Stefano Gumina
Editor

Rotator Cuff Tear

Pathogenesis, Evaluation and Treatment

Springer

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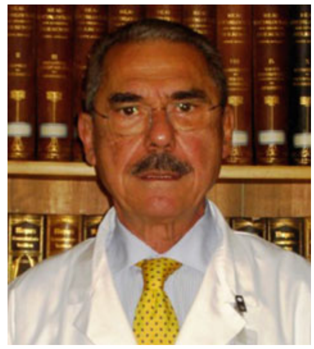
To my daughter Sara, to her eyes and her smile. I will never be able to thank God enough for having her in my life.

To my angel in heaven.

Foreword



In the last three decades, rotator cuff tear of the shoulder has become one of the most frequent diagnoses in orthopedics. Many thousands of scientific studies have been published on this topic. Nonetheless, monographs specifically written on rotator cuff tear are rare and, to the best of my knowledge, those published in this century can be counted on the fingers of one hand. Usually a monograph, even when dealing with all features of a single pathologic condition, is scientifically less worthy than an original study providing a crucial contribution to the knowledge of a condition. However, monographs have an intrinsic scientific importance and usefulness either for the experts in the subject who can find a collection of the knowledge gained so far and for those less experienced who aim at learning more on few, or many, features of the topic. This holds even more when a single person is the author, alone or with a small number of colleagues, of the vast majority of the chapters of the volume.

This textbook consists of 48 chapters, more than 260 figures and almost 1600 references. Many of the chapters are short, though exhaustive, whereas others are more than 20 pages long. One of the latter is the first chapter that deals with the history of shoulder pain and rotator cuff conditions, starting from the ancient Egypt to arrive to the most recent history pioneered by Charles Neer. This chapter exalts the skill and pleasure of the author to narrate and illustrate with outstanding pictures the history of medicine. Extremely complete and accurate is also the chapter on the anatomy of the rotator cuff and subacromial space, in which Stefano Gumina reports his numerous anatomical studies on dry scapulae and humeri, and his experience with anatomical dissections on fresh cadaver specimens. The series of chapters analyzing the predisposing factors to the cuff tear as well as that on the natural history of the disease are noteworthy. I found particularly interesting the chapter on treatment of reparable postero-superior lesions, which provides a meticulous description of the arthroscopic repair of the cuff tears, certainly useful for those young orthopedic surgeons who are interested in shoulder surgery. Many other parts of the monograph are interesting and original, and the entire book is written in a concise and clearly understandable language. Its main worthiness is that none of the multiple features of rotator cuff tear is neglected, which makes it a milestone in the literature concerning this condition.

I am grateful for being given the opportunity to congratulate Stefano Gumina and his colleagues on this excellent textbook.

Roma, Italy

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Foreword

The subject of this textbook is conditions of the rotator cuff and their treatment. This textbook represents a significant contribution to the orthopedic literature. Its 48 chapters and over 260 illustrations represent a comprehensive view of the anatomy, pathophysiology, and treatment of a broad spectrum of conditions that affect the rotator cuff. Rotator cuff pathology is among one of the most common and frequently treated shoulder disorders. This textbook has contributions from many many leading authorities in rotator cuff pathology and treatment. Each chapter has the strong contribution of its Editor, Professor Stefano Gumina. Professor Gumina is an internationally recognized authority in the pathology and treatment of the rotator cuff. This provides an authoritative and comprehensive review of the subject. The text is supplemented by superb illustrations and photographs as well as a comprehensive list of relevant references. This contribution to the literature provides both important and new information that will be of interest to both the new student of shoulder pathology as well as the advanced expert.

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Foreword

It is a great honor to be invited to write the preface for *Rotator Cuff Tears: Pathogenesis, Evaluation and Treatment*. The editor, Dr. Professor Stefano Gumina, should be congratulated on selecting this collaboration of scientists and authors to identify critical issues in treating a common shoulder problem. There has been a great deal of new information on this mechanical and biological challenge that can disable otherwise active individuals of all ages. This textbook will provide a resource for treating surgeons, revealing the state-of-the-art treatment options.

The rotator cuff tear can affect almost all ages. Early on, this is a traumatic injury and may be associated with a traumatic dislocation or repetitive overhead activity. More commonly, this is found in the active, middle-aged individual who is disabled due to pain, loss of motion, and functional deficits limiting their occupation or sport. This critical population requires maximum benefit from treatment and good prognosis for many decades. The biologic challenge here is not only mechanical success, but also satisfactory tendon healing. This textbook provides important chapters on risk factors, including aging, smoking, elevated cholesterol, postural abnormalities, that clearly play a role in the outcome. Although there are scattered reports in the literature, this textbook can be an important reference on these potential obstacles to healing.

The textbook design is easy to navigate, provides excellent information as a reference, and is instructional for management. It has a section on evaluation, including the cervical spine, and then provides separate chapters on state-of-the-art techniques to surgically repair and reconstruct the deficient shoulder.

As the affected population becomes elderly, there has been a controversy of reconstruct or replace. This becomes a great expense to the patient and community. Many of these individuals wish to remain active in their seventh and eighth decades. Additional techniques are provided to allow surgeons and patients to consider. The treatment section of this text begins with common surgical techniques and extends into more complex patterns that incorporate additional biologic factors including stem cells, PRP, and grafting. Although these techniques are time consuming, they offer an improvement in pain, gain in functional movement, and allow additional time before an arthroplasty option is selected.

This is a well-illustrated, well-written work on the rotator cuff tear. All treating shoulder surgeons can benefit from the provided information and referencing that this text has organized in one collection. Stefano Gumina deserves to be congratulated for this valuable addition to the shoulder literature. He is a great friend to me, and to all that embrace this textbook.

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Preface

The rotator cuff of the shoulder consists of the supraspinatus, infraspinatus, teres minor, and subscapularis tendons. Together, they wrap around the humeral head, such as the bathing cap of a swimmer. The first three tendons prevalently permit external, subscapularis to internal rotation. Intrinsic or extrinsic factors may be responsible for cuff tear. Cadaveric studies reported that the prevalence of the cuff tear varies from 5 to 44 %. This lesion has always attracted great interest because it may cause shoulder pain, loss of strength, simple or complex disabilities, and partial or total inability to work, reducing quality of life. Data in the literature indicate that more than 50 % of patients with symptomatic rupture undergo an increase in the size of the lesion in the subsequent two years. The goals of cuff repair are to restore footprint anatomy with biomechanically secure, tension-free construction that promotes biological healing at the tendon-to-bone interface. Even today, there is still cause for discussion about when and how to perform surgical repair and on what to do in cases of irreparable rupture.

This textbook is designed to cover important aspects of managing simple or complex cuff tears.

Chapters relative to etiopathogenesis are the result of recent studies; they will help to better understand why the tear occurs and what treatment should be proposed in relation to the degeneration of the musculotendineous unit.

This monograph is designed for shoulder surgeons and rehabilitation specialists, each of whom will find useful information for daily practice. However, in my heart, I hope that this monograph will be useful for young residents and shoulder fellows who, as it happened to me more than 25 years ago, have gradually developed a passion for diagnosis and treatment of shoulder diseases.

Roma, Italy
June, 2016

Stefano Gumina
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Part I

Basic Science

History of Shoulder Pain and Rotator Cuff Pathology

Stefano Gumina, Daniele Passaretti, and Vittorio Candela

A historical study on the treatment of rotator cuff tear should necessarily refer to the symptoms it causes, because only at the end of 1800, the lesion of these tendons has been identified among the causes which most frequently lead to pain, loss of strength, and range of motion.

Egyptian Period

Thousands of years before Christ, the art of medicine in Egypt was soaked with religion and magic rituals. Even before Greek and Roman scientific culture dictated the principles of "the art of healing," the Pharaohs archiatri wrote observations about anatomical, pathophysiological, and clinic aspects of medicine.

In 1930, Breasted [1] translated a papyrus bought in Egypt by Edwin Smith and then given to the History Society of New York. In the 377 lines of the papyrus, 48 cases of pathological conditions needing possible surgical treatment are reported: wounds, fractures, dislocations, and neoformations. In the papyrus, a case of possible glenohumeral dislocation is mentioned, but no information of shoulder pain with no glenohumeral dislocation is present. We can suppose that quotations about patients with "arms unawareness" referred to outcomes of trauma with spinal cord injury instead of tendon tears.

For the ancient Egyptians, the heart was the site where pain originated; from the heart all the vessels originated. These, in addition to the blood, could carry a "toxic principle," of fecal origin, which was responsible for all illness. Vessels could also carry algogenic and pathogenic substances, entered in the body through the nose and the ears causing pain.

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It has been hypothesized that the Egyptians used the term "metu" to indicate ligaments, muscles, nerves, and also tendons. The different kinds of joint pain, including the shoulder one, were treated with a calcareous "magic stone" extracted near Memphis.

Dioscorides (40–90 AD), medical doctor of Nero's Army, says that Egyptians induced a sort of local anesthesia with this stone, ground to a powder and then applied to the affected area [2].

Pliny the Elder (23–79 AD) described a potion obtained with the magic stone and the vinegar [3]. This should have given off gas, which once inhaled would have decreased pain. In a paper published in 1932 on poisons used in Egypt, Baslez [4] has suggested that the potion with the magic stone, in contact with the flame, could release bituminous vapor capable of stunning the patient or that the mixture obtained was silica and opium based (called shepen).

Leca believes that the potion made from magical stone was known by the priests of Thot (the god who had the task of protecting the suffering humanity) and that they were the only ones who can sell it [5]. The magic stone, or any other mixture, was applied by the Egyptian doctors only from the fourth day after the onset of pain. In fact, Aristotle says that any treatment performed earlier would put at risk the doctor; it is however unclear whether the risk would be incurred only in the event of treatment failure [6].

In Ramesseum V Papyrus, 20 useful recipes for decontracting muscles and reducing joint stiffness and muscle spasms are given [5]. Animal fats were the essential basis of ointments to be applied on the sore joint. Among the recipes, the one with natron, beans, tun, white oil, hippopotamus, crocodile, fish fats t and hydrocarbons, turpentine resin, wax, frankincense, and honey was used for painful and stiff joints. Ingredients were cooked all together and spread over the bandages which were then applied to the painful area until symptoms remission.

The Ebers Papyrus [5] contains at least 60 paragraphs (n. 627–696) concerning the treatment of muscles, tendons,

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and ligaments diseases. The description of the medications, however, is not very precise. In Hearst papyrus [5], a potion made of elytra and beetles bodies was described; this medication, if applied on a sore joint, should have decreased shoulder pain and stiffness.

Unfortunately no paintings regarding medications on a nontraumatized shoulder were found; therefore, the one of the Upuy tomb (year 1200 BC), about a medical doctor who is probably going to reduce a dislocated shoulder, remains the only artistic Egyptian document known, and dear, to shoulder surgeons.

Greek, Etrurian and Roman Period

For Hippocrates (460–357 BC) (Fig. 1a), the concept of disease, hence of pain, arises from a humoral vision of health. In many treaties [7], “the father of medicine” states that the man is perfectly healthy when the four elements (blood, phlegm, yellow bile, and black bile; linked to the four bodily excretions: blood, phlegm (catarrh), urine, and feces) are in the correct mix of ratio, strength and quantity. Disease and pain occur when one of these principles is excessive or insufficient, or when one of the four elements, isolating itself

Fig. 1 (**a**) Fresco of the twelfth century, depicting Hippocrates and Galen. Cathedral of Anagni, near Rome. (**b**) The Asklepeion is an ancient medical centre placed in Kos Town. It dates from the first half of the 3rd century BC and it was built to honor the god of health and medicine, Asklepios, after the death of Hippocrates. The arrows show the remains of the Doric Temple of Asklepeion. Besides, the “abaton” the place where the sicks waited for Asklepios to appear in their dreams and heal them. (**c**) The square in front of the Temple where the sicks were praying

from the body, is not combined with everything else. The lack of balance between the various moods may be caused by "bad weather," such as external factors: nutrition, miasma, climate, meteorology, water, and winds. Hippocrates also admits a benign course of disease attributable to nature, which often acts to restore a proper balance between the elements. The four humors could be expurgated by nose, mouth, anus, and urinary tract. Furthermore, you could make out them through the bloodletting, to be practiced early in the disease course and to the vein closest to the pain. Willow leaves, medicinal substances commonly used by Hippocrates, had the task to soothe the pain.

The modern pharmacology has also found that these leaves contain acetylsalicylic acid as active ingredient. The various medicaments were given in the form of ointments, powders, pills, poultices, and patches. Some substances were given by inhalation, gargling, douching, or fumigation. However, it is very unlikely that shoulder pain caused by rotator cuff tear could be affected favorably by many of these treatments, commonly used by Hippocrates and his students with the aim of inducing evacuation and vomit in the patient (Fig. 1b, c).

A general guidance for pain is reported in the "Treatise on Diseases" [8]; it consists in hot water lotions applied on the sore area, fumigation and fasting. After the acute phase, the patient would have to ingest a purge and cooked donkey milk.

In a votive relief dedicated to Amphiaraus (350 BC) (Fig. 2a), the mythological God with healing powers, an example of the presence of a shoulder disease manually

Fig. 2 (**a**) Votive relief dedicated to Amphiaraus. (Anonymous c. 350 BC) National Archaeological Museum, Athens. (**b**) Votive relief with representation of "nekrodeipno" (banquet for the dead) and Cybele enthroned (Roman house, Kos)

treated, is shown. According to some interpretations [9], Alchino is represented in the right of the figure, entering the sanctuary. At the center, the same Alchino dreams Amphiaraus' snake sucking the moods collected in the sick right shoulder; and finally on the left, Amphiaraus – the bearded figure – manually concludes his work of healing. A votive relief of the same period depicting a snake biting a shoulder is kept at Kos (Greece) (Fig. 2b).

The information about how the Etrurians treated the painful joints comes from Greek and Roman texts. Unfortunately, there are no specific references on the treatment of shoulder pain; however, as for the Egyptians, it is supposed that the principles of treatment were common to all painful joints [10]. It is well known that Etrurian medical doctors suffered a strong influence by Greeks archiatri, who settled in Sicily, Asians, and Phoenicians [10a]. In fact, in some of the tombs, knives, pliers, explorers, and cauteries were found, attesting that Etrurian priests practiced the surgeon profession according to what it had been taught them by Greek colleagues. The effect of water had a high regard.

Horace says that he was invited by Antonio Musa, medical doctor to Emperor Augustus, to the Clusinae Fontes, an ancient Etruscan thermal centre near the current Chiusi (Tuscany) [11]. The water of this spring held many healing properties, especially, the one of "chasing away rheumatism from the bones" [10b, 11].

Theophrastus, Greek philosopher and botanist of the IV-III century BC, describes the skills of the Etruscans doctors in preparing potions and drugs [12]. Pliny mentions an ancient potion based on Myriophyllum (grass lawn) and pork fat that was used to treat diseases of animal and human tendons [10c, 13]. Finally, Marcus Terentius Varro a Roman writer of the first century AC, in "De Agricoltura," reports that on the Soratte mountain, near Rome, there was a college of Etrurians priests who owned the secrets for preparing substances able to remove pain [10c, 14]. Cato the Elder (243–146 BC), interested in medicine, treated pain with domestic remedies related, essentially, to the assumption of cabbage (used as a panacea for all the pain) and wine used as a vessel for the active substances [15].

Among the potions proposed by Cato, the one containing wine and juniper was used specifically to soothe joint pain [15].

Celsus (14 AC-37dC) in "De Re Medica" [16a] (Fig. 3a, b) does not recommend the use of cold to older people and to those who suffer scapular pain. In the Book 3 [16b], Celso provided some advice on how to manage tendon pain; the author suggests not to sweat but to drink water and get massaged. He also recommended to grease the painful part with nitro and water and submitted it to sulfur

Fig. 3 Aulus Cornelius Celsus' Portrait (**a**). Front page of "De Re Medica" in eight books, 1566 (**b**)

fumigations which would have been developed from sweet embers placed near the patient. To achieve an adequate benefit, the treatment would have been made to a fasting patient. Another ointment applied to the painful area was made up of equal parts of henbane seed and nettle (mixed with tallow?); water where sulfur had been previously boiled in was added. In Book 4 [16c], Celsus advised to apply heat on the painful but not swollen shoulder. In particular, during the night, heated poultices with malvavischio root boiled in wine were applied to the painful area. If the pain was particularly intense, poppy cortex mixed with wax and pork fat was boiled in wine. In Book 5 [16d], for the treatment of painful joint, the action of malagma was enhanced: potion of herbs and sprouts of sweet-smelling plants. The "Euticleo's" one was used specifically in tendon diseases. It was composed of soot incense, resin, galbanum, ammoniac gum, and bdellium. The soothing effect of these plants on the pain had already been described by Hippocrates (De victu in acutis) and Dioscorides [2]. The "Sosagora's" one was another malagma composed of various vegetable substances, poppy and molten lead [16]. An additional advice for the management of shoulder pain consisted of immersing into gritty bathrooms [17] and making use of suction cups [16]. The latter were applied on intact skin (to remove air) or scarified (to extract the blood) and exploited the principle of the "vacuum" created by the flame (Fig. 4).

Fig. 4 Drawings of bowls and cups corresponding to the description of Celsus, found at Pompeii and Herculaneum and conserved in R. Museum of Naples

Dioscorides (doctor of Greek culture-Anazarbo-Turkey – 25? AD) wrote, between 50 and 70 AD, the "De Materia Medica": it is a herbarium written in Greek language, destined to have an important influence on the medical literature [17] (Fig. 5a). The work was in fact translated and commented in many languages up to the seventeenth century. For joint pain, Dioscorides suggested to take a decoction made from "cucumer sylvestris" [18]. He also suggested the intake of decoctions made from "ferrule galbaniflua" (Fig. 5b), formerly used as a universal remedy for the treatment of ulcers, cough, seizures, fractures, headaches, stomach aches, menstrual cramps, sore teeth, snake bites, labor

Fig. 5 Antique miniature of Dioscorides (**a**) sitting on a bench. He is offering a student the mandrake. Drawing taken from "De Materia Medica" and representing the "ferrule galbaniflua" plant used by the author for the treatment of joint pain (**b**)

pains, indigestion, and flatulence. In chronic pain, he suggested to apply to the painful area heated goat dung, contained in an oiled cloth [2].

Among Roman physicians, Galen was the one who provided additional information on the genesis and the treatment of joint pain. He was born in Pergamum in 129 AC, the site where a temple and a medical school dedicated to Asclepius was located; he was able to improve his knowledge on orthopedic and trauma because it soon became the gladiator doctor of his city and because he had a passion for operative medicine which he practiced in public squares on pigs and monkeys. He moved to Rome, where he became a physician to Marcus Aurelius; he stated again the utility of bloodletting to relieve many pains (De Sanguinis Mission) [19]. Galen continued the Hippocratic concept of Nature medicatrix and argued that the doctor "is the minister of Nature" and should therefore follow primarily the criterion of "contraria contrariis," which consisted in applying, for example, the heat if the pain was caused by cold and vice versa cold if the painful area was hot. It is said that Galen used a potion called theriaca composed of various ingredients including: alcohol, opium, viper venom, and honey. This medicine, considered for many centuries as "panacea for all the illness," was also used for joint pain, especially in older people [20].

According to Galen (De ratione victus in acutis; De Elementis juxta sententiam Hippocratis) [19], pain was due to the philosophical "passion." Later he came to the conclusion that the only cause of pain was the "solution of continuity" (De simpl. Medic., Chap. 2 "Subacromial Space and Rotator Cuff Anatomy") [19].

Arabic Period

The Arabic medicine can be conventionally divided into a first period (between 750 and 900), where traditional medicine is gradually mixed with the Greek and Latin ones, and in a second one (between 900 and 1100) where many scholars detach from their teachers to take on an increasingly clear and independent personality, entirely directed toward new research and acquisitions. It is in this phase of maximum glory that personalities as Avicenna and Albucasi emerge.

In the "Canon," the "prince of medicine" (Avicenna 936? -993?) (Fig. 6) suggested to use several herbs as a base for analgesic infusions, including juniper, chamomile, marjoram, rue, lavandula, mandrake, and opium. His concept of pain follows the celsiano one regarding inflammation. It also argues that pain itself may be the disease and not the symptom. He actually distinguished 15 forms of pain (including the articular one) which he used to treat with exercise, heat (if the joint was not swollen and hot), or cold

Fig. 6 Image depicting Ibn Sina, or Avicenna, better known as "the prince of medicine." X-XI century

in the form of snow or ice water. The pain adverse to treatment with herbs and decoctions was treated with cauterization.

The Albucasi "Practice" (Al Tesrif) (Cordoba: 912? -1002?) (Fig. 7a, b) is considered a connection between the decadent Greek medicine and the Salerno and Bologna schools. With Albucasi, medicine surgery switches from empiricism to anatomical study and experience (experimental method). In the preface to the section on "Surgery" (Book XXX), the author states that "If you ignore the anatomy, you will fall into error" [21]. Joint pain, presumably shoulder pain too, was treated with cauterization; bloodletting, and cups or suction cups. In contrast to what practiced until then, Albucasi runs cauterization in every season and not only in spring. The iron cautere is preferred by the author with respect to the gold one because the latter cools immediately and melts when it is brought to high temperature. The bloodletting was practiced by Albucasi from five upper limb veins: cephalic, median basilica, cubital, and "Salvatella" (2 branches). He used the wide knife for the voluminous vessels containing dirty blood and the small one for smaller vessels containing tenuous and bilious blood. Albucasi also suggested to run bloodletting in spring and to a fasting patient; instead he discouraged it in children younger than 14 years, in the sixties, in tired, drunk, with indigestion, vomiting, and diarrhea patients. The amount of blood to be removed should be proportionate to patient forces. The cups used by Albucasi were made from horn, glass, copper, and wood. He used them with or without scarification, as Paul of Aegina did [21].

Constantine the African, Roger of Frugardo, Rolando from Parma, Lanfranc of Milan, Guido de Chauliac, and

Fig. 7 Albucasi (**a**), Arab physician, chemist, and scientist who lived between the tenth and eleventh century. Pages of the Kitab al-Tasrif (**b**), an encyclopedia of medicine and surgery written around 1000 by the author

Fabrizio "d'Acquapendente" were those who followed and put into practice Albucasi's teachings.

Byzantine Period

With the fall of the Western Roman Empire, in 476 AD, everything that was still "civil" emigrated to Bosphorus in Istanbul, due to the barbaric invasions. Thanks to its special geographical position, Roman/Latin knowledge joins the Greek, eastern, and African ones in this place. Constantinople (Istanbul) will be the center of medical culture until its fall, due to Turks, in 1453.

Medical doctors who distinguished themselves in this period were four: Oribasius of Pergamon, Aetius of Amida, Alessandro of Tralles, and Paul of Aegina. The latter was born in a Greek island near Athens in 620 AD (Fig. 8). We know about him that he was a pupil at the school of

Fig. 8 Paolo D'Aegina's effigy, taken from a version of author's works published in London in 1574

Alexandria and based his theories on the observation of the patients, the study of symptoms and the experience.

In Chapter XLI of Book VI of his "Memorial" [22–24], Paul describes the use of plastic cups for the treatment of painful areas. The clay cups were used, according to the author, to evacuate "moods." The evacuation must be carried out on intact skin (if the involved area was not meaty) and with scarification (if it was meaty). The clay cups were preferred to those made of glass or horn. Paul also described the size of the cup that had to be proportionate to the area to be treated. Clay cups with long neck and large cavities were preferred to the others [22–24].

Middle Ages and Renaissance

In Italy, after the barbarian invasions, a desolate atmosphere of decadence that involved all the arts was present. However, the ancient practice of caring for the sick continued in ecclesiastical institutions and convents. Several monasteries and convents were founded, thanks to Saint Benedict of Nursia, including the one of Monte Cassino, built on the motto "the care of the sick first and foremost." In an ancient parchment found at Monte Cassino, written by an unknown doctor, the first description of how to prepare a sedation (made of opium, mandrake and henbane juice) to get a deep sleep in case of surgery was found. "Mandrake" was one of the main ingredients for most mythological and legendary potions. The name, probably derived from the Persian (mehregiah), was assigned by Hippocrates. It was depicted in some texts on "alchemy" as a man or a child and was considered a creature belonging to both the plant and the animal kingdom such as the less known vegetable lamb of Tartary (a legendary plant whose fruits were sheep) (Fig. 9a, b).

Also in southern Italy, particularly in Salerno, some religious hospitals were born, including the one founded by the archdeacon Adelmo (820 AD) and that was built with incomes left by Matthew of Ajello (1183 AD), the grand chancellor of the emperor. The collection of these religious institutions created the preconditions for the emergence of a medical school that will be the prelude (to herald) to the establishment and the development of the university. According to the legend, the Salerno school was born from the meeting of four members, coming, respectively, from the Latin medical culture (Salernus), Jewish (Elinus), Greek (Pontus), and Arabic (Adelus) ones.

In a series of dictates concentrated in the "Regimen Sanitas Salerni" [25] (Fig. 10), which for two centuries have been the compendium of medical knowledge, medicinal herbs, such as nettle and penny royal, useful for the treatment of joint pain were described. In the therapeutic area, it was given much importance to the use of the "simple," as the growing of medicinal plants. Many convents were equipped with an infirmary and a garden of medicinal plants, which were then stored in the "armarium pigmentatorium" which, some years later, will become the pharmacy. Therefore, these places of prayer became the site where those more learned in medicine, the heirs of Hippocrates and Galen, met the poorer ones in order to treat both body and soul. However, if the intensity of joint pain was particularly intense, a sort of mandatory pathway which initially consisted of using spices and then bloodletting was performed. In fact, Musandinus (De Cibis et potibus aegrotantium) [26] proposed this treatment for almost all diseases in patients older than 15 years.

Gariopontus (? -1056) in the "Passionarius" [26] described the cauterization as a healing technique used by doctors of that time; Bruno Longoburgo in 1252 in the "Major surgery and minor surgery" gave the same description [27]. William from Saliceto in his work entitled "Cyrurgia (finished in 1268)" [28] first suggested to use the knife instead of the cautery.

Taddeo Alderotti (1215–1295), mentioned by Dante in Canto XII of "the Paradise," contributed to spread medicine teachings at the University of Bologna. In his "Consilia," he attributed to alcohol so high healing properties as to consider it a sort of Galenic "theriaca," a panacea for many aches. In fact, the original theriaca was alcohol based.

In the Middle Ages, cadaver dissections were criticized and limited because of religious and popular beliefs. During the period of the "Crusades," autopsies were only allowed to remove organs and to facilitate the transport of the dead to

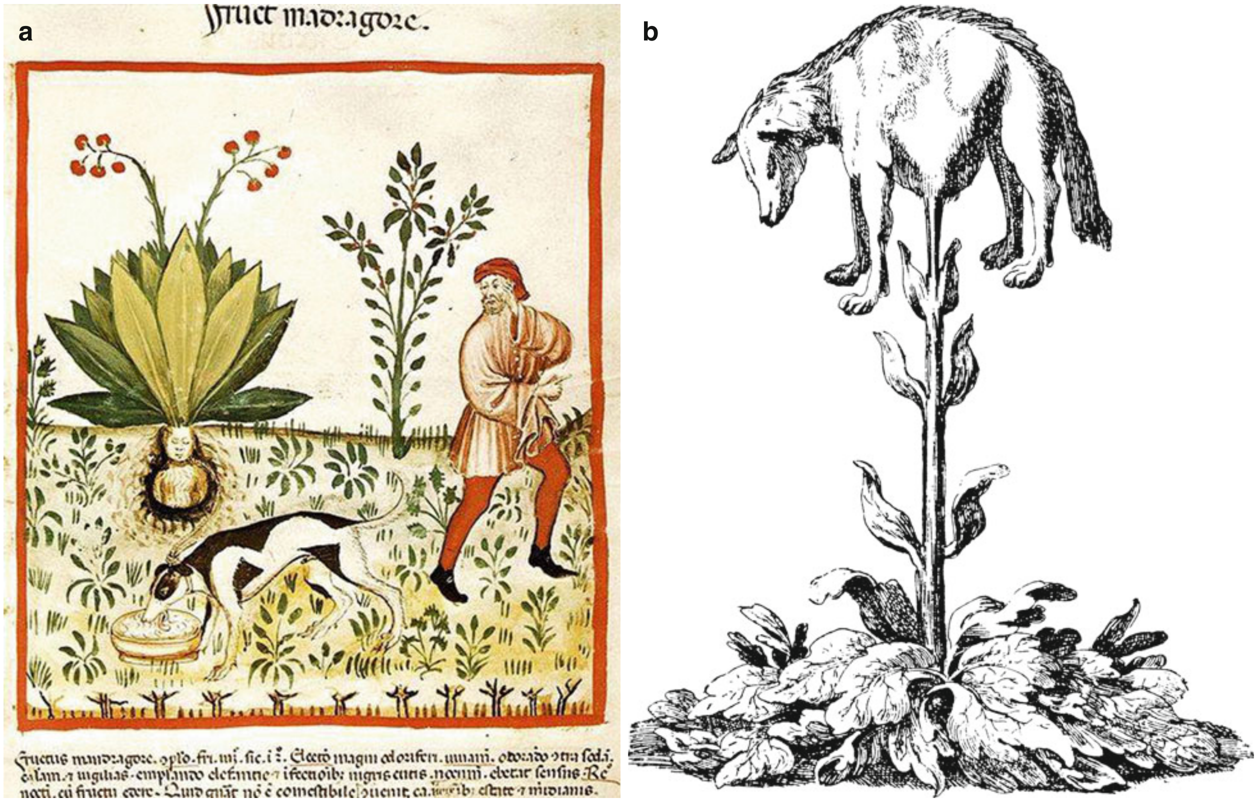

Fig. 9 Drawing made by Ibn Butlan (1390) depicting the Mandragora (**a**). The root of the plant had human form. The extirpation from the soil would have caused a deadly scream. Taken from "Tacuinum Sanitatis," Austrian National Library. The Vegetable Lamb of Tartary (**b**) in a picture taken from "The Vegetable Lamb of Tartary" by Lee H., London, 1887

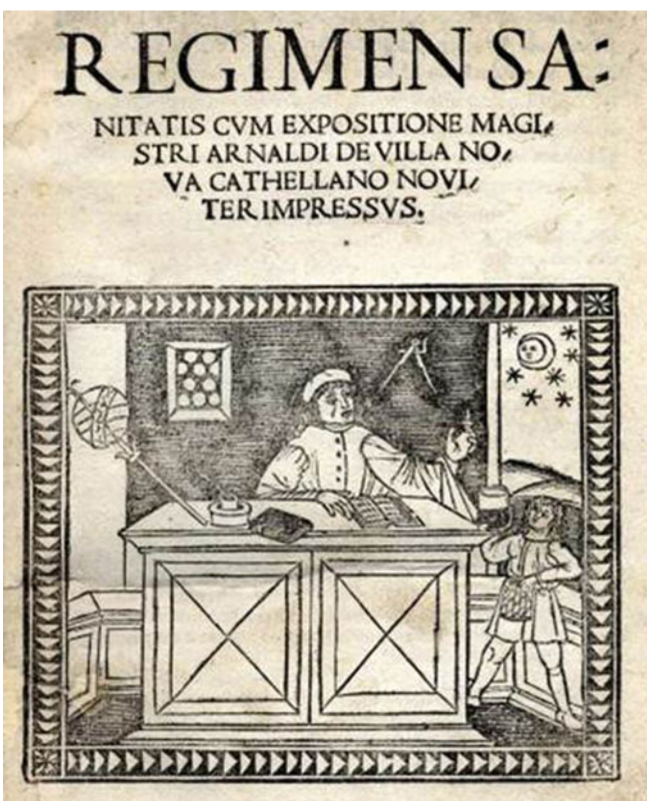

Fig. 10 Cover of "Regimen Sanitatis Salernitanum" (Rule Health Salerno) (1050) by Luigi Cornaro, Venice, 1662

homeland. The continuous relics and human bones trading forced Pope Boniface VIII in 1300 to promulgate the Papal Bull "De sepolturis," in order to prohibit manipulation of human bodies [29, 30]. This was in contrast with what Frederick II published in 1240, in an imperial decree, allowing the practice of dissection. The Popes, succeeded in that years, promulgated more bulls allowing dissection during Lent and on women, as they were considered soulless. The first official dissection in the Middle Ages was performed at the University of Bologna by Mondino de'Liucci (Sec. 1270–1326), author of "Anathomia Mundini" (Fig. 11). This book has been used to study anatomy for more than 200 years [31] even though it had no illustrative tables or figures. Guido da Vigevano (1280–1349), a Mondino pupil, continued the practice of cadaver dissections and his manuscript "Anathomia," published in 1345, is the first example of a text with anatomical illustrations. Guido da Vigevano's drawings, based on empirical observations [32], represented a guide to the anatomists of the Renaissance, a period in which the association between science and art reached the highest degree, especially in 1543, thanks to the work "de Humani Corporis Fabrica" of Andreas Vesalius [33]. Guido da Vigevano also wrote "Anatomy designated for figures" (1345), which included illustrations. In the second section of the book, he describes the veins used for bloodletting, a practice still used for persistent joint pain [30, 34].

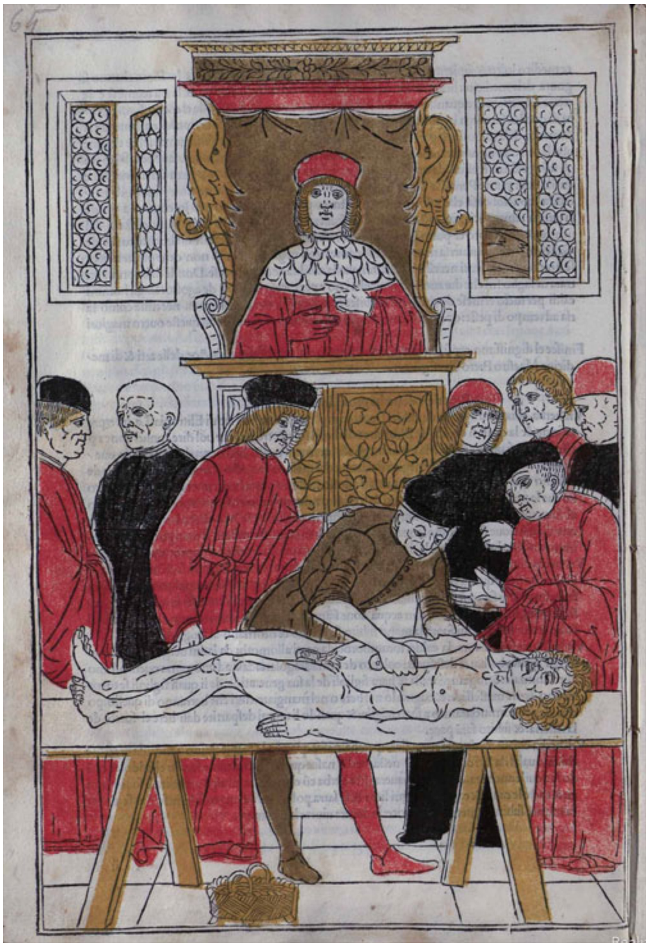

Fig. 11 Cover of Mondino de' Liuzzi's "Anathomia" (1316). In the image the author while seated is depicted as witnessing a dissection. The incision is part of the "fasciculus medicinae" (1493)

In 1491, a Latin text written by Juan de Cuba and entitled "Hortus Sanitatis" [35] was published (Fig. 12a). It is unclear whether the work is original or if it is the translation of an ancient herbarium of Greek origin. The text is composed of several chapters, one of which is dedicated to plant trade and their healing use. Although the text does not contain specific citations for the treatment of shoulder pain, there is a miniature depicting a doctor in the act of treating a shoulder (Fig. 12b).

In 1544, the "sienese Pietro Andrea Mattioli" (1501–1578) published the translation from the Greek of the "De Materia Medica" (1544), Dioscorides' famous herbarium, with the addition of his speeches, comments and new plants [18] (Fig. 13a, b). The author also describes the use of earthworms, cooked in oil and applied to the "suffering joint," as able to mitigate the pain [18].

In addition to bloodletting, herbs, or cauterization, it is deduced that shoulder pain, not caused by trauma, was managed with immobilization bandages. This concept has an indirect confirmation in a painting of "Priamo della Quercia," dated between 1432 and 1439 (Ospedale S. Maria della Scala, Siena), representing a suffering beggar with the left shoulder immobilized in a bandage. Another example is contained in a miniature of the Avicenna Canon of the fifteenth century (anonymous), which depicts a patient with an immobilized arm standing in front of a doctor (Fig. 14).

Seventeenth and Eighteenth Centuries

In a book published in 1657 entitled "De'joint and podagrici" [36], James Miccioni summarized those which were considered to be the two main causes of joint pain at the time: an excessive influx of moisture (dampness) into the joint (Galenic conception) and the confluence of moods in different areas far from their natural placing [36a] (Fig. 15). The text also refers to the thought of two prominent doctors in 1500: "Fernelio" and "Ludovico Mercato" (royal doctor of Federico II Catholic majesty). The first one believed that pain was due to the confluence in the joint of a white and slimy pituitary mood, usually expelled from the nose and bronchi. The latter agreed with the humoral theory of Hippocrates and Galen, according to the classical teachings. In the text, genetics as a possible cause of joint pain is also admitted [36a]. According to the author, the doctor is responsible for establishing pain causes, before performing any treatment on it [36b], since the same treatment could be both helpful and harmful to a joint. In particular, it was necessary to know if pain depended on the heat or cold or on a combination of the two cases. If it was caused by the heat, the doctor would have to observe or perceive "the mood" present in the joint (blood or bile) as he would have done if the cause was the cold; in this case "the mood" would have been represented by a pituitosa or malanconica substance. Much of the book is devoted to the preparation of decoctions which were spread on bandages, applied to the painful area. Among the ingredients mentioned for the preparation of these potions are vinegar and oil rose, egg whites, lentils, milk, saffron, bread crumbs, nuts, cypress, chamomile, and tobacco leaves. Also river frogs and earthworms, washed thoroughly in water and white wine, are suggested in some recipes (mentioned by Mattioli [18]). A method for the treatment of joint pain consisting in applying goat's milk on the painful area is also mentioned [36b]. Earthworms have been used for the treatment of joint pain also by Tarduccio Salvi. In "The Surgeon, Short Treaty" of 1642 [37] (p. 150) (Fig. 16), the

Fig. 12 Cover of "Hortus Sanitatis" (**a**) Juan De Cuba (Mainz, 1500), currently preserved at the Bayerische Staatsbibliothek. In the drawing (**b**) a doctor in the act of treating the shoulder of a patient is depicted. The original image was a woodcut in black and white that was colored after printing

author advised to boil a pound of worms, of olive oil, and white wine together until the complete consumption of wine. The concoction obtained was smeared (spread) on the sore place.

In the book, the beneficial effects on the painful joint of goat dung and oil, extracted from a herb called Arabic stigados, are also described (p. 147). Tarduccio Salvi revisited also the use of bloodletting (phlebotomy) whose purpose is to leak blood present in large amounts, to the point of collapse on the vessel wall, or in impure form, of cauterization, leeches, and suckers (Fig. 17a, b).

In a herbarium of the fifteenth century [38] written, or simply translated, by "Guillelmus De Seyton," the action of the afodilli and betonicha herbs for the sedation of tendon pain is explained; however, it can be deduced that these herbs have not been used for shoulder pain since the responsibility of the cuff tendons in the genesis of pain was unknown.

Surgical treatment for shoulder disorders was practiced often in barber shops. A confirmation comes from the works of the painter Gerrit Lundens (Amsterdam 1622–1683?). The Artist has repeatedly painted scenes representing shoulder surgery performed in dark and messy workshops. In at least three works, the unlucky patient is treated without anesthesia, with surgical access "a spallina" and without the most elementary cautions to avoid infections (Fig. 18a–c). It is not known why Lundens has shown the same scene in three different works; possibly, the painter himself had experienced such a painful procedure. In a print made by David Teniers the Younger in 1703, the same scene is present (Fig. 18d).

Fig. 13 Pietro Andrea Mattioli, an Italian physician and humanist of the sixteenth century (**a**). (**b**) Photo of (a version of) the "Commentarii in sex libros de Pedacii Dioscoridis Anazarbei Materia Medica" (Venice, 1565)

Fig. 14 Internal of a Hospital (detail) from the "Canon Medicinae" of Avicenna. Anonymous miniaturist from Ferrara of the fifteenth century. Laurentian Library, Florence

PREVIDENZA, E PROVIDENZA
De'
DOLORI ARTICOLARI,
E PODAGRICI.
OPERA DEL DOTTORE
GIACOMO MICCIONI
DA ANGHIARI.
Medico, Fisico, e Cittadin Perugino.
DEDICATA
All'Illustriss. & Eccellentiss. Signore
MARC' ANTONIO BORGHESE
PRINCIPE DI SVLMONA.
IN PERVGIA, Appresso Sebastiano Zecchini. 1657.
CON LICENZA DE' SVPERIORI.

Fig. 15 Cover of "Dé dolori articolari e podagrici" by Giacomo Miccioni (published 1657). The major causes of joint pain are described in the text

Once again, a supposed surgeon, or a barber, performs an operation on a shoulder. The surgical access is "superior" and the patient is in a sitting position which is the same as in Lundens paintings.

Modern History

It is not known who first used the term "rotator cuff." It is said instead that the anatomist surgeon of the "Hunterian Theatre" in London, John G Smith, first described in 1834 the damage to these tendons on the London Medical Gazette [39]. However, this statement does not seem to be true, because in a book entitled "A description of all bursal mucosa of the human body," written by A. Monro [40], the first iconography of a lesion of the supra- and infraspinatus is probably depicted (Fig. 19). This work was also cited in 1951 by Moseley [41] and in 1952 by Bonola, in his monograph entitled "Shoulder Periarthritis" [42]. It is likely that Smith was also the one who performed, in 1871, the autopsy to Charles Babbage, widely considered as the "father of the computer" [43].

Flower, in 1861, wrote that the rotator cuff tendon tear was not a rare occurrence [44].

Petersson, in a historical review [45], said that Jean Francois Jajavay [46] in 1867 was the first who observed an inflammation of the subacromial bursa in four cases, following a trauma (Fig. 20a). His observations were later resumed by Heineke in 1868 [47] and by Vogt in 1881 [48]. In 1869,

Fig. 16 Cover of Tarduccio Salvi's, "The Surgeon, Short Treaty" kept in the Abbey of St. Eutizio in Preci (Perugia) (edition of 1642)

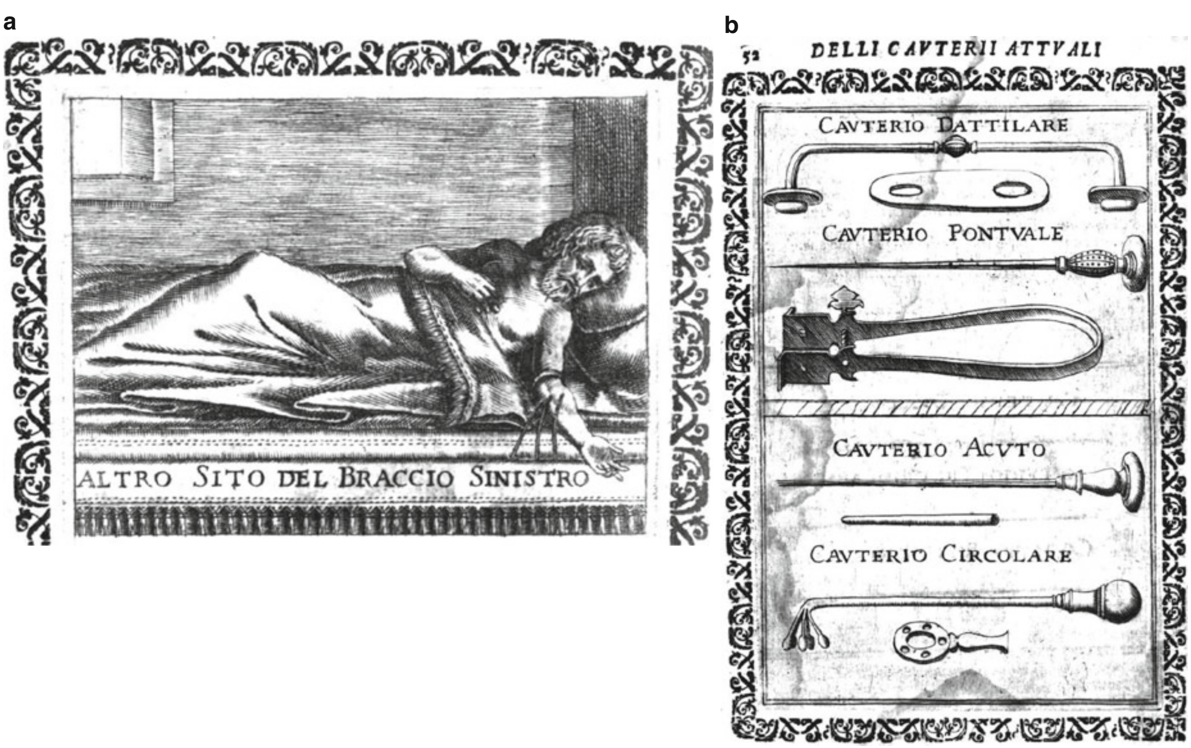

Fig. 17 Images from Tarduccio Salvi's "The Surgeon, Short Treaty" (edition of 1642), depicting veins phlebotomy of the left arm (**a**) and some cauteries that author used in surgical practice (**b**)

Fig. 18 Paintings of the mid-1600s performed by G. Lundens depicting the same surgical scene (**a–c**). Three patients are operated on the shoulder by a barber. In all cases, the surgical access is superior. Surgery is performed in a dirty and dark workshop and with no anesthesia. The same scene was painted by David Teniers the Younger in 1678 and engraved by Jacques Coelemans in 1703 (**d**)

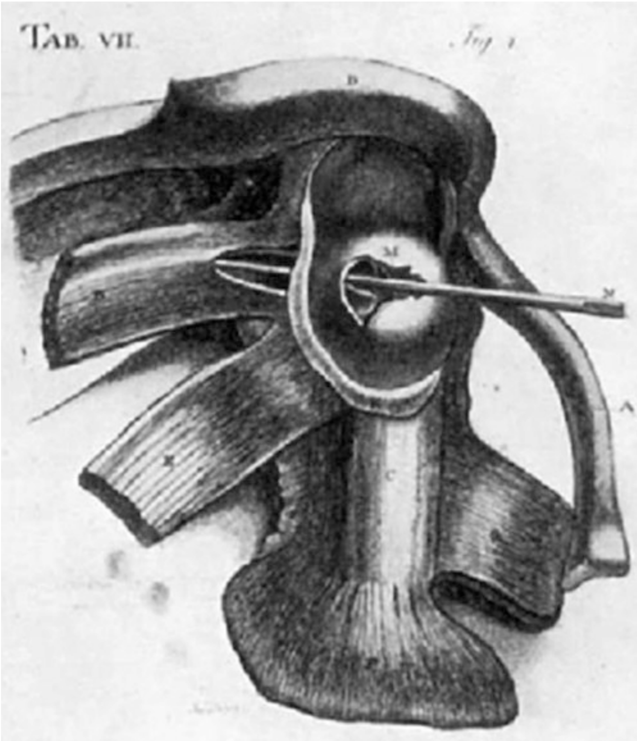

Fig. 19 First illustration of a rotator cuff tear (Taken from: Monro, "A description of all the bursae mucosae of the human body." Edinburgh, 1778) [41]. The tendon rupture is indicated by a probe

J. Ashurst in the book "Science and Art of Surgery" [49] described some cases of cuff tears caused by shoulder dislocations. Hüter, in 1870, quoted by Cramer, first resected the humerus head and replaced rotator cuff tendons to the proximal metaphysics [50]. It is instead due to Emmanuel Simon Duplay (Fig. 20b) in 1872, the classic description of the syndrome that will take his name (or scupular-humeral periarthritis) [51], characterized by shoulder stiffness and pain resulting from trauma. Duplay also has the merit of being the first to describe the function and pathology of the subacromial space – which he calls "second joint" to distinguish it from the "first" (glenohumeral joint)– of having showed macroscopic pathological anatomy in a deceased patient he treated; of having described the symptoms of other eight cases; and of having first attempted, successfully, joint mobilization under anesthesia [42]. He wrongly attributed the higher responsibility of the syndrome to the subacromial bursa whose removal was the basis for the evolution of the disease [45]. Duplay hypothesis found many supporters [52, 53], but also fierce detractors. Among them, Duronea, Desplats, and Pingaud labeled periarthritis as a rheumatic affection or as a neuritic pathology [54–56]. In 1873, Adams believed that the cause of rotator cuff tear was a rheumatic disease rather than a traumatic event [57]. Bardenheuer, in 1886, observed that rotator cuff tears could be repaired with

Fig. 20 Portrait of Jean Francois Jajavay (**a**), the first to observe an inflammation of the subacromial bursa (1967), and of Emmanuel Simon Duplay (**b**), who, in 1872, described the syndrome that would lead his name

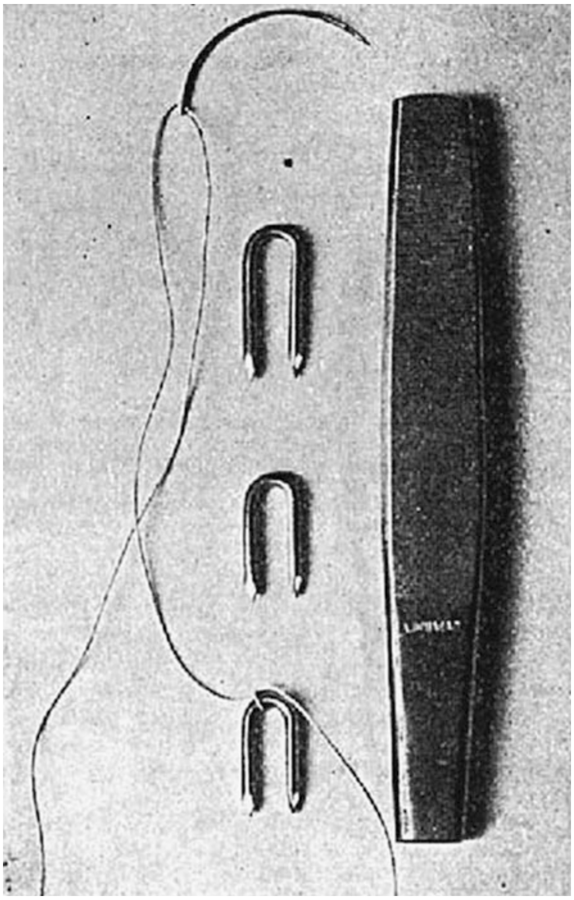

Fig. 21 Picture of 1906 taken from a Von Perthes' publication. Metal cambre with eyelet (prototypes of the current anchors) and catgut thread used in rotator cuff repairing

sutures [58]. Müller used catgut sutures to repair cuff tendons during an operation for shoulder instability [59]. In 1906, Von Perthes, professor at the University of Leipzig, repaired three cuff lesions using metal staples with a loop, in which a string of catgut passed [60]. These staples are considered ancient prototypes of the current suture anchors (Fig. 21).

The advent of X-rays allowed a greater knowledge of scapular-humeral periarthritis. It is due to the American painter, in 1907, the description of the first radio opaque shadows of the second joint of the shoulder which he interpreted as calcification of the subacromial bursa [61]. The same finding was subsequently observed by Stieda, who gave a similar interpretation [62]. The presence of calcium led to coin the term "borsite calcarea sottoacromiale" or "Subdeltoid" or "bursolite" [63, 64]. Moscowitz Wrede, in 1912 and later in 1915, shifted the attention from the subacromial bursa to the supraspinatus tendon identifying it as the site of periarthritis origin [65, 66]. After viewing X-rays and having directly observed the case of an operated patient, Wrede realized that the calcific deposit was in the

Fig. 22 Photo of Ernest Amory Codman, the "Father of shoulder modern surgery"

context of the supraspinatus tendon and not in the subacromial bursa [65].

Over time, more and more shoulder diseases were distinct from periarthritis. Sievers [67]` described cases of acromioclavicular joint arthropathy responsible for symptoms similar to those of periarthritis. Bettman, Meyer, and Kessler observed deformed bicipital grooves able to determine changes on the biceps long head [68, 69]. Goldthwait identified in the acromion shape and length, in the coracoid process, and in the arthrosic acromioclavicular articulation possible causes of rotator cuff tear [70]. In 1909, Stevens described the biomechanics of rotator cuff and how alterations of the force pairs could be responsible for subacromial pain [71].

The title of "Father of modern surgery of the shoulder" is universally attributed to E Amory Codman (1868–1940) (Fig. 22). In 1934, Codman published the first monograph entirely dedicated to the shoulder ("The Shoulder") [72] whose fifth chapter is dedicated to supraspinatus tear (Fig. 23a). The text is full of information, innovative for its time, and still current today. Codman describes two cases operated in 1909 and 1911 for a massive tear of the posterosuperior rotator cuff. In both cases, the author performed a partial repair, reinserting the anterior and posterior edges to the greater tuberosity. After few months, the two patients were able to reperform the abduction movement. Codman regret consisted of not having been able to observe the lesion at its beginning as early treatment would allow a complete repair and the complete recovery of shoulder function. The author also provides information on cuff tears etiology, which is visible in elderly patients and in those who perform heavy work, and on the clinic examination, giving to the tendon tear the responsibility of limiting the elevation and the abduction of the arm. Codman also reports that cuff lesion is not appreciable radiographically and that, in some subjects, it is possible to touch it by

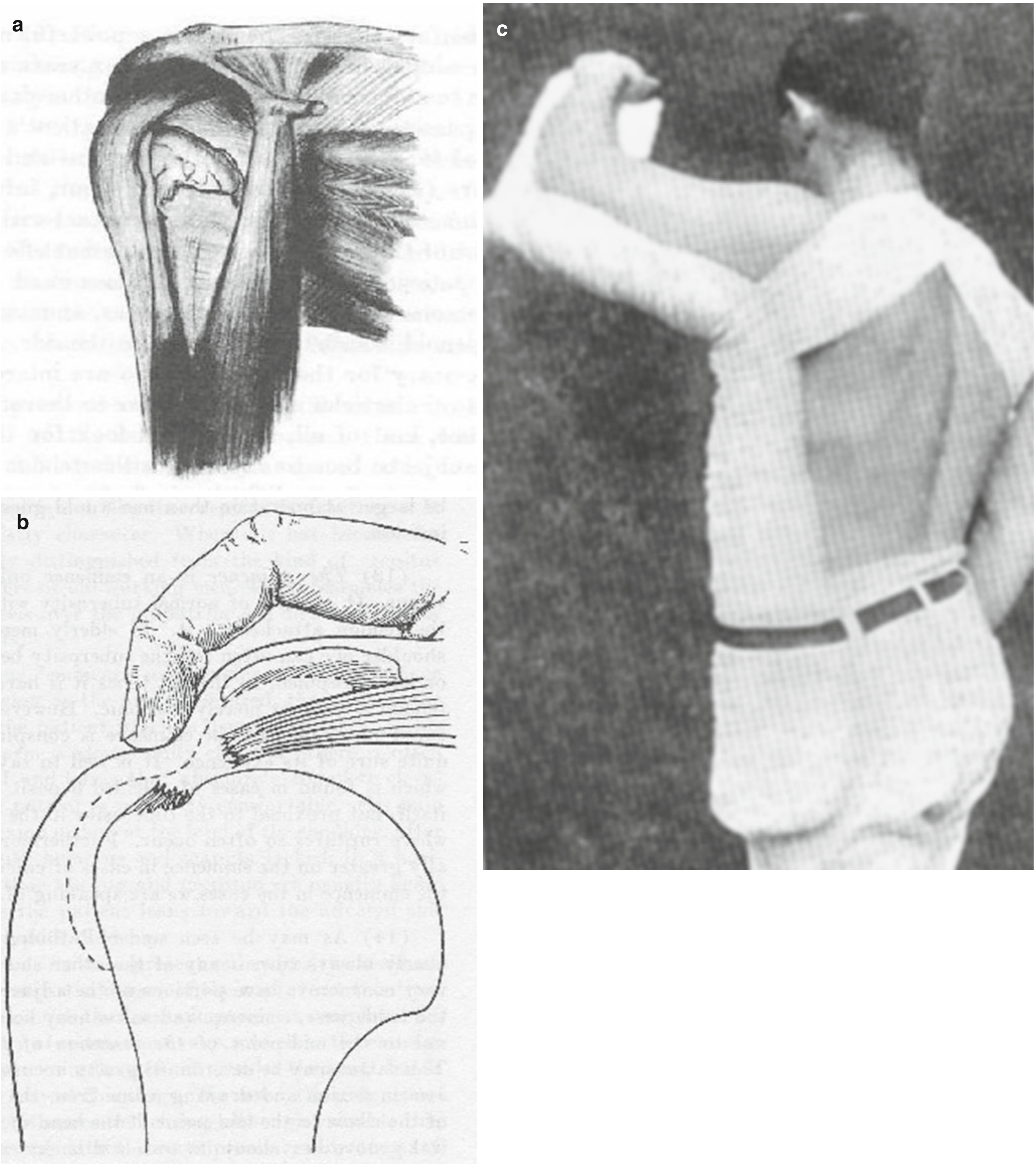

Fig. 23 Images taken from "The shoulder," monograph by EA. Codman (Boston, 1934) [73]. Tendon tear of the supraspinous muscle (**a**). Palpation of cuff tear by placing the index finger below the anterolateral margin of the acromion (**b**). Sling which kept the arm in abduction to be used in partial cuff tears (**c**)

placing the index finger below the anterolateral margin of the acromion (Fig. 23b). In 1908, he also described a special sling, which kept the arm in abduction, to be used in partial cuff tears [73] (Fig. 23c).

In 1937, Codman published in the *Journal of Bone and Joint Surgery* [74] a comment on the article written by Smith in 1835 on 7 shoulders (5 patients) with rotator cuff tear (3 females – 2 males, mean age 41 years). Three of the seven cases involved the subscapularis tendon too; two also had a rupture of the long head of the biceps; a patient had an os acromiale. On the basis of these seven cases and his personal experience, Codman drew other innovative conclusions for its time: cuff tear is much more frequent than it was considered until that moment (7 cases out of 40 dissections performed by the author −17 %-); the lesion may be caused by physical stress or trauma; it may be bilateral; the margins (edges) of the lesion may retract over time; and the lesion may be associated with rupture or dislocation of biceps' long head.

The nontraumatic origin of the lesion was expressed also by Wilson in 1931 [75].

In the article, Codman provides indication for surgical injuries to tendon tears large enough to put the subacromial bursa in communication with the joint, and he recommends young surgeons to become skilled in rotator cuff tear repairing during anatomical dissections.

An important contribution for preoperative diagnosis of cuff tears was given by Oberholzer in 1933 with the first shoulder arthrography placing air as a contrast (medium) [76]; Lindblon and Palmer in 1939 conceived the radio opaque contrast arthrography [77]. These authors described two stages of cuff tear: the tendon thinning (with possible partial tear) and the full-thickness tears [77].

In the next two decades, the focus shifted to the possible role of the anterior inferior margin of the acromion in the genesis of the rupture of the rotator cuff. These are the years in which legendary shoulder surgeons – as Armstrong [78], Hammond [79, 80], Lippmann [81], McLaughlin [82], Moseley [83], Smith- Petersen [84], Watson-Jones [85] – profoundly change the therapeutic approach to shoulder pain, recommending the total or partial removal of the acromion.

In 1952, in Italy, Robecchi published a monograph entitled "Shoulder periarthritis" [86]. The author believed that more than one anatomical structure of the subacromial space could be involved by the disease, so admitting that pathology (illness) could spread from one tissue to another. Robecchi also stated that the origin of periarthritis should have occurred in the supraspinatus tendon due to biomechanical reasons and for its lack of vascular supply. In the text, the author lists all the treatments used for periarthritis from the time Duplay gave its definition until the publication of the work. "Piramidone" (2–3 g per day); histamine iontophoresis; application of ointments made of tetrahydrofurfuryl ester of nicotinic acid; physical care (mud baths, diathermy [87, 88], mobilization, and massage therapy, röntegenterapia [89]); and infiltration with novocaine [90], nicotinic acid, benzilimidazolina, or hydrocortisone are mentioned. Surgery should instead be reserved for those who did not respond to conservative treatment, with the aim to remove any adhesions or calcifications [91–94]. In 1972, Charles Neer identified in the impingement between acromion and rotator cuff the pathogenic mechanism of the degeneration of cuff bursal side [95] (Fig. 24). In 1983, the same author completed the physiopathology of the syndrome distinguishing three stages: I characterized by edema and hemorrhage, II by fibrosis and inflammation, and III by tendon tear associated with acromial spurs [96].

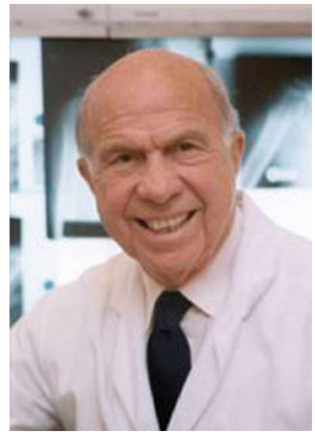

Fig. 24 Photo of Charles Neer, who first considered the impingement, due to the antero-inferior margin of the acromion, as the cause of rotator cuff tendon degeneration

The years following Neer's intuitions are part of the most recent modern history. The work written by Bigliani et al. [97], his pupil, on the morphology of the acromion and the possible role in the genesis of the syndrome hooked acromion friction, has been quoted in countless studies on the rotator cuff of the last two decades. Charles Rockwood and Joseph Iannotti have been aware (frame) of rotator cuff tear etiology and treatment, thanks to their beautiful monographs devoted to shoulder pathology [98, 99]. Snyder's monographs [100], Gartsman's [101], and Burkhart's [102] have been a guide for many young colleagues in the arthroscopic treatment of cuff tear. Michael Wirth, Tony Romeo, and Jeffrey Abrams, of which I am honored to be a friend, are just some of the names of fellow students of shoulder pathology that have not only enriched my knowledge on rotator cuff diseases with their insights and surgical skills, but also that of many colleagues who, like me, share the passion for this field of orthopedic surgery.

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Subacromial Space and Rotator Cuff Anatomy

Stefano Gumina

Subacromial Space

This is the space delimited above by the coracoacromial arc (anterior-inferior margin of the acromion, coracoacromial ligament, apex and distal third of the posterior surface of the coracoid) and below by the humeral head, by the tendons of the rotator cuff and of the long head of the biceps (Fig. 1a, b). The area between the tendons of the supraspinatus and the subscapularis is called the rotator interval.

Coracoacromial Arc

Acromion

The acromion is flat in shape and extends laterally, then antero-laterally. We distinguish an upper surface, in close contact with the skin, bearing rough scores and vascular orifices; an inferior concavity, which forms the tip of the glenohumeral joint; a lateral margin, the bundles from which the deltoid muscle originates; and a medial margin where the surface of the acromioclavicular joint is.

In the last 30 years, the shape of the acromion has been the object/topic of several studies because it was considered the cause predisposing aliments such as subacromial impingement and rotator cuff tendon tears [1]. In an anatomical study, Bigliani et al. [2] have classified the acromion as types I, II, and III based on the orientation and shape of their lower surface and identified the type likely to cause a reduction in the anatomical space between the acromion and the humeral head. According to this classification, the lower surface of the type I acromion is flat (flat acromion), while in the II and III acromion type it is curvilinear (curved acromion) and hooked (hooked acromion), respectively (Fig. 2a–c). Shoulders with a type III acromion are more prone to have a narrow subacromial space. Other studies have confirmed the correlation between subacromial impingement and rotator cuff tear [3–5].

In a study of ours, during which we examined 500 dry scapulae belonging to Caucasians, we evaluated the shape (on the basis of the Bigliani's classification) [2] and some morphometric features of the acromion. The shape of the acromia was flat in 38.9 %, curvilineous in 39.4 %, and hooked in 21.7 % of the scapulae examined. The percentage of hooked acromia was higher in the scapulae of those aged over 60 (26 %); thus, the hook-shaped acromion is currently considered as being acquired (ossification of the coracoacromial ligament) and not as something that is genetically determined. This observation seems to be confirmed by the studies of Natsis et al. [7] and Schippinger et al. [8]. Other kinds of acromion recently described are the type IV (convex) [9] and the chiglia-like [10]. In an anatomical study, Zuckerman et al. [11] have not been able to identify the three types of acromion described by Bigliani. The authors concluded that the correlation between type of acromion and cuff tear is not clear and further studies are needed to support the role of extrinsic factors in the genesis of cuff tear [11]. Chang et al. [12], after having performed a three-dimensional analysis of the acromion with MRI, came to the conclusion that impingements of any kind caused by the acromion are not the primary cause of cuff tendon rupture.

In our study [6], the average thickness of the acromion was 8.5 mm; in addition, there was a direct linear correlation with the size of the scapula [6]. The acromia of the scapulae as well as the type III acromion belonging to male subjects were significantly thicker than those of females. The torsion angle of the acromion is between 0° and 40° and that of inclination between 20° and 70° [13].

In another study, we conducted on 200 dry scapulae [13], the acromia were distinguished on the basis of Edelson's classification [14] that differentiates them according to the position of the articular facet with respect to the acromioclavicular joint tip. In 33 % of the acromia, the facet of the acromioclavicular joint was at a distance from the apex of

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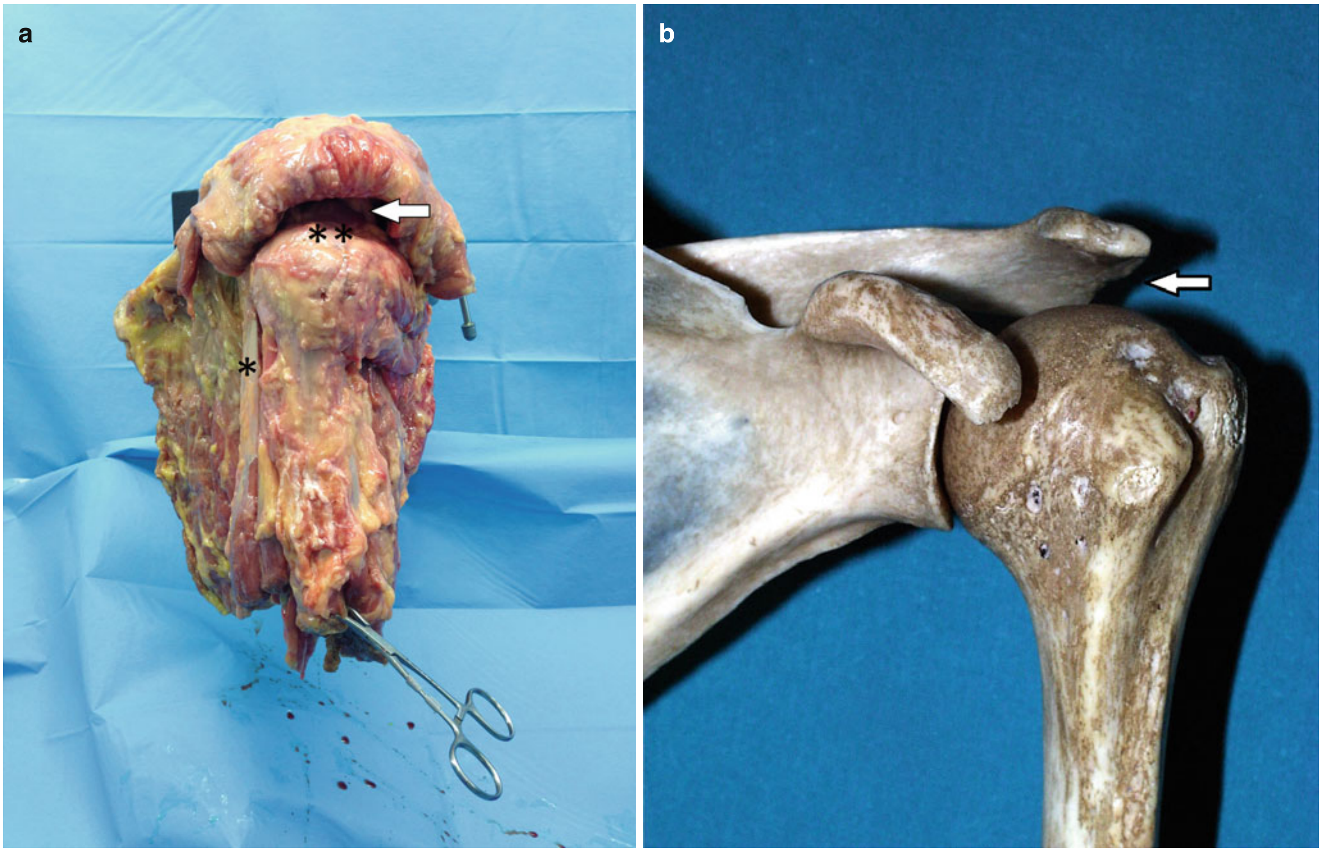


Fig. 1 Lateral (**a**) and anterior (**b**) view of a left shoulder. The *arrows* indicate the subacromial space. * The long head biceps tendon. ** Rotator cuff

the acromion (type “cobra head acromion”), 22 % were on the apex (type “squared acromion”), and 45 % in an intermediate position (such as “intermediate acromion”) (Fig 3a–c). The average length of the scapular facet of the acromioclavicular joint was 12.7 mm (range: 8–22 mm). Two forms of facet were identified: one to “drop” (31 %) and “elliptical” (69 %). The “drop” type belonged to elderly subjects, and the edge of the veneer often presented degenerative changes. No dependency between the form and the spatial arrangement of the facet was discovered/found.

The lack of fusion of one or more growth centers located in the apex of the acromion (os acromialis) occurs in about 8 % of scapulae (Fig. 4) [15]. When the unfused core is found at the apex of the acromion, it is defined as preacromion; instead, when it is found more distally, it is named, respectively, mesacromion, metacromion, and basiacromion [16]. The correlation between os acromialis and subacromial impingement is still a matter of discussion [17–19]. A study of ours has shown that the longer the distance between the acromioclavicular joint and the apex of the acromion, the higher the possibility that fusion of the growth nuclei will not occur [20].

Baechler and Kim [21] have observed that there is a relationship between the degree of humeral coverage by the lateral margin of the acromion and rupture of the rotator cuff. This association is thought to be due to the friction that is likely to occur during abduction. Nyffeler et al. [22] consider that the sum of the forces brought to bear in flexion/abduction favors humeral proximal migration in cases of greater degrees of acromial coverage. Torrens et al. [23] observed that the prevalence of acromia with higher degrees of humeral coverage was greater in patients with cuff tears than in those belonging to the control group.

Coracoacromial Ligament (CAL)

It is located between the base of the coracoid and the inferomedial surface of the acromion (Fig. 5). It fits on top of the acromion, right in front of the acromioclavicular joint’s surface, and along the entire lateral section of the coracoid. An artery (a branch of the suprascapular) is constantly present on the posterior surface of the ligament. Macroscopically, it presents no homogeneous morphological characteristics.

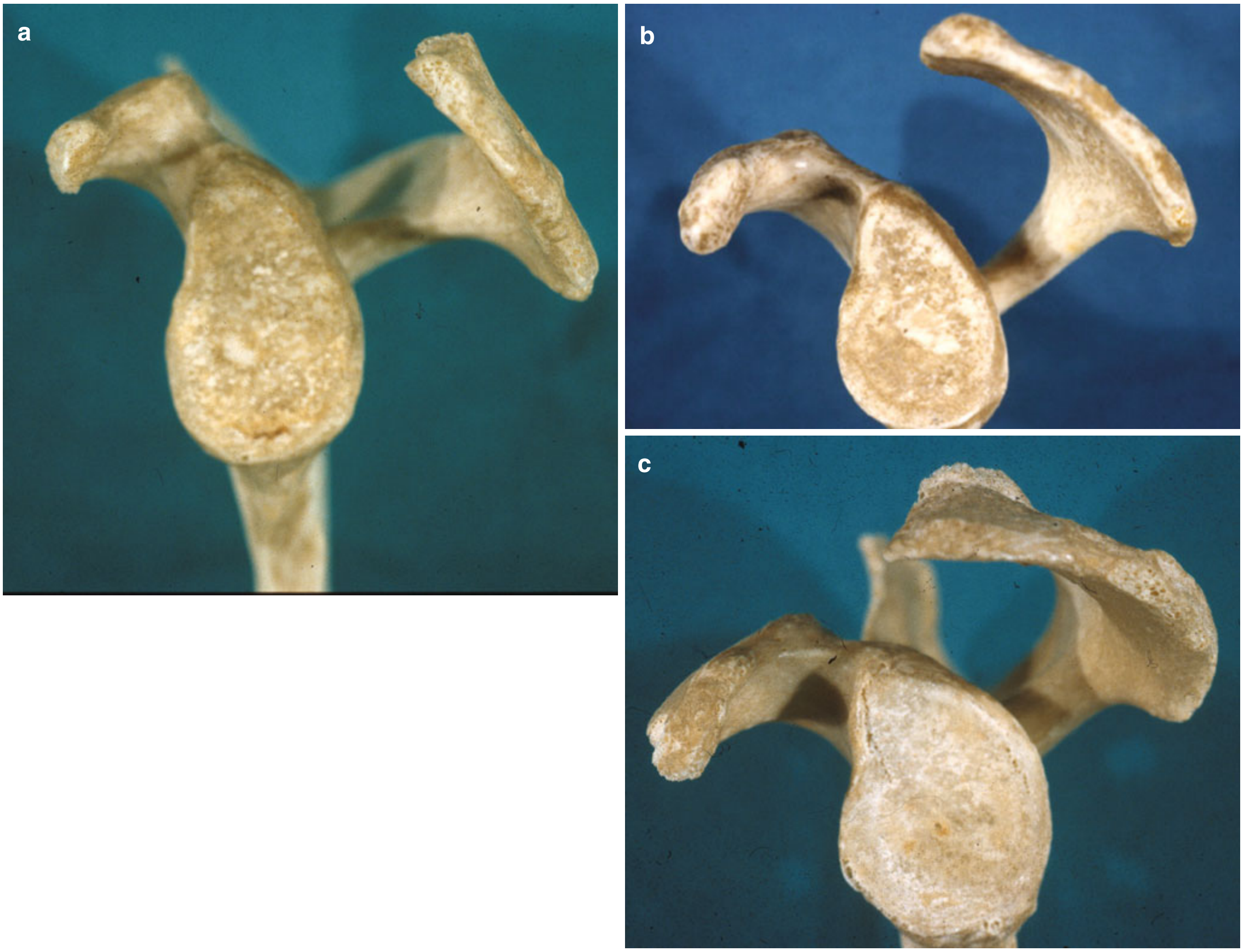


Fig. 2 (**a**) Type I (flat) acromion; (**b**) Type II (curved) acromion; (**c**) Type III (hooked) acromion

An anatomic study revealed that 60 % of the shoulders had a bipartite coracoacromial ligament, a single ligament in 25 % and tripartite in 15 % of the cases [24]. In the latter case, the coracoid insertion of the third band was more medial and may not be visible until a resection of the lateral third of the clavicle is performed. Kesmezacar et al. [25] argued that there are five possible anatomical variants of the CAL (type I: Y-shape, type II: single broadband, type III: quadrangular, type IV: V-shape, and type V: multiband). The Y-shape inserts itself in a unique manner into the acromion. The two bands of the "Y," which are inserted on the coracoid, are separated by a thin membrane. Of the two bands, one side is thicker and wider. The width of the two insertions of the single broadband variation (type II) is similar [26]. The ligament maintains its width along its entire extension. In type III, the width of the insertion on the coracoid is wider than that of type II. Type IV differs from type I because of the two arms that appear to be separate after the acromial insertion. Even in this case, the side of the higher band is thicker and wider. Type V does not present homogeneous morphological features. Of all the variants, the most common type is the "Y" (41 %), the rarest are types IV and V (both 11 %). For the authors, none of the variants predisposes rupture of the cuff more than the others. However, CALs with the greatest number of bands seem to have a significant association with the degeneration of the cuff. Kopuz et al. [27] conducted an anatomical study on neonatal CALs and observed that the variants at birth are simply three: square, single broadband, and "U." This observation suggests that the final shape of the ligament is acquired over time. In rare cases, where the pectoralis minor muscle inserts on the capsule of the glenohumeral joint rather than on the coracoid, the tendon passes through the bands of the CAL [28].

In an anatomical study, Fremery et al. [29] observed that shoulders with cuff tears have CAL bands shorter compared to those without tendon rupture and that the CAL changes its morphological and biomechanical features over time. The

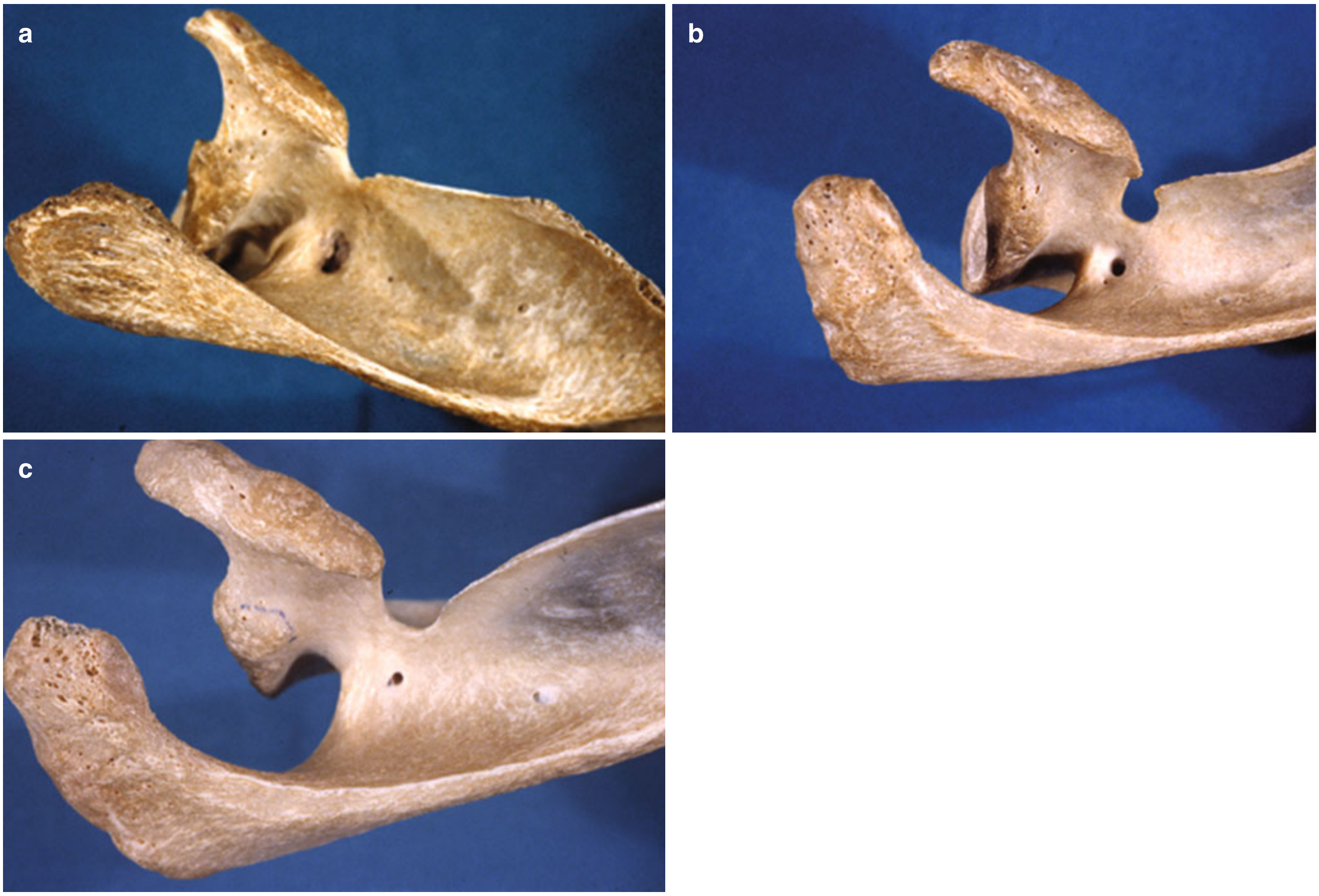


Fig. 3 (**a**) Cobra-head acromion; (**b**) squared acromion; (**c**) intermediate acromion

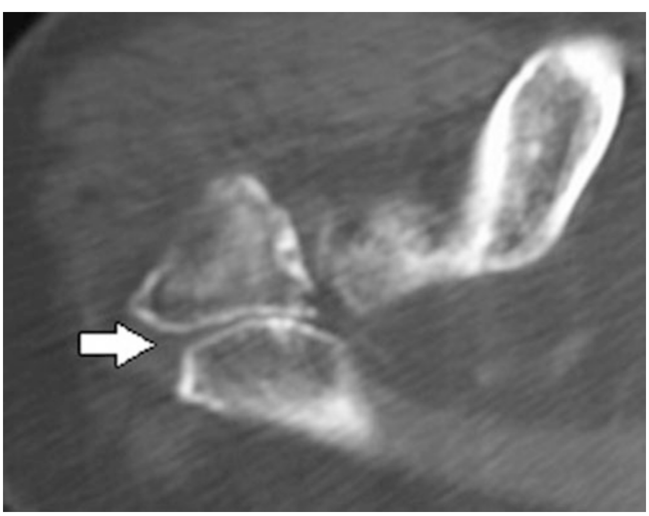


Fig. 4 MR scan of a left shoulder. Axial view. The *arrow* indicates the os acromialis

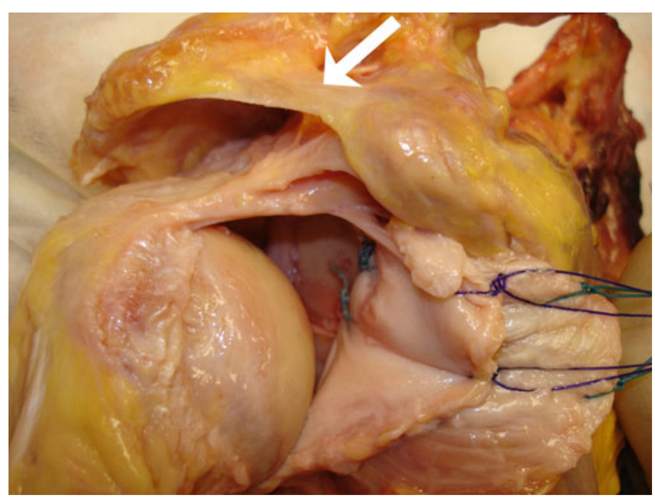


Fig. 5 Cadaveric right shoulder. The *arrow* indicates the coracoacromial ligament

insertional areas are constituted by fibrocartilage [30]. With aging, the fibrocartilage is also present in the middle portion of the ligament [30].

It was observed [31] that the CAL contains four types of nerve endings: free, Pacinian corpuscles, and Ruffini and Golgi receptors. In addition to these typical endings, other "atypical" ones were observed. All these endings are equally distributed on the surface of the subacromial side of the ligament and in correspondence with the acromial and coracoid insertion [30, 31]. The number of nerve endings decreases in older subjects and in those with subacromial impingement. This observation suggests that in these two categories of persons, the proprioceptive activity of the shoulder is reduced.

With aging, the portion of the ligament that fits onto the acromion may experience ossification (enthesopathy) [30]. The new bone can modify the profile of the antero-inferior acromion, increasing the downward curvature. This explains why the percentage of the hooked acromion increases with aging. In the case of two-part ligament (anterolateral and posteromedial band), spur formations occur predominantly on the anterolateral band [32]. This has led to the hypothesis that of the two bands, the anterolateral is that subjected to greater functional stresses [32]. Ogata and Uhthoff [33] argued that the development of enthesopathy is the result of the transmission of tensile forces within the ligament and that the formation of this spur determines transition from a dysfunctional syndrome to an organic stenosis. Kijima et al. [34] observed that the modulus of elasticity of the CAL of patients with cuff tear is higher than that recorded in the ligaments of subjects without tendon rupture. This shows that physiological tissue degeneration causes progressive rigidity of the ligament. Even Sarkar [35] and Schiavone-Panni [36] observed that tissue disorganization and loss of normal orientation of the collagen fibers is more common in the CAL of patients with subacromial impingement, especially in the deep layer of the ligament.

The CAL is perhaps the only ligament subtended between two transverse processes belonging to the same bone. It has been speculated that this reduces the movement which both the acromion and the coracoid face during the action, respectively, of the deltoid and the conjoint tendons/pectoralis minor [37]. The CAL opposes the upward migration of the humeral head in the case of massive cuff tears [38, 39]. In a study of cadavers, Fagelman et al. [40] have shown that reinsertion of the CAL prevents upper static instability and contributes to refocusing the humeral head inside the coracoacromial arch.

Coracoid

Anteriorly to the glenoid and laterally to the scapular notch, there is an apophysis that due to its shape, like a crow's beak, was formerly called coracoid (χ ο ρ α ξ = *chorax* = crow).

The coracoid apophysis originates from the anterior-upper extremity of the neck of the scapula and protrudes at first upwards and forward from the side and subsequently arranges itself almost horizontally. The conjoint tendons (short head of the biceps and coracobrachialis) fit onto the anterior apex of the coracoid; further back and laterally onto the coracohumeral and the coracoacromial ligament; medially, onto the tendon of the pectoralis minor muscle (Fig. 6a); and superiorly, onto a rough surface, the coracoclavicular ligaments (conoid and trapezoid) (Fig. 6b).

In a study conducted on 204 dry blades [41], we carried out measurements of the length of the coracoid (L) and the thickness of the coracoid tip (T), the apex of the coracoid prominence over the glenoid plane (cp), the minimum distance between the coracoid tip and the anterior-superior margin of the glenoid (cgd), the distance between the horizontal plane, tangential to the lower edge of the coracoid tip, and the horizontal plane tangential to the cranial glenoid (d). The inclination of the coracoid (cs) (Fig. 7a, b), in the cranial-caudal direction, was measured using Edelson and Taitz's method [14]. Then, we analyzed the shape of the space delimited by the posterolateral margin of the coracoid and the anterior-superior edge of the glenoid.

The range, the mean, and the standard deviation of *L*, *T*, cp, cs, cgd, and *d* were:

	L (mm)	*T* (mm)	cp (mm)	cgd (mm)	cs (°)	*d* (mm)
Max	50	10.2	22	22.1	42	12
Min	31	5	11	11.8	19	0.5
Mean	38.15	7.19	14.62	16.23	25.57	7.11
SD	3.97	1.04	1.96	1.7	4.71	1.23

Three types of configuration of the coraco-glenoid space were identified (Fig. 8a–c). In the type I configuration, this space had a " round parenthesis" shape, while in type II and III, respectively, the shape was that of a " bracket" and a "hook." The configuration of type I was observed in 45 % of the shoulder blades and type II and III in 34 % and 21 %, respectively. The minimum coraco-glenoid distance was found in the shoulder blades with a type I configuration. In a study of cadavers, Ferreira Neto et al. [42] observed that in females the distance between the apex of the coracoid and lesser tuberosity is lower than that measured in males. Therefore, women appear to be more likely to develop a syndrome of subcoracoid impingement. Richards et al. [43], availing of MRI scans, measured the coracohumeral distance and observed that patients with a lesion of the subscapularis present a significantly smaller distance than the people in the control group. The possible morphological and morphometric correlation between the coracoid and the subcoracoid impingement was challenged instead by Radas and Pieper [44] who correlate the development of this syndrome to anterior glenohumeral joint instability.

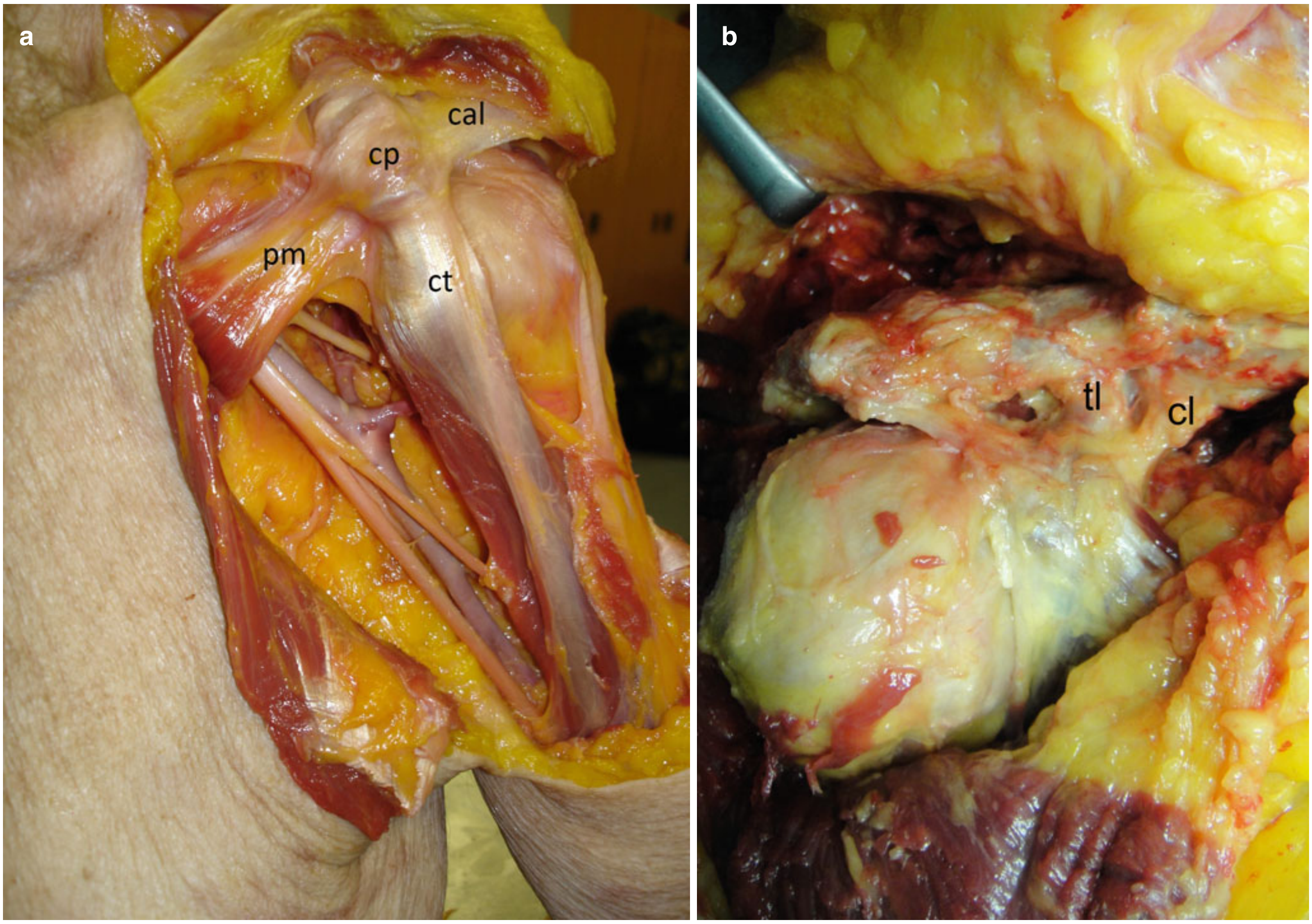


Fig. 6 (**a**) *Left* shoulder of a cadaver. *cp* coracoid process, *pm* pectoralis minor, *ct* conjoint tendons, *cal* coracoacromial ligament. (**b**) *Right* shoulder: *cl* conoid ligament, *tl* trapezoid ligament

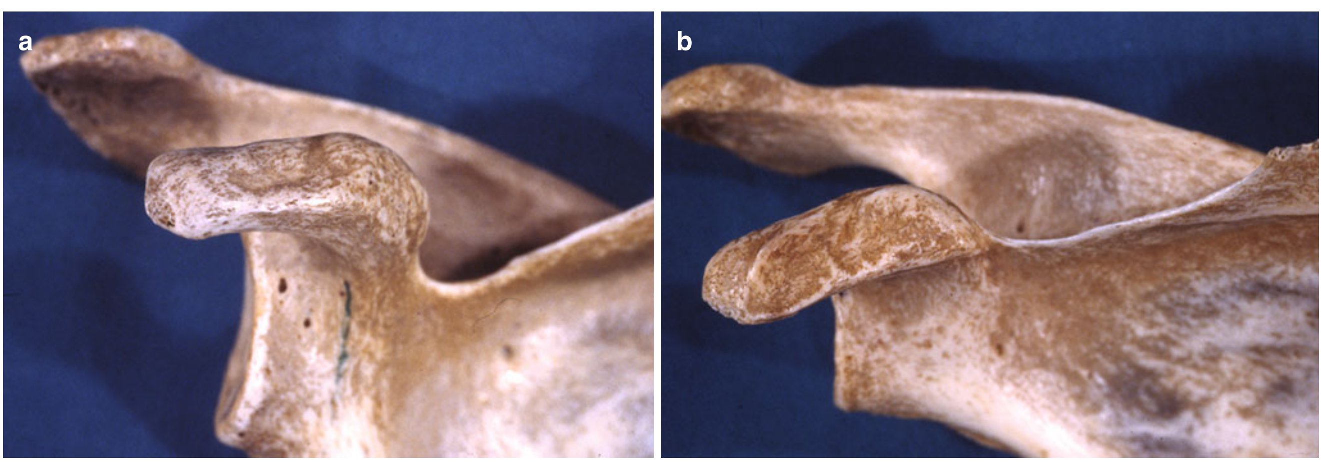


Fig. 7 (**a**, **b**) Coracoid processes (right samples) with different inclination

Schulz et al. [45] correlated the position of the apex coracoid to rupture of the rotator cuff. Employing true anteroposterior radiographs, the authors divided coracoids into two classes: those whose apex is projected into the lower half of the glenoid (type I) and those which project their peak into the mid-upper glenoid (type II). The study found that type I coracoids are more frequently found in patients with rupture of the supraspinatus, while those of type II are more

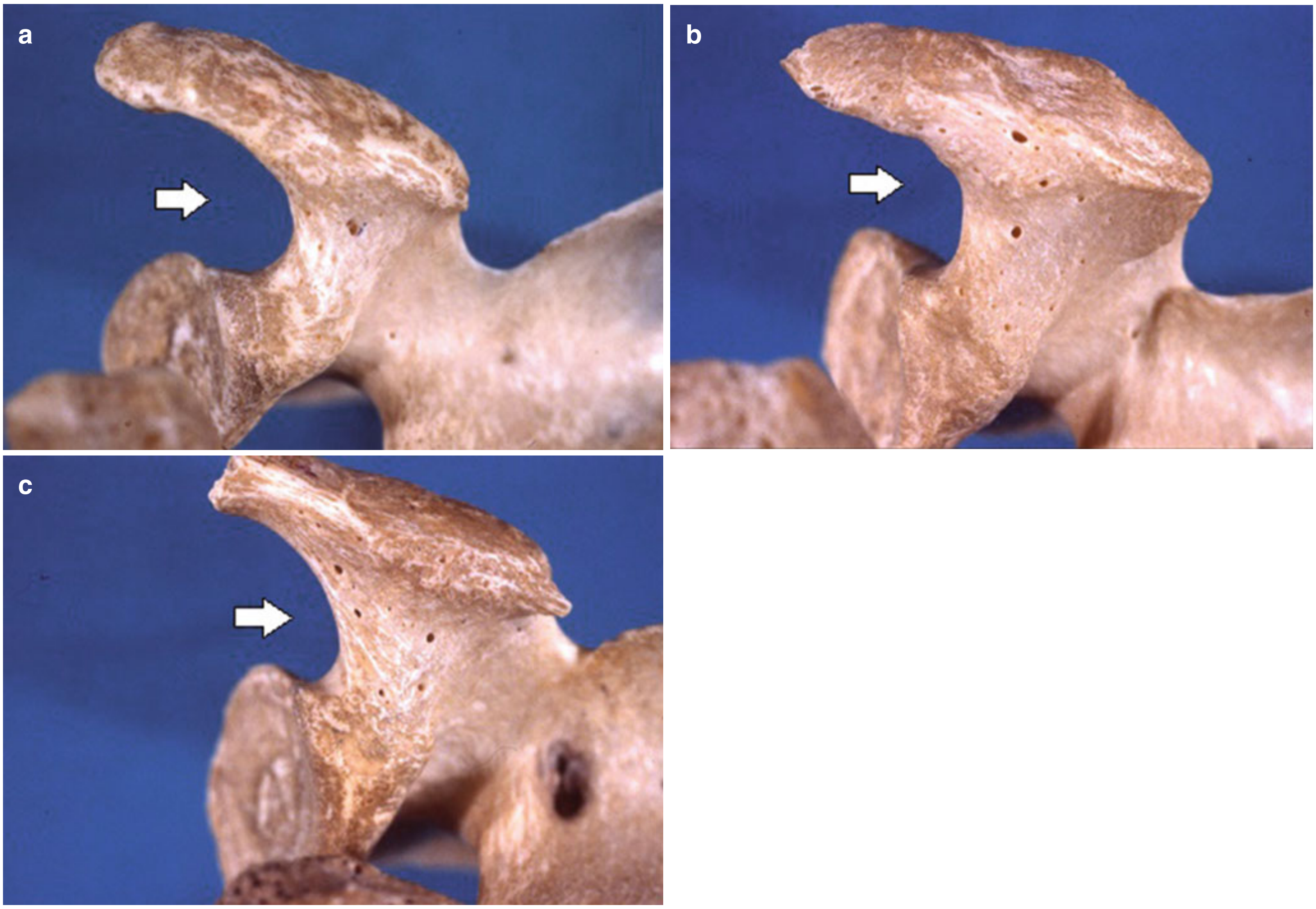


Fig. 8 (**a**–**c**). Three types of configuration of the coraco-glenoid space (*arrows*)

frequently observed in patients with injury to the subscapularis tendon.

Humeral Tuberosities and Bicipital Groove

The greater tuberosity represents the posterolateral region of the humeral head (Fig. 9). On it, there are three areas onto which the tendon of the supraspinatus, the infraspinatus, and the teres minor (see rotator cuff) may be fixed. The bone mineral density of the two tuberosities is an important factor in the surgical treatment of cuff lesions. Osteopenia of the greater tuberosity may, in fact, complicate surgical repair of the supra- and infraspinatus and hinder the healing of the two tendons. The tendon of the subscapularis muscle is inserted instead onto the lesser tuberosity that is placed antero-medially. Along with the greater tuberosity, the lesser tuberosity helps to delimit the bicipital groove within which the tendon of the long head of the biceps brachii and the arcuate artery, a branch of the anterior humeral circumflex, slide (Fig. 9). Proximally, it is wide and deep and is lost, gradually, on the front face of the shaft, mingling with the roughness of the bone corresponding to the insertional area of the teres major. Data regarding the morphological and morphometric features of the groove emerging from studies of dry shoulders are mixed. This has been attributed to the extreme variability of the ethno-geographical origin and age of the samples examined (Fig. 10a–c). A radiographic study performed on 200 humeri [46], of which the sex and approximate age were known, showed that the average value of the opening angle (Fig. 11a) of the groove is 102° (extreme 28–160°), while the medial angle (Fig. 11b) is 46° (range 16–78°). The depth and the average width of the groove are, respectively, 4.3 mm and 12.2 mm. Statistically significant differences between the sexes were found only for values regarding the average width (M:13.1 – F:10.2).

Rotator Cuff

This consists of the supraspinatus, infraspinatus, teres minor, and subscapularis tendons (Fig. 12). The first three (external rotators) are fixed onto the greater tuberosity, the other (internal rotator) on the lesser tuberosity. At about 15 mm from the

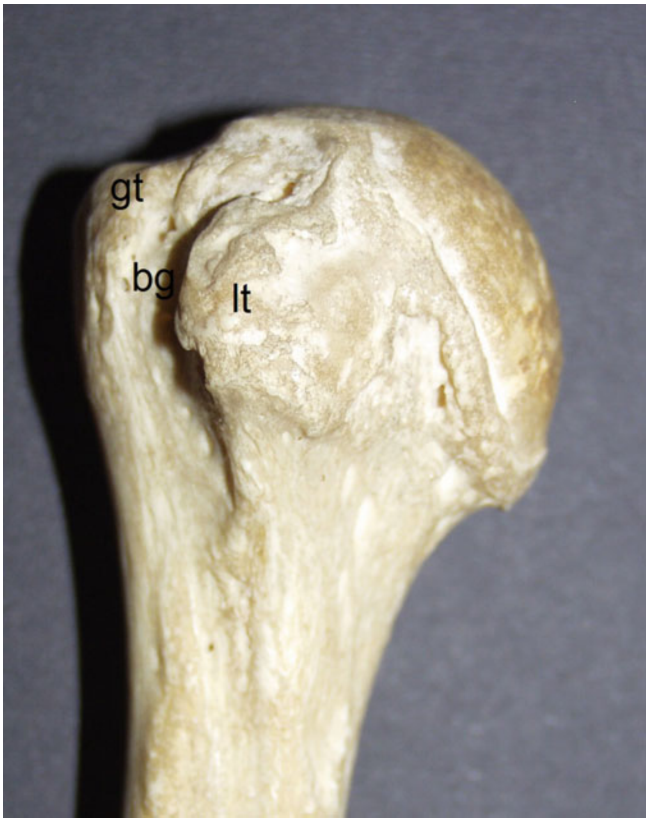


Fig. 9 Dry (*right*) humeral head. *gt* greater tuberosity, *lt* lesser tuberosity, *bg* bicipital groove

insertion on the humerus, the external rotator tendons are seemingly fused together, in particular those of the supra- and infraspinatus. However, if the coracohumeral ligament and connective tissue that overhang the two tendons near their insertion are removed, the front edge of the infraspinatus is more easily highlighted and the boundary between the two muscles becomes more apparent. The front edge of the infraspinatus is slightly more prominent than that of the adjacent rear supraspinatus. This is because the front of the infraspinatus partially covers the portion of the posterolateral supraspinatus.

If the infraspinatus is removed, leaving the capsule below intact, we note that the greater tuberosity is constituted by three distinct areas (the higher, middle, and lower) [47]. Mochizuki et al. [48] observed that the insertion of the infraspinatus occupies about half of the higher and the whole of the middle area. The anteriormost region of the humeral insertion of the infraspinatus almost reaches the anterior margin of the highest part of the greater tuberosity. Because the infraspinatus fits laterally, it can be argued that it can also play an important role in abduction. These new acquisitions concerning insertion of the infraspinatus suggest that the frequent atrophy of the infraspinatus muscle, visible in MRI scans on the occasion of apparent isolated lesions of the supraspinatus, is not attributable to lesions of the suprascapular nerve (due to traction caused by supraspinatus retraction) [49] but to a direct involvement of the infraspinatus itself in the lesion.

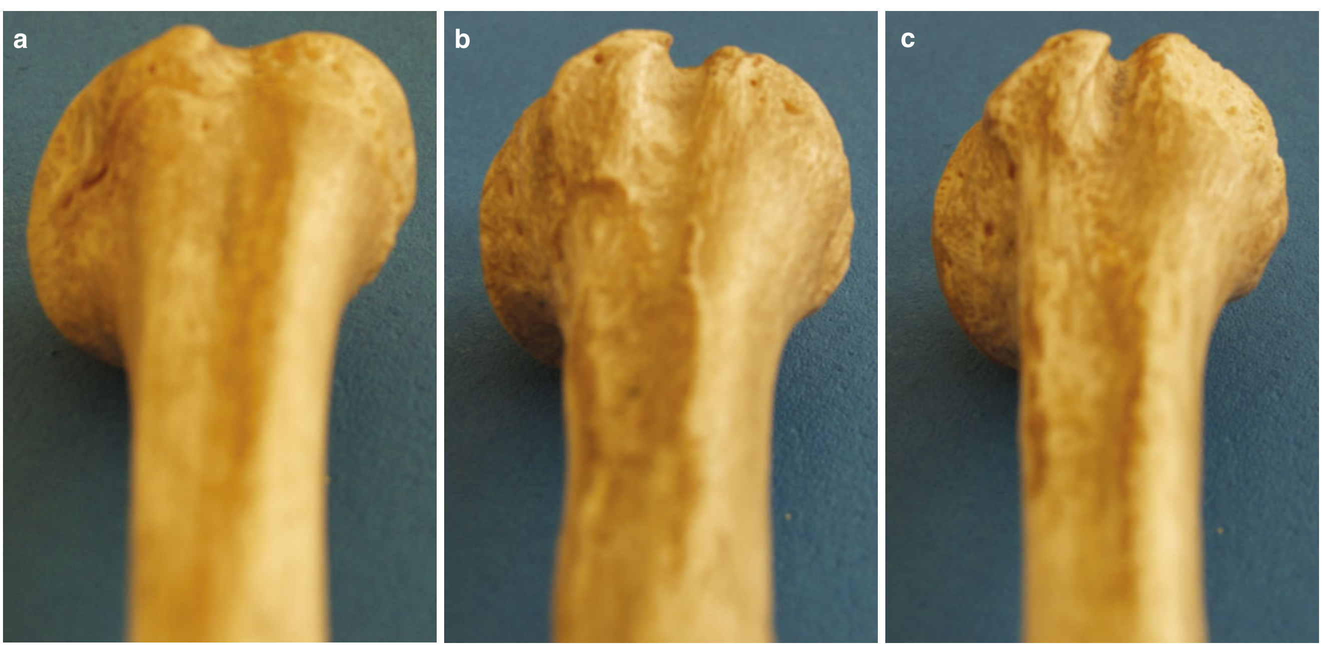


Fig. 10 (**a**–**c**) Dry humeri. Bicipital grooves with different depth and width

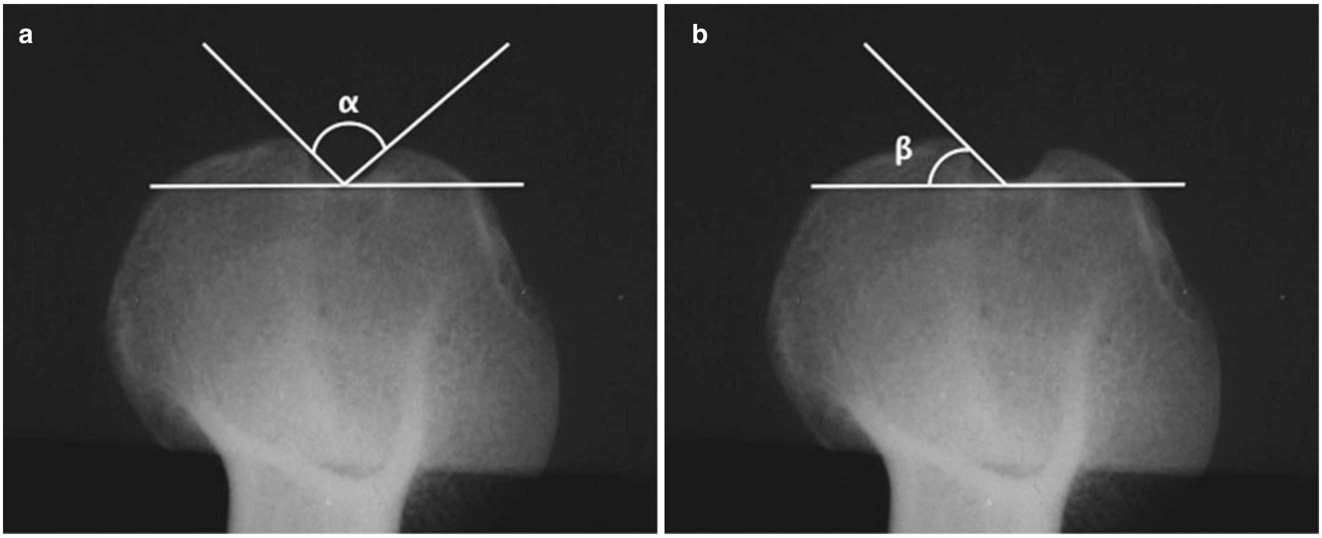


Fig. 11 Radiograms of dry humeri. Opening (**a**) and medial (**b**) angle of the bicipital groove.

Upon removing the supraspinatus, it can be noted that it fits onto the highest antero-medial part of the greater tuberosity.

The footprint of the supraspinatus is triangular in shape, with the longer side toward the articular surface; it is wider at the front and narrower at the back. The supraspinatus also fits onto the lesser tuberosity in 21 % of cases. In these cases, the anteriormost part of the tendon covers the top of the bicipital groove.

Mochizuki et al. [48] measured the maximum length (from medial to lateral) and width (front to rear) of the footprints of the supra- and infraspinatus. That of the supraspinatus is triangular in shape. The maximum length was 6.9 ± 1.4 mm. Instead, the maximum width of the medial margin was 12.6 ± 2.0 mm, while the lateral measured 1.3 ± 1.4 mm. The footprint of the infraspinatus is trapezoidal, wider laterally and medially. Its maximum length was 10.2 ± 1.6 mm. The maximum medial width was 20 ± 6.2 mm; the lateral was 32.7 ± 3.4 mm.

Previous studies assumed that the footprint of the supra- and infraspinatus were longer [50–52] probably because the joint capsule was included in the measurements. The tendon of the supraspinatus is composed of two portions: the anterior half is long and thick, the posterior short and thin. Itoi et al. [53, 54] arbitrarily divided the tendon into three portions (anterior, middle, and posterior) and observed that the anterior third is significantly stronger and tougher than the other two portions. However, the anterior portion, which fits onto the greater tuberosity for an extension corresponding to only 40 % of the tendon insertion, bears proportionately higher mechanical stress, which makes it more vulnerable and predisposed to rupture [55, 56]. In view of these findings, during the repair of the supraspinatus tendon, considerable attention should be paid to reinsertion of the anterior portion.

The so-called critical zone of the supraspinatus tendon is that at about an inch from the insertion of the middle third of the tendon [57]. Nakajima et al. [58] performed a histological and biomechanical study of tendons of the supraspinatus and identified four independent structural subunits. The “real tendon” extends from the myo-tendinous junction to about two inches from the insertion on the greater tuberosity. It consists of parallel collagen dossiers oriented along the stress axis. The “ fibrocartilage” extends from the tendon to the greater tuberosity and is mainly composed of intertwined collagen fibers. The “rotator cable” extends from the coracohumeral ligament to the infraspinatus, lying between the surface layer and the depth of the true tendon. The “capsule” is composed of thin collagenous sheets, each consisting of fibers with the same orientation. The combination of these subunits provides the supraspinatus with dispersive load and compression stress resistance properties [59].

The term “ cable” (Fig. 13) is commonly used to indicate the rope-like thickening consisting of fibers oriented perpendicularly to the axis of the tendon of the supraspinatus; arthroscopically it becomes visible by pointing the camera lens at the intraarticular tendon insertion. Clark and Harryman [60] assumed the cable to be a deep extension of the coracohumeral ligament. It is believed that the task of this structure is to bypass the mechanical stresses to which the supraspinatus tendon insertion (crescent) would be subjected. This explains why, arthroscopically, it is possible to observe a kneeling of the cuff next to the insertional area in the presence of a well-represented cable. It has been suggested that some shoulders may be defined as “cable dominant,” others as “crescent dominant.” The former seems to preserve the tendon insertion from excessive mechanical stress; the others seem more prone, therefore, to tendon

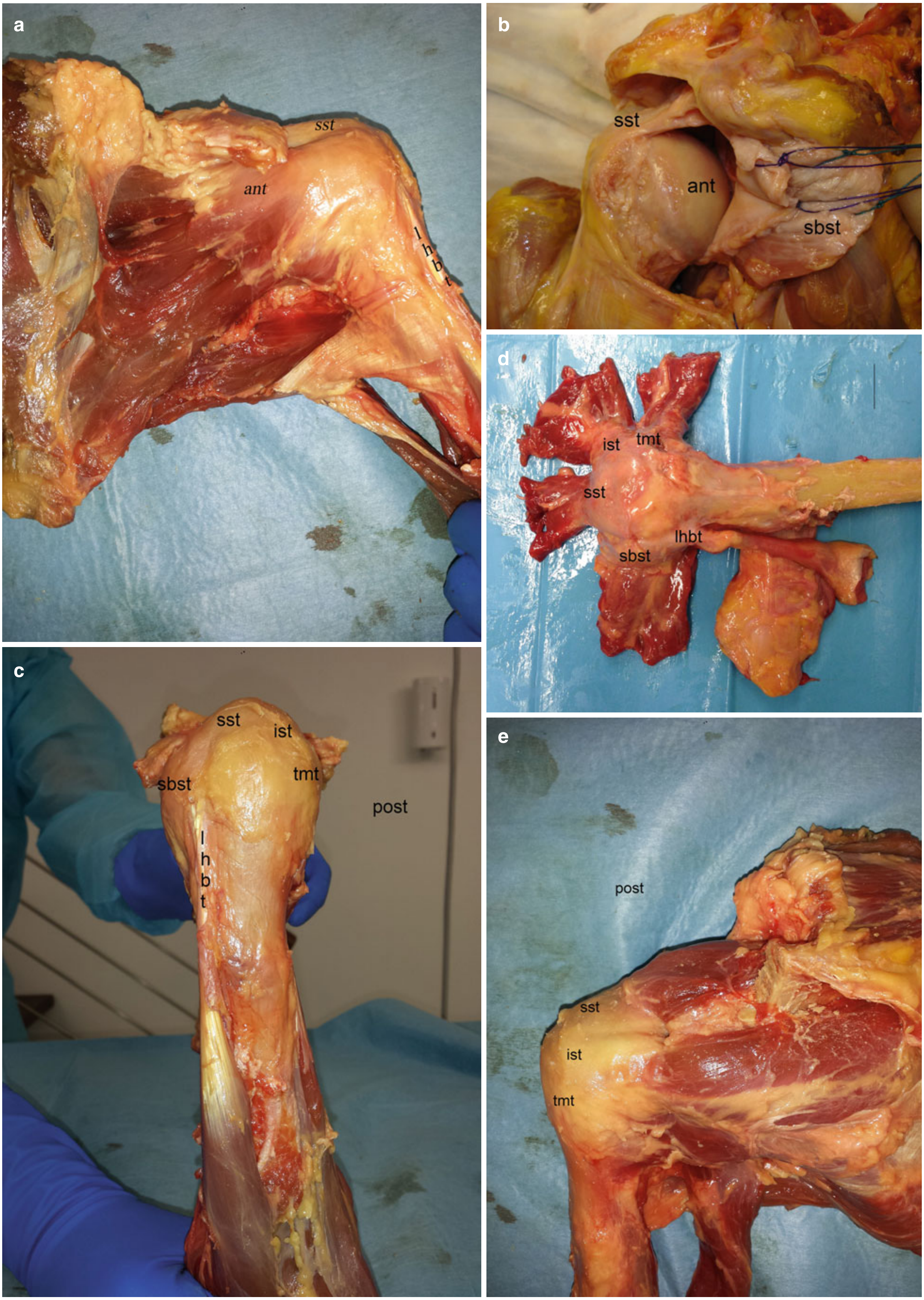


Fig. 12 Rotator cuff tendons. (**a**, **b**) Anterior views. (**c**, **d**) Lateral views; (**e**) posterior view; the scapular spine was removed. *sbst* subscapularis tendon, *sst* supraspinatus tendon, *ist* infraspinatus tendon, *tmt* teres minor tendon, *lhbt* long head biceps tendon, *ant* anterior, *post* posterior

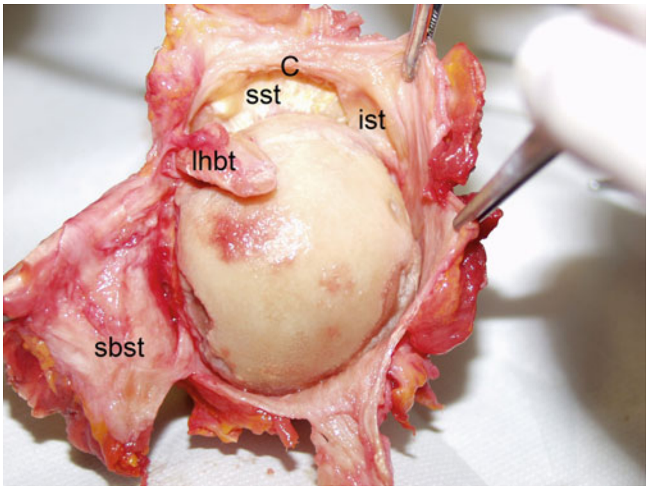


Fig. 13 *Right* shoulder of a cadaver. *C* cable, *sbst* subscapularis tendon, *sst* supraspinatus tendon, *ist* infraspinatus tendon, *lhbt* long head biceps tendon

injuries. Burkhart [61] suggested that lesions of the crescent, in the presence of an intact and well-represented cable, might even be considered functional and therefore manageable by availing of conservative treatment.

Clark and Harryman [60] observed that the supra- and infraspinatus tendons are composed of five layers. The first (1 mm) is represented by fibrous expansions of the coracohumeral ligament, the second (3–5 mm), by bands of tendon fibers crossed by fine arterioles, and the third (3 mm) by bands formed by smaller tendon bundles arranged in a disorderly manner. The arterioles present in this layer have an even smaller diameter than those closer to the surface. The underlying layer (the fourth) is formed by connective tissue with thick collagen fibers lying on the surface layer of the articular capsule (therefore, they are extra-articular). Finally, the last layer (2 mm) is formed by the joint capsule.

The tendon of the teres minor runs obliquel, from the bottom upwards, and is particularly adherent to the articular capsule of the glenohumeral joint. Much of the tendon is inserted into the so-called low area of the greater tuberosity; a small portion, instead, is inserted directly below this area.

The tendon of the subscapularis is made up of tendon and collagenic bands arranged in a parallel fashion. Only close to the insertion on the lesser tuberosity, the bands differ in range. On the surface, they are close to one another; deeper down (near the joint capsule) they are separated by abundant connective tissue. Expansions of the subscapularis rise to cover the greater tuberosity, between the first and third layer of the "fibrous plate" of the rotator interval, on the floor of the bicipital groove.

Cooper et al. [62] observed that the upper portion of the subscapularis is intraarticular (IASS = Intraarticular subscapularis). The IASS is only 86 % of the sagittal diameter of the entire subscapularis and 25 % of the upper part of the tendon [28–63]. The tendon inserts onto the lesser tuberosity forming a "comma." The footprint has an average length of 40 mm (range 35–55 mm) and an average width of 20 mm (range: 15–25) [50]. Like other tendons, with aging, the rotator cuff grows progressively thinner, with degeneration and reduction of its tensile properties. This predisposes to stress failure and progressively lower loads.

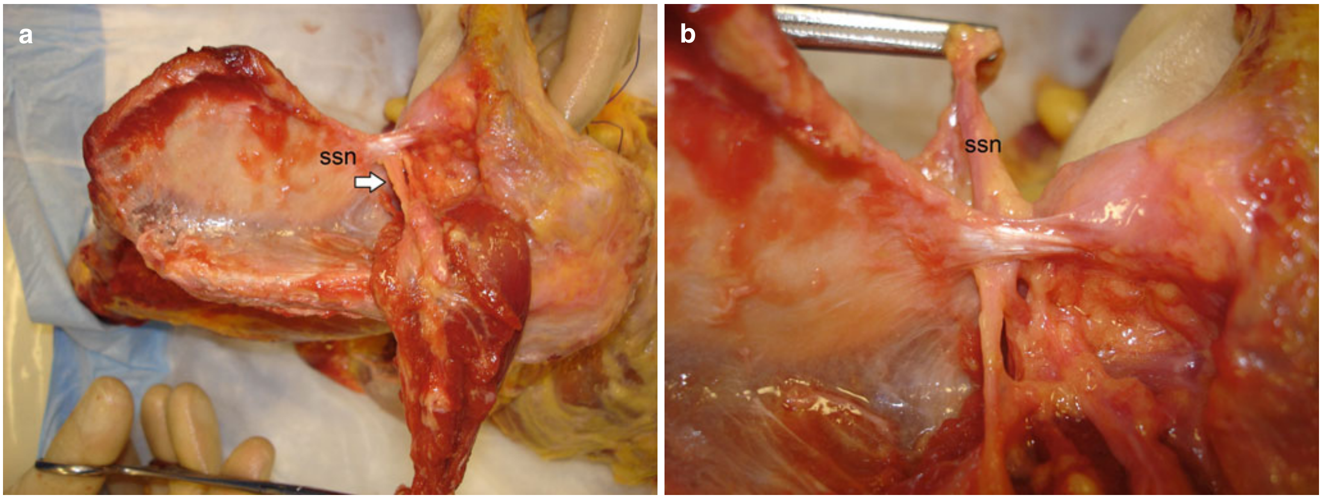
Rotator Cuff Muscles

The muscles of the rotator cuff of the shoulder are the supraspinatus, infraspinatus, teres minor, and subscapularis. The first three act predominantly as external rotators of the shoulder, while the subscapularis is an internal rotator. They are also dynamic stabilizers of the glenohumeral joint with other muscles of the shoulder [64]. In fact, the shoulder muscles because of their extensive mutual connection and insertion generate rotational movements. If you wish to perform a movement without rotation, this requires a partial neutralization by other muscles. For example, to perform an internal rotation, the latissimus dorsi needs to be neutralized by the headset and the deltoid otherwise this too would generate adduction.

It originates from the supraspinatus fossa of the scapula and extends anteriorly and laterally toward the greater tuberosity into which it fits with a tendon located between that of the infraspinatus (posterolateral) and the coracohumeral ligament (front) (Fig. 14). There are two muscular corpora: the first and forwardmost (anterior muscle belly) is essentially fusiform and originates entirely from the supraspinatus fossa. Along its front runs an intramuscular tendon (intramuscular core), the thickness of which increases progressively close to its insertion. The second muscle corpus (posterior muscle belly) is smaller, a single-band devoid of intramuscular tendon cores. It originates mainly from the spine of the scapula and the neck of the glenoid.

The supraspinatus is innervated by the suprascapular nerve (C5-C6) which enters the muscle near the coracoid base, after passing through the scapular notch. The vascular supply is mainly ensured by the suprascapular artery, which passes over the notch and penetrates into the muscle in proximity to the homonymous nerve and, to a lesser extent, the scapular dorsal artery. The muscle is involved in elevation movements of the shoulder [65, 66].

It originates from the infraspinatus fossa of the scapula (Fig. 15). It is a tri-band muscle in 80 % of cases and a double-single band one in the remaining 20 %. The median raphe can easily be confused with a cleavage plane between the infraspinatus and the teres minor. It inserts onto the greater tuberosity, posterior and laterally to the tendon of the supraspinatus. Like the supraspinatus, it is innervated and vascularized, respectively, by the suprascapular nerve and artery. An anatomical study, however, has also revealed a vascular supply



Figs. 14 (**a**) View from above of the *right* shoulder of a cadaver. The supraspinatus muscle was detached from the scapular supraspinatus fossa and overturned laterally. Suprascapular nerve (ssn) as it passes through the scapular notch. (**b**) Particular of the nerve

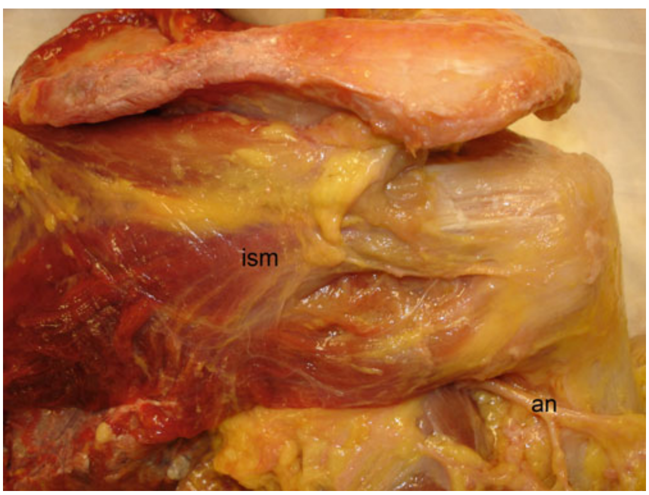


Fig. 15 Rear view of the right shoulder of a cadaver. Double band infraspinatus muscle (ism). *an* axillary nerve

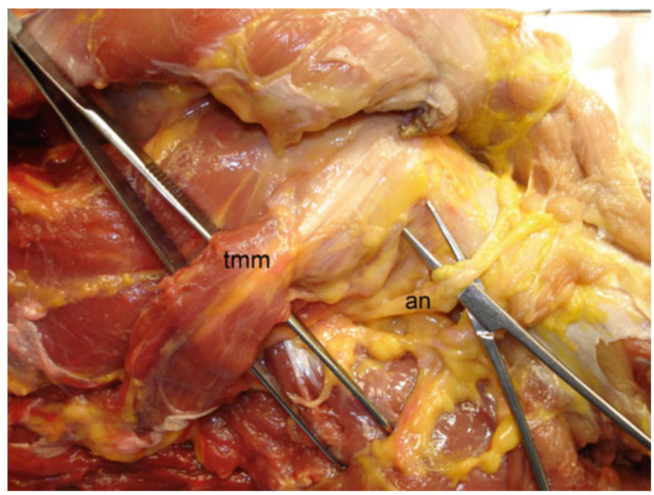


Fig. 16 Rear view of the right shoulder of a cadaver. Teres minor muscle (tmm). *an* axillary nerve

from the dorsal artery and subscapular circumflex branch [67]. The nerve penetrates the muscle after passing the spinoglenoid notch of the scapula. Here, it can be pulled during movements of abduction and external rotation and injured if this action is repeated sharply for professional reasons or sport. The muscle is predominantly an external rotator. It has been calculated that it produces 60 % of the strength in cases of external rotation [65]. During internal rotation, it opposes posterior dislocation, while during abduction and external rotation it opposes the anterior subluxation [68].

This muscle originates from the middle portion of the lateral margin of the scapula and from the thick end of the infraspinatus (Fig. 16). It passes antero-laterally and inserts itself onto the lower part of the greater tuberosity. With its lower margin, the muscle belly delimitates the quadrilateral space laterally and the triangular one medially. It is innervated by the posterior branch of the axillary nerve (C5); the vascular supply is provided by several vessels, but the main contribution is provided by the humeral posterior circumflex artery [67]. The teres minor is predominantly an external rotator (45 % of the entire strength) and it opposes, along with the infraspinatus, anterior dislocation [65].

The subscapularis constitutes the anterior portion of the rotator cuff and originates from the subscapularis fossa covering a large area (Fig. 17). It fits predominantly onto the lesser tuberosity and with a small contingent of musculotendinous

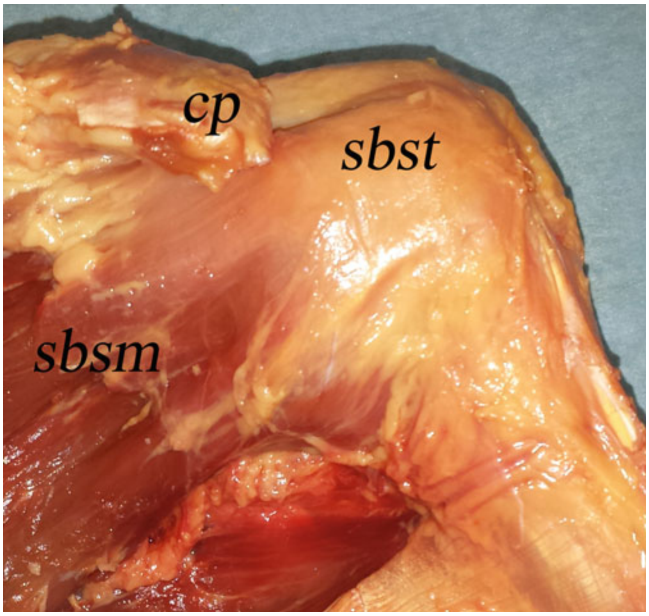


Fig. 17 Front view of the left shoulder of a cadaver. Subscapularis muscle (sbsm). *sbst* subscapularis tendon, *cp* coracoid process

fibers to the bottom of the lesser tuberosity. The subscapularis muscle is multibranched and rich in collagen fibers arranged in parallel formation on the surface layer and in a disorderly manner in the deep one. The upper portion of the fibers of this layer is inserted along the groove of the biceps.

Anteriorly, the subscapularis is bounded by the axillary space and by the coracobrachialis pouch, above the coracoid. In depth with respect to the muscle, in the quadrilateralspace, the axillary nerve and the posterior humeral circumflex artery pass. In a more medial position within the triangular space, the circumflex artery of scapula starts. The subscapularis's deeper surface covers the glenohumeral articulation joint. The relationship with the capsule is such as to make it difficult to find a cleavage plane. The middle glenohumeral ligament begins near the upper end of the subscapularis; the anterior band of the inferior glenohumeral ligament is placed lower down.

The upper (C5) and lower (C5-C6) subscapular nerves innervate the upper and lower portion of the muscle, respectively. The vascular supply comes from the axillary artery and from the circumflex (subscapular artery branches) and dorsal scapula artery [67, 69, 70].

Due to its close relationships with the glenohumeral joint, the subscapularis is considered one of the passive stabilizers in cases of subdislocating stresses of the humeral head [71, 72]. It is predominantly an internal rotator, but it contributes, along with the deltoid, to elevation of the shoulder. The upper musculotendinous portion withstands greater mechanical stresses than those recorded for the lower portion. This explains why lesions of the subscapularis most frequently involve the upper third of the tendon [73].

Deltoid

This muscle has a conical shape and is the widest of the scapulo-humeral muscles (Fig. 18). The deltoid consists of three parts: the front, midway, and back. The first (mono-branched) originates from the lateral third of the clavicle, the middle part (multibranched) and posterior (mono-branched), respectively, from the acromion and the spine of the scapula. The insertion of the three parts is located on the deltoid tuberosity of the humerus.

The three parts of the deltoid differ in their internal structure. The anterior and posterior have parallel fibers and a longer excursion, the middle section is multibranched and stronger. Of the three portions, the medial has the highest collagenic content [28].

Medially, it is in contact with the edge of the pectoralis major muscle. The triangular space between the two muscles constitutes the delto-pectoral interval through which the surgeon reaches the subscapularis tendon and the front face of the glenohumeral joint. The muscular interval contains the cephalic vein and smaller vessels from the thoraco-acromial artery (Fig. 19).

Deep down, a very thick band covers the muscle belly; this structure must be reinserted necessarily with the deltoid when detached from the acromion; otherwise, a subcutaneous depression, which is accentuated and painful during abduction against resistance, will appear.

The front and midway fibers ensure elevation movement on the scapular plane [74]. During abduction, the contribution of the anterior fibers decreases, while that of the posterior fibers increases. The decrease implies the triple action of the front and midway fibers and combined fibers of the pectoralis major and the biceps. It has been calculated that the deltoid supplies 60 % of all abduction force [65]. That the role of the deltoid in the stability of the glenohumeral joint is still a matter of debate. Motzkin et al. [75], in a study of cadavers, showed that the contribution made to lower stability of the shoulder by the deltoid is irrelevant. The same conclusion was reached by Markhede et al. [76] who observed that patients devoid of the deltoid due to deltoid cancer do not suffer from a severe impairment of the stability of the glenohumeral joint. A study by Kido et al. [77] has demonstrated, instead, how this muscle contributes towards the anterior stability of the shoulder. It has been hypothesized that contributions towards stability happen thanks to four

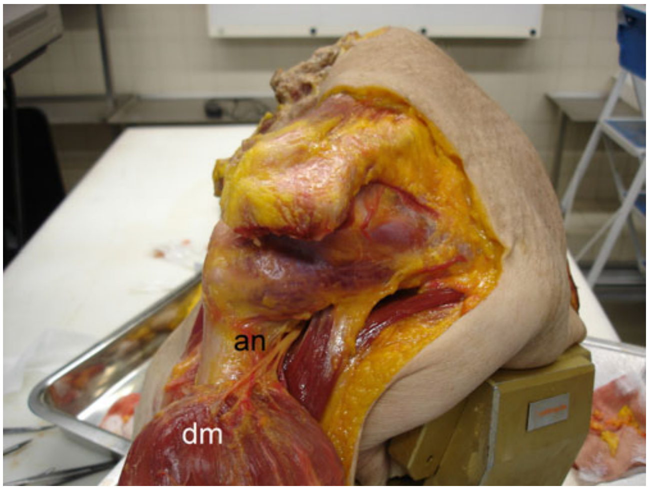


Fig. 18 Lateral view of the left shoulder of a cadaver. The deltoid muscle (dm) has been detached from the clavicle and scapula and lower overturned. *an* axillary nerve

Fig. 19 The cephalic vein

mechanisms: tension produced by the muscle mass itself, compression due to the contraction of the muscle, ligament tension secondary to the movement, and a barrier effect caused by muscle contraction [78].

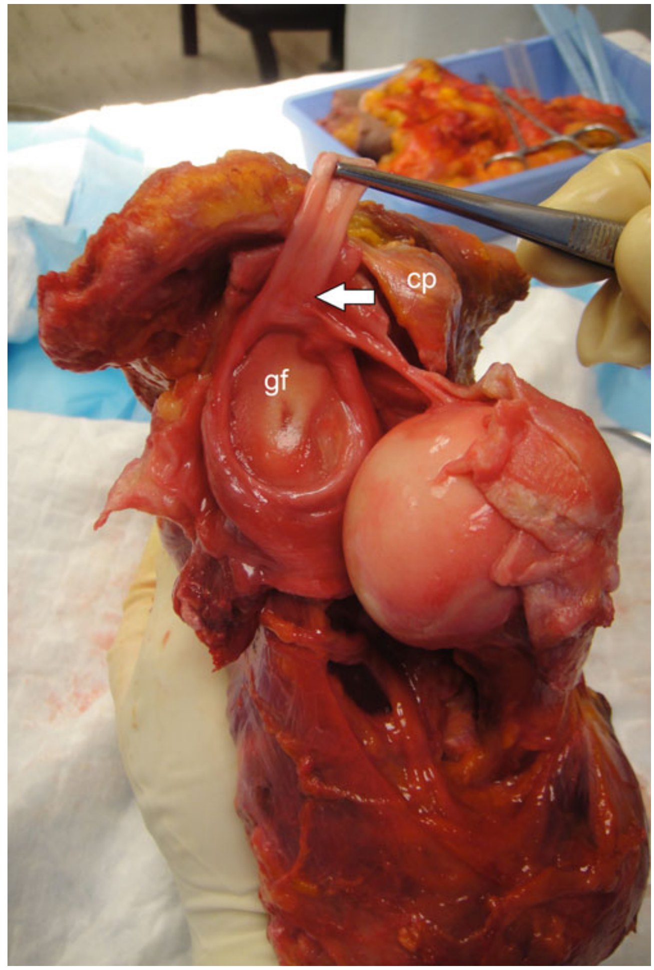


Fig. 20 Lateral view of the right shoulder of a cadaver. The *arrow* shows the long head biceps tendon insertion and its continuity with the labrum. *cp* coracoid process, *gf* glenoid fossa

The deltoid is innervated by the axillary nerve (circumflex) (C5-C6) and vascularized by the posterior circumflex artery [79].

Long Head Biceps Tendon (LHBT)

The long head of the biceps tendon (LHBT) originates with different individual characteristics from the labrum (45 %) and glenoid tuberculum (30 %) (Fig. 20). In the remaining cases (25 %), the tendon originates from both the labrum and tuberculum [28, 80]. In a study of 100 shoulders, Vangsness et al. [81] divided insertion of the tendon into four types: posterior (22 %), predominantly posterior (33 %), central (37 %), and anterior (8 %). The thickness of the tendon is greatest close to the glenoid insertion. In an ecographic study [82], it was observed that thickness depends on gender and

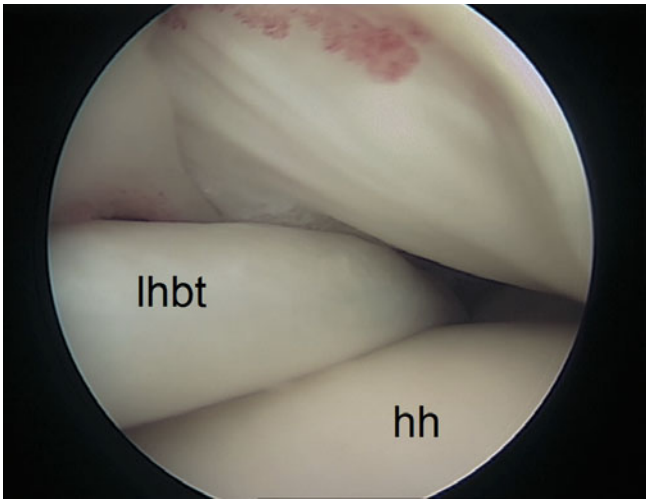


Fig. 21 *Right* shoulder. Arthroscopic view of the long head biceps tendon (lhbt). *hh* humeral head

on sporting activities. Near to the insertion, the average diameter is 8.4 mm × 3.4 [83].

The intermediate section is the area with the lowest resistance to mechanical stress. It runs obliquely downward and laterally as far as the entrance of the bicipital groove (Fig. 21), and thereafter, it passes in a straight line along the volar facet of the humerus. Its average length is 10 cm (range: 9.0–14.5 cm, depending on the sex), with no major differences between the two limbs. It seems to be true that the taller the subject, the longer the tendons.

The CLB is intraarticular but extrasynovial, in fact, the synovial sheath is folded back on itself and covers the tendon. Classically, the CLB was divided into two parts: the intraarticular and that within the bicipital groove (Fig. 22). However, this classification is incorrect. It is known that the fibrocartilaginous shower slips onto the tendon and not vice versa; therefore, the extension of the intraarticular portion of the tendon varies depending on the position of the arm. The intraarticular portion of the tendon is highest when the arm adducts.

The CLB is maintained inside the groove thanks to the coracohumeral ligament, the superior glenohumeral ligament, and expansions of the supraspinatus and subscapularis tendon (Fig. 23). A meso-tendon containing ascending branches of the anterior humeral circumflex artery constrains the CLB to shower in the proximal segment. Little is known, however, of the stabilizing function of the transverse ligament. A histological study [46] of ours showed that the surface layer of the transverse ligament is in contact with the expansions of the subscapularis tendon and of the coracohumeral ligament that constitute the second layer of the lateral portion of the rotator interval (Fig. 24). For this reason, we believe that

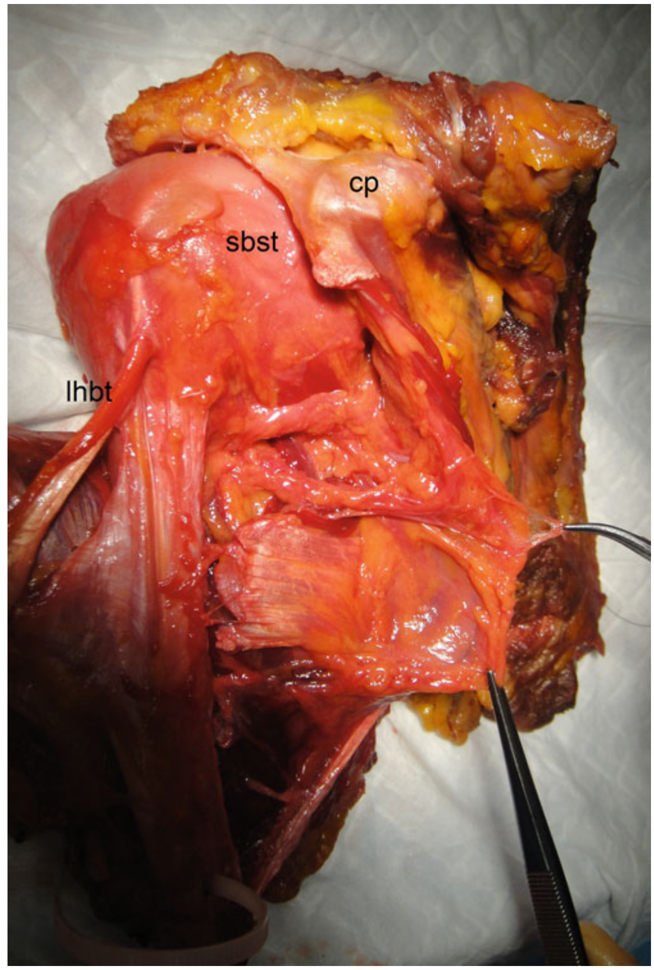


Fig. 22 Front view of the right shoulder of a cadaver. The long head biceps tendon (lhbt). *cp* coracoid process; *sbst* subscapularis tendon

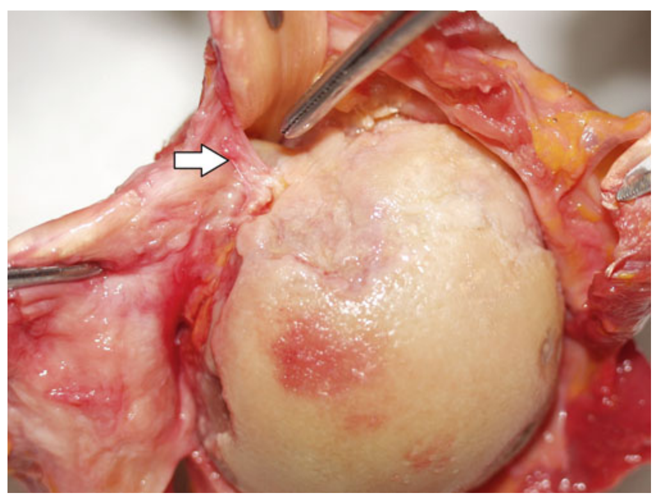


Fig. 23 Front view of the right shoulder of a cadaver. The *arrow* shows the medial vincula of the long head biceps tendon. They are mainly represented by the superior glenohumeral ligament and coracohumeral ligament; supraspinatus and subscapularis tendon expansions contribute to stabilize the tendon

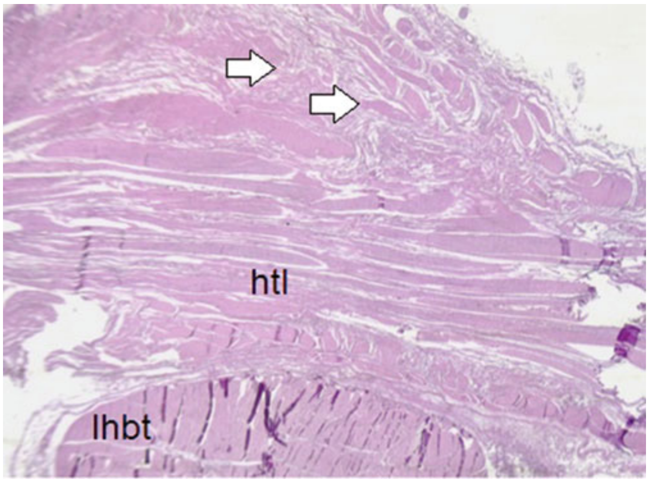


Fig. 24 Histological study. Humeral transverse ligament (htl) is in contact with the expansion of the subscapularis tendon and of coracohumeral ligament (*arrows*). *lhbt* long head biceps tendon

the transverse ligament is part of the ligament-tendinous complex of the rotator interval. After resection of the other stabilizers, the transverse ligament is able to oppose the medial displacement of the CLB (Fig. 25a, b). Recently, MacDonald et al. [84] have suggested that the transverse ligament is not a distinct structure, but formed, rather, by the union of the fibers of the tendon of the subscapularis, supraspinatus, and pectoralis major. In an anatomical study of 20 shoulders, Arai et al. [85] argued that to maintain a stable biceps tendon in its groove, the integrity of the superior glenohumeral ligament and of the upper portion of the subscapularis tendon is essential.

The function of the biceps is that of flexing and supinating the forearm. Recently, its role as depressor of the humeral head, through the long head, has been revised. Our studies of patients with inveterate rupture of the long head of the biceps have shown that the absence of the tendon does not prepare systematically for a rupture of the cuff due to secondary subacromial impingement [86]. The rupture of the long head results in a reduction of strength during supination, but this reduction is not felt by the patient.

The muscle is innervated by the musculocutaneous nerve (C5-C6) and vascularized mainly by the biceps branch of the brachial artery [47].

In case of rotator cuff tear, subacromial biceps stability is strongly compromised (Fig. 25c–e).

Rotator Interval

The rotator interval is the space between the front edge of the supraspinatus tendon and the upper end of the subscapularis. Fealy et al. [87] stated that this space is already observable in a 14-week-old fetus. The interval is triangular in shape (Fig. 26). The base of the triangle is formed by the coracoid and by the coraco-glenoid ligament; laterally, it is bounded by the bicipital groove, the transverse humeral ligament (assuming this ligament as a structure distinct from the coracohumeral ligament), and the oblique fascicle. It is delimited above by the coracohumeral ligament and superior glenohumeral ligament and below by the middle glenohumeral ligament. Gohlke et al. [88] have pointed out that the capsular floor of the interval is composed of the coracohumeral and superior glenohumeral ligaments. Abe et al. [89] have suggested that the shape of the interval changes over time depending on the mechanical stresses it undergoes; thus, anatomical reconstructions after lesions of the anterior-superior cuff should take the specific individual requirements into due account.

Arthroscopically, this space is formed by the superior and the middle glenohumeral ligament and corresponds to that formerly known as Weitbrecht's foramen. Therefore, in common practice, the term "rotator interval" may refer either to the tissue anatomically connecting the supraspinatus and the subscapularis (if we are treating a superior-anterior cuff tear) or to the triangular capsular space between the superior and middle glenohumeral ligaments (if we are dealing with unstable glenohumeral joint).

During internal rotation of the arm, the interval is the almost obliterated, while it is large during external rotation

Jost et al. [90] divided the rotator interval into two ends, lateral and medial, formed, respectively, by two to four layers. The surface layer of the lateral end is formed by fibers of the coracohumeral ligament that intersect with those of the supraspinatus and subscapularis tendons. Cross fibers of these tendons form the second layer. Through the bicipital groove, some fibers of the supraspinatus reach the lesser tuberosity insertion of the subscapularis, while others from the subscapularis arrive at the greater tuberosity. The third layer is formed by fibers of the coracohumeral ligament fitted predominantly onto the greater tuberosity and to a lesser extent onto the lesser tuberosity. The fourth layer consists of the glenohumeral ligament and the superior articular capsule. The two layers of the medial end are represented, respectively, by the coracohumeral ligament, closer to the surface, and by a combination of superior glenohumeral ligament and joint capsule, more in depth. The first three layers of the lateral end form the so-called fibrous plate which limits the external rotation when the arm is adducted. Instead, the medial end limits lower translation and external rotation. Neer et al. [91] observed that the resection (in cadavers) of the coracohumeral ligament results in an average increase of 32° in external rotation.

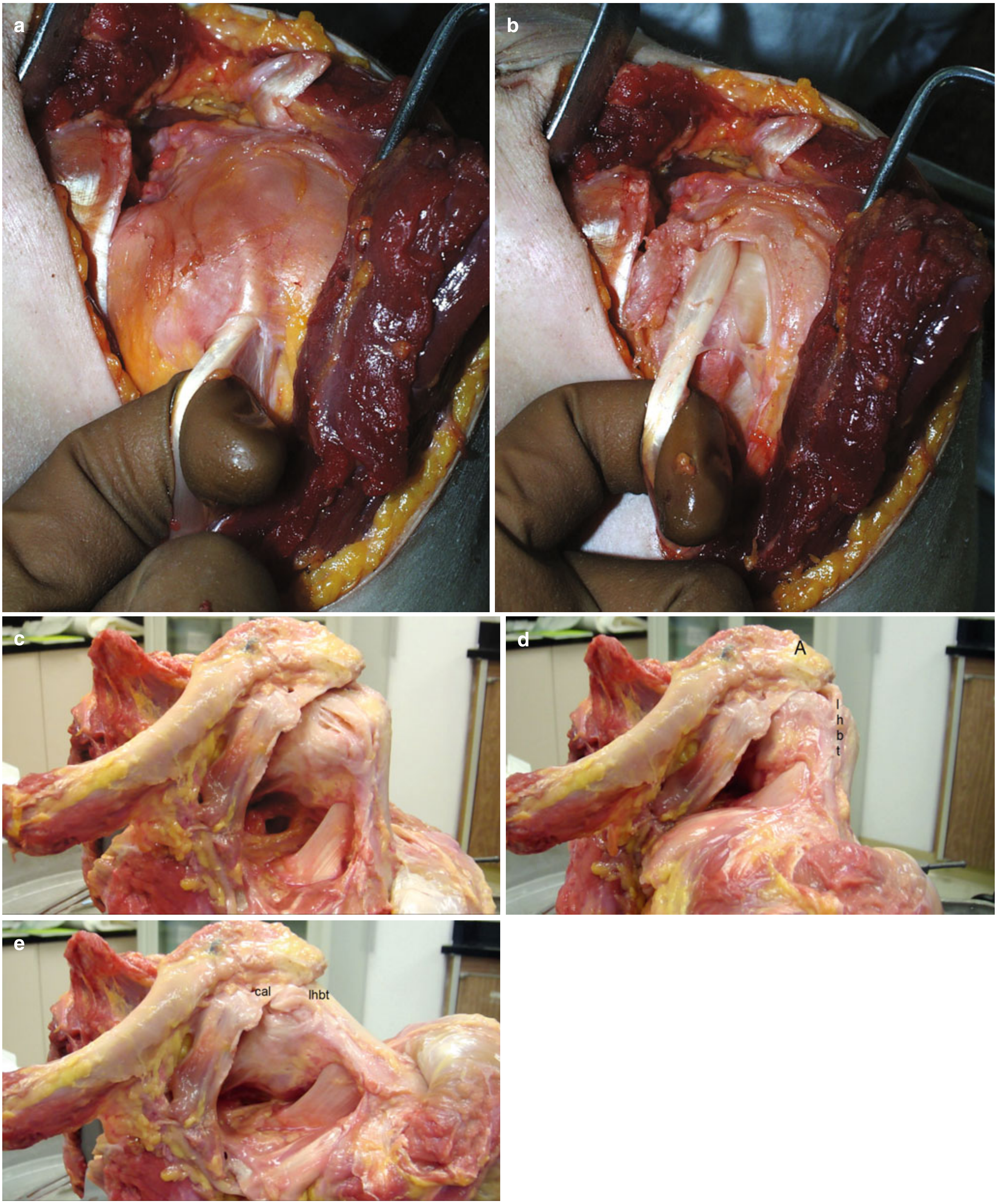


Fig. 25 (**a**) the humeral transverse ligament is still able to maintain the stability of the biceps tendon alone even when coracohumeral ligament is detached. (**b**) In the absence of the transverse ligament, the medial traction of the tendon causes its dislocation. When the antero-superior cuff is torn (**c**) and the shoulder is flexed (**d**) or abducted (**e**), the unstable biceps tendon (lhbt) comes in contact with the lateral margin of the acromion (A) and with the coracoacromial ligament (cal), respectively

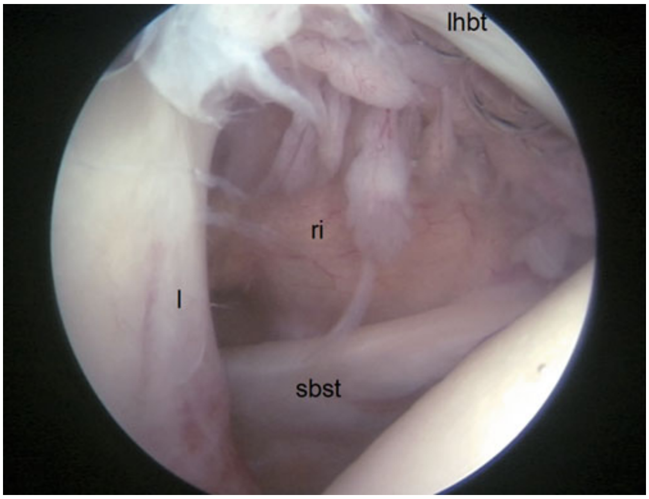


Fig. 26 Arthroscopic view from the posterior portal of a right shoulder. The rotator interval (ri) is defined by the labrum (l), long head biceps tendon (lhbt), and upper portion of the subscapularis tendon (sbst)

Kolts et al. [92] conducted a study of cadavers and found that the range of the cuff is composed of three parts, each of which represented by macroscopic anatomical structures. The lateral portion is reinforced by the presence of the semicircular humeral ligament (cable) and the anterior fibers of the supraspinatus. The mid-upper part is composed of the coracohumeral and coraco-glenoid ligaments. The middle-lower portion is reinforced by the superior and middle glenohumeral ligament.

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Rotator Cuff Biomechanics

Stefano Carbone and Stefano Gumina

The rotator cuff has two main functions: to allow the humerus to change position with respect to the scapula and stabilize the humeral head in the glenoid fossa. These two functions cooperate; in fact, when a rotator cuff muscle is working, at the same time the antagonist must remain immobile/still. Any alteration of this mechanism will lead to a reduction in the range of motion and in the stability of the shoulder [1]. Beyond these two functions, cuff tendons have complex and partially unknown biomechanical tensile and compressing properties. Tension is the consequence of muscle contraction; compression is caused by the pull of the cuff, which is constricted between the humeral head and the coracoacromial arch. In the light of recent studies that have considered the movement, stability, and biomechanical properties of the cuff, it is possible to understand how a small rotator cuff tear will lead to an alteration of the factors reported above and a redistribution of the load to the remaining tendons, thus determining the progression of the tear in the tendon [2].

Role of the Rotator Cuff in Gleno-Humeral Motion

To understand how muscles and tendons of the rotator cuff work in relation to gleno-humeral motion and to transmission of force, it is necessary to consider three main features: dimension and strength, orientation, and activity.

Dimension and Strength

The dimension of a muscle, which is directly proportional to its strength, is not simply the area of a certain muscular section, but it derives from the ratio between the volume of the muscle and the length of the muscular fibers [3]. Even if it is difficult to determine, some authors have worked on the issue [4–6]. The strength created by each area of the muscular section of each cuff muscle is still a matter of discussion [7, 8]. Generally, the mean value is thought to be 90 N/cm^2.

Orientation

The loads working on a shoulder in a certain position are influenced by the orientation of each muscle. Unfortunately, it is difficult to define the orientation of shoulder muscles, because it changes in relation to the position of the joint [9–12]. An approximate value of the orientation of a muscle in a given position can be obtained by signing and linking the two opposite insertions of the muscle [7]. A more precise result may be obtained by considering the center of the sequential transverse muscular section of the muscle closest to the joint's center of rotation. By linking the centers of the section areas, the muscle's orientation may be determined exactly in the various positions [6]. In the past, the lever arm of shoulder muscles and the muscle's various orientations with regard to the scapula were determined availing of X-ray [13, 14]. Recent data have shown that the classical subdivision of rotator cuff tendons into external (supraspinatus, infraspinatus, teres minor) and internal (subscapularis) rotators is obsolete. In fact, depending on the different position of the humerus relative to the scapula, the subscapularis, for example, may elevate, abduct, rotate the humerus internally, even externally [12–15]. Obviously, the classical subdivision in external and internal rotators is not awkward, but it is correct when the arm is at rest in neutral position (Fig. 1).

Activity

To define the activity or contraction of a muscle, it is necessary to consider the motion and position of the shoulder joint. Muscles permitting shoulder motion were defined by

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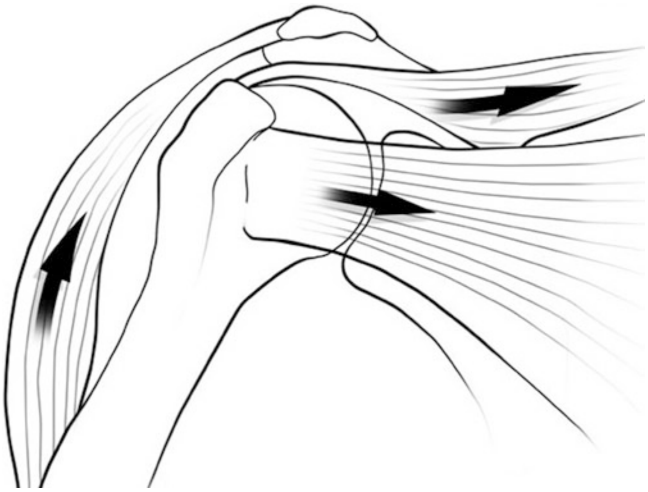

Fig. 1 Directions of vector line of deltoid, supraspinatus, subscapularis

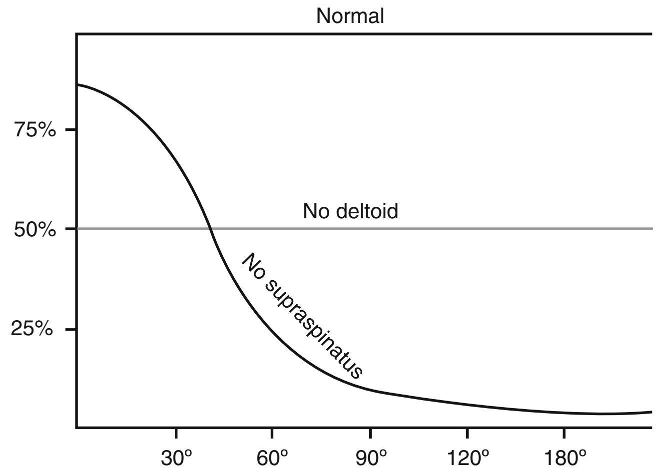

Fig. 2 Relative contribution of deltoid and supraspinatus to flexion and abduction of the arm

Duchenne by means of electric stimuli [16]. Recently, electromyography (EMG) has redefined the activity of all scapular muscles [17–21]. Ackland and Pandy [22] have shown that internal rotation is caused by contraction of the lower portion of the subscapularis; on the contrary, the lower part of the infraspinatus and teres minor are the most important external rotators. The supraspinatus acts as external rotator during abduction and as internal rotator during flexion of the arm. These same authors suggest that it is possible to understand the effect of a cuff tear if the lever arm of the submuscular regions is defined [22]. In addition, in another study, the authors have concluded that a further subdivision of rotator cuff muscles in multifeathered bundles may provide evidence of differences in activity that depend on the position of the shoulder joint [23].

Rotator Cuff Tendon Function in Gleno-Humeral Motion

Supraspinatus

This muscle originates from the supraspinatus fossa of the scapula and ends on the greater tuberosity of the humerus, with a footprint much smaller than that believed in the past [24]. In fact, its footprint occupies a very restricted area of the greater tuberosity, while the infraspinatus and subscapularis fibers are interested in the remaining area. On the basis of this new information, it is possible to understand why the supraspinatus tendon during external rotation is much less important than it was believed to be in the past, with much more relevant flexion/abduction functions [11]. Nevertheless, the function of the whole muscle-tendon unit is still a matter of discussion [25–33]. The supraspinatus, cooperating with the deltoid and other cuff muscles, performs an important function in the flexion of the arm [25]. These observations are confirmed by Liu et al. [25], who proposed to strengthen the rotator cuff and other peri-scapular muscle in case of rotator cuff tear. In addition, literature evidences that a cuff tear causes scapular dyskinesis [34]. Several rehabilitation programs have been proposed, all of them focusing on strengthening and stretching the scapular muscles availing of exercises aimed at improving scapular protraction, retraction, depression, elevation, and rotation [34–36]. Even these exercises should be considered during rehabilitation after repair of rotator cuff and other shoulder pathologies related to scapular malposition and dyskinesis [37].

The functional relation between deltoid and supraspinatus has been described by Sharkey [31]. When the deltoid function is not working properly, there is a uniform reduction of strength during flexion and abduction, whatever position the joint may assume. On the other hand, when the cuff function is not working, strength in the first few degrees of flexion/abduction remains normal, while there is an important deficit beyond 30° of flexion/abduction (Fig. 2).

Later, the relation between deltoid and supraspinatus was reviewed. Thompson et al. [27] showed that in cases of paralysis of the supraspinatus, the strength of the lateral deltoid necessary needs to increase to 101 %; furthermore, it is necessary to obtain an increase of 12 % to achieve complete abduction, showing that the supraspinatus is an important abduction trigger. Howell et al. [14] have studied dynamometric data concerning abduction in subjects presenting a lidocaine block of the axillary or supraspinatus nerve. They experienced an equivalent decrease in flexion/abduction strength if the supraspinatus or deltoid were inactivated. These data were confirmed by the clinical experiences of Markhede et al. [28], who observed that patients devoid of deltoids enjoyed good overall functionality of the shoulder. On the contrary, Oh et al. [29] argued that when the supraspinatus is completely detached from its footprint, shoulder flexion/abduction is very limited; when the tendon tear involves the infraspinatus too, the global kinematic of the shoulder changes. In addition, in the presence of a larger tear, the pectoralis major and the latissimus dorsi improve the function which permits them to stabilize the humeral head in the glenoid fossa. Wuelker et al. [30] observed that when the supraspinatus is completely torn, the deltoid improves its function and it is able to guarantee the strength of the shoulder even if it is much weaker than the supraspinatus, availing of only one-third of its strength. These authors also affirm that the supraspinatus has a less effective flexile function than the deltoid. Itoi et al. [33] studied the isokinetic strength of shoulders with an isolated tear of the supraspinatus and observed that the overall strength of the shoulder is reduced to two-thirds of the initial value. The latter data reflect the effective contribution made by the supraspinatus to shoulder strength. Harris and colleagues studied a cohort of patients treated conservatively for rotator cuff tear and concluded that it is possible to obtain a functional and asymptomatic shoulder if scapular dyskinesis is treated with specific exercises to strengthen flexion and abduction [38].

The Infraspinatus and Teres Minor

In literature, the infraspinatus and teres minor are often considered together, especially as far as biomechanics is concerned [12, 30, 32, 39]. These studies, except for the review by Longo and colleagues “Biomechanics of the rotator cuff” [32], precede new anatomic concepts by Mochizuchi et al. [24], who have observed that the footprint of the infraspinatus is much wider than it was believed in the past and that this tendon is always torn considerably in the presence of postero-superior cuff tears. With the arm at rest, the supra- and infraspinatus act as external rotator and flexor/abductor [39]; the functions are also the same with the arm in other positions. In particular, the infraspinatus and teres minor flexor function was shown by Sharkey et al. [39]. The authors highlighted the fact that when the supraspinatus is functioning, the deltoid strength necessary to permit forward elevation of the arm decreases to 72 %, to 64 % when the infraspinatus and teres minor are functioning, and to 41 % when all rotator cuff muscles are functioning. Otis et al. [15] showed that the infraspinatus acts more as an abductor when the arm rotates internally, while during external rotation the subscapularis assumes this function. Furthermore, the infraspinatus and teres minor are of crucial importance as depressors of the humeral head [30–32]. In fact, tears extending to the postero-superior cuff are associated with a greater upward migration of the humeral head and bear a direct relationship with the size of the tear [31]. This depressor function has been confirmed by Su et al. [40], who have studied the lower part of the infraspinatus as the most important depressor. The role of the long head of the biceps tendon as depressor has to be revised, as Gumina and colleagues [41] pointed out in a study including a 30-year follow-up.

The Subscapularis

The subscapularis muscle originates from the anterior aspect of the scapula and ends mostly in the lesser tuberosity of the humerus, while a small portion ends in the greater tuberosity [24]. Besides other cuff tendons, the classical interpretation of the subscapularis as internal rotator needs to be revised/re-evaluated/re-examined. Internal rotation remains its main function, of course, while its secondary roles change depending on the position of the humeral head with respect to the scapula. Consequently, this tendon is an abductor, a flexor, an extensor, and a depressor [42]. Because of the shared insertion of the supraspinatus and subscapularis, it is possible that in certain positions of the arm, the subscapularis may work as external rotator [12, 15, 24].

Because of its broad medial insertion, the muscle-tendon unit was studied in different areas with different functions. In 1989, Kato studied the subscapularis of 40 cadavers and identified three different branches: the upper, midway, and lower [43]. Kadaba et al. [44], on the contrary, found two parts: the upper and lower, with separate innervations. The authors examined the electromyographic activity of the two portions during isometric contraction during internal rotation with the arm at 0° and 90° of abduction [44]. The main result of the study is that abduction influences the activity of the two parts of the deltoid [44]. Otis et al. [15] subdivided the subscapularis into three portions (Fig. 3) and found that the upper part acts prevalently as flexor. Recently, the subscapularis was found to enhance its function and muscle thickness in cases of postero-superior cuff tear in order to rebalance the biomechanics of the shoulder [45]. The function of the subscapularis as flexor/abductor is still a matter of discussion. In the past, Poppen and Walker [13] pointed out that the main function of the subscapularis was not to flex the arm. Gerber et al. [46], studying a cohort of 16 patients with a tear in the upper subscapularis, experienced a flexion strength deficit. In a recent paper, Itoi and colleagues studied the metabolism of the subscapularis after flexion exercises of the arm and found it had increased; it was not clarified whether this muscle is a simple flexor of the arm or if it stabilizes the glenohumeral joint in cooperation with other muscles [47]. Recently, it emerged that during flexion electromyographic activity increases much more for the subscapularis than for other cuff muscles [48]. Furthermore, Kuechle et al. [11] have shown that the subscapularis is a more important flexor than the supra- and infraspinatus.

Because of its forward position, a subscapularis tear cannot be balanced by the remaining tendons. In 2009, Su et al. [49] pointed out that a superior cuff tear including the upper third of the subscapularis alters the biomechanics of the shoulder significantly and causes antero-superior subluxation of the

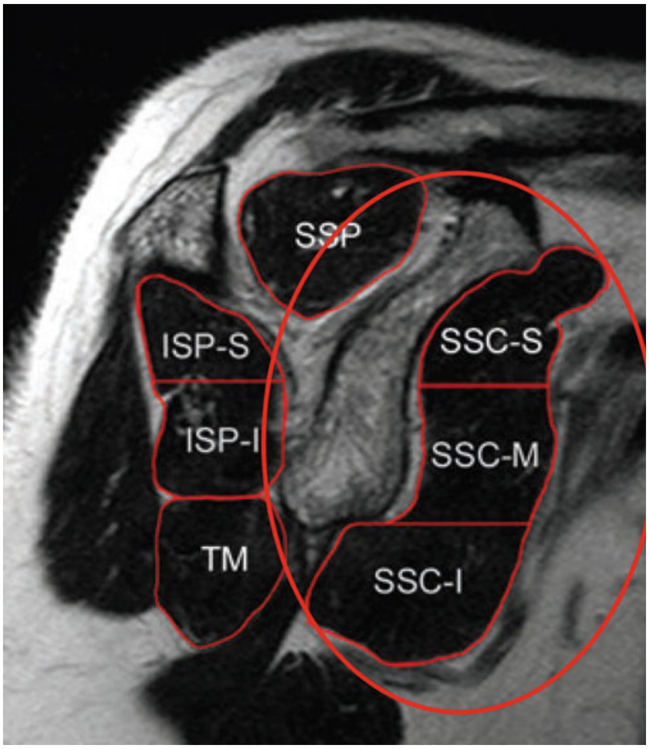

Fig. 3 The three different portions of the subscapularis muscle (SSC-S; SSC-M; SSC-I)

humeral head. Rotator cuff cable integrity, as described by Burkart et al. [50], is essential to the biomechanics of the shoulder. If preserved, the lower part of the subscapularis suffices to guarantee normal biomechanics of the shoulder. Rupture of the entire tendon alters the biomechanics of any situation. Upper fibers enhance abduction, lower ones adduction [51]. Anteriorly, the subscapularis muscle stabilizes the shoulder joint actively and passively during external and internal rotation. On the axial plane, the muscle-tendon unit balances the activity of the infraspinatus, while on the coronal plane it opposes the upward migration caused by deltoid activity.

Rotator Cuff Function in Gleno-Humeral Stability

The contact area between the glenoid and humeral head articular surface is relatively limited. The capsule, gleno-humeral ligaments, and the labrum make the congruity and the contact area more efficient (static stability). Most of the stabilizing effect of the gleno-humeral joint is due to muscles surrounding the shoulder (dynamic stability). Rotator cuff tendons and muscles, in particular, acting as dynamic stabilizers, favor shoulder stability, thanks to their position and orientation with respect to the joint [52] (Fig. 4).

The rotator cuff, together to other shoulder girdle muscles, makes the joint stable during its entire range of movement. Muscles and ligaments have to balance out low articular surface congruity, providing a more important function compared to other joints endowed with greater congruity efficiency. The dynamic stability of the joint is also the result of neuromuscular synchronism between scapula-thoracic and rotator cuff muscles. The scapula-thoracic muscles favor neural feedback from rotator cuff muscles and gleno-humeral ligaments while helping to prevent pathological subluxation of the joint [52]. This neural feedback causes a rapid and efficient proprioceptive response of the shoulder muscles, thus improving shoulder stability [53].

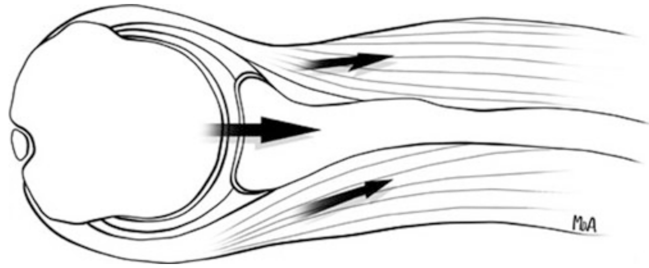

Fig. 4 Compression of the humeral head in the glenoid fossa

Muscles and tendons of the rotator cuff may improve shoulder stability because of (a) passive muscular tension determined by the bulky effect of the muscle, in cooperation with the deltoid; (b) muscular contraction which causes compression between the two articular surfaces; (c) line force orientation in the center of the glenoid cavity, thanks to muscular coordination [54]. The stabilizing effect of cuff tendons is powered by a negative pressure of 5 mmHg inside the joint, which creates a suction effect between the humeral head and the glenoid. A recent biomechanical study has highlighted the fact that the cuff muscle-tendon unit has a more important stabilizing role with respect to other shoulder girdle muscles [53]; this is possible due to very precise responses to external stimuli, whether expected or not by the patient. The compression mechanism is possible thanks to the anterior position of the subscapularis and the posterior position of the infraspinatus and teres minor [55]. In cases of tendon tear, this mechanism may fail, with important effects on gleno-humeral stability [2]. Different tendon tears may alter shoulder stability differently, with greater modifications in the case of an infraspinatus/teres minor and subscapularis tear. In the past, an isolated supraspinatus tear was thought to be potentially balanced by other rotator cuff tendons, because not responsible for stability and for upward migration [52]. In recent years, on the contrary, Kim and coworkers [56, 57] found that the majority of asymptomatic tears were located from between 13 and 17 mm behind the long head of the biceps tendon, which is not the footprint of the supraspinatus. In addition, the same authors noted that the supraspinatus is not totally detached from its insertion if the tendon tear does not involve the most forward side of the cuff. This concept is in line with what Mochizuchi et al. [24] reported.

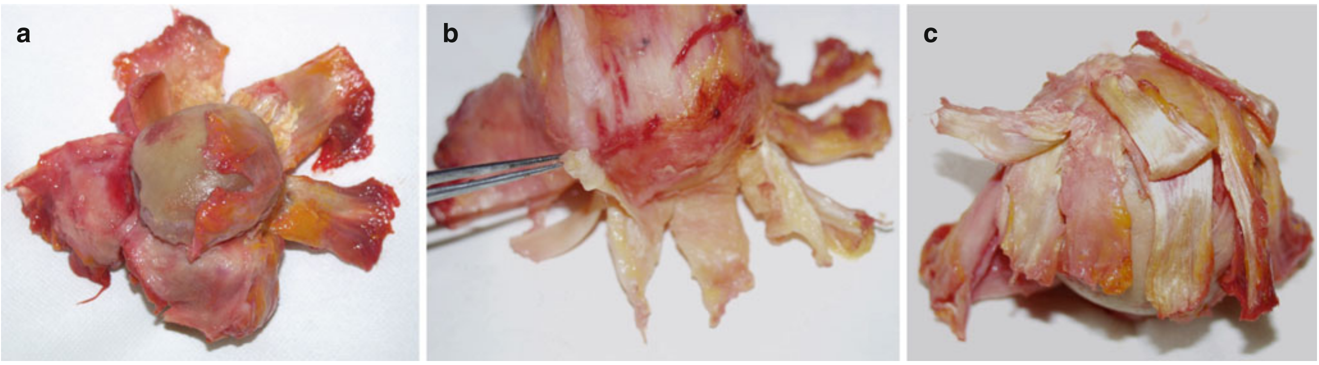

Fig. 5 The humeral head of fresh cadavers with the tendons of supraspinatus, infraspinatus, and teres minor subdivided in anterior and posterior portion (**a**, **b**); then, the anterior portion is sectioned with a dermatome in articular and bursal side (**c**)

Mechanical Properties of the Postero-Superior Rotator Cuff

Rotator cuff tendons have inhomogeneous biomechanical properties. Itoi observed that the anterior portion of the supraspinatus tendon is more resistant to tearing than the midway and posterior portion [58]. Lee et al. [59] studied the stiffness of the bursal and articular sides of the supraspinatus. The stiffness of the bursal side of the anterior third of the tendon resulted much greater than that of the other two-thirds. The same result was obtained when the articular side was valued. In another biomechanical study [60], the infraspinatus tendon was subdivided into three portions: the anterior, midway, and posterior. The last two resulted more resistant during the pull-out test than the anterior. Because partial tears are more frequent with respect to full thickness [61], Gumina and coworkers have studied the biomechanical properties of postero-superior cuff tendons, differentiating the bursal and articular sides [62]. In this study, eight humeral heads from fresh cadavers and intact cuffs were used. Each tendon was subdivided into an anterior and posterior portion. Then, the anterior portions were prepared with a dermatome in a bursal and articular portion, having the same thickness (Fig. 5). The pull-out test was performed using a ZWICK Z010 machine with anchorage of the tendon's most distal side after freezing, to obtain a better grip of the tendon (Fig. 6). During the test, the rupture load (measured in newton necessary to tear the tendon) and the stiffness (the extent to which it resists deformation in response to the degree of force applied) were studied. The results confirmed the data obtained by Itoi [58], with the bursal side of the supraspinatus, resulting much more resistant than the articular side. This may be due to distribution of tendon fibers, arranged in large parallel bands on the bursal side. Failures of the tendon were found in the tendon/bone interface, probably because of degeneration of the tendon in the critical area [63]. The stiffness on the bursal side of the supraspinatus resulted significantly higher than that on the articular side. The mean

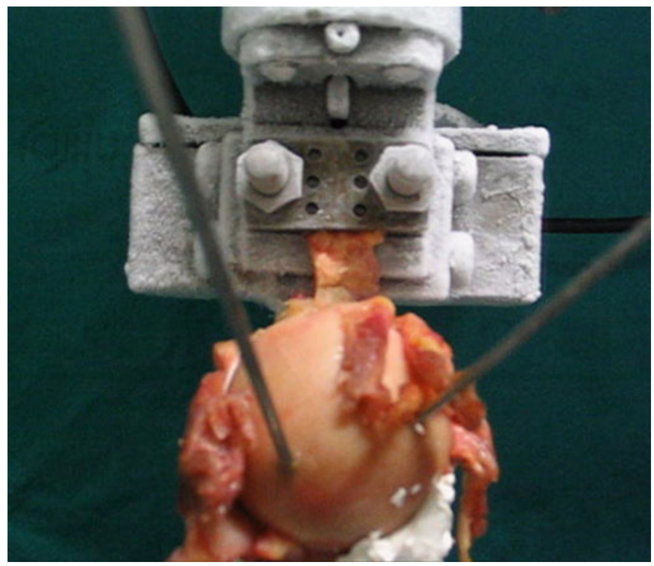

Fig. 6 The pull-out test performed using a ZWICK Z010 machine

resistance of the anterior side of the infraspinatus was greater than that of the posterior; stiffness too was greater on the bursal side. The characteristics of the teres minor were the same. From this study, it is possible to conclude that the supraspinatus tendon is much more resistant (Fig. 7). In actual fact, the results emerging from this study may be criticized because of Mochizuchi et al's. [24] new anatomic findings where the footprint of the supraspinatus is much smaller than what was previously believed, while the footprint of the infraspinatus extends into most of the greater tuberosity [24]. Thus, it is possible that Gumina et al. [62] considered as supraspinatus only some tendon tissue comprising an intersection of supra and infraspinatus fibers. This aspect also highlights the fact that most superior tendon tears involve the infraspinatus tendon. On the basis of the results reported above, it may be argued that partial lesions of the bursal side of the supra- and infraspinatus should be surgically treated in all cases because the tear is likely to affect the full thickness of the extension.

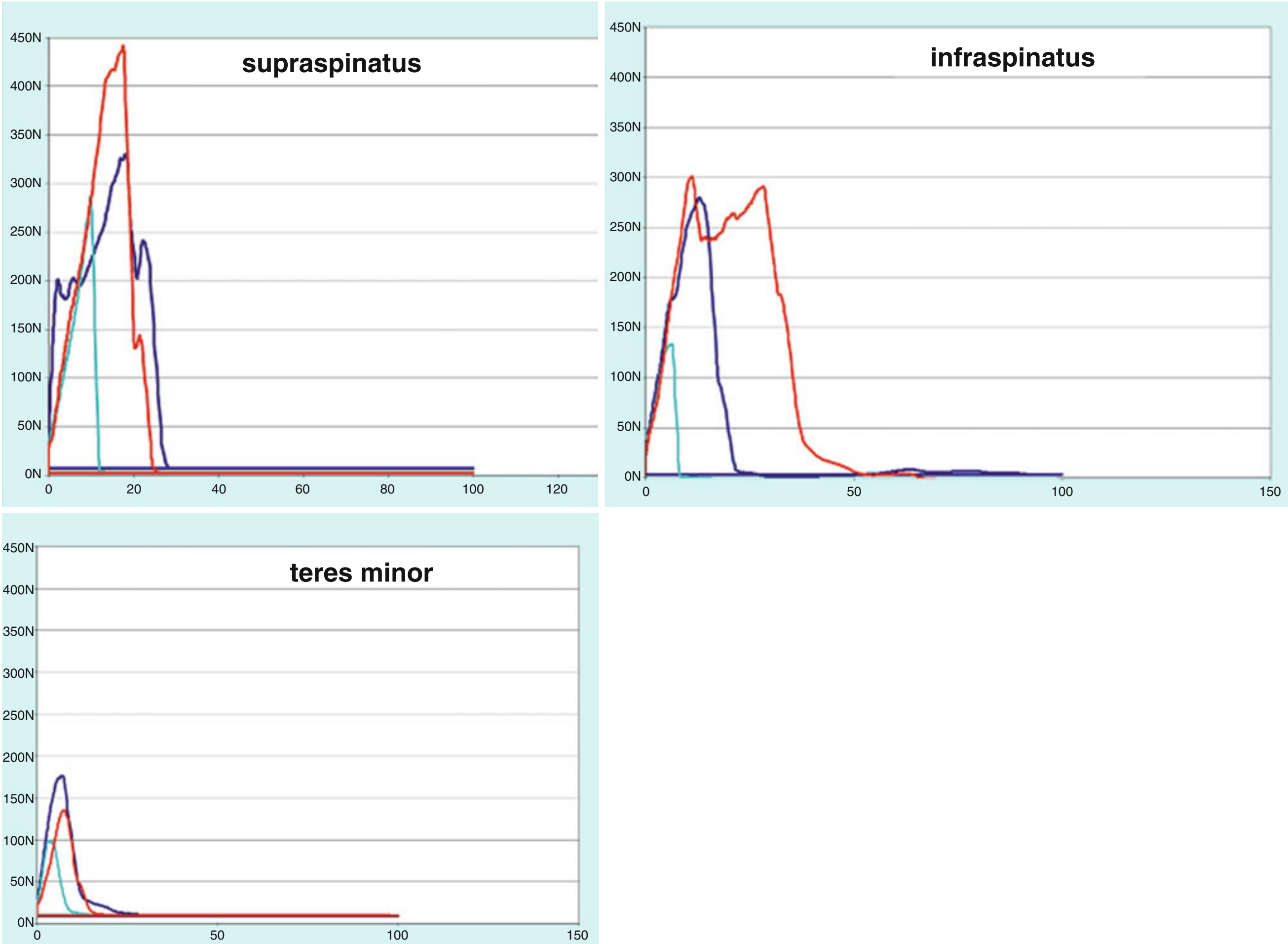

Fig. 7 The biomechanical properties of the supraspinatus tendon are superior than infraspinatus and teres minor

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Epidemiology and Demographics of the Rotator Cuff Tear

Stefano Gumina, Daniele Passaretti, and Vittorio Candela

A lot of epidemiologic studies have been carried out to determinate the prevalence and incidence of the rotator cuff tear, the average age of the patients affected, the work activities that cause the lesion and a possible sex-linked predisposition. These works have been performed on cadavers, on healthy people, and on patients with shoulder pain.

Prevalence and Incidence

Cadaveric Studies

Many studies cited in literature do not specify the age of the cadavers examined; this explains why the prevalence of the cuff tear varies from 5 to 44 % [1–30].

In 1834, Smith [1], examining 40 cadavers whose age was not mentioned, observed the full thickness rotator cuff tear in seven cases (18 %). After about a century, Keyes [2] stated that the prevalence was 19 %. In modern era, the lowest percentages reported in literature are the ones of Cotton [3] (8 %) and Neer [4] (5 %), deduced from studies carried out in 1964 and in 1983, respectively.

Examining 219 shoulders, Yamanaka et al. [5] reported a prevalence of partial and full thickness tears of 13 % and 8.4 %, respectively. Of all partial tears, 3 % were on bursal side, 3 % were on articular side, and 7 % were intratendinous. Otherwise, De Palma [10] and Uhthoff [11], examining 192 and 612 shoulders, affirmed that 75 % and 50 % of the subjects had a cuff tear. In these two series, the prevalences of partial tears were 58 % and 37 %, whereas the ones of full thickness tears were 9 % and 20 %.

Yamanaka et al. [5] and Fukuda et al. [6–8] observed that the prevalence of a partial or full thickness lesion was 0 % in the subjects younger than 40 years old, 30 % in those older.

Differently, Lehman et al. [9] asserted that prevalence was 6 % in subjects younger 60 years old and 30 % in those more elderly.

Studies on Asymptomatic Subjects [31–37]

Milgrom et al. [31] have performed 180 ultrasound scans of shoulders on 90 asymptomatic subjects and have observed partial and full thickness tears in 18 % and 17 % of cases, respectively. In addition, the authors have stated that the prevalence of the tears increases with the age of the patients and is greater than 80 % in subjects with more than 80 years old. Figure 1 shows the prevalence of the lesion in the different ages.

In a similar study, performed on 411 shoulders of asymptomatic subjects that had more than 50 years old, Tempelhof [32] observed full thickness tears in 23 % of the cases.

Sher et al. [33] have subjected to a MRI evaluation 192 asymptomatic shoulders (96 subjects). The authors have observed a partial or a complete cuff tear in 20 % and in 15 % of the cases, respectively. Furthermore, they have shown that the prevalence of tears increases with the age and it is 4 % in subjects younger than 40 years and 54 % in those older than 60 years (Fig. 2).

Other authors [34–37] have observed a prevalence of cuff lesions between 5 and 36 %.

Studies on Symptomatic Patients

Ultrasound-based studies [38–49] have shown that the prevalence of full thickness rotator cuff tear in subjects older than 40 years old with pain and/or functional limitation and/or loss of strength of the shoulder is between 16 and 69 %. The studies of Crass et al. [39] and Minagawa et al. [40] have enrolled big populations of patients: 500 and 1328 shoulders, respectively. In both, the prevalence of rotator cuff tear has been 22 %. Moreover, Minagawa et al. [40] have divided

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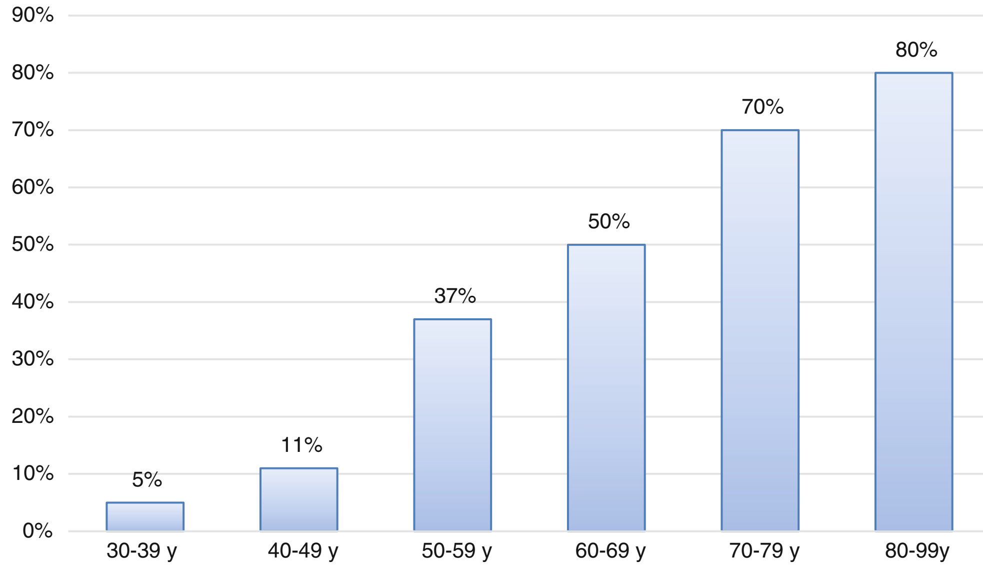
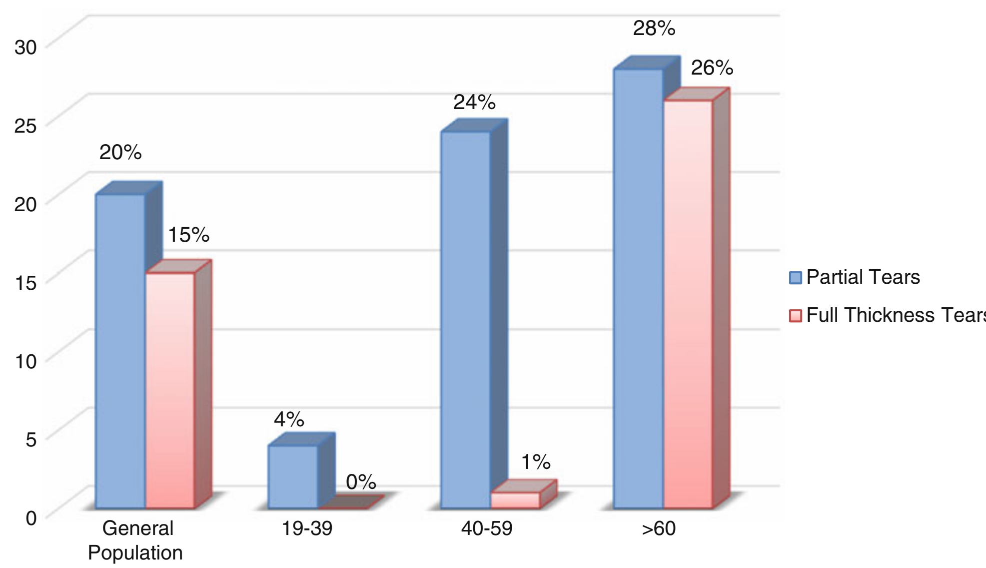


Fig. 1 Prevalence of rotator cuff tear on dominant limb in asymptomatic subjects that have undergone ultrasound examination, in the various age groups. (Milgrom, 1995)

Fig. 2 Prevalence of partial and full thickness tears in asymptomatic subjects that have undergone MRI examination, in the various age groups. (Sher, 1995)



their population in age-related groups and have shown that the ones aged under 50 years old had a prevalence of tears of 0 %, the ones aged between 50 and 59 of 11 %, between 60 and 69 of 15 %, and between 70 and 79 of 26 %. The prevalence in patients of more than 80 years raised up to 37 %.

Yamaguchi et al. [58] in 2006 have performed an echographic study of both shoulders in 558 patients with symptoms only at one of the two joints; 36 % of the studied subjects had normal cuffs, 34 % of the population had unilateral tears, and 30 % a bilateral ones. The authors have observed that a cuff tear was present in 64 % of symptomatic patients. Moreover, subjects with unilateral full thickness lesions had the possibility to have a partial or complete tear of the contralateral cuff in 20.8 % and 35.5 % of cases, respectively. On the contrary, in the case of incomplete tears, the probabilities to have a partial or full thickness lesion of the contralateral cuff were 29.3 % and 4.3 %, respectively.

As it was already noted in previous studies [5, 6, 8, 9, 31, 33, 40, 57], Yamaguchi et al. [58] showed that the prevalence of rotator cuff tear increases with age: in fact the group of patients without rupture had a mean age of 48 years, the one with unilateral lesions of 58 years and the one with bilateral tears of 67 years. Figures 3 and 4, taken from the study of Yamaguchi et al. [58], display the percentages of partial and full thickness tears in the patients with unilateral and bilateral disease.

The prevalence of rotator cuff tears increases if the shoulder is studied with magnetic resonance. Epidemiologic studies made in the last two decades using this technology demonstrate that it ranges between 28 and 77 % [48, 50–56].

Study on Mixed Population (Asymptomatic and Symptomatic)

Yamamoto [57] in 2010 has studied 683 patients from a little Japanese city by echography (1366 shoulders). The population included subjects aged between 22 and 87 years old (mean 58 years). The prevalence of full thickness rotator cuff tear has been 21 %, dropping to 17 % in asymptomatic patients and increasing to 36 % in symptomatic ones. Even in this study the prevalence increased with age reaching 80 % in patients aged more than 80 (Fig. 5).

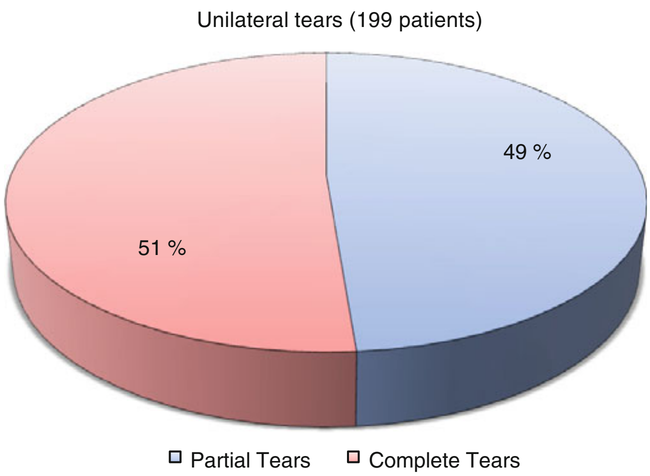


Fig. 3 Percentages of partial and full thickness tears in patients with unilateral tear (Yamaguchi et al. [58])

Our Experience

Age, Sex, Side, and Dominant Arm

Our data have been taken out of the examination of 718 consecutive patients (341 M: 47.5 % and 377 F: 52.5 %) that undergone surgical repair of full thickness rotator cuff tears. Mean age of the patients was 65 years old (range: 37–84 years, standard deviation (SD): 8.65). Right side was affected in 74.2 % of the patients and left one in 25.8 %. In 74.5 % of the patients, the tear involved the shoulder of the dominant arm. In particular way, in 72.9 % of this cases the lesion was

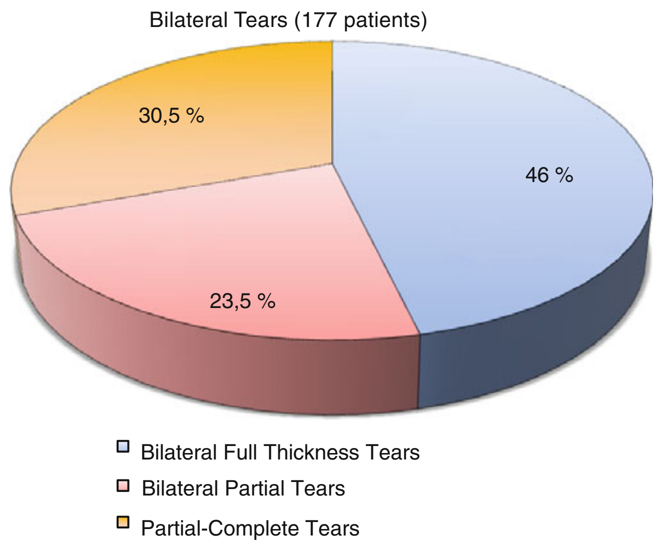


Fig. 4 Percentages of partial tears, full thickness tears and partial associated to full thickness tears, in the group of patients with a bilateral cuff lesions (Yamaguchi et al. [58])

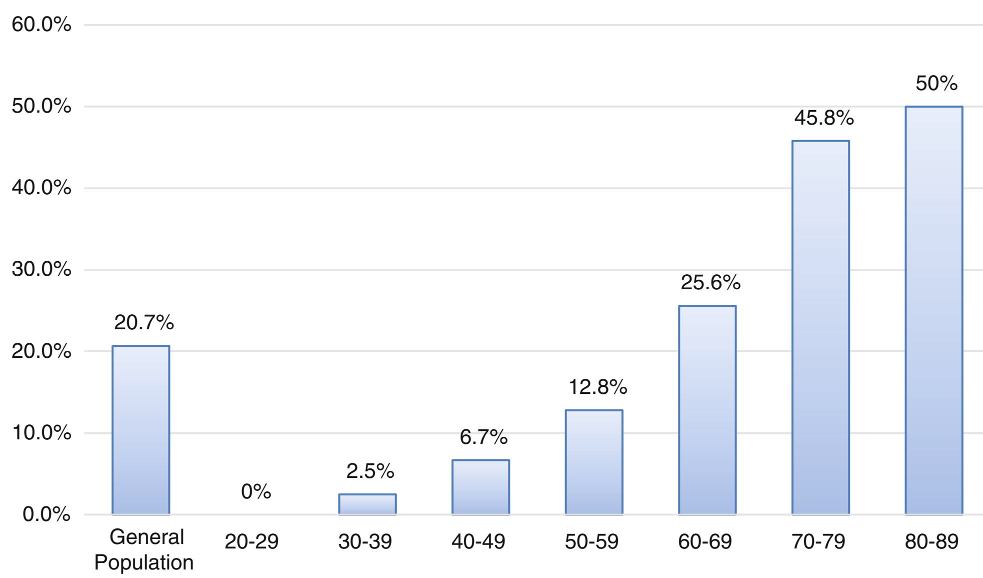


Fig. 5 Prevalence of rotator cuff tear in general population (Yamamoto 2010)

at the right shoulder, whereas in 1.6 % it was at the left one (Tables 1 and 2).

In the subgroup including male patients, the mean age was 64 years (range: 37–84 years; SD: 9.05) and the involved side was the right one in 76.8 % of the cases. In the subgroup of females, mean age was 66 years (range: 40–84 years; SD: 8.23). Right shoulder was involved in 72.6 % of the cases (Tables 1 and 2).

Occupation

22.3 % of the patients were, or had been, manual laborers (workers, construction workers, mechanics, cleaners, metal-workers, painters, farmers, etc.). 54.2 % of the patients were employers, businessmen, professionals, retailers. Finally, 23.6 % of the patients who undergone surgical repair were housewives (Table 3).

Table 1 Data of our 718 patients (sex, age)

	n.	%	SD
Asymptomatic patients	718	100	
Males	341	47.49	
Females	377	52.51	
Average age and range	65 [37–84]		8.65
Males' average age and range	64 [37–84]		9.05
Females' average age and range	66 [40–84]		8.23

n absolute values, % percentages, *SD* standard deviations

Table 2 Data of our 718 patients (dominant limb, tear side)

		%
Right-handed pts		96.77
	Right-handed pts with a Right tear	72.9
Left-handed pts		3.23
	Left-handed pts with a Left tear	1.62
Tear on dominant limb		74.52
Right tears		74.2
Left tears		25.8
Males		
	Right tears	76.76
	Left tears	23.24
Females		
	Right tears	72.62
	Left tears	27.38

Table 3 Data of the work activities of our patients

Occupation	%
Heavy (upper limb)	22.26
Not heavy (upper limb)	54.19
Housewife or pensioners	23.55

Tear Size

Out of simplicity, in this paragraph the tears were divided in small, large, and massive. We did not consider the various possible shapes of the lesions, nor have contemplated the patients that only had a partial lesion of the cuff (Table 4).

Of the 718 patients, 120 (16.7 %) (53 M: 44.2 %; 67 F: 55.8 %) had a small tear. The average age of these patients was 62 years (range: 41–78, SD: 8.95).

The tears that were classified as large were 62.1 % (446 patients). The average age of the patients with this type of lesion was 65 years (range: 37–84, DS: 8.58). 210 patients were males (47.1 %) and 236 were females (52.9 %).

Finally, 21.2 % of our patients (152) had a massive tear. The average age of these subjects was 69 years (range: 44–84, DS: 7.3). The percentages of males and females were 51.3 % (78 patients) and 48.7 % (74 patients), respectively. In 38.6 % of the cases, it has not been possible to repair the tendons. The average age of the patients with irreparable tears (56.8 % M and 43.9 % F) was 69 years (range: 45–78, DS: 6.69).

Statistical Analysis of Our Data

1. In our records, 47 % of all patients were males (341) and 52 % were females (377). The *one-sample binomial test*

Table 4 Data about tear size

Tear size		*n.*	%
Small		120	16.71
	Average age	62	
	Max-min age	78–41	
	SD	8.95	
	Males	53	44.17
	Females	67	55.83
Large		446	62.12
	Average age	65	
	Max-min age	84–37	
	SD	8.58	
	Males	210	47.09
	Females	236	52.91
Massive		152	21.17
	Average age	69	
	Max-min age	84–44	
	SD	7.3	
	Males	78	51.31
	Females	74	48.69
Massive-irreparable			38.6
	Average age	69	
	Max-min age	78–45	
	SD	6.69	
	Males		56.82
	Females		43.18

n absolute values, % percentages, *SD* standard deviations

Table 5 Percentages of male and female with different tears size

	Small	Large	Massive
M	44.2 %	47.1 %	51.3 %
F	55.8 %	52.9 %	48.7 %

shows that there is not a significant difference between the sexes ($p = 0.191$).

2. The patients that had a small tear were 120 (53 M: 44.2 %; 67 F: 55.8 %), those with a large tear were 446 (210 M: 47.1 %; 236 F: 52.9 %), and those with a massive tear were 152 (78 M: 51.3 %; 74 F: 48.7 %). In none of the groups, there is a significant difference between the sexes ($p = 0.494$, *Fisher's exact test*).
3. The *t-Student test* has shown a significant difference between the average age of the males (64 years) and females (66 years) that had a cuff tear ($p = 0.024$).
4. The *univariate ANOVA* has shown that there is a statistically significant difference between the average age of the patients that had a small tear (62 years), a large tear (65 years), and a massive tear (69 yeas) ($p < 0.001$). Furthermore, by applying the *t-Student test* it is clear that there is the same significant difference ($p < 0.001$) also comparing small and large tears, large and massive tears, and small and massive tears.
5. There were no significant differences between the average age of the males that had different sized tendinous tears (*univariate ANOVA*; $p > 0.05$). However, by applying *t-Student test*, it does emerge that there is a significant difference ($p < 0.001$) between large tears and massive tears and between small and massive tears.
6. The same tests applied to the female sample have shown that there is also a significant difference ($p < 0.001$) between the different sized tears (small vs large; large vs massive; small vs massive).
7. Table 5 shows that with the increase of the tear size, it does also increase the number of male patients and, consequently, decreases the one of female patients.
8. These data are confirmed by *Kendall's tau test* which shows a weak inverse correlation (value: −0043) between the percentages of males and those of females in relation to the tear size. However, this correlation is not statistically significant ($p = 0.231$).

Conclusions

- The most significant result that emerges from the epidemiological studies is that the prevalence of rotator cuff tear increases with the age and that the tear should be considered as a physiological condition related to the progressive degeneration of tissues, because it is observed in a high percentage of patients older than 80 years.
- Of the epidemiological studies oriented to notice the prevalence of cuff tear, the most reliable are those conducted on a mixed population (asymptomatic and symptomatic subjects, without limit of age) and by magnetic resonance imaging. In fact, those carried out on cadavers overestimate the percentage of lesions due to the fact that the criteria established by hospitals and/or law for postmortem procedures may involuntarily select a population more predisposed to have lesions (patients with chronic diseases, metabolic disorders, homeless).
- The studies carried out with echographic examinations are widely criticized because they are influenced by operators and have low reproducibility and low concordance.
- The prevalence of cuff tear is, obviously, lower in groups of asymptomatic subjects compared to the one of those symptomatic; moreover, pain and/or functional limitation are not constant in cuff tear so the percentage of tear in asymptomatic subjects is low but not null.

Epidemiological studies performed on a large number of patients with cuff tear [59–66], and the data extrapolated from our clinical records do indicate that there is a sex-linked predisposition for rotator cuff tear.

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Part II

Etiopathogenesis of the Cuff Tear

Rotator cuff tear has a multifactorial etiology. Age [1–3], altered biology [4, 5], tendon hypovascularity [6–9], smoking habit [10, 11], and tendon overload-overuse [12, 13] are generally believed to be intrinsic factors. They are responsible for a series of cellular changes mainly represented by increased matrix metalloproteinases and reduced tissue inhibitors of metalloproteinases [14, 15], nitric oxide synthetases [16], and chondroid metaplasia [17]. All of these changes disturb the turnover rate and proliferation of collagen, leading tendon to degeneration and apoptosis [18–20].

Distinct anatomic variants of the scapula (subacromial and subcoracoid impingement), acromioclavicular joint arthropathy, and pathology of the thoracic spine (thoracic hyperkyphosis) are usually listed among the extrinsic factors causing cuff tear. According to the extrinsic theory, anatomic structures are responsible, in a dynamic fashion, for degenerative changes observed in rotator cuff tendinopathy.

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Histopathology of Rotator Cuff Tear

Claudio Di Cristofano, Carlo Della Rocca, and Stefano Gumina

The pathogenesis of rotator cuff tear is multifactorial. Tendon abnormalities include alteration of collagen fiber structure, tenocytes, cellularity, and vascularity. Ruptured tendon shows marked collagen degeneration and disordered arrangement of collagen fibers. Fibroblast population decreases as tear size increases. The larger fibroblast population, seen in the smaller tears, is also actively proliferating and is part of an active reparative process. Inflammatory cell infiltrate correlates inversely to cuff tear size in the torn supraspinatus tendon samples, with larger tears showing a marked reduction in all cell types. As tear size increases, there is also a progressive decrease in the number of blood vessels. Whether rotator cuff tear could heal spontaneously is an important pathologic and clinical question.

In the tendon healing process, three phases can be distinguished:

1. Inflammatory, characterized by hematoma, fibrin deposition, inflammatory cells, fibroblasts, beginning of collagen and elastin fibrillogenesis
2. Proliferative, characterized by angiogenesis and fibroblast proliferation with collagen fibers displayed in random arrangement
3. Remodelling, with hypocellularity, normal vascularization, tendon crimps, collagen, and elastic fibers [1].

The most important histopathological finding in ruptured tendons consists mainly of disarray (i.e., loss of structural organization), poor or absent neoangiogenesis, chondral metaplasia, and fibrosis. All these features seem to give to the tendon tissue a low healing capability, so that it may therefore explain why cuff lesions are at high risk of retear. It seems possible to refer to a condition of healing failure rather than retear, introducing the new concept of "nonhealing." Considering the subacromial bursa, the main histopathological features consist of absence of disarray, neoangiogenesis, absence of chondral metaplasia, hyperplasia/hypertrophy, and absence of necrosis. These aspects might suggest a high reparative potential linked to the bursal tissue [2, 3].

In detail, considering the time elapsed from the onset of symptom, interesting differences can be observed: in recent lesions tendon fibrosis, which could be interpreted as the first attempt to "close the hole," and necrosis, which decreases during time, are present; in addition bursal tissue inflammation, which could be interpreted as an activation of this tissue to allow tendon repair, is also detected. Unfortunately as time passes (such as in inveterated lesions) bursal tissue inflammation decreases so that bursal tissue hyperplasia and hypertrophy are the results of this "reparative burst." Tendon neoangiogenesis and inflammation sensibly decrease as patient's age increases; on the contrary, bursal neoangiogenesis, hypertrophy/hyperplasia, and inflammation directly increase with age. These aspects could be interpreted as an attempt to repair starting from the bursal tissue [2, 3].

By these aspects, it is possible to speculate that in younger people the repair process could start from the tendon tissue, but as age increases, the repair process seems more to depend from bursal tissue that tries to lead to tendon healing.

Some histopathological features could explain why in young people there are more possibilities of tendon healing after rotator cuff tears [4]. These aspects could be interpreted as an anatomical repair process: as the lesion size is greater the more the tendon tissue needs vessels and cells to allow a repair. In small lesions, fibrosis of bursal tissue can be seen, but as size becomes greater fibrosis decreases, while inflammation and hyperplasia increase; it could be speculated that this aspect could be related to an increased activation of the bursal tissue to allow the tendon repair. It could be possible that in small lesion, the repair process could start from the tendon tissue, but in large lesions the attempt to repair starts with the activation of the bursal tissue.

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Pathological and genetic studies on rotator cuff disease have emphasized the importance of intrinsic factors, but little information regarding the process of tendon degeneration is available.

Characteristic histopathological changes have been described in spontaneous tendon tears (with no traumatic cause) with degenerative changes that were evident in most cases and included features of hypoxic degenerative tendinopathy, mucoid degeneration, tendolipomatosis, and calcifying tendinopathy, either individually or in combination [2, 3].

The progressive tendon degeneration is characterized by thinning of the collagen fibers, a loss of collagen structure, myxoid degeneration, hyaline degeneration, metaplasia chrondroid, and fatty infiltration [5]. What is termed as "chondroplasia," in which the tendon tissue is replaced by fibro-cartilage tissue-like phenotype, develops [6].

Tendon is highly mechanically adaptive, and the progressive mechanical failure to bear the physical demands placed upon it is a characteristic feature of rotator cuff tears [7]. In the tendon disease, total collagen content decreases, while there is a significant increase in the percentage of type II and type III collagen compared to type I.

The change in collagen type takes place together with a transformation of the matrix from a structure composed of large-organized fibrils into small-disorganized fibrils with an obvious decreasing of the mechanical properties. The mature and hydroxylysine cross-links significantly increase, and this pattern may be a feature of the incomplete remodeling found in scar tissue [8]. The increase in the glyco-proteins tenascin-C and fibronectin is consistent with a wound healing process occurring in degenerate tendon.

Changes to several different proteoglycans in rotator cuff tear are varied, but the overall picture appears to be the one of fibro-cartilaginous tissue; this is characterized by increased aggrecan and biglycan, with decreased decorin.

The role of tendon stem cells (TSCs) remains to be determined, but their responses to differing mechanical stimuli hint towards an important role [9–11]. TSCs have been shown to proliferate and produce collagen in response to exercise, while they have been shown to differentiate into nontenocytes if excessively mechanically loaded. A report suggested that an extracellular matrix-rich niche, organized partly by biglycan and fibromodulin, controls the self-renewal and differentiation of TSCs [12]. The self-renewal capacity and differentiation capability of TSCs reduces with increasing age, and this is likely to be important in explaining the age-related nature of rotator cuff tears [13, 14] (Figs. 1, 2, 3, and 4).

Summarizing, histopathological findings suggest that changes in collagen and proteoglycans types and amount, degenerative modifications, and chondrometaplasia lead tendons to weakness and predispose it to the tear; the bursal tissue may play a prominent role in the healing process; stem cell role has to be deeply investigated.

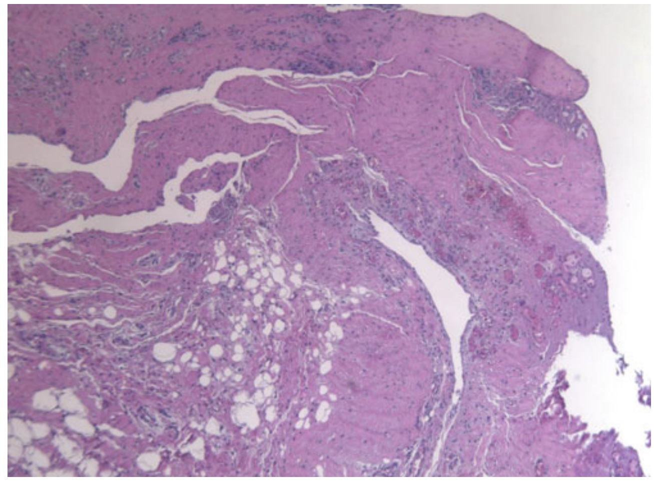

Fig. 1 The figure shows the hematoxylin and eosin staining of the rotator cuff tear (Å~5). Chronic inflammatory infiltrate, fibroblasts proliferation, and sclerosis, that are related to neoangiogenesis, are observable

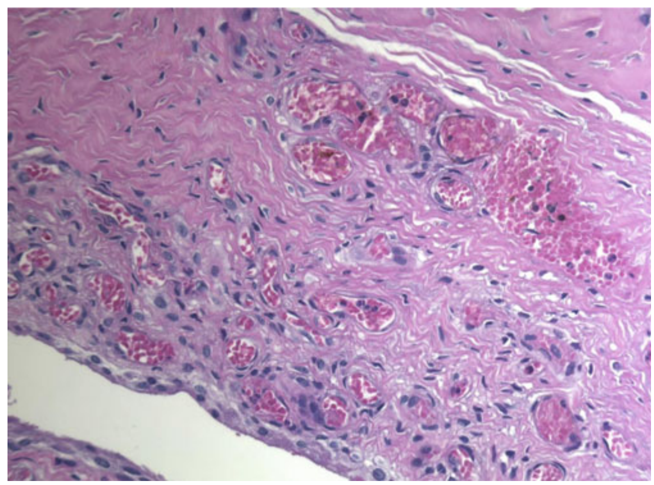

Fig. 2 The figure shows a characteristic neoangiogenesis and fibroblast proliferation with collagen fibers displayed in random arrangement (E/E 20×)

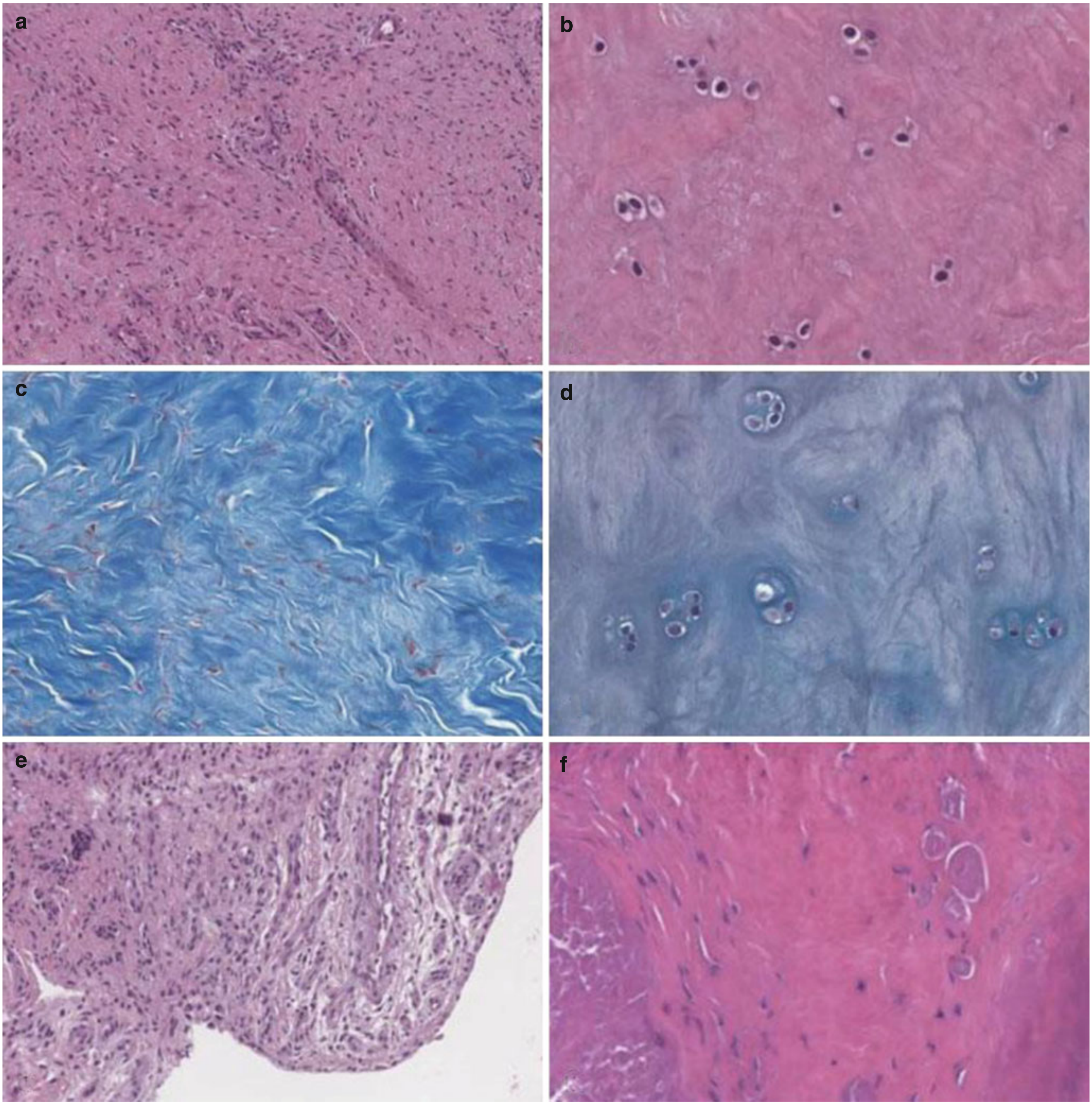

Fig. 3 (**a**) Tendon: capillary proliferation and increased cellularity (H/E 109). (**b**) Tendon: chondral metaplasia: chondrocytes-like cells were either clustered in groups or randomly dispersed in the matrix (H/E 40×). (**c**) Tendon: collagen fibers appear discontinuous and disorganized (Masson's trichrome 209). (**d**) Tendon: chondral metaplasia: alcian blue staining provides the histochemical demonstration of the presence of sulfated glucosaminoglycans (40×). (**e**) Bursa: bursal samples showed edema, capillary proliferation, and hypertrophy/hyperplasia of synoviocytes (H/E 10×). (**f**) Bursa: fibrosis, necrosis, and calcifications (H/E 20×)

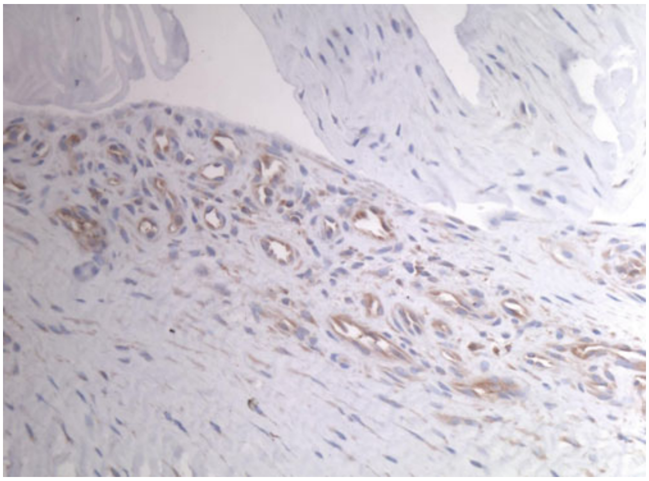

Fig. 4 The figure shows the positive cells (*brown*) after immunohistochemical stain for anti-p65 antibody on the margins of the rotator cuff tear

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The Impact of Aging on Rotator Cuff Tear Size

Stefano Gumina and Stefano Carbone

Classically, most authors consider that the incidence of rotator cuff tears increases with age [1–11]. Previous cadaveric studies have demonstrated a large prevalence of cuff tears with increasing frequencies in older patients. Milgrom et al. [6], using ultrasonography, reported that 65 % of their study population older than 70 years had a rotator cuff tear. As it arises from previous literature, a consistent part of subjects/patients older than 60 years has a rotator cuff tear. On the other side, there is an almost complete lack of information about the link between age, gender, and rotator cuff tear size. It was only Yamagouchi et al. [8] who stated that age is not significantly related to tear size using ultrasonographic evaluations. To our knowledge, no study has yet related patient's age to rotator cuff tear dimension detected during surgery.

Recently, we performed a study to evaluate whether age over 60 years and aging in general may influence cuff tear size [12]. Therefore, an observational study design was used. The cases included 586 consecutive patients who underwent arthroscopic treatment for a rotator cuff tear. For the purposes of the study, patients were divided into two groups depending on whether their age was older or younger than 60 years. Exclusion criteria for all participants were primary osteoarthritis of the operated or contralateral shoulder, a previous operation the shoulder, os acromiale, and inflammatory joint disease. The mean age of the case group was 59 years old (range 46–73). Out of 586 patients, there were 280 males and 306 females. The Southern California Orthopaedic Institute (SCOI) classification of complete rotator cuff tears was used to classify tendon tears intraoperatively [13].

We considered tendon tears as definitely irreparable when two or more tendon tears had been associated with retraction beyond the glenoid articular surface and/or significant fatty degeneration of the respective muscles (Goutallier 3–4) [14].

The preoperative evaluation included a physical examination, X-ray (true AP, outlet and axillary view), and MRI studies. We studied the relationship between aging and shoulder tendons tears using the following steps. First, we applied a multinomial logistic regression model to explore the association between the age older than 60 years and each type of tear (small, large, or massive). Second, we used the analysis of covariance (ANCOVA) method to determine whether mean age increases from small to large up to massive tear. All analyses were adjusted for gender.

Sample characteristics are reported in Table 1. Adjusting for gender, the overall risk of tear occurrence was twice as high in patients older than 60 years compared to younger patients (OR = 2.12, 95 % CI 1.44–3.0). While no association was detected between age older than 60 years and the probability of a small tear (OR = 0.58, 95 % CI 0.27–1.07), subjects older than 60 years were twice more likely to experience a large tear (OR = 2.29, 95 % CI 1.51–3.27) and three times more likely to experience a massive tear (OR = 3.09, 95 % CI 2.07–5.38) as opposed to younger subjects. Mean age significantly increased from small tear (53.8 years) to large tear (66.8 years) up to massive tear (69.4 years) (ANCOVA: $F(2, 437) = 16.487$, $p = 1.51$ 9 10–7).

It seems that the age of 60 years is a sort of threshold for developing a rotator cuff tear. This concept arises from previous studies in which a significant proportion of patients over the age of 60 years have a rotator cuff tear [6, 7, 11]. The authors reported the results by using different tools, such as magnetic resonance and ultrasound. Obviously the adopted methodologies have been widely accepted in orthopedic community, with ultrasound comparable to magnetic resonance and arthrography [6, 15], but the validity of an arthroscopic evaluation is certainly superior. All patients evaluated in this study had the arthroscopic evaluation of tear dimensions. Such a potential limitation present in other studies has been overcome. In addition, correlation with cuff tear size was unavailable in these studies; only a retrospective study of 2006 with a huge number of patients affected by cuff tear (588) examined ultrasonographically the correlation between tear dimension (in mm) and age, with age not significantly related to the size of the tear in shoulders with or without pain

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Table 1 Descriptive of cases

	Mean age (SD)[a]	Gender M	Gender F	*N* subjects older than 60[b]
Small tear patients (*N* = 130)	53.8 (8.4)	72	58	20 (15.38)
Large tear patients (*N* = 312)	66.8 (7.9)	143	169	179 (57.37)
Massive tear patients (*N* = 144)	69.4 (3.8)	65	79	94 (65.2)

SD Standard deviation
[a]Age is measured in years
[b]Percentage of subjects older than 60 years is shown in parentheses

[11]. In this study, we analyzed a large cohort of patients comparable to those of Yamagouchi et al. [11] with a symptomatic rotator cuff tear and undergoing surgery. As it is an observational study, we were not able to obtain scientific data about time elapsed from the beginning of the symptomatology, and, more interestingly, when their rotator cuff initially torn which resulted in not having direct data of progression of tear dimension over time, however, previous literature can support our concept. In fact, the tear size in both symptomatic [16] and asymptomatic [8] cuff tear patients, nonoperatively treated, was increased, and there was a greater probability of increasing the tear size in older patients rather than in younger ones. Considering that all patients of this study requested surgery and that it is current practice in our institution to operate only symptomatic patients, it is conceivable that being the most of the cohort with an at least large tear older than 65 years aging is directly correlated with cuff tears size dimensions. Certainly, there are other factors working in the progression of a cuff tear that might be related to the patient's age. Cardiovascular disease and comorbidities in general [17], cigarette smoking [18], and tendon hypovascularity [19, 20] compromise the tendon and cause degeneration of the tendon itself; moreover, each of the mentioned factors, adjusted for age and gender, coparticipate in the most common tendinous injury in the adult population.

The study we performed has a limitation that needs to be addressed: it is an observational study, and therefore, it could not completely resolve issues concerning temporality about aging and tear dimension in respect to symptomatology. The continuing study involves a larger cohort of patients, showing that larger tears are not characterized by a worse symptomatology.

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Smoking Habit

Stefano Carbone and Stefano Gumina

Smoking is a commonly recognized cause of morbidity and mortality; its relationship to cardiovascular and pulmonary disease is well established [1]. An association of tobacco along with musculoskeletal pain and dysfunction has been reported [2]. Recent experimental studies of the adverse consequences of smoking relative to bone and soft-tissue healing showed that cigarette smoking interfered with bone graft and wound healing [3, 4], with infection rates in smokers [5], and with musculoskeletal pain and dysfunction [6]. A recent study observed a dose-dependent and time-dependent relationship between smoking and rotator cuff tears. Two substances commonly present in a cigarette, nicotine, and carbon monoxide have different roles, but both of them are harmful. Nicotine is recognized to be a potent vasoconstrictor that decreases the delivery of oxygen to tissues. The role of nicotine has been also recognized as one of the reasons of delayed healing of tendon to bone after rotator cuff repair surgery [7], while carbon monoxide decreases cellular oxygen tension levels necessary for cellular metabolism. Vascular insufficiency to the critical portion of the supraspinatus/infraspinatus tendon has a well-defined contribution to the genesis of rotator cuff tear [8]. With the understanding that tobacco smoking creates a plethora of microvascular diseased tissues, ranging from the skin to the heart, it is not hard to imagine that smoking tobacco also would decrease the vascular supply of an already vascularly challenged tissue [9] such as the critical portion of the rotator cuff insertion.

In the series of Mallon et al. [10], 42 % of patients who underwent open rotator cuff repair were smokers. The same authors found that smokers who undergo rotator cuff repair have poorer postoperative results than nonsmokers. Baumgarten et al. [11] found that 61.9 % of patients with rotator cuff tear had a history of daily tobacco smoking. Similarly, Kane et al. [12] evaluated the rotator cuffs of 72 cadaveric shoulders and investigated 36 shoulders that exhibited macroscopic rotator cuff tears; 23 (64 %) were from deceased donors with a history of smoking and only 13 had no history of smoking.

To our knowledge, no study has focused on the correlation between cigarette smoking and rotator cuff tear size. We hypothesized smoking may influence rotator cuff tear size; therefore, we undertook a study of the smoking habits of the patients with rotator cuff tears who had undergone arthroscopic cuff repair.

We studied 408 consecutive patients who underwent arthroscopic repair of a full-thickness rotator cuff tear. The Southern California Orthopedic Institute (SCOI) classification of complete rotator cuff tears [13] was used to classify tendon tears intraoperatively as:

- A small, complete tear, such as a puncture wound (type I)
- A moderate tear (usually <2 cm) that still encompasses only one of the rotator cuff tendons, with no retraction of the torn ends (type II)
- A large, complete tear involving an entire tendon, with minimal retraction of the torn edge, usually 3–4 cm (type III)
- A massive rotator cuff tear involving two or more rotator cuff tendons, frequently with associated retraction and scarring of the remaining tendons ends, and often an L-shaped tear that is frequently irreparable (type IV)

For analysis, patients were placed in one of two groups by their smoking history. Current smokers, defined as any patient who was smoking at least 10 cigarettes per day at the time of surgery, and those with a smoking history of more than 40 pack-years were included in the study group, and all others were classified as nonsmokers [10]. The mean age of the study group was 59 years (standard deviation, 11.3; range, 47–68 years); 228 patients were men, and 180 were women.

Exclusion criteria for all participants were primary osteoarthritis of the operated-on or contralateral shoulder, a

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previous operation on the shoulder, and inflammatory joint disease.

The analysis started by comparing the frequencies of smokers among the patients with different types of tears. At this stage, the analysis was based on crude $\chi 2$ as well as on adjusted odds ratios (OR) within logistic regression models that included age and gender as covariates. Subsequently, the analysis proceeded by considering only smokers and investigating the association of the amount and duration of smoking exposure with the type of tear. The amount of smoking exposure was estimated as the average number of cigarettes smoked per day or total number of cigarettes smoked in life (average smoked daily per duration); the duration was estimated as the difference between the patient's age and the age at which the patient started smoking. The average number of cigarettes per day and the total number of cigarettes in life were compared among the patients with the different types of tears by using the analysis of covariance (ANCOVA) method with age and gender as covariates.

After the results were analyzed as described, data of two or more categories were amalgamated. It is reasonable to combine categories showing similar frequencies of a certain exposure of interest or categories including such low numbers of participants that statistical inference becomes unfeasible. This increases the likelihood of obtaining a statistical significant result [14].

We classified 131 patients as smokers (32.1 %), and the remaining 277 (67.9 %) were nonsmokers. Tears were small (type I) in 95 patients (23.3 %), medium (type 2) in 214 (52.5 %), large (type III) in 74 (18.1 %), and massive (type IV) in 25 (6.1 %). The frequency of smokers increased across patients with increasing severity of tears. The frequency was 23.2 % (22 patients) in those with type I tears, 33.6 % (72 patients) in those with type II tears, 36.5 % (27 patients) in those with type III tears, and 40 %(10 patients) in those with IV tears. In the nonsmoker group of 277 patients, 73 (26.4 %) had type I tear, 142 (51.3 %) had type II tear, 47 (17 %) had type III tear, and 15 (5.4 %) had type IV tear. These and other results are summarized in Table 1. Although suggestive of a trend, the difference in frequency was not significant ($\chi 23 = 5.088$; $p = 0.165$). When amalgamating type II and type III tear patients into the same category, which seemed reasonable given the small difference in the frequencies of smokers, the association approached the significance level ($\chi 22 = 4.884$, $p = 0.087$).

In the light of the relatively low number in the type IV tear category, as well as to minimize random variability, patients reporting type IV tears were combined with those reporting type II tears. By doing this, the frequency of smokers among the patients with at least a type II tear resulted in 34.8 % and differed significantly from the 23.2 % frequency among the type I tear patients ($\chi 21 = 4.550$, $p = 0.033$). A logistic regression model using positive smoking history as the outcome variable and including age and gender as covariates showed increasing frequencies of smokers across patients with increasing severity of tears, with all frequencies being significantly higher compared with patients with a type I tear. Similar results were obtained when combining type II with type III tear patients, or type II with type III and type IV tear patients. When considering only 131 smokers, the ANCOVA model incorporating age, gender, and duration of smoking exposure as covariates showed increasing daily average numbers of cigarettes across patients with increasing severity of tears, although the differences were only suggestive of significance ($F(3.124) = 2.133$, $p = 0.099$). The number of daily cigarettes and standard deviation per type of cuff tear are shown in Fig. 1. These differences had significant results when amalgamating type II with type III tear patients ($F(2.125) = 3.222$, $p = 0.043$), or type II with type III and type IV tear patients ($F(1.126) = 4.317$, $p = 0.040$). The ANCOVA model also indicated that adjusting by age and gender, the total number of cigarettes smoked in life differed significantly between patients with a type I tear and those with at least a type II tear ($F(1.127) = 4.694$, $p = 0.032$).

The nicotine inhaled from cigarette smoking has been implicated as a major vasoconstrictor [15]. Vasoconstriction

Table 1 Distribution of different types of rotator cuff tear between smoker and nonsmoker patients

		Type of tear				
		Type I	Type II	Type III	Type IV	Total
	Number	73	142	47	15	277
Nonsmokers	% within nonsmokers	26.4	51.3	17	5.4	100
	% within type of tear	78.8	66.4	63.5	60	
	% total	17.9	34.8	11.5	3.7	67.9
Smokers	Number	22	72	27	10	131
	% within smokers	16.8	55	20.6	7.6	100
	% within type of tear	23.2	33.6	36.5	40	
	% total	5.4	17.6	6.6	2.5	32.1
Total	Number	95	214	74	25	408
	% total	23.5	52.5	18.1	6.1	100

in an already hypovascular tendon could likely have an adverse effect on rotator cuff metabolism and healing. Given that one of the important factors in effective rotator cuff metabolism is the maintenance of a good vascular supply to the tendon, it would seem that cigarette smoking could impair metabolism because it negatively affects vascularity. The edge of the cuff tear has been found to be rich in fibrocytes and dystrophic calcifications; away from the edge, the tendon appears hypocellular, containing areas of myxoid and fatty degeneration [16]. It is understandable that tobacco smoking has an important part in tendon degeneration processes because it causes hypoxia in an already hypovascular zone. In our study group, smokers represented one-third of the cohort. This rate is probably the most reliable because it was obtained from the widest studied cohort. Furthermore, this rate is higher than the 25 % reported in 2010 which was the national prevalence in the general Italian population aged 45–64 years [17].

Our study showed that larger rotator cuff tears tend to develop more in smokers than in nonsmokers and that tears increase in severity with an increasing average daily numbers of cigarettes. There seems to be a dose-dependent relationship showing that with increasing amount of tobacco use, the risk of a larger rotator cuff tear will increase concomitantly.

This study is in line with others that negatively relate smoking to rotator cuff tear as it evidences a negative correlation between tobacco and rotator cuff tear. Compared with other scientific reports considering tobacco smoking as a risk factor for the development of rotator cuff tears, our study group of 408 patients is wider. Furthermore, differently from previous studies that used ultrasonography [11], cadaveric dissections [12], and open surgery [10], the diagnosis of rotator cuff tear in our study was confirmed arthroscopically.

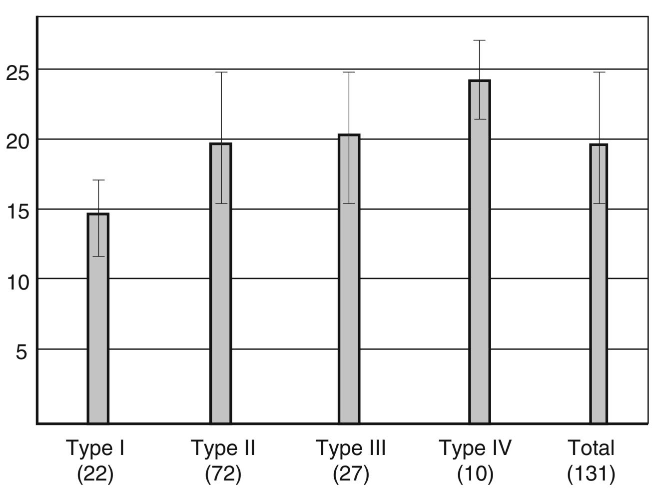

Fig. 1 Graph showing number of cigarettes per day and standard deviation per type of cuff tear

By linking our results to preceding data on the perioperative management of patients with cuff tears, we can hypothesize that the rotator cuff tears that develop in smokers are more severe and challenging both to manage and repair, and moreover, these tears are more susceptible to repeat tear. In fact, large and massive tears are more frequent in smokers than in nonsmokers. As highlighted by Sugaya et al. [18], the repeated tear rate for shoulders with large and massive tears remains higher than that the one for smaller tears, and shoulders with large repair defects demonstrate significantly inferior functional outcomes. Similarly, large and massive rotator cuff tears result in more postoperative weakness after repair than small tears do [8].

Our study has a potential limitation. We chose a 40 pack-year history of smoking, along with a history of active smoking at the time of the arthroscopy, to indicate a significant level of smoking that might affect the dimensions of the rotator cuff tear. These criteria were used in another important study that linked rotator cuff tear and smoking habit [10]. However, they are arbitrary, because no scientific study has provided evidence on the effects of smoking on bone and soft-tissue metabolism.

Take Home Message

- Smoking habit has a relationship with cuff tear severity: in particular, there is a linear relationship between the number of cigarettes daily smoked and the progression of tear size.

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Arterial Blood Hypertension

Stefano Gumina and Paolo Albino

Multicenter studies in different countries have published data about the higher risk of cardiac disease and stroke in patients affected by hypertension [1]; unfortunately, the possible degenerative effects of hypertension on osteotendinous junctions still have to be brought to light. The genesis of rotator cuff rupture is multifactorial. Intrinsic factors, such as rotator cuff hypovascularity [2], have been taken into consideration. Arterial hypertension is a cause of peripheral hypovascularity; therefore, patients with arterial hypertension could conceivably have a more frequent prevalence of rotator cuff tear.

Although the relationship between high blood pressure and rotator cuff tear has already been highlighted, no previous studies have analyzed whether hypertension is also related to the size of rotator cuff tears. We performed the first study [3] whose aim was to show the relationship between arterial hypertension and cuff tear size.

The cases were 408 consecutive patients who underwent arthroscopic repair of a rotator cuff tear between January 2009 and May 2010 and were treated by two of the authors (S.G., V.C.). The control group included 201 individuals who underwent orthopedic examination because of pathologies not affecting the shoulder. For the purposes of this study, participants were divided into two groups depending on the presence or absence of hypertension. Participants were provided with information booklets explaining the aim of the study, and informed consent documents were signed before participation.

Current hypertensive patients had been diagnosed with hypertension on the basis of a 24-h-pressure Holter assessment at the time of the hypertension diagnosis, defined as systolic blood pressure (SBP) >125–130 mmHg and diastolic blood pressure (DBP) >80 mmHg, requiring three office measurements of blood pressure >140 (SBP)/90 (DBP) mm Hg. Furthermore, they were receiving antihypertensive therapy when the cuff tear was diagnosed (Guidelines Committee 2003). Six blood pressure thresholds (mm Hg) for the definition of hypertension with different types of measurements are summarized in Table 1. In addition, all included patients had a new series of three office measurements of blood pressure at the time of surgery to determine whether they had good arterial blood pressure control. Exclusion criteria for all participants were primary osteoarthritis of the operated-on or contralateral shoulder, a previous operation on the shoulder, os acromiale, and inflammatory joint disease. The 408 patients (228 men, 180 women) were of a mean age of 59 years (range, 47–68 years). The 201 controls (92 men, 109 women) were of a mean age of 62 years (range, 47–75 years). The Southern California Orthopaedic Institute [4] classification of complete rotator cuff tears was used to classify tendon tears intraoperatively:

A small, complete tear, such as a puncture wound or a tear (usually <2 cm), that still encompasses only one rotator cuff tendon, with no retraction of the torn ends

A large, complete tear involving an entire tendon, with minimal retraction of the torn edge, usually 3–4 cm

A massive rotator cuff tear involving two rotator cuff tendons, frequently with associated retraction and scarring of the remaining tendon ends and often an L-shaped tear that is frequently irreparable.

The preoperative evaluation included a physical examination, x-ray imaging (true anteroposterior, outlet and axillary

Table 1 Blood pressure thresholds (mmHg) for definition of hypertension with different types of measurement

	SBP[a]	DBP[b]
Office or clinic	140	90
24-h	125–130	80
Day	130–135	85
Night	120	70
Home	130–135	85

[a]*SBP* systolic blood pressure

[b]*DBP* diastolic blood pressure

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Table 2 Descriptive of cases and controls

	Mean age[a] (SD)	Gender M	Gender F	N subjects with hypertension[b]	Mean duration[c] (SD) of antihypertensive therapy
Controls (*N* = 201)	63.9 (8.9)	99	102	66 (32.8)	21 (37)
Small tear patients (*N* = 95)	56.5 (8.4)	49	46	16 (16.8)	13 (33)
Large tear patients (*N* = 215)	64.8 (7.9)	106	109	109 (50.7)	38 (44)
Massive tear patients (*N* = 98)	70.4 (4.0)	44	54	73 (74.5)	75 (54)

SD standard deviation
[a]Age is measured in years
[b]Percentage of hypertensive subjects is shown in parentheses
[c]Duration of therapy is measured in months

view), and magnetic resonance imaging. The cohort underwent a detailed medical history evaluation with the focus on the presence of hypertension. Therapy with antihypertensive agents was also recorded. We used three steps to study the relationship between hypertension and shoulder tendons tears: First, we applied a logistic regression model to investigate if hypertension affects the risk of a tear. Second, we applied a multinomial logistic regression model to explore the association between hypertension and each type of tear (small, large, or massive). Third, we used the analysis of covariance method to determine if the duration of hypertension influenced the severity of the tear.

We compared the mean duration of antihypertensive therapy in patients with a small, large, or massive tear. All analyses were adjusted for age and sex.

Baseline characteristics of four study groups are reported in Table 2. Patients with a massive tear were slightly older than the control participants and also older than patients with a small or a large tear; therefore, age was included as a covariate in the subsequent statistical analyses. The proportions of men and women were similar in the control group and in each patient category. Adjusted for age and sex, the risk of tear occurrence was twice as high in hypertensive individuals as in normotensive participants (odds ratio [OR], 2.05, 95 % confidence interval [CI], 1.41–2.98).

Although hypertension did not affect the probability of a small tear (OR, 0.63; 95 % CI, 0.33–1.19), hypertensive individuals were two times more likely to experience a large tear (OR, 2.09; 95 % CI, 1.39–3.16) and four times more likely to experience a massive tear (OR, 4.30; 95 % CI, 2.44–7.58) compared with normotensive individuals. The mean duration of antihypertensive therapy significantly increased from 13 to 38 to 75 months in patients with, respectively, a small, medium, or massive tear (analysis of covariance F(2,403) =16.357, $P = 1.48 \times 10^{-7}$).

Our observations show that patients with hypertension have a significantly higher prevalence of large and massive tears. Owing to the fact that our results are not influenced by age, they are therefore not affected even by the natural history of the lesion, which might be responsible for the extension of the tear size, and it may be deduced that a wide insertional area of the cuff is degenerated because of impairment in the microvasculature. The mean duration of antihypertensive therapy significantly increased from small to large and to massive tear patients. Our study is based only on macroscopic intraoperative observations, limiting us to the following hypotheses.

Hypertension is the consequence of an artery wall disease; therefore, the degenerative changes of the rotator cuff footprint occur simultaneously or even before the onset of hypertension; thus, the cuff footprint is already compromised when the patient starts antihypertensive therapy. If this assumption is true, the time elapsed from the beginning of the artery wall disease is more important than the time elapsed from the beginning of antihypertensive therapy. In addition, arterial hypertension is a subtle disease, because it is completely asymptomatic at the beginning. It is conceivable that during the period between the onset of hypertension and the beginning of the drug therapy, tendinous tissue resulted in a state of hypoxia that was responsible for degenerative changes in the footprint.

Some of the most-used pharmacologic treatments angiotensin-converting enzyme (ACE) inhibitors, b -blockers, and angiotensin-II receptor antagonist work more on the great vessels than on the microcirculation; therefore, in patients who use these drugs, the tendon tissue continues to be in a state of hypoxia, leading to tendon degeneration and to the subsequent wide rupture.

Take Home Message

- Patients with hypertension are more likely to develop a large or massive cuff tear.
- A longer duration of antihypertensive therapy, interpreted as duration of disease, is correlated with an increased severity of tear.

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Obesity

Stefano Gumina, Vittorio Candela, and Daniele Passaretti

Obesity is a common condition in many societies, and its incidence is rising [1]. It is defined as an excess of body fat, which may contribute to cause peripheral vascular deficiencies through its known associations with atherosclerosis [2, 3], elevated cholesterol level [2–4], and diabetes and metabolic syndrome [5]. All these correlated pathologies may lead to hypoxia of the rotator cuff critical area; the consequent release of many reactive oxygen species causing oxidative stress and cell apoptosis may cause degeneration of the tendon and predispose it to rupture [6].

Adiposity is difficult to measure; however, increased body fat is accompanied by increased total body fat, so indices of relative weight are commonly used to diagnose obesity [7, 8].

One of the most used and approved indices of relative weight is the Quetelet index, more commonly known as body mass index (BMI) [9]. BMI (weight in kilograms divided by height squared in meters) was not originally intended as an obesity index, but it is now employed as such in many epidemiologic studies where it accurately predicts obesity-related morbidity and mortality [7, 8].

Some authors have suggested that this index inadequately predicts percentage of body fat (%BF) and that %BF is the most predictive measure to assess obesity [10].

A body mass index (BMI) of at least 30 kg/m^2 is considered obese in men and women [11]. The alternative definition of obesity is based on percentage of body fat (% BF). A % BF greater than or equal to 25 % of body weight in men and greater than or equal to 30 % in women is considered obese [12].

To our knowledge, only Wendelboe et al. [13] have investigated the associations between obesity, measured by BMI, and different shoulder conditions, included RCT. However, no previous studies have analyzed whether obesity is related not only with RCT but also with the dimension of the tear. Recently, we performed a study [14] whose aim was to verify if obesity, measured by BMI and %BF (obtained through plicometry), increases the risk of RCT and influences tear size.

The cases consisted of 381 consecutive patients (180M-201F; mean age ± SD: 65.5 ± 8.52; range 43–78) who underwent arthroscopic repair of a full-thickness RCT between January 2011 and May 2013. The control group included 275 consecutive healthy men and women asymptomatic for shoulder pathologies, enrolled in the outpatient clinic of our hospital. All these subjects have no history of shoulder pathologies and were all submitted to a physical examination of both the postero-superior and anterior rotator cuff tendons, in order to evaluate rotator cuff integrity; in case that one of the tests was positive, subject was excluded from the control group since they could have an asymptomatic rotator cuff tear. Finally, the control group consisted of 220 subjects (103M and 117F; mean age ± SD = 65.16 ± 7.24; range 42–77) since one or more tests resulted as positive in 55 subjects; therefore, they were excluded. For the purposes of the study, participants were divided into two groups depending on the BMI value: BMI ≥ 25 kg/m^2 (Group A) or BMI <25 kg/m^2 (Group B). Anthropometric measures were taken by one of the authors while participants were lightly clothed and wore no shoes. Body weight was measured to the nearest 0.1 kg using a calibrated scale (Seca Inc., Hamburg, Germany). Standing height was measured without shoes to the nearest 0.5 cm using the height rod attached to the scale. Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Circumferences were measured with a heavy-duty inelastic plastic fiber tape measure to the nearest 0.5 cm while the subject stood balanced on both feet, with the feet touching each other and both arms hanging freely.

Percent body fat (%BF) estimates were determined using a calibrated Harpenden plicometer with a constant pressure of 10 g/mm^2, through the Siri's formula and the Durnin and

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Womersley's equations [11, 15, 16]. Moreover, Bicipital, tricipital, subscapolaris, and suprailiac skinfolds were taken.

The Southern California Orthopedic Institute (SCOI) classification of complete rotator cuff tears [17] was used to classify tendon tears intraoperatively. To limit the number of groups and make the sample more representative, we considered the lesions belonging to type I as small, those of the type II and III as large, and those of the type IV as massive.

A statistical analysis was performed using statistical package for social sciences (SPSS) version 18 for calculations. Differences with p-values ≤0.05 were considered to be statistically significant, and all the results were expressed with a 95 % confidence interval. After using a Kolmogorov–Smirnov test to verify that the variables were normally distributed, we applied parametric tests.

Regression analyses were used to investigate the relationships between BMI and % BF. According to BMI and %BF, two-way ANOVA was performed to evaluate the differences between two groups. Significance levels for multiple comparisons were adjusted with the Bonferroni–Holm procedure. Power analysis determined that at least 209 patients were required in each group (G Power3 power analysis program).

A total of 601 subjects [mean age ± standard deviation (SD) = 65.38 ± 8.0; range 42–78, 319 females and 282 males] were enrolled in the study. Of the sample, the 66.5 % (N = 440) was enrolled in Group A and the 33.5 % (N = 161) in Group B, according to BMI. The baseline characteristics are shown in Table 1.

Figure 1 and Table 2 show the regression analysis between BMI and BF%.

The 69 % (N = 303) of Group A and the 48 % (N = 78) of Group B had a rotator cuff tear (Table 3). Patients with RCT had a BMI value higher than subjects with no RCT in both groups (p = 0.031 in Group A; p = 0.02 in Group B).

Chi-square test demonstrated significant relationship between BMI value and the presence of the RTC (chi-square = 21.17, p < 0.001). In particular, significance was achieved for subjects of Group A (odds ratio = 2.35; 95 % confidence interval = 1.63–3.40; p < 0.001).

Moreover, significance was achieved for both men (odds ratio = 2.10; 95 % confidence interval = 1.27–3.52; p = 0.0036) and women (odds ratio = 1.94; 95 % confidence interval = 1.18–3.18; p = 0.0082) with a BMI between 25.00 and 30.00 kg/m^2 as well as for both men (odds ratio = 2.49; 95 % confidence interval = 1.41–3.90; p = 0.0037) and women (odds ratio = 2.31; 95 % confidence interval = 1.38–3.62; p = 0.0071) with a BMI of ≥ 30.00 kg/m^2 (Fig. 2 and Table 4).

BMI values in RCT patients and in healthy subjects were, respectively, 28.80 ± 5.0 and 27.66 ± 6.0. We found significant differences between two groups (p = 0.014).

Table 1 Baseline characteristics of the two groups

	Group A (BMI ≥ 25) (N = 440)	Group B (BMI < 25) (N = 161)
Age	64.90 ± 7.70	66.70 ± 8.78
Sex	224 F, 216 M	95 F, 66 M
BMI ± SD (Range)	30.52 ± 4.66 (25.03–66.17)	22.52 ± 2.15 (14.35–24.97)
%BF ± SD (Range)	38.51 ± 5.51 (18.88–57.41)	34.70 ± 5.61 (19.55–48.59)

BMI body mass index, *%BF* body fat percentage, *SD* standard deviation, *F* female, *M* male

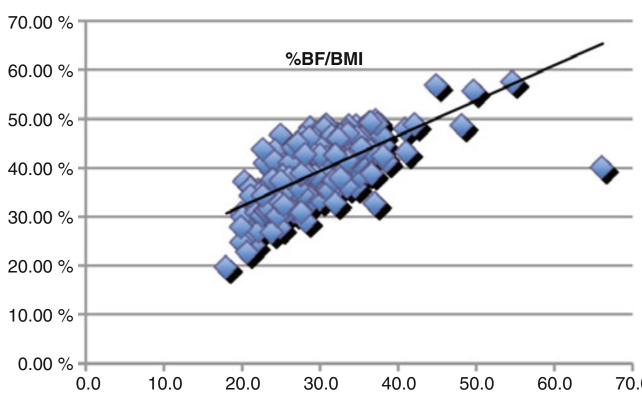

Fig. 1 Linear equations relating % BF to BMI in Groups A and B. *BMI* body mass index, *% BF* body fat percentage

Table 2 Linear equations relating body fat percentage and body mass index

Standardized coefficients beta	r^2	Adjusted r^2	SEE	p value
0.338	0.114	0.113	5,14054	<0.001

SEE standard error of the estimate

Table 3 BMI and % BF of the two groups

	Group A (BMI ≥ 25) (N = 440)		Group B (BMI < 25) (N = 161)	
	RCT (N = 303)	Control (N = 137)	RCTs (N = 78)	Control (N = 83)
BMI ± SD (Range)	31.18 ± 4.71 (25.16–48.55)	30.23 ± 4.62 (25.03–46.17)	22.23 ± 1.54 (18.02–24.97)	21.86 ± 2.42 (14.35–24.80)
BF% ± SD (Range)	37.64 ± 5.71 (19.55–57.41)	36.70 ± 5.63 (18.88–48.67)	38.09 ± 5.87 (22.60–55.57)	37.68 ± 6.19 (24.65–56.73)

BMI body mass index, *%BF* body fat percentage, *SD* standard deviation, *RCT* rotator cuff tear, *N* number

Table 5 shows the average values of BMI and %BF of patients with different sized RCT. Patients with massive RCT have a BMI and %BF, respectively, of 29.93 ± 6.11 and 39.43 ± 5.68; moreover, the same values in patients with small tears are 27.85 ± 4.39 and 37.63 ± 5.53; significant differences were found between the two groups ($p = 0.004$; $p = 0.031$), according to both BMI and % BF (Table 6).

Our data show that obesity is a significant risk factor for the occurrence of rotator cuff tear. These findings also emerged in the Wendelboe's series [13] that was constituted by a case group of patients with rotator cuff disorders and a control group of subjects with no shoulder diseases. The authors observed an association between obesity and RCT. These results might be explained by the possible role that obesity plays in rotator cuff hypovascularity. In fact, body fat is associated with an increased production of adipokines (leptin, adiponectin, plasminogen activator inhibitor, TNFα, angiotensinogen, and interleukins 6, 8, 10, and 18); these molecules are able to induce oxidative stress, inflammation, thrombosis, and endothelial dysfunction. Consequently, adiposity may induce peripheral hypovascularity and worsen the hypoxia of the rotator cuff critical zone [18].

We observed differences in the BMI and in the %BF among patients with different sizes of tear. Patients with massive tear have a BMI and a % BF greater than those registered in patients with small tears. We hypothesize that patients with a higher degree of adiposity have a greater impairment in the microvasculature of the insertional area that might justify a wider extension of the degenerated tendon tissue. Since our results are not influenced by age, they are not affected even by the natural history of the lesion, which might be responsible for the extension of the lesion.

In fact, the statistical analysis showed no significant differences between patients with small and massive tear, according to age and gender.

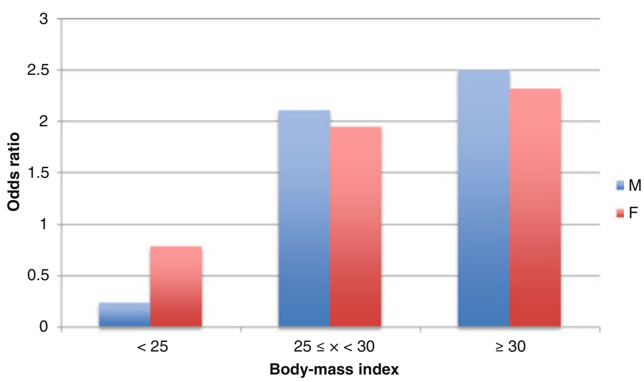

Fig. 2 Relationship between rotator cuff tear and body mass index according to gender

Table 6 Differences in BMI and % BF among Group A patients, according to different sized RCTs

	Mean difference	Confidence intervals (CI) Lower	Upper	*p* value
Small vs large				
BMI	−0.65	−2.17	0.86	$p = 0.909$
%BF	−0.66	−2.32	0.98	$p = 0.999$
Small vs massive				
BMI	−2.07	−3.62	−0.52	**$p = 0.004$**
%BF	−1.80	−3.48	−0.12	**$p = 0.031$**
Large vs massive				
BMI	−1.42	−2.88	0.04	$p = 0.060$
%BF	−1.13	−2.72	0.45	$p = 0.259$

In bold the significant *p* value
BMI body mass index, *%BF* body fat percentage

Table 4 Risk estimates for RCTs according to body mass index for men and women

	Men ($N = 283$)				Women ($N = 318$)			
BMI (kg/m^2)	OR	95 % CI		*p* value	OR	95 % CI		*p* value
≤24.99	0.23	0.13	0.39	**<0.0001**	0.78	0.45	1.36	0.3984
25.00–30.00	2.1	1.27	3.52	**0.0036**	1.94	1.18	3.18	**0.0082**
≥30	2.49	1.41	3.90	**0.0037**	2.31	1.38	3.62	**0.0071**

In bold the significant *p* value
BMI body mass index, *OR* odds ratio

Table 5 Baseline characteristics of RCT patients, according to the different sized RCTs

RCTs	Mean BMI ± Std. deviation	95 % confidence interval Lower	Upper	Mean %BF ± Std. deviation	95 % confidence interval Lower	Upper
Small ($N = 112$)	27.86 ± 4.39	27.03	28.67	37.63 ± 5.53	35.61	38.14
Large ($N = 139$)	28.50 ± 4.20	27.80	29.21	38.29 ± 4.86	36.33	39.80
Massive ($N = 130$)	29.92 ± 6.11	28.86	30.98	39.43 ± 5.68	37.55	41.07

BMI body mass index, *%BF* body fat percentage, *RCT* rotator cuff tear, *N* number

Take Home Message

- Our study shows that adiposity, measured both as BMI and % BF, is greater in patients with RCT than in those without tear. Therefore, not only it increases the risk of tear but also influences tear size, regardless of gender and age.

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Hypercholesterolemia

Stefano Gumina, Vittorio Candela, and Daniele Passaretti

It is known that high levels of cholesterol, triglycerides, and low-density lipoprotein (LDL) may determine vessel wall damage. As it is also known that tendon tissue insertion to the greater tuberosity of the humerus normally receives a poor blood supply, especially with the arm in adducted position [1], some authors have hypothesized that hypercholesterolemia may be an additional risk factor for tissue degeneration and, consequently, for rotator cuff tear.

The National Cholesterol Education Program defines hypercholesterolemia as a blood cholesterol concentration greater than or equal to 240 mg/dl with concentrations between 200 and 239 mg/dl considered borderline high [2].

In the US population aged 20 years and older, hypercholesterolemia rate is about 17 % [3]. In Italy, 21 % and 23 %, respectively, of male and female population aged from 35 to 75 years is affected by hypercholesterolemia. Percentage rises to 24 % and 39 %, respectively, when the sample is considered to be between the ages of 65 and 74 years (data extracted from the National Center of Epidemiology). Diet, physical exercise, smoking habit, and genetics can influence serum level of cholesterol.

Klemp et al. [4] observed that 38 % of patients with juvenile familiar hypercholesterolemia had musculoskeletal system manifestations. Small variations of cholesterol deposition occur, with age, in human muscles. Variations are larger in adipose tissue and skin and even larger in the dense connective tissues (i.e., tendons) of elderly individuals [5]. Some studies have emphasized correlation between hypercholesterolemia and human tendon lesion, in particular of the Achilles tendon. Kiortsis et al. [6] observed a link among Achilles tendon thickness, hypercholesterolemia, and intima-media thickness of the carotid artery and suggested that thickening of the Achilles tendon might be considered a potential indicator of atherosclerosis. However, this thickening was not observed in rotator cuff tendon. In fact, Benson et al. [7] found no differences in cross-sectional area comparing supraspinatus tendon from normal and hypercholesterolemic animals. In the Ozgurtas et al.' series [8], patients who sustained an Achilles tendon rupture had high serum level of cholesterol, triglycerides, and LDL than the control group. Contrarily, serum level of high-density lipoprotein (HDL) resulted abnormally low in patients with Achilles tendon rupture. Similarly, Mathiak et al. [9] observed that 83 % of their patients with an Achilles tendon rupture had high serum level of cholesterol. Beeharry et al. [10] have observed that frequent episodes of Achilles pain are very common in patients with familial hypercholesterolemia, even if the tendon seems to be macroscopically normal.

Mechanism that leads to tendinous xanthomas has been elucidated. LDL accumulates into tendons and becomes oxidized. Oxidized-LDL (oxLDL) contains different oxidatively modified phospholipids and cholesterols, isoprostanases, oxidized arachidonoyl residues, lysolipids, and lysophosphatidic acid [11]. The effects of oxLDL on inflammatory cells are complex. Specific oxidative-truncated phospholipids rapidly enter nucleated cell, travel to the mitochondria, and initiate the mitochondrial-dependent pathway to apoptotic cell death [11].

Observing a familial form of massive tendon xanthomatosis, it has been demonstrated a decreased HDL-mediate cholesterol efflux associated with genetic variation in the reverse cholesterol transport and LDL oxidation pathways [12, 13]. Xanthomatosis and atherosclerosis share these genetic abnormalities; therefore, they might result from the same pathophysiological mechanisms. It has also been hypothesized that microscopic cholesterol deposition inside the tendons might initiate maintaining a low-grade, persistent inflammation, above all in nonfamilial hypercholesterolemia subjects. The inflammation would promote chronic tendon degeneration and biomechanical changes, as shown by studies of the rotator cuff and patellar tendons [14]. Histologically, cholesterol deposition is observed both extracellularly and inside histiocytes and other foam cells, which have numerous

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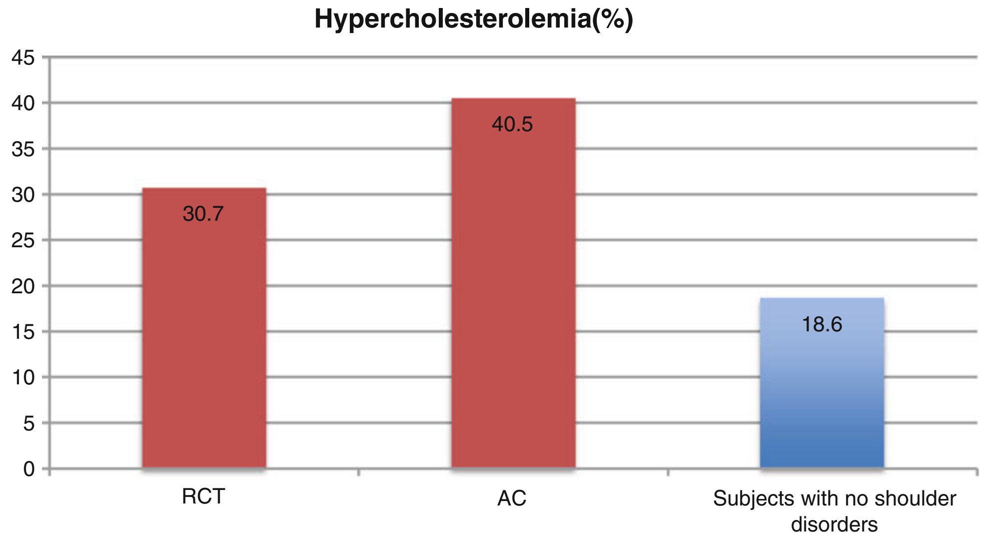

Fig. 1 Percentage of hypercholesterolemia among patients with rotator cuff tear (*RCT*)/with adhesive capsulitis (*AC*) and subjects with no shoulder disorders

intracytoplasmic lipid vacuoles, lysosomes, and myelin figures [15]. Esterified fraction of cholesterol resulted elevated in biopsies from degenerated Achilles tendon [16].

It has been suggested that hypercholesterolemia may contribute to increased tendon injuries in several ways.

1. Intratendinous xanthomas might change mechanical properties [17, 18].
2. Hypercholesterolemia might alter tendon's extracellular matrix causing increased susceptibility to rupture or a lesser healing ability. In an experimental study, Ronnemaa et al. [17] found embryonic fibroblasts reacted differently to hypercholesterolemic rat serum than to rat with normal level of cholesterol. Hypercholesterolemic serum was less likely to stimulate noncollagenous protein synthesis or incorporate glucosamine and cytidine (normally present in extracellular matrix) compared with serum with normal level of cholesterol.
3. In hypercholesterolemic rats, baseline elastic modulus and strength results reduced when compared to controls. This indicates a detrimental effect of hypercholesterolemia on tendon properties [7, 14].
4. Hypercholesterolemia causes macro- and microangiopathy. The impaired blood supply to tendon would cause premature tissue degeneration [19–21].

There is only one study that we are aware of that did not find a correlation between hypercholesterolemia and rotator cuff tear [22]. In fact, authors, in a case control study, observed that 120 patients (range 40–83 years; mean age 64.8 years) with different sized rotator cuff tear who had undergone arthroscopic cuff repair had triglycerides and cholesterol serum level similar to that one registered in 120 patients (range 38–78 years; mean age 63.9 years) submitted to arthroscopic meniscectomy for a meniscal tear.

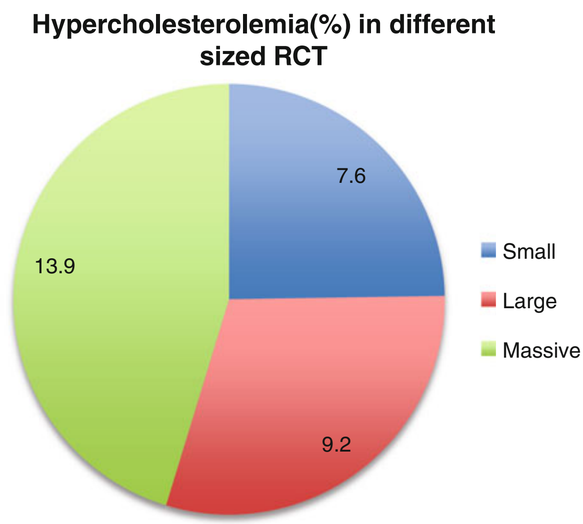

Fig. 2 Percentage of hypercholesterolemia among patients with rotator cuff tear (*RCT*), according to the different size of tear

We recorded the levels of total serum cholesterol in patients with different sized rotator cuff tear and with adhesive capsulitis. Results were compared with those registered in a control group. Figure 1 shows that the percentage of hypercholesterolemia was higher in patients with shoulder disorders than that registered in subjects with no shoulder diseases (Gumina S, 2014. Unpublished data). In addition, among patients with a rotator cuff tear, higher levels of serum total cholesterol were registered in those who had a massive tear (Fig. 2). On the other hand, the lowest values were observed in patients with small tears. Obviously these data do not have a large scientific reliability as they have not been submitted to a statistical analysis, and moreover, they have been extrapolated from patients with adhesive capsulitis, who, as it is known, are usually younger than those with rotator cuff tear. However, they represent a highly probative trend for considering the hypercholesterolemia as a risk factor for shoulder adhesive capsulitis and cuff tear. Furthermore, these data indicate that high level of serum total cholesterol, as for diabetes, also affects cuff tear size.

Recently, in an animal model study, Beason et al. [23] have observed that hypercholesterolemia might also have a detrimental biomechanical effect on rat rotator cuff healing.

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Diabetes

Stefano Gumina, Vittorio Candela, and Daniele Passaretti

Diabetes mellitus is a major public health problem worldwide. It is a clinical entity associated with a large number of complications such as nephropathy, retinopathy, autonomic neuropathy, heart disease, stroke, and musculoskeletal diseases (stiff hand syndrome, various types of tendinitis, plantar fasciitis, carpal tunnel syndrome, and Dupuytren's contracture) [1–3]. Attar [3] believes that musculoskeletal manifestations occur in 18 % of adult diabetic patients; Cagliero et al. [4] retain that these disorders are present in almost 40 % of cases. Although musculoskeletal manifestations are more common in patients with type I than type II diabetes, type of diabetes is not associated with hand and shoulder syndromes after adjusting for duration of diabetes [4].

It is also well known that diabetic patients have a higher prevalence of shoulder pain and stiffness and that even for those conditions, they have a lower quality of life.

In an epidemiological study, Czelusniak et al. [5] observed that shoulder pain and dysfunction were present, respectively, in 63 % and 53 % of type II diabetes mellitus patients and that 27 % of patients rated shoulder performance as bad. Furthermore, these disorders affect more women and elderly patients. Jenkins et al. [6] believe that shoulder stiffness incidence is 10–36 % in diabetic patients and 2–5 % in those not affected by the disease. It was also hypothesized that out of diabetic patients, those belonging to lower socioeconomic levels might be more susceptible to shoulder disorders because they might have poorer control of their glycemia [5]. Thomas et al. [7] observed that 26 % of diabetic patients have shoulder pain; however, only 4.3 % of diabetic patients fulfilled the criteria of shoulder stiffness. Therefore, it is reasonable to hypothesize that a significant proportion of diabetic patients with shoulder pain might have other shoulder pathologies. In our series (unpublished data) (Figs. 1 and 2) constituted by 180 patients with adhesive capsulitis of the shoulder, 40 (22 %) were suffering from diabetes mellitus. Out of the diabetic patients, 17 (9.4 %) were insulin dependent and 23 (12.6 %) were taking oral hypoglycemic drugs. The percentage of insulin-dependent and non-insulin-dependent diabetic patients, in a control group of 220 subjects not affected by shoulder diseases, was, respectively, 1.8 % (4/220) and 6.3 % (14/220).

The association between shoulder stiffness and glycemic control is controversial. Laslett et al. [8] have observed an increased incidence of shoulder pain in diabetic patients with higher hemoglobin A_{1c} levels and previous eye surgery. This result was not confirmed by others [5, 7, 9].

Causes of this predisposition to shoulder disorders remain unclear. The possible pathomechanisms include the alteration of collagen synthesis and overaccumulation of advanced glycation end products [7]. It was hypothesized that the link between shoulder pain or disability and diabetes is to be excessive glycosylation of connective tissue, particularly collagen [10]. In 1999, Monnier et al. [11] observed that the patients who had had long-term intensive treatment of their diabetes showed to have lower levels of skin collagen glycosylation, glycoxidation, and cross-linking. Salmela et al. [12] revealed in that group of patients also slower rates of accumulation of advanced glycosylation end-points (AGEs) than the patients treated under conventional regimes. The formation of AGEs is associated with microvascular complication in diabetes. They have been observed to decrease vascular elasticity in experimental studies [2]. Siu et al. [13] noted that diabetic patients have higher proinflammatory IL-1β levels in the subacromial fluid than nondiabetic patients. In 2002, Mentink et al. [14] performed a murine study and observed that tendons may be directly affected by nonenzymatic glycosylation processes which change collagen cross-link. The biosynthesis of collagen is characterized by modifications such as glycosylation of the polypeptide chains which are unique to collagen and some other proteins [15]. Collagen modification due to glucose fixation on free amino groups is characterized by an altered solubility,

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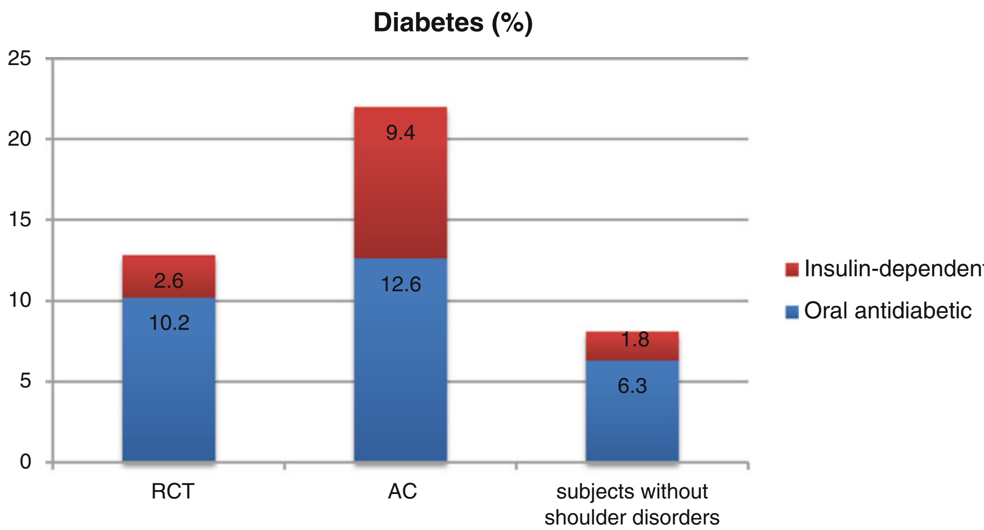

Fig. 1 Percentage of diabetes among patients with rotator cuff tear (RCT)/with adhesive capsulitis (AC) and healthy subjects

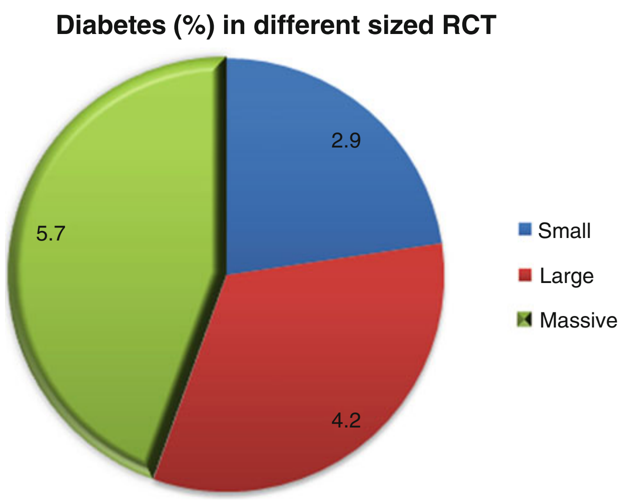

Fig. 2 Percentage of diabetes among patients with rotator cuff tear, according to the different size of tear

increased resistance to enzymatic action and variations in cross-linking [15].

In 2008, Longo et al. [16], in a case-control study performed on 194 patients, observed that normal, but in the higher part of the normal range, increasing plasma glucose levels may be a risk factor for rotator cuff tear. In fact, according to the statistics, patients with a cuff tear had significantly higher fasting plasma glucose levels within the normoglycemic range than a controlled group represented by patients who had undergone arthroscopic meniscectomy for a meniscal tear and with no evidence of shoulder pathology.

Miranda et al. [17] observed that patients with only insulin-treated diabetes had an increased risk of chronic rotator cuff tendinitis. These data suggest type I diabetes as the underlying condition. However, since type II diabetes is more common than type I, it is likely that patients with type II diabetes dominate in the studies over those who do not have specified diabetes type.

In 1999, Duh and Aiello [18] proposed that vascular endothelial growth factor (VEGF) – a glycoprotein that plays an important role in neovascularization and increases vascular permeability – can cause endocrine changes responsible for systemic neovascularization in diabetes mellitus, thereby inducing microangiopathy. Yanagisawa et al. [19] have found that expression of this growth factor in subacromial bursa induces neovascularization and synovial proliferation in patients with rotator cuff disease, causing shoulder pain. In 2003, Handa et al. [20] examined 67 patients (14 type II diabetics and 53 nondiabetics) with rotator cuff diseases (36 with complete rotator cuff tears; 20 with partial tears and 11 with subacromial bursitis) and investigated whether VEGF had been also involved in the development of shoulder contracture in diabetics with rotator cuff disease. The mean preoperative active forward flexion significantly differed between two groups (104° in diabetics and 125 in no diabetics). Specimens of subacromial bursa were obtained from all patients during surgery. Expression and localization of VEGF were evaluated by using the reverse transcriptase chain reaction and immunohistochemistry, respectively. Number of vessels was evaluated based on CD34 immunoreactivity. Results showed that VEGF was expressed in significantly more diabetics (14/14 = 100 %) than in no diabetics (37/53 = 70 %) and that it was localized in both vascular endothelial cells and synovial lining cells. The mean number of VEGF-positive vessels and the vessels area were also significantly greater in diabetics. Using shoulder joint contracture Keating's method [21], authors observed that shoulder contracture was significantly greater in diabetics (8/14 = 57 %) than in no diabetics (9/53 = 14 %). Furthermore, they observed that contracture was also significantly correlated with VEGF mRNA expression. These results indicate that shoulder contracture is associated with diabetes and with the soluble isoforms of VEGF.

Correlation between diabetes and rotator cuff tear seems to be confirmed by our data (unpublished data). In fact, out of a series consisting of 381 consecutive patients who underwent arthroscopic repair for a postero-superior rotator cuff tear, 49 (12.8 %) were suffering from diabetes mellitus. Out of these patients, 10 (2.6 %) were insulin-dependent and 39 (10.2 %) non-insulin-dependent diabetics. In the control group, consisting of 220 subjects without shoulder disorders, the percentage of patients with diabetes was 8.1 % (insulin dependent = 1.8 %; non-insulin dependent = 6.3 %).

Figs. 1 and 2 show the percentage of diabetics among the patients with rotator cuff tear of different size. Data indicate that the percentage of diabetic patients increases along with increasing of tear size, and moreover, the increase is particularly evident among insulin-dependent diabetics. Usually, the latter patients have a long history of hyperglycemia, with a scarcely controlled blood sugar level, only responsive to hexogen insulin.

It is still the motive for discussion whether diabetes may interfere with cuff healing after a surgical repair. In 2003, Chen et al. [22] compared the outcomes of cuff repair in 30 diabetic patients with those of a matched, nondiabetic population. The authors concluded that diabetics may improve their shoulder function than nondiabetic counterparts. However, surgeons should know that a higher rate of complications, infection in particular, may occur after cuff repair in diabetic population. Similarly, Clement et al. [23] compared the results of cuff repair in 32 diabetic patients with the outcome in 32 nondiabetic patients matched for age, gender, comorbidities, and size of tear. They observed that diabetic patients showed improvement of shoulder pain and function following surgical repair in the short term, but less than their nondiabetic counterparts. Analogously, Fermont et al. [24] consider diabetes as a negative prognostic factor for successful recovery after arthroscopic rotator cuff repair. Dhar et al. [25] noted that patients without diabetes had greater forward flexion, abduction, and external rotation than diabetic patients. Finally, Chung et al. [26] observed that failure rate, after arthroscopic cuff repair, was significantly higher in patients with diabetes mellitus. Bedi et al. [27] studied the effect of sustained hyperglycemia on tendon-to-bone healing in 48 male rats that underwent unilateral detachment of superior cuff followed by immediate anatomic repair with transosseous technique. In 24 rats, diabetes was induced preoperatively via intraperitoneal injection of streptozotocin and confirmed with both pre- and poststreptozotocin injection intraperitoneal glucose tolerance tests. Authors observed a significant impairment of glycemic control in the diabetics compared to control rats. In addition, mean HBA1c level in two weeks postoperatively was higher in diabetic group. These rats had significantly fewer fibrocartilage and less organized collagen in addition to increased AGE deposition at the tendon-bone interface than the control group. Furthermore, the healing tissue of diabetic rats demonstrated a significantly reduced ultimate load-to-failure and stiffness compared to control rats.

In conclusion, diabetes has to be considered a risk factor for rotator cuff tear; it facilitates extension of tear size and compromises tendon healing.

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The Role of Genetics

Vittorio Candela and Stefano Gumina

Genetics has been investigated as a factor involved in the occurrence, progression, and clinical presentation of rotator cuff pathology. As rotator cuff disease is multifactorial, no single gene is directly involved in the pathology. Phenotypic expression of genetic susceptibility manifests at the level of tendon ultrastructure operating through the regulation of apoptosis and regenerative capacity [1].

In recent years, few studies have reported the investigation of the genetic susceptibility to rotator cuff tears basing on clinical information collected from affected individuals, their siblings, and matched controls.

Harvie et al. in 2004 [2] performed a prospective, cross-sectional study on individuals with full-thickness tears of the rotator cuff. They evaluated 213 patients, 150 spouses, and 129 siblings. The participants completed the Short Form-36 Health Survey Questionnaire, the Oxford Shoulder Score, and the Score of Constant and Murley for each shoulder, and, in addition, they all underwent ultrasound examinations of both shoulders. The study showed that siblings had more than twice the risk of developing tears of the rotator cuff (relative to a control group) ($p < 0.001$) and nearly five times the risk of experiencing symptoms ($p < 0.001$). This illustrates that there is a significant genetic susceptibility towards the development of full-thickness tears of the rotator cuff and the associated symptoms.

Gwilym et al. in 2009 [3], considering that progression of cuff tear, in terms of its size, would be influenced by the same genetic factors that predisposed the individual to develop a tear in the first instance, investigated a group of siblings of patients with a tear of the rotator cuff and of controls studied 5 years earlier. The authors determined the prevalence of the rotator cuff tears with and without associated symptoms using ultrasound and the Oxford Shoulder Score. This hypothesis was confirmed, with a tear in a patient's sibling with known rotator cuff disease being significantly more likely to progress in size than one in a control subject without a first-degree family history of rotator cuff disease.

They found that 16.1 % of the sibling group had progressed in terms of tear size, as opposed to 1.5 % of the control group. The association of pain with a tear of the rotator cuff also appeared to be influenced by genetic factors. A tear in a patient's sibling with a painful tear had a relative risk of being painful of 1.44, compared to 1.00 in a control subject. This finding adds support to the growing evidence that pain perception itself has a hereditable component and potentially offers pathology of the shoulder as a model for research into the genetics of pain.

The role of COL5A1 and TNC genes, which are both located in close proximity with the ABO gene, is still debated. Polymorphisms within the COL5A1 and TNC genes have been shown to be associated with Achilles tendon injury in a physically active South African Caucasian population [4, 5]. The functions of these polymorphisms are currently unknown, and it remains to be investigated whether these polymorphisms are also associated with either rotator cuff.

Motta et al. in 2014 [6] investigated 23 single-nucleotide polymorphisms within six genes involved in repair and degenerative processes (DEFB1, DENND2C, ESRRB, FGF3, FGF10, and FGFR1, Table 1) in 410 patients, 203 with a diagnosis of rotator cuff disease (RCD), and 207 presenting with absence of cuff pathologies. Exclusion criteria were patients younger than 45 years and older than 60 years, with a history of trauma, rheumatoid arthritis, autoimmune syndrome, pregnancy, and use of corticosteroids. Genomic DNA was obtained from saliva samples. The authors concluded that female sex and being white are risk factors for RCD development. A significant association of haplotypes CCTTCCAG in ESRRB, CGACG in FGF3, CC in DEFB, FGFR1 rs13317, FGF10 rs11750845, and rs1011814 with RCD were observed. Identification of these variants can clarify causal pathways and provide a clue for therapeutic targets.

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Table 1 Genes studied by Motta et al. [6]

Genes	Full name	Role
DEFB1	Defensin beta 1	Defensins could act on many immune cells through Toll-like receptor 4, regulating the entire immune response
		The involvement of b-defensin with progressive muscle degeneration in mice was identified
DENND2C	DENN domain containing 2C	Promotes the exchange of GDP to GTP, converting inactive GDP-bound Rab proteins into their active GTP-bound form
ESRRB	Estrogen-related receptor b	High levels of hypoxia-inducible factor (HIF) in torn rotator cuffs are present
		ESRRB has been identified as an essential cofactor of HIF in mediating the adaptation to this hypoxic environment
FGF3	Fibroblast grow factor 3	Plays a critical role in angiogenesis and mesenchymal cell mitogenesis
		Mediates the cellular responses by binding to and activating a family of 4 receptor tyrosine kinases (FGF receptors FGFR1-FGFR4)
		Associated with collagen synthesis and turnover
FGF10	Fibroblast grow factor 10	Plays a critical role in angiogenesis and mesenchymal cell mitogenesis
		Mediates the cellular responses by binding to and activating a family of 4 receptor tyrosine kinases (FGF receptors FGFR1-FGFR4)
		Associated with collagen synthesis and turnover
FGFR1	Fibroblast grow factor receptor	Receptor of FGF 3 and 10

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The Association Between Alcohol Consumption and Rotator Cuff Tear

Stefano Gumina, Daniele Passaretti, and Vittorio Candela

Many studies [1–7] on human and animals have proved that habitual high dose intake of ethanol is responsible for various toxic effects on capillary microcirculation and tissue perfusion, depending on the total dose consumed per day and on the duration of the habit. Furthermore, these negative effects are different in males and females. In fact, the same amount of alcohol consumed leads to a greater blood level of ethanol and has more toxic effects in females rather than in males [8].

Considering the relative poor perfusion that characterizes rotator cuff tendon insertion [9, 10], we hypothesized that long-term alcohol intake may negatively influence cuff perfusion and therefore be directly associated with rotator cuff damage. Little is known about the relationship between alcohol intake and rotator cuff tear (RCT). Only 1 study [11] has assessed such a relationship, and the authors found that alcohol intake was not associated with rotator cuff disease. However, this conclusion was reached without precisely considering the amount of alcohol ingested by participants on a daily basis, how long they had this habit, and possible differences between males and females.

Therefore, we performed a case–control study to verify if long-term intake of high doses of alcohol may be a risk factor for both occurrence and severity of RCT [12]. The cases consisted of 249 consecutive patients, mean age 64 (54–78) years (139 men), who were treated arthroscopically for a full-thickness rotator cuff tear. The tear had been diagnosed by physical examination, plain radiography, and magnetic resonance imaging. Exclusion criteria were a previous operation of the shoulder, inflammatory or rheumatologic joint disease, primary osteoarthritis of the affected shoulder, BMI > 25, and having hypertension, diabetes mellitus, or hypercholesterolemia and not receiving the correct drug therapy. The Southern California Orthopedic Institute classification of complete RCTs [13] was used to classify tendon tears intraoperatively. To limit the number of groups and make the sample more representative, we considered the lesions belonging to type I as small, those of the type II and III as large, and those of the type IV as massive.

The control group started with 428 consecutive subjects with no history of shoulder pathologies who had been enrolled at the outpatient clinic of our hospital. All the controls were given a physical examination of both the anterior rotator cuff tendons (lift-off test, Napoleon test, bear-hug test) and the posterosuperior rotator cuff tendons (full can test, Patte test, external rotation lag sign, strength in external rotation) [14] and to an ultrasound (US) examination of both shoulders. Subjects were excluded from the control group if 1 or more of the tests were positive and/or if US examination revealed an asymptomatic RCT. After examination, the control group consisted of 356 subjects with a mean age of 66 (58–82) years (186 men and 170 women). A standardized questionnaire was used to obtain information about smoking habits (never-smoker, current smoker, or former smoker), diabetes mellitus (presence or absence), and alcohol consumption. The types of alcoholic beverage consumed and the amount and duration of use were investigated in detail. Data for beer consumption, wine consumption (wine + fortified wine), and liquor consumption (aperitif + spirit) were analyzed separately and then summed to estimate the total alcohol consumption per day. Alcohol intake for a particular beverage, in grams per day, was calculated by multiplying the frequency of consumption by its respective ethanol content (1 bottle of beer = 330 mL, 1 mL beer = 0.046 g ethanol; 1 glass of wine = 125 mL, 1 mL wine = 0.104 g ethanol; 1 glass of fortified wine = 90 mL, 1 mL fortified wine = 0.167 g ethanol; 1 glass of aperitif = 40 mL, 1 mL aperitif = 0.25 g ethanol; 1 shot of spirit = 30 mL, 1 mL spirit = 0.33 g ethanol). In our country, a standard alcoholic unit (AU) contains 12 g of alcohol [15]. The guidelines for healthy nutrition recommend to consume no more than 2–3 AUs per day for men and 1–2 AUs per day for women. Therefore, we considered men and women separately. Nondrinkers were defined as those individuals who

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consumed less than 0.01 g of ethanol per day. Male subjects were classified as nondrinkers and drinkers (subjects who had drunk more than 0.01 g of alcohol a day for at least 2 years). Male drinkers were further divided into moderate drinkers (subjects who consumed less than 36 g per day) and excessive drinkers (subjects who consumed more than 36 g per day). Women were classified as nondrinkers and drinkers (subjects who had drunk more than 0.01 g of alcohol a day for at least 2 years). In the same way, female drinkers were further divided into moderate drinkers (subjects who consumed less than 24 g per day) and excessive drinkers (subjects who consumed more than 24 g per day).

A statistical analysis was performed and calculation of sample size was done using G*Power 3 software (Heinrich-Heine-University, Dusseldorf, Germany). According to logistic regression, we determined that at least 603 patients would be required, assuming an odds ratio value of 1.1, a 2-tailed α-value of 0.05 (sensitivity of 95 %), and a β-value of 0.10 (with a study power of 90 %). We used parametric tests after using the Kolmogorov–Smirnov test to verify that the variables were normally distributed. Unpaired sample *t*-test was performed to evaluate differences between RCT subjects and control subjects according to total alcohol intake and wine, beer, and liquor intake. To evaluate the risk of RCT in drinkers and nondrinkers (both men and women), odds ratios (ORs) were calculated according to Altman. Nondrinkers were excluded to assess a potential dose response relationship in drinkers only. An OR of >1.0 would mean that alcohol consumption was associated with a statistically significantly higher risk of rotator cuff tear. One-way ANOVA was used to evaluate differences in alcohol intake levels between subjects with RCT. Significance levels for multiple comparisons were adjusted with the Bonferroni–Holm procedure. Logistic regression was used to identify risk factors for RCTs using the following factors as explanatory variables: age, sex, daily alcohol intake, smoking habit, and diabetes mellitus. All statistical tests were two-sided with a probability level of 0.05, and all results are expressed with 95 % confidence interval. SPSS version 18 was used for calculations.

Age, sex distribution, and BMI were similar in the cases and controls (Table 1). Total alcohol consumption, wine consumption, and history of alcohol intake were statistically significantly higher in both men and women with RCT than in both men and women in the control group. Moreover, there was higher consumption of beer in men with RCT than in male control subjects (Table 2). We observed an association between drinking and the presence of RCT (OR = 2.0, CI: 1.4–2.9; $p < 0.001$) in both men (OR = 1.8, CI: 1.1–3.0; $p = 0.002$) and women (OR = 2.2, CI: 1.3–3.7; $p = 0.003$). No statistically significant risks from moderate drinking were observed in men (OR = 1.4, CI: 0.81–2.5; $p = 0.2$) as opposed to women (OR = 1.8, CI: 1.0–3.3; $p = 0.04$). Significant risks were found for excessive drinkers of both sexes (men: OR = 3.0, CI: 1.5–6.0, $p < 0.001$; women: OR = 3.6, CI: 1.7–7.8, $p < 0.001$). Regarding the duration of alcohol consumption, we found small but significant risks for the occurrence of RCT in men [OR = 1.04, (CI: 1.0–1.1); p < 0.001] but not in women [OR = 0.97, (CI: 0.95–1.0); p = 0.02] (Table 3). We found higher alcohol consumption in patients with massive RCTs than in those with small RCTs ($p = 0.01$) and large RCTs ($p = 0.03$) (Table 4). Finally, logistic regression analysis revealed that daily alcohol intake, smoking, and diabetes mellitus—all considered individually—were associated with the occurrence of rotator cuff tear ($p < 0.001$, $p = 0.03$, and $p < 0.001$, respectively) (Table 5).

Table 1 Baseline characteristics of the studied group

Cases	249	
Tear type:		
Small	94	
Large	88	
Massive	67	
Controls	356	
Sex, M/F	325, 280	$p = 0.08$
Mean age (range), years		
Cases	64 (54–78)	$p = 0.2$
Controls	66 (58–82)	
BMI		
Males	23 (18–25)	$p = 0.2$
Females	23 (19–24)	

We observed that men and women with RCT had a longer history of alcohol intake than corresponding controls; moreover, they consumed higher amounts of alcohol per day, irrespective of whether one considers total alcohol intake or wine intake only. Regarding beer consumption, we found significant differences only between men with RCT and male controls. No significant difference was found regarding consumption of spirits. We explain these data as being a result of the higher consumption of wine in our country than that of beer or spirits. One must therefore consider the statistical bias due to the small number of patients and healthy subjects who were drinkers of beer and spirits, and the low amounts of these drinks that were consumed. We observed that excessive consumption of alcohol was a significant risk factor for the occurrence of RCT in both men and women. There was no risk associated with moderate alcohol intake. These results may be explained by direct toxic effects of alcohol on tendons through inhibition of fibroblast proliferation and collagen synthesis [16] when alcohol consumption is greater than the recommended doses (<3 alcohol units (AUs) for men and < 2 AUs for women). Furthermore, the duration of the habit of drinking alcohol was a significant risk factor for the onset of cuff rupture. We also found that rotator cuff tear size increased with increasing alcohol consumption. Patients with higher alcohol intake may have greater impairment in the

Table 2 Mean values (range) of history of alcohol intake, total alcohol intake, wine, beer, and liquor intake in cases and controls, according to sex

	Females	*p*-value	Males	*p*-value
Years of alcohol intake				
Cases	31 (14–45)	0.02	35 (18–58) 29	0.04
Controls	26 (15–40)		(17–42)	
Total alcohol intake[a]				
Cases	15 (3–38)	**0.04**	29 (3–40)	**0.03**
Controls	13 (2–36)		25 (3–39)	
Ethanol from wine[a]				
Cases	9.9 (1–22)	**0.04**	24 (0–32)	**<0.001**
Controls	7.8 (0–18)		20 (0–28)	
Ethanol from beer[a]				
Cases	2.9 (0–6)	0.5	6.2 (0–12)	**0.03**
Controls	2.5 (0–7)		4.4 (0–9)	
Ethanol from liquor[a]				
Cases Controls	0.9 (0–2) 0.7 (0–2.5)	0.6	0.8 (0–2.1) 0.8 (0–2)	0.7

[a]g/per day

Table 3 Numbers of cases and controls according to alcohol intake, and odds ratios (ORs) with 95 % CI

	Controls (*n*)	Cases (*n*)	OR	(95 % CI)
Males				
Alcohol intake				
None	65	32	1.0	Ref
Moderate drinkers	92	64	1.4	(0.81–2.5)
Excessive drinkers	29	43	3.0	(1.5–6.0)
Years of alcohol intake			1.04	(1.0–1.1)
Females				
Alcohol intake				
None	77	30	1.0	Ref
Moderate drinkers	73	52	1.8	(1.0–3.3)
Excessive drinkers	20	28	3.6	(1.7–7.8)
Years of alcohol intake			1.2	(0.95–1.0)

Table 4 Mean values (range) and comparison of total alcohol intake, wine, beer, and liquor intake in patients with different-sized RCTs

		Mean (range) ethanol intake in g per day		
RCT size	Total	From wine	From beer	From liquor
Small	24 (3–40)	9.2 (0–30)	2.4 (0–8)	0.72 (0–1.8)
Large	23 (3–38	11 (2–32)	2.6 [1–12]	0.79 (0–2.1)
Massive	30 (4–40)	13 (0–32)	3.8 (0–12)	0.91 (0.2–2.0)
P-value				
Small vs. large	1.0	0.1	1.0	1.0
Small vs. massive	0.001	<0.001	0.06	0.3
Large vs. massive	0.03	0.05	0.05	0.06

RCT rotator cuff tear

Table 5 Logistic regression analysis of age, sex alcohol intake, smoking, and diabetes mellitus and odds ratios (ORs) with 95 % CI

	Cases (*N*=249)	Controls (*N*=356)	OR	95 % CI	*p*-value
Age (range), years	64 (54–78)	66 (58–82)	0.96	(0.94–0.98)	<0.001
Sex, M/F	139/110	186/170	1.2	(0.83–1.6)	0.9
Alcohol intake (Range) in g per day	23 (1–40)	19 (2–94)	1.02	(1.01–1.04)	<0.001
Smoking (yes/no)	102/147	176/180	0.71	(0.51–0.98)	0.004
Diabetes mellitus (presence/absence)	93/156	122/234	3.2	(2.3–4.5)	<0.001

microvasculature of the insertional tendon area. Moreover, as revealed by logistic regression analysis, we found that heavy alcohol intake was an independent risk factor for the onset of RCT in both sexes, even when adjusting for other known risk factors such as smoking habit and diabetes. Our study had some limitations. First, the controls were not examined by MRI to preclude the possibility of an asymptomatic RCT, but only to physical and ultrasound examination. We believe that since the tests and the ultrasonography that we performed had great sensitivity, accuracy, and specificity for RCT diagnosis, our results would not be substantially affected by this. Secondly, the amount of alcohol consumed per day may have been underreported by subjects who felt that they consumed more alcohol than they should.

Conclusion

Our study shows that:

- The daily alcohol consumption by patients with rotator cuff tear was greater than that in healthy controls, and their alcohol-drinking habit had lasted for a longer time.
- A daily consumption of more than 3 AUs for men and 2 AUs for women was found to be a significant risk factor for RCT occurrence.
- An excessive alcohol intake, greater than that recommended, was a significant risk factor for tendon damage and severity of the tear.

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Subacromial Impingement

Stefano Gumina

Since the middle of the last century, many studies have been performed with the aim to identify factors predisposing to cuff tendon tear. Since it was known that the acromion could have different shapes and different degrees of inclination, it has been simple to attribute these acromion features the responsibility of a pathological narrowness of the subacromial space. In fact, studies conducted between 1943 and 1969 [1–8] concluded that cuff tendon impingement against the antero-inferior margin of the acromion was the determining cause of tendon injury. Despite the fact that this belief was almost universal, the proposed treatments were discordant; Armstrong [3], Watson-Jones [4], Hammond [5], and Diamonds [6, 7] suggested performing total acromionectomy in case of symptomatic rotator cuff tear; Smith-Petersen et al. [1] and McLaughlin [2] suggested the removal of the lateral margin of the acromion because they believed that cuff tendons could rub only against this acromial portion.

In 1972, Charles Neer [9, 10], performed a study on 100 dry scapulae and observed that 11 of them had an acromion with a prominent anterior margin and a nonphysiological trend of the coracoacromial ligament. The author therefore believed that the supraspinatus tendon and the long head of the biceps, in the groove, could rub during arm flexion above 60°. This repeated impingement had supported, initially, the onset of a chronic inflammatory process of the subacromial bursa, then a partial tear, and finally, a full-thickness rotator cuff tear.

The term "impingement" (from the Latin "impingo": to impact) was introduced by Neer to indicate a pathological narrowness of the subacromial space responsible for shoulder pain due to chronic bursitis and partial and/or complete rotator cuff tear. Neer identified three stages of the disease characterized by increasing severity: stage I: typical of the young (<25 years), characterized by edema and reversible hemorrhage; stage II: frequently found in 25- to 40-year-old subjects, in whom cuff suffered because of fibrosis and tendonitis; stage III, observed in subjects older than 40 years, characterized by acromial spurs and tendon injuries. According to Neer, spurs were the result of calcific tendinopathy suffered by the acromial insertion of the coracoacromial ligament. The author recommended removing the antero-inferior margin of the acromion only in cases of full-thickness tear or in those of chronic bursitis and partial cuff tear together with marked limitation of the range of motion.

Alternative therapeutic approaches consisted in the section of the coracoacromial ligament, in the acromioclavicular joint resection, and in long head of the biceps tenotomy [11–18].

In the past years, many authors, in agreement with Neer's theory, have turned their attention to the acromial morphology and the presence of spur and their correlation with complete cuff tear [19–35].

Bigliani et al. [19, 20, 36] studied cadaveric scapulae by X-rays and proposed a classification based on the acromial morphology. According to the authors, it was possible to detect three types of acromion: the flat (type I), the curve (type II), and the hooked one (type III), respectively, with a prevalence of 19 %, 42 %, and 39 % (see chapter "Anatomy"). They believed that the hooked acromion, characterized by the presence of "spur," and/or osteophytes of the acromioclavicular joint, would reduce the subacromial space, causing cuff tear through an impingement mechanism. It was so obvious to suggest the removal of osteophytes or to expand the subacromial space by removing the antero-inferior margin of the acromion.

Farley et al. [26] in an MRI study evaluated the acromial morphology of 57 subjects with no history of shoulder pathology, and the same evaluation was made on 76 patients with symptomatic lesion of rotator cuff. The authors added the forth type of acromion characterized by a convex inferior surface (type IV) to Bigliani's classification and observed that shoulders with cuff tears frequently had a type III acromion; the coracoacromial ligament was thicker; and acromioclavicular joint had osteophytes that often protruded into the subacromial space.

The mechanical theory, supported also by Choo and Yoo [25], contrasted with the one linked to tissue degeneration

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caused by vascular hypoperfusion of the cuff insertional area on the greater tuberosity (critical zone) [20, 21, 33, 37]. According to this theory, the reduction of the subacromial space, due to the presence of spurs, was the result, rather than the cause, of the lesion. In fact, cuff tear alters the stability of the humeral head and conduces to its rise, with an increase of coracoacromial ligament tension and consequent onset of enthesophytes. Furthermore, the morphological changes of the acromion varied by age [27, 34, 38] and were not genetically dictated. Therefore, a type I acromion could result in a type II and III if there were any predisposed adverse mechanical conditions.

This concept has caused serious doubts on the real effectiveness of acromioplasty as an essential phase of the surgical cuff repair [39–43].

Mc Callister et al. [40] stated that there is no utility in completing surgical cuff repair with acromioplasty. Similarly, Garstman et al. in 2004 [41] performed a prospective, randomized study on patients with large cuff tear and observed that there were no differences in outcomes between patients who were submitted to acromioplasty and those who were not.

The same work was also conducted by Milano et al. [42] in 2005 and by Shin et al. [43] in 2012. In both cases, the results obtained were similar to those by Garstman.

Does Overuse or Genetics Play a Greater Role in Determining the Subacromial Space Width?

More than 40 years ago, Neer hypothesized that the presence of a spur at the antero-inferior aspect of the acromion might be the main cause of mechanical abrasion between the rotator cuff and the coracoacromial arch [9]. Subsequently, Bigliani et al. [19] classified the acromion shape into three patterns that were more or less prone to rotator cuff tendinopathy. A higher prevalence of rotator cuff tears was also attributed to a flatter slope of the acromion and to a decreased lateral acromial angle [44, 45]. Oh et al. [46] classified acromial spurs into distinct morphologies and suggested that the most common heel-type spur might be a risk factor for full-thickness rotator cuff tears.

Even though many years have passed since these milestone publications, we still debate whether the subacromial space width (primarily the result of the acromion shape) is influenced by possible overloading or is genetically determined. Wang and Shapiro [38] were proponents of the first hypothesis, observing that the shape of the acromion progressed from flat to curved or hooked as age increased. Analogously, in 2001, Shah et al. [34] conducted a macroscopic, radiographic, and histologic study on 18 cadaveric shoulders (12 pairs from six cadavers and six unpaired) and observed a common pattern of degeneration of collagen, fibrocartilage, and bone in all of the curved and hooked acromions. Therefore, they concluded that the shape of the acromion is acquired in response to traction forces applied via the coracoacromial ligament and is not congenital in origin. However, the results of both publications lacked supporting statistical analysis and did not provide information on the impact of the various acromion shapes on the subacromial space. In addition, the authors did not provide information on the limb dominance or occupation of the subjects. Mahakkanukrauh and Surin [47] supported the same theory. They performed an anatomical study on 346 skeletons and observed that occurrence of acromial osteophytes and increasing age were significantly correlated; furthermore, no sex differences were noted in the frequency of osteophytes.

Even today, it remains unclear whether the subacromial space width is primarily genetically determined (and only in part influenced by external factors) or changes over time according to the loads to which the shoulder is subjected (regardless of genetic predisposition).

To clarify this unresolved question, we compared the subacromial space width between elderly monozygotic (identical) and dizygotic (fraternal) twins [48], and we used the twin study design [49] to separate the contributions of shared and unique environments. We identified 50 pairs of twins in the same age range (50 to 75 years) since most patients who are treated surgically for a rotator cuff tear are in this range [50]. The acromiohumeral distance and rotator cuff status (structural and qualitative condition) of the dominant shoulder were assessed by MRI. The acromiohumeral distance was calculated in the coronal oblique projection as the distance between the most caudal point of the lower surface of the acromion and the most cranial point of the proximal aspect of the humerus. We interviewed all participants about employment, recording specific information regarding both type and duration. Occupations were divided into three groups: “heavy manual workers” (cleaners, laborers, craft workers, transportation workers, and equipment operators), “administrative support workers” (administrative workers, technicians, and housewives), and “professional workers” (professionals and managers). All data were submitted to a very sophisticated statistical analysis.

All the results are summarized in Tables 1, 2, and 3.

The resulting heritability index showed genetic factors to be the main cause of the variability of the acromiohumeral distance, with shared and unique environmental factors contributing only slightly to the variability.

The role of genetic factors is also supported by the results of the acromiohumeral distance comparisons of the three groups of workers. No significant differences were found among groups who performed or had performed different types of labor. This was confirmed both in the whole study cohort and within the monozygotic and dizygotic subjects. These data appear to be partially in contrast to those of Frost and Andersen [51], who observed that shoulder-intensive work was a risk factor for impingement syndrome.

Table 1 Baseline characteristics of the cohort

	MZ twins[a] ($N=30^{b}$)	DZ twins[a] ($N=28^{c}$)	p value
Age (year)	63.66 ± 4.32 (53–72)	63.78 ± 1.96 (60–66)	
Female	62.40 ± 6.3 (53–72)	63.77 ± 2.03 (60–66)	0.264
Male	64.30 ± 2.86 (61–71)	63.80 ± 1.83 (61–66)	0.978
Acromiohumeral distance (mm)	10.13 ± 1.70	9.69 ± 1.74	0.197

[a]The values are given as the mean and standard deviation, with or without the range in parentheses
[b]10 female and 20 male
[c]18 female and 10 male

Table 2 Summary of acromiohumeral distance heritability analysis

MZ twins				DZ twins				
	p value of mean squares				p value of mean squares			
Mean difference (mm)	Within pairs	Among pairs	ICC	Mean difference (mm)	Within pairs	Among pairs	ICC	Heritability
−0.13	<0.001	0.450	0.91	0.10	<0.001	0.849	0.50	0.82

MZ monozygotic, *DZ* dizygotic, *ICC* intraclass correlation coefficient

Table 3 Acromiohumeral distance (AHD) differences according to occupation

	Monozygotic twins		Dizygotic twins	
Occupation	AHD[a] (mm)	p value	AHD[a] (mm)	p value
HMW	10.25 ± 1.88	0.842 vs. ASW	9.55 ± 1.89	1.00 vs. ASW
ASW	9.88 ± 2.30	1.00 vs. PW	9.60 ± 0.80	1.00 vs. PW
PW	10.60 ± 1.31	1.00 vs. HMW	9.80 ± 1.79	1.00 vs. HMW

HMW heavy manual workers, *ASW* administrative support workers, *PW* professional workers
[a]The values are given as the mean and standard deviation

Analogously, van Rijn et al. [52] noted that highly repetitive work was associated with the occurrence of subacromial impingement, and Roquelaure et al. [53] observed that skilled blue-collar workers were more likely to develop subacromial impingement, especially if forced to abduct the arm repeatedly. Finally, in a longitudinal study, Svendsen et al. [54] showed that forceful work, work with elevated arms, and repetitive work each doubled the risk of surgery for subacromial impingement.

Our study suggests that the anatomical features that influence the width of the subacromial space are mainly genetically determined. However, if the subacromial space is already constitutionally narrow, external factors would strongly contribute to further reduction of the space, making it too tight. This might occur as a consequence of the ossification of the acromial insertion of the coracoacromial ligament [9]; of contracture of the posterior capsule of the glenohumeral joint, which would lead to upward migration of the humeral head [55–57]; or of scapular muscle performance deficits [58].

Rotator Cuff Integrity in Patients with Antique Unilateral Upper-Limb Amputation

In order to test the role of the extrinsic factors in the genesis of the rotator cuff tear, we evaluated by an MRI exam, both shoulders of 25 patients with antique unilateral upper-limb amputation (Fig. 1a, b).

Rotator Cuff Tendon Status (Structural and Qualitative Condition) According to Sugaya Classification [59] and Rotator Cuff Muscle Tropism According to Fuchs Classification [60]

Oblique coronal, oblique sagittal, and axial T2-weighted spin-echo MRI images were obtained in all subjects. Coronal oblique shoulder images were in plane parallel to the supraspinatus tendon. The patients were examined in the supine position with the arm at the side, the palm facing up, and the hand under the hip in order to keep the shoulder motionless. The acromiohumeral distance (AHD) of both shoulders was also measured in the participants with full thickness cuff tear. The AHD was calculated in coronal oblique projection as the distance between the most caudal point of acromion lower surface and the most cranial point of proximal humerus.

The results are summarized in Tables 4 and 5 Gumina S, 2015. Table 4 shows the healthy status of rotator cuffs in the studied group according to Sugaya classification. The general tendency showed not significant repartitions between the amputated and the healthy side ($p=0.18$). When each shoulder was separately evaluated, a significant prevalence of Sugaya type II category in the amputated side ($\chi^2=12.5$, $p=0.02$) and of Sugaya type I category in healthy side ($\chi^2=25.5$, $p<0.001$) was found. Considering only the 19 participants with no rotator cuff tear, the mean values of the AHD of the amputated and healthy side were 0.81 cm (SD: 0.11) and 0.87 cm (SD: 0.13), respectively; thus, a significant difference was found ($p=0.02$).

Fig. 1 Evaluation of active shoulder flexion (**a**) and abduction (**b**) in a 72 years old male with a right upper-limb amputation

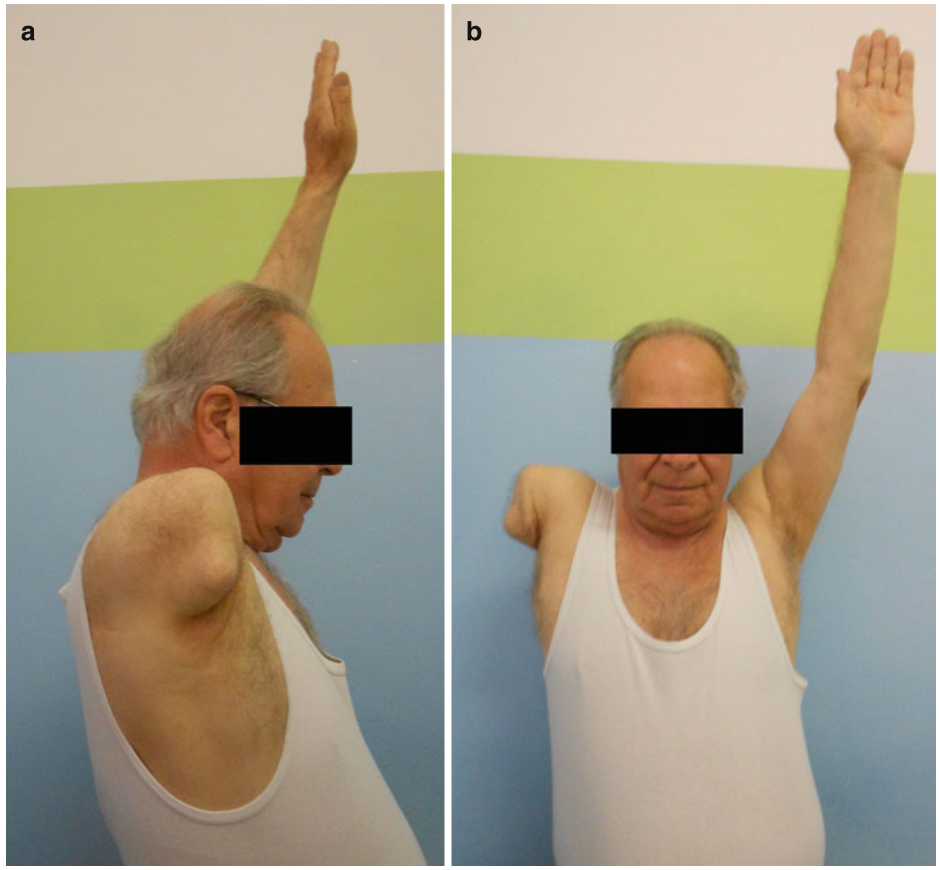

Table 4 Distribution of the sample according to Sugaya classification

	Amputated side	Healthy side
Type I	7 (28 %)	**13** (**52 %**)
Type II	**10** (**40 %**)	7 (28 %)
Type III	4 (16 %)	2 (8 %)
Type IV	1 (4 %)	1 (4 %)
Type V	3 (12 %)	2 (8 %)
	χ^2 = **12.5**, p = **0.02**	χ^2 = **25.5**, p < **0.001**

The hypothesis was that the two repartitions were identical

Table 5 Distribution of the sample according to Fuchs' classification

	Amputated side	Healthy side	*p*-value[a]
Type 0	–	1(4 %)	**0.033**
Type I	8 (32 %)	**13** (**52 %**)	
Type II	7 (28 %)	8 (32 %)	
Type III	5 (20 %)	1(4 %)	
Type IV	5 (20 %)	2 (8 %)	
	χ^2 = 1.08, p = 0.78	χ^2 = **22.8**, p < **0.001**	

[a]The hypothesis was that the two repartitions were identical

Table 5 shows the number and proportion of sample according to Fuchs classification. The general tendency revealed different repartitions between the amputated and the healthy side ($p = 0.033$), showing a significant prevalence of Fuchs type II in the healthy side ($\chi^2 = 22.8$, $p < 0.001$).

According to the sample frequency distribution based on Sugaya and Fuchs classifications, we found a significant relationship between both the amputated ($\chi^2 = 10.15$, $p = 0.001$) and the healthy side ($\chi^2 = 8.40$, $p = 0.004$).

We did not find significant differences in repartition between the rotator cuff status of amputated and healthy side according to the five types of Sugaya classification. Instead, a significant prevalence of Sugaya type II category (slightly degenerated cuff) in the amputated side and of type I category (normal and healthy cuff) in healthy side was found. In addition, only 20 % of the cuffs in the healthy side had a partial or a full thickness tear, while the percentage rose to 32 % in the amputee side. Our results indicate that the cuff of the healthy side undergoes degeneration and rupture with increasing age, as it physiologically occurs.

Furthermore, our data indicate that cuff degeneration, and consequently cuff tear, is not affected by functional overload. In fact, paradoxically, rotator cuff of the amputee side, which is inevitably submitted to minor functional stresses, is healthy in just 28 % of cases compared with 52 % of nonamputee side. This cannot be attributed to the decrease in subacromial space width, which was observed in the amputee side with respect to the healthy side, because this difference is less than 1 mm. It is possible that a scarce nutritional intake may be the main cause of the cuff degeneration in the amputee side. We believe that this assumption can be supported by one or more of three possible explanations:

1. In 1970, Rathbun and McNab [61] hypothesized that the muscle-tendon vascularity of the superoposterior cuff is “squeezed” when the arm is held in the resting position of neutral rotation and adduction, which is the position mostly assumed from the amputee shoulder. Therefore, according to this hypothesis, the rotator cuff of the amputee side would be scarcely vascularized.
2. To date, no study has investigated the possible effusion of the synovial fluid into the rotator cuff during shoulder motion. If this occurs, certainly the poor mobility of the amputee limb will not allow effusion.
3. We find significant differences in repartition between muscle belly status of amputated and healthy side according to five types of Fuchs classification; significant prevalence of Fuchs type II category in the healthy side was found. Fuchs degree of the muscle belly was III or IV in 40 % and 12 % in the amputee and healthy side, respectively. Progressive muscular atrophy is the result of decreased protein synthesis and increased protein degradation at the cellular level. Protein synthesis is reduced due to a decrease in metabolic activity; the degradation of cellular proteins, carried out mainly through the way of the ubiquitin-proteasome, is stimulated by disuse, which activates the ubiquitin ligase, thus catalyzing the union of the small ubiquitin peptide to the cellular proteins and causing their degradation in the proteasomes [62, 63]. Consequent to progressive muscle atrophy, a reduction of the capillary-to-fiber ratio (C/F) occurred in skeletal muscle submitted to disuse [64, 65]. This ratio reflects the number of capillaries around a fiber. Increased interstitial collagen around vessels and muscle fibers with disuse [66, 67] further separates the muscle fibers from their reduced capillary supply and can contribute with the capillary loss to hypoxia-induced atrophy of the muscle fibers [67]. The microcirculation can also be impaired by the characteristic interstitial fibrosis with disuse and cause capillary loss which in turn can trigger further fibrosis [66].

Based on these microvascural and structural changes, it is possible that the impairment of the vascular supply to the muscle results in a decrease in the nutritional contribution to the tendon itself provided by the muscle branches [68].

Surprisingly, some cuff muscles of the amputee side preserved a good tropism. Other studies will be needed to determine which stimuli can still receive a scarcely used muscle.

Conclusions

Our data on patients with unilateral ancient upper limb amputation indicate that the rotator cuff degeneration, and consequently cuff tear, is poorly dependent on shoulder overuse. In fact, these pathological changes are most frequently found in amputee side which is inevitably less involved in daily activities. Therefore, in such patients, rotator cuff degeneration and rupture are probably more due to poor nutritional intake (intrinsic factors).

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Acromioclavicular Joint Degeneration

Stefano Carbone and Stefano Gumina

The concept of shoulder impingement was first described by Meyer in 1937. Afterwards, Neer expanded on Meyer's study, describing the different stages of impingement. Shoulder impingement syndrome is caused by an anatomic narrowing of the subacromial space by the structures that form the coracoacromial arch leading to progressive bursitis, tendinitis, and rotator cuff tear. Acromioclavicular joint degeneration and pain may exist alone or in addition to shoulder impingement.

The space between the undersurface of the acromion and the superior aspect of the humeral head is called the subacromial space. This space is normally narrow but maximally narrow when the arm is abducted. Any condition that further narrows this space can cause impingement. Impingement is a cause of rotator cuff tears [1]. It occurs between the undersurface of the anterior third of the acromion and the rotator cuff and involves the coracoacromial ligament and the acromioclavicular joint. In the etiology of impingement, most anatomic studies focused on one component of the coracoacromial arch—the acromion—and its morphology in relation to rotator cuff tears. Few addressed the influence of the acromioclavicular joint on the supraspinatus outlet.

Degenerative disease of the acromioclavicular (AC) joint is a common pathology affecting the shoulder [2, 3]. It depends on the patient's age, but in contrast to rotator cuff (RC) damage, it begins in the third decade of life as a degeneration of the intra-articular disk [2]. The coexistence of RC damage and AC joint arthritis is a common phenomenon. Some authors have found correlation between the presence of osteophytes in the inferior aspect of the joint and the prevalence of symptoms of subacromial impingement syndrome or RC damage [4, 5]. Most cases of progressive, degenerative disease of the AC joint remain asymptomatic [6]. Despite these findings, some authors believe that subclinical osteophytes at the inferior surface of the shoulder joint can mechanically irritate RC tendons, ultimately causing them to break [7, 8, 9, 10] (Fig. 1).

Anatomy and Biomechanics

The AC joint connects the lateral aspect of the clavicle to the acromion. Via the sternoclavicular joint, it provides the linkage between the shoulder girdle and the axial skeleton. It is a diarthrodial joint with a fibrocartilaginous disk and hyaline articular cartilage, which with age is gradually replaced by fibrocartilage [11]. Despite the existence of wide variation, the joint space is approximately 9 mm by 19 mm in adults [12]. Also the joint inclination varies, ranging from flat, through oblique to curved one [13]. The most common inclination is superolateral to inferomedial with the articular surface of the clavicle overhanging the acromial surface [14]. Sensory innervation is provided by the branches of the axillary, suprascapular, and lateral pectoral nerves.

The fibrocartilaginous disk contains stabilizing fibers that are contiguous with the superior joint capsule. Recently, the AC joints were classified into three major types depending on the presence or absence of the articular disk [15]. In this study, histological observation revealed that the upper part of

Fig. 1 X-Ray of a left shoulder. The *arrow* shows degenerative changes of the AC joint

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the articular disk of the ACJ comprised fibrocartilage, while the lower part comprised dense connective tissue. In cases where the ACJ appears to be an ellipsoid joint, its limited axial rotation restricts posterior tilting of the scapula during arm elevation, which could contribute to shoulder impingement syndrome. While the function of the disk is still a matter of discussion, it is well known that it is implicated in degenerative conditions of the AC joint because this structure undergoes significant degeneration during the third and fourth decades of life [3, 11, 14]. The AC joint is surrounded by a thin synovial capsule reinforced by the AC ligaments that are located anteriorly, posteriorly, superiorly, and inferiorly. These ligaments are the stabilizers of the joint; the acromioclavicular ligaments provide the primary restraint to the horizontal clavicular translation, while the coracoclavicular one represents the primary restraint to vertical translation [16]. Global stability of the AC joint relies on the cooperation of AC and CC ligaments, but it is difficult to describe the individual contribution of each structure. There is surprisingly little motion at the AC joint, despite the significant degrees of freedom of the upper extremity. As Codman reported, during abduction or forward flexion, the AC joint has only 5 to 8 degrees of motion, while the clavicle and scapula have approximately 45°. Studies have demonstrated that stabilization of this joint has little effects on shoulder range of motion, and it may help to understand why arthrosis of this joint is often asymptomatic [17]. On the other side, disruption of the joint stability by a Rockwood type III AC joint dislocation alters significantly the kinesis of the shoulder girdle [18].

Degenerative Acromioclavicular Joint

The AC joint commonly has degenerative changes within the third decade of life. This is due to the degeneration of the intra-articular disk and fibrocartilage replacement of the hyaline articular cartilage [3, 11, 14, 19]. In order to classify the degenerative changes of the joint, a MRI grading classification is used which is based on joint space narrowing, capsular distension, and subacromial irregularity. There are four grades altogether: grade 1 means that AC joint is normal (no degenerative changes); grade 2 is characterized by mild joint space narrowing and possible capsular distension; grade 3 has capsular distension, joint space narrowing, subacromial fat/bursal effacement, and marginal osteophyte formation; finally, grade 4 involves severe degeneration with joint irregularity, joint space obliteration, and large inferior osteophyte formation. Again, despite the large occurrence of degenerative changes, few patients have a correlation between radiographic and clinical examination of this joint (Fig. 2).

Conclusion

In case of rotator cuff tear and subacromial impingement, it is important to identify the architectural changes in shoulder anatomy, the area of impingement, and the offending aspect of the coracoacromial arch. Treatment of rotator cuff disease should include evaluation of the acromioclavicular joint, as its degeneration affects the magnitude of encroachment. The impingement by acromioclavicular osteophytes must be aggressively cleared

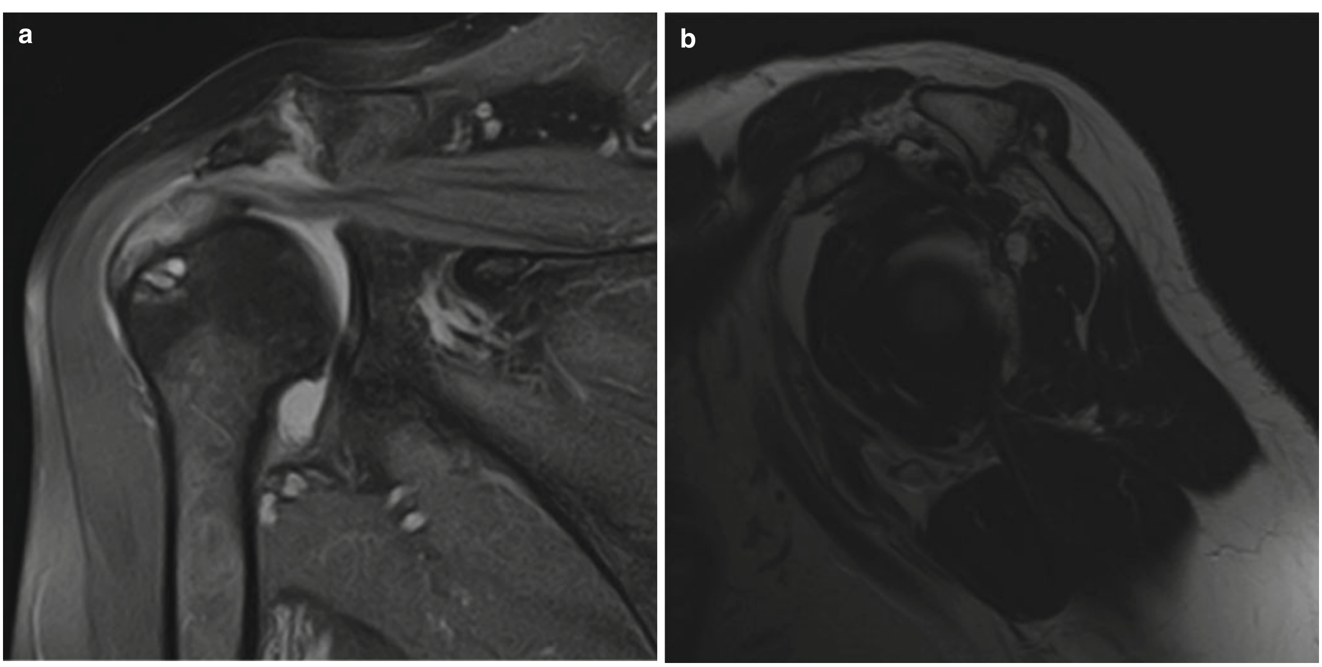

Fig. 2 (**a**, **b**) MRI scans of 57y male patient showing degenerative changes of the AC joint and of the superior rotator cuff

during subacromial decompression with rotator cuff repairs. In severe acromioclavicular degeneration, distal clavicular excision in combination with anterior acromioplasty is recommended, even in cases with an asymptomatic acromioclavicular joint, so as to prevent further osteophytes formation.

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Thoracic Hyperkyphosis

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Despite the huge quantity of papers on subacromial impingement, the relationship with malposition of the scapula, as a consequence of thoracic hyperkyphosis, has not been fully elucidated. In a masterly review, Bigliani and Levine [1] have listed the primary extrinsic causes of impingement syndrome; however, thoracic hyperkyphosis is not cited. To our knowledge, only sporadic studies have considered thoracic hyperkyphosis as a cause of subacromial impingement. Matsen and Craig [2] observed that stretched and weakened scapular and midthoracic kyphosis are common companions of subacromial primary extrinsic syndrome and also stated that the pathological spatial orientation of the scapula, owing to thoracic kyphosis, may decrease the subacromial space. Celli et al. [3] have verified that in patients with midthoracic hyperkyphosis, the great tuberosity passes precociously under the acromion (40°) during the forward flexion; therefore, they have hypothesized that in patients older than 50 years old, hyperkyphosis may be considered a cause of subacromial impingement. Grimsby and Gray [4] stated that in patients with forward head, rounded shoulders and increased thoracic kyphosis, the scapula rotates forward and downward, depressing the acromial process and changing the direction of the glenoid fossa. Therefore, as the patient attempts to elevate the arm, the supraspinatus tendon may become impinged against the anterior portion of the acromion. On the contrary, Lewis et al. [5] have determined the forward head and the forward shoulder posture by calculating some angles between fixed points on the dominant and painful side of asymptomatic subjects and patients affected by subacromial impingement syndrome, respectively. They concluded that a clear relationship between posture and subacromial width does not exist.

Burkhart et al. [6] have frequently observed a malposition of the scapula in the dominant throwing shoulder and named this condition SICK syndrome (Scapular malposition, inferior medial border prominence, coracoid pain and malposition, and dyskinesis of the scapular movement). This malposition was attributed to muscle activation disturbances that produce altered kinematics of the scapula upon dynamic use. Patients with SICK syndrome have been seen to have impingement-like symptoms due to the anteroinferior angulation of the acromion caused by scapular protraction. Warner et al. [7], using a modification of the standard technique of Moiré topographic analysis in asymptomatic subjects and in patients with impingement syndrome, observed a scapulothoracic asymmetry, respectively, in 14% and 57%. Rubin and Kibler [8] reported that postural dysfunction is frequently associated with a dyskinesis, and so with an asynchronism, of the scapula and considered primary subacromial impingement a cause of scapular dyskinesis.

Ludewing and Cook [9] observed that excessive scapular protraction is associated with an antetilting of the acromion responsible for subacromial impingement syndrome. Lukasiewicz et al. [10] noticed that patients with impingement syndrome had approximately 10° less posterior tilting compared with asymptomatic subjects.

Considering the lack of knowledge and contradictory results, we have measured [11], on X-ray films and CT scans, the subacromial space in 47 patients with idiopathic or acquired dorsal hyperkyphosis [>40° according to the Cobb's method [12] (Fig. 1)] and compared the results with those from volunteers without shoulder pain, radiographic signs of shoulder instability, or a well-known pathological condition responsible for subacromial impingement syndrome.

The subacromial space was measured, in the true AP view, from the dense cortical bone marking the inferior aspect of the acromion at a point directly above the humeral

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Fig. 1 Cobb's method

head and recorded as the smallest distance between this point and the articular cortex of the humeral head, as suggested by Petersson and Redlund-Johnell [13]. Magnification was estimated as 11%. All patients with hyperkyphosis and 16 volunteers were submitted to right shoulder CT evaluation too, in order to verify X-ray measurement reliability.

Subacromial space of our patients with hyperkyphosis was narrower than that of controls (Table 1). Gender and age did not influence this result. It is plausible that narrowness of the subacromial space may be attributed to the less posterior tilting of the scapula. This hypothesis is supported by Kebaetse and coworkers' study [14]. Authors observed that patients with a slouched posture have less posterior tilt and less upward rotation of the scapula with respect to trunk-erect subjects, and that this anomalous orientation of the acromion may create a bony block that causes, or contributes to, impingement pathology with repetitive overhead activity. Our data confirmed Petersson's method. Mean CT measure was slightly less than that calculated on X-ray radiographs. This could be due to the fact that the CT exam was performed with the patient in the supine position; therefore, the superior limb did not suffer from gravity effect. Another possible explanation might be that hyperkyphosis may slightly decrease in the supine position, thus decreasing antetilting. Imaging also confirmed that subacromial space is wider in males than in females and decreases with increasing age. Our patients with thoracic hyperkyphosis greater than 50° had a subacromial space lesser than that measured in patients with a less severe kyphosis (Fig. 2a–d). This suggests that subacromial width is directly related to severity of

Table 1 Acromio-humeral distance (expressed in millimeters) in volunteers without and in patients with thoracic hyperkyphosis

	Females						Males					
	Without			With			Without			With		
	NO°	AVG	SD ±	NO°	AVG	SD ±	NO°	AVG	SD ±	NO°	AVG	SD ±
X-ray radiograms												
Total	104	8.99	1.60	43	7.13	2.40	71	9.52	1.80	4	8.25	3.59
Yrs <60	78	9.14	1.56	13	8.53	1.56	51	9.76	1.80	3	10.0	1.00
Yrs >60	26	8.53	1.92	30	6.53	2.5	20	8.90	1.77	1	5.10	—
CT scans												
Total	17	7.99	1.80	43	6.29	1.70	4	8.60	1.90	4	7.20	2.7

Fig. 2 Patients with thoracic hyperkyphosis, respectively, lesser (**a**) and greater than 50° (**b**). X-ray (lateral view) (**c**) and a MRI image (**d**) of two different patients with a severe (>50°) thoracic hyperkyphosis

thoracic kyphosis. Since hyperkyphosis of patients with osteoporotic vertebral fractures may make it worse over time, due to possible occurrence of new vertebral fractures, subacromial decompression could give only temporary shoulder pain relief.

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Subcoracoid Impingement

Stefano Gumina

The subcoracoid space is occupied in vivo by several soft tissue structures, such as the articular capsule of the glenohumeral joint, the subscapularis tendon, and the subacromial bursa. The thickness of these tissues may vary from case to case, but entity of variations is scarce and does not affect the width of the subcoracoid space, unless there is local pathology. The shape and size of this space depend on its limiting skeletal structures [1, 2]. Therefore, anatomical morphometric studies of these structures may provide information to the etiology of the subcoracoid impingement syndrome [3].

Few patients had idiopathic impingement (Fig. 1a, b), which appeared to be often caused by a long coracoid process projecting more laterally than normally. Dines et al. [4] reported coracoid impingement in seven patients, all of whom underwent surgical excision of the coracoid tip. Many shoulder surgeons, including Codman [5], have expressed doubt about the existence of this idiopathic syndrome. In my experience, subcoracoid impingement is common in cases of congenital deformity of the humeral head (Fig. 2a, b).

In 1999, we performed an anatomical morphometric study on a large number of coracoid processes in dry scapulae and a CT morphometric study on some of the specimens [6]. The aim is to determine if anatomical variations of the coracoid process might predispose to the idiopathic impingement syndrome. Gender and side of the scapulae were not taken into account, since these factors did not appear to influence the anatomical features of the coracoid process [7]. A total of 204 scapulae (76 right and 128 left) entered into the study; most (82 %) were from cadavers with the presumed age between 30 and 60 years. Sixty-eight pairs of scapulae were from the same skeletons. None of the scapulae showed degenerative changes of the coracoid process.

We found no significant correlations among length or thickness of the coracoid process, coracoglenoid distance, coracoid slope, and prominence of the coracoid tip beyond the anterior edge of the glenoid. Furthermore, no correlations were found between these anatomical features and the dimensions of the whole scapula as revealed by the length-width ratio. Since the anatomical characteristics, which were found to be extremely variable, cannot be precisely evaluated in radiographs of the shoulder, no information on the dimensions of the coracohumeral space can be obtained by radiographic studies.

The anterosuperior border of the glenoid and the posterolateral margin of the coracoid process enclose an arch-like space of varying shape. We found out that this space may have three configurations: In Type I this space had a "round bracket" configuration, whereas in Type II and III it had the shape of a "square bracket" and a "fish hook," respectively. Type I configuration was observed in 45 % of scapulae, and Type II and III configuration in 34 % and 21 % of specimens, respectively. Subacromial space presents the shortest dimensions in the Type I scapulae. Furthermore, the scapulae with this configuration were found to have, on CT, the lowest mean values of the coracoglenoid angle (formed by the line originating from the anterior glenoid rim and running tangentially to the most prominent part of the tip of the coracoid; and the line passing through the anterior and posterior glenoid rims) [7] and coracoid overlap (distance by which the coracoid process overlaps the plane of the glenoid fossa) [7]. It has been shown that values of these parameters are related to the width of the coracohumeral space, since it was found to be small in the presence of small coracoglenoid angles and small coracoid overlap [7]. Therefore, Type I configuration implies a short coracohumeral distance.

Measurements of the coracoglenoid space on standard CT scans, which are much easier than measurements of the coracoglenoid angle and coracoid overlap, may identify subjects with a narrow coracohumeral space. This information, however, is not sufficient to diagnose idiopathic subcoracoid impingement. In fact, in 4 % of Type I scapulae, other anatomical characteristics were present predisposing to narrowing of the coracohumeral space, and this is a higher

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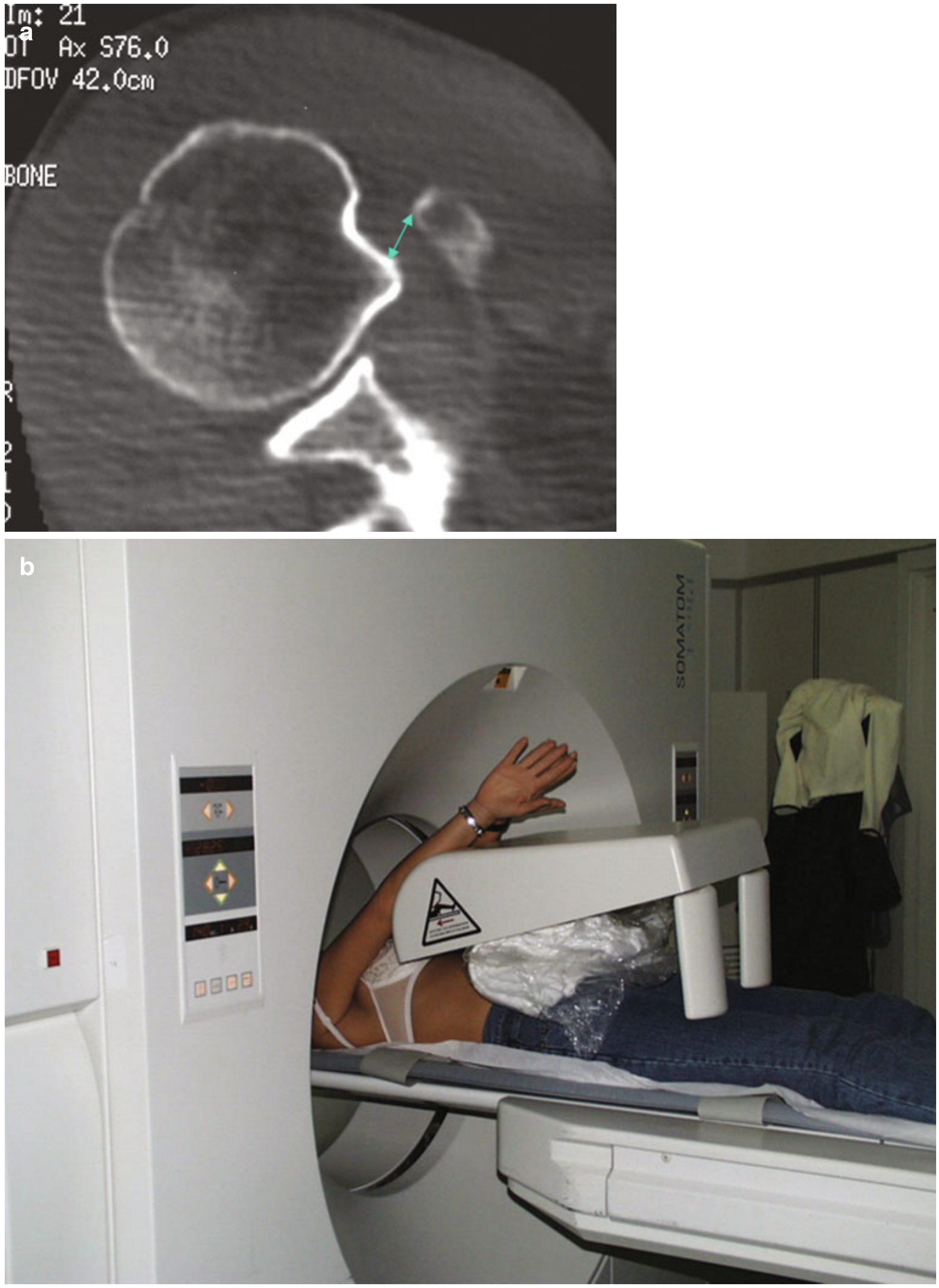

Fig. 1 A 52-year-old lady with clinical evidences of subcoracoid impingement. The CT exam (**a**), performed with the upper limbs in flexion, adduction, and internal rotation (**b**), showed that the distance between the coracoid tip and the lesser tuberosity was less than 7 mm (it is considered the minimum tolerated distance)

figure than the incidence of the clinical syndrome. It is thus conceivable that constitutional anomalies (e.g., prominence of the lesser tuberosity) or pathological conditions of the local soft tissues or bony structures (ganglia or calcification of the subscapularis tendon, or superior migration of the humeral head) [3, 8] should also be present for the clinical syndrome to develop.

Severe degenerative changes of the coracoid pillar were not observed in our skeletons, even when the acromion showed anterior spurs or a pseudoarticular surface for the humeral head. This suggests that the coracoid process is not involved in, or affected by, subacromial impingement. Furthermore, degenerative changes have not been observed in patients with subcoracoid impingement [4]. In conclusion, our study suggests that subjects who are at risk of developing an idiopathic subcoracoid impingement syndrome are those showing a Type I configuration, associated with severe narrowing of the coracoglenoid space. The morphometric characteristics of this space may be easily evaluated on standard CT scans of the shoulder.

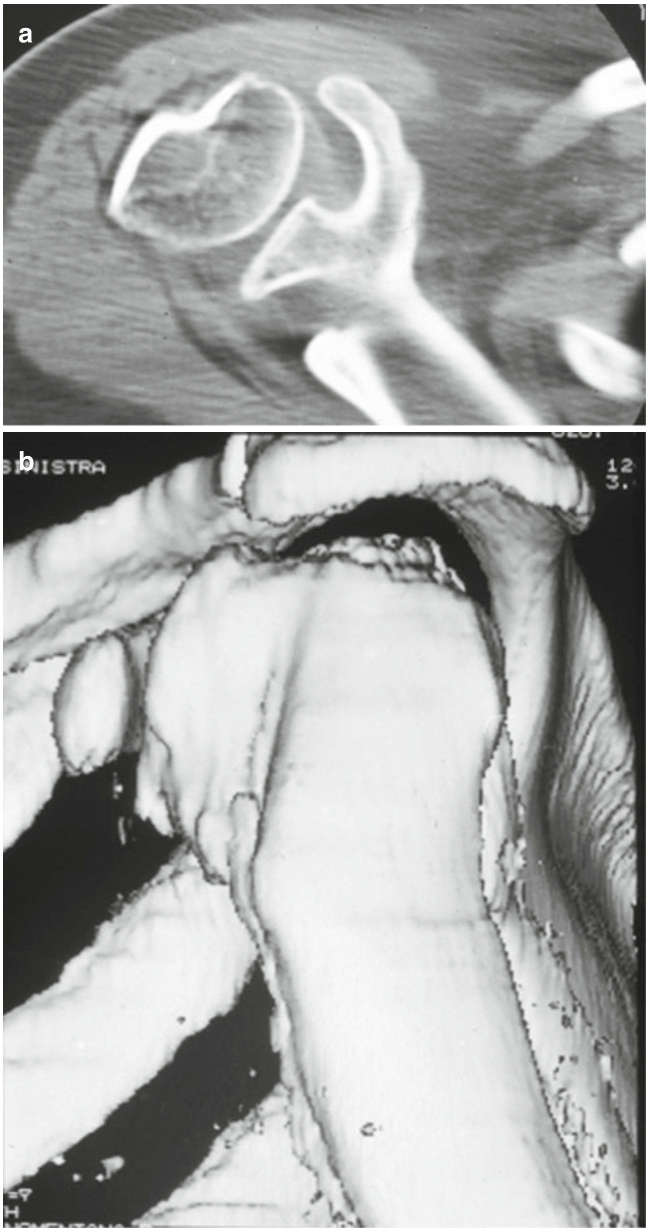

Fig. 2 (**a**, **b**) CT exam performed on the left shoulder of a male patient with congenital deformity of the humeral head and with a pathological narrowing of the subcoracoid space

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Other Causes: Pigmented Villonodular Synovitis

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Pigmented villonodular synovitis (PVNS) is a reactive benign tissue proliferation that involves synovium, tendon sheath, and bursa. From the literature, it emerges that it is a rare condition that affects approximately 1.8 cases per 1 million people [1]; the incidence peak is between 30 and 50 years of age and both genders are equally affected [2].

Generally, PVNS is a mono-articular disease, and of all the joints, the knee is affected in about 80 % of cases [3]. In a review of the literature, Mehieu et al[4] observed that fewer than 30 cases of PVNS of the shoulder had been published and that the prevalence of this disease affecting the shoulder joint should be considered less than 2 %. During the last decade, only few papers concerning shoulder PVNS were published and almost all of them are case reports [4–11] describing above all middle-aged or elderly patients [3, 5, 6, 12, 13]. Only two papers reported one case of PVNS of the shoulder occurring in two adolescent males [10, 14]. Cho et al. [11] reported a case of localized extra-articular PVNS of the subacromial space that was satisfactorily treated with open excisional biopsy and subacromial bursectomy after a diagnostic glenohumeral arthroscopy. A similar case was also reported by Sawmiller et al. [13]. Excluding papers relating to case reports and those in which patients were treated with shoulder arthroplasty, the only study on PVNS of the shoulder associated with massive rotator cuff tear and osteoarthritis, treated with arthroscopic synovectomy and partial rotator cuff repair (4 patients) or debridement (1 patient), was reported by Chiang et al. [3]. The study group was composed of five patients: 3 males and 2 females, ranging from 60 to 83 years of age who were functionally evaluated after a mean follow-up period of 22 months using the ASES and UCLA shoulder scoring system.

Macroscopic anatomo-pathological finding of shoulder PVNS is characterized by a yellowish brown pigmentation over the entire joint capsule (Fig. 1) and subacromial space that is generally associated with a massive rotator cuff tear and to osteoarthritis with cystic erosions, usually on the humeral side.

Few cases of PVNS were accidentally discovered during surgery for joint instability or rotator cuff repair [4, 14–17]. In some patients, PVNS causes shoulder swelling, due to an excessive production of articular fluid or to a massive intraarticular hemorrhage. In all cases, the pathology is responsible for serious shoulder pain and a decrease in range of motion. These symptoms are even more evident if PVNS is associated with rotator cuff tear and/or glenohumeral osteoarthritis. We believe that PVNS may worsen rotator cuff tearing or cause itself a cuff tearing because of its proliferating nature, with a secondary degenerating effect of cuff tendons. It is

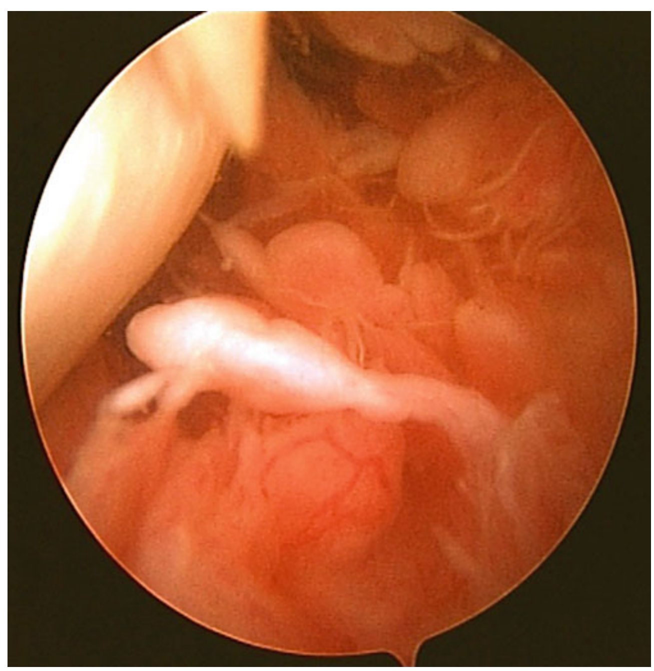

Fig. 1 Arthroscopic view of a shoulder affected by PVNS (pigment villonodular synovitis)

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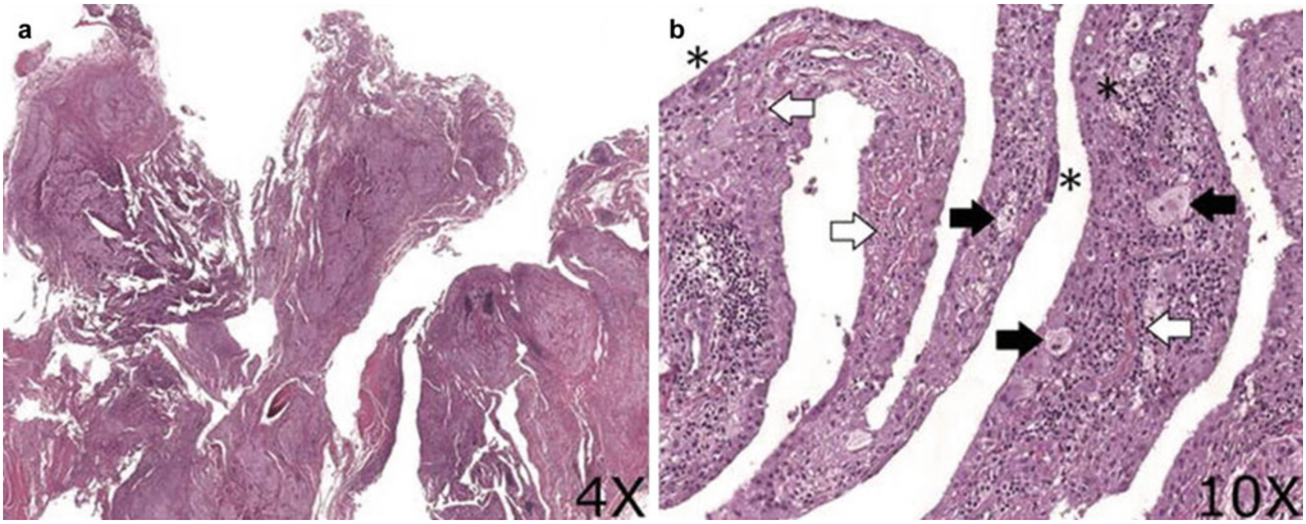

Fig. 2 The hyperplastic synovial villi (4×) (**a**) showed fibroblastic proliferation (*white arrow*), histiocytic foam cell infiltration (*black arrow*), and multinuclear giant cells component (*asterisk*) (10×) (**b**)

also plausible that it may be due to the release of cytokines with tendon tearing effect.

Generally, total synovectomy is the standard treatment for PVNS; however, when the shoulder is involved, rotator cuff and articular surface status have to be considered because the final clinical outcome is strongly influenced by tendinous and cartilage conditions. Since the almost totality of the rotator cuff tear in cases of shoulder PVNS is classified as massive and because all cases of shoulder PVNS have different degrees of degenerative changes of articular surfaces, the recommended surgical options which should be associated with synovectomy are as follows: arthroscopic debridement of cuff tear [3, 5], partial cuff repair [3], shoulder hemiarthroplasty [6, 7], and total shoulder arthroplasty [8].

Recently, we examined the largest series of patients with shoulder PVNS, massive irreparable rotator cuff tear, and glenohumeral osteoarthritis treated with arthroscopic debridement and synovectomy [18]. Our purpose is to evaluate the result of the treatment in patients with shoulder PVNS and to compare these results to those obtained from patients of similar age and having massive irreparable cuff tear associated with hemorrhagic synovitis with or without glenohumeral arthropathy treated with debridement and synovectomy.

From 2003 to 2013, we prospectively treated nine patients (six females and three males, mean age 65.8 years, range 63–70 years; seven right shoulders; right side dominant in all cases) with PVNS of the shoulder (group I) and who responded to these inclusion criteria: age between 60 and 70 years and presence of a massive and irreparable rotator cuff tear with slight glenohumeral arthropathy [scored as Grade 1 or 2 according to Hamada method [19]], and arthroscopic histology confirming the diagnosis of PVNS characterized by pigment deposition, histiocytic cell infiltration, multinuclear giant cells, and foam cells in the hyperplastic synovial villi as the major histologic findings (Fig. 2a, b).

Age was considered as a primary factor because it was our intention to compare clinical results obtained after arthroscopic synovectomy and debridement to those registered in a control group (group II) composed of 20 consecutive patients (12 females and 8 males recruited in the same period, from 2003 to 2010), of comparable age (mean age: 66.7; range 62–70 years), and who had undergone arthroscopic debridement for massive and irreparable cuff tear associated with hemorrhagic synovitis (confirmed by mean of arthroscopic histology) and who had no (12 patients: 6 females and 6 males) or slight (8 patients: 6 females and 2 males) glenohumeral arthropathy (Grade 1 or 2 according to Hamada method). In group II, patients without glenohumeral arthropathy refused a latissimus dorsi transfer because they preferred to wait and to verify the clinical results of the arthroscopic treatment. Furthermore, patients of this group were not considered as candidates to receive a reverse shoulder prosthesis because of their young age and/or because the quality of the glenohumeral joint was interpreted as good or scarcely degenerated.

Shoulder arthroscopy was performed in the beach-chair position. Common posterior, lateral, anterolateral, and midglenoid portals were used. Synovectomy, tenotomy of the long head of biceps, and debridement of the cuff tear margins and of the degenerated articular surfaces plus regularization of the glenoid labrum were carried out. We did not perform acromioplasty to prevent coracoacromial ligament damage and shoulder cranialization. Patients affected by PVNS did not receive any method of intraarticular radiation therapy because the diagnosis was not known at the moment of the surgical procedure. After surgery, the shoulder was immobilized for 24–48 h in an internal rotation sling for

Table 1 Demographic data and pre- and postoperative shoulder assessment (Constant) in patients with PVNS (group I) and with massive irreparable rotator cuff tear associated with hemorrhagic synovitis with or without glenohumeral arthropathy (group II)

	PVNS	*P* values	Hemorrhagic synovitis
Enrolled	9	–	20
Mean age (range)	65.8 (63–70)	0.8	68.8 (62–70)
Preoperative			
Pain (range)	0 (0)	0.018	5.15 (0–10)
ADL (range)	1.33 (0–2)	0.021	7.62 (2–10)
ROM (range)	9.11 (6–12)	0.017	17.33 (10–28)
Power (range)	1.55 (0–4)	0.048	4.84 (0–8)
Constant (range)	12 (6–16)	0.02	34.96 (12–54)
Postoperative			
Pain (range)	8.33 (5–10)	0.8	10 (5–10)
ADL (range)	7.55 (7–9)	0.046	12.84 (6–16)
ROM (range)	20.44 (16–24)	0.049	25.39 (16–30)
Power (range)	4.44 (2–6)	0.82	5.81 (2–12)
Constant (range)	40.76 (32–47)	0.045	54.04 (35–73)
			With arthrosis
Constant			
Preoperative	12	0.037	29.8
Constant			
Postoperative	40.76	0.056	46
			Without arthrosis
Constant			
Preoperative	12	0.021	36.5
Constant			
Postoperative	40.76	0.046	52.69

Table 2 Demographic data and pre- and postoperative shoulder assessment (subjective shoulder value) in patients with PVNS (group I) and with massive irreparable rotator cuff tear associated with hemorrhagic synovitis with or without glenohumeral arthropathy (group II)

	PVNS	*P* values	Hemorrhagic synovitis
Enrolled	9	–	20
Preoperative			
Subjective shoulder value (range)	7 (0–15)	0.01	30 (10–60)
Postoperative			
Subjective shoulder value (range)	50 (25–65)	0.049	60 (30–80)
			With arthrosis
SSV			
Preoperative	10	0.039	25
SSV			
Postoperative	50	0.046	60
			Without arthrosis
SSV			
Preoperative	10	0.015	40
SSV			
Postoperative	50	0.04	65

comfort; then, passive and active exercises were permitted once the sling was removed.

Upon follow-up, none of the 9 patients with PVNS showed sign of a recrudescence of the pathology. The demographic data of patients relating to the two groups and those relating to their shoulder function preoperatively and at the follow-up are reported in Table 1 (Constant score) and Table 2 (subjective shoulder value). Results of each patient with PVNS are reported in Table 3.

There were no statistically significant differences between the mean age of patients in the two groups. The preoperative shoulder function in patient group I was reduced with respect to patient group II (CS: 12 vs. 35, SSV: 7 vs. 30). Although in/during follow-up period, the values were lower in patient group I than in group II (CS: 40 vs. 54, SSV: 50 vs. 60), the mean increase in the scores recorded in the 9 patients with PVNS (+28 points and +43 points) was higher with respect to the other group (+14 points and +30). The increase obtained using the Constant score involved all the score items. In fact, in patients affected by PVNS, shoulder post-operative pain, ADL, range of motion, and power score increase of 8.3, 6.2, 11.3, and 2.9 points, while in patients

Table 3 Results of each patient with PVNS

	Preoperative		Postoperative		
	CS	SSV	CS	SSV	GH arthritis
Pt 1	15	10	40	50	II
Pt 2	12	10	42	55	II
Pt 3	10	5	38	45	II
Pt 4	17	5	47	55	I
Pt 5	6	0	32	25	II
Pt 6	10	5	40	45	II
Pt 7	14	10	45	60	I
Pt 8	16	15	47	65	I
Pt 9	8	3	35	50	II

affected by massive tears and hemorrhagic synovitis, the scores increase was of 4.4, 5.2, 8.1, and 1 points, respectively. In the preoperative period, the differences between the two groups with respect to the CS and to each item of the score were always statistically significant; instead, in/during the follow-up, significant differences emerged only in the CS value, ADL, and range of motion. Finally, differences relating to preoperative CS value, observed in groups I and II (with or without glenohumeral arthropathy), were statistically significant, while at the follow-up, statistically significant differences emerged only between CS value of patients with PVNS and that of patient group II without glenohumeral arthrosis. Differences using the SSV were always statistically significant. After synovectomy, in patients affected by PVNS, we could have performed in a short time, a latissimus dorsi transfer (considering the relatively young age and the absence of absolute contraindication: subscapularis and teres minor tears neurologic damages, excessive upward migration of the humeral head); however, considering the possible development and recrudescence of PVNS, we preferred to wait and to perform debridement only.

Patients with PVNS have a worse postoperative outcome with respect to patients affected by irreparable massive tear with hemorrhagic synovitis. This difference cannot be attributed to patients' age because it was similar in the two groups. However, if we compare the final functional outcome of patients with PVNS to that of patients with irreparable tear of the cuff with hemorrhagic synovitis and with glenohumeral arthropathy, we note that no statistically significant differences emerge using the constant score. Thus, it is deducible that arthroscopic synovectomy and debridement are effective to treat PVNS and that the poor functional outcome can be attributed to the coexistence in all patients of group I of the glenohumeral arthropathy.

In no recent review [2], it was found that the incidence of erosive bone lesions in PVNS of the shoulder is 75 %. In Chiang's series [3], all patients with PVNS of the shoulder had chondral lesions. Of the 12 patients in our series, including the 3 not responding to inclusion criteria because they had severe osteoarthritis, all had a glenohumeral arthropathy. The reason for the chondral and bony lesions remains unclear. It was postulated that the degenerative changes might be the consequence of a high intraarticular pressure due to joint effusion [17, 20, 21].

A further possible reason is the cuff tear arthropathy. However, percentage of degenerative changes is higher than what may be observed as a possible consequence of an untreated massive rotator cuff tear, as it emerges from this study control group. Therefore, this is more plausible that the pigmented villonodular synovitis may release into joint fluid factors such as cytokines and growth factors which play a role in the development of glenohumeral osteoarthritis, as postulated for the cuff tearing.

The limitation of the study causes the lack of knowledge on whether patients with PVNS had a previous cuff tear or they developed the tear in concomitance with the proliferating synovitis. We hypothesize that the pigmented villonodular synovitis may have a direct role both in cuff tearing and in damaging the articular surface of the shoulder.

Conclusions

Arthroscopic synovectomy and debridement is an effective surgical treatment for PVNS; nevertheless, the poor functional outcome can be attributed to the coexistence of the glenohumeral arthropathy. In fact, all patients with PVNS had at least slight shoulder osteoarthritis; this percentage cannot be simply attributed to natural history of massive irreparable cuff tears; thus, a direct role of pigmented villonodular synovitis has to be hypothesized.

PVS may have a direct role both in cuff tearing and in damaging the articular surface of the shoulder.

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Part III

Clinical and Instrumental Evaluation

Classifications of the Rotator Cuff Tears

Stefano Gumina and Mario Borroni

Classifying a rotator cuff tear, defining its shape and size and the number of involved tendons, allows the etiology of the lesion and the biomechanical principles that cause a tear enlargement to be better understood. Classification also enables the surgeon to acquire data and to communicate clinical and functional results obtained with different treatments to the scientific community, in order to compare his or her data with those of other colleagues.

A high surgical experience is needed in order to classify a rotator cuff lesion. The surgeon must be able to easily invert arthroscopic portals and at the same time he should be skilled to interpret the images from all viewpoints. The surgeon, during the intra-articular assessment, should follow a step-by-step evaluation protocol in order to verify the integrity of each structure and to find possible partial lesions, especially on the articular side that could be ignored during the subacromial space exploration.

Only after an exact characterization of the lesion, the surgeon can apply the correct guidelines that lead to best results.

Partial or Incomplete Lesions

Harvard Ellman [1] in 1990 unfolded the criteria to diagnose and treat an incomplete rotator cuff lesion, while Codman and Akerson [2] were the first to classify it. A further classification was proposed by Wasilewski and Frankl in 1989 [3] during the Annual AAOS Meeting.

Articular Side Lesion Codman and Akerson [2] identify as "rim rents" those lesions corresponding to the bending area of the articular capsula, near to the humeral articular surface (Fig. 1). The authors observed an increase in the distance between the rotator cuff and the articular surface, corresponding to the gradual tear enlargement. This finding was done half a century before the modern concept of footprint enlargement, which actually influences the treatment choice (conservative or surgical). They also described the cortical eburnation and subchondral cystic areas that usually are present in the footprint. Over time, the autoptic studies conducted by De Palma [4] as well as by Lohr and Uhthoff [5] established the prevalence of these lesions and their correlation with tendon degeneration.

Bursal Side Lesions In the early 1990s, the practice of shoulder arthroscopy was at the beginning stage; nevertheless, Ellman [1] was already able to define the prevalence of the partial lesions both in the bursal and articular side. He stated that the bursal side lesions were clearly less frequent than the articular one. This consideration, that over time was confirmed, represents the background for the modern hypothesis concerning etiopathogenesis of rotator cuff tears. Previously, the attention was focalized on the conflict between the rotator cuff and the coraco-acromial arc; nowadays, the concept that tendon degeneration represents the primum movens of a cuff tear and that the partial tear is more prevalent on the articular side is widely accepted. Codman and Akerson [2] stated that the circular lesion of the supraspinatus tendon might be due to friction phenomena. Yamanaka and Fukuda [6] observed that the prevalence of incomplete lesions in their autoptic survey was 13 % and that only 2.4 % was localized on the bursal side.

Ellman [1] suggests exploring the cuff from the posterior arthroscopic portal in order to correctly identify the lesion and to perform a complete bursectomy (Fig. 2a, b). The "thin strap" tear of the supraspinatus tendon was described by Codman as a multi-stratum lesion whose tendon laminae were parallel to the articular surface. Ellman considered the removal of the antero-inferior aspect of the acromion as the only treatment for this type of lesion.

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Intratendinous Tears The intratendinous tears are those identified by MRI or arthro-MRI [7] but that are not visible either in the articular or in the bursal side during arthroscopic surgery. Codman [2] firstly hypothesized this type of lesion basing his idea exclusively on his clinical and anatomo-pathological findings. If one of the two sides presents a defect, it is correct to consider it as a deep partial lesion involving the articular or the bursal side and not as an intratendinous tear. Many authors proposed suggestions on how to intraoperatively identify the presence of the intratendinous lesion. Gartsman [7] proposed to inject a saline solution or methylene blue into the area where the presence of the intratendinous lesion is suspected. If the lesion is present, tendon tissue would look swollen and eventually stained.

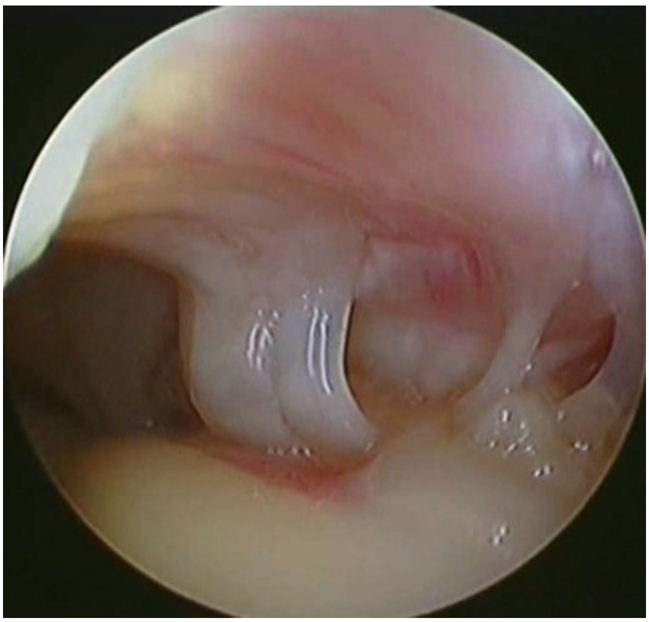

Fig. 1 Partial tear. Arthroscopic view from the posterior portal: articular side lesion

Even the classification of Wasilewski and Frankl [3] considers three lesion groups: lesion visible (A) from the articular side; (B) from both sides; and (C) from the bursal side. However, it is curious to note that of 50 consecutive patients who underwent arthroscopic surgery for suspected lesions of rotator cuff tear and subacromial impingement (clinical and arthrographic diagnosis), 62 % had a partial tear (A = 22 %, B = 36 %; C = 4 %) and only 38 % had a full-thickness tear.

Ellman's classification [1] suggested classifying partial lesions into three degrees, considering the average thickness of healthy tendon to be about 10–12 mm:

I degree	Depth < 3 mm
II degree	3 < Depth < 6 mm (or involving less than a half tendon)
III degree	Depth > 6 mm (or involving more than a half tendon)

A further classification was proposed by Gartsman's [7]:

I degree	Less than 1/4 of the tendon thickness is involved
II degree	Less than a half of the tendon thickness is involved
III degree	More than a half of the tendon thickness is involved

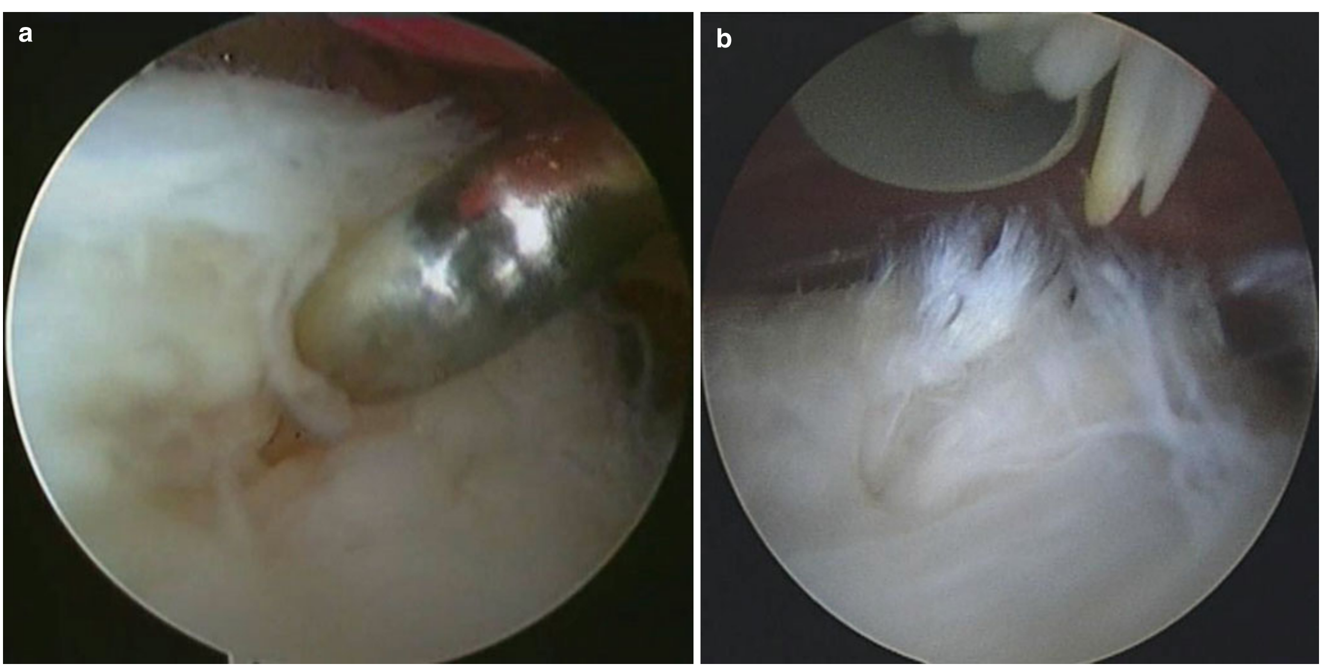

Fig. 2 (**a**, **b**) Partial tear. Arthroscopic view from the posterior portal: bursal side lesions

Of partial lesions, those belonging to I, II, and III degrees occurred, respectively, in 45, 40, and 15 % of cases.

Snyder [8] divided partial lesions into two categories, the articular (A) and the bursal (B) types; each of the two categories is further divided into five subcategories (Table 1):

For greater simplicity, the five subcategories (0–IV) can be divided into two groups:

- Group of minimal lesions: including subcategories 0, I, and II. According to the author, these lesions do not require specific treatment except for a slight debridement and/or acromioplasty.
- Group of complex lesions: including subcategories III and IV. The repair of the lesion with the trans-tendon technique or arthroscopic tear completion and repair are the recommended treatments. Tears A3 or A4, involving the supraspinatus tendon, are identified by the author with the acronym PASTA (Partial Articular Supraspinatus Tendon Avulsion) lesion.

In 2008, Habermayer and colleagues [9] proposed a new classification of the partial articular side lesion, because, according to the authors, previous Ellman [1] and Snyder [8] classifications do not provide information on the lesion depth on the coronal (Fig. 3) and sagittal (Fig. 4) plane nor they are related to their etiology and pathomorphology.

On the coronal plane, lesions are divided into:

Type 1	Small tear within transition zone from cartilage to bone
Type 2	Extension of tear up to center of footprint
Type 3	Extension of tear up to greater tuberosity

On the sagittal plane, the classification includes three types of lesions:

Type A	Tear of coracohumeral ligament continuing into medial border of supraspinatus tendon
Type B	Isolated tear within crescent zone
Type C	Tear extending from lateral border of pulley system over medial border of supraspinatus tendon up to area of crescent zone

Forty-three percent of partial articular lesions observed by the authors belonged to type 1C or 2C. In addition, 64 % of patients had a concomitant disease of the long head biceps tendon; 57 % had fraying of the superior labrum; 42 % had a lesion of the superior glenohumeral ligament; and 9 % had a partial tear of the middle glenohumeral ligament.

Table 1 Snyder classification for partial lesions [8]

	Articular side (A) and bursal side (B) lesions
0	Normal rotator cuff with synovitis and/or bursitis
I	Slight inflammation with no lesion of the tendons
II	Slight degeneration of the tendon, without flap
III	Degeneration and fragmentation of the tendon, good quality of the tendon tissue
IV	Wide lesion with degeneration and fragmentation of the tendon or flap with two tendons involved

Full-Thickness Lesions

The full-thickness lesions have an extension from the articular to the bursal side of the tendon; therefore, a direct contact between the joint and the subacromial space occurs, resulting in a mutual fluid exchange between the two anatomical spaces. Over time, a huge number of classifications were proposed. They considered both size and location of the lesion.

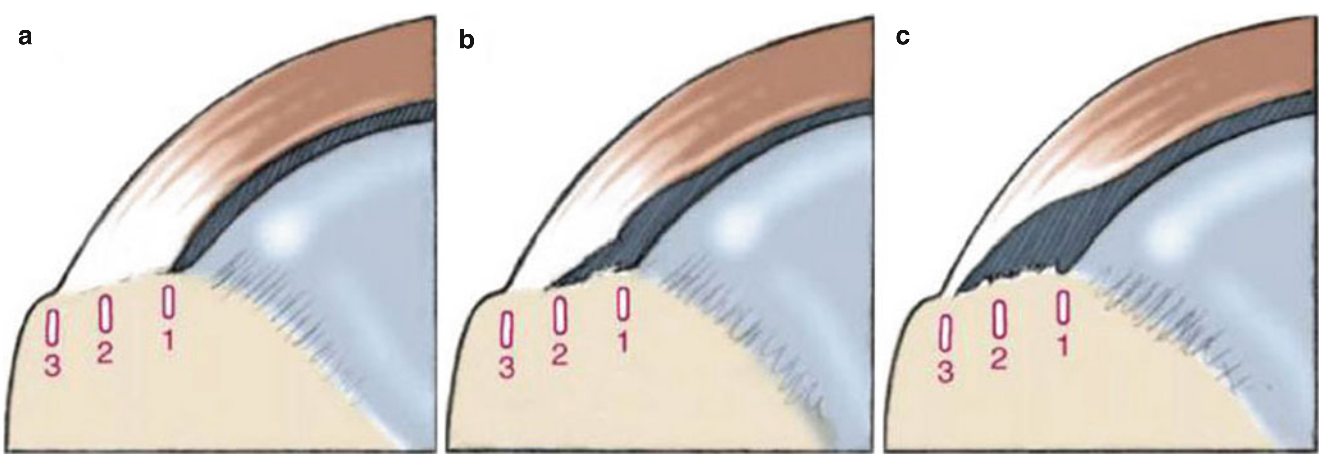

Fig. 3 Habermeyer et al.'s classification of the partial lesions. Extension of articular-sided supraspinatus tendon tear in coronal plane. (**a**) Type 1 tear. Small tear within transition zone from cartilage to bone. (**b**) Type 2 tear. Extension of tear up to center of footprint. (**c**) Type 3 tear. Extension of tear up to greater tuberosity

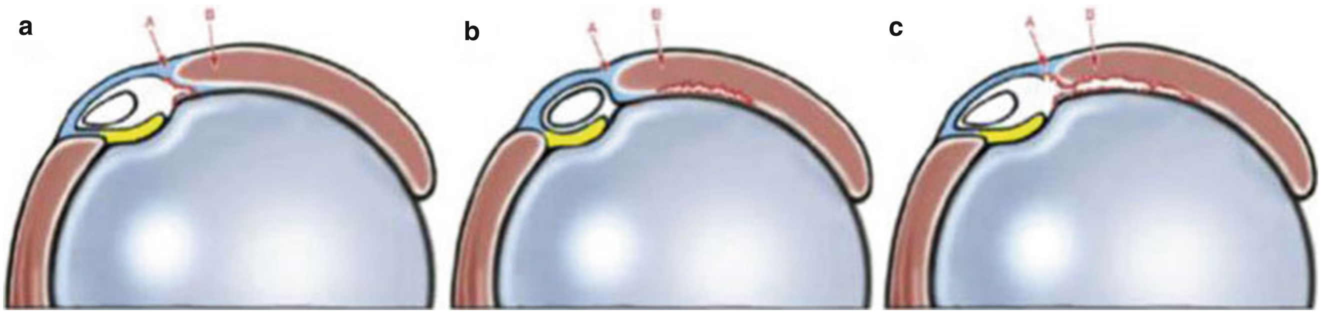

Fig. 4 Habermeyer et al.'s classification of the partial lesions. Extension of articular-sided supraspinatus tendon tear in transverse plane. (**a**) Type A tear. Tear of coracohumeral ligament continuing into medial border of supraspinatus tendon. (**b**) Type B tear. Isolated tear within crescent zone. (**c**) Type C tear. Tear extending from lateral border of pulley system over medial border of supraspinatus tendon up to area of crescent zone

Table 2 Classification of full-thickness tears according to Snyder [8]

	Complete (C) rotator cuff tears
CI	A small, complete tear, such as a puncture wound
CII	A moderate tear (usually < 2 cm) that still encompasses only one of the rotator cuff tendons with no retraction of the torn ends
CIII	A large, complete tear involving an entire tendon with minimal retraction of the torn edge; usually 3–4 cm
CIV	A massive rotator cuff tear involving two or more rotator cuff tendons, frequently with associated retraction and scarring of the remaining tendon ends and often L-shaped tear. The CIV classification can also be modified with the term "irreparable," indicating that there is no possibility of direct repair

Snyder's Classification

Of the proposed classifications, that of Snyder [8] obtained the greatest success and spread widely. The numerical designation is from type I to IV (Table 2). Tear degree is preceded by the letter "C" that indicates that the tear is complete; furthermore, it increases with the increase of size and complexity of the lesion; therefore, the classification also provides information on the repairability of the tendon.

Type C1 tears (Fig. 5a, b) are small; by definition they are less than 1 cm. To determine whether it is a full-thickness tear, a probe has to be used. The probe permits to establish if a direct connection between the subacromial space and the glenohumeral joint exists.

The width of C2 tears (Fig. 6a–c) is about 2–3 cm. Usually a single tendon is involved (supraspinatus) and the tear has a crescent shape; therefore the tear margin retraction is minimal and tendon repair is easily obtainable.

Type C3 tears (Fig. 7) involve two tendons. The lesion may longitudinally extend assuming an "L" or "V" shape. When this occurs, a "side-to-side" repair and a capsular release are recommended in order to facilitate the mobility of the stump tendon.

When the lesion involves two tendons and is associated with degeneration and retraction of the tendon stump and fatty degeneration of the respective muscles, it is indicated by the initials C4 (Fig. 8). These lesions are partially repairable; after that a capsular release and/or a single or double "interval slide" are performed.

Geometric Classification

Davidson and Burkhart [10] emphasized that some of the existing classifications only describe the length of the larger diameter of the tear or the number of the tendons involved. According to the authors, these classifications (Table 3) do not consider the three-dimensional information that could be extrapolated from a preoperative (MRI scans) or intraoperative (arthroscopy) evaluation.

The geometric classification considers four types of lesions (Table 4).

Type I is represented by the short and wide lesions, commonly called "crescent tears" (Fig. 9). The length (from medial to lateral) of these tears is less than the width (from anterior to posterior). These lesions can be easily mobilized from medial to lateral and, therefore, they can be repaired by fixing directly the margin of the stump tendon on the abraded greater tuberosity. According to Davidson and Burkhart, type I lesions can be easily diagnosed by carefully evaluating MRI scans in the coronal and sagittal planes. In fact, a length on the coronal scan equal or less than the width on the sagittal plane and a length of less than 2 cm gives evidence of a "crescent" lesion that can be easily repairable and that may presumably lead to good or excellent results.

The shape of type II lesions is relatively long and narrow ("U" and "L" shapes). The length from medial to lateral is larger than the width from anterior to posterior. These lesions can be mobilized from anterior to posterior and can be repaired by converging the margins using "side-to-side" sutures. In fact, if it were possible to mobilize the apex of the

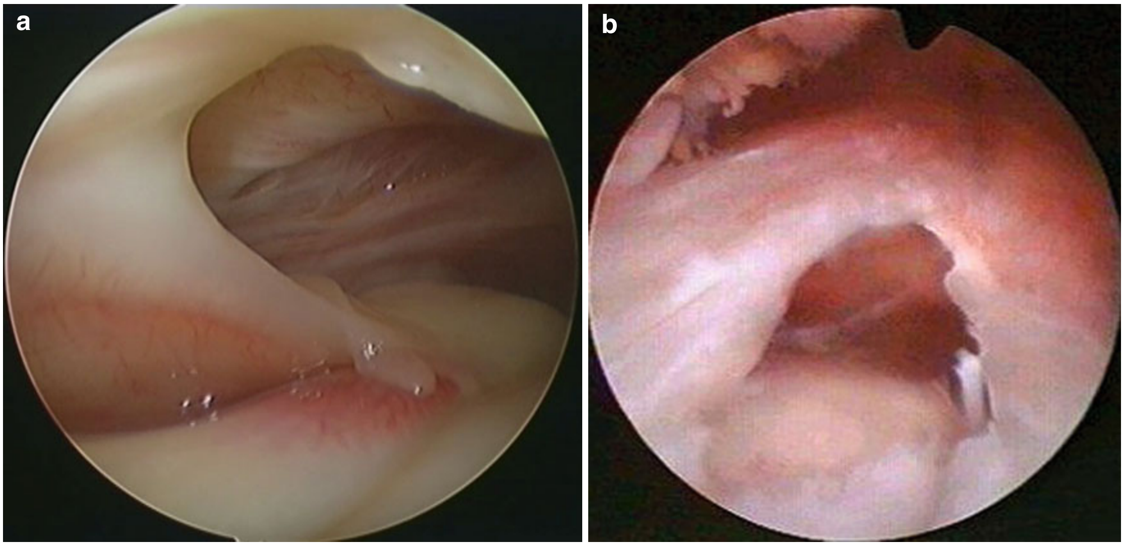

Fig. 5 Full-thickness tear. Type C1 tear according to Snyder's classification. Arthroscopic view from the posterior portal. (**a**) Intra-articular view. (**b**) Subacromial view

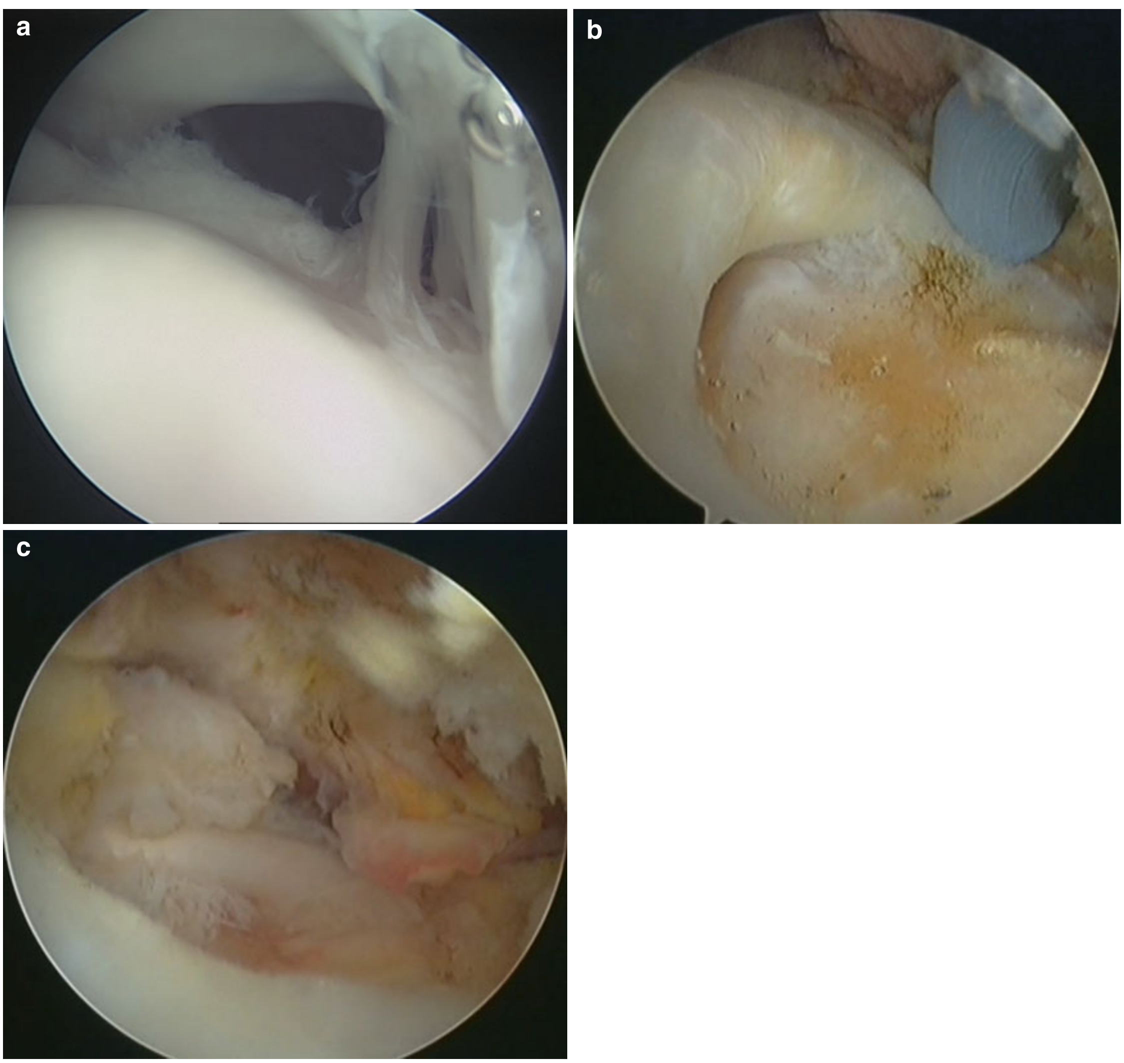

Fig. 6 Full-thickness tear. Type C2 tear according to Snyder's classification. Arthroscopic view from the posterior portal. (**a**) Intra-articular view. (**b**, **c**) Subacromial view

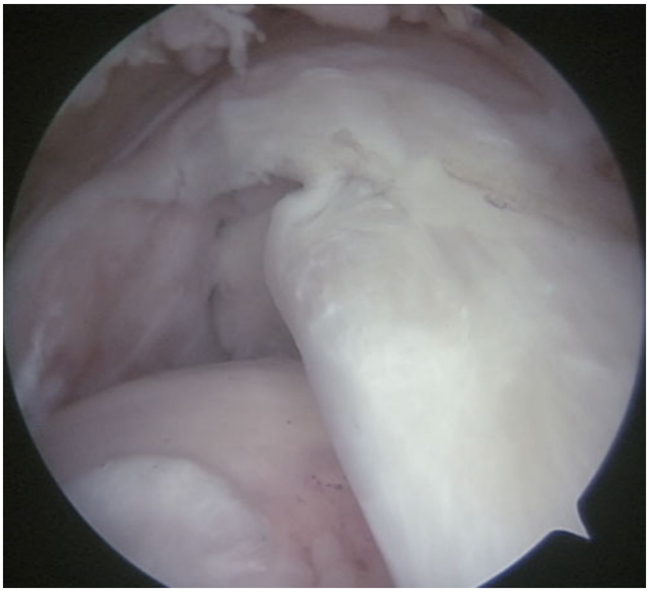

Fig. 7 Full-thickness tear. Type C3 tear according to Snyder's classification. Arthroscopic view from the posterior portal

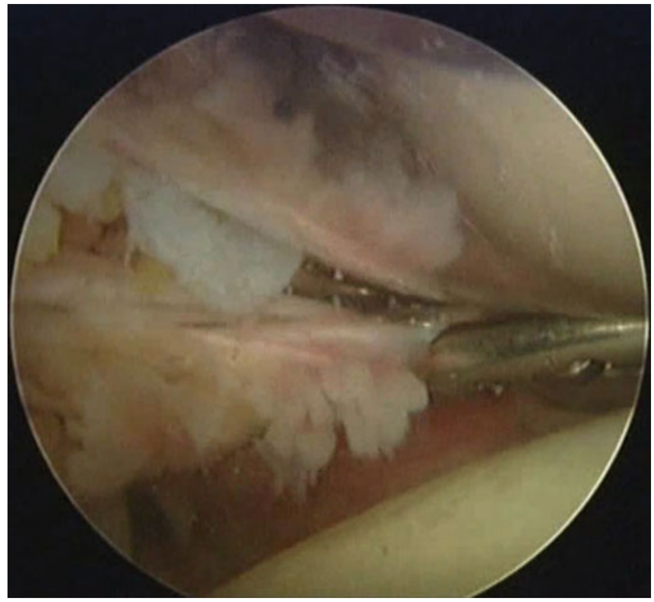

Fig. 8 Full-thickness tear. Type C4 tear according to Snyder's classification. Arthroscopic view from the posterior portal

Table 3 Classifications based on cuff tear size and tendons involved

Monodimensional classification		
Authors	Classification method	Weak point
McLaughlin [11] DePalma [12]	Transverse Vertical Retracted	Poor consideration, formulated before MRI
DeOrio and Cofield [13]	Length of the major diameter of the lesion	Monodimensional May overestimate tendon repairability
Harryman et al. [14]	Number of tendons involved	Tears are not differentiated No indication to surgical treatment
Gerber et al. [15]	Number of tendons involved	Tears are not differentiated No indication to surgical treatment

Cited by Davidson and Burkhart [10]

Table 4 Davidson and Burkhart geometric classification for complete (full-thickness) lesions

Type	Description	Preoperative evaluation (MRI)	Treatment	Prognosis	References
1	Crescent	Short and wide tear	Reinsertion to the bone	Good/excellent	[16, 17]
2	Longitudinal "L" or "V" shape	Long and narrow tear	Side-to-side	Good/excellent	[16, 17]
3	Massive, retracted	Long and wide >2×2 cm	Interval slide or partial repair	Good/poor	[17–19]
4	Cuff arthropathy	Cuff arthropathy	Shoulder prosthesis	Good/poor	

lesion bringing it close to the abraded greater tuberosity (foot print), the suture would be excessively tensioned, creating the conditions for a surgical and functional failure. It was noted that good or excellent results were obtained after suturing with "side-to-side" technique [16]. Therefore, if the width (W) measured by MRI is less than 2 cm and the length (L) greater than the width (L>W; W<2 cm) (Fig. 10a, b), it is deducible that the lesion belongs to Type II tear and that, consequently, it can be repaired with the aforementioned technique, with the possibility of getting good or excellent results.

Type III lesions are massive and retracted. These tears are excessively extensive in length; therefore, it is extremely difficult to repair the lateral margin up to the greater tuberosity, and tear is excessively wide for a side-to-side repair.

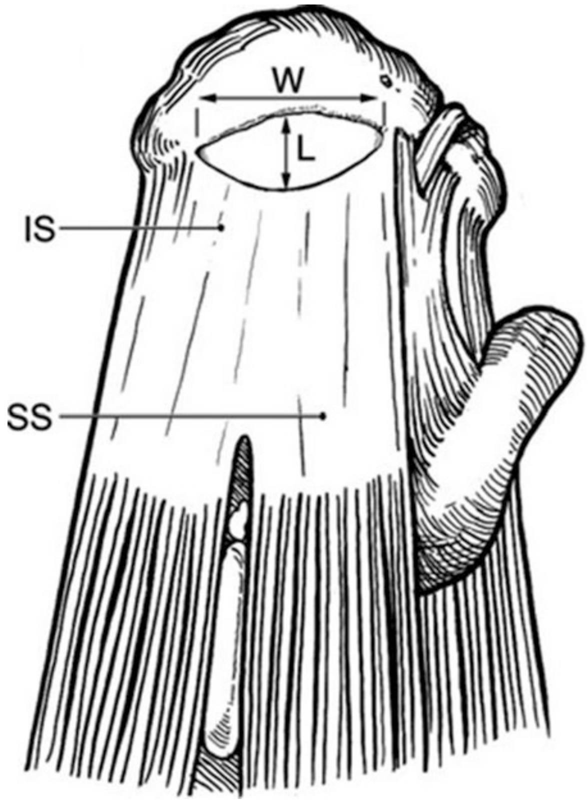

Fig. 9 A Type 1. Crescent-shaped tear is characterized by a medial to lateral length (*L*) less than the anterior to posterior width (*W*). (*IS* infraspinatus, *SS* supraspinatus)

The authors proposed to perform a single or double "interval slide" or a partial repair. The formula (L ≥ 2 cm; W ≥ 2 cm) (Fig. 11), extrapolated by the MRI evaluation, should predict a partial repairability of the tear; therefore, the surgeon should be prepared to perform a repair knowing that the functional outcome might be limited.

Type IV lesions are associated with glenohumeral arthropathy and with an upper ward migration of the humeral head (superior static instability), with narrowing of the subacromial space up to a direct contact between the humerus and the antero-inferior margin of the acromion. These tears cannot be arthroscopically or open repaired. Shoulder pain and functional reduction are due to inflammation and deformity of the glenohumeral joint; therefore, it is more useful to implant a reverse prosthesis rather than performing a partial tear repair.

The authors consider the lack of information regarding the eventual associated lesions of the subscapularis tendon, long head biceps tendon, acromioclavicular joint, fatty degeneration of the cuff muscles as a limit of this classification.

Classification Method Proposed by Kuhn et al. [20]

More than a real method, it is the extrapolation, and the simultaneous application of some classification systems. It distinguishes the full-thickness tears according to size [13], shape [8], configuration [1] and number of involved tendons [14].

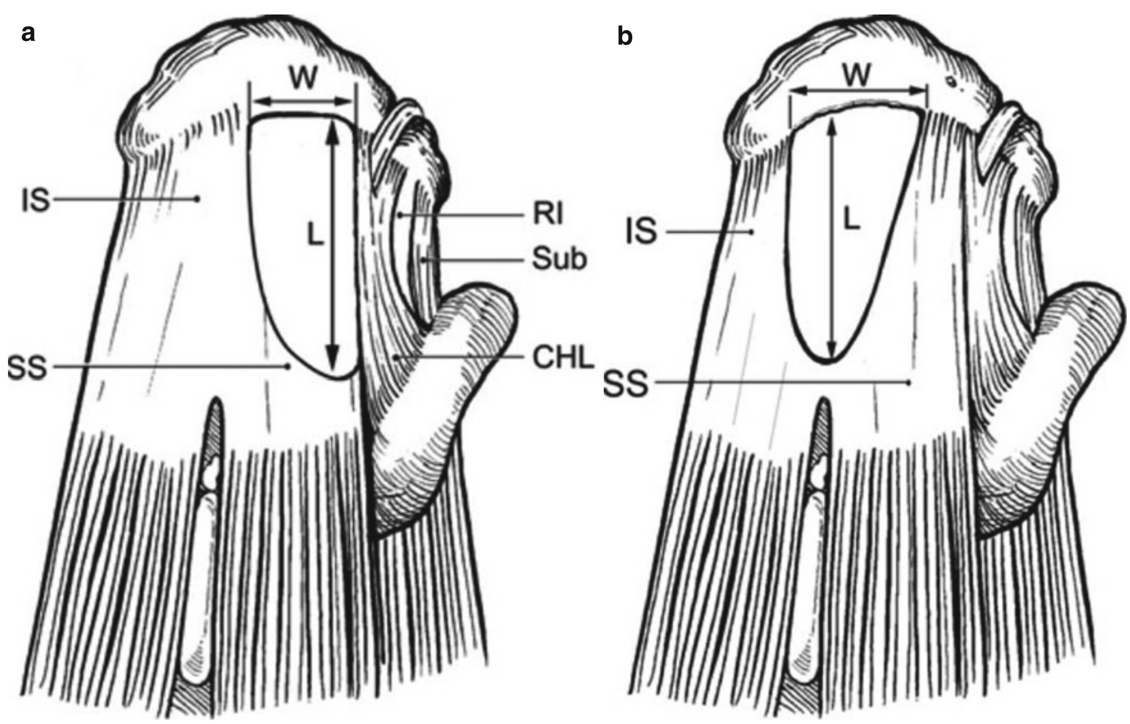

Fig. 10 (**a**) Type 2, L-shaped longitudinal tear. The length (*L*) is greater than the width (*W*). (*IS* infraspinatus, *SS* supraspinatus, *RI* rotator interval, *Sub* subscapularis, *CHL* coracohumeral ligament). (**b**) Type 2, U-shaped longitudinal tear. The length (*L*) is greater than the width (*W*). (*IS* infraspinatus, *SS* supraspinatus)

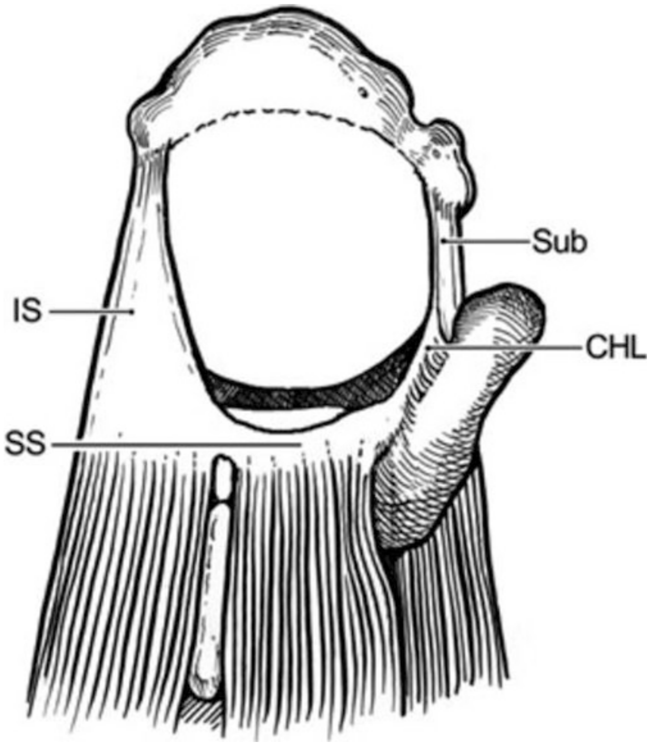

Fig. 11 Type 3, massive contracted tear is long and wide. (*IS* infraspinatus, *SS* supraspinatus, *Sub* subscapularis, *CHL* Coracohumeral ligament)

Tear size is considered small if the maximum diameter is less than 1 cm; large between 1 and 3 cm; wide between 3 and 5 cm and massive if >5 cm.

On the basis of the shape, tears are classified as: (a) transverse, (b) triangular or crescent, and (c) massive; depending on the configuration, tears are classified as: (1) transverse linear (supraspinatus – without retraction), (2) crescent, (3) "L" shaped (with extension between the supra and infraspinatus), (4) inverted "L" shaped (involvement of the rotator interval), (5) "V" shaped, and (6) massive (with the involvement of teres minor or subscapularis tendons).

Finally, IB tears are those where only supraspinatus tendon is involved; II = supraspinatus and a portion of the infraspinatus; III = supraspinatus, infraspinatus and subscapularis; IV = massive tear associated with a glenohumeral arthropathy (cuff tear arthropathy).

Finally, to classify a cuff tear means to utilize a methodological scheme that helps the physician to better understand the specific treatment for that type of lesion. Few literature data have diminished the importance of the classification as a method of scientific diffusion [20]. In fact, the concordance between different surgeons in classifying the lesion in the same manner is high if we merely differentiate a partial or a full-thickness tear (0.95; k = 0.85) or establish the degree of retraction (0.70; k = 0.54) but very low when the operators are invited to comment on the depth of a partial tear (0.9; k = 00:19).

Useful Tips

- MRI scans on coronal and sagittal plane (especially those T2-weighted) may suggest shape, size, and degree of repairability of the lesion.
- The evaluation (on the MRI) of the degree of fatty degeneration of cuff muscles and the bone quality on where the tear should be repaired is essential.
- Require MRI of excellent quality.
- Be able to evaluate the lesion using several portals. The lateral one is the best to determine the lesion characteristics.
- Carefully evaluate the condition of the articular side of the cuff (the most common site of occurrence of partial tears).
- If clinical and MRI images give evidence of a massive lesion (e.g., C4 according to Snyder), be prepared to treat a cuff tear that might be only partially repaired.

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Shoulder Pain Intensity and Distribution

Stefano Gumina, Daniele Passaretti, and Vittorio Candela

Rotator cuff has always attracted great interest because it may be responsible for shoulder pain, loss of strength, simple or complex disabilities, partial or total inability to work, thus reducing quality of life. Several studies have been performed with the aim to understand the etiology and natural history of the lesion and how to treat it. In addition, countless studies have been conducted regarding clinical maneuvers that may help the physician to better understand if the cuff is healthy or torn; if the lesion has involved the anterior or postero-superior cuff; if it is probably a small-large or massive (repairable or unrepairable) tear; if the pain originates from the shoulder; or is caused by a cervical spine diseases.

In an immunohistochemical and microscopic study, Soifer et al. [1] observed that the subacromial tissues (subacromial bursa, rotator cuff tendons, long head biceps tendon, transverse humeral ligament) are rich in free nerve fibers. Nociceptive information relayed by these fibers may be responsible for pain associated with different subacromial disorders. Harmful stimuli, both of mechanical and chemical type, are picked up from nociceptors. They consist in the peripheral endings (type Aδ myelinated and unmyelinated C-type) of primary sensory neurons whose cell bodies are located in the dorsal root and in the trigeminal ganglia. Nociceptive information is transmitted from the spinal cord to the thalamus and cerebral cortex along five ascending pathways. In addition, the limbic system plays an important role in determining what is defined as the "emotional component" of pain. Therefore, nociception has to be considered as a multimodal experience [2].

Nowadays, information regarding shoulder pain is still scarce. It is known that patients with rotator cuff tear may be painless or painful, that pain arises during the night causing sleep disturbance, and that it may compromise shoulder function [3–5].

Modern pain mapping was introduced in 1949 by Palmer [6] who provided outlined diagrams of the human body and asked patients to score on the charts the area where they experienced pain. The use of maps of pain in clinical practice is now extremely widespread.

To our knowledge, only one study [7] focused the attention on shoulder pain intensity and distribution in patients with shoulder disorders. Using a pain mapping and asking to indicate on the map which of the different types of pain patients were feeling, Bayam et al. [7] observed that patients with rotator cuff tear have predominantly sharp pain around the front of the shoulder and dull, aching pain affecting the rest of the arm and forearm. Unfortunately, these observations have been obtained by only 22 patients whose tear size was unknown.

In a recent study, we have investigated the intensity and distribution of shoulder pain on a sample of 285 patients with different sizes of postero-superior rotator cuff tears and to analyze any differences between patients with acute symptoms and those whose pain was persisting by more than 6 months.

Materials and Methods

The study comprised 285 consecutive patients who underwent arthroscopic repair of a full-thickness postero-superior rotator cuff tear. Before surgery, all patients completed an upper limb pain map.

We used the dermatome map made by Keegan and Garrett [8] (Fig. 1). This map illustrates areas of radiation (including the anterior and posterior parts of the arm, neck, and shoulder). Shoulder pain intensity was assessed with a visual analogue scale (VAS). Patients rated pain intensity on a continuum from "no pain" to "maximal, worst pain imaginable" [9]. Patients were also distinguished in two main

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subgroups: those whose symptoms were persisting by less or more than 6 months.

Exclusion criteria were: neck pain symptoms, clinical features indicating subscapularis tears; neck pathology; ipsilateral upper limb problems (elbow; wrist and hand pathologies, neuropathies due to intrinsic or extrinsic factors); traumatic tears, biceps and/or labral pathologies; diabetes, os acromiale; degenerative arthritis of the gleno-humeral joint; autoimmune or rheumatologic disease; previous surgery in the same shoulder; and Workers' Compensation claims. Furthermore, we excluded patients who were submitted to physical and/or non-steroidal anti-inflammatory drug therapy and those whose symptoms arose by more than 12 months.

All operations were performed by the senior of us (SG), with patients in the beach chair position under general anesthesia and interscalene block. A standard arthroscopic pump was used in all cases, and standard posterior, lateral, anterolateral, and mid-glenoid portals were used to perform a thorough diagnostic examination. After the intra-articular evaluation, the scope was placed in the subacromial space. Subacromial bursa was removed to gain a clear view of the RCT. The Southern California Orthopedic Institute (SCOI) classification of complete rotator cuff tears [10] (see the Chapter "Classifications of the Rotator Cuff Tears") was used to classify tendon tears intraoperatively.

To limit the number of groups and make the sample more representative, we considered the lesions belonging to type I as small, those of the type II and III as large, and those of the type IV as massive.

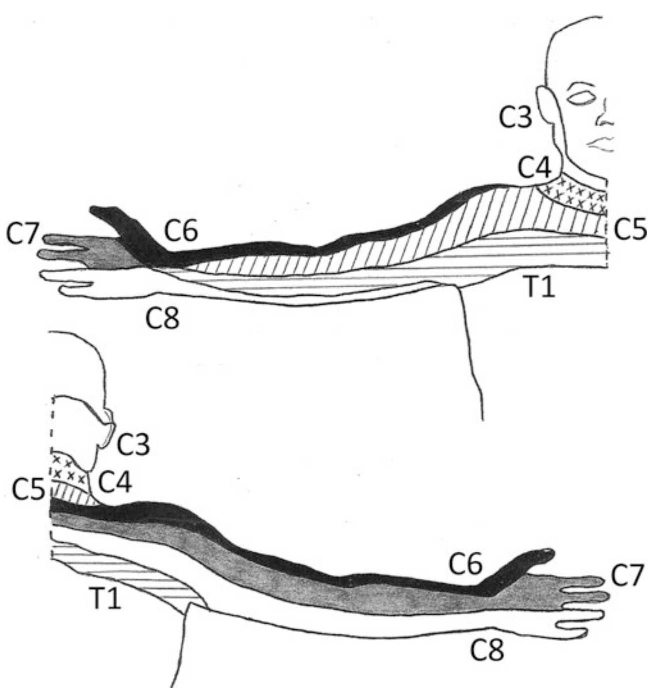

Fig. 1 Upper limb dermatomes

For the statistical analysis, we used parametric and non-parametric tests (Kolmogorov-Smirnov's test and Levene's test). The chi-square test was used to evaluate the differences in prevalence of tears between male and female, or right and left side. Moreover, according to rotator cuff tear size, we used chi-square test to analyze the relationship between dermatomes involved.

According to tear's size group, we used the unpaired t test to analyze the pain level differences between males and females, right and left side and history of the symptoms.

Mann-Whitney test was performed to analyze the VAS score differences between patients that had pain until and over the elbow.

The one-way ANOVA test was used to evaluate the pain level differences between patients in regard to age and rotator cuff tear size.

The calculation of sample size was performed using G*Power 3 software.

Results

One hundred forty-seven patients were men [mean age: 64.31 (37–82)] and 138 were women [mean age: 66.39 (40–80)] ($p = 0.503$). The right shoulder was involved in 211 cases (74.03 %) and the left one in 74 (25.96 %) ($p < 0.001$) (Table 1).

The main important results derived from the study:

- The average of pain intensity in male and female was 5.1 (0.67–10) and 5.63 (0–9.33), respectively. Overall, a significant difference between the two groups was found ($p = 0.024$); however, this result is exclusively influenced by patients with a large tear (Table 2).
- We did not find a significant difference between the average of pain intensity on right and left side in patients with the same severity of tear ($p = 0.630$).

Table 1 Baseline characteristics of patients

Mean age
65.32 (37–82)
Sex
Male: 147 (51.6 %)
Female: 138 (48.4 %)
Shoulder
Right: 211 (74 %)
Left: 74 (26 %)
Tear size
Small: 87 (30.5 %)
Large: 100 (35.1 %)
Massive: 98 (34.4 %)
Pain history
<6 months: 123 (43.1 %)
>6 months: 162 (56.9 %)

- No statistically significant differences were found between pain intensity in patients older than 65 years old and those younger ($p = 0.307$).
- The average of pain intensity was lower in patients with massive tears than in those with small or large tears (Table 3).
- We did not find significant differences, about pain intensity, between patients whose pain arose by less than 6 months and those whose symptoms arose by more than 6 months (Table 4).
- Out of our 285 patients, only 38 referred that their pain involved also the forearm. These patients also referred a higher intensity of shoulder pain.
- 86 % of patients (247) referred that their pain was localized on the antero-lateral area of the shoulder with irradiation downwards the lateral surface of the arm until the elbow.

Independent on rotator cuff tear size, dermatomes C5 and C6 were the most involved. This result was confirmed also when data were distinguished by rotator cuff tear size (Table 5 and Fig. 2).

Analyzing pain distribution according to rotator cuff tear size, we observed that patients with massive tears suffered by a more extended pain. In fact, the number of patients with massive tears who referred to have a pain on C5, C6, C7, C8, and T1 dermatomes was higher than that registered in patients with small or large tears (Table 5 and Fig 2).

- No statistical difference emerged between patients with small and large tears regarding all the dermatomes analyzed (from C3 to T1).

Table 2 Comparison between pain intensity and different sized RCTs, according to gender

	Gender	Mean VAS (range)	Mean difference	95 % confidence interval of the difference		*p* value
				Lower	Upper	
Small F vs M	43 F 44 M	5.84 (2–9.33) 5.13 (0.67–8.67)	0.70	–0.08	1.49	0.78
Large F vs M	51 F 49 M	6.05 (1.33–9.33) 5.31 (2–9.33)	0.73	0.05	1.40	**0.034**
Massive F vs M	44 F 54 M	5.30 (0.67–10) 4.60 (0–8.67)	0.69	–0.19	0.59	0.126

In bold the significant *p* value

F female, *M* male

Table 3 Comparison between pain intensity registered in patients with different sized RCTs

RCTs	Mean difference	95 % confidence interval of the difference		*p* value
		Lower	Upper	
Small vs large	–0.20	–0.899	0.486	1.0
Small vs massive	0.56	0.1285	1.264	**0.045**
Large vs massive	0.77	0.1029	1.447	**0.018**

In bold the significant *p* value

Table 4 Comparison between pain intensity and different sized RCTs according to pain history

	Pain	Mean VAS [range]	Mean difference	95 % confidence interval of the difference		*p* value
				Lower	Upper	
Small <6 vs >6 months	<6 months (36) >6 months (51)	5.55 [0.67–8.67] 5.43 [2–9.33]	0.117	0.69	0.63	0.775
Large <6 vs >6 months	<6 months (50) >6 months (50)	5.81 [1.33–9.33] 5.57 [2.67–9.33]	0.240	–0.45	0.93	0.492
Massive <6 vs >6 months	<6 months (37) >6 months (61)	4.99 [1.33–9.33] 4.87 [0–10]	0.116	–0.79	1.02	0.804

In round brackets the number of patients

Table 5 Correlation between different sized RCTs according to dermatomes involved

	C3		C4		C5		C6		C7		C8		T1	
	Chi-square	*p* value	Chi-square	*p* value	Chi-square	*p* value	Chi-square	*p* value	Chi-square	*p* value	Chi-square *p* value		Chi-square *p* value	
Small vs large	0.025	0.874	0.307	0.580	0.394	0.534	0.209	0.647	0.735	0.391	0.793	0.373	0.342	0.599
Small vs massive	0.072	0.789	0.410	0.522	7.843	**0.005**	3.171	0.075	5.317	**0.021**	8.923	**0.003**	9.750	**0.002**
Large vs massive	0.001	0.978	0.004	0.951	4.306	**0.038**	1.407	0.236	1.674	**0.000**	17.738	**0.000**	6.441	**0.011**

In bold the significant *p* value

Discussion

We observed that pain intensity registered in females was higher than that revealed in males. Actually, this finding was already observed. In fact, in Kindler's series [11], constituted by patients with shoulder pain, women experienced greater clinical pain and enhanced sensitivity to pressure pain. This difference could reside in the C fibers processing method that would lead to the development of a central sensitization greater in women than in men. However, it is plausible that the difference might also be due to specific psychological situations related to post-menopausal period or to an occult gleno-humeral instability caused by a poorer representation of periarticular muscles in females with respect to males.

To our knowledge, there is not a hemibody that is more painful than the other nor an anatomopathologic condition that may generate different pain intensities on symmetric organs. Our data demonstrated that rotator cuff tear causes similar pain intensity between the two sides and that probably there is no modulation made by the two cerebral hemispheres that are potentially able to modify the pain perception.

We observed no differences in pain intensity based on patient age. This figure can be interpreted in two different ways: (a) rotator cuff tear determines a shoulder pain whose intensity is independent by any age; (b) really, there is a different perception of pain between young and elderly patients, but the threshold of this different perception is before 50 years of age.

Our data indicate that patients with massive rotator cuff tear have lower pain intensity than those with small or large tears. This might be due to the lower amount of bursal tissue usually present in massive tears compared to that observable in small and large tears [12]. Due to the fact that out of the subacromial structures bursa is the one with the highest concentration of free nerve fibers [1], it is plausible that shoulders with massive tears are potentially less painful. It is also conceivable that massive tears are the more antique; in these cases, the nociceptors located on the edges of the lesion could have undergone a "receptor adaptation" [2]. According to this theory, if the chemical or mechanical stimuli acting on the receptor are prolonged, receptor activation decreases determining, in patients with rotator cuff tear, a less painful shoulder.

It is known that shoulders with rotator cuff tear may be painless or may become painless over time. Our data indicate that if pain persists within 1 year, it maintains a constant intensity. These data do not contradict the theory of receptor adaptation because they do not take into account all those patients who become painless over time and therefore decided not to consult the physician or not to do the check.

We observed that when the pain irradiates downwards the arm distal to the elbow it has a higher intensity with respect to pain distributed only on the shoulder. A possible explanation is that patients who have high pain intensity fail to accurately discriminate the boundaries of pain. It is also possible that patients with widespread pain have greater impairment of the entire upper limb, so they are inclined to enhance the intensity of the pain for a greater emotional involvement.

The vast majority of our patients referred that pain was localized at the antero-lateral area of the shoulder with irradiation downwards the lateral surface of the arm until the elbow. The precise location of pain does not always correlate with the site of the pathology, especially in orthopedics. In fact, pain arising from structures deeper than the skin, like the shoulder, is diffuse and sometimes it has an unexpected distribution [13] because of the proximal location which the shoulder has in the sclerotome and the extensive convergence of afferent signals from this area to the dorsal horn of the spinal cord [14].

Our data indicate that dermatomes C5 and C6 are the most involved, independent on rotator cuff tear size.

This result is easily understood because the suprascapular nerve (responsible for the innervation of the supraspinatus and the infraspinatus muscles) derives from the "upper main trunk" consisting of the anterior branches of C5-C6 roots and a collateral of C4; and the axillary nerve (responsible for the innervation of teres minor) derives from the "posterior secondary trunk" which consists of the posterior branches of the three main trunks (C4-5-6-7-8 and T1).

In our series, patients with massive rotator cuff tear suffered by a more extended pain. This finding may be due to the fact that massive tears involve two or more musculotendinous units which are innervated by branches which originate from different cervical levels.

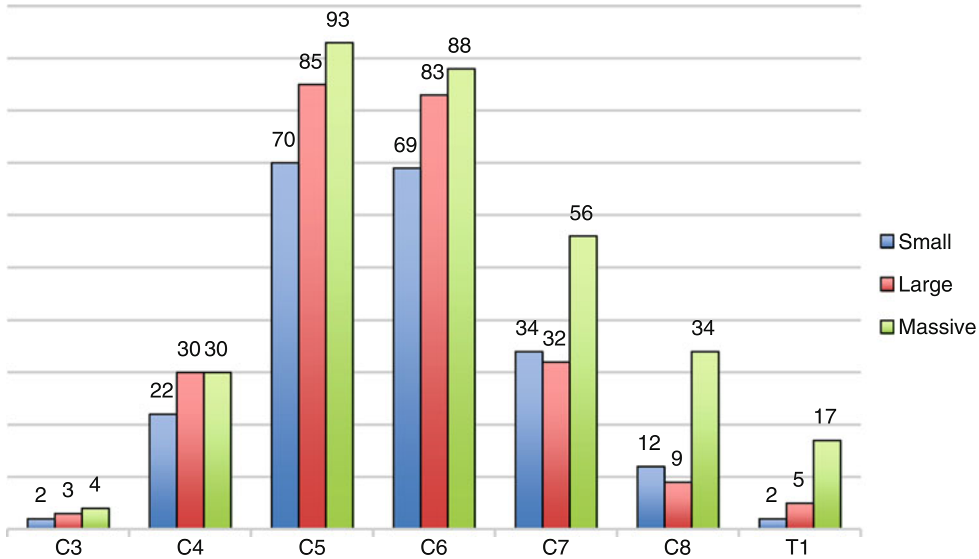

Fig. 2 Number of patients with different sized rotator cuff tears for each indicated dermatome

We observed that the pain suffered by the patients with small or large rotator cuff tear is distributed not only on C4-5-6 dermatomes but also on those of C7-C8-T1. This finding corroborates the hypothesis that the shoulder pain is not due solely to the rotator cuff tear but also to the inflammation involving subacromial structures and the likely occult joint instability deriving from the tendon torn.

Take-Home Message

- Shoulder pain intensity caused by rotator cuff tear is higher in females; it is lower in massive tears and in patients whose pain is distributed to the shoulder only. Furthermore, if the pain persists for more than 6 months it keeps the same intensity. Pain is localized predominantly on dermatomes C5-C6, is more extended in massive tears, and only in one-seventh of cases it extends beyond the elbow. When pain intensity is high, its distribution is widespread and it is difficult to be delimited.
- Cuff tear pain distribution principally involves antero-lateral aspect of the shoulder with irradiation downwards the lateral surface of the arm until the elbow.

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Clinical Evaluation

Stefano Gumina and Vittorio Candela

In the early 1990s, about 30 tests were described with the aim of diagnosing a rotator cuff tear [1]. Of the last 1,000 scientific articles on rotator cuff cited in PubMed, 3 % is about new semeiological tests acting to reveal a lesion. In fact, many of these tests only retain historical importance because they have been handed down, cited, and interpreted even if they have never been validated. The value of validation is given by the number of times the test was positive or negative in the affected population and in the control group (homogeneous for age and sex) consisting of healthy subjects for that disease [2].

Therefore, clinical trials should be evaluated in terms of sensitivity, specificity, and positive and negative predictive value. Sensitivity is given by the percentage of individuals who are identified as suffering from the disease in the actually affected population; instead, percentage of individuals identified as healthy in the actually healthy population in relation to that pathology indicates the specificity. The positive predictive value indicates the probability that a person tested positive actually has the disease; and the negative one indicates the probability that a person considered to be healthy after the test is really healthy. Table 1 shows how to extrapolate these data.

In a recent prospective study [3], it was observed that of 23 different tests performed out on the shoulders of 400 subjects with or without cuff tears, only those that reveal the weakness of supraspinous and subscapularis and those specific for subacromial impigement, are predictors of cuff tear. Furthermore, it was noted that the possibility of rotator cuff tear is high (98 %) if three tests are positive, or in case that two tests are positive and patient is over sixty.

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Recently, data extracted from clinical and instrumental examinations have been compared with arthroscopic findings in order to verify the reliability of clinical and instrumental semeiology in the diagnosis of cuff tear. Results showed that all clinical tests underestimate tear size and that no method is able to determine the size of a partial lesion [4].

Before setting up treatment for a shoulder disease, it is necessary that it is well-defined. Diagnosis may result from information provided by patient's medical history, and by clinical and/or instrumental data. It may happen that so collected data are in disagreement with each other. When this happens, it is usually the clinical evaluation to be questioned. This is because reports that are linked to the instrumental examinations are, for the less experienced, irrefutable evidence of disease.

Medical History

The clinical examination starts with medical history. Information regarding the characteristics of pain can be obtained from the following: intensity and mode of occurrence; site; periodicity; irradiation; aggravating factors, the presence of paresthesia, interference with daily work and sport activities, and finally, response to drugs or physiotherapy. In addition, the patient will report if pain is predominantly during day or night, localized in a precise point or diffuse, if it undermines range of motion and if they feel clicks (and/or) joints crackles. Usually patient is asked to indicate pain intensity on a visual analogue scale. In addition, information on patient general health and on their lifestyle (smoking, alcohol assumption, etc.) is gathered. The initial impression made by the patient on the examiner may suggest how to set the examination. The physiological age and patient's appearance, his body habitus, and the movements made during the act of undressing can be attributed, for example, to a degenerative disease or to a joint instability.

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Table 1 How to extrapolate data relative to sensitivity, specificity, positive predictivity, negative predictivity

	Current status of the disease		
Test result (T)	Positive	Negative	Total
Positive	a	b	$a+b$
Negative	c	d	$c+d$
Total	$a+c$	$b+d$	

Sensitivity: Probability (T^+/Dx^+) = $a/a+c$
Specificity: Probability (T^-/Dx^-) = $d/b+d$
Positive predictivity: Probability (Dx^+/T^+) = $a/a+b$
Negative predicitivity: Probability (Dx^-/T^-) = $d/c+d$

In our experience, the "identikit" of the patient with a rotator cuff tear can be described in the following terms:

An over-60 male, often overweight, suffering from diseases that affect the peripheral microcirculation, smoker, ex-manual worker, with anterolateral shoulder pain, mainly during the night, which persists for several months, and who gets little benefit from drugs or physiotherapy.

Inspection

The inspection can often lead to a diagnosis. Female patients must be sufficiently covered so that they can feel at ease during the whole time of the visit. Skin characteristic and bony prominences must be well examined. The cause of any scars, deformities, and asymmetries must be investigated. A prominent sternoclavicular or acromioclavicular joint may be normal anatomic variants; in other cases, prominence is the result of trauma or joints degeneration. On the other hand, the prominence of the scapula may be indicative of a paralysis of the serratus anterior, trapezius, or rhomboidei. Patients with congenital or acquired dorsal kyphosis usually have a scapular anti-tilting that can lead to a pathological reduction of the subacromial space. The lowering of the scapula in young sports people, engaged in throwing activities, can be observed in the clinical evaluation of the SICK syndrome (Scapular malposition; Infero prominence of the medial edge of the scapula, pain on the Coracoid; dysKinesis of scapular movement).

Fig. 1 Deltoid atrophy of the left shoulder

Through inspection the examiner will assess profile and tropism of shoulder muscles. Atrophies may be due to "non-use", however when a restricted district is interested, it may be the expression of specific diseases. Deltoid atrophy can be linked to a lesion of the axillary nerve, occurring, for example, during an anterior dislocation of the glenohumeral joint, or a more complex lesion of the brachial plexus (Fig. 1). Atrophy of the supra or infra spinatus loggia may be indicative, in an elderly patient, of a cuff tear while, in the young sportspeople, of a lesion of the suprascapular nerve due to entrapment (Fig. 2).

Elderly patients with a massive rotator cuff tear may develop a pseudocyst of the acromioclavicular joint, often mistaken for a lipoma. The humeral head rise, resulting from the cuff tear, causes the rupture of the inferior acromioclavicular joint capsule. Therefore, the synovial fluid of the glenohumeral joint capsule enters the acromioclavicular joint, shakes it, producing the pseudocyst (Fig. 3).

In contrast, patients with chronic synovitis, with or without associated glenohumeral arthropathy, have great swelling in the anterior surface of the shoulder.

Frequently, in a department dedicated to shoulder pathologies, patients are predominantly heavy workers,

Fig. 2 Bilateral supra and infraspinatus loggia atrophy

males in senile age reporting sudden pain on the front of the shoulder often in combination with a snap and pulling sensation. After a few hours, these patients notice the appearance of a hematoma which is in the same anatomical region and is associated with a deformity of the biceps muscle's profile due to a subcutaneous rupture of the long head of the biceps tendon (arm wrestling sign – Popeye sign) (Fig. 4a, b).

Young people, who practice body building or related sports, can develop a subcutaneous lesion of the sternal head of the pectoralis major tendon. The hematoma extends along the medial surface of the arm and on the chest. When hematoma is reabsorbed, the deformity of muscle's profile becomes more evident (Fig. 5).

Palpation

Palpation begins with the appreciation of the protruding bones: the clavicle, the acromioclavicular and sternoclavicular joint, the anterolateral margin and the posterolateral acromial corner, the coracoids, and the spine of the scapula. The examiner palpates and presses on the painful areas. Patients with rotator cuff tear often have an acromioclavicular joint arthropathy and an inflammation of the long head of the biceps tendon. Therefore, the pressure exerted on the joint and along the bicipital groove is often painful. The pressure in the subacromial space, below the anterolateral margin of the acromion, is constantly painful.

Patients with cuff tears and articular synovitis (Milwaukee syndrome; villonodular synovitis) have a warm, swollen skin with fluid ballottement (Fig. 6).

Palpation of the deltoid or parascapular muscles can bring out depressions (from detachments tendon or muscle damage) or swelling (hematoma, neoplasms). The examiner will also palpate the cervical paraspinal muscles, up to the base of the cranium, because many disorders defined as "shoulder diseases" by the patient are actually cervical spine pathologies with pain irradiation to the shoulder.

Fig. 3 Acromioclavicular joint cyst on an elderly female with a massive rotator cuff tear

Evaluation of the Range of Motion

In my clinical practice, I evaluate active range of motion of both shoulders even before I perform the common semeiological tests. The assessment can be made with the patient standing or sitting. Personally I prefer the latter position since the compensatory movements of the spine and pelvis are reduced. Commonly I write down in the clinical record the degrees of flexion, abduction, and external and internal rotations. The external rotation is performed starting from the position with the limb along the side or in abduction to 90° (in both cases the elbows are flexed at 90°), while the internal rotation is performed with the arm moved to the back (the vertebral level reached by the thumb is reported). The motion degrees are registered with a goniometer or by performing the movements behind a wall where a graduated

Fig. 4 Acute subcutaneous long head biceps tendon rupture. (**a**) Hematoma. (**b**) Deformity of the arm

Fig. 5 Acute rupture of the right pectoralis major tendon

Fig. 6 Milwaukee syndrome of the left shoulder in an elderly female

circle hangs. The decision of performing the active range of motion evaluation at the beginning of the visit is motivated by the need to transcribe in the clinical record the information that is not affected by the pain which could appear/increase during the execution of some tests. If patient agrees, I take some photos of the extreme degrees reached. This documentation may be useful for future medical lax disputes (Fig. 7).

In all cases, I observe also the active range of motion of the joint between the scapula and the toracic surface. Any dyskinesias are clearly visible on the return from the position of maximum flexion. The movement of the scapula can also be reduced or altered as the result of trauma, adhesions, or neoformations.

This phase ends with the assessment of the passive mobility while patient is first sitting and then supine. This allows the examiner to appreciate any stiffness, intra-articular or pathological snaps.

Evaluation of Strength

Flexion

The main flexors of the shoulder are the deltoid (anterior portion) (axillary nerve, C5-C6), the pectoralis major (clavicular portion; lateral pectoral nerve, C5-C6), and the coracobrachialis and biceps (musculocutaneous nerve, C5-C7). The evaluation is performed by placing a resistance to about 90° of flexion.

Abduction

This movement is possible through the action of the lateral portion of the deltoid (axillary nerve, C5-C6) and the supraspinatus muscle (suprascapular nerve, C5). The resistance is applied when the limb is abducted to 90°, slightly anteponed of about 20° and in full pronation.

Fig. 7 Range of motion evaluation. (**a**) Active flexion. (**b**) Active abduction. (**c**) Active external rotation. (**d**) Active internal rotation

External Rotation

This movement is realized through the infraspinatus (suprascapular nerve, C5-C6) and teres minor muscles (axillary nerve, C5-C6). The posterior portion of the deltoid participates only minimally (axillary nerve, C5-C6). The assessment can be performed with the limb at the side or abducted to 90°. In both cases, the elbow is flexed to 90°.

Internal Rotation

The main internal rotator muscles are the subscapularis (upper subscapular, C5; and lower subscapular nerves, C5-C6) and the pectoralis major (lateral pectoral nerve, C5-C7; medial pectoral, C8-T1). The resistance is applied to the volar surface of the forearm while the arm is at the side, the elbow is flexed and in neutral rotation.

Any muscular deficit must be quantified and reported in the medical card. The classification of muscle strength we use is shown in Table 2.

Impingement Syndrome

Subacromial Impingement

Soft tissues, such as tendons, capsule, and ligaments, can be rubbed or compressed by the surrounding bony epiphysis or apophysis. The resulting symptoms give rise to the so-called impingement syndrome. Among these, the subacromia one is the most common. In this case, because of the acquired narrowness of the subacromial space, the upper cuff tendons touch the antero-inferior margin of the acromion during the arc of movement between 60° and 120° of flexion.

Table 2 Classification of muscle strenght

Strength quantification	Strength degree
0: none	No contraction
1: barely hinted	Slight contraction; no movement, even in the absence of gravity
2: scarce	Slight movement only in the absence of gravity
3: discreet	Limited movement in the presence of gravity
4: good	Movement also against resistance – almost normal
5: excellent	Normal movement against resistance

Patients with subacromial impingement, without rotator cuff tear, are usually older than 40 years old. Younger patients often have posterior capsular contracture or lesser forms of instability that simulate the clinical picture of the subacromial impingement syndrome. Male subjects engaged in manual labor (carpenters, painters, masons, builders, etc.) are statistically more involved. Pain is localized at the front, under the anterior acromial margin and radiates along the anterior and lateral surface of the arm. The appearance or intensification of pain during flexion of the arm is a distinctive feature, in particular, during the range of motion between 60° and 120° of flexion (painful arc). Nocturnal pain is not constant, but it is much more common if the impingement has caused a degeneration of the bursal side of cuff tendons. Shoulder range of motion is generally complete but painful during flexion (painful arc). However, mobility will be reduced if the impingement is associated with adhesive capsulitis or with a cuff tear, even partial one.

There are three tests described in the literature to reveal this form of impingement: Neer's test, Neer's sign, and Hawkins' tests.

Neer's test consists of injecting about 10 cc of xylocaine 2 % in the subacromial space. Generally, the anesthetic is injected through the path that corresponds to the posterior arthroscopic portal (1.5 cm inferiorly and medially to the posterolateral corner of the acromion). The tip of the needle is directed superiorly and addressed to the anterolateral margin of the acromion. After the infiltration, patient is observed in the next 3 h and then asked to make movements that would normally cause pain. The test is positive when the pain decreases by at least 80 %. However, a positive test indicates that the structures present in the subacromial space are suffering, but the suffering is not necessarily caused by impingement.

Personally, I do not ever run this test because it will be positive even in the case of a subacromial bursitis without impingement, of an acromioclavicular joint arthropathy and of rotator cuff tears. Moreover, some patients, although rarely, may develop an allergic reaction to the anesthetic; so I consider taking any risks to the patient useless.

Neer's sign [5] is positive when the examiner, passively flexing the shoulder, causes anterior or deltoid pain over movement between 60° and 120°. Pain is much more intense, and the sign most sensitive, if the examiner, in addition to flexing the limb, exerts a downward pressure of the anterior margin of the acromion [6] (Fig. 8a).

Hawkins' test [7] consists of flexing the arm to 90°, while the elbow is flexed, and then performing an internal rotation and an adduction of the shoulder. In this position, and in case of a pathological narrowness of the acromiohumeral distance, a painful impingement occurs between the upper portion of rotator cuff tendons and the acromion (Fig. 8b).

Results of a prospective study showed that the sensitivity of Neer's sign of and Hawkins' tests for the diagnosis of subacromial bursitis is, respectively, 75 % and 92 %, while that for rotator cuff tear is 85 % and 88 % [8].

Subcoracoid Impingement

In rare cases, subscapularis tendon can be compressed between the lesser tuberosity and the apex of the coracoid (subcoracoid impingement). When it occurs, there is always a combination of anatomical constitutional factors (long or with too much inclination coracoid process; restricted coraco-glenoid space); acquired (calcific tendinitis of subscapularis tendon) or iatrogenic (e.g., results of surgery for joint stabilization according to Latarjet) [9, 10]. Usually patients feel pain during flexion and internal rotation of the limb (driving a car, writing on a board). There are three tests commonly used to detect this form of friction (Fig. 9):

The first is that of *passive flexion-internal rotation* that arouses or increases pain, because in this position the distance between the apex of the coracoid and the lesser tuberosity becomes smaller (Fig. 9a).

The *anesthetic infiltration test* (5 cc xylocaine 2 %) is the most sensitive. The xylocaine is introduced just laterally to the coracoid apex. The test is positive if, after infiltration, flexion and internal rotation do not cause more pain. The effect of the anesthetic is exhausted in 3–24 h (Fig. 9b).

The last test is the "*reduced motion in flexion-adduction-internal rotation*". With the hand of the affected side, patient is not able to touch the spine of the controlateral scapula; the same movement they can do easily with the hand of the healthy side (Fig. 9c).

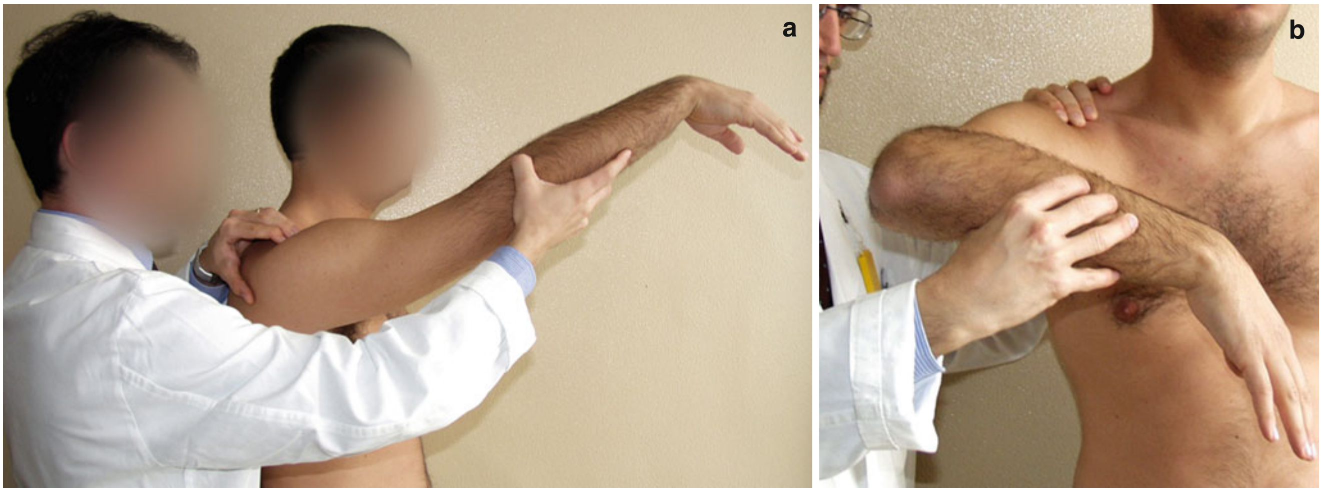

Fig. 8 Subacromial impingement tests. (**a**) Neer's Sign. In case of subacromial impingement, the passive flexion of the upper limb, over between 60° and 120°, evokes pain. It is more marked and the test is more sensitive if the examiner exerts pressure over the acromion. (**b**) Hawkins's test. The test is positive when, starting from a position of 90° of flexion and neutral rotation, the passive internal rotation evokes suacromial or deltoid pain

Internal Impingement

Recently, after a dynamic arthroscopic evaluation performed on 16 patients with chronic pain caused by flexion and internal rotation of the shoulder, Gerber and Sebesta [11] showed an internal impingement between biceps long head, upper glenohumeral ligament, coracohumeral ligament, and superior glenoid labrum. This occurs when limb is flexed more than 90°; if the degree of flexion is inferior, the impingement may involve the subscapularis tendon, the superior glenoid labrum, and the bony margin of the glenoid.

Postero-Superior Impingement

In patients involved in throwing activities, pain caused by abduction and full external rotation of the shoulder should raise the suspicion of an impingement between the deep portion of the supraspinatus tendon and the postero superior glenoid joint line [12].

Rotator Cuff Tear

Anterior Rotator Cuff (Subscapularis)

Among the tests designed to detect a lesion of the subscapularis tendon, the *lift-off test* is the best known. The patients individually moved the back of the hand to the lumbar region (L2-L5). This may not be possible when shoulder is markedly painful or stiff (adhesive capsulitis). After that, they are invited to shift his hand from the trunk. If it fails, the test is considered positive [13]. Usually I prefer to run the *internal rotation lag sign* (*IRLS*) [14]. The examiner grasps the patient's hand by the thumb and moves it back toward the lumbar region (L2-L5), keeping it departed from the trunk. He/she then invites the patient to independently maintain this position (Fig. 10a). If the back of the hand "falls" on the lumbar spine, the test is considered positive (Fig. 10b). The IRLS results more sensitive than lift-off, as it can detect even partial tears [15].

In 1996, Gerber et al. [16] described a test to be performed in case of marked painful stiffness in internal rotation. The test was called *belly press test*, and it is performed with the arm along the side, the shoulder in internal rotation, and the elbow flexed to 90°. The patient presses the abdomen with the palm of his hand while keeping the limb internally rotated. The examiner assesses the resistance offered when trying to deviate the hand from the abdomen of the patient. The test is considered positive in case of evident weakness compared to the controlateral limb, or when patient, in an attempt to oppose the force of the examiner, extends the shoulder. *Napoleon's sign* (by analogy with the position taken by the famous historical character) is a variant of the belly press test. Barth et al. [17] consider the test as positive, when patient, while pressing his hand on the abdomen, does not keep the wrist (radio -carpal joint) in line with the forearm, but flexed it to 30–60° (intermediate deficit) or to 90° (severe deficiency) (Fig. 10c, d). For this test, the evaluation is performed by comparison. The lesion of the subscapularis tendon is also suspected when there is an *increase in the passive external rotation* compared to the healthy side [18].

Beaudreuil et al. [19] performed a systematic review of the literature. The authors noted that the "lift off" test has a high specificity (range 85–100 %) and a lower sensitivity

Fig. 9 Subcoracoid impingement tests. (**a**) The passive flexion and internal rotation of the arm evokes or increases pain on the anterior shoulder. (**b**) Test with anesthetic: it is positive when the introduction of 5 cc of anesthetic, laterally at the apex of the coracoid, is able to momentarily decrease pain. (**c**) Patient with subcoracoid impingement is not able, with the affected arm, to get the spine of the contralateral scapula; patient is able to reach with the healthy arm the scapula body

(range 59–62 %). Hertel et al. [15] believe that the IRLS has a specificity of 96 % and a sensitivity of 97 %.

The *bear-hug test* is the test from which I get the most reliable information [17] (Fig. 10e, f). The palm of the hand of the involved side is placed on the opposite shoulder. Fingers are extended and the elbow is placed in front of the body. The examiner grasps the patient's hand and tries to lift it by applying to the forearm a perpendicular force in external rotation. The patient should oppose this attempt to deviate the hand. The test is considered as positive when patient fails to keep the palm of the hand on his shoulder. Barth et al. [17] believe that the bear-hug test is not very sensitive (60 %); however, it is definitely more sensitive than the lift off (18 %), belly-press (40 %), and Napoleon tests (25 %). In contrast, the specificity of the four tests is very high: bear-hug test: 92 %; lift off: 100 %; Napoleon and belly-press tests: 98 %. On the basis of intraoperative findings, the authors argue that the positivity of the bear-hug and belly-press tests suggests a lesion of at least 30 % of the subscapularis tendon, while a positive Napoleon test indicates that more than 50 % of the subscapularis is injured. In addition, the lift off test becomes positive when at least 75 % of the tendon is lesioned. In conclusion, the bear-hug test increases the chance to appreciate even the smallest of subscapularis tears, but only the execution of all four tests helps to predict the size of the tear.

Superior Rotator Cuff (Supraspinatus)

Jobe and Moynes [20] observed that the supraspinatus' function can be appreciated singly during the elevation of the arm, abducted to 90° (in the scapular plane), anteponed of 20°, and completely internally rotated (*Jobe test or Empty can test*). According to Jobe and Bradley [21], the test is positive when there is a strength deficit secondary to the supraspinatus tendon tear or if it causes pain as a result of a subacromial impingement (Fig. 11a). However, test interpretation is controversial [15–22]. EMG studies showed that the

Fig. 10 Tests for the anterior rotator cuff. (**a**) IRLS. The examiner grasps the patients's hand by the thumb and brings it to the lumbar region (L2-L5), keeping it departed from the trunk. (**b**) Test is considered positive if patient is not able to autonomously maintain this position. (**c**) Napoleon's sign. Patient is asked to press his/her hand against the abdominal region (**d**) The inability to maintain the elbow anteposted is a sign of subscapularis failure. (**e**, **f**) A 44-year-old man with a subscapularis tendon tear of the left shoulder. Bear-Hug Test. The palm of the hand of the involved side is placed on the opposite shoulder. Fingers are extended and the elbow is placed in front of the body. The examiner grasps the patient's hand and tries to lift it by applying to the forearm a perpendicular force in external rotation

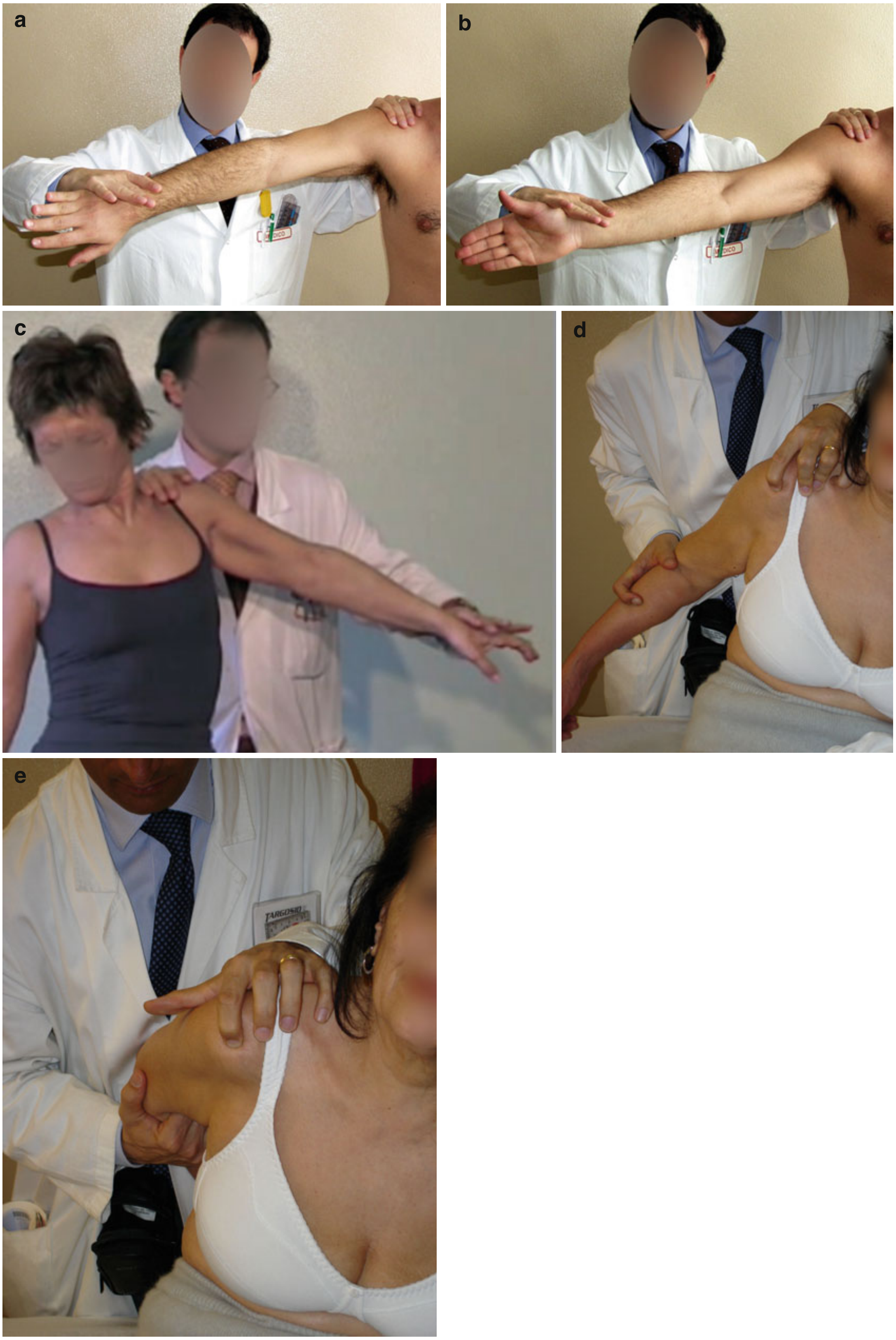

Fig. 11 Tests for the superior rotator cuff. (**a**) Jobe's test. Patient raises the limb from a position of abduction and anteposition of 90° and 20°, respectively. The examiner, placed behind the patient, is opposed to lifting. The test is positive when the examiner appreciates a strength deficit compared with the healthy limb. Pain, often elicited, can make the test as false positive. (**b**) The same maneuver, but with the arm in external rotation (full can test), allows you to appreciate equally the loss of strength, but evoking less pain. (**c**) Strength in abduction (45°). The examiner stands behind the patient. With one hand stops the scapula rotation and with the other one evaluates the strength over movement between 45° and 90° of abduction. (**d**, **e**) Rent test. The examiner stands behind the patient. With one hand he/she holds the elbow flexed to 90°, and with the index finger of the other hand palpates the subacromial region. Then he/she extends the arm and executes external (**d**) and internal rotation movements (**e**)

activity of the supraspinatus is the same whether the limb is placed in internal or 45° of external rotation (*Full can test*, Fig. 11b); however, in external rotation the test causes less pain [22]. Itoi et al. [23] found that muscle weakness is the only parameter to be considered, because, in contrast to pain, it does not reduce the specificity of the test. In addition, they observed that both tests are equivalent in terms of accuracy. Therefore, considering that Full can test causes less pain, it should be preferred to Jobe's one. Our data indicate that Jobe's test has a high sensitivity and low specificity. This means that if the test is carried out on a group of both healthy subjects and patients, it is able to identify all true positives; however, it will be positive even in some healthy subjects.

Itoi et al. [23] believe that Jobe test has a 77 % of sensitivity for the strength, while the specificity, positive and negative predictive value, and accuracy are 68 %, 44 %, 90 %, and 70 % respectively. The same values for the Full can test are: 77, 74, 49, 91, and 75 %.

Data of a clinical and MRI study [24] indicate that the Jobe and Full can tests specificity is higher if we exclude partial tears.

Gillooly et al. [25] prefer to perform Jobe test with the arm abducted to 90° in the coronal plane and in internal rotation so that, with the elbow flexed to 90°, the fingers point downwards and thumb is directed medially. This test, called Lateral Jobe, is positive when the examiner, exerting against resistance a force directed downwards and applied on the arm, feels a weakness. According to the creators, the "Lateral Jobe" and "Jobe" tests have 81 % and 58 % of sensitivity, respectively, while the specificity is nearly equal: 89 % and 88 %.

When there is a lesion of the supraspinatus tendon, the *strength in abduction* may be also compromised. In order to evaluate it, the examiner stands behind the patient. With one hand stops the scapula rotation and with the other one evaluates the strength over movement between 45° and 90° of abduction (Fig. 11c). Data of our unpublished study indicate that the sensitivity, specificity, and positive and negative predictive value of the test are 74 %, 91 %, 75 %, and 88 %, respectively.

Wolf and Agrawal [26] described a method to appreciate cuff tear with a transdeltoideus palpation (*Rent test*). The examiner stands behind the patient. With one hand he holds the elbow flexed to 90°, and with the index finger of the other hand palpates the subacromial region. Then he extends the arm and executes internal and external rotation movements. If there is a tear, the index palpates the greater tuberosity and an "empty" area, corresponding to the failure tendon insertion on the tuberosity (Fig. 11d, e). The sensitivity of the positive predictive values for this test was 95 %, while the specificity and negative predictive value were 96 %. These values are questionable because, as one might guess, the test can be performed only in slim patients with a poor representation of the deltoid muscle.

Postero-Superior Cuff (Supraspinous and Infraspinatus Muscles)

If there is a suspicion that the patient has posterior-superior cuff pathology, it is good practice to perform, after the joint function evaluation, tests that do not cause pain and, therefore, do not affect their validity. Among these, the *external rotation lag sign* (*ERLS*) and the *drop sign* [15] are the most used. During the execution of both tests, the examiner stands behind the patient, who is sitting. The ERLS (for supra and infraspinatus) consist of supporting (from the elbow) the limb under examination in slight abduction and flexion (20°) and close to maximum external rotation (the maximum external rotation would result in a physiological elastic return after releasing the arm). The examiner should check that patient does not rotate the trunk. Then, the patient is asked to maintain independently this position. The test is positive when at least 10° of external rotation are lost (Fig. 12a, b). The interpretation of this test can be difficult when the passive external rotation is reduced (capsulitis) or increased (subscapularis tear). In these cases, it is possible to obtain, respectively, false negatives and false positives.

The drop sign (for infraspinatus) is performed with the arm in abduction (90°) and close to maximum external rotation. The elbow is flexed to 90°. The examiner holds the elbow with one hand and the wrist of the patient with the other one, checking that he does not rotate the trunk. Then, the patient is asked to maintain independently the position set. The test is positive when the limb loses the external rotation or drops in internal rotation (Fig. 12c, d).

Castoldi et al. [27] have used ERLS to evaluate 401 consecutive patients with shoulder diseases and found that the sensitivity and specificity of the test for full thickness supraspinatus tears were 56 % and 98 %, respectively. Instead, the sensitivity increases considerably to 98 %, when the lesion involves the infraspinatus and teres minor. In addition, the authors observed that there is a strong correlation between tear severity and the lag degrees. In fact, it goes from 7° (mean) for the lesions of the supraspinatus only, to 26° for lesions that extend to the teres minor.

Hertel et al. [15] believe that the sensitivity, specificity, positive and negative predictive values, and accuracy of the drop sign are 21 %, 100 %, 100 %, 32 %, and 43 %, respectively. These data do not differ much from those obtained from our series consisting of only patients with a full thickness tear of the infraspinatus: 34 %, 100 %, 100 %, 30 %, and 46 %.

As a rule, the *assessment of the strength in external rotation* is performed after the drop tests. The patient keeps the arm along the side with the elbow flexed at 90°. The examiner, placed behind the patient, supporting the elbow of the patient with one hand and the wrist with the other, assesses the strength in external rotation (Fig. 12e). A value from 0 to

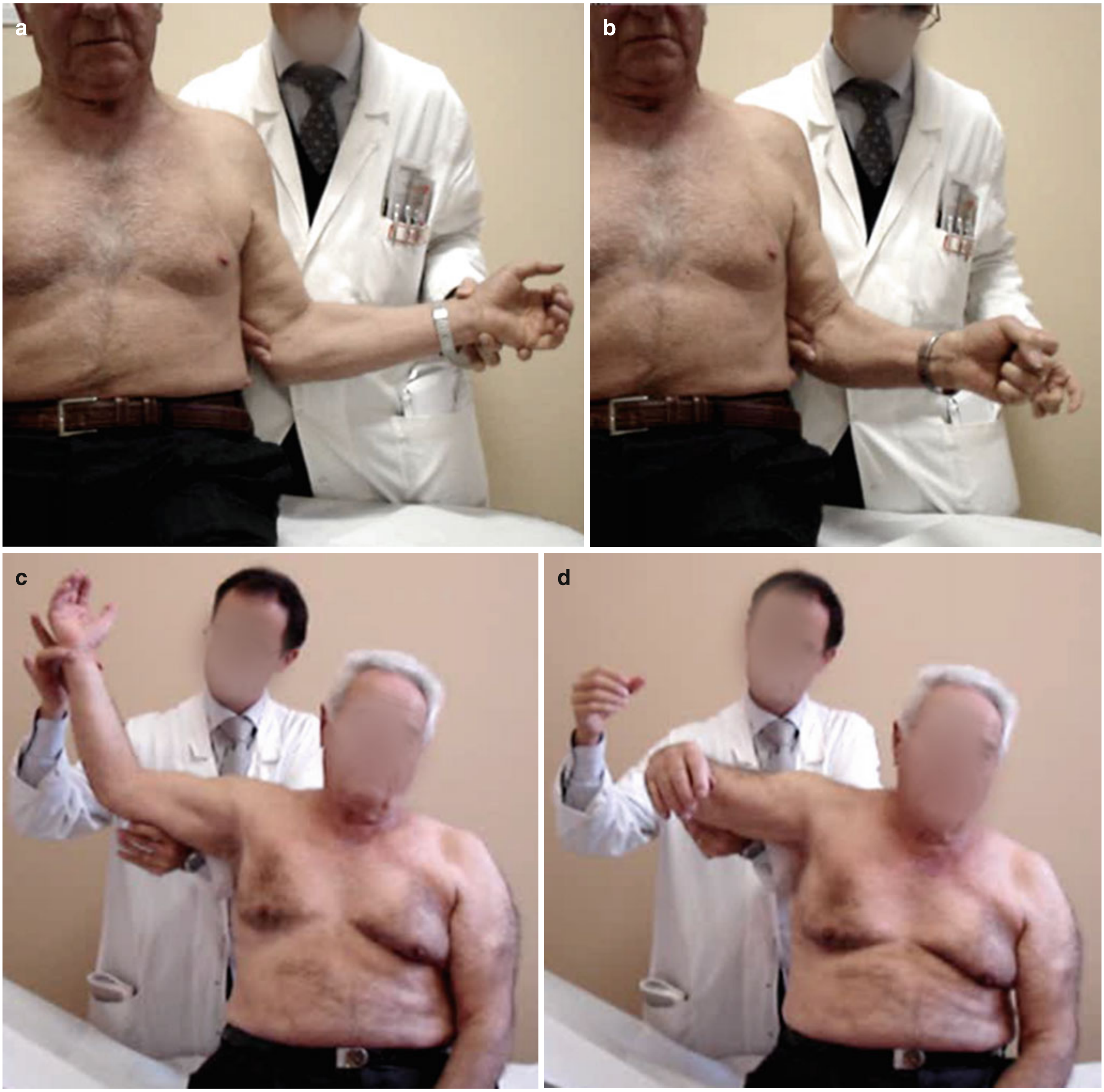

Fig. 12 Tests for the postero-superior rotator cuff. (**a**) ERLS. Limb is passively adducted along the side and 45° externally rotated. The examiner should check that the patient does not rotate the trunk. (**b**) Test is positive when the patient is not able to autonomously maintain the external rotation (loss of at least 10°). (**c**) Drop sign. Limb is placed passively in abduction and external rotation of 90°. Patient is then asked to independently maintain the starting position. (**d**) Test is positive when the limb is no longer supported, loses some extrarotation and abduction degrees (10°). (**e**) Strength in external rotation. (**f**, **g**) Patte maneuver

Fig. 12 (continued)

5 is assigned. Walch et al. [28] assess the strength starting from 45° of external rotation.

The test can also be performed by placing the limb in abduction of 90°, anteponed of 20°, with the elbow flexed (90°) and in internal rotation (*Patte maneuver*) [29–31], but this position can increase pain and compromise the next tests (Fig. 12f, g). The sensitivity of the evaluation of the external rotation strength and of the Patte test was 76% and 79%, respectively, while the specificity was 57% and 67% [30, 31].

Gum-Turn Test (or Test of Resistence) [32] This test, of our design, is performed in a standing position with the affected arm at 90° of abduction, place forward of 20–30° and in external rotation (as in the Full can test). From this position, the patient is asked to follow for 20 laps with the index finger the path of a spiral drawn on a sheet of paper; 1 turn = from the center of the loop to its end, and in the other direction (loop width: 20 cm). After 10 laps, patient is allowed to rest for 1 min. The spiral is colored with colors that reduce visual problems associated with gesture repetition. Test is considered as positive when patient is not able to conclude it because of pain or for the inability to keep the limb raised (lack of strength). The data on the validity of the resistance test are shown in Table 3.

Our test is scarcely reliable for the diagnosis of subacromial impingement and not very reliable for a small cuff tear. When the resistance test is positive, there is a high probability of a subacromial space pathology; on the other hand, when it is negative, there is a high probability that a large or massive poster-superior rotator cuff tear is not present.

Posterior Cuff (Teres Minor)

In a retrospective study, Walch et al. [28] observed that a maneuver commonly used to assess muscle function in patients with obstetric paralysis [33] has a sensitivity of 100% and a specificity of 93% for detecting lesions of the teres minor tendon, with type 3–4 Goutallier muscle atrophy (assessment performed on CT scans) [34]. The maneuver (*horn blower test*) is considered positive when the patient, who was invited to bring his/her hand to the mouth, is not able to make this gesture or makes it abducting the affected limb (Fig. 13a, b). The authors believed that a positive test is indicative of an irreparable cuff tear. Moreover, in case of positivity of both horn blower test and ERLS, the examiner should desist from surgical cuff repair because of poor results.

Acromioclavicular Joint Cyst

The acromioclavicular joint cyst is a well-defined oval mass overlying the superior aspect of a hypertrophied and degenerative AC joint. It was firstly described by Craig [35] in 1984 who magistrally observed the coexistence between a massive, and not recent, rotator cuff tear and degenerative changes of the AC joint. In 1986, the same author [36] postulated two possible hypotheses able to generate these cysts: (a) AC spurs firstly determine an impingement syndrome that progressively causes a rotator cuff tear; consequently, the abundant glenohumeral fluid, product by the hypertrophic synovia, would pass throughout the cuff and inferior AC capsule tears, extending the superior AC capsule and forming the cyst; (b) the upperward migration of the humeral head, consequent to rotator cuff tear, injures the inferior AC capsule, creating a direct connection between the glenohumeral and AC joints. Even in this case, the glenohumeral fluid would cause a distension of the superior AC capsule. Currently, the latter hypothesis enjoys greater credit.

In 2010, these pseudo-cysts were classified by Hiller et al. [37] as type II cysts, to distinguish them from type I cysts dependent on degenerative changes of the AC joint due to trauma, infection, metabolic disease, or repetitive overuse. Overtime, degenerative changes could be responsible for synovium irritation leading to an overproduction of fluid resulting in cyst formation superficial to the AC joint. Generally, in these cases, rotator cuff is intact (Fig. 14).

Clinically, patients with acromioclavicular joint cysts have also an atrophy of the external rotator muscles, a decrease in external rotation strength and, frequently, the range of motion of the involved shoulder is compromised. The MRI shows the geyser effect [35].

From 1984 to present, 54 cases of acromioclavicular joint cyst have been reported in English literature [35–39].

This unusual presentation of full thickness rotator cuff tear, associated with AC degenerative changes, has been treated by watchful waiting, excision with or without rotator

Table 3 data on the resistance test (Gum-Turn test)

	Sensibility (%)	Specificity (%)	Positive predictive value (%)	Negative predictive value (%)	Accuracy (%)
Subacromial impingement	37	98	94	64	69
Cuff tear (in general)	65	98	98	66	79
Supraspinous tear	55	98	97	68	76
Supraspinous + infraspinatus tear	91	98	95	96	96

Fig. 13 Horn blower test. (**a**) Patient is invited to bring his hand to the mouth. (**b**) Test is considered as positive when he/she is not able to make this gesture or makes it abducting the affected limb

cuff repair, lateral clavicle resection with or without the use of allograft patch, hemiarthroplasty, and reverse shoulder prosthesis [36–47]. Aspiration with steroid injection has been also a widely used treatment [36–47].

In 1986, Craig [36] described the experience of an 86-year-old man whose cyst had been submitted to several aspirations, followed by re-accumulation within a few weeks. An attempt to surgically excise the lesion was unsuccessful, as the cyst promptly recurred after surgery. Corticosteroids were injected into the lesion without successful resolution.

Out of the three cases presented by Postacchini et al. [45] in 1993, one patient (a 75-year old man) had been undergone repeated aspirations before being operated of cyst excision and lateral clavicle resection with a final resolution of the lesion.

A chronic cyst overlying the acromioclavicular joint was managed with hemiarthroplasty in four patients, by Groh et al. [42] (2003). All patients had been previously submitted to aspiration of the cyst with recurrence.

In the Tshering Vogel's et al. [46] (2005) series, constituted by 9 patients (7M-2F; mean age of 67 years; range 57–86), aspiration of the cyst was performed in two patients and CPPD (calcium pyrophosphate dehydrate) crystals were demonstrated in the aspirate; subsequently, both underwent surgery due to recurrence.

Mullet et al. [47] in 2007 described the case of 75-year-old man who was submitted to arthroscopy of the AC joint and debridement of a voluminous AC joint cyst in the lateral decubitus position. The major rotator cuff tear of supraspinatus and infraspinatus was confirmed. A conservative subacromial decompression and AC joint excision arthroplasty was performed; as the superior AC ligament was opened, dark brown gelatinous material was seen emanating from the cyst. A thorough debridement of the cyst was performed until the lavage fluid was clear. At last follow-up 6 months after surgery, the shoulder remained asymptomatic with no evidence of recurrence of the cyst. The authors concluded that arthroscopic treatment of a massive AC joint cyst allows assessment of associated pathology, is minimally invasive, and allows early rehabilitation.

In 2009, Nowak et al. [44] described a case of a 77-year-old, right hand–dominant woman who underwent cuff tear repair after two aspiration attempts with a rapid re-accumulation of the fluid. In the same year, Murena et al. [43] submitted a 81-year-old male to lateral clavicle resection after four ultrasound-guided aspirations of the cyst and steroid injections.

Of the four cases presented by Hiller et al. [37] in 2010, two underwent cyst aspiration; one of them had a recurrence. In 2012, an 84-year-old man was treated with cyst excision

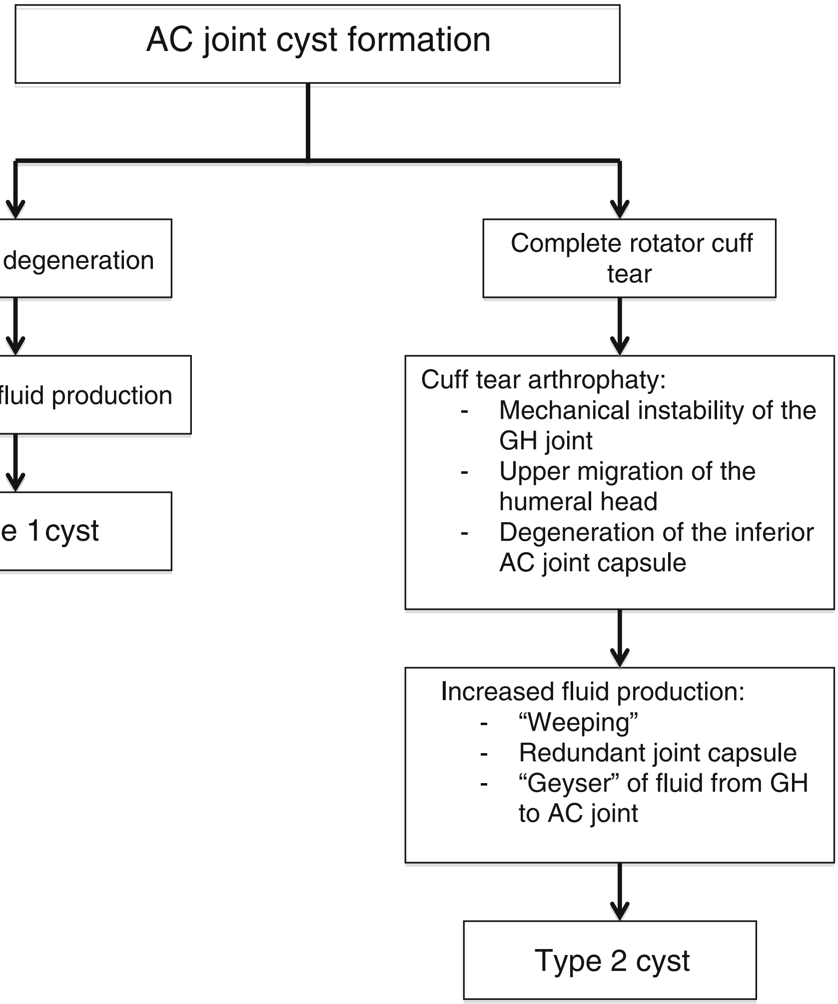

Fig. 14 AC joint cyst formation

and allograft patch of acromioclavicular region by Skedros and Knight [41] after 1 year of observation and 3 aspirations.

Data suggest that the choice treatment is the cyst excision associated with the lateral clavicle resection and the rotator cuff repair, if it is possible. In cases of cuff tear arthropathy, reverse shoulder prosthesis is indicated in addition to cyst excision, as described by Shaarani et al. [40].

However, patients with acromioclavicular type II cysts usually have no severe shoulder pain and their general health status contraindicates any type of complex surgery (ASA 3 or 4 patients), so watchful waiting may be justified. In rare cases, the oval cyst mass can grow to significant sizes to endanger the integrity of the overlying skin, with the possibility to undergo serious complications. In these selected cases, aspiration seems to be the only possible treatment. However, it remains unclear how long the recurrence occurs and if the size of the re-accumulation is similar to that before aspiration.

We hypothesized that if recurrence occurred after a long time and the cyst was smaller than that before treatment, aspiration would be considered an effective temporary solution in inoperable patients. We retrospectively observed the clinical course, in the short and medium term, of four ASA 3–4 patients (3F-1M; mean age 83 years, range 78–87 years) with voluminous type II cyst who underwent aspiration and steroid injection regarded as the only possible treatment to avoid possible skin complications [48].

All patients had a voluminous oval, no mobile, no fluctuant cyst (wide, at least, 7 cm and high, at least, 6 cm) overlying the AC joint. All patients referred that the cyst was rapidly increased in volume (within 2 months). The cysts had a firm consistency, were covered by telangiectatic vessels, and were scarcely painful (Fig. 15). All patients underwent MRI examination to avoid the suspicion of neoplasia; in all cases, the MRI showed the geyser effect. None of our patients had a lymphadenopathy.

All participants had an atrophy of external rotator muscles, visible in both physical examination and confirmed by MRI and a compromised active range of motion of the involved shoulder (mean forward flexion: 110°; mean abduction: 80°; mean external rotation -side- 5°; mean internal rotation L5).

Fig. 15 A 85-year-old right-handed woman, with a voluminous acromioclavicular type II cyst on her left shoulder

Patients were merely submitted to cyst aspiration (utilizing only one posterior via, to not increase the risk of infection and draining sinus) and steroid injection (methylprednisolone 40 mg) (Fig. 16). The content of the cyst was microscopically analyzed. After aspiration, in all cases a compression bandage was performed.

Patients were clinically evaluated on the day of aspiration, after 14 and 30 days and after 1 year. In each control, the Constant score and pain intensity through the VAS were registered.

We were able to aspirate 80–150 ml of joint fluid; at the microscopic analysis, the fluids were amorphous, without crystals or typical cells.

At the first follow-up, all patients had a recurrence of the cyst (average size: width 2 cm and height 3 cm). All patients referred that they experienced a lower grade of tension of the skin overlying the cyst and also a very little decreasing of pain intensity. After a month from aspiration, the cysts of the four patients had the same size as that present before aspiration (Fig. 17). The consistency of the cysts returned to be the same as that appreciated before treatment.

The range of motion, the average value of the pain intensity, and the mean Constant score were similar to those recorded before aspiration (Tables 4 and 5). In no case signs of infection or draining sinus occurred. No patient had a rise in body temperature. No patient had a lymphadenopathy.

All patients were deeply disappointed with the clinical result and no one was willing to repeat the same treatment. Only one of the patients underwent surgery (excision of the cyst and removal of the lateral third of the clavicle) 3 months after the aspiration, accepting the operative risks associated with his health status. At 1 year after surgery, this patient had no recurrence of the cyst, but not even an increase in the Constant score. The other three patients continue to have, after a year, a voluminous cyst with telangiectatic vessels. No complications (fistula or ischemia of the overlying skin) occurred in these patients.

Acromioclavicular Joint Cyst: Take Home Message

- The choice treatