Most of the cutaneous innervation of the thigh is provided by the **lateral and posterior cutaneous nerves** of the thigh and cutaneous branches of the femoral nerve.
  - Anterior cutaneous nerves from the femoral nerve in addition to the anterior aspect of the thigh also supply the most of the medial aspect of the thigh.
  - Cutaneous innervation of the leg on its anteromedial aspect is provided by the saphenous nerve, the posterolateral aspect by the sural nerve, and the anterolateral aspect by the superficial peroneal nerve.
  - Cutaneous innervation of dorsum of the foot is mostly provided by the superficial peroneal nerves.
  - Cutaneous innervation of the sole of the foot is provided by the cutaneous branches of the medial and lateral plantar nerves

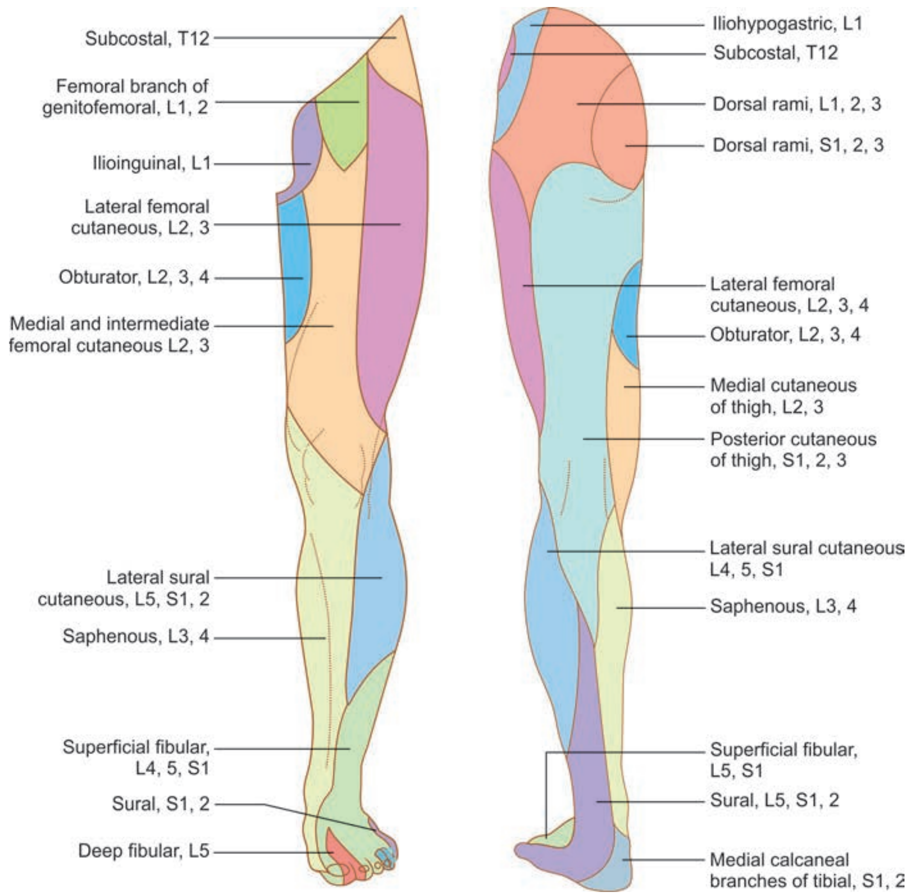


Fig. 42: The cutaneous nerves of the lower limb: areas of distribution and spinal segments of origin. A, Anterior aspect. B, Posterior aspect. C, The sole of the foot. D, The dorsum of the foot

Table 8: Cultaneous nerves of lower limb			
Nerve	**Oringin (contributing spinal Nerve)**	**Course**	**Distribution in lower limb**
Subcostal	T12 anterior ramus	Courses along inferior border of 12th rib. lateral cutaneous branch descends over iliac crest	Lateral cutaneous branch supplies skin of hip region inferior to anterior part of iliac crest and anterior to greater trochanter
Iliohypogastric	Lumbar plexus (L1: ocsionally T12)	Parallels iliac crest; divides into lateral and anterior cutaneous branches	Lateral cutaneous branch supplies superolateral quadrant of buttocks
Ilioinguinal	Lumbar plexus (L1: occasionally T12)	Passes through inguinal canal; divides into fermoral and scrotal or labial branches	Femoral branch supplies skin over medial femoral triangle
Genitofemoral	Lumbar plexus (L1–L2)	Descends anterior surface of psoas major; divides into genital and femoral branches	Femoral branch supplies skin over lateral part of femoral triangle; genital branch supplies anterior scrotum or labla majora
Lateral cutaneous nerve of thigh	Lumbar plexus (L2–L3)	Passes deep to inguinal ligament 2–3 cm medical to anterior superior iliac spine	Supplies skin on anterior and lateral aspects of thigh

Nerve	Oringin (contributing spinal nerve)	Course	Distribution in lower limb
Anterior cutaneous branches	Lumbar plexus via fermoral nerve (L2–L4)	Arise in femoral triangle; pierce fascia lata along path of sartorius muscle	Supply skin of anterior and medial aspects of thigh
Cutaneous branch of obturator nerve	Lumbar plexus via obturator nerve, anterior branch (L2–L4)	Following its descent between adductors longus and brevis, anterior division of obturator nerve pierce fascia lata to reach skin of thigh	Skin of middle part of medial thigh
Posterior cutaneous nerve of thigh	Sacral plexus (S1–S3)	Enters gluteal region via infrapiriform portion of greater sciatic foramen deep to gluteus maxiums; then descends deep to fascia lata	Terminal branches pierce fascia lata to supply skin of posterior thigh and popliteal fossa
Saphenous nerve	Lumbar plexus via femoral nerve (L3–L4)	Traverses adductor canal but does not pass through adductor hiatus; crossing medial side of knee deep to sartorius	Skin on medial side of leg and foot
Superficial fibular nerve	Common fibular nerve (L4–S1)	Courses through lateral compartment of leg; after supplying fibular muscles, perforates deep fascia of leg	Skin of anterolateral leg and dorsum of foot, excluding web between great and 2nd toes
Deep fibular nerve	Common fibular nerve (L5)	After supplying muscles on dorsum of foot, pierces deep fascia superior to heads of 1st and 2nd metatarsals	Skin of web between great and 2nd toes
Sural nerve	Tibial and common fibular nerves (S1–S2)	Medial sural cutaneous branch of tibial nerve and lateral sural cutaneous branch of fibular nerve merge at varying levels on posterior leg	Skin of posterolateral leg and lateral margin of foot
Medial plantar nerve	Tibial nerve (L4–L5)	Passes between first and second layers of plantar muscles, then between medial and middle muscles of first layer	Skin of medial side of sole, and plantar aspect, sides, and nailbeds of medial 3½ toes
Lateral plantar nerve	Tibial nerve (S1–S2)	Passes between first and second layers of plantar muscles, then between middle and lateral muscles of first layer	Skin of lateral sole, and plantar aspect, sides, and nailbeds of lateral 1½ toes
Calcaneal nerves	Tibial and sural nerves (S1–S2)	Lateral and medial branches of tibial and sural nerves, respectively, over calcaneal tuberosity	Skin of heel
Superior clunial nerves	L1–L3 posterior rami	Penetrate thoracodorsal fascia, course laterally and infenorily in subcutaneous tissue	Skin overlying superior and central parts of buttocks
Medial clunial nerves	S1–S3 posterior rami	Emerge from dorsal sacral foramina, directly enter overlying subcutaneous tissue	Skin of medial buttocks and intergluteal cleft
Interior clunial nerves	Posterior cutaneous nerve of thigh (S2–S3)	Arise deep to gluteus maximus, emerge from beneath inferior border of muscle	Skin of inferior buttocks (overlying gluteal fold)

Table 9: Nerves of gluteal and posterior thigh regions

Nerve	Origin	Course	Distribution
Clunial			
Superior	As lateral cutaneous branches of posterior rami of L1–L3 spinal nerves	Pass inferolaterally across iliac crest	Supply skin of superior buttocks as far as tubercle of iliac crest
Middle	As lateral cutaneous branches of posterior rami of S1–S3 spinal nerves	Exit through posterior sacral formaina and pass laterally to gluteal region	Supply skin over sacrum and adjacent area of buttocks
Inferior	Posterior cutaneous nerve of thigh (anterior rami of S2–S3 spinal nerves)	Emerges from inferior border of gluteus maximus and ascends superficial to it	Supply skin of inferior half of buttocks as far as greater trochanter

Dermatomes

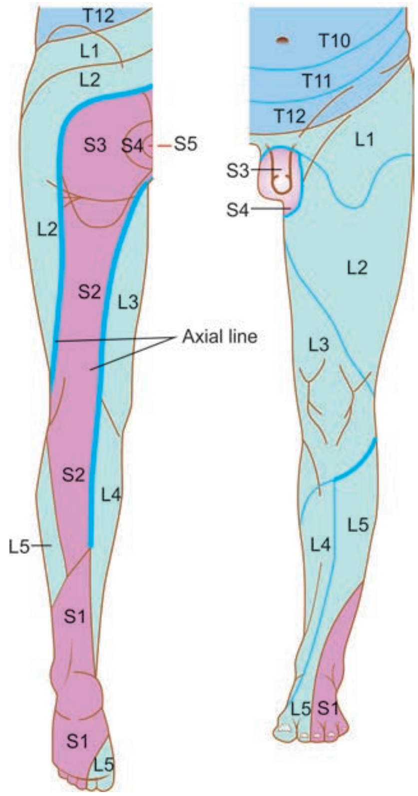


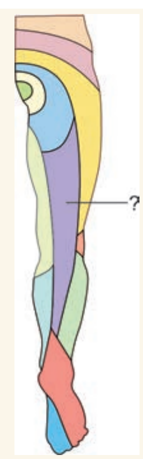
Fig. 43: The cutaneous nerves of the lower limb: Areas of distribution and spinal segments of origin. A. Anterior aspect. B. Posterior aspect. C. Sole of the foot. D. The dorsum of the foot.

Dermatome	Area supplied
L1	Inguinal area (over inguinal canal)
L2	Anterior and lateral part of upper 2/3rd of thigh.
L3	Anterior, Lateral and Medial part of lower 1/3rd of thigh and knee
L4	Medial side of leg, medial malleolus
L5	Lateral side of leg. Medial half of dorsum of foot, dorsum of first web space
S1	Posterior surface of ankle, and lateral half of dorsum of foot
S2	Posterior of thigh and leg
S3	Gluteal area around perianal region, Groin
S4	Perianal skin and Groin

ASSESSMENT QUESTIONS

1. **Dermatomal supply of the perianal skin is:** *(NEET Pattern 2012)*
   a. S1
   b. L2
   c. L3
   d. S4

2. **Marked dermatome is:**
   a. L–4
   b. L–5
   c. S–1
   d. S–2



3. **Posterior cutaneous nerve of thigh supplies skin overlying:** *(PGIC-2012)*
   a. Lateral aspect of thigh
   b. Posterior inferior aspect of buttock
   c. Scrotum
   d. Back of thigh
   e. Popliteal fossa

4. **During laparoscopic hernia repair a tack was accidently placed below and lateral to the iliopubic tract. Post-operatively the patient complained of pain in the thigh. This is due to the involvement of:**
   a. Lateral cutaneous nerve of thigh *(AIIMS-2015)*
   b. Ilio-inguinal nerve
   c. Genito-femoral nerve
   d. Obturator nerve

5. **Meralgia paresthesia is due to involvement of:**
   a. Lateral cutaneous nerve of thigh *(AIIMS-2015)*
   b. Ilio-inguinal nerve
   c. Genitofemoral nerve
   d. Saphenous nerve

6. **Root value of medial cutaneous nerve of thigh:**
   a. L1, L2 *(NEET Pattern 2014)*
   b. L2, L3
   c. Superficial peroneal nerve
   d. Saphenous nerve

7. **Medial aspect of great toe is supplied by:**
   a. Saphenous nerve
   b. Deep peroneal nerve
   c. Superficial peroneal nerve
   d. Sural nerve

8. **The skin overlying the region where a venesection is made to access the great saphenous vein is supplied by:** *(AIPG 2008)*
   a. Femoral nerve
   b. Sural nerve
   c. Tibial nerve
   d. Superficial peroneal nerve

9. **Postero-lateral herniation of nucleus pulposus at L5–S1 vertebrae level will result in pain located along the:**
   a. Anterior aspect of the thigh
   b. Medial aspect of the thigh
   c. Antero-medial aspect of the leg
   d. Lateral side of the foot

10. **Knowledge of the segmental cutaneous innervation of the skin of the lower extremity is important in determining the level of intervertebral disk disease. Thus, S1 nerve root irritation will result in pain located along the:**
   a. Anterior aspect of the thigh *(AIIMS 2004)*
   b. Medial aspect of the thigh
   c. Anteromedial aspect of the leg
   d. Lateral side of the foot

11. **Deep peroneal nerve sensory innervation:** *(AIIMS 2009)*
   a. 1st web space
   b. 5th web space
   c. Antero lateral dorsum of foot
   d. Lateral part of leg

ANSWERS WITH EXPLANATIONS

1. **d. S4**
   - Perianal skin is supplied by S4 root value of the pudendal nerve.

2. **Ans. d. S-2**
   - Posterior calf and thigh region has S2 dermatome.

3. **b. Posterior inferior aspect of buttock, c. Scrotum, d. Back of thigh, e. Popliteal fossa**
   - The root value of posterior cutaneous nerve of thigh is **S – 1, 2, 3**.
   - It supplies the cutaneous region of posterior thigh and popliteal fossa.
   - It also covers the cutaneous region on posterior inferior aspect of buttock region and scrotum

4. **a. Lateral cutaneous nerve of thigh**
   - Iliopubic tract runs parallel and deeper to inguinal ligament. The nerve damaged in this scenario is lateral cutaneous nerve of thigh.
   - **Lateral femoral cutaneous nerve** arises from the lumbar plexus (L2–L3), passes under the inguinal ligament near the anterior-superior iliac spine and supply skin on the anterolateral aspect of thigh.

5. **a. Lateral cutaneous nerve of thigh**
   - In meralgia paresthesia there is constant pain and abnormal perception in the outer side of the thigh, occasionally extending to the knee.
   - The nerve involved is lateral cutaneous nerve of thigh.

6. **b. L2, L3**
   - Medial cutaneous nerve of the thigh (L2, L3) is a branch of the anterior division of the femoral nerve.
   - It divides into anterior and posterior branches, which run medially across the femoral vessels, pierce the fascia lata at the mid-thigh, and supply the skin on the medial side of the thigh.

7. **c. Superficial peroneal nerve**
   - Most of the dorsum of foot is supplied by superficial peroneal nerve, including medial side of great toe.
   - Saphenous nerve supplies the medial side of the dorsum of foot, only till the ball of great toe.
   - Lateral side of the great toe is supplied by the deep peroneal nerve. It supplies the 1st web space on the dorsum of foot.

8. **a. Femoral nerve**
   - The nerve injured is saphenous nerve (branch of femoral nerve).
   - Great saphenous vein anterior to medial malleolus is the most preferred site of venesection (cut-down) in emergency.
   - The saphenous nerve accompanying the vein should be identified and secured, during the procedure.

9. **d. Lateral side of the foot**
   - The nerve root involved in this case of slip disc is S-1, and the corresponding dermatome involved is the lateral side of the foot and little toe.

10. **d. Lateral side of the foot**
   - Sural nerve supplies the skin over little toe and lateral margin of foot, bearing the dermatome S1.

11. a. 1st web space

- Peroneal nerve has 2 branches: superficial and deep. The superficial peroneal nerve supplies almost the entire dorsum of foot, whereas, deep peroneal nerve supplies the **dorsum of first web space** (interdigital cleft).
- The area over the great saphenous vein is supplied by the branches of femoral nerve, mainly the medial cutaneous branch of thigh and the saphenous nerve in the leg.
- Altered sensation over the area of great saphenous vein in leg may occur secondary to damaged saphenous nerve, as might occur during venae-section of great saphenous vein.
- Tibial nerve supplies the sensations over the back of the leg and the sole of the foot.
- Sural nerve is a branch of tibial nerve and runs along the short saphenous vein and supplies the dorsum of foot along its lateral border (including the little toe).

Motor Nerves

Table 10: Segmental innervation of the muscles of the lower limb

Segment	Muscles supplied
L1	Psoas major, psoas minor
L2	Psoas major, iliacus, sartorius, gracilis, pectineus, adductor longus, adductor brevis
L3	Psoas major, quadriceps femoris, adductors (magnus, longus, brevis)
L4	Psoas major, quadriceps femoris, tensor fasciae latae, adductor magnus, obturator externus, tibialis anterior, tibialis posterior
L5	Gluteus medius, gluteus minimus, obturator internus, semimembranosus, semitendinosus, extensor hallucis longus, extensor digitorum longus, fibularis tertius, popliteus
S1	Gluteus maximus, obturator internus, piriformis, biceps femoris, semitendinosus, popliteus, gastrocnemius, soleus, fibularis longus and fibularis brevis, extensor digitorum brevis
S2	Piriformis, biceps femoris, gastrocnemius, soleus, flexor digitorum longus, flexor hallucis longus, some intrinsic foot muscles
S3	Some intrinsic foot muscles (except abductor hallucis, flexor hallucis brevis, flexor digitorum brevis, extensor digitorum brevis)

Table 11: Segmental innervation of joint movements of the lower limb

Region	Muscles supplied	Segment
Hip	Flexors, adductors, medial rotators Extensors, abductors, lateral rotators	L1–3 L5, S1
Knee	Extensors Flexors	L3, 4 L5, S1
Ankle	Dorsiflexors Plantar flexors	L4, 5 S1, 2
Foot	Invertors Evertors Intrinsic muscles	L4, 5 L5, S1 S2, 3

Autonomic Nerves

- Autonomic nerve supply to the limbs is exclusively sympathetic.
  - Preganglionic sympathetic fibres to the lower limb are derived from neurones in the lateral horn of the lower thoracic (T10, T11 and T12) and upper lumbar (L1, L2) spinal cord segments.
  - Fibres pass in white rami communicantes to the sympathetic trunk and synapse in the lumbar and sacral ganglia.
  - Postganglionic fibres pass in grey rami communicantes to enter the lumbar and sacral plexuses; many are distributed to the skin via the cutaneous branches of the nerves derived from these plexuses.
  - The blood vessels to the lower limb receive their sympathetic nerve supply via adjacent peripheral nerves.
  - Postganglionic fibres accompanying the iliac arteries are destined mainly for the pelvis but may supply vessels in the proximal thigh.

Clinical Correlations

- Lumbar sympathectomy may be indicated in arterial disease and in the management of plantar hyperhidrosis, and may be used to treat rest pain or other troublesome sensory symptoms of arterial disease or in causalgia.
- A segment of the sympathetic trunk (including L-2,3 ganglia) is removed. L-1 root value is preserved - if lesioned, may result in retrograde ejaculation.

Gluteal and Posterior Thigh Region

Table 12: Nerves of gluteal and posterior thigh regions

Nerve	Origin	Course	Distribution
Sciatic	Sacral plexus (anterior and posterior divisions of anterior rami of L4–S3 spinal nerves)	Enters gluteal region via greater sciatic foramen inferior to piriformis and deep to gluteus maximus; descends in posterior thigh deep to biceps femoris; bifurcates into tibial and common fibular nerves at apex of popliteal fossa	Supplies no muscles in gluteal regions; supplies all muscles of posterior compartment of thigh (tibial division supplies all but short head of biceps, which is supplied by common fibular divison).
Posterior cutaneous nerve of thigh	Sacral plexus (anterior and posterior divisions of anterior rami of S1–S3 spinal nerves)	Enter gluteal region via greater sciatic foramen inferior to piriformis and deep to gluteus maximus, emrging from interior border of latter; descends in posterior thigh deep to fascia lata.	Supplies skin of inferior half of buttocks (through inferior clunial nerves). Skin over posterior thigh and popliteal fossa, and skin of lateral perineum and upper medial thigh (via its perineal branch)

Nerve	Origin	Course	Distribution
Superior gluteal	Sacral plexus (posterior divisions of anterior rami of L4–S1 spinal nerves)	Enters gluteal region via greater sciatic foramen superior to piriformis; courses laterally between gluteus medius and minimus as far as tensor fasciae latae	Innervates gluteus medius, gluteus minimus, and tensor fasciae latae muscles
Nerve to quadratus femoris	Sacral plexus (anterior divisions of anterior rami of L4–S1 spinal nerves)	Enters gluteal region via greater sciatic foramen inferior to piriformis, deep (anterior) to sciatic nerve	Innervates hip joint, inferior gemellus, and quadratus femoris.
Pudendal	Sacral plexus (anterior divisions of anterior rami of S2–S4 spinal nerves)	Exits pelvis via greater sciatic foramen inferior to piriformis; descends posterior to sacrospinous ligament; enters perineum through lesser sciatic foramen	Supplies no structures in gluteal region or posterior thigh (principal nerve to perineum)
Nerve to obturator internus	Sacral plexus (Posterior divisions of anterior rami of L5–S2 spinal nerves)	Exist pelvis via greater sciatic foramen inferior to piriformis; descends posterior to sacrospinous ligament; enters perineum through lesser sciatic foramen	Supplies superior gemellus and obturator internus

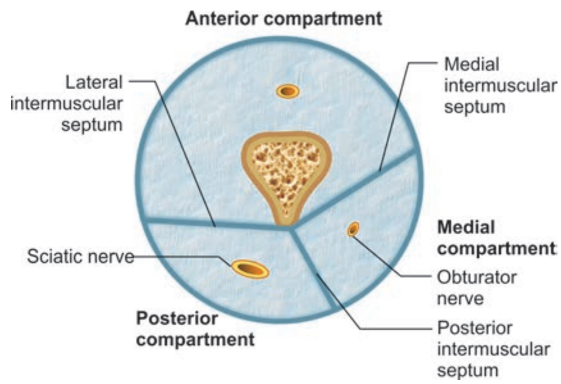


Fig. 44: Fascial compartments of thigh and the corresponding nerves in each compartment

Leg Region

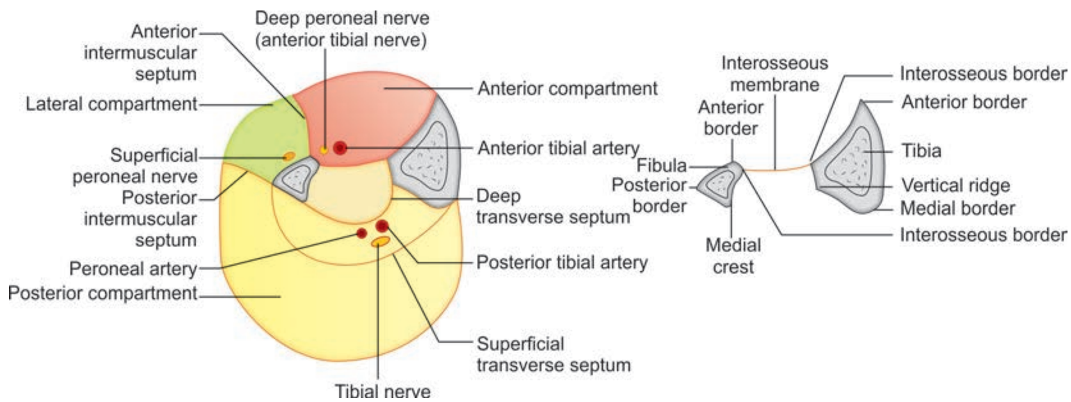


Fig 45: Osseofascial compartments of the leg. Figure in the inset shows transverse section through the tibial and Note the attachment of interosseous membrane

Table 13: Nerves of leg			
Nerve	**Origin**	**Course**	**Distribution in Leg**
Saphenous	Femoral nerve	Descends with femoral vessels through femoral triangle and adductor canal and then descends with great saphenous veins	Supplies skin on medial side of ankle and foot
Sural	Usually arises from branches of both tibial and common fibular nerves	Descends between heads of a gastrocnemius and becomes superficial at middle of leg; descends with small saphenous vein and passes inferior to lateral malleolus to lateral side of foot	Supplies skin on posterior and lateral aspects of leg and lateral side of foot
Tibial	Sciatic nerve	Forms as sciatic bifurcates at apex of popliteal fossa; descends through popliteal fossa and lies on popliteal; runs inferiorly on tibialis posterior with posterior tibial vessels; terminates beneath flexor retinaculum by dividing into medial and lateral plantar nerves	Supplies posterior muscles of leg and knee joint

Nerve	Origin	Course	Distribution in Leg
Common fibular (peroneal)	Sciatic nerve	Forms as sciatic bifurcates at apex of popliteal fossa and follows medial border of biceps femoris and its tendon; passes over posterior aspect of head of fibula and then winds around neck of fibula deep to fibularis longus. where it divides into deep and superficial fibular nerves	Supplies skin on lateral part of posterior aspect of leg via the lateral sural cutaneous nerve; also supplies knee joint via its articular branch
Superficial fibular (peroneal)	Common fibular nerve	Arises between fibularis longus and neck of fibula and descends in lateral compartment of leg; pierces deep fascia at distal third of leg to become subcutaneous	Supplies fibularis longus and brevis and skin on distal third of anterior surface of leg and dorsum of foot
Deep fibular (peroneal)	Common fibular nerve	Arises between fibularis longus and neck of fibula; passes through extensor digitorum longus and descends on interosseous membrane crosses distal end of tibia and enters dorsum of foot.	Supplies anterior muscles of leg, dorsum of foot and skin of first interdigital cleft; sends articular branches to joints it crosses.

ASSESSMENT QUESTION

1. **Following are the nerves and muscles of the leg. Choose the correct pair:**
   a. Superficial peroneal: Soleus
   b. Deep peroneal: Peroneus brevis
   c. Tibial nerve: Tibialis anterior
   d. Common fibular nerve: Short head of biceps

ANSWER WITH EXPLANATION

1. **d. Common fibular nerve: Short head of biceps**
   - Short head of biceps is supplied by the common peroneal nerve.
   - Soleus is calf muscle supplied by posterior tibial nerve.
   - Peroneus brevis is a lateral leg muscles innervated by superficial peroneal nerve.
   - Tibialis anterior is supplied by deep peroneal nerve.

Gluteal Nerves

- Gluteal nerves (L4, L5, S1, S2)
  - Gluteal nerves arise from the posterior divisions of the sacral plexus.
  - Superior gluteal nerve (L4, L5, S1) leaves the pelvis through the greater sciatic foramen superior to piriformis and supplies gluteus medius, gluteus minimus, tensor fasciae latae and the hip joint.
  - Inferior gluteal nerve (L5, S1, S2) passes through the greater sciatic foramen inferior to piriformis and supplies gluteus maximus.
- Superior gluteal nerve supplies the trio — Gluteus medius, Gluteus minimus and Tensor fascia latae.
  - This trio has three major actions at the hip joint — Abduction and Medial rotation and pelvic rotation (If the foot is fixed it raises the opposite hip).
  - If one foot is fixed this trio will raise the unsupported hip — as happens during walking to clear off the leg from the ground.
  - Lesion of superior gluteal nerve gives Trendelenburg test positive.
  - The unsupported hip sags down instead of going upwards. Lesion of right superior gluteal nerve leads to sagging down of left hip.
  - Superior gluteal nerve originates in the sacral plexus from the dorsal divisions of the fourth and fifth lumbar and first sacral nerves.
  - It leaves the pelvis through the greater sciatic foramen above the piriformis, accompanied by the superior gluteal artery and the superior gluteal vein.

ASSESSMENT QUESTIONS

1. **Which nerve does NOT supply gluteal region?** *(AIIMS 2012)*
   a. Superior gluteal nerve
   b. Sciatic nerve
   c. Nerve to quadrates femoris
   d. Nerve to obturator internus

2. **Superior gluteal nerve acts at hip joint for:**
   a. Abduction and lateral rotation
   b. Abduction and medial rotation
   c. Adduction and medial rotation
   d. Adduction and lateral rotation

3. **Superior gluteal nerve supplies all EXCEPT:** *(AIIMS 2010)*
   a. Gluteus minimus
   b. Gluteus medius
   c. Tensor fascia lata
   d. Gluteus maximus

ANSWERS WITH EXPLANATIONS

1. **b. Sciatic nerve**
   - Sciatic nerve supplies back of thigh, the leg and foot region.
   - It passes through the gluteal region, but doesn't supply the area.
2. **b. Abduction and medial rotation**
   - Superior gluteal nerve supplies three muscles: gluteus medius, gluteus minimus and tensor fascia lata, which act at the hip joint for abduction, medial rotation and pelvic rotation.
3. **d. Gluteus maximus**
   - Gluteus maximus is supplied by the inferior gluteal nerve.
   - Superior gluteal nerve supplies the trio – Gluteus medius, Gluteus minimus and Tensor fascia latae.

Femoral Nerve

- Femoral nerve (L2–4)
  - Femoral nerve is the nerve of the anterior compartment of the thigh.
  - It arises from the posterior divisions of the L2–4 ventral rami, descends through psoas major and emerges on its lateral border to pass between it and iliacus.
  - It enters the thigh behind the inguinal ligament and lateral to the femoral sheath.
  - Its terminal branches form in the femoral triangle about 2 cm distal to the inguinal ligament.
  - In the abdomen, the nerve supplies small branches to iliacus and a branch to the proximal part of the femoral artery.
  - It subsequently supplies a large cutaneous area on the anterior and medial thigh, medial leg and foot, and gives articular branches to the hip, knee and ankle.
  - Damage to the femoral nerve causes impaired flexion of the hip and impaired extension of the leg resulting from paralysis of the quadriceps femoris.
- **Saphenous nerve** is a branch of femoral nerve given in the femoral triangle and descends with the femoral vessels through the **femoral triangle** and the **adductor canal**.
  - Then it is accompanied by the great saphenous vein to reach the medial margin of the foot.
  - It innervates the skin on the medial side of the leg and foot.
  - It is vulnerable to injury during venesection at the medial malleolus.

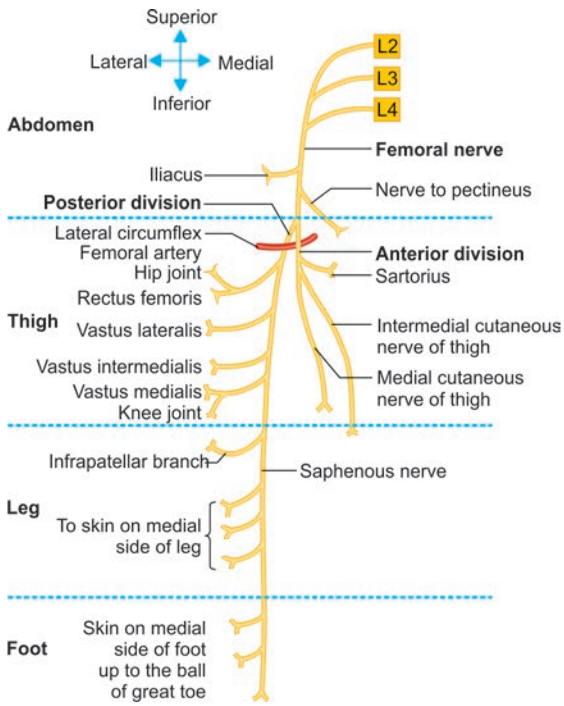


Fig. 46: Summary of branches of the femoral nerve. Note all the muscles on the front of thigh are supplied by posterior division except sartorius which is supplied by the anterior division

Lateral Femoral Cutaneous Nerve (LFCN)

- **Lateral femoral cutaneous nerve** arises from the lumbar plexus (L2–L3), passes under the inguinal ligament near the anterior-superior iliac spine and supply skin on the anterolateral aspect of thigh.
- It might get involved in **meralgia paraesthetica**.

- It becomes injured by entrapment or compression where it passes between the upper front hip bone (ilium) and the inguinal ligament near the attachment at the anterior superior iliac spine (the upper point of the hip bone).
- Less commonly, the nerve may be entrapped by other anatomical or abnormal structures, or damaged by diabetic or other neuropathy or trauma such as from seat belt injury in an accident.

Sciatic Nerve

- Sciatic nerve is the thickest nerve in the body, about 1.5 to 2 cm wide at the beginning.
  - It arises from sacral plexus in the pelvis and consists of two parts—tibial part and common peroneal part.
  - Tibial part is formed by the ventral divisions of anterior primary rami of L4, L5; S1, S2, S3.
  - Common part is formed by the dorsal divisions of anterior primary rami of L4, L5; S1, S2.
  - The two parts are usually enclosed in a common sheath of the connective tissue.
  - It enters the gluteal region through the greater sciatic foramen below the piriformis.
  - It runs downward and slightly laterally under cover of gluteus maximus midway between the greater trochanter and the ischial tuberosity, and enters the back of the thigh at the lower border of the gluteus maximus.
  - In its descent along the posterior thigh, it is crossed by the long head of biceps femoris and divides into the tibial and common fibular (peroneal) nerves proximal to the knee.
  - Sciatic nerve sends articular branches to the hip joint through its posterior capsule and to the knee joint.
  - The posterior thigh muscles, including the ischial part of adductor magnus but not the short head of biceps femoris, are supplied by the medial (tibial) component of the sciatic nerve.
  - The short head of biceps femoris is supplied by the lateral (common fibular) component.

Clinical Correlations

- Sciatic nerve may be injured in misplaced IM injections (most common cause), posterior dislocation of the hip, fracture of the pelvis, hip surgery, piriformis syndrome (anomalous relationship between muscle & nerve).
- Damage to the sciatic nerve causes impaired extension at the hip and impaired flexion at the knee, loss of dorsiflexion (foot drop) and plantar flexion at the ankle, inversion and eversion of the foot, and high-stepping gait (increased flexion) at the hip to lift the dropped foot off the ground.
- Sciatica is pain in the lower back and hip region, which radiates inferiorly along the posterior thigh to the leg. It is often caused by a herniated intervertebral disc, compressing the L5 or S1 ventral rami.
- **Piriformis syndrome** is a condition in which the **piriformis muscle** irritates and places pressure on the sciatic nerve, causing pain in the lower back, buttocks, and referring pain along the course of the sciatic nerve. This referred pain is called **sciatica**.

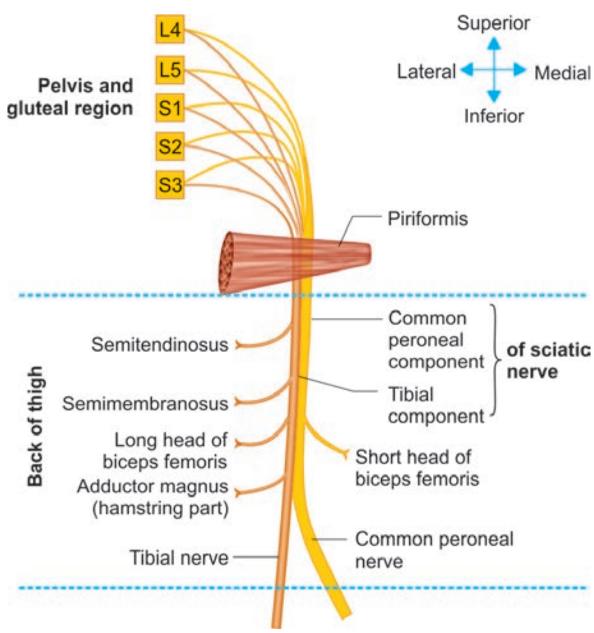


Fig. 47: Summary of branches of the sciatic nerve in the thigh. Ventral divisions of ventral rami are shown by green colour and dorsal division of ventral rami by grey colour. Note all the muscles on the back of thigh are supplied by tibial component of sciatic nerve except short head of biceps femoris which is supplied by its common peroneal component

Obturator Nerve

Obturator Nerve (L2–4)

- It is the nerve of the medial compartment of the thigh.
- It arises from the anterior divisions of the L-2, 3, 4 ventral rami, descends through psoas major and emerges from its medial border at the pelvic brim.

- It crosses the sacroiliac joint behind the common iliac artery and lateral to the internal iliac vessels, runs along the lateral pelvic wall medial to obturator internus, and enters the thigh through the upper part of the obturator foramen.
- Near the foramen, it divides into anterior and posterior branches, which are separated at first by part of obturator externus and more distally by adductor brevis.
- It provides articular branches to the hip and knee, and may supply skin on the medial thigh and leg.
- Damage to the obturator nerve causes a weakness of adduction and a lateral swinging of the limb during walking because of the unopposed abductors.

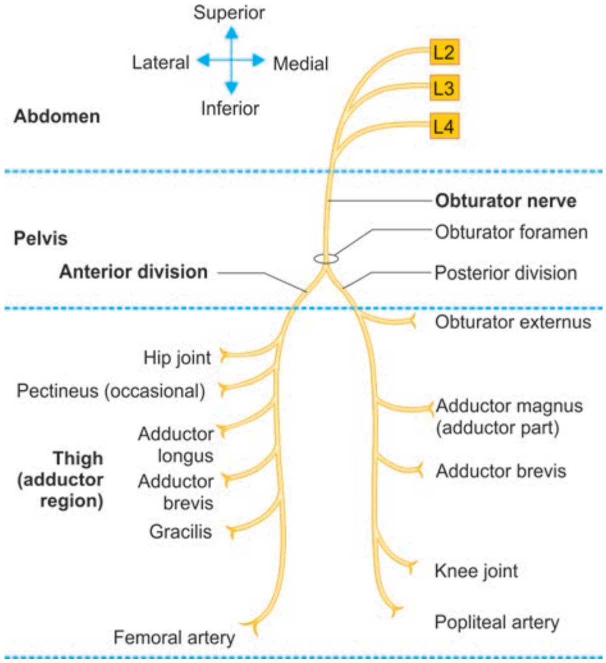


Fig. 48: Summary of main branches of the obturator nerve

ASSESSMENT QUESTIONS

1. Obturator nerve enters thigh at: *(NEET Pattern 2014)*
   a. Adductor canal
   b. Obturator canal
   c. Superficial inguinal ring
   d. Femoral canal

2. Obturator nerve innervates all of the following muscles except: *(NEET Pattern 2014)*
   a. Adductor longus
   b. Pectineus
   c. Obturator internus
   d. Obturator externus

3. A patient present with defective adduction of the hip joint and pains in the hip and knee joint. Which nerve is involved? *(AIIMS 2000)*
   a. Obturator nerve
   b. Femoral nerve
   c. Saphenous nerve
   d. Sciatic nerve

ANSWERS WITH EXPLANATIONS

1. b. Obturator canal
- Obturator canal is a passage way formed in the obturator foramen by part of the obturator membrane.
- It connects the pelvis to the thigh and lets pass the obturator neurovascular bundle through it.

2. c. Obturator internus
- Obturator internus is supplied by the nerve to obturator internus (L5; S1, S2), a special nerve from the sacral plexus.

3. a. Obturator nerve
- The nerve working for hip adduction is obturator nerve by supplying medial thigh muscles.
- It gives articular branch to hip as well the knee joint, hence explains pain at both during a lesion.

Tibial Nerve

Tibial Nerve (L4, L5, S1–3)

- It is derived from the anterior divisions of the sacral plexus and is a component of sciatic nerve.
- It descends along the posterior thigh and popliteal fossa to the distal border of popliteus, then passes anterior to the soleus with the popliteal artery and continues into the leg.
- In the popliteal fossa, it lies lateral to the popliteal vessels, becomes superficial to them at the knee and crosses to the medial side of the artery.

- In the leg, it is the nerve of the posterior compartment (called posterior tibial nerve) and descends with the posterior tibial vessels to lie between the heel and the medial malleolus.
- It ends deep to the flexor retinaculum by dividing into the medial and lateral plantar nerves.
- The tibial nerve supplies articular branches to the knee and ankle joints.
- Its cutaneous supply, including its terminal branches, supplies the back of the calf, the sole, the lateral border of the foot and the medial and lateral sides of the heel.

Clinical Correlations

- Tibial nerve is vulnerable to direct injury in the popliteal fossa, may be damaged in compartment syndrome that affects the deep flexor compartment of the calf.
- Tibial nerve or the medial and lateral plantar nerves may become entrapped beneath the flexor retinaculum or the so-called plantar tunnels (beneath the fascia of the abductor hallucis) at the ankle, resulting in tarsal tunnel syndrome.
- The foot remains in dorsiflexed position. (as a result of loss of plantar flexion of foot, due to paralysis of the flexors muscles of calf).
- Inability to stand on the toes, due to loss of plantarflexion of foot.
- There is impaired inversion resulting from paralysis of the tibialis posterior.
- The loss of sensation is in the sole and plantar aspects of the toes including the dorsal aspects of their distal phalanges, due to involvement of the cutaneous branches.
- Tarsal tunnel syndrome: It occurs due to compression of the tibial nerve in the osseofibrous tunnel under the flexor retinaculum of the ankle. It clinically presents as pain and paresthesia in the sole of the foot, which often becomes worse at night.

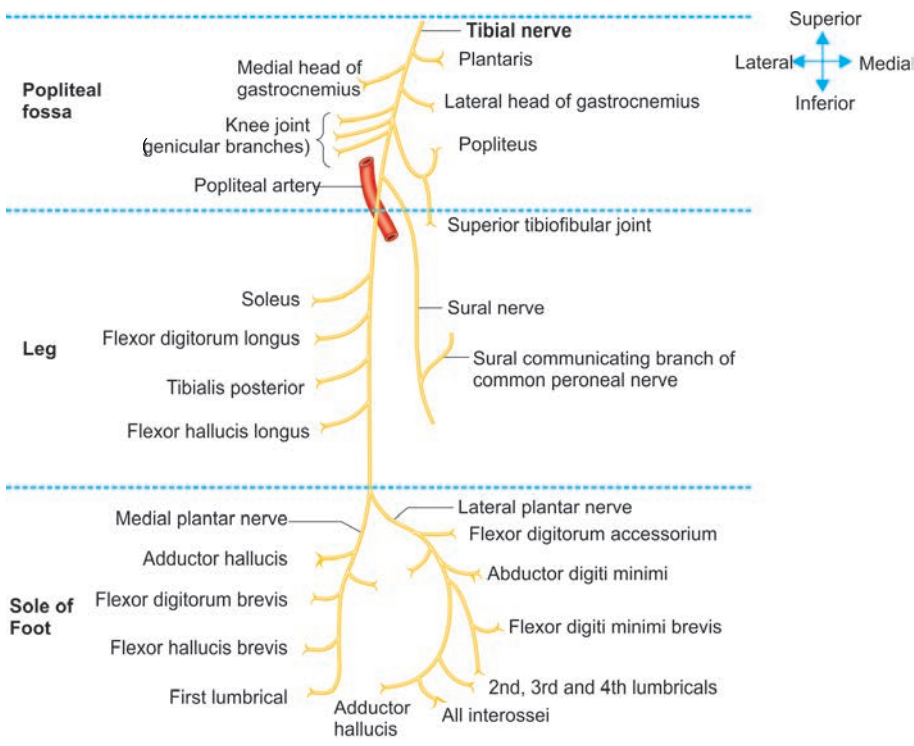


Fig. 49: Summary of main branches of the tibial nerve. Note all the muscular branches in the popliteal fossa arise from lateral side except for the medial head of gastrocnemius

ASSESSMENT QUESTION

1. Tibial nerve injury causes: *(PGIC 2012)*

a. Dorsiflexion of foot at ankle joint
b. Plantar flexion of the foot at ankle joint
c. Loss of sensation of dorsum of foot
d. Paralysis of muscles of anterior compartment of leg
e. Loss of sensation over the medial border of foot

ANSWER WITH EXPLANATION

1. a. Dorsiflexion of foot at ankle joint

- In tibial nerve injury posterior leg (calf) muscles and sole muscle are paralysed and there is sensory loss on the posterior calf region, lateral foot and sole skin.
- The patient is unable to do plantar flexion and the foot remains in dorsiflexion.

Peroneal Nerves

Common Fibular Nerve (L4, L5, S1, S2)

- It is derived from the posterior divisions of the sacral plexus.
- It is a component of sciatic nerve and supplies the short head of biceps femoris in posterior thigh.
- It is the nerve of anterior and lateral compartments of leg region.
- It descends obliquely along the lateral side of the popliteal fossa to the fibular head, lying between the tendon of biceps femoris and the lateral head of gastrocnemius; curves lateral to the neck of the fibula, lying on the bone deep to fibularis longus, and divides into superficial and deep fibular (peroneal) nerves.
- Before it divides, it gives branches to the knee and superior tibiofibular joints, and to the skin.
- The cutaneous area supplied by the common fibular nerve and its terminal branches includes the anterolateral leg and most of the dorsum of the foot.
- Sural communicating nerve arises from CPN near the head of the fibula and crosses the lateral head of gastrocnemius to join the sural nerve. It may descend separately as far as the heel.

Clinical Correlations

- Common peroneal nerve is vulnerable to injury as it winds around the posterolateral aspect of the neck of the fibula.
- At this site it may be injured by the direct trauma, fracture neck of fibula, or tightly POP cast.
- It may also become entrapped by a fascial band beneath fibularis longus within the so-called fibular tunnel, between the attachments of fibularis longus to the head and shaft of the fibula.
- The Patient presents with foot drop (paralysis anterior leg dorsiflexors of the foot), loss of toe extension (paralysis of extensor digitorum hallucis and longus). There is loss of foot eversion (paralysis of peroneus longus and brevis).
- These patients cannot stand on the heel and walk with a high stepping gait (alongwith foot slap).
- There is sensory loss on the anterolateral aspect of the leg, and whole of dorsum foot except the areas supplied by the saphenous and sural nerves.
- In Common peroneal nerve injury at the neck of fibula, more proximally innervated muscles (short head of biceps femoris) is normal; inversion and plantar flexion are normal. The ankle reflex is preserved.

Superficial Fibular Nerve

- It begins at the bifurcation of the common fibular nerve.
- It lies deep to fibularis longus at first, then passes anteroinferiorly between fibularis longus and brevis and extensor digitorum longus, and pierces the deep fascia in the distal third of the leg.
- It supplies fibularis longus, fibularis brevis and the skin of the lower leg and most of the dorsum of foot.
- Branches of the superficial fibular nerve supply the skin of the dorsum of all the toes except that of the lateral side of the fifth toe (supplied by the sural nerve) and the adjoining sides of the great and second toes (supplied by the medial terminal branch of the deep fibular nerve).

Clinical Correlations

- Lesion of the superficial fibular nerve causes weakness of foot eversion and sensory loss on the lateral aspect of the leg that extends on to the dorsum of the foot.
- The nerve can be subject to entrapment as it penetrates the deep fascia of the leg and it may also be involved in compartment syndrome that affects the lateral compartment of the leg.

Deep Fibular Nerve

- Deep fibular (peroneal) nerve begins at the bifurcation of the common fibular nerve, between the fibula and the proximal part of fibularis longus.
- It passes obliquely forwards deep to extensor digitorum longus to the front of the interosseous membrane and reaches the anterior tibial artery in the proximal third of the leg.
- It descends with the artery to the ankle, where it divides into lateral and medial terminal branches.
- As it descends, the nerve is first lateral to the artery, then anterior, and finally lateral again at the ankle.
- It supplies muscles of anterior leg compartment (tibialis anterior, extensor hallucis longus, extensor digitorum longus and fibularis tertius), and gives articular branch to the ankle joint.
- The lateral terminal branch crosses the ankle deep to extensor digitorum brevis, enlarges as a pseudoganglion and supplies extensor digitorum brevis. It supplies the skin at the dorsum of the first web space.

Clinical Correlations

- Isolated injury to the deep fibular nerve may result from compartment syndrome that affects the anterior compartment of the leg or from an intraneural ganglion cyst.
- Patients develop weakness of ankle dorsiflexion and extension of all toes but normal foot eversion.
- Sensory impairment is confined to the first interdigital web space.

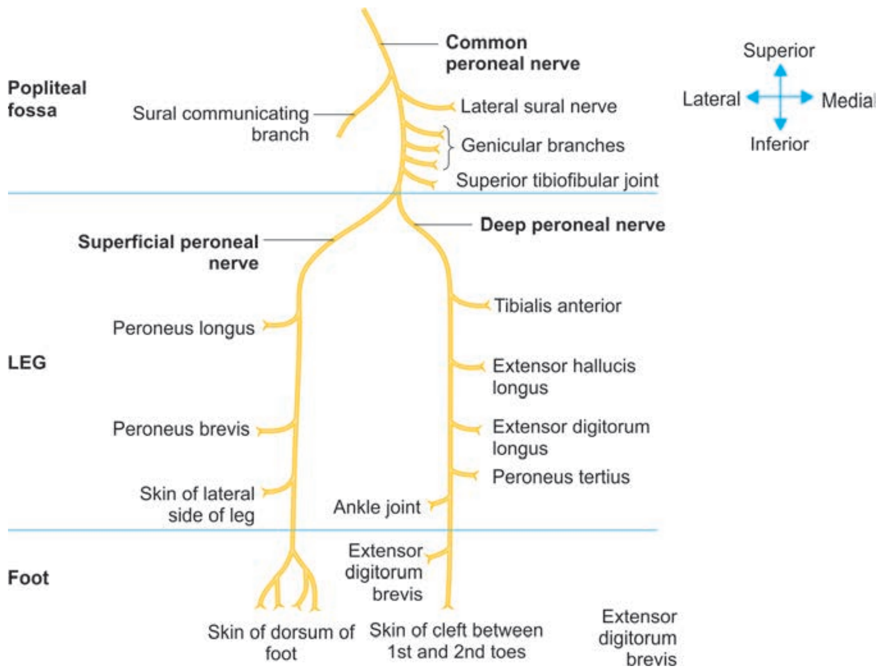


Fig. 50: Summary of main branches of the common peroneal nerve

ASSESSMENT QUESTIONS

1. Injury of common peroneal nerve at the lateral aspect of head of fibula result in all of the following EXCEPT: *(AIIMS 2004)*
   a. Weakness of ankle dorsi flexion
   b. Foot drop
   c. Loss of ankle reflex
   d. Sensory impairment on lateral aspect of leg extending to the dorsum of foot

2. Deep peroneal nerve sensory innervation: *(AIIMS 2009)*
   a. 1st web space
   b. 5th web space
   c. Anterolateral dorsum of foot
   d. Lateral part of leg

3. An person is unable to dorsiflex the foot and there is loss of sensations on dorsal foot. Possible nerve injury is: *(PGIC 2013)*
   a. Damage to common peroneal nerve at neck of fibula
   b. Damage to common peroneal at medial malleolus
   c. Compression of anterior tibial nerve at ankle
   d. Damage to superficial peroneal nerve
   e. Damage of deep peroneal nerve

4. Features seen in common peroneal nerve injury: *(PGIC 2010)*
   a. Inversion inability
   b. Loss of sensation of sole
   c. Foot drop
   d. Loss of extension of great toe
   e. Seen in fibular neck fracture

5. Which of the following may occur in common peroneal nerve injury? *(PGIC 2015)*
   a. Loss of dorsiflexion of toe
   b. Foot drop
   c. High stepping of foot
   d. Eversion of foot affected
   e. Loss of sensation over sole

ANSWERS WITH EXPLANATIONS

1. c. Loss of ankle reflex
- Triceps surae muscles work for plantar flexion in ankle reflex are supplied by tibial nerve, which is not lesioned in this patient.

2. a. 1st web space
- Peroneal nerve has 2 branches: superficial and deep. The superficial peroneal nerve supplies almost the entire dorsum of foot, whereas, deep peroneal nerve supplies the dorsum of first web – space (interdigital cleft).
- The area over the great saphenous vein is supplied by the branches of femoral nerve, mainly the medial cutaneous branch of thigh and the saphenous nerve in the leg.
- Tibial nerve supplies the sensations over the back of the leg and the sole of the foot.
- Sural nerve is a branch of tibial nerve and runs along the short saphenous vein and supplies the dorsum of foot along its lateral border (including the little toe).

3. c. Compression of anterior tibial nerve at ankle, e. Damage of deep peroneal nerve
- Isolated injury to the deep fibular nerve may result from compartment syndrome, from an intraneural ganglion cyst etc.
- Individuals with lesions of the deep fibular nerve have weakness of ankle dorsiflexion and extension of all toes but normal foot eversion.
- Sensory impairment is confined to the first interdigital web space.

4. **c. Foot drop, d. Loss of extension of great toe, e. Seen in fibular neck fracture**
   - Fracture neck of fibula results in common peroneal nerve injury, leading to loss of dorsiflexion at the ankle (foot drop) and toes, alongwith inability of foot eversion (and not inversion).
   - There is loss of sensation on the dorsum of the foot (and not sole).

5. **a. Loss of dorsiflexion of toe; b. Foot drop; c. High stepping of foot; d. Eversion of foot affected**
   - Common peroneal nerve injury leads to loss of dorsiflexion at the ankle (foot drop) and toes, alongwith inability of foot eversion.
   - There is loss of sensation on the dorsum of the foot (and not sole).

Reflexes

Knee Reflex (L2–4)

- With the patient sitting and the knee supported and partially flexed, the patellar ligament is struck with a knee hammer, resulting in a sudden contraction of the quadriceps femoris (extension of the knee joint).
- Its afferent and efferent impulses are transmitted in the femoral nerve (L2–L4).

Ankle-jerk (Achilles) reflex (S1, 2)

- With the patient sitting and the lower limb laterally rotated and partially flexed at the hip and knee, the foot is dorsiflexed by the examiner and the calcaneal tendon struck with a knee hammer.
- A reflex twitch of the triceps surae is induced which causes plantar flexion of the foot.
- Both afferent and efferent limbs of the reflex arc are carried in the tibial nerve.
- This results in plantar flexion of the foot.

Plantar reflex

- With the foot relaxed, the outer edge of the sole is stroked longitudinally with a blunt object such as the tip of the handle of a knee hammer.
- Normally, this action elicits flexion of the toes.
- However, in patients with upper motor neurone lesions, the response includes extension of the great toe (Babinski's sign).

IM Injections

- IM injections are given on the upper outer (superolateral) quadrant of gluteal region, to prevent iatrogenic damage to the sciatic nerve.
- The needle should reach into the gluteus medius (rather than into gluteus maximus).
- A safe alternative is to inject into the lateral aspect of the thigh (vastus lateralis).

Nerve Lesions

Pelvic girdle and lower limb: overview and surface anatomy

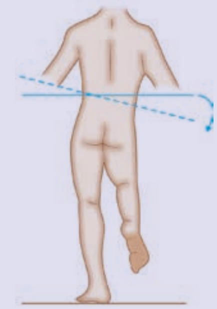
Table 14: The movements and muscles tested to determine the location of a lesion in the lower limb

Movement	Muscle	Upper motor neurone*	Spinal nerve level	Reflex	Nerve
Hip flexion	Iliopsoas	++	L1, 2		Femoral
Hip adduction	Adductors	+	L2, 3	(+)	Obturator
Hip extension	Gluteus maximus		L5, S1		Inferior gluteal
Knee flexion	Hamstrings	+	S1		Sciatic
Knee extension	Quadriceps femoris		L3, 4	++	Femoral
Ankle dorsiflexion	Tibialis anterio	++	L4		Deep fibular
Ankle eversion	Fibularis longus and fibularis brevis		L5, S1		Superficial fibular
Ankle inversion	Tibialis posterior		L4, 5		Tibial
Ankle plantar flexion	Gastrocnemius/soleus	+	S1, 2	++	Tibial
Great toe extension	Extensor hallucis longus		L5		Deep fibular

*The muscles listed in the 'upper motor neurone' column are those that are preferentially affected in upper motor neurone lesions. The root level is the principal supply to a muscle.

Table 15: Nerve lesions

Nerve injury	Injury description	Impairments	Clinical aspects
Femoral nerve	Trauma at femoral triangle Pelvic fracture	Flexion of thigh is weakened extension of leg is lost Sensory loss on anterior thigh and medial leg	Loss of knee-jerk reflex Anesthesia on anterior thigh

Nerve injury	Injury description	Immpairments	Clinical aspects
Obturator nerve	Anterior hip dislocation Radical retropubic prostatectomy	Adduction of thigh is lost Sensory loss on medial thigh	
Superior gluteal nerve	Surgery Posterior hip dislocation Poliomyelitis	Gluteus medius and minimus function is lost Ability to pull pelvis down and abduction of thigh are lost	Gluteus medius limb or waddling gait Positive Trendelenburg sign Contralateral 
Inferior gluteal nerve	Surgery Posterior hip dislocation	Gluteus maximus function is lost Ability to rise from seated position, climb stairs, or jump is lost	Patient will lean the body trunk backward at heel strike. 
Common fibular nerve	Blow to lateral aspect of leg Fracture of neck of fibula	Eversion of foot is lost Dorsiflexion of foot is lost Extension of toes is lost Sensory loss on anterolateral leg and dorsum of foot	Patient will present with foot plantar flexed ('FOOT DROP') and inverted Patient cannot stand stand on heels 'Foot slap'. 
Tibial nerve at popliteal fossa	Trauma at popliteal fossa	Inversion of foot is weakened Plantar flexion of foot is lost Flexion of toes is lost Sensory loss on sole of foot	Patient will present with foot dorsiflexed and everted Patient cannot stand on toes.

ASSESSMENT QUESTIONS

1. **A person is unable to dorsiflex the foot and there is loss of sensations on dorsal foot. Possible nerve injury is:** *(PGIC-2012)*
   a. Damage to common peroneal nerve at neck of fibula
   b. Damage to common peroneal at medial malleolus
   c. Compression of anterior tibial nerve at ankle
   d. Damage to superficial peroneal nerve
   e. Damage of deep peroneal nerve

2. **An altered sensation over the area of great saphenous vein in leg is seen due to injury to which of the following nerve:** *(APGI- 2008)*
   a. Femoral
   b. Tibial
   c. Sural
   d. Peroneal

3. **In L5 root involvement, which among the following is NOT affected:** *(AIPG-2011)*
   a. Thigh abduction
   b. Knee flexion
   c. Knee extension
   d. Toe extension

4. **Injury to nerve which passes superior to piriformis and winds around greater sciatic notch paralyzes:** *(NBEP- 2012)*
   a. Gluteus medius
   b. Gluteus maximus
   c. Obturator internus
   d. Piriformis

ANSWERS WITH EXPLANATIONS

1. **a. Damage to common peroneal nerve at neck of fibula**
   - Common peroneal nerve is prone to injury as it winds around the neck of fibula.
   - The patient presents with features of foot drop (loss of dorsiflexion at ankle) and problems of foot eversion, alongwith sensory loss on the dorsum of foot.

2. **a. Femoral**
   - The area over the great saphenous vein is supplied by the branches of femoral nerve, mainly the medial cutaneous branch of thigh and the saphenous nerve in the leg.
   - Altered sensation over the area of great saphenous vein in leg may occur secondary to damaged saphenous nerve, as might occur during venaesection of great saphenous vein.
   - Tibial nerve supplies the sensations over the back of the leg and the sole of the foot.
   - Sural nerve runs along the short saphenous vein and supplies the dorsum of foot along its lateral border (including the little toe).
   - Peroneal nerve has 2 branches: superficial and deep. The superficial peroneal nerve supplies almost the entire dorsum of foot, whereas, deep peroneal nerve supplies the dorsum of first interdigital cleft.

3. **c. Knee extension**
   - Knee extension is carried out by L-2, 3 and 4 (Femoral nerve).
   - Injury at the level of L- 5, doesn't affect knee extension.
   - Knee flexion is carried out by the root value: L -5 and S-1 (Tibial nerve).
   - Toe extension requires L-5 (deep peroneal nerve)

4. **a. Gluteus medius**
   - **Superior gluteal nerve** passes through the greater sciatic foramen (above the piriformis muscle) to supply *three* muscles: **gluteus medius, gluteus minimus and tensor fascia lata.**
   - **Superior gluteal nerve** passes through the *greater sciatic foramen* (above the piriformis muscle) to supply three muscles: **gluteus medius, gluteus minimus and tensor fascia lata.**

Myotomes

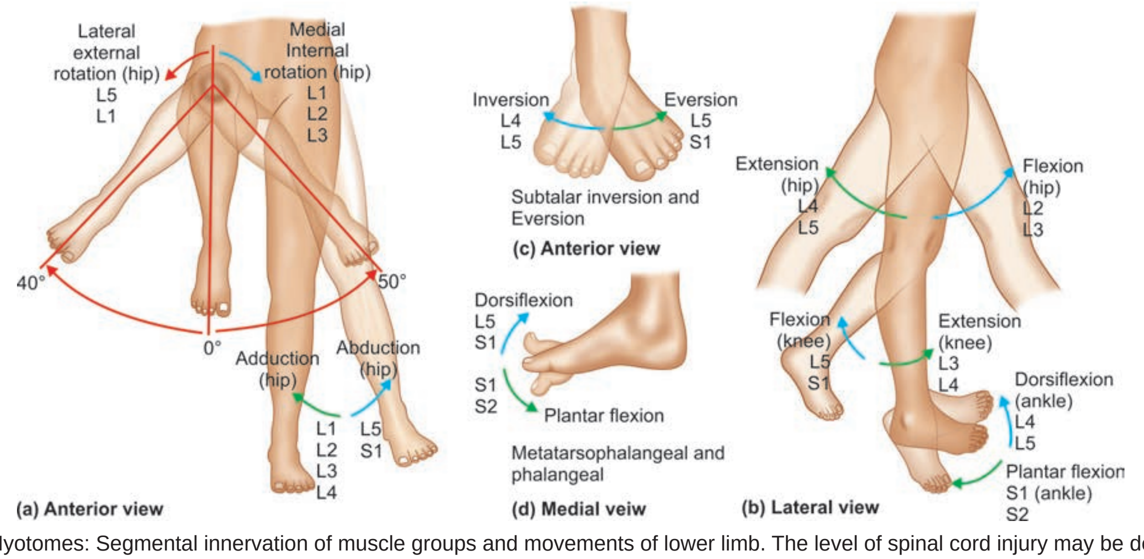


Fig. 51: Myotomes: Segmental innervation of muscle groups and movements of lower limb. The level of spinal cord injury may be determined by the strength and ability to perform particular movements

Muscles

Muscles of Thigh

- The presence and position of the femoral neck cause the femoral shaft to lie obliquely; consequently, the anterior (extensor) muscle group, quadriceps femoris, runs obliquely distally and medially and so applies a pull to the patella that is both laterally and proximally directed.
- The adductor muscles occupy the region between quadriceps femoris and the medial margin of the thigh. They are attached distally to the posterior surface of the femur and lie more posteriorly than quadriceps femoris.

- The posterior muscle group, the hamstrings, lie behind the adductors.
- Muscles of the gluteal region are abductors and rotators of the thigh; muscles of the anterior Compartment of the thigh are flexors of the hip joint and extensors of the Knee Joint and muscles of the posterior compartment of the thigh are extensors of the hip Joint and flexors of the Knee Joint.
- Fascia Lata is a membranous, deep fascia covering muscles of the thigh and forms the lateral and medial intermuscular septa by its inward extension to the femur.
- It is attached to the pubic symphysis, pubic crest, pubic rami, ischial tuberosity, inguinal and sacrotuberous ligaments, and the sacrum and coccyx.

High Yield Points

- Longest muscle in the body is sartorius.
- The **gluteus maximus** is the strongest extensor of the thigh at the hip and especially important when walking uphill, climbing stairs, or **rising from a sitting position**.
- The **iliopsoas** muscle is a powerful flexor of the thigh and attaches to the lesser trochanter.
- The **tensor fascia lata** and rectus femoris muscles can flex the thigh at the hip joint and extend the leg at the knee.
- The sacrospinous ligament is often regarded as a degenerate part of coccygeus.
- In lower limb, **gracilis** is the most common muscle used for surgical **grafting**.
- **Sartorius** muscle causes flexion at *both hip* and knee joint (Sartor – Tailor).
- **Tibialis anterior** is the muscle, which works in **stance** as well as **swing** phase of walking cycle.
- **Obturator externus** is supplied by *lumbar plexus* (obturator nerve).

Anterior Thigh

- Iliac region describes a group of three muscles that originate from the lumbar vertebral column (**psoas major** and minor) and the ilium (**iliacus**).
- Psoas major and iliacus are attached together on the femur as flexors of the hip joint and are often considered as a functional unit, **iliopsoas**.
- Psoas minor only reaches the pubis, and acts on the spine and sacroiliac joint.
- The muscles of the anterior compartment include **sartorius** and **rectus femoris**, which can act at both the hip and knee joints, and vasti medialis, lateralis and intermedius, which act only at the knee.
- **Adductor longus** and **pectineus** are sometimes considered to be part of both the anterior and the adductor compartments.

Quadriceps Femoris

- **Rectus femoris and three vasti** attach to the base of the patella (a sesamoid bone), continue as the patellar ligament, extending from the patellar apex to the tibial tuberosity. These muscles pull the tibia anterior (knee extension).
- Rectus femoris helps to flex the thigh on the pelvis; if the thigh is fixed, it helps to flex the pelvis on the thigh.
- Vastus medialis counter this lateral vector on the patella during knee motion, inadequacy results in patellar instability and pain.
- **Articularis genus** belongs to anterior thigh muscles, retracts the synovial suprapatellar bursa proximally during extension of the leg, presumably to prevent interposition of redundant synovial folds between patella and femur.

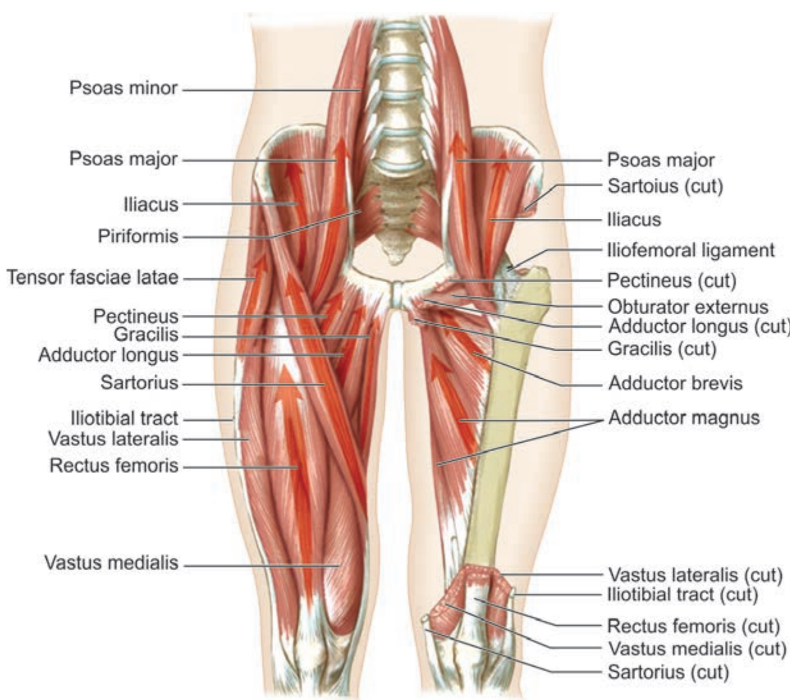


Fig. 52: Muscle of anterior-medial thigh and iliac region

Table 16: Muscles of anterior thigh: Flexors of hip joint				
Muscle	**Proximal attachment**[a]	**Distal attachment**	**Innervation**[b]	**Main action(s)**
Pectineus	Superior ramus of pubis	Pectineal line of femur, just inferior to lesser trochanter	Femoral nerve (**L2**–L3); may receive a branch from obturation nerve	Adducts and flexes thigh; assists with medial rotation of thigh
Iliopsoas	Sides of T12–L5 vertebrae and discs between them; transverse processes of all lumbar vertebrae	Lesser trochanter of femur	Anterior rami of lumbar nerves (**L1**, **L2**, L3)	
Psoas minor	Sides of T12–L1 vertebrae and intervertebral discs	Pectineal line, iliopectineal eminence via iliopectineal arch	Anterior rami of lumbar nerves (L1, L2)	
Iliacus	Iliac crest, iliac fossa, ala of sacrum, and anterior sacro-ligaments	Tendon of psoas major lesser trochanter, and femur distal to it	Femoral nerve (L2, L3)	
Sartorius	Anterior superior iliac spine and superior part of notch interior to it	Superior part of medial surface of tibia	Femoral nerve (L2, L3)	Flexes abducts, and laterally rotates thigh at hip jonit; flexes leg at knee joint. (medially rotating leg when knee is flexed)[d]

[a]The latin word insertio means attachment. The terms insertion and origin (L. origo) have not been used here (or elsewhere) since they change with function.
[b]The spinal cord segmental innervation is indicated (e.g. L1, L2, L3 means that the nerves supplying the psoas major are derived from the first three lumbar segments of the spinal cord). Numbers in boldface (**L1**, **L2**) indicate the main segmental innervation. Damage to one or more of the listed spinal cord segments or to the moto nerve roots arising from them results in parelysis of the muscles concerned.
[c]The psoas major is also a postural muscle that helps control the deviation of the trunks and is active during standing.
[d]The four actions of the sartorus (L. sartor, tailor) produce the once common cross legged sitting positon used by tailors, hence the name.

Table 17: Muscles of anterior thigh: extensors of knee				
Muscle	**Proximal attachment**	**Distal attachment**	**Innervation**[a]	**Main action**
Quardriceps femoris				
Rectus femoris	Anterior inferior illiac spine and ilium superior to acetabulum	Via common tendinous (quadriceps tendon) and independent attachment to base of patella; indirectly via patellar ligament or tibial tuberosity; medial and lateral vasti also attach to tibia and patella via aponeuroses (medial and lateral patellar rtinacula)	Femoral nerve (L2, **L3**, **L4**)	Extend leg at knee joint; rectus femoris also steadies hip joint and helps illiopsoas flex thigh
Vastus lateralis	Greater trochanter and lateral lip of linea aspera of femur			
Vastus medialis	Inter-trochanteric line and medial lip of linea aspera of femur			
Vastus intermedius	Anterior and lateral surfaces of shaft of femur			

[a]The spinal cord segmental innervation is indicated (e.g.,"L1, L2, L3") means that the nerves supplying the quadriceps femoris are derived from the first three lumbar segments of the spinal cord). Number in boldface **(L3, L4)** indicate the main segmental innervation. Damage to one or more of the listed spinal cord segments or to the motor nerve roots arising from them results in paralysis of the muscles concerned.

ASSESSMENT QUESTIONS

1. **Lateral dislocation of patella is prevented by:** *(NEET Pattern 2015)*
   a. Rectus femoris
   b. Vastus intermedius
   c. Vastus lateralis
   d. Vastus medialis

2. **Strongest flexor of the hip joint is:** *(NEET Pattern 2012)*
   a. Sartorius
   b. Gluteus maximus
   c. Iliopsoas
   d. Pectineus

3. **Rectus femoris is a part of quadriceps femoris causes:**
   a. Hip flexion and knee extension
   b. Hip and knee flexion
   c. Hip and knee extension
   d. Hip extension and knee flexion

4. **Action of sartorius muscles includes all except:** *(NEET Pattern 2015)*
   a. Flexion of thigh
   b. Flexion of leg
   c. Extension of leg
   d. Lateral rotator of thigh

ANSWERS WITH EXPLANATIONS

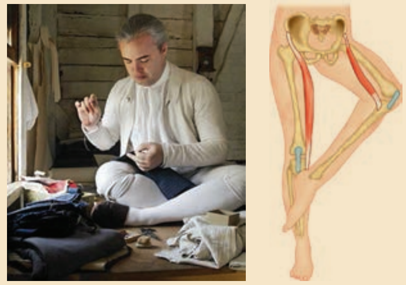
1. **d. Vastus medialis**
   - Vastus medialis stabilizes patella bone and prevents its lateral dislocation on femur.

2. **c. Iliopsoas**
   - Iliopsoas is the chief flexor at hip joint, assisted by sartorius and pectineus as the accessory muscles.
   - Gluteus maximus is the chief extensor at hip joint, assisted by hamstrings as the accessory muscles.

4. a. Hip flexion and knee extension
- Rectus femoris, a part of quadriceps femoris pulls the tibia anterior for knee extension.
- Rectus femoris also act at the hip joint along with iliopsoas for hip flexion.

5. c. Extension of leg
- Sartorius muscle help to attain the sartor (tailor) posture.
- It causes flexion at both the hip and knee joints.
- It also causes abduction and lateral rotation at hip joint.

Action of rectus femoris at hip and knee joints



Sartor (tailor posture) attained by the activity of sartorius muscle: Flexion at both hip and knee joints and abduction & lateral rotation at hip joint.

High Yield Points

- Rectus femoris arises by two tendons : one attached to anterior inferior iliac spine; the other to the brim of the acetabulum and the capsule of hip joint.
- Restraining action of the medial patellofemoral ligament help in preventing lateral displacement of patella.

Medial Thigh

- Muscles of the adductor compartment — gracilis, pectineus, adductor longus, adductor brevis, and adductor magnus have evolved, as their nerve supply suggests, from both flexor and extensor columns.
- All five muscles cross the hip joint but only gracilis reaches beyond the knee.
- Adductors magnus and longus are probably medial rotators of the thigh.
- The adductors are inactive during adduction of the abducted thigh in the erect posture (when gravity assists), but active in other postures, such as the supine position, or during adduction of the flexed thigh when standing.
- They are also active during flexion (longus) and extension (magnus) of the thigh at the hip joint.
- Adductor magnus is composite and is doubly innervated by the obturator nerve and by the tibial division of the sciatic nerve (L2, 3 and 4), which supplies the ischiocondylar part. Both nerves are derived from anterior divisions in the lumbosacral plexus, indicating a primitive flexor origin for both parts of the muscle.

Table 18: Muscles of medial thigh: adductors of thigh

Muscle[a]	Proximal attachment	Distal attachment	Innervation[b]	Main action
Adductor longus	Body of pubis inferior to pubic crest	Middle third of linea aspera of femur	Obturator nerve, branch of, anterior division (L2, **L3**, L4)	Adducts thigh
Adductor brevis	Body and inferior ramus of pubis	Pectineal lines and proximal part of linea aspera of femur		Adducts thigh; to some extent flexes it
Adductor magnus	Adductor part: inferior ramus of pubis, ramus of ischium Hamstrings part: ischial tuberosity	Adductor part: gluteal tuberosity, linea aspera, medial supracondylar lines Hamstring part: adductor tubercle of femur	Adductor part: obturator nerve (L2, **L3**, **L4**), branches of posterior division Hamstring part: tibial part of sciatic nerve (L4)	Adducts thigh Adductor part: flexes thigh Hamstrings part: extends thigh
Gracilis	Body and inferior ramus of pubis	Superior part of medial surface of tibia.	Obturator nerve (**L2**, L3)	Adducts thigh; flexes leg; helps rotate leg medially
Obturator externus	Margins of obturator foramen and obturator membrane	Trochanteric fossa of femur	Obturator nerve (L3, **L4**)	Laterally rotates thigh; steadies head of femur in acetabulum

[a]Collectively, the five muscles listed are the adductors of the thigh, but their actions are more complex (e.g., they act as flexors of the hip joint during flexion of the knee joint and are active during walking).
[b]The spinal cord segmental innervation is indicated (e.g.,"L2, L3, L4" means that the nerves supplying the adductor longus are derived from the second to fourth lumbar segments of the spinal cord). Numbers in boldface (**L3**) indicated the main segmental innervation. Damage to one or more of the listed spinal cord segments or to the motor nerve roots arising from them results in paralysis of the muscles concerned.

Adductor magnus is composite and is doubly innervated by the obturator nerve and by the tibial division of the sciatic nerve (L2, 3 and 4), which supplies the ischiocondylar part. Both nerves are derived from anterior divisions in the lumbosacral plexus, indicating a primitive flexor origin for both parts of the muscle

ASSESSMENT QUESTION

1. **What is TRUE about adductors of thigh:** *(NEET Pattern 2015)*
   a. Ischial head of adductor magnus is an adductor
   b. Profunda femoris artery is the main blood supply
   c. Ischial head of adductor magnus originates from adductor tubercle
   d. Adductor magnus is the largest muscle

ANSWER WITH EXPLANATION

1. **d. Adductor magnus is the largest muscle, > b. Profunda femoris artery is the main blood supply**
   - Adductor magnus is the largest muscle and is a hybrid muscle having two parts.
   - Posterior ischial head of adductor magnus, takes origin from ischial tuberosity and is a hamstring part (not adductor).
   - Profunda femoris artery provides major supply to all the three compartments of thigh including medial (adductor) compartment.

Posterior Thigh

- Posterior thigh muscles, biceps femoris, semitendinosus and semimembranosus, are termed the **'hamstrings'.**
- They cross **both** hip and knee joints, and integrate e**xtension at the hip** with **flexion at the knee**.
- As the muscles span the back of the knee, they form the proximal lateral and medial **margins of the popliteal fossa**.
- Actions of posterior thigh muscles acting from above, the posterior thigh muscles flex the knee.
- Acting from below, they extend the hip joint, pulling the trunk upright from a stooping posture against the influence of gravity, biceps femoris being the main agent.
- When the knee is semi-flexed, biceps femoris can act as a lateral rotator and semimembranosus and semitendinosus as medial rotators of the lower leg on the thigh at the knee.
- When the hip is extended, biceps femoris is a lateral rotator and semimembranosus and semitendinosus are medial rotators of the thigh.
- Some authors equate **sacrotuberous ligament** with the degenerated developmental remnant of the tendon of the long head of the **biceps femoris**.

Clinical Correlations

- Hamstring injuries or strains (pulled or torn hamstrings) are very painful and common in persons who are involved in running, jumping, and quick-start sports.
- Avulsion of the ischial tuberosity (the origin of the hamstrings) may result from forcible flexion of the hip with the knee extended.

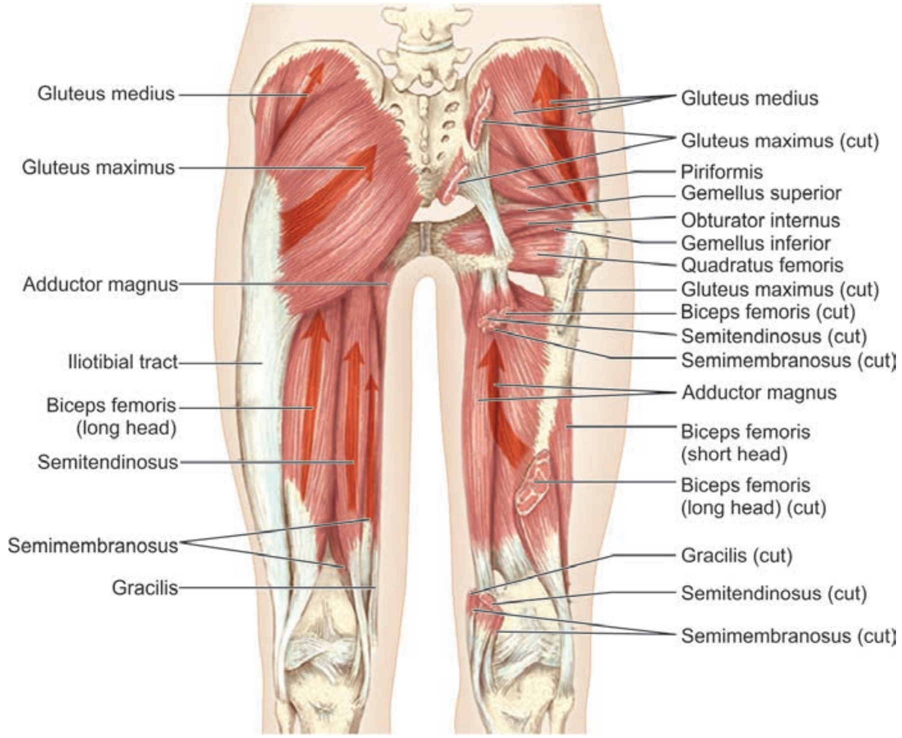


Fig. 53: Muscles in the gluteal region and posterior thigh

Table 19: Muscles of posterior thigh extensors of hip and flexors of knee

Muscle[a]	Proximal attachment	Distal attachment	Innervation[b]	Main action
Semitendinosus	Ischial tuberosity	Medial surface of superior part of tibia	Tibial division of sciatic nerve part of tibia **(L5, S1, S2)**	Extend thigh; flex leg and rotate it medially when knee is flexed; when thigh and leg are flexed, these muscles can extend trunk
Semimembranosus		Posterior part of medial condyle of tibia; reflected attachment forms oblique popliteal ligament (to lateral femoral condyle)		
Biceps femoris	Long head: ischial tuberosity Short head: linea aspera and lateral supracondylar line of femur	Lateral side of head of fibula; tendon is split at this site by fibular collateral ligament of knee	Long head: tibial division of sciatic nerve **(L5, S1, S2)** Short head: common fibular division of sciatic nerve **(L5, S1, S2)**	Flexes leg and rotates it laterally when knee is flexed; extends thigh (e.g., accelerating mass during first step of gait).

[a]Collectively these three muscles are known as hamstrings
[b]The spinal cord segmental innervation is indicated (e.g., "LS, S1, S2" means that the nerves supplying the semitendinosus are derived from the fifth lumbar segment and first two sacral segments of the spinal cord). Numbers in boldface **(L5, S1)** indicate the main segmental innervation. Damage to one or more of the listed spinal cord segments or to the motor nerve roots arising from them results in paralysis of the muscles concerned.

Fig. 54: Hamstring injuries or strains (pulled or torn hamstrings) are very painful and common in persons who are involved in running, jumping, and quick-start sports. Avulsion of the ischial tuberosity (the origin of the hamstrings) may result from forcible flexion of the hip with the knee extended

ASSESSMENT QUESTIONS

1. **The following are part of hamstrings:** *(PGIC 2014,15)*
   a. Semitendinosus
   b. Semimembranosus
   c. Gracilis
   d. Short head of biceps femoris
   e. Sartorius
2. **TRUE regarding semitendinosus:** *(NEET Pattern 2015)*
   a. Supplied by common peroneal part of sciatic nerve
   b. Proximal flashy distal thin
   c. Distal flashy proximal thin
   d. Proximal and distal thin middle fleshy
3. **Biceps femoris, a hamstring muscle causes:**
   a. Hip flexion and knee extension
   b. Hip and knee flexion
   c. Hip and knee extension
   d. Hip extension and knee flexion

ANSWERS WITH EXPLANATIONS

1. **a. Semitendinosus, b. Semimembranosus**
   - Hamstrings are: semitendinosus, semimembranosus, long head of biceps femoris and posterior part of adductor magnus.
2. **b. Proximal flashy distal thin**
   - Semitendinosus is fleshy in the upper part and forms a cord-like tendon in the lower part, which lies posterior to semimembranosus muscle.
   - It is a hamstring muscle supplied by the tibial part of sciatic nerve.
3. **d. Hip extension and knee flexion**
   - Biceps femoris is one of the **hamstring** muscles along with semitendinosus, semimembranosus, and ischial head of the adductor magnus, which extend the thigh at the hip and flex the leg at the knee.

Gluteal Region

Table 20: Muscles of gluteal region: abductors and rotators of thigh

Muscle	Proximal attachment	Distal attachment	Innervation[a]	Main action
Gluteus maximus	Ilium posterior to posterior gluteal line; dorsal surface of sacrum and coccyx; sacrotuberous ligament	Most fibers end in iliotibial tract, which inserts into lateral condyle of tibia; some fibers insert on gluteal tuberosity	Inferior gluteal nerve (L5, **S1, S2**)	Extends thigh (especially from flexed position) and assists in its lateral rotation; steadies thigh and assists in rising from sitting position
Gluteus medius	External surface of ilium between anterior and posterior gluteal lines	Lateral surface of greater trochanter of femur	Superior gluteal nerve (**LS, S1**)	Abduct and medially rotate thigh; keep pelvis level when ipsilateral limb is weight-bearing and advance opposite (unsupported) side during its swing phase
Gluteus minimus	External surface of ilium between anterior and inferior gluteal lines	Anterior surface of greater trochanter of femur		
Tensor fasciae	Anterior superior iliac spine; anterior part of iliac crest	Iliotibial tract, which attaches to lateral condyle of tibia		
Piriformis	Anterior surface of sacrum; sacrotuberous ligament	Superior border of greater trochanter of femur	Branches of anterior rami of **S1**, S2	Laterally rotate extended thigh and abduct flexed thigh; steady femoral head in acetabulum
Obturator internus	Pelvic surface of obturator membrane and surrounding bones	Medial surface of greater trochanter (trochanteric fossa) of femur[c]	Nerve to obturator intemus (LS, **S1**)	Laterally rotate extended thigh and abduct flexed thigh; steady femoral head in acetabulum
Superior and inferior gemelli	Superior: ischial spine Inferior: ischial tuberosity	Medial surface of greater trochanter (trochanteric fossa) of femur[b]	Superior gemellus : same nerve supply as obturator internus Inferior gemellus: same nerve supply as quadratus femoris	
Quadratus femoris	Lateral border of ischial tuberosity	Quadrate tubercle on inter-trochanteric crest of femur and area inferior to it	Nerve to quadratus femoris (L5, S1)	Laterally rotates thigh; steadies femoral head in acetabulum

[a]The spinal cord segmental innervation is indicated (e.g., "S1.S2"s means that the nerves supplying the piriformis are derived from the first two sacral segments of the spinal cord). Numbers in boldface (S1) indicate the main segmental innervation. Damage to one or more of the listed spinalcord segments or to the motor nerve roots arising from them. Results in paralysis of the muscles concerned.

[b]The gemelli muscles blend with and share the tendon to the obturator internus as it attaches to the greater trochanter of the femur, collectively forming the triceps coxae.

[c]There are six lateral rotators of the thigh: piriformis, obturator internus, superior and interior gemelli, quadratus temoris, and obturator externus. These muscles also stabilize the hip joint.

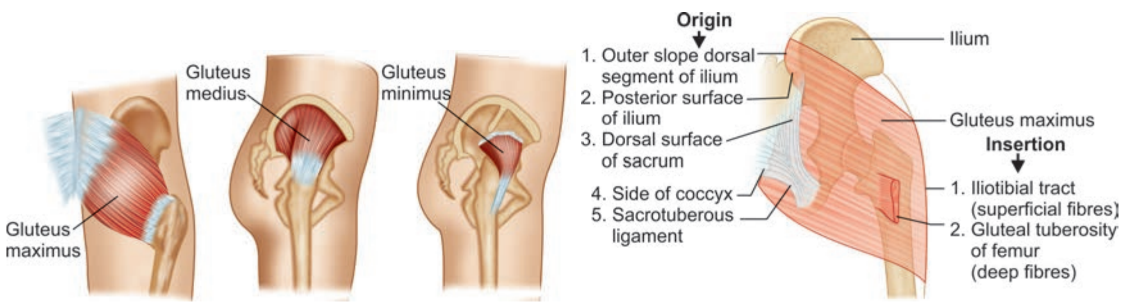


Fig. 55: Origin and insertion of the gluteus maximus

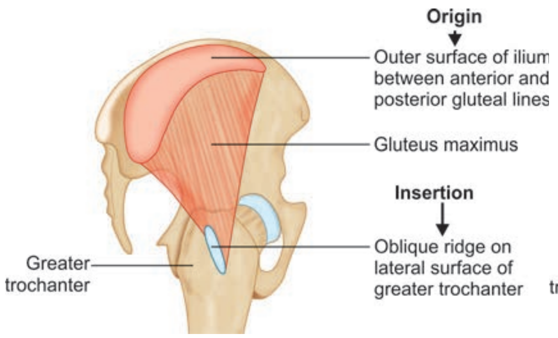


Fig. 56: Origin and insertion of the gluteus medius

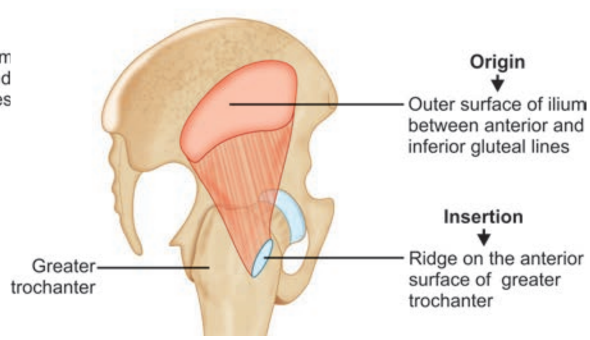


Fig. 57: Origin and insertion of the gluteus minimus

ASSESSMENT QUESTIONS

1. **Gluteus maximus is inserted on:** *(NEET Pattern 2014)*
   a. Lesser trochanter
   b. Greater trochanter
   c. Spiral line
   d. Iliotibial tract

2. **TRUE regarding origin and insertion of piriformis:** *(NEET Pattern 2015)*
   a. Origin from sacrum and ilium and insertion on LT
   b. Origin from sacrum and ilium and insertion on GT
   c. Origin from Ischial tuberosity and insertion on LT
   d. Origin from ischial tuberosity and insertion on GT

3. **Muscle attached to lateral surface of greater trochanter:** *(NEET Pattern 2014)*
   a. Gluteus maximus
   b. Gluteus medius
   c. Gluteus minimus
   d. Piriformis

4. **Gluteus medius is supplied by the nerve:** *(AIPG-2010)*
   a. Superior gluteal
   b. Inferior gluteal
   c. Femoral
   d. Sciatic

ANSWERS WITH EXPLANATIONS

1. **d. Iliotibial tract**
   - For gluteus maximus insertion, most fibers end in iliotibial tract, which inserts into lateral condyle of tibia; some fibers insert on gluteal tuberosity.

2. **b. Origin from sacrum and ilium and insertion on GT**
   - Piriformis muscle takes its origin from anterior surface of sacrum, gluteal surface of ilium and sacrotuberous ligament.
   - Its round tendon inserts on the medial side of the greater trochanter.

3. **b. Gluteus medius**
   - Gluteus medius attaches to the **lateral** surface of greater trochanter.
   - Gluteus minimus attaches to the **anterior** surface of greater trochanter.
   - Gluteus maximus attaches on **posterior** aspect of femur bone at gluteal tuberosity.

4. **a. Superior gluteal**
   - Gluteus medius is supplied by superior gluteal nerve. Superior gluteal nerve supplies three muscles: gluteus medius, gluteus minimus and tensor fascia lata.
   - Inferior gluteal nerve supplies gluteus maximus muscle (chief muscle for hip extension).
   - Femoral nerve supplies the anterior thigh muscles like quadriceps femoris.
   - Sciatic (tibial and peroneal) nerve supplies the posterior thigh muscles and the muscles of the leg and sole.

Anterior and Lateral Leg

- Muscles of the leg consist of an anterior group of extensor muscles, which produce dorsiflexion (extension) of the ankle; a posterior group of flexor muscles, which produce plantar flexion (flexion); and a lateral group of muscles, which evert the ankle and which are derived, embryologically, from the anterior muscle group.
- In the anterior compartment two of the muscles, extensor digitorum longus and extensor hallucis longus, also extend the toes, and two muscles, tibialis anterior and fibularis tertius, have the additional actions of inversion and eversion, respectively.
- The lateral compartment contains fibularis (peroneus) longus and fibularis (peroneus) brevis. Both muscles evert the foot and are plantar flexors of the ankle.

Table 21: Muscles of anterior and lateral compartments of leg

Muscle	Proximal attachment	Distal attachment	Innervation[a]	Main action
Anterior compartment Tibialis anterior (1)	Lateral condyle and superior half of lateral surface of tibia and interosseous membrane	Medial and inferior surfaces of medial cuneiform and base of 1st metatarsal	Deep fibular nerve (**L4**, L5)	Dorsiflexes ankle and inverts foot
Extensor digitorum longus (2)	Lateral condyle of tibia and superior three quarters of medial surface of fibula and interosseous membrane	Middle and distal phalanges of lateral four digits		Extends lateral four digits and dorsiflexes ankle
Extensor hallucis longus (3)	Middle part of anterior surface of fibula and interosseous membrane	Dorsal aspect of base of distal phalanx of great toe (hallux)		Extends great toe and dorsiflexes ankle
Fibularis tertius (4)	Inferior third of anterior surface of fibula and interosseous membrane	Dorsum of base of 5th metatarsal		Dorsiflexes ankle and aids in eversion of foot
Lateral compartment Fibularis longus (5)	Head and superior two thirds of lateral surface of fibula	Base of 1 st metatarsal and medial cuneiform	Superficial fibular nerve (**L5, S1**, S2)	Everts foot and weakly plantarflexes ankle
Fibularis brevis (6)	Inferior two thirds of lateral surface of fibula	Dorsal surface of tuberosity on lateral side of base of 5th metatarsal		

[a]The spinal cord segmental innervation is indicated (e.g., "L4. L5" means that the nerves supplying the tibialis anterior are derived from the fourth and filth lumbar at the spinal cord). Numbers in boldface (L4) indicate the main segmental innervation. Damage to one or more at the listed spinal cord segments or to the motor nerve roots arising from them results in paralysis of the muscles concerned.

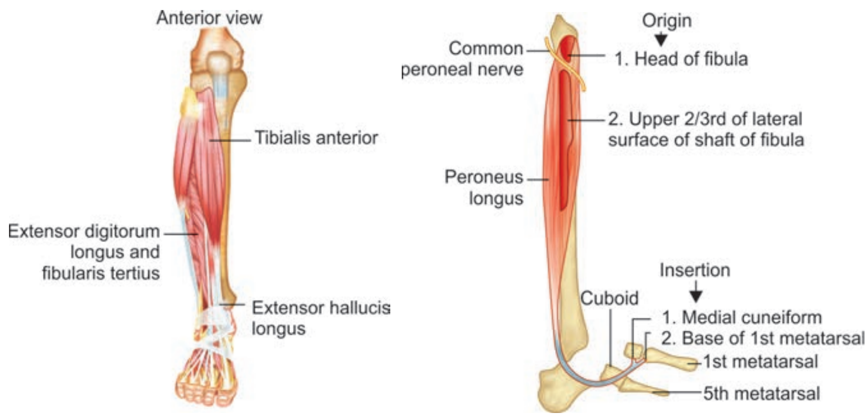


Fig. 58: Origin and insertion of the peroneus longus muscle

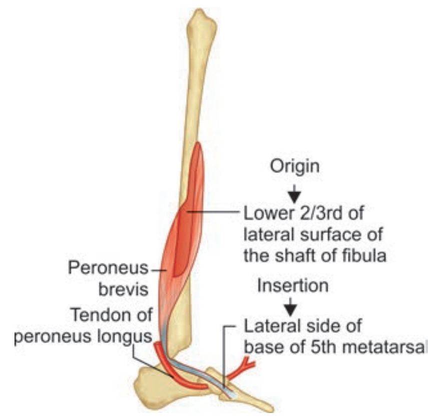


Fig. 59: Origin and insertion of the peroneus brevis muscle

ASSESSMENT QUESTIONS

1. **Anterior compartment of leg contains all muscle EXCEPT:** *(NEET Pattern 2012)*
   a. Peroneus brevis
   b. Peroneus tertius
   c. Extensor hallucis longus
   d. Tibialis anterior

2. **Action of tibialis anterior:** *(NEET Pattern 2015)*
   a. Plantar flexion of foot
   b. Adduction of foot
   c. Inversion of foot
   d. None of the above

3. **All are true about anterior compartment of leg EXCEPT:** *(NEET Pattern 2015)*
   a. Tibialis anterior causes dorsiflexion of foot
   b. EHL causes extension of MTP joint of big toe
   c. Peroneus longus causes eversion of foot
   d. Nerve supply is through deep peroneal nerve

4. **Violent inversion of the foot will lead to avulsion of tendon of the following muscle attached to the tuberosity of the 5th metatarsal:** *(AIIMS 2007)*
   a. Peroneus brevis
   b. Peroneus longus
   c. Peroneus tertius
   d. Extensor digitorum brevis

5. **Peroneus longus:** *(NEET Pattern 2015)*
   a. Invertor of foot
   b. Supplied by deep peroneal nerve
   c. Maintains arches of foot
   d. Arises from tibia

ANSWERS WITH EXPLANATIONS

1. **a. Peroneus brevis**
   - Peroneus longus and brevis belong to lateral leg compartment.
   - Peroneus tertius is present in anterior leg compartment with extensors Tom, Dick & Harry. (T - Tibialis anterior, D- Extensor digitorum longus, H - Extensor Hallucis longus).
2. **c. Inversion of foot**
   - Tibialis anterior is a muscle of anterior (extensor) leg compartment for extension (dorsiflexion) at the ankle joint.
   - It works with tibialis posterior for movement of inversion as well.
3. **c. Peroneus longus causes eversion of foot**
4. **a. Peroneus brevis**
   - Peroneus longus and brevis cause eversion of foot at subtalar joint.
   - Tibialis anterior and posterior cause inversion of foot at subtalar joint.
5. **c. Maintains arches of foot**
   - Peroneus longus causes foot eversion and maintains lateral longitudinal and transverse arches of foot.
   - It takes its origin from fibula and is supplied by superficial peroneal nerve.

Posterior Leg (Calf)

- Muscles in the posterior compartment of the lower leg form superficial and deep groups, separated by the transverse intermuscular septum.
- **Superficial flexor group** are (GPS): Gastrocnemius, plantaris and soleus (Triceps surae)
  - Gastrocnemius and plantaris act on both the knee and the ankle joints, soleus on the latter alone
  - Actions of triceps surae: Gastrocnemius and soleus are the chief plantar flexors of the foot; gastrocnemius is also a flexor of the knee.
- **Deep flexor group** lies beneath (anterior to) the transverse intermuscular septum and consists of popliteus, which acts on the knee joint, and flexor digitorum longus, flexor hallucis longus and tibialis posterior, which all produce plantar flexion at the ankle.

- When the foot is off the ground, both flexor hallucis longus and flexor digitorum longus muscles flex the phalanges, acting primarily on the distal phalanges.
- When the foot is on the ground and under load, they act synergistically with the small muscles of the foot and, especially in the case of flexor digitorum longus, with the lumbricals and interossei to maintain the pads of the toes in firm contact with the ground, enlarging the weight-bearing area.
- **Plantaris** has a long slender tendon giving the appearance of a nerve (hence termed freshman's nerve).
  - It is a vestigial muscle (absent in 5–10% population), tendon is used for grafting.
  - **Soleus** is called **peripheral heart**, as it helps pumping the blood in the circulatory system.
- **Popliteus** 'unlocks' the joint at the beginning of flexion of the fully extended knee.
  - It rotates the tibia medially on the femur or, when the tibia is fixed, rotates the femur laterally on the tibia.
  - It retracts the posterior horn during lateral rotation and continuing flexion, via its attachment to the lateral meniscus, and so prevents traumatic compression.
  - It provides dynamic stability to the posterolateral part of the knee by preventing excessive lateral rotation of the tibia, partly by its direct action, but more significantly by tensing the popliteofibular ligament.

Table 22: Superficial muscles of posterior compartment of leg

Muscle	Proximal attachment	Distal attachment	Innervation[a]	Main action
Gastrocnemius (1)	Lateral head: lateral aspect of lateral condyle of lemur	Posterior surface of calcaneus via calcaneal tendon	Tibial nerve (S1, S2)	Plantarflexes ankle when knee is extended; raises heel during walking; flexes leg at knee joint
	Medial head: popliteal surface of femur; superior to medial condyle			
Soleus (2)	Posterior aspect of head and superior quarter of posterior surface of fibula; soleal line and middle third of medial border of tibia; and tendinous arch extending between the bony attachments			Plantarflexes ankle independent of position of knee steadies leg on foot
Plantaris (3)	Inferior end of lateral supracondylar line of femur; oblique popliteal ligament			Weakly assists gastrocnemius in plantarflexing ankle

[a]The spinal cord segmental innervation is Indicated (e.g., "S1, S2' means that the nerves supplying these muscles are derived from the first and second sacral segments of the spinal cord). Damage to one or more of the listed spinal cord segments or to the motor nerve roots arising from them results in paralysis of the muscles concerned.

Plantaris has a long slender tendon giving the appearance of a nerve (hence termed freshman's nerve).
It is a vestigial muscle (absent in 5–10% population), tendon is used for grafting.
Soleus is called peripheral heart, as it helps pumping the blood in the circulatory system.

Table 23: Deep muscles of posterior compartment of leg

Muscle	Proximal attachment	Distal attachment	Innervation[a]	Main action
Popliteus	Lateral surface of lateral condyle of femur and lateral meniscus	Posterior surface of tibia, superior to soleal line	Tibial nerve (L4, LS, S1)	Weakly flexes knee and unlocks it by rotating femur 5° on fixed tibia; medially rotates tibia of unplanted limb
Flexor hallucis longus (4)	Inferior two thirds of posterior surface of fibula; inferior part of interosseous membrane	Base of distal phalanx of great toe (hallux)	Tibial nerve (S2. S3)	Flexes great toe at all joints; weakly plantarflexes ankle: supports medial longitudinal arch of fool
Flexor digitorum longus (5)	Medial part of posterior surface of tibia inferior to soleal line; by a broad tendon to fibula	Bases of distal phalanges of lateral four digits		Flexes lateral four digits; plantarflexes ankle; supports longitudinal arches of foot
Tibialis posterior (6)	Interosseous membrane: posterior surf ace of tibia inferior to sole al line: posterior surf ace of fibula	Tuberosity of navicular. cuneiform. cuboid, and sustentaculum tali of calcaneus; bases of 2nd. 3rd, and 4th metatarsals	Tibial nerve (L4, LS)	Plantarflexes ankle: inverts foot

[a]The spinal cord segmental innervation is indicated (e.g. 'S2, S3' means that the nerves supplying the nexor hallucis longus are derived from the second and third sacral segments of the spinal cord). Damage to one or more of the listed spinal cord segments or to the motor nerve roots arising from them results in paralysis of the muscles concerned.

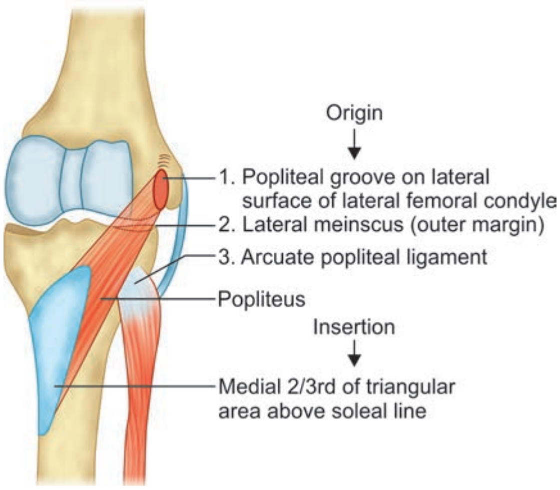


Fig. 60: Popliteus muscle - origin and insertion

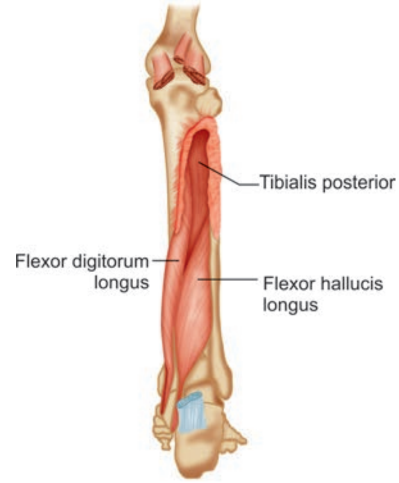


Fig. 61: Posterior leg (calf) muscles: Deeper group

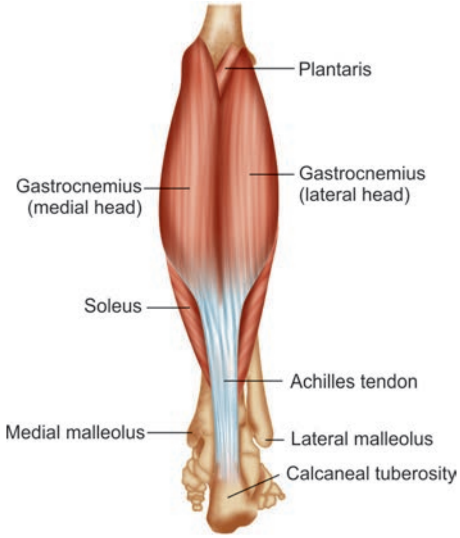


Fig. 62: Posterior leg (calf) muscles: Superficial group

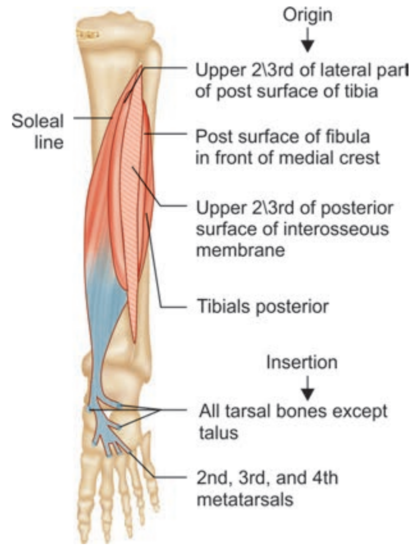


Fig. 63: Origin and insertion of the tibialis posterior

ASSESSMENT QUESTIONS

1. **Which of the following tendons more likely to rupture during violent dorsiflexion of the foot:** *(NEET Pattern 2013)*
   a. EHL
   b. EDL
   c. FHL
   d. Plantaris

2. **Muscle acting both at knee and ankle joint is/are:** *(PGIC-2014, 15)*
   a. Gastrocnemius
   b. Soleus
   c. Plantaris
   d. Tibialis posterior
   e. Flexor hallucis longus

3. **All are true about popliteus EXCEPT:** *(NBEP-2013)*
   a. Flexes the knee
   b. Unlocks the knee
   c. Inserted on medial meniscus
   d. Is intracapsular

4. **Which of the following muscles is included in Triceps surae:** *(NBEP- 2014)*
   a. Gastrocnemius
   b. Popliteus
   c. Extensor hallucis longus
   d. Extensor digitorum longus

5. **Which muscle originates from both tibia and fibula and interosseus membrane:** *(NEET Pattern 2014)*
   a. Popliteus
   b. Flexor digitorum longus
   c. Flexor hallucis longus
   d. Tibialis posterior

6. **INCORRECT statement regarding popliteus is:**
   a. Intracapsular origin
   b. Attaches to medial lemniscus
   c. Supplied by tibial nerve
   d. Causes flexion and medial rotation at knee joint

7. **Tibialis posterior is inserted in all the tarsal bones EXCEPT:**
   a. Calcaneus
   b. Intermediate cuneiform
   c. Cuboid
   d. Talus

ANSWERS WITH EXPLANATIONS

1. d. Plantaris
- Plantaris is a muscle of calf region, which get stretched in dorsiflexion, and might get ruptured.

2. a. Gastrocnemius, c. Plantaris
- The only muscles which cross the knee joint as well as ankle joint are gastrocnemius & plantaris.
- They both cause flexion at knee joint and plantar flexion at ankle joint.

3. c. Inserted on medial meniscus
- Popliteus muscle is inserted to lateral meniscus of knee joint.

4. a. Gastrocnemius
- Triceps surae include three muscle (GPS): Gastrocnemius, plantaris and soleus.

5. d. Tibialis posterior

6. b. Attaches to medial meniscus.
- Popliteus muscle has intracapsular origin from the lateral condyle of femur, has attachment with the lateral lemniscus (not medial) and inserts into the posterior surface of tibia (floor of popliteal fossa).
- It is supplied by **tibial nerve** and unlocks the knee joint by **medial rotation** of tibia (in unplanted foot). It also works with hamstring muscles for **knee flexion**.

7. d. Talus
- Tibialis posterior muscle has extensive attachments on the foot bones, but is not attached to talus bone. **Talus** bone in the foot and **Incus** bone in the middle ear cavity has no has no muscle attachments.

Iliotibial Tract

- Iliotibial tract is the thickening of fascia lata on the lateral surface of thigh.
- It originates at the anterolateral iliac tubercle portion of the external lip of the iliac crest and inserts at the on the anterolateral aspect of the lateral condyle of the tibia (Gerdy›s tubercle).
- The upper end of the tract splits into two layers, where it encloses and anchors tensor fasciae latae and receives, posteriorly, most of the tendon of gluteus maximus.
- Some deeper fibres are attached to the capsule of the hip joint.
- Iliotibial tract stabilizes the knee both in extension and in partial flexion; works constantly during walking and running.
- On leaning forward with slightly flexed knees the iliotibial tract is the main support of the knee against gravity and prevents the individuals from falling forward.

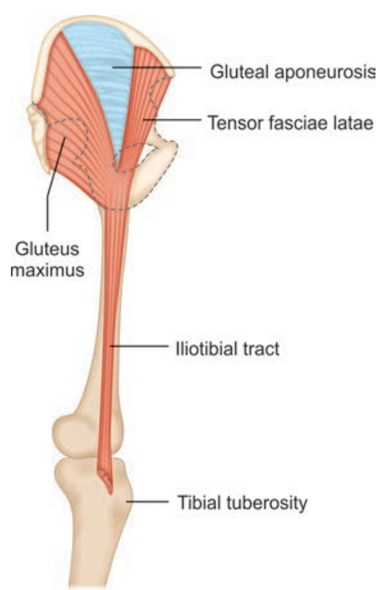


Fig. 64: Attachment of the iliotibial tract. Note superficial portion of gluteus maximus and tensor fasciae latae insert into the iliotibial tract from opposite directions

ASSESSMENT QUESTION

1. True about iliotibial tract all EXCEPT: *(NEET Pattern 2015)*
a. Receives insertion of gluteus maximus
b. Derived from fascia lata
c. Inserted on tibial tuberosity
d. Supports knee in semiflexed and extended position

ANSWER WITH EXPLANATION

1. c. Inserted on tibial tuberosity

- Iliotibial tract is inserted on the Gerdy's tubercle, on anterolateral surface of the lateral tibial condyle.

Trendelenburg Test

- Three muscles (gluteus medius, gluteus minimus and tensor fascia lata) carry out three activities and are supplied by a single nerve (superior gluteal nerve).
- The three activities (hip abduction, medial rotation and pelvic rotation) are shown below.

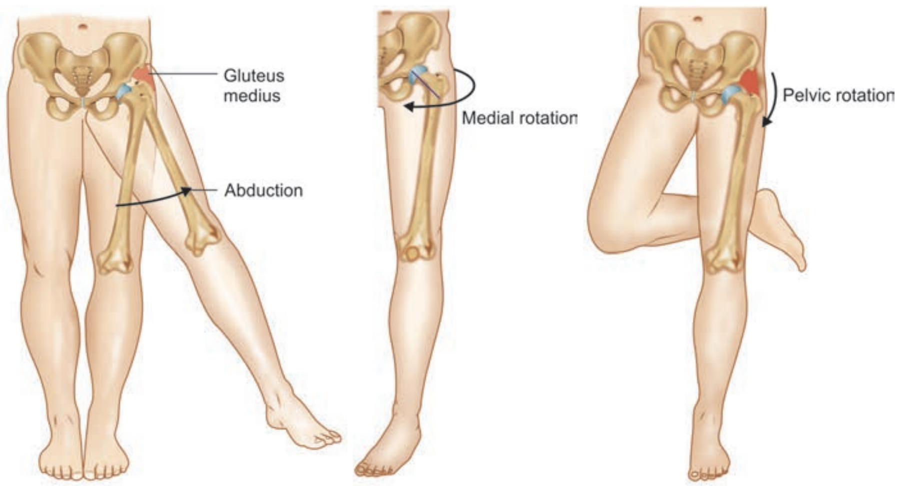


Fig. 65: Three actions of the three muscles (gluteus medius, gluteus minimus and tensor fascia lata)

- Pelvic rotation: Gluteus medius and gluteus minimus muscles constitute the major abductors of the hip and are demonstrated by asking the subject to stand on one limb.
- The ipsilateral muscles contract to stabilize the centre of gravity and maintain a relatively horizontal pelvic position.
- During walking, gravity tends to tilt pelvis and trunk to the unsupported side, these muscles prevent this unwanted movement, by counteracting gravity from the opposite side.
- Paralysis of thee muscles causes pelvic tilt towards the unsupported, contralateral side (Trendelenburg's sign).

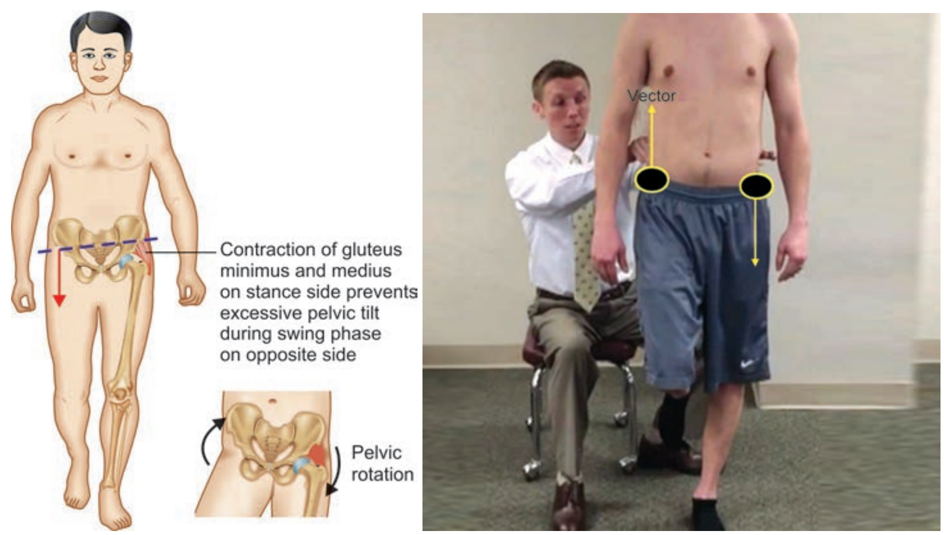


Fig. 66: Trendelenberg test: Normally in swing phase of walking cycle, a vector is generated, to counter gravity on the side of the elevated limb. This is generated by the opposite side muscles (gluteus medius and minimus) by causing pelvic rotation. The muscles pull the left hip bone down, so that the right hip bone goes up (pelvic rotation) and balance the gravity on right side pelvis

- **Trendelenburg test** is used to assess hip stability.
- The patient is asked to stand unassisted on each leg in turn, whilst the examiner's fingers are placed on the anterior superior iliac spines.
- The foot on the contralateral side is elevated from the floor by bending at the knee.
- In normal function, the hip is held stable by gluteus medius acting as an abductor in the supporting leg.
- If the pelvis drops on the unsupported side - positive Trendelenburg sign - the hip on which the patient is standing is painful or has a weak or mechanically-disadvantaged gluteus medius.

- Positive **Trendelenburg** sign is seen in the fracture of the femoral neck, hip dislocation (head of femur), or weakness and paralysis of the gluteus medius (abductor).
- If the left gluteus medius muscle is paralyzed, the right side (sound side) of the pelvis falls (sags) instead of rising; normally, the pelvis rises on the unsupported side.
- When the pelvis descends on the unsupported side, the lower limb becomes, in effect, too long and does not clear the ground when the foot is brought forward in the swing phase of walking.
- To compensate, the individual leans away from the unsupported side, raising the pelvis to allow adequate room for the foot to clear the ground as it swings forward. This results in a characteristic "waddling" or gluteal/lurching gait.

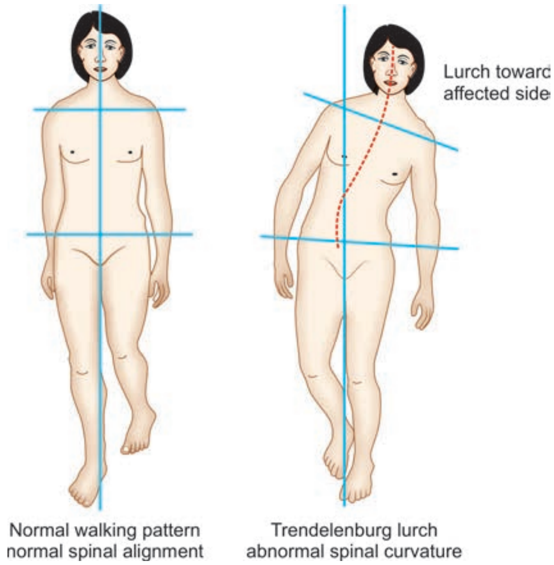


Fig. 67: Lurching gait in a case of left superior gluteal nerve injury (left gluteus medius palsy). Patient's right lower limb keep falling down during swing phase of walking cycle (limb length becomes more) and is unable to clear the foot from the ground leading to a lurch to clear it from ground

ASSESSMENT QUESTIONS

1. In walking, gravity tends to tilt pelvis and trunk to the unsupported side, major factor in preventing this unwanted movement is:

a. Adductor muscles
b. Quadriceps
c. Gluteus maximus
d. Gluteus medius and minimus

2. Wrong about Trendelenburg test is:

a. Contraction of gluteus maximus is assessed
b. Positive in superior gluteal nerve damage
c. Right pelvis drops down in left superior gluteal nerve lesion
d. Bilateral damage results in Waddling gait

3. Trendelenburg test is positive due to injury to the nerve: *(AIIMS 2008)*

a. Inferior gluteal
b. Superior gluteal
c. Obturator
d. Tibial

4. An 83-year-old man has trouble walking. At his physician›s office, he is asked to stand on his right foot and his left hip drops. Which of the following nerves is most likely damaged, causing his problem:

a. Left inferior gluteal
b. Left superior gluteal
c. Right inferior gluteal
d. Right superior gluteal

5. Inability to maintain pelvis position while standing on one leg, nerve paralysed: *(JIPMER - 2016)*

a. Superior gluteal nerve
b. Inferior gluteal nerve
c. Tibial part of sciatic nerve
d. Common peroneal nerve

ANSWERS WITH EXPLANATIONS

1. d. Gluteus medius and minimus

- During walking, gravity tends to tilt pelvis and trunk to the unsupported side, these muscles prevent this unwanted movement, by counteracting gravity from the opposite side.

2. a. Contraction of gluteus maximus is assessed.

- **Trendelenburg test** is to check the gluteus medius and minimus muscle (**not** the gluteus maximus). **Superior gluteal nerve** lesion paralyses gluteus medius and minimus, which leads to fall of contralateral pelvis during *swing phase* of walking cycle.
- If the nerve injury is bilateral, it leads to bilateral lurching (**waddling** gait).

3. b. Superior gluteal
- **Superior gluteal** nerve, if injured, paralyses the 3 muscles: gluteus medius, gluteus minimus and tensor fascia latae and hence lead to Trendelenberg test positive.
- These 3 muscles, especially the gluteus medius raises the unsupported hip during walking, which otherwise will be pulled down by the gravity.
- In Trendelenberg test this action of gluteus medius (superior pelvic tilt of contralateral hip) is absent and we actually observe that there is a downward drop of the unsupported hip -due to unopposed action of gravity.
- This leads to Lurching gait in the patient.

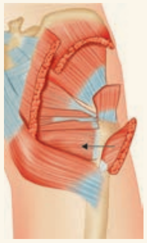
4. d. Right superior gluteal
- In this patient, the right superior gluteal nerve is damaged, leading to **failure** of abductor mechanism of gluteus medius.
- There is also the **failure** of muscle to cause an upward lift of left hip, when the patient is asked to stand on his right foot.
- Normally the superior gluteal nerve leads to pelvic stability while a person stands on a single foot, by elevating the opposite hip- the job being performed by gluteus medius.

5. a. Superior gluteal nerve
- When a person who has suffered a lesion of the superior gluteal nerve is asked to stand on one leg, the pelvis on the unsupported side descends, indicating that the gluteus medius and minimus on the supported side are weak or non-functional.
- This sign is referred to clinically as a positive Trendelenburg test.

ASSESSMENT QUESTIONS

1. Hybrid muscles are all EXCEPT:
a. Pectineus
b. Adductor magnus
c. Tensor fascia lata
d. Biceps femoris

2. Identify the marked muscle in the gluteal region:
a. Obturator externus
b. Obturator internus
c. Quadratus femoris
d. Piriformis



3. Which of the following muscle is involved in movement from sitting to standing position: *(NEET Pattern-2014)*
a. Gluteus maximus
b. Obturator internus
c. Gluteus medius
d. Gluteus minimus

4. Which of the following muscle has intracapsular origin: *(PGIC-2012)*
a. Anconeus
b. Coracobrachialis
c. Long head of biceps femoris
d. Popliteus
e. Peroneus longus

5. With foot off the ground and knee flexed, medial rotation of tibia is brought about by: *(JIPMER 2007)*
a. Popliteus
b. Vastus medialis
c. Gastrocnemius
d. Adductor magnus

ANSWERS WITH EXPLANATIONS

1. c. Tensor fascia lata
- Tensor fascia lata is supplied by a single nerve - superior gluteal nerve.

2. c. Quadratus femoris
- Under cover of gluteus maximus, a quadrangular muscle, attached to bone femur is called quadratus femoris.

3. a. Gluteus maximus
- Gluteus maximus works as an extensor of trunk on thigh, when raising the trunk from sitting, acting from the pelvis, it an extend the flexed thigh and bring it in line with the trunk.

4. d. Popliteus.
- Long head of biceps brachii and the popliteus muscle has intracapsular origin.

5. a. Popliteus
- Popliteus muscle causes unlocking of knee joint, when foot is in the air, by rotating tibia medially.

Arterial Supply

- **Femoral artery** (the continuation of the **external iliac artery**) provides the principal arterial supply to the lower limb distal to the inguinal ligament .
  - The femoral artery courses within the subsartorial (adductor) canal, which is located on the anteromedial aspect of the thigh, passes through the adductor hiatus to become the **popliteal artery** on entering the posterior compartment of the thigh and soon thereafter divides into the **anterior** and **posterior tibial arteries**.
  - The **obturator** and **inferior gluteal** vessels also contribute to the supply of the proximal part of the limb.
  - In the embryo, the **inferior gluteal artery** supplied the **main axial artery** of the limb, which is represented in the adult by the artery to the sciatic nerve.

- The muscles of the three thigh compartments receive their blood supply from the profunda **femoris artery**, most importantly through the first perforator given off from this artery.
- The **cruciate anastomosis** of the buttock is formed by a branch of the first perforating artery, the inferior gluteal artery, and the transverse branches of the medial and lateral femoral circumflex arteries.
- The cruciate anastomosis allows blood to bypass an obstruction of the external iliac or femoral artery.

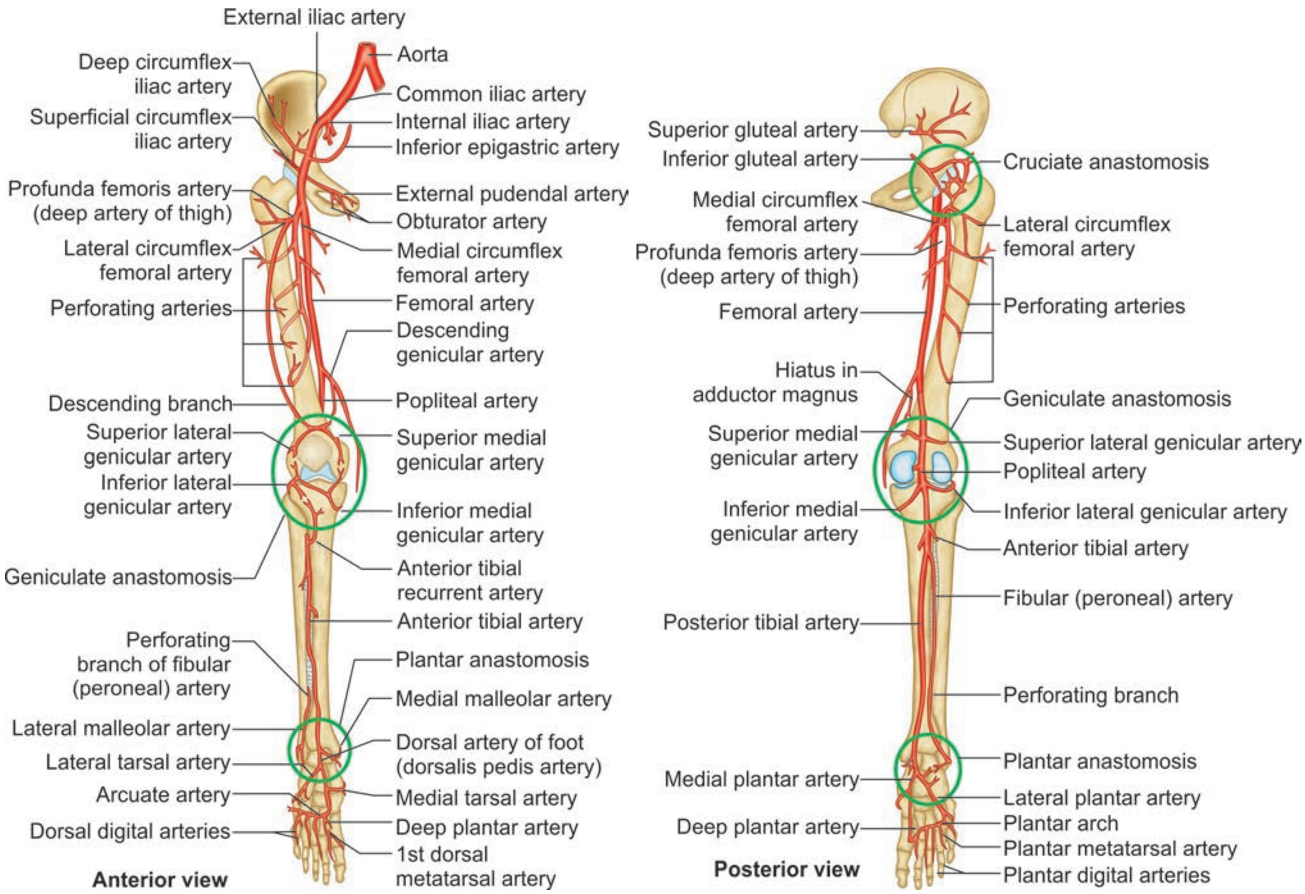


Fig. 68: Arterial supply of lower limb

- The muscles of the three thigh compartments receive their blood supply from the profunda femoris artery, most importantly through the first perforator given off from this artery.
- The cruciate anastomosis of the buttock is formed by a branch of the first perforating artery, the inferior gluteal artery, and the transverse branches of the medial and lateral femoral circumflex arteries. The cruciate anastomosis allows blood to bypass an obstruction of the external iliac or femoral artery.

Anterior and Medial Thigh

Table 24: Arteries of anterior and medial thigh

Artery	Origin	Course	Distribution
Femoral	Continuation of external iliac artery distal to inguinal ligament	Descends through femoral triangle bisecting it; then courses through adductor canal; terminates as it traverses adductor hiatus, where its name becomes popliteal artery	Branches supply anterior and anteromedial aspects of thigh
Profunda femoris artery (deep artery of thigh)	Femoral artery 1-5 cm inferior to inguinal ligament	Passes deeply between pectineus and adductor longus; descending posterior to latter on medial side of femur	Three to four perforating arteries pass through adductor magnus muscle, winding around femur to supply muscles in medial. posterior, and lateral part of anterior compartments
Medial circumflex femoral	Profunda femoris artery: may arise from femoral artery	Passes medially and posteriorly between pectineus and iliopsoas; enters gluteal region and gives rise to posterior retinacular arteries; then terminates by dividing into transverse and ascending branches	Supplies most of blood to head and neck of femur: transverse branch takes part in cruciate anastomosis of thigh; ascending branch joins inferior gluteal artery

Artery	Origin	Course	Distribution
Lateral circumflex femoral		Passes laterally deep to sartorius and rectus femoris, dividing into ascending, transverse, and descending arteries	Ascending branch supplies anterior part of gluteal region; transverse branch winds around femur; descending branch joins genicular periarticular anastomosis
Obturator	Internal iliac artery or (in –20%) as an accessory or replaced obturator artery from the inferior epigastric artery	Passes through obturator foramen; enters medial compartment of thigh and divides into anterior and posterior branches, which pass on respective sides of adductor brevis	Anterior branch supplies obturator externus, pectineus, adductors of thigh, and gracilis; posterior branch supplies muscles attached to ischial tuberosity

Gluteal and Posterior Thigh Region

Table 25: Arteries of gluteal and posterior thigh regions

Artery[a]	Course	Distribution
Superior gluteal	Enters gluteal region through greater sciatic foramen superior to piriformis; divides into superficial and deep branches; anastomoses with inferior gluteal and medial circumflex femoral arteries	Superficial branch: supplies gluteus maximum Deep branch: runs between gluteus readies and maximus and supplies them and tensor fasciae latae
Inferior gluteal	Enters gluteal region through greater sciatic foramen inferior to piriformis: descends on medial side of sciatic nerve; anastomoses with superior gluteal artery and participates in cruciate anastomosis of thigh, involving first perforating artery of profunda femoris and medial and lateral circumflex arteries	Supplies gluteus maximus, obturator internus, quadratus femoris, and superior parts of hamstrings
Internal pudendal	Enters gluteal region through greater sciatic foramen: descends posterior to ischial spine: enters perineum through lesser sciatic foramen	Supplies external genitalia and muscles in perineal region; does not supply gluteal region
Perforating	Enters posterior compartment by perforating aponeurotic portion of adductor magnus attachment and medial intermuscular septum: after providing muscular branches to hamstrings continues to anterior compartment by piercing lateral intermuscular septum	Supplies majority (central portions) of hamstring muscles, then continues to supply vastus lateralis in anterior compartment

[a]All of these arteries arise from the internal iliac artery

Leg Region

Table 26: Arteries of leg

Artery[a]	Origin	Course	Distribution in leg
Popliteal	Continuation of femoral aretery at adductor hiatus in adductor magnus	Passes through popliteal fossa to leg: ends at lower border popliteus muscle by dividing into anterior and posterior tibial arteries	Superior, middle, and inferior genicular arteries to both lateral and medial aspects of knee
Anterior tibial	Popliteal	Passes between tibia and fibula into anterior compartment through gap in superior part of interosseous membrane and descends this membrane between tibialis anterior and extensor digitorum longus	Anterior compartment of leg
Dorsalis pedis (Dorsal artery of foot)	Continuation of anterior tibial artery distal to inferior extensor retinaculum	Descends anteromedially to first interosseous space and divides into plantar and arcuate arteries	Muscles on dorsum of foot; pierces first dorsal interosseous muscles as deep plantar artery to contribute to formation of plantar arch
Posterior tibial	Popliteal	Passes through posterior compart-ment of leg and terminates distal to flexor retinaculum by diving into medial and lateral plantar arteries	Posterior and lateral compartments of leg: circumflex fibular branch joins anastomoses around knee: nutrient artery passes to tibia
Fibular	Posterior tibial	Descends in posterior compartment adjacent to posterior intermuscular septum	Posterior compartment of leg: perforating branches supply lateral compartment of leg

Femoral Artery

- **Femoral Artery** is the continuation of the external iliac artery distal to the inguinal ligament, descends through the femoral triangle, and enters the adductor canal. Branches of femoral artery:
  - Superficial Epigastric Artery runs subcutaneously upward toward the umbilicus.
  - Superficial Circumflex Iliac Artery runs laterally almost parallel with the inguinal ligament.
  - Superficial External Pudendal Artery emerges through the saphenous ring, runs medially over the spermatic cord (or the round ligament of the uterus), and sends inguinal branches and anterior scrotal (or labial) branches.
  - Deep External Pudendal Artery passes medially across the pectineus and adductor longus and is distributed to the skin of the perineum, scrotum, or labium majus.
  - Profunda Femoris (Deep Femoral) Artery arises from the femoral artery within the femoral triangle.
  - It descends in front of the pectineus, adductor brevis, and adductor magnus muscles but behind the adductor longus muscle.
  - It gives rise to the medial and lateral femoral circumflex and muscular branches and provides, in the adductor canal, four perforating arteries that perforate and supply the adductor magnus and hamstring muscles.
  - The first perforating artery sends an ascending branch, which joins the cruciate anastomosis of the buttock.
  - Medial Femoral Circumflex Artery arises from the femoral or profunda artery in the femoral triangle.
  - It runs between the pectineus and iliopsoas muscles, continues between the obturator externus and adductor brevis muscles, and enters the gluteal region between the adductor magnus and quadratus femoris muscles.
  - It gives rise to muscular branches and an acetabular branch to the hip joint and then divides into an ascending branch, which anastomoses with branches of the superior and inferior gluteal arteries, and a transverse branch, which joins the cruciate anastomosis.
  - Lateral Femoral Circumflex Artery arises from the femoral or profunda femoris artery and passes laterally deep to the sartorius and rectus femoris muscles.
  - It divides into three branches: an ascending branch, which forms a vascular circle with branches of the medial femoral circumflex artery around the femoral neck and also anastomoses with the superior gluteal artery; a transverse branch, which joins the cruciate anastomosis; and a descending branch, which anastomoses with the superior lateral genicular branch of the popliteal artery.
  - Descending Genicular Artery arises from the femoral artery in the adductor canal just before it passes through the adductor hiatus.
  - It divides into the articular branch, which enters the anastomosis around the knee, and the saphenous branch, which supplies the superficial tissue and skin on the medial side of the knee.

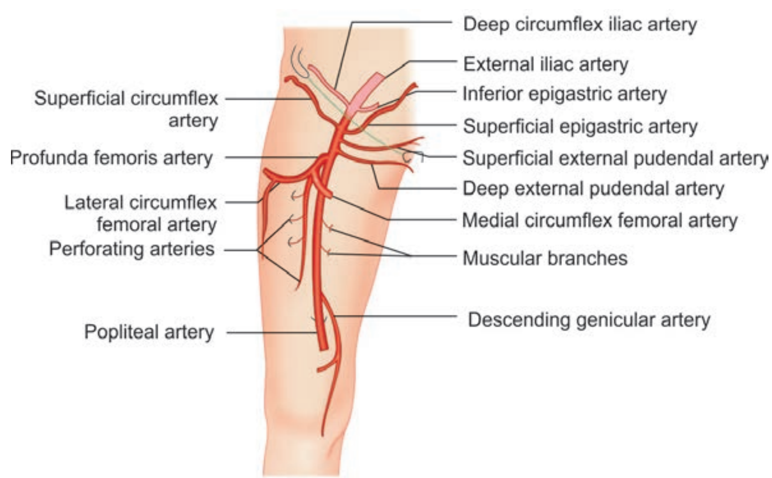


Fig. 69: Branches of the femoral artery

Popliteal Artery

- **Profunda Femoris** (Deep Femoral) artery is a branch of femoral artery within the femoral triangle.
  - It descends in front of the pectineus, adductor brevis, and adductor magnus muscles but behind the adductor longus muscle.
  - It gives the medial and • lateral femoral circumflex and muscular branches.
  - In the adductor canal it gives four perforating arteries that perforate and supply the adductor magnus and hamstring muscles.
  - The first perforating artery sends an ascending branch, which joins the cruciate anastomosis of the buttock.

Pulses

- **Popliteal artery** is the most difficult of the peripheral pulses to feel because it lies deep in the popliteal fossa. In flexed knee (popliteal fascia relaxed) it is felt over the midline of the fossa by deep pressure against the popliteal surface of the femur.
- **Posterior tibial artery** pulse can be felt by gentle palpation posterior to the medial malleolus as the artery lies between the tendons of flexor hallucis longus and flexor digitorum longus, approximately one-third of the way along a line connecting the posterior border of the medial malleolus to the calcaneal tendon.

- **Dorsalis pedis artery** pulse is found by palpation against the underlying tarsals, immediately lateral to the tendon of extensor hallucis longus, from the midpoint between the malleoli to the proximal end of the first intermetatarsal space.

ASSESSMENT QUESTIONS

1. **The superficial external pudendal artery is a branch of:** *(NEET Pattern 2015)*
   a. Femoral artery
   b. External iliac artery
   c. Internal iliac artery
   d. Aorta

2. **Superficial epigastric artery is a branch of:** *(NEET Pattern 2015)*
   a. Internal pudendal artery
   b. External pudendal artery
   c. Internal iliac artery
   d. Femoral artery

3. **The blood supply to femoral head is mostly by:** *(NEETR Pattern 2013)*
   a. Lateral epiphyseal artery
   b. Medial epiphyseal artery
   c. Ligamentum teres artery
   d. Profunda femoris

4. **The blood supply to femoral head is:** *(PGIC 2014, 2003)*
   a. Obturator artery
   b. Internal pudendal artery
   c. Lateral circumflex femoral artery
   d. Femoral artery
   e. Profunda femoral artery

5. **In the following nutrient arteries to bones, choose the WRONG pair:**
   a. Humerus: Profunda brachii
   b. Radius: Anterior interosseous
   c. Fibula: Peroneal
   d. Tibia: Anterior tibial

6. **Middle genicular artery is a branch of:**
   a. Femoral artery
   b. Popliteal artery
   c. Anterior tibial artery
   d. Posterior tibial artery

7. **Popliteal artery is difficult to palpate because:** *(AIPG 2009)*
   a. It is not superficial
   b. Does not pass over prominent bony structure
   c. Superficial but does not pass over prominent bony structure
   d. Not superficial and does not pass over prominent bony structure

ANSWERS WITH EXPLANATIONS

1. **a. Femoral artery**
   - Superficial external pudendal artery is one of the three pudendal arteries.
   - Deep external pudendal artery is also a branch of femoral artery whereas, Internal pudendal artery is a branch of internal iliac artery (anterior division).

2. **d. Femoral artery**
   - Superficial epigastric artery is a branch of femoral artery.
   - Inferior epigastric artery arises from external iliac artery. Superior epigastric artery is a branch of internal thoracic artery.

3. **a. Lateral epiphyseal artery**
   - The **lateral epiphyseal artery** (the terminal branch of the **medial circumflex femoral artery**) is the *primary* blood supply and runs along the postero-superior aspect of the femoral neck before terminating into 2-4 **retinacular arteries** that enter the femoral head.
   - The **femoral head** receives blood supply mostly from the MFCA (**medial circumflex femoral artery**).
     - Also from the anastomoses that contribute to the blood supply of the femoral head, the most important is the anastomosis with the IGA (**inferior gluteal artery**) via the piriformis branch, which can also be a dominant vessel supplying the femoral head.
     - The anterior nutrient artery of the femoral neck—originating from the **lateral circumflex artery**—and **the obturator artery**, via the artery of the ligamentum teres, constitute a **minor component** of the blood supply to the femoral head.

4. **a. Obturator artery, c. Lateral circumflex femoral artery, d. Femoral artery, e. Profunda femoral artery**
   - Femoral head is supplied by branch of **obturator artery**, medial & lateral **circumflex arteries** and **inferior** & superior gluteal arteries.
   - Medial circumflex artery may be a direct branch of **femoral artery** occasionally.
   - It is also supplied by 1st perforating branch of **profunda femoral artery**.

5. **d. Tibia: Anterior tibial**
   - Nutrient artery to tibia is a branch of posterior tibial artery.

6. **b. Popliteal artery.**
   - Five genicular arteries are given by popliteal artery (including **middle genicular** artery) to supply knee joint.
   - There are two superior (medial & lateral) and two inferior (medial & lateral).

7. **d. Not superficial and does not pass over prominent bony structure**
   - Popliteal artery is the most difficult of the peripheral pulses to feel because it lies deep in the popliteal fossa and does not pass over prominent bony structure.

High Yield Points

- The **cruciate anastomosis** of the buttock is formed by a branch of **the first perforating artery**, the **inferior gluteal artery**, and the transverse branches of the **medial** and **lateral femoral circumflex arteries**. The cruciate anastomosis allows blood to bypass an obstruction of the external iliac or femoral artery.
- **Oblique popliteal ligament** is pierced by **middle genicular artery,** a branch of popliteal artery.

Venous Drainage

- Veins of the lower limb are subdivided into **superficial** (subcutaneous) and **deep** groups.
  - **Deep veins** (deep to the deep fascia), accompany the major arteries and have more number of valves comparatively.
  - Perforating (communicating) veins drain the blood from the superficial into deeper veins.
  - The two major superficial veins are the long and short saphenous veins.
  - Plantar digital veins connect with dorsal digital veins and unite to form four plantar metatarsal veins.
  - These run in the intermetatarsal spaces and connect with dorsal veins by means of perforating veins.
  - These veins connect with each other to constitute a deep plantar venous arch adjacent to the deep plantar arch.
  - From this venous arch, medial and lateral plantar veins run near the corresponding arteries; they communicate with the long and short saphenous veins before forming the posterior tibial veins posterior to the medial malleolus.
  - The posterior tibial veins accompany the posterior tibial artery, receive veins from the calf muscles, especially the venous plexus in soleus, and connect with superficial veins and with the fibular veins.
  - The anterior tibial veins are continuations of the venae comitantes of the dorsalis pedis artery. They ascend superiorly and pass through the proximal end of the interosseous membrane to unite with the posterior tibial veins, at the distal border of popliteus, to form the popliteal vein.
- **Venous muscular pumps:** Muscular venous plexuses are components of the 'muscle pump mechanism that communicates with the axially running deep veins.
  - Venous return from the lower limb is assisted by muscular activity, by the contraction of the calf and foot muscle.
  - Perforating veins connect the long saphenous vein with the deep veins, particularly near the ankle, distal calf and knee.
  - Their valves are arranged so as to prevent flow of blood from the deep to the superficial veins.
  - Incompetent valves in the perforating veins, become sites of high-pressure leaks during muscular contraction, leading to dilated, elongated and tortuous superficial veins (varicosities).
- **Femoral vein** is the upward continuation of the popliteal vein beginning at the adductor opening and ending posterior to the inguinal ligament as the external iliac vein.
  - It is posterolateral to the femoral artery in the distal adductor canal.
  - More proximally in the canal, and in the distal femoral triangle (i.e. at its apex), the vein lies posterior to the artery and proximally, at the base of the triangle, the vein lies medial to the artery.
  - Tributaries: veins accompanying the superficial epigastric, superficial circumflex iliac and external pudendal arteries join the long saphenous vein before it enters the saphenous opening.
  - Other tributaries are profunda femoris vein, lateral & medial circumflex femoral veins, deep external pudendal vein.
  - There are usually four or five valves in the femoral vein; the two most constant are just distal to the entry of profunda femoris and near the inguinal ligament.

Long (Great) Saphenous Vein

- Longest vein in the body, is superficial (subcutaneous) and is considered pre-axial vein developmentally.
- It starts distally as a continuation of the medial marginal vein of the foot, and ends in the femoral vein a short distance inferior to the inguinal ligament.
- It begins on the dorsum of the foot by the union of the medial end of the dorsal venous arch and medial marginal vein, runs upward in front of the medial malleolus (2.5 cm anterior), and ascends on the medial side of the leg.
- It is posteromedial to the knee (lying the breadth of the subject's hand posterior to the medial edge of the patella), and then ascends the medial aspect of the thigh.
- Passes through the saphenous opening (fossa ovalis) after piercing the cribriform fascia & the femoral sheath to drain into the femoral vein.
- It is accompanied by saphenous nerve which lie anterior to the vein at the knee, in the leg and foot.
- It has 10–20 valves, which are more numerous in the leg than in the thigh. One is present just before the vein pierces the cribriform fascia, another at its junction with the femoral vein (sapheno-femoral valve).
- The 'centre' of the opening is often said to be 2.5–3.5 cm inferolateral to the pubic tubercle, and the vein is then represented by a line drawn from this point to the adductor tubercle.
- **Tributaries**:
  - At the ankle, the long saphenous vein drains the sole by medial marginal veins.
  - In the leg, it often connects with the short saphenous vein and with deep veins via perforating veins.
  - Posterior arch vein
    - Posterior arch vein collects the blood from the posteromedial aspect of the calf and begins of a series of small venous arches connecting the three medial ankle-perforating veins (perforators).
    - It connects with posterior tibial venae comitantes by a series of perforating (communicating) veins.
  - In the thigh it receives postero-medial and anterolateral veins along with perforating veins.
  - As GSV traverses the saphenous opening, it is joined by the superficial epigastric, superficial circumflex iliac and superficial external pudendal veins.
    - Superficial epigastric and circumflex iliac veins drain the inferior abdominal wall, the latter also receiving tributaries from the proximolateral region of the thigh.
    - Superficial external pudendal veins drain part of the scrotum/labia; one is joined by the superficial dorsal vein of the penis/clitoris.
    - The last tributary to great saphenous at the saphenous opening is deep external pudendal veins (drainage area: perineum).

Clinical Correlations

- Great saphenous vein anterior to medial malleolus is the most preferred site of venesection (cut- down) in emergency.
- The saphenous nerve accompanying the vein should be identified and secured, during the procedure.
- Great saphenous vein can be harvested for grafts used in coronary arterial surgery.

Small (Short) Saphenous Vein

- Dorsal vein from the fifth digit (smallest toe) merge with the lateral end of dorsal venous arch of the foot to form the short saphenous vein, at the lateral aspect of the foot (inferior and posterior to the lateral malleolus).
- It ascends superiorly in the lower third of the calf, it lateral to the calcaneal tendon, and is accompanied by the sural nerve on its lateral side.
- It keeps ascending in the middle of the back of the leg, pierces the deep fascia, ascend a little further and reaches the middle of the popliteal fossa, to open into the popliteal vein (3–7.5 cm above the knee joint).
- The vein contains 7–13 valves, one of those near termination.

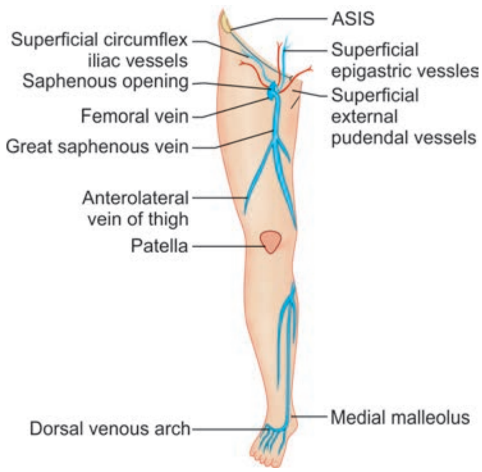


Fig. 70: Superficial vessels on the front of the thigh. (ASIS: Anterior superior iliac spine)

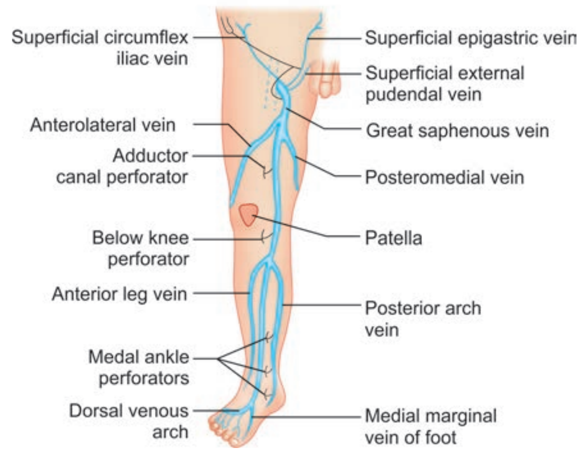


Fig. 71: Formation, course, termination, and tributaries of the great saphenous vein

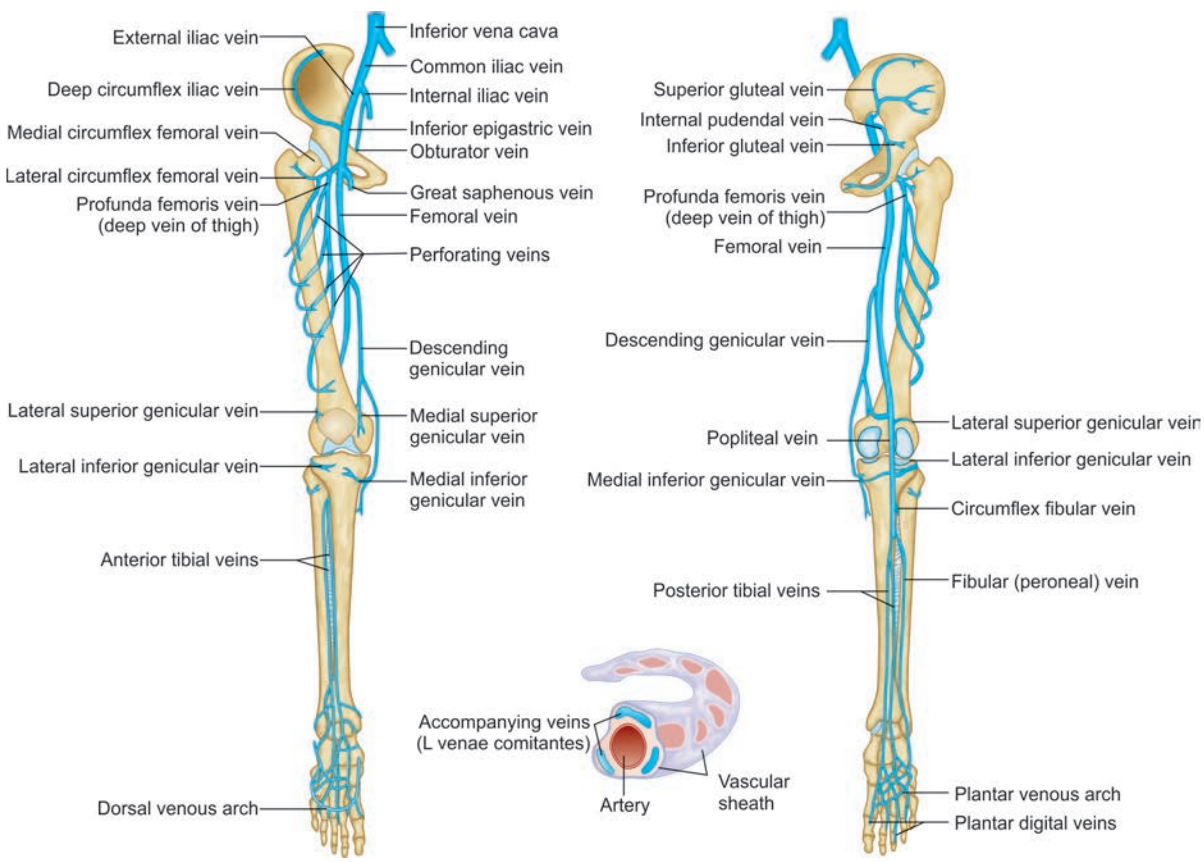


Fig. 72: Venous drainage of lower limb

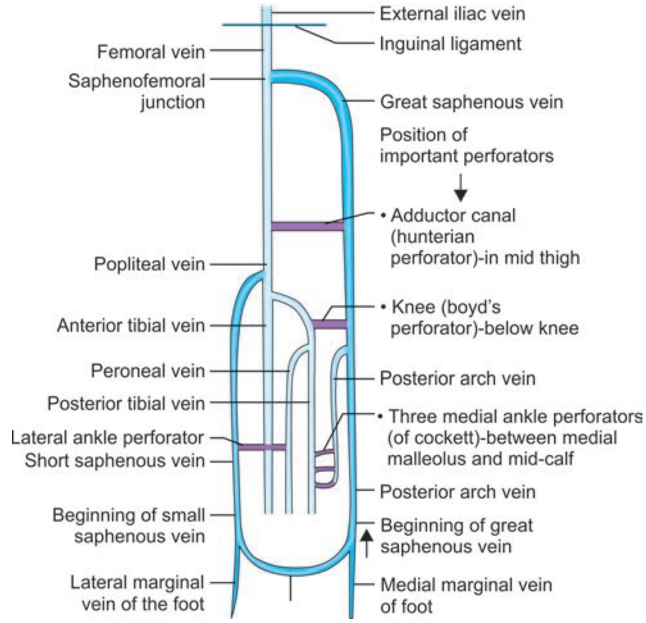


Fig. 73: Schematic representation of the veins of the lower limb (deep vein = light blue colour, superficial veins = deep blue colour, perforating vein = violet colour

Perforators	Location	Connection
1. Mid-thigh (Hunterian perforator)	Just above knee (lower part of adductor canal)	Great saphenous with femoral vein
2. Knee (Boyd's perforator)	Just below knee	Great saphenous with posterior tibial vein
3. Leg (lateral ankle)	At the junction of middle of lower third of leg	Short saphenous with peroneal vein
4. 4, 5, 6. Leg (three medial ankle; Cockett's perforator)	a. Upper medial: junction of middle and lower third of leg b. Middle medial: 4 cm above the medial malleolus c. Lower medial: posteroinferior to medial malleolus	Posterior arch vein to posterior tibial vein

ASSESSMENT QUESTIONS

1. TRUE regarding saphenous vein: *(PGIC 2014)*
a. Long saphenous vein formed as continuation of medial side of deep venous arch
b. Long saphenous vein — situated posterior to medial malleolus
c. Long saphenous vein— closely related to saphenous nerve
d. Short saphenous vein— open into great saphenous vein
e. Short saphenous vein associated with sural nerve

2. TRUE statement about great saphenous vein: *(NEET Pattern 2015)*
a. It begins at lateral end of dorsal venous arch
b. It runs anterior to medial malleolus
c. It is accompanied by sural nerve
d. Terminates into popliteal vein

3. All are true about short saphenous vein EXCEPT: *(NEET Pattern 2015)*
a. Runs behind lateral malleolus
b. Runs on lateral side of leg
c. Accompanied by sural nerve
d. Achilles tendon is medial to vein

4. A patient was on DVT prophylaxis. All of the following has perforators which connect superficial veins to the deep veins EXCEPT: *(AIIMS 2007)*
a. Ankle
b. Below inguinal ligament
c. Mid-calf
d. Lower thigh

5. Hunterian perforators are seen in: *(NEET Pattern 2013)*
a. Upper thigh
b. Lower thigh
c. Calf
d. Mid-thigh

6. All are Valveless EXCEPT:
a. Dural venous sinus
b. Hepatic veins
c. Inferior vena cava
d. Femoral vein

7. The direction of the flow of venous blood in conditions of valve incompetence affecting perforating veins of lower limb is: *(AIIMS 2005)*
a. Along gravity
b. Superficial to deep
c. Along osmotic gradient
d. Deep to superficial

8. Inferior epigastric vein drains into: *(NEET Pattern 2015)*
a. Femoral vein
b. External iliac vein
c. Internal iliac vein
d. Internal pudendal vein

9. **TRUE about saphenous opening:** *(NEET Pattern 2014)*
   a. Transmits saphenous nerve
   b. Lies 4 cm lateral and superior to pubic tubercle
   c. Covered by cribriform fascia
   d. Opening in cribriform fascia

ANSWERS WITH EXPLANATIONS

1. **a. Long saphenous vein formed as continuation of medial side of deep venous arch; c. Long saphenous vein- closely related to saphenous nerve; e. Short saphenous vein associated with sural nerve**
   - Long saphenous vein is formed by the union of the medial end of dorsal venous arch with the medial marginal vein which drains the medial side of great toe. It passes upwards anterior (not posterior) to the medial malleolus.
   - The saphenous nerve has a course along with the long saphenous vein.
   - Short saphenous vein is accompanied by the sural nerve and opens into the popliteal vein (not great saphenous vein).
2. **b. It runs anterior to medial malleolus**
   - Great saphenous vein begins at the medial end of dorsal venous arch, runs anterior to medial malleolus, is accompanied by saphenous nerve and terminates into femoral vein.
   - Short saphenous nerve begins at the lateral end of dorsal venous arch, runs posterior to lateral malleolus, is accompanied by sural nerve and terminates into popliteal vein.
3. **b. Runs on lateral side of leg**
   - Short saphenous nerve begins at the lateral end of dorsal venous arch, runs superiorly behind the lateral malleolus, along the lateral edge of tendocalcaneus, and is accompanied by the sural nerve on its lateral side.
   - It keeps ascending in the middle of the back of the leg eventually terminates into popliteal vein.
4. **b. Below inguinal ligament**
   - There is no perforator veins below the inguinal ligament.
5. **d. Mid-thigh**
   - Hunterian perforator is present in mid-thigh at the lower part of adductor (Hunterian) canal.
   - It connects great saphenous vein with the femoral vein, in the mid-thigh.
6. **d. Femoral vein**
   - Femoral veins contain between one and six valves, and popliteal veins contain between zero and four valves.
   - Deep vein valves are consistently located in the common femoral vein (within 5 cm of the inguinal ligament), the femoral vein (within 3 cm of the deep femoral vein tributary) and in the popliteal vein near the adductor hiatus.
7. **d. Deep to superficial**
   - Incompetent valves affecting perforating veins of lower limb makes the blood flow from deep to superficial direction.
   - This makes the superficial veins overfilled with blood and they become dilated, elongated and tortuous – varicose veins.
   - Normally the venous blood flows from the superficial to deep veins via the perforating veins, which have valves to make sure this unidirectional flow of blood.
8. **b. External iliac vein**
   - Inferior epigastric vein drains into the external iliac vein and anastomoses from the superior epigastric vein.
   - It is accompanied by the inferior epigastric artery, which itself is a branch of external iliac artery.
9. **c. Covered by cribriform fascia**
   - Saphenous opening is an oval defect in the fascia lata in front of the thigh, for the passage of great saphenous vein into the femora vein.
   - The centre of the opening is about 4 cm inferolateral to the pubic tubercle.
   - The saphenous opening is closed by a membrane of areolar tissue—the cribriform fascia which is pierced by great saphenous vein, superficial epigastric and superficial external pudendal vessels and lymph vessels connecting superficial and deep inguinal lymph nodes.

High Yield Point

- G**reater saphenous vein** drains venous blood from the dorsal venous arch, ascends along the medial side of the lower limb, passes through the saphenous opening (fossa ovalis) in the fascia lata, and joins the femoral vein, whereas the **small saphenous vein** drains blood from the lateral dorsal venous arch, ascends the lateral leg, and enters into the popliteal vein.

Lymphatic Drainage

- **Lymphatics** from the lower limb traverses a large intermediary inguinal group of nodes.
  - Peripheral nodes are few and all are deeply sited. Except for an inconsistent node lying proximally on the interosseous membrane near the anterior tibial vessels, they occur only in the popliteal fossa.
  - Enlarged popliteal nodes are often due to inflammation, malignancy or injury to the lateral side of the foot.
  - Inguinal lymph nodes are found superficial and deep to the deep fascia.
  - The deep nodes are few and lie alongside the medial aspect of the femoral vein.
  - The superficial nodes may be divided into a lower vertical group that clothe the proximal part of the long saphenous vein, and an upper group that lie parallel to, but below, the inguinal ligament and which are related laterally to the superficial circumflex iliac and medially to the superficial external pudendal vessels.

    Lymph from lower limb is mostly drained into the inguinal lymph nodes, either directly (mostly) or indirectly (partly) through the popliteal and anterior tibial nodes.

- From the inguinal lymph nodes it passes to the external and common iliac nodes, and ultimately drains to the lateral aortic nodes.
- The gluteal region and upper part of the back of thigh accompany the gluteal vessels and drain into the internal iliac nodes and common iliac lymphatic vessels.

- The lymph nodes are classified into **two categories**
  - Superficial lymph nodes: Superficial inguinal nodes
  - Deep lymph nodes: Deep inguinal nodes, popliteal nodes, anterior tibial nodes
- **Superficial inguinal nodes**:
  - Present in the superficial fascia of the inguinal region
  - Arranged in two groups: upper and lower, in a T shape fashion
  - The upper horizontal group lie below the inguinal ligament.
  - Lymphatics from penis including prepuce and scrotum in male, vulva and vagina (below the hymen), anal canal (below dentate line) drain into upper medial superficial group.
  - The lower vertical superficial group is placed along both sides of the terminal part of great saphenous vein. It receive lymphatics from most of the lower limb (great saphenous territory), except from buttock & posterolateral calf (short saphenous territory).
  - Note: Superficial inguinal nodes lymphatics pierce the cribriform fascia and terminate into the deep inguinal nodes.
- **Deep inguinal nodes**
  - The deep inguinal nodes vary from one to three, and lie on the medial aspect the femoral vein in the femoral triangle.
  - One lies just distal to the sapheno-femoral junction, another in the femoral canal, and the most proximal node of this group (gland of Cloquet or Rosenmüller) lies in the femoral canal.
  - These lymph nodes receive afferents from: (i) the superficial inguinal nodes, (ii) popliteal nodes, (iii) glans of penis/clitoris, and (iv) deep lymphatics of the lower limb accompanying femoral vessels.
  - Deep inguinal lymph efferents traverse the femoral canal to drain into the external iliac nodes.
  - Popliteal lymph nodes are present at the termination of the small saphenous vein and receive lymphatics from:
    - The territory of small saphenous vein (i.e., lateral side of the foot, heel, and lateral half of the back of leg)
    - Deep parts of the leg, running along the anterior and posterior tibial vessels, and Knee joint.
- Popliteal lymphatics run along the popliteal and femoral vessels to terminate into the deep inguinal nodes.

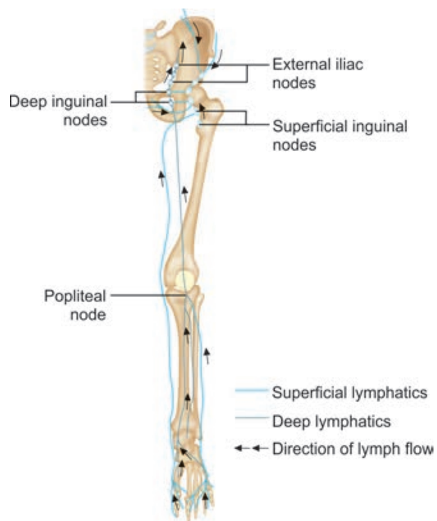


Fig. 74: An overview of the lymphatics of the lower limb

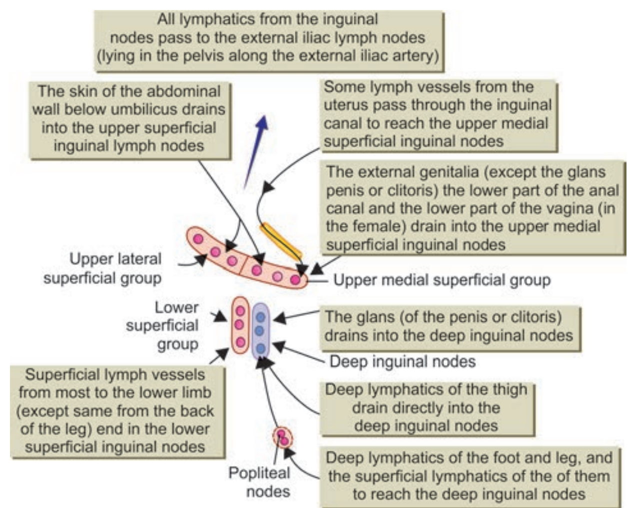


Fig. 75: Lymphatic drainage into inguinal lymph nodes

ASSESSMENT QUESTIONS

1. Skin and fascia of great toe drains into: *(NEET Pattern 2015)*
   a. Superficial inguinal lymph nodes
   b. External iliac nodes
   c. Internal iliac nodes
   d. Deep inguinal nodes

2. Skin and facia covering the ball of the big toe drain the lymphatics into: *(NEET Pattern 2015)*
   a. Vertical group of superficial inguinal lymph nodes
   b. Horizontal group of superficial inguinal lymph nodes
   c. Popliteal lymph nodes
   d. Deep inguinal lymph nodes

ANSWERS WITH EXPLANATIONS

1. a. Superficial inguinal lymph nodes
- Skin and fascia of drain into the superficial lymphatics, most of which end in superficial inguinal lymph nodes.

2. a. Vertical group of superficial inguinal lymph nodes
- Lymphatics from skin and superficial fascia of great toe accompany great saphenous vein and drain into superficial inguinal lymph nodes (vertical group).

Regions

Femoral Triangle

- Has inverted triangular outline
  - Base: inguinal ligament
  - Lateral boundary is the medial margin of sartorius
  - Medial boundary is the medial margin of adductor longus
  - Floor is provided laterally by iliacus & psoas major, and medially by pectineus & adductor longus
  - Roof: fascia lata
- Contents: The femoral vessels (artery & vein), pass from mid-base to apex, lying lateral is the femoral nerve (outside femora sheath).

Others:

- Deep inguinal lymph nodes.
- Lateral cutaneous nerve of the thigh. Femoral branch of the genitofemoral nerve
  Note: Genitofemoral nerve is not a content of femoral triangle.

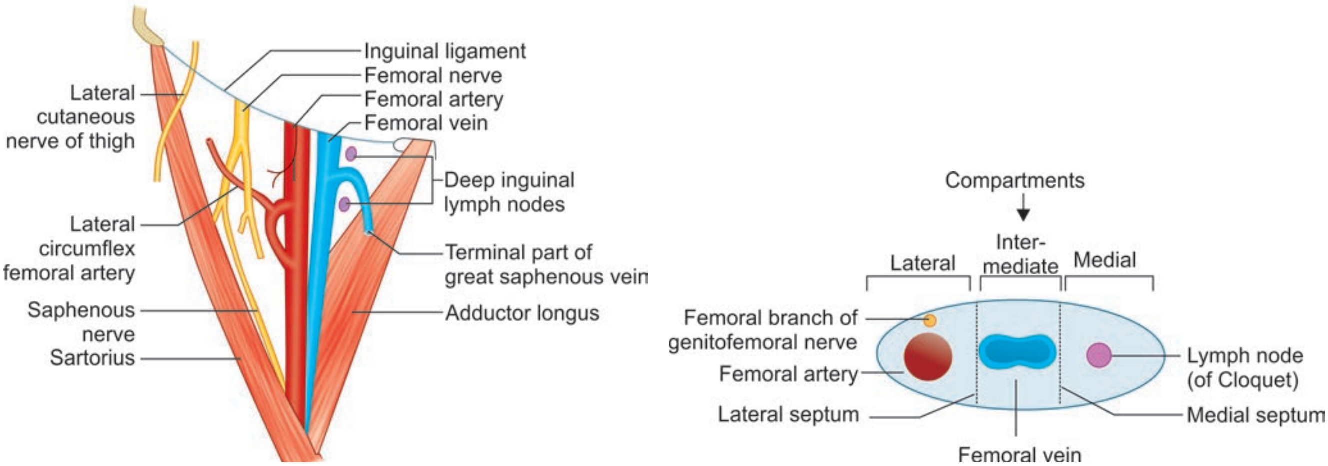


Fig. 76: Compartments of the femoral sheath

- **Femoral sheath** is a funnel-shaped distal prolongation of extraperitoneal fascia, formed of transversalis fascia anterior to the femoral vessels, and of the iliac fascia posteriorly.
  - It is wider proximally and its tapered distal end fuses with the vascular adventitia 3 or 4 cm distal to the inguinal ligament.
  - The femoral branch of the genitofemoral nerve perforates its lateral wall.
  - The medial wall slopes laterally and is pierced by the long saphenous vein and lymphatic vessels.
  - Three compartments are described: a lateral one containing the femoral artery; an intermediate one for the femoral vein; and a medial compartment, the femoral canal, which contains lymph vessels and an occasional lymph node embedded in areolar tissue.
  - The presence of this canal allows the femoral vein to distend.
  - The canal is conical and approximately 1.25 cm in length. Its proximal (wider) end, termed the femoral ring, is bounded in front by the inguinal ligament, behind by pectineus and its fascia and the pectineal ligament, medially by the crescentic, lateral edge of the lacunar ligament and laterally by the femoral vein.
  - The spermatic cord, or the round ligament of the uterus, is just above its anterior margin, while the inferior epigastric vessels are near its anterolateral rim.
  - It is larger in women than in men: this is due partly to the relatively greater width of the female pelvis and partly to the smaller size of the femoral vessels in women.
  - The ring is filled by condensed extraperitoneal tissue, the femoral septum, which is covered on its proximal aspect by the parietal peritoneum. Numerous lymph vessels that connect the deep inguinal to the external iliac lymph nodes traverse the femoral septum.
  - Femoral sheath is continuous with the transversalis fascia anteriorly and the iliopsoas fascia posteriorly.
- **Femoral hernia** protrudes through the femoral ring, which is normally closed by a femoral septum of extraperitoneal tissue, and is therefore a site of potential weakness.
  - In females, the ring is relatively wider and changes during pregnancy, which helps to explain why femoral hernias account for about 20% of all groin hernias in women but less than 1% of groin hernias in men.
  - When a tongue of omentum or a loop of intestine bulges through the ring, it pushes out a hernial sac of peritoneum that is covered by extraperitoneal tissue (the femoral septum) and descends within the femoral canal to the saphenous opening. It is prevented from descending further by the configuration of the femoral sheath and by the attachment of fascia to the inferior rim of the saphenous opening.

- The hernial sac hence turns forwards, stretching the cribriform fascia and curving upwards over the inguinal ligament within the subcutaneous tissues.
- While in the canal, the hernia is usually small because it is contained by the surrounding tissues, but it enlarges as it expands into the subcutaneous tissues.
- When the lacunar ligament is being divided to release the neck of the hernia, care must be taken to avoid or control an **aberrant obturator artery**.
- The **pubic tubercle** can be a useful landmark when attempting to distinguish an inguinal from a femoral hernia; a femoral hernia lies below and lateral to this landmark, whilst an inguinal hernia is above.

ASSESSMENT QUESTIONS

1. What is most medial in the femoral triangle? *(AIIMS 2009)*
 a. Lymphatics
 b. Nerve
 c. Vein
 d. Artery

2. All are contents of femoral triangle EXCEPT: *(NEET Pattern 2015)*
 a. Femoral artery
 b. Femoral vein
 c. Superficial inguinal lymph nodes
 d. Nerve to pectineus

3. All are contents of femoral sheath EXCEPT: *(JIPMER 2001,4; NEET Pattern 2012)*
 a. Femoral artery
 b. Femoral nerve
 c. Femoral vein
 d. Genitofemoral nerve

ANSWERS WITH EXPLANATIONS

1. a. Lymphatics
- Femoral triangle has the deep inguinal lymph nodes in the medial most region.
- Femoral triangle is present in the anterior thigh and is bounded by superior - inguinal ligament; medial - medial margin of the adductor longus muscle and lateral - medial margin of the sartorius muscle.
- The contents (lateral to medial) are: Lateral cutaneous nerve of thigh; terminal part of the femoral nerve and its branches; the femoral branch of genitofemoral nerve; femoral sheath having three compartments with contents (lateral to medial): Femoral artery and its branches; femoral vein and its tributaries and femoral canal, which contains lymphatic vessels and deep inguinal lymph nodes.

2. c. Superficial inguinal lymph nodes
- The superficial inguinal lymph nodes are found deep to Camper's fascia and superficial to fascia lata.
- Since femoral triangle is a sub-fascial space (fascia lata being the roof), it is only the deep inguinal lymph nodes, which are contents of femoral triangle.

3. b. Femoral nerve
- Femoral nerve is a content of femoral triangle, but is not covered by femoral sheath.

Adductor Canal

- **Adductor canal** ((Hunter's/sub sartorial canal)
  - Intermuscular tunnel occupying the mid- third of the medial aspect of the thigh.
  - It starts at the apex of the femoral triangle and extends distally as far as the distal attachment of the tendon of adductor magnus.
  - It is triangular in section and is bounded anterolaterally by vastus medialis; posteromedially by adductor longus and adductor magnus.
  - The roof (antero-medially) has a fascia that extends from the medial surface of vastus medialis to the medial edge of the adductors longus and magnus, overlaps the femoral vessels in the adductor canal.
  - Sartorius muscles overlies the fascia on the roof (hence termed subsartorial fascia).
  - The adductor canal contains the femoral artery and vein (along with descending genicular branches) , the saphenous nerve, and the nerve to vastus medialis.
  - The femoral vessels pass from the adductor canal into the popliteal fossa (via adductor hiatus).
  - The femoral artery can be exposed and ligated in the adductor canal during surgery for aneurysm of the popliteal artery.
- **Adductor hiatus** is an opening in the tendon of adductor magnus adjacent to the femoral shaft, between the aponeurotic distal attachment of the adductor part of the adductor magnus and the tendinous distal attachment of the hamstring part.
  - It is the termination of the adductor canal and lies about 8-13.5 cm. superior to the adductor tubercle.
  - It transmits the femoral artery and vein from the adductor canal in the thigh to the popliteal fossa posterior to the knee.
  - The saphenous nerve does not leave through the adductor hiatus but penetrates superficially halfway through the adductor canal.

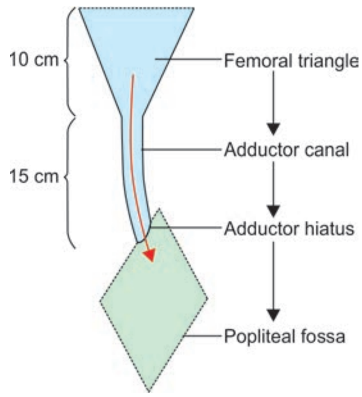


Fig. 77: Three parts of thigh showing three regions and their continuation

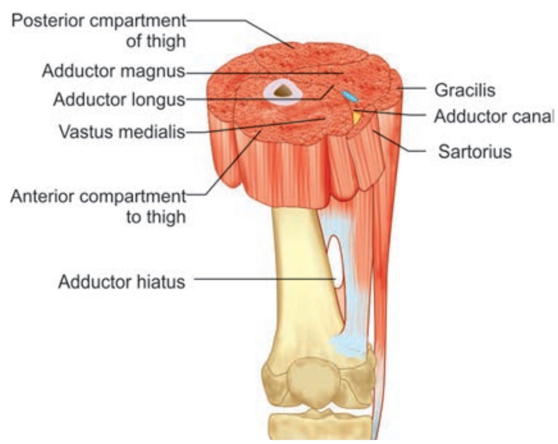


Fig. 78: Location and relations of adductor canal in mid-thigh

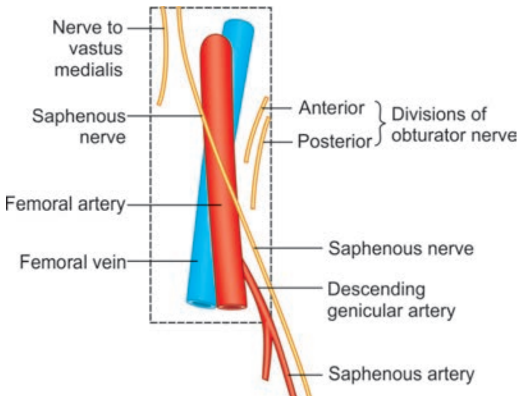


Fig. 79: Location and relations of adductor canal in mid-thigh

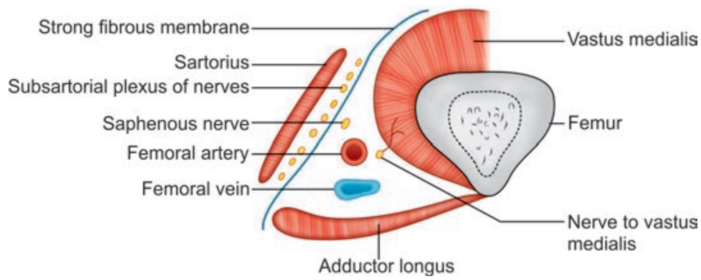


Fig. 80: Boundaries and contents of the adductor canal as seen in the transverse section through middle one-third of the thigh

ASSESSMENT QUESTIONS

1. **All of the following pairs regarding adductor canal are true EXCEPT:** *(JIPMER 2010)*
   a. Roof: Sartorius muscle
   b. Contents: Femoral nerve
   c. Floor: Adductor longus and magnus
   d. Antero-lateral boundary: Vastus medialis

2. **Which of the following structure(s) pass through adductor magnus?** *(PGIC 2015)*
   a. Femoral vessels
   b. Femoral nerve
   c. Femoral sheath
   d. Saphenous nerve
   e. Tibial nerve

ANSWERS WITH EXPLANATIONS

1. **b. Contents: Femoral nerve**
   - Femoral nerve is **not** a content of adductor canal.

2. **a. Femoral vessels**
   - Adductor magnus has a hiatus through which pass the femoral artery and vein from the adductor canal to enter the popliteal fossa.
   - Femoral artery, vein and nerve are present in femoral triangle, artery and vein inside the femoral sheath (nerve being outside the sheath).
   - Saphenous nerve is a branch of femoral nerve in femoral triangle, enters the adductor canal, but does not leave through the adductor hiatus instead penetrates superficially halfway through the adductor canal.
   - Tibial nerve is located in the posterior thigh and descend inferiorly to become a content of popliteal fossa.

High Yield Point

- Adductor canal (Sub-sartorial/Hunter's canal): This passes from the apex of the femoral triangle to the popliteal fossa.

Popliteal Fossa

- P**opliteal fossa** is the diamond-shaped space, approximately 2.5 cm wide.
  - It is bounded superomedially by the semimembranosus and semitendinosus, **superolaterally by the biceps femoris**, inferomedially by the medial head of the gastrocnemius, and inferolaterally by the lateral head of the gastrocnemius (and plantaris).

- Roof: is perforated by the short saphenous vein, posterior cutaneous nerve of thigh and medial and lateral sural cutaneous nerves.
- Floor : Has popliteus muscle.
- It contains the popliteal vessels, the common peroneal and tibial nerves, and the small saphenous vein.
- The common fibular nerve descends laterally immediately medial to the tendon of biceps femoris.
- The popliteal artery is crossed superficially by popliteal vein from the lateral to medial side; which in turn is crossed superficially by the tibial nerve from the lateral to medial side.

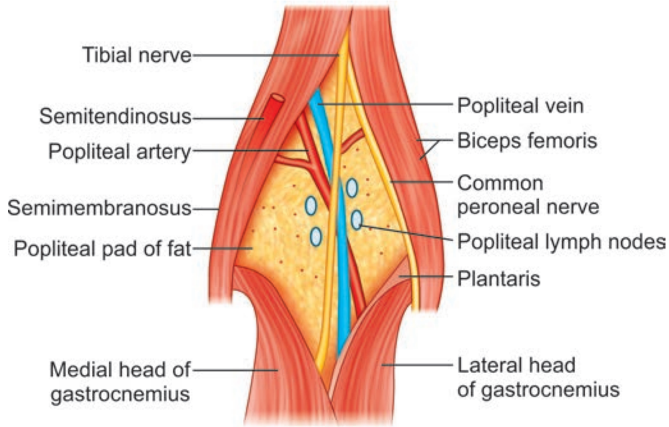


Fig. 81: Popliteal fossa: Boundaries and contents

ASSESSMENT QUESTION

1. All of the following pairs for boundaries of popliteal fossa are correct EXCEPT

a. Supero-medial boundary: semimembranosus
b. Supero-lateral boundary: Biceps femoris
c. Infero-lateral: Gastrocnemius and plantaris
d. Infero-medial: Gastrocnemius and soleus

ANSWER WITH EXPLANATION

1. d. Infero-medial: Gastrocnemius and soleus

- Soleus muscle is not in the boundary of popliteal fossa.

Ankle Region Retinacula

Retinacula at the Ankle

- In the vicinity of the ankle joint, the tendons of the muscles of the leg are bound down by localized, band-shaped thickenings of the deep fascia termed **retinacula**, which collectively serve to **prevent bowstringing** of the underlying tendons during muscle contraction.
- There are superior and inferior extensor retinacula, superior and inferior fibular retinacula, and a flexor retinaculum.
- **Superior Extensor Retinaculum** lies anteriorly just above the ankle joint.
  - Medially, it is attached to the lower part of the anterior border of the tibia, then extends laterally to attach to the lower part of the anterior border of the fibula.
  - Laterally, it blends with the superior fibular retinaculum and medially with the upper border of the extensor retinaculum.
  - Medially, it splits to enclose the tendon of tibialis anterior with its synovial sheath.
  - Note: Tendon of tibialis anterior is the only extensor tendon that possesses a synovial sheath at the level of the superior extensor retinaculum.
- **Inferior extensor retinaculum** is a Y-shaped band of the deep fascia, situated in front of the ankle joint.
  - Stem of the inferior extensor retinaculum is attached to upper surface of calcaneus in front of sulcus calcanei.
  - Passing medially the stem divides into two bands. Upper band (superior lip) passes upwards and medially to be attached to tibial malleolus. Lower band (inferior lip) extends downwards and medially to blend with plantar aponeurosis.
  - The stem of Y forms a loop around the tendons of extensor digitorum longus and peroneus tertius with their common synovial sheath.
  - The upper band of Y splits to enclose the tendons of tibialis anterior and extensor hallucis longus with their synovial sheaths.
    - The anterior tibial artery and deep peroneal nerve pass deep to it.
  - The lower band of Y passes superficially to the tendons of tibialis anterior and extensor hallucis longus with their separate synovial sheaths, and also superficially to the dorsalis pedis artery and deep peroneal nerve.

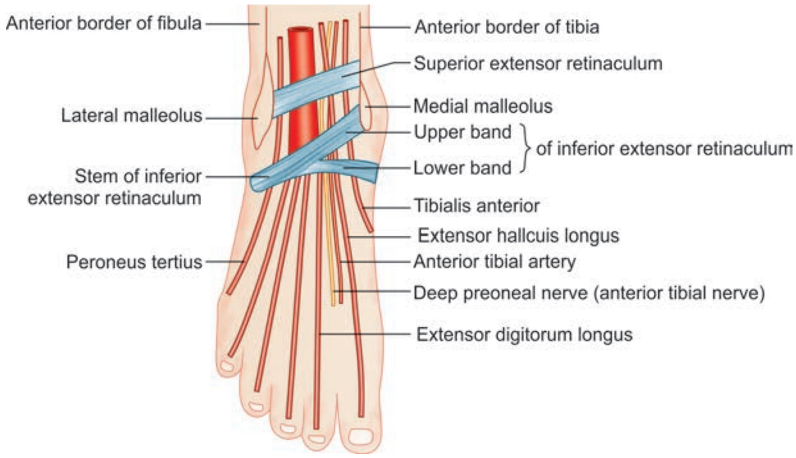
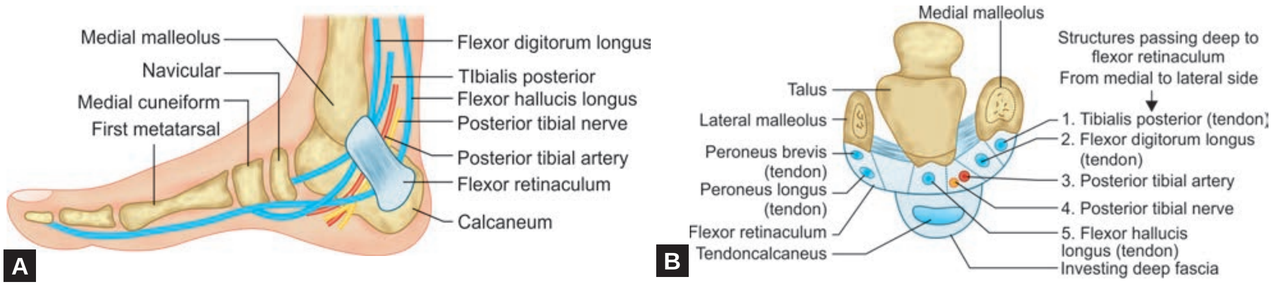


Fig. 82: Arrangement of structures (medial to lateral) in front of ankle joint: Tibialis anterior, extensor hallucis longus, anterior tibial artery, deep peroneal nerve, extensor digitorum longus, peroneus tertius

- Flexor retinaculum is attached anteriorly to the medial malleolus, then extends posteroinferiorly to attach to the medial process of the calcaneus (and the plantar aponeurosis).
- It forms the **tarsal tunnel** and holds three tendons and blood vessels and a nerve in place deep to it (in anteromedial to posterolateral direction): **T**ibialis posterior, flexor **D**igitorum longus, posterior tibial **A**rtery (and vein), tibial **N**erve, and flexor **H**allucis longus (Mnemonic: **Tom, Dick ANd Harry**).
- **Tarsal tunnel syndrome** is a complex symptom resulting from compression of the **tibial nerve** or its medial and lateral plantar branches in the tarsal tunnel, with pain, numbness, and tingling sensations on the ankle, heel, and sole of the foot. Symptoms can be relieved by surgical division of the retinaculum.



Figs. 83A and B: (A) Flexor retinaculum of the ankle and the structures passing deep to it; (B) Transverse section of the ankle showing the flexor retinaculum and the structures passing deep to it

- **Peroneal retinacula** retain the tendons of peroneus longus and brevis in position as these tendons cross the lateral aspect of the ankle region.
  - S**uperior peroneal retinaculum** is situated just behind the lateral malleolus. It is attached to the lateral malleolus and extends posteriorly to attached lateral surface of the Calcaneum. .
    - The tendons of peroneus longus & brevis enclosed in a common synovial sheath, pass deep to the retinaculum.
  - I**nferior peroneal retinaculum** is attached superiorly to the anterior part of superior surface of calcaneum, close to the stem of inferior extensor retinaculum.
    - Inferiorly it is attached to the lateral surface of calcaneum.
    - Some of its fibres are fused with the periosteum on the fibular trochlea (peroneal trochlea or tubercle) of the calcaneus, forming a septum between the tendons of fibularis longus and brevis.

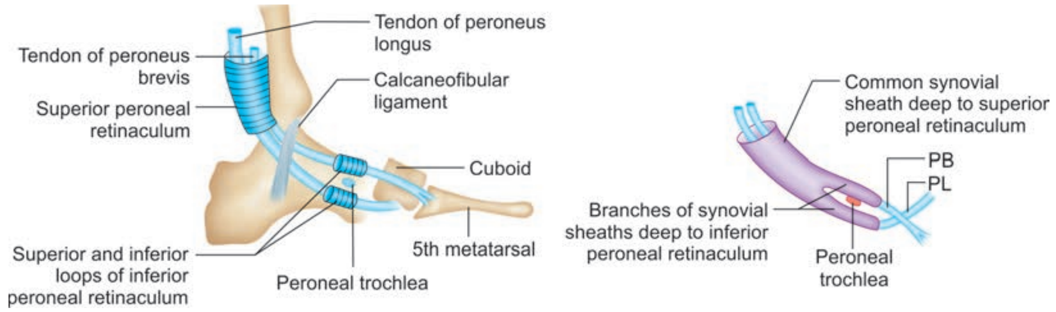


Fig. 84: Peroneal trochlea. Figure in the inset shows synovial sheaths around the peroneal tendons (PL – peroneus longus; PB = peroneus brevis)

ASSESSMENT QUESTIONS

1. Structure passing deep to flexor retinaculum is: *(NEET Pattern 2015)*
a. Post tibial artery
b. Long saphenous vein
c. Tibialis anterior
d. Peroneus tertius

2. All of the following pass under the flexor retinaculum EXCEPT: *(PGIC 2000)*
a. Tibialis anterior
b. Tibialis posterior
c. Posterior tibial artery
d. Deep peroneal nerve
e. Anterior tibial nerve

3. NOT true about inferior extensor retinaculum: *(NEET Pattern 2015)*
a. Y shaped
b. Superior slip attached to lower end of fibula
c. Inferior slip attached to deep fascia of sole
d. Lateral attached to calcaneum

4. Neurovascular bundle of anterior compartment of leg passes between the tendons of: *(NEET Pattern 2013)*
a. Tibialis anterior and extensor hallucis longus
b. Extensor hallucis longus and extensor digitorum longus
c. Extensor hallucis longus and peroneus tertius
d. Extensor digitorum longus and peroneus tertius

ANSWERS WITH EXPLANATIONS

1. a. Post tibial artery
- Flexor retinaculum is present on the medial side of ankle and let pass the long tendons of calf region towards the foot, along with the posterior tibial neurovascular bundle.
- Tibialis anterior and peroneus tertius passes under anterior (extensor retinacula).

2. a. Tibialis anterior; d) Deep peroneal nerve; e) Anterior tibial nerve
- Tibialis anterior and deep peroneal (anterior tibial) nerve pass under the anteriorly placed **extensor retinaculum**.

3. b. Superior slip attached to lower end of fibula
- Superior lip of inferior extensor retinacula attach to the medial malleolus of tibia.

4. b. Extensor hallucis longus and extensor digitorum longus
- Arrangement of structures (medial to lateral) in front of ankle joint: Tibialis anterior, extensor hallucis longus, anterior tibial artery, deep peroneal nerve, extensor digitorum longus, peroneus tertius.

Foot

Bones

- **Tarsus** consists of seven tarsal bones: talus, calcaneus, navicular bone, cuboid bone, and three cuneiform bones.
- **Talus** transmits the weight of the body from the tibia to the foot and is the only tarsal bone without muscle attachments.
  - It has a neck with a deep groove, the sulcus tali, for the interosseous ligaments between the talus and the calcaneus.
  - The body has a groove on its posterior surface for the flexor hallucis longus tendon.
  - The head serves as keystone of the medial longitudinal arch of the foot.
  - T**alar neck fracture** causes avascular necrosis of the body of the talus, because most of the blood supply to the talus passes through the talar neck.

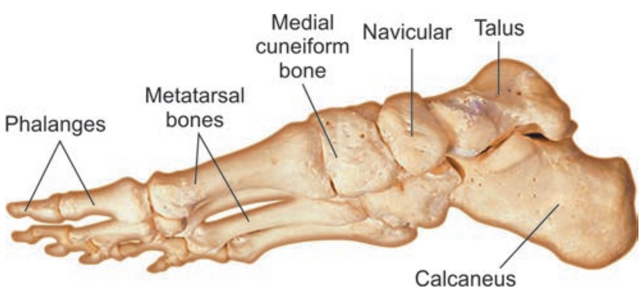


Fig. 85: Foot bones (medial view)

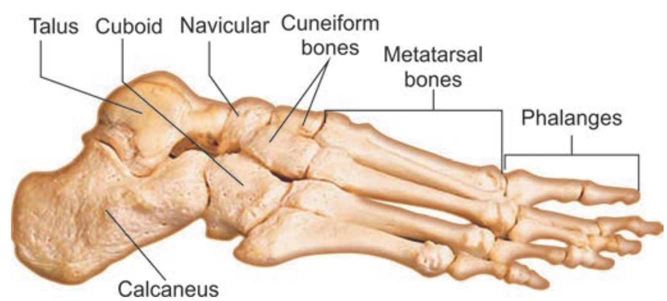


Fig. 86: Foot bones (lateral view)

- **Calcaneum** is the largest and strongest bone of the foot and lies below the talus.
  - It forms the heel of the foot, articulates with the talus superiorly and the cuboid anteriorly, and provides an attachment for the Achilles tendon.
  - It shows a shelf like medial projection called the **sustentaculum tali,** which supports the head of the talus (with the spring ligament).

Sustentaculum Tali

- The upper surface of this process assists in the formation of talocalcaneonavicular joint.
- The groove on the lower surface is occupied by the tendon of flexor hallucis longus and the margins of groove give attachment to the deep part of flexor retinaculum.
- The medial margin provides attachment to
  - Spring ligament anteriorly.
  - Tibialis posterior in the middle.
  - Deltoid ligament (superficial fibers) along the whole length.
  - Medial talocalcaneal ligament posteriorly.

- Tendon of flexor digitorum longus is related to the medial margin and may groove it.
- Flexor digitorum accessorius (Medial head) is attached distal to the groove for flexor hallucis longus.

Navicular is a boat-shaped tarsal bone lying between the head of the talus and the three cuneiform bones.

Cuboid is the most laterally placed tarsal bone and has a groove for the peroneus longus muscle tendon.

- It serves as the keystone of the lateral longitudinal arch of the foot.

Cuneiform bones are three wedge-shaped bones that form a part of the medial longitudinal and proximal transverse arches.

- They articulate with the navicular bone posteriorly and with three metatarsals anteriorly.

Metatarsus consists of five metatarsals and has prominent medial and lateral sesamoid bones on the first metatarsal.

Phalanges consists of 14 bones (two in the first digit and three in each of the others).

ASSESSMENT QUESTIONS

1. Which tendon passes below sustentacula tali? *(AIPG 2010)*
a. **Tibialis anterior**
b. **Tibialis posterior**
c. **Flexor hallucis longus**
d. **Flexor digitorum longus**

2. Which of the following tendons has attachment on sustentaculum tali? *(AIPG 2010)*
a. Tibialis Anterior
b. Tibialis posterior
c. Flexor digitorum longus
d. Flexor hallucis longus

3. Which of the following ligament is NOT attached to talus? *(NBEP 2013)*
a. **Talonavicular ligament**
b. **Deltoid ligament**
c. **Spring ligament**
d. **Cervical ligament**

ANSWERS WITH EXPLANATIONS

1. c. Flexor hallucis longus
- The tendon of **flexor hallucis longus** passes in a groove between the two tubercles of the posterior talus and then lower surface of the sustentaculum tali.
- It uses sustentaculum tali as a pulley to pull and flex the great toe (flexor/hallux). This tendon also passes deep to the flexor retinaculum along with the other long muscles of the posterior leg - **Tibialis posterior** and **Flexor digitorum longus**, which insert into the sole bones.

2. b. Tibialis posterior
- Tibialis posterior attaches to the medial margin on sustentaculum tali.

3. c. Spring ligament
- **Spring ligament** is calcaneo-navicular ligament attaching to calcaneum and navicular bones. It supports the head of the talus but is **not attached** to talus.

Joints

Functionally, there are three compound joints in the foot:
- Clinical subtalar joint between the talus and the calcaneus, where inversion and eversion occur about an oblique axis.
- Transverse tarsal joint, where the midfoot and forefoot rotate as a unit on the hindfoot around a longitudinal axis, augmenting inversion and eversion
- Remaining joints of the foot, which allow the pedal platform (foot) to form dynamic longitudinal and transverse arches.

Table 27: Joints of foot

Joint	Type	Articulating Surfaces	Joint capsule	Ligaments	Movements	Blood supply	Nerve supply
Subtalar (talocalcaneal, anatomical subtalar joint)	Plane synovial joint	Inferior surface of body of talus (posterior calcaneal articular facet) articulates with superior surface (posterior talar articular surface) of calcaneus	Fibrous layer of joint capsule is attached to margins of articular surfaces	Medial, lateral, and posterior talocalcaneal ligaments support capsule; interosseous talocalcaneal ligament binds bones together	Inversion and eversion of foot	Posterior tibial and fibular anteries	
Talocalcaneo-navicular	Synovial joint Talonavicular part is ball and socket type	Heads of talus articulates with calcaneus and navicular bones	Joint capsule incompletely encloses joint	Plantar calcaneonavicular (spring) ligament supports head of talus	Gliding and rotatory movements possible	Anterior tibial artery via lateral trasal artery, a branch of dorsalis pedis artery (dorsal artery of foot)	Plantar aspect: medial or lateral plantar nerve

Joint	Type	Articulating Surfaces	Joint capsule	Ligaments	Movements	Blood supply	Nerve supply
Calcaneocuboid	Plane synovial joint	Anterior end of calcaneus articulates with posterior surface of cuboid	Fibrous capsule encloses joint	Dorsal calcaneocuboid ligament, plantar calcaneocuboid, and long plantar ligaments support joint capsule	Inversion and eversion of foot; circumduction		Dorsal aspect: deep fibular nerve
Cuneonavicular joint		Anterior navicular articulates with posterior surfaces of cuneiforms	Common capsule encloses joints	Dorsal and plantar cuneonavicular ligaments	Little movement occurs		
Tarsometatarsal		Anterior tarsal bones articulate with bases of meatatarsal bones	Separate joint capsules enclose each joint	Dorsal, plantar, and interosseous tarsometatarsal ligaments bind bones together	Gliding or sliding		Deep fibular: medial and lateral plantar nerves: sural nerve
Intermetatarsal	Plane synovial joint	Bases of metatarsal bones articulate with each other	Separate joint capsules enclose each joint	Dorsal, plantar, and interosseous intermetatarsal ligaments bind lateral four metatarsal bones together	Little individual movement occurs	Lateral metatarsal artery (a branch of dorsalis pedis artery)	
Metatarso-phalangeal	Condyloid synovial joint	Heads of metatarsal bones articulate with bases of proximal phalanges		Collateral ligaments support capsule on each side; plantar ligament supports plantar part of capsule	Flexion, extension, and some abduction, adduction, and circumduction		Digital nerves
Interphalangeal	Hinge synovial joint	Head of one phalanx articulates with base of one distal to it		Collateral and plantar ligaments support joints	Flexion and extension	Digital branches of plantar arch	

Subtalar (Talocalcaneal) Joints

- There are two joints between the talus and calcaneum: **Posterior** talocalcaneal joint and **anterior** talocalcaneonavicular joint.
  - The posterior talocalcaneal joint is often designated as subtalar joint.
    - It is a plane type of synovial joint.
    - It is formed between the concave facet on the inferior surface of the body of talus and convex facet on the middle one-third of the superior surface of the calcaneum.

Ligaments

- Lateral & medial talocalcaneal ligaments, interosseous talocalcaneal ligament, cervical ligament.
- **Interosseous** talocalcaneal ligament is the chief bond of union between the talus and calcaneum, occupies sinus tarsi and separates the talocalcaneal joint from the talocalcaneonavicular joint.
  - It extends obliquely from the sulcus tali to the sulcus calcanei. It becomes taut in eversion.
- **Cervical** ligament is lateral to sinus tarsi. It extends upward from upper surface of the calcaneum to the tubercle on the inferolateral aspect of the neck of talus. It becomes taut in inversion.

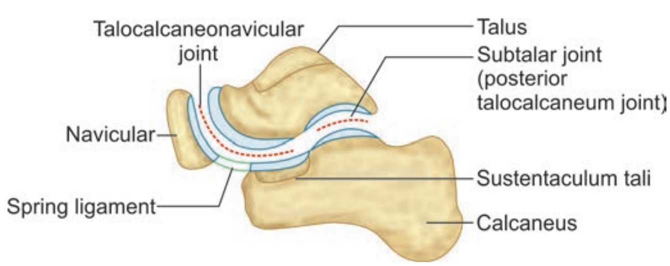


Fig. 87: Subtalar and talocalcaneonavicular joints

Talocalcaneonavicular joint is a ball & socket synovial joint, for the movements of inversion & eversion.

- The round head of the talus fits into the socket formed by the calcaneum, navicular, and spring ligament.
- It is a compound articulation consisting of anterior talocalcaneal and talonavicular joints.

Ligaments: Spring ligament, Medial limb (calcaneonavicular part) of bifurcate ligament.

Spring ligament (plantar calcaneonavicular ligament) extends from the anterior margin of the sustentaculum tali to the plantar surface of navicular bone between its tuberosity and articular margin.

- It takes part in forming the socket for the head of the talus.
- Spring ligament is made up of two distinct structures: the superomedial calcaneonavicular portion and the inferolateral calcaneonavicular portion.
- The dorsal surface of the superomedial calcaneonavicular portion has a triangular fibrocartilaginous facet on which part of the talar headrests.
- Its plantar surface is supported medially by the tendon of tibialis posterior and laterally by the tendons of flexors hallucis longus and digitorum longus; its medial border is blended with the anterior superficial fibres of the medial (deltoid) ligament.
- It is an important ligament to maintain the medial longitudinal arch.
- Transection of the spring ligament leads to instability of the hindfoot, including talar head plantar flexion and adduction, consistent with pes planovalgus (adult acquired flatfoot) deformity.

Calcaneocuboid Joint is a saddle type of synovial joint.

Ligaments: Lateral limb (calcaneocuboid part) of bifurcate ligament, Long plantar ligament, Short plantar ligament.

Bifurcate ligament is Y-shaped. Its stem is attached to the anterolateral part of the sulcus calcanei.

- Its medial limb (calcaneonavicular part) is attached to the dorsolateral surface of the navicular bone and its lateral limb (calcaneocuboid part) to the dorsomedial surface of the cuboid bone.

Long planar ligament extends from triangular plantar surface of the calcaneum to the lips of the groove on cuboid and beyond it to the bases of the middle three metatarsals (second to fourth).

- It converts the groove on the plantar surface of cuboid into a tunnel for the passage of tendon of peroneus longus.
- Morphologically, it represents the separated tendon of the gastrocnemius.

Transverse Tarsal (Chopart's Midtarsal) Joint

- It is a compound joint consisting of calcaneocuboid and talonavicular joints, involved in inversion and eversion of the foot.
- These joints have same transverse plane but different axes of movements.

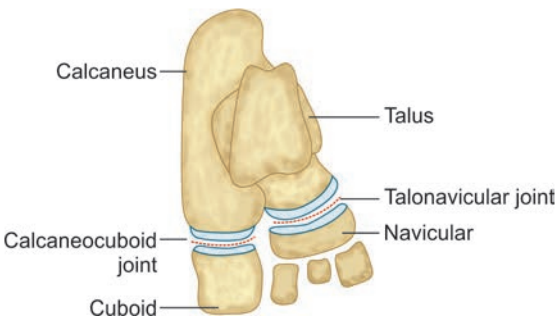


Fig. 88: Transverse tarsal (midtarsal) joint

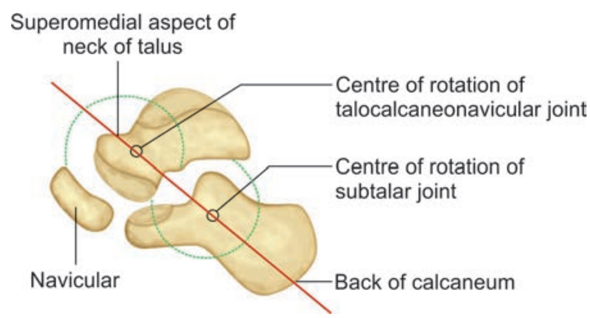


Fig. 89: Axis of inversion and eversion (red line)

Inversion and Eversion

- Inversion: Medial border of the foot is raised so that the sole faces inside (medially).
- Eversion: Lateral border of the foot is raised so that the sole faces outside (laterally).
- Inversion and eversion occurs mainly at sub-talar joint.
  - Major movements occur at talocalcaneonavicular joint.
  - Other involved joints are transverse tarsal/midtarsal joints (calcaneocuboid & talonavicular).

Axis of Movements

The movements of inversion and eversion take place around an oblique axis which runs forward, upward, and medially passing from the back of calcaneum through the sinus tarsi to emerge at the superomedial aspect of the neck of talus.

Range of Movements

Movement	Inversion	Eversion
When foot is off the ground	• Range of motion is more • Inversion consists of adduction of the forefoot, lateral rotation (supination) of the forefoot, and plantar flexion of the ankle	• Range of motion is more • Eversion consists of abduction of the forefoot, medial rotation (pronation) of the forefoot, and dorsiflexion of the ankle
When foot is on the ground	• Range of motion is less • Inversion consists of only lateral rotation (supination) of the forefoot • Heads of the medial 2 metatarsals are raised	• Range of motion is less • Eversion consists of only medial rotation (pronation) of the forefoot • Heads of the lateral 3 metatarsals are raised

Fig. 90: Foot movements: Supination and pronation

ASSESSMENT QUESTIONS

1. Spring ligament consists of all EXCEPT: *(JIPMER 2011; NEET Pattern 2015)*
- a. Plantar calcaneocuboid ligament
- b. Plantar calcaneonavicular ligament
- c. Medial calcaneonavicular ligament
- d. Lateral calcaneonavicular ligament

2. Ligament supporting the talus is: *(NEET Pattern 2014)*
- a. Spring ligament
- b. Deltoid ligament
- c. Talonavicular ligament
- d. Cervical ligament

3. Eversion occurs at which of the following joint?
- a. Subtalar
- b. Tibiotalar
- c. Inferior tibiofibular
- d. Ankle

4. In foot pronation, the axis of which two joints become parallel? *(AIIMS 2014)*
- a. Talo-calcaneal and talonavicular
- b. Talo-calcaneal and calcaneocuboid
- c. Subtalar and Lisfranc
- d. Talo-navicular and calcaneo-cuboid

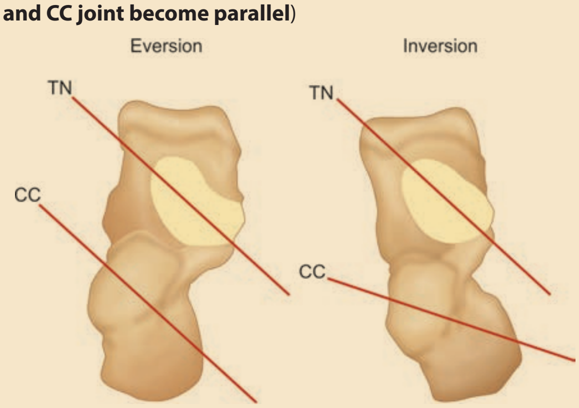
ANSWERS WITH EXPLANATIONS

1. a. Plantar calcaneocuboid ligament
- Spring (calcaneo-navicular) ligament attaches calcaneum to navicular bone (and not cuboid).
- It is made up of two distinct structures: the superomedial calcaneonavicular portion and the inferolateral calcaneonavicular portion.

2. a. Spring ligament
- Spring ligament supports the head of the talus.
- Spring (plantar calcaneonavicular) ligament **supports the head of the talus** and the medial longitudinal arch.
- The spring ligament is fairly elastic, hence its name.

3. a. Subtalar
- Inversion and eversion occurs mainly at sub-talar joint.
- Major movements occur at talocalcaneonavicular joint.
- Other involved joints are transverse tarsal/midtarsal joints (calcaneocuboid & talonavicular).

4. d. Talo-navicular and calcaneo-cuboid.
- Transverse tarsal (Midtarsal) joint is a collective term for the talonavicular (TN) part of the talocalcaneonavicular joint and the calcaneocuboid (CC) joint.
- The two joints are separated anatomically but act together functionally.
- During supination of foot, the soles face each other and there occurs inversion, whereas, in **pronation**, soles move outwards and is accompanied by eversion (**TN and CC joint become parallel**)



High Yield Points

- Ligament below the head of talus is **spring ligament.**
- **Deltoid ligament** is attached to **medial malleolus** (and not lateral malleolus).
- **Inversion** occurs at the **sub-talar joint** and **turns the sole of the foot inward.**
- **Tarsometatarsal Joint (Lisfranc Joint)** is the articulation of the tarsal bones with the metatarsals.

Arterial Supply

- **Dorsalis pedis artery** lies between the extensor hallucis longus and extensor digitorum longus tendons midway between the medial and lateral malleolus, where the **dorsal pedal pulse** can be palpated.
  - The dorsalis pedis artery gives off the following branches.
    - **Lateral tarsal artery** anastomoses with the arcuate artery.
    - **Arcuate artery** runs laterally across the bases of the lateral four metatarsals and gives rise to the **second, third, and fourth dorsal metatarsal arteries**. The dorsal metatarsal arteries branch into two **dorsal digital arteries**.
    - **First dorsal metatarsal artery**
    - **Deep plantar artery** enters the sole of the foot and joins the lateral plantar artery to form the **plantar arch**.
  - The **sole** of the foot receives blood from the medial and lateral **plantar arteries** derived from the **posterior tibial artery**.

Nerves

Table 28: Nerves of foot

Nerve[a]	Origin	Course	Distribution in Foot
Saphenous	Femoral nerve	Arises in femoral triangle and descends through thigh and leg: accompanies great saphenous vein anterior to medial malleolus: ends on medial side of foot	Supplies skin on medial side or foot as far anteriorly as head of 1st metatarsal
Superficial fibular	Common fibular nerve	Pierces deep fascia in distal third of leg to become cutaneous; then sends branches to foot and digits	Supplies skin on dorsum of foot and all digits, except lateral side of 5th and adjoining sides of the 1st and 2nd digits
Deep fibular		Passes deep to extensor retinaculum to enter dorsum of foot	Supplies extensor digitorum brevis and skin on contiguous sides of 1st and 2nd digits
Medial plantar	Larger terminal branch of tibial nerve	Passes distally in foot between abductor hallucis and flexor digitorum brevis; divides into muscular and cutaneous branches	Supplies skin of medial side of sole of foot and sides of first three digits; also supplies abductor hallucis, flexor digitorum brevis, flexor hallucis brevis, and first lumbrical
Lateral plantar	Smaller terminal branch of tibial nerve	Passes laterally in foot between quadratus plantae and flexor digitorum brevis muscles; divides into superficial and deep branches	Supplies quadratus plantae, abductor digiti minimi, digital minim brevis; deep branch supplies plantar and dorsal interossei, lateral three lumbricals, and adductor hallucis; supplies skin on sole lateral to a line splitting 4th digit
Sural	Usually arises from branches of both tibial and common fibular nerves	Passes inferior to the lateral malleolus to lateral side of foot	Lateral aspect of hindfoot and midfoot
Calcaneal branches	Tibial and sural nerves	Pass from distal part of the posterior aspect of leg to skin on heel	Skin of heel

Cutaneous Innervation of Foot

- Peroneal nerve has 2 branches: superficial and deep.
  - The superficial peroneal nerve supplies almost the entire dorsum of foot, whereas, deep peroneal nerve supplies the dorsum of **first web–space** (interdigital cleft).
  - The area over the great saphenous vein is supplied by the branches of **femoral nerve**, mainly the medial cutaneous branch of thigh and the saphenous nerve in the leg.
  - Altered sensation over the area of great saphenous vein in leg may occur secondary to damaged saphenous nerve, as might occur during venae-section of great saphenous vein.
- Tibial nerve supplies the sensations over the back of the leg and the sole of the foot.
- Sural nerve is a branch of tibial nerve and runs along the short saphenous vein and supplies the dorsum of foot along its lateral border (including the little toe).

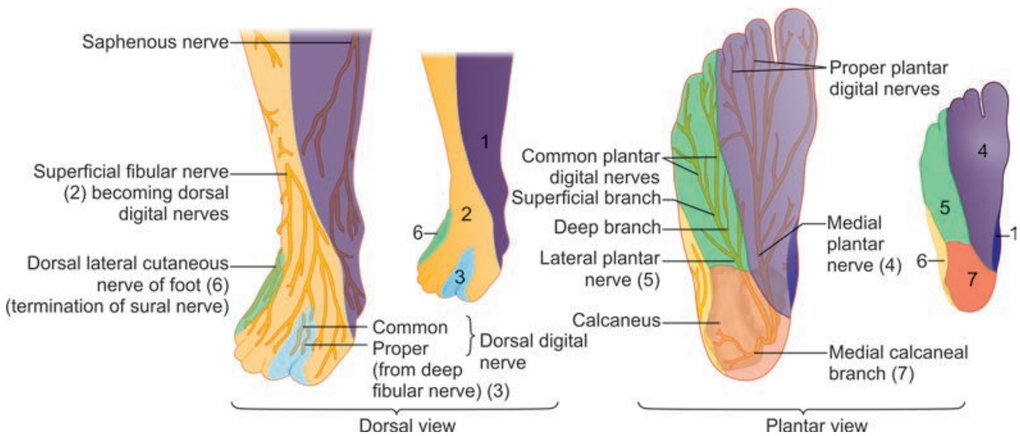


Fig. 91: Nerves of foot

- **Medial plantar nerve** supplies 4 muscles: Abductor hallucis, flexor digitorum brevis, Flexor hallucis brevis. and first Lumbrical. Rest all foot muscle are usually supplied by **lateral plantar nerve.**

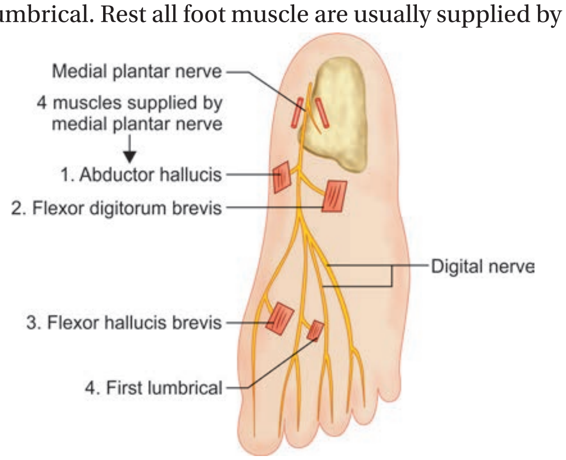


Fig. 92: Course and motor distribution of medial plantar nerve

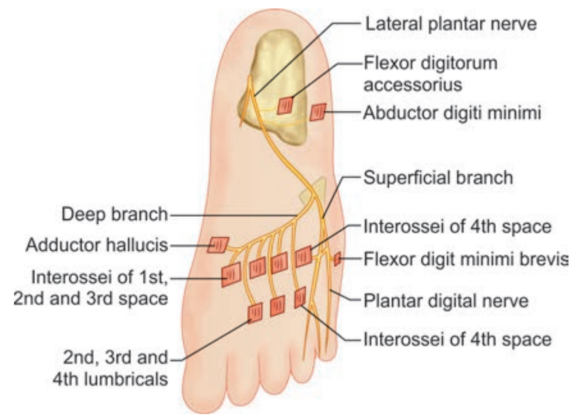


Fig. 93: Course and motor distribution of lateral plantar nerve

Arches

Foot arches provide the resilience necessary for walking, running, and jumping, and are maintained by four layers of passive, fibrous support, plus the dynamic support provided by the intrinsic muscles of the foot, and the long fibular, tibial, and flexor tendons.

- **Lateral longitudinal** arch is contributed by the calcaneus, the cuboid bone, and the lateral two metatarsal bones.
  - The **keystone is the cuboid bone**.
  - It is supported by the peroneus longus tendon and the long and short plantar ligaments.
- **Medial longitudinal arch** is contributed and maintained by the of the talus, calcaneus, navicular, cuneiform, and three medial metatarsal bones.
  - The **keystone** is the head of the talus, which is located at the summit between the sustentaculum tali and the navicular bone.
  - It is supported by the **spring ligament** and the tendon of the flexor hallucis longus.
  - **Flat foot** (pes planus or talipes planus) is a condition of disappearance or collapse of the medial longitudinal arch with eversion and abduction of the forefoot and leads to pain as a result of stretching of the plantar muscles and straining of the spring ligament and the long and short plantar ligaments.
- **Transverse arches**:
  - **Proximal** (metatarsal) arch is formed by the navicular bone, the three cuneiform bones, the cuboid bone, and the bases of the five metatarsal bones of the foot. It is supported by the tendon of the peroneus longus.
  - **Distal** arch is formed by the heads of five metatarsal bones. It is maintained by the transverse head of the adductor hallucis.

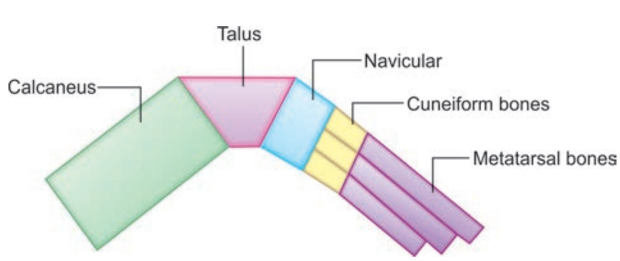


Fig. 94: Medial longitudinal arch

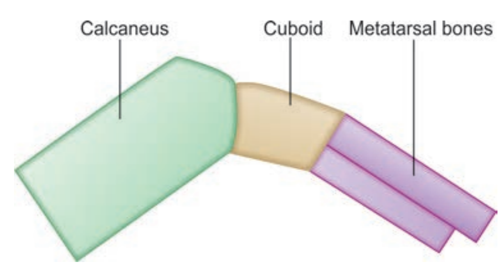


Fig. 95: Lateral longitudinal arch

Table 29: Differences between the medial and lateral longitudinal arches	
Medial longitudinal arch	**Lateral longitudinal arch**
• Formed by more bones and more joints	• Formed by less bones and less joints
• Characteristic features is resiliency	• Characteristic feature is rigidity
• Higher and more mobile	• Lower and less mobile
• Involved in propulsion during locomotion (i.e., initiating the next step during walking)	• Involved in receiving and supporting the body weight
• Summit is formed by the talus	• Summit is formed by the calcaneum
• Main joint is talocalcaneonavicular joint (the most vulnerable part of the arch)	• Main joint is calcaneocuboid (the most vulnerable part of the arch)

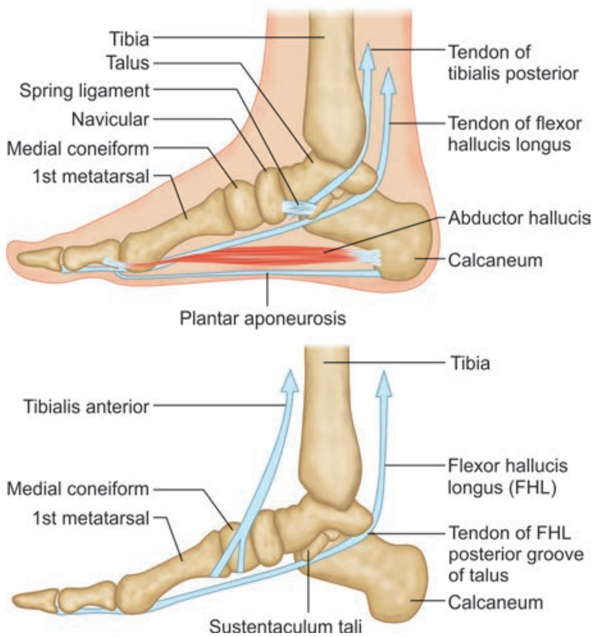


Fig. 96: Medial longitudinal arch

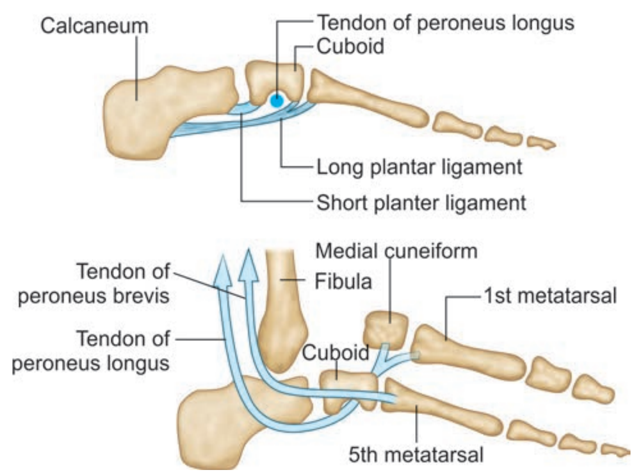


Fig. 97: Lateral longitudinal arch

ASSESSMENT QUESTIONS

1. **Medial longitudinal arch of the foot is maintained by all EXCEPT:** *(NEET Pattern 2015)*
   a. Peroneus longus
   b. Tibialis posterior
   c. Flexor digitorum longus
   d. Plantar aponeurosis

2. **Which is NOT a part of medial longitudinal arch of foot?**
   a. Third metatarsal
   b. Cuboid
   c. Calcaneum
   d. Talus

3. **Transverse arch of foot is maintained by:**
   a. Flexor digitorum brevis
   b. Adductor hallucis
   c. Abductor hallucis brevis
   d. Peroneus brevis

ANSWERS WITH EXPLANATIONS

1. **a. Peroneus longus**
   - Peroneus longus and brevis support the lateral longitudinal arch.
2. **b. Cuboid**
   - **Cuboid** bone is present at the lateral aspect of the foot, articulates with calcaneum (CC joint is saddle synovial) and both bones contributes to **lateral longitudinal arch**.
   - Cuboid bone is the keystone bone for the arch. Cuboid bone has a groove for the tendon of peroneus longus muscle.
3. **b. Adductor hallucis**
   - The **transverse arches** are strengthened by the interosseous, plantar, and dorsal ligaments, by the short muscles of the first and fifth toes (especially the transverse head of the Adductor hallucis), and by the Peroneus longus, whose tendon stretches across between the piers of the arches.

Muscles

- The intrinsic muscles of the plantar surface of the foot are arranged in **four layers** and divided into four fascial compartments.
  - A tough plantar aponeurosis overlies the central compartment, passively contributing to arch maintenance and, along with firmly bound fat, protecting the vessels and nerves from compression.

1st layer	2nd layer	3rd layer	4th layer
Abductor hallucis	Lumbricals	Adductor hallucis	Plantar interossei (three muscles)
Flexor digitorum brevis	Quadratus plantae	Flexor hallucis brevis	Dorsal interossei (four muscles)
Abductor digiti minimi		Flexor digit minimi brevis	

Table 30: Muscles of foot: 1st and 2nd layers of sole

Muscle	Proximal attachment	Distal attachment	Innervation[a]	Main action[b]
1st layer				
Abductor hallucis	Medial tubercle of tuberosity of calcaneus; flexor retinaculum; plantar aponeurosis	Medial side of base of proximal phalanx of 1st digit	Medial plantar nerve (S2, S3)	Abducts and flexes 1st digit (great toe, hallux)
Flexor digitorum brevis	Medial tubercle of tuberosity of calcaneus; plantar aponeurosis; intermuscular septa	Both sides of middle phalanges of lateral four digits	Medial plantar nerve (S2, S3)	Flexes lateral four digits
Abductor digiti minimi	Medial and lateral tubercles of tuberosity of calcaneus; plantar aponeurosis; intermuscular septa	Lateral side of base of proximal phalanx of 5th digit	Lateral plantar nerve (S2, S3)	Abducts and flexes little toe (5th digit)
2nd layer				
Quadratus planae	Medial surface and lateral margin of plantar surface of calcaneus	Posterolateral margin of tendon of flexor digitorum longus	Lateral plantar nerve (S2, S3)	Assists flexor digitorum longus in flexing lateral four digits
Lumbricals	Tendons of flexor digitorum longus	Medial aspect of expansion over lateral four digits	Medial one: medial plantar nerve (S2, S3) Lateral three: lateral plantar nerve (S2, S3)	Flex proximal phalanges, extend middle and distal phalanges of lateral four digits

[a]The spinal cord segmental innervation is indicated (e.g., "S2, S3" means that the nerves supplying the abductor hallucis are derived from the second and third sacral segments of the spinal cord). Damage to one or more of the listed spinal cord segments or to the motor nerve roots arising from them results in paralysis of the muscles concerned.
[b]Despite individual actions, the primary function of the intrinsic muscles of the sole of the foot is to resist flattening or maintain the arch of the foot.

Table 31: Muscles of foot: 3rd and 4th layers of sole

Muscle	Proximal attachment	Distal attachment	Innervation[a]	Main action[b]
1st layer				
Flexor hallucis brevis	Plantar surfaces of cuboid and lateral cuneiforms	Both sides of base of proximal phalanx of 1st digit	Medial plantar nerve (S2, S3)	Flexes proximal phalanx of 1st digit
Muscle	**Proximal attachment**	**Distal attachment**	**Innervation[a]**	**Main action[b]**
Adductor hallucis	Oblique head: bases of metatarsals 2–4 Transverse head: plantar ligaments of metatarsophalangeal (MTP) joints	Tendons of both heads attach to lateral side of base of proximal phalanx of 1st digit	Deep branch of lateral plantar nerve (S2, S3)	Traditionally said to adduct 1st digit; assists in transverse arch of foot by metatarsals medially
Flexor digiti minimi brevis	Base of 5th metatarsal	Base of proximal phalanx of 5th digit	Superficial branch of lateral plantar nerve (S2, S3)	Flexes proximal phalanx of 5th digit. thereby assisting with its flexion
4th layer				
Plantar interossei (three muscles)	Plantar aspect of medial sides of shafts of metatarsals 3–5	Medial sides of bases of phalanges of 3rd–5th digits	Lateral plantar nerve (S2, S3)	Adduct digits 3/5 and flex metatarsophalangeal joints
Dorsal interossei (four muscles)	Adjacent sides of shafts of metatarsals 1–5	1st: medial side of proximal phalanx of 2nd digit; 2nd–4th: lateral sides of 2nd–4th digits		Abduct digits 2–4 and flex metatarsophalangeal joints

[a]The spinal cord segmental innevation is indicated (e.g. "S2, S3" means that the nerves supplying the flexor hallucis brevis are derived from the second and third sacral segments of the spinal cord). Damage to one or more of the listed spinal cord segments or to the motor nerve roots arising from them results in paralysis of the muscles concerned.
[b]Despite individual actions, the primary function of the intrinsic muscles of the sole of the foot is to resist flattening or maintain the arch of the foot.

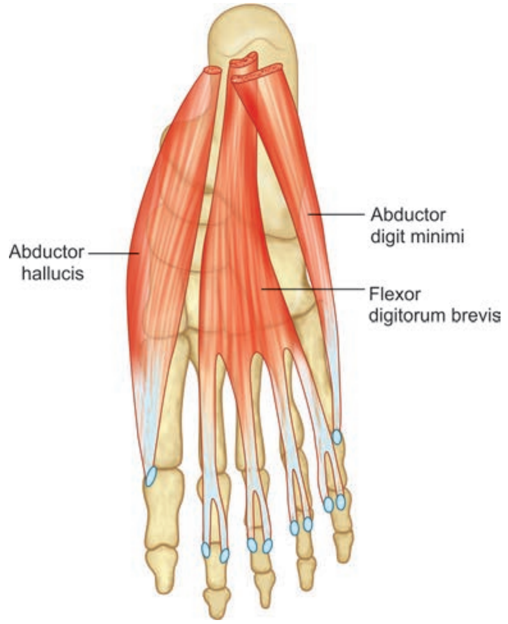


Fig. 98: Muscles of the first layer of the sole

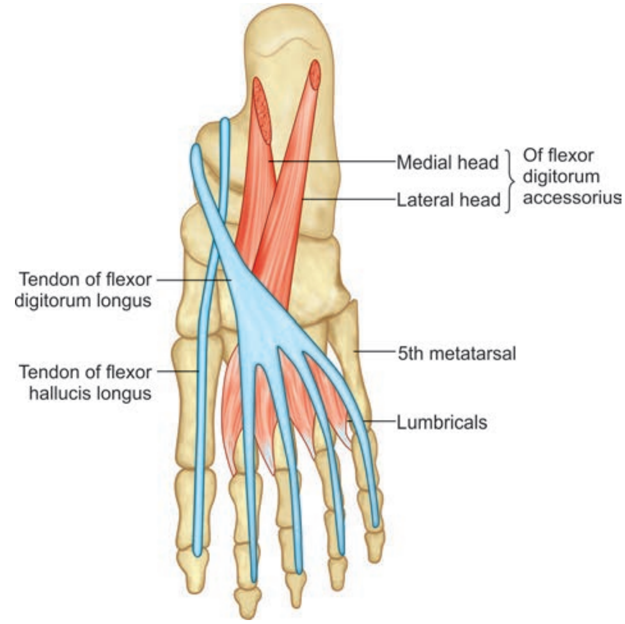


Fig. 99: Muscles of the second layer of the sole

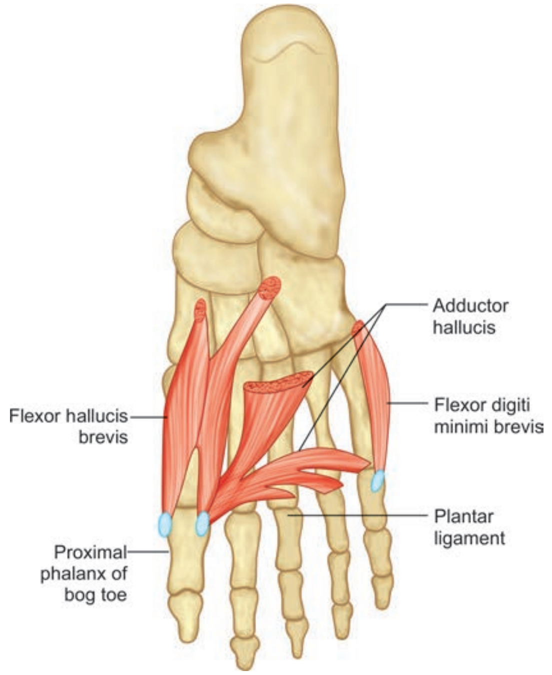


Fig. 100: Muscles of the third layer of the sole

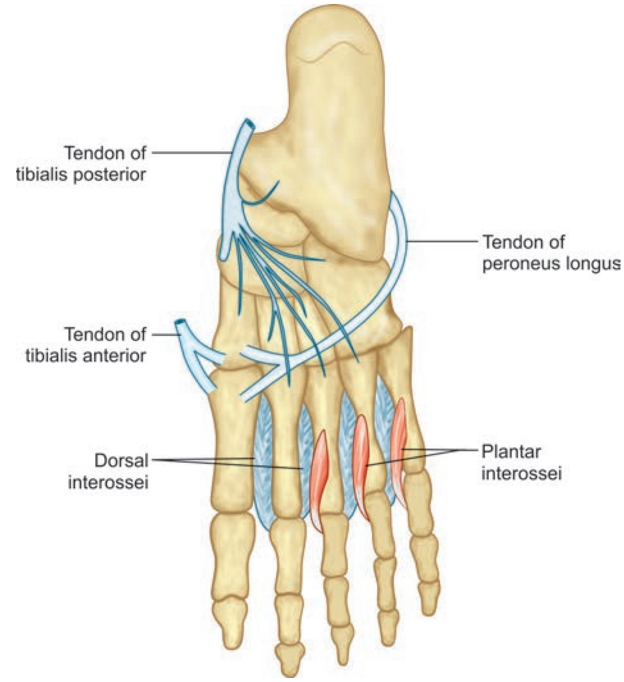


Fig. 101: Muscles of the fourth layer of the sole

Table 32: Muscles of foot: Dorsum of foot

Muscle	Proximal attachment	Distal attachment	Innervation[a]	Main action
Extensor digitorum brevis	Calcaneus (Floor of tarsal sinus), interosseous talocalcaneal ligament; stem of inferior extensor retinaculum	Long extensor tendons of four medial digits (toes 2–4)	Deep fibular nerve (L5 or S1 or both)	Aids the extensor digitorum longus in extending the four medial toes at the metatarsophalangeal and interphalangeal joints
Extensor hallucis brevis	In common with extensor digitorum brevis (above)	Dorsal aspect of base of proximal phalanx of great toe (digit 1)		Aids the extensor hallucis longus in extending the great toe at the metatarsophalangeal joint

[a]The spinal cord segmental innervation is indicated (e.g., "L5 or S1" means that the nerve supplying the extensor digitorum brevis is derived from either the fifth lumbar segment of first sacral segment of the spinal cord). Damage to one or more of the listed spinal cord segments or to the motor nerve roots arising from them results in paralysis of the muscles concerned.

ASSESSMENT QUESTIONS

1. First layer of sole has: *(NEET Pattern 2014)*
a. Abductor hallucis
b. Flexor hallucis longus
c. Flexor hallucis brevis
d. Adductor hallucis

2. 3rd and 4th lumbrical of foot are supplied by: *(NEET Pattern 2015)*
a. Medial planter nerve
b. Lateral plantar nerve
c. Peroneal nerve
d. Posterior tibial nerve

3. All of the following pairs concerning layers of sole muscles are correct EXCEPT:
a. First layer: Adductor hallucis
b. Second layer: Lumbricals
c. Third layer: Flexor hallucis
d. Fourth layer: Interossei

ANSWERS WITH EXPLANATIONS

1. a. Abductor hallucis
- Abductor hallucis muscle belongs to first layer of sole.
- Tendon of flexor hallucis longus is found in second layer.
- Flexor hallucis brevis and adductor hallucis belong to the third layer.

2. b. Lateral plantar nerve
- First lumbrical of foot is supplied by medial plantar nerve and the lateral three are supplied by the lateral plantar nerve.

3. a. First layer: Adductor hallucis
- Adductor hallucis belongs to third layer of sole

High Yield Point

- Dorsal **interossei** abduct (DAB) toes and flex metacarpophalangeal (MP) joints, whereas the plantar interossei adduct (PAD) toes and flex MP joints. Paralysis of lumbrical & interossei leads to claw foot.

Radiology

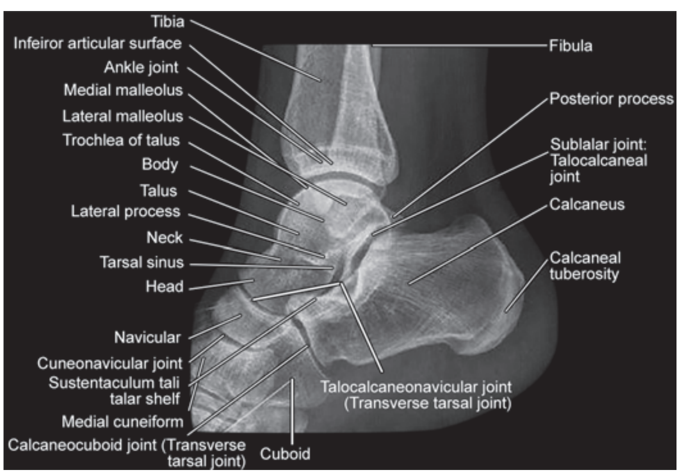


Fig. 102: X-ray of ankle region—lateral view

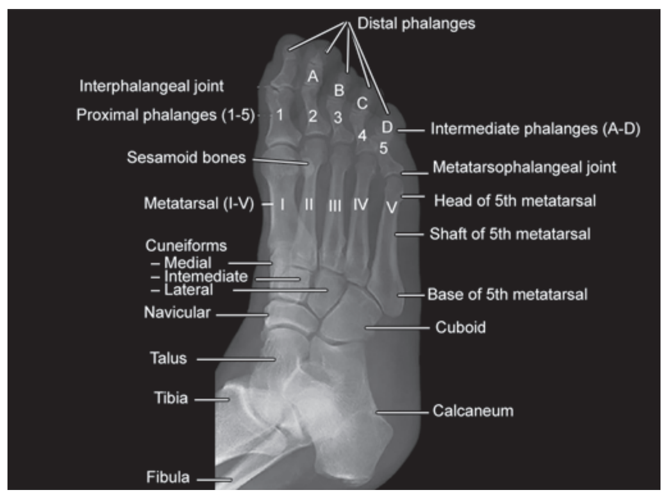


Fig. 103: X-ray of ankle and foot region

Clinical Correlations

- **March fracture** is found most commonly in the mid to distal diaphysis of the second metatarsal (and less often in the third).
  - Fracture lies within the shaft of the metatarsal, at the point one-third from the head and two-thirds from the base, but stress fractures of the first and fifth metatarsals tend to affect the more proximal part of the bone shaft.
  - Seen in belle dancers, prolonged walking event.
- **Flat foot** (pes planus or talipes planus) results from collapse of the medial longitudinal arch with eversion and abduction of the forefoot, causing greater wear on the inner border of the soles and heels of shoes.
- **Pes cavus** is an abnormally high medial longitudinal arch.
- **Club foot** (talipes equinovarus) is a condition in which the foot is plantar-flexed, inverted, and adducted.
  - The heel is elevated and turned medially.
- **Bunion** is a swelling at the medial side of the first metatarsal head that is caused by an inflamed bursa or a bony projection and is unusually associated with hallux valgus.
- **Hallux valgus** is a deviation of the big toe toward the lateral side of the foot.
- **Hallux varus** is a deviation of the big toe toward the medial side of the foot.
- Forced eversion of the foot avulses the medial malleolus or ruptures the deltoid ligament, whereas forced inversion avulses the lateral malleolus or tears the lateral collateral (anterior and posterior talofibular and calcaneofibular) ligament.

Compartment Syndrome

The fascial boundaries that limit the osteofascial compartments are inelastic, and any condition that leads to an increase in the volume of the compartmental contents, e.g. muscle swelling caused by trauma, haemorrhage or local infection, leads to an increase in intracompartmental pressure.

- There occurs compressive occlusion of the vessels in the compartment and consequent ischaemic damage to the muscles and nerves of the compartment (compartment syndrome).
- Fasciotomy is one of the definitive treatments of the syndrome.
- **Anterior tibial compartment syndrome** is an ischemic necrosis of the muscles of the anterior compartment of the leg, resulting from compression of the anterior tibial artery and its branches by swollen muscles following excessive exertion.
  - It is accompanied by extreme tenderness and pain on the anterolateral aspect of the leg.

ASSESSMENT QUESTION

1. **In posterior compartment syndrome, which passive movement causes pain:** *(AIIMS 2008)*
   a. Dorsiflexion of foot
   b. Foot inversion
   c. Toe dorsiflexion
   d. Foot abduction

ANSWER WITH EXPLANATION

1. **a. Dorsiflexion of foot**
   - Passive stretching of the muscles produce pain in compartment syndrome and hence, **dorsiflexion of foot** causes pain.
   - Posterior compartment of leg is concerned with plantar flexion of foot, and is supplied by the tibial nerve and posterior tibial vessels.
   - **Compartment syndrome** is caused by increased pressure in an enclosed space that leads to compromise of circulation and function of tissues in that space.
   - Patient usually hold injured part in a position of plantar-flexion to maximally relax the fascia/muscles and reduce pain.
   - E.g., Clawing of the toes is a common sequela of post-traumatic compartment syndrome within the deep posterior compartment following a distal third tibia fracture.

Walking Cycle

Movements of the lower limbs during **walking** are divided into alternating **swing** and **stance** phases.

- The **stance** phase begins with a heel strike, when the heel begins to assume the body's full weight (loading response), and ends with a push off by the forefoot, which is a result of plantar flexion.
- The **swing** phase begins after push off when the toes leave the ground and ends when the heel strikes the ground.
- In the walking cycle the **swing phase occupies 40%** and the stance phase 60%.
- The stance phase is longer than the swing phase because it begins and ends with relatively short periods (each 10% of the cycle) of double support (both feet are contacting the ground) as the weight is transferred from one side to the other, with a more extended period of single support (only one foot on the ground bearing all body weight) in between as the contralateral limb swings forward.
- The time and percentage of the stance phase is reduced in running, since there is no period of double support.

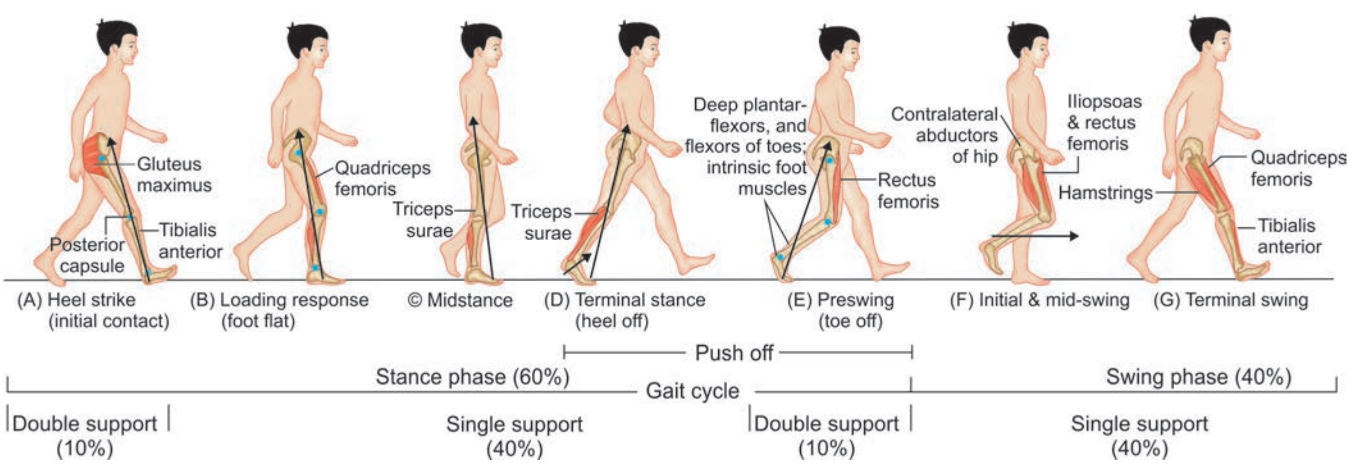


Fig. 104: Gait cycle. The activity of one limb between two repeated events of walking. Eight phases are typically described, two of which have been combined in (F) for simplification

Table 33: Muscle action during gait cycle

	Phase of gait	Mechanical goals	Active muscle groups	Examples
Stance phase	**Heel strike** (initial contact)	**Lower forefoot to ground**	Ankle dorsiflexors (eccentric contraction)	**Tibialis anterior**
		Continue deceleration (reverse forward swing)	Hip extensors	Gluteus maximus
		Preserve longitudinal arch of foot	Intrinsic muscles of foot	Flexor digitorum brevis
			Long tendons of foot	Tibialis anterior
	Loading response (flat foot)	**Accept weight**	Knee extensors	**Quadriceps**
		Decelerate mass (slow dorsi-flexion)	Ankle plantar flexors	Triceps surae (soleus and gastrocnemius)
		Stabilize pelivs	Hip abductors	**Gluteus medius and minimus; tensor fasciae latae**
			Intrinsic muscles of foot	Flexor digitorum brevis
		Preserve longitudinal arch of foot	Long tendons of foot	Tibialis posterior; long flexors of digits
	Midstance	**Stabilize knee**	Knee extensors	Quadriceps
		Control dorsiflexion (preserve momentum)	Ankle plantar flexors (eccentric contraction)	Triceps surae (soleus and gastrocnemius)
		Stabilize pelvis	Hip abductors	**Gluteus medius and minimus; tensor fasciae latae**
		Preserve longitudinal arch of foot	Intrinsic muscles of foot	Flexor digitorum brevis
			Long tendons of foot	Tibialis posterior; long flexors of digits
	Terminal stance (heel off)	**Accelerate mass**	Ankle plantar flexors (concen-tric contraction)	**Triceps surae (soleus and gas-trocnemius)**
		Stabilize pelvis	Hip abductors	**Gluteus medius and minimums; tensor faciae latae**
		Preserve arches of foot; fix forefoot	Intrinsic muscles of foot	Adductor hallucis
			Long tendons of foot	Tibialis posterior; long flexors of digits
	Preswing (toe off)	Accelerate mass	Long flexors of digits	Flexor hallucis longus; flexor digitorum longus
		Preserve arches of foot; fix forefoot	Intrinsic muscles of foot	Adductor hallucis
			Long tendons of foot	Tibialis posterior; long flexors of digits
		Decelerate thigh; prepare for swing	Flexor of hip (eccentric contraction)	Iliopsoas; rectus femoris
Swing phase	**Initial swing**	**Accelerate thigh; vary cadence**	**Flexor of hip (concentric contraction)**	**Iliopsoas; rectus femoris**
		Clear foot	**Ankle dorsiflexors**	**Tibialis anterior**
	Midswing	**Clear foot**	**Ankle dorsiflexors**	**Tibialis anterior**
	Terminal swing	Decelerate thigh	Hip extensors (eccentric contraction)	Gluteus maximus; hamstrings
		Decelerate leg	Knee flexors (eccentric contraction)	Hamstrings
		Position foot	**Ankle dorsiflexors**	Tibialis anterior
		Extend knee to place foot (control stride); prepare for contact	**Knee extensors**	Quadriceps

Pressure and energy variations during walking cycle

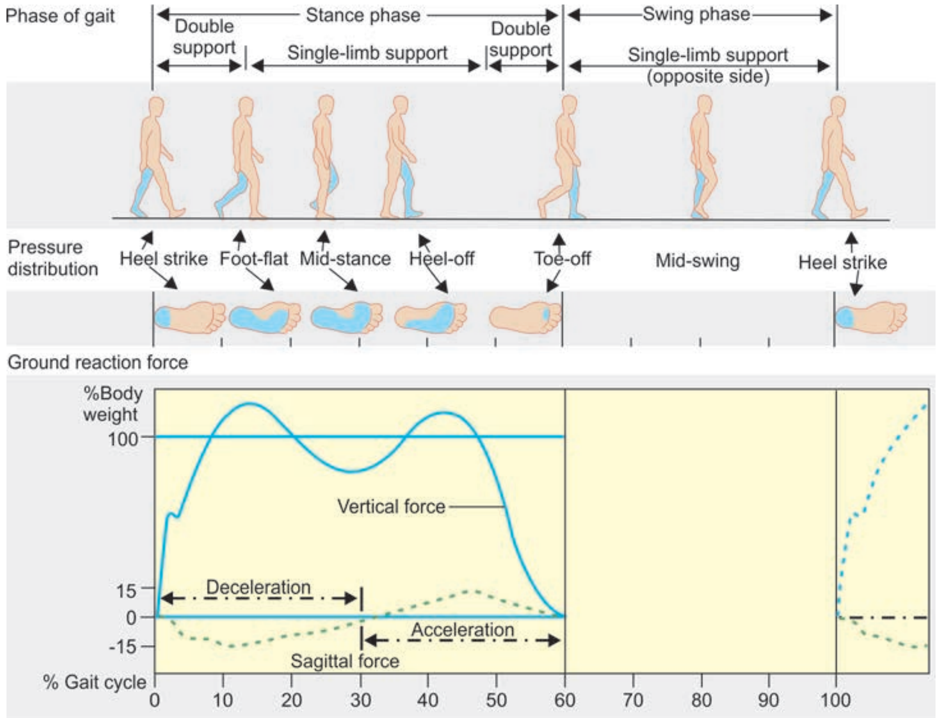


Fig. 105: The events that occur during the different phases of a normal gait cycle. Depicted are: distribution of foot; changes in the angles of hip, knee and ankle joints, together with activity in the corresponding muscle groups; and vertical and horizontal (sagittal plane) components of the ground reaction force during stance phase. (Chart collated from various sources by Michael Gunther, Department of Human Anatomy and Cell Biology, University of Liverpool)

ASSESSMENT QUESTIONS

1. The kinetic energy of the body is least in one of the following phases of walking cycle: *(AIIMS 2003)*

a. Heel strike
b. Mid-stance
c. Double support
d. Toe-off

2. Muscle used in normal walk during stance and swing: *(AIIMS 1994)*

a. Iliopsoas
b. Tibialis anterior
c. Popliteus
d. Gastrocnemius soleus

ANSWERS WITH EXPLANATIONS

1. b. Mid-stance

- The kinetic energy of body is least in **mid-stance phase** of walking cycle, since it is a single support phase.
- Single support phase means the body is supported only on one foot, the other foot being in air.
- The kinetic energy of the body passes through its maximum in each phase of double support, where both the feet are on ground.

2. b. Tibialis anterior

- In all the phases of swing and in the initial phase of stance, **tibialis anterior** muscle is active.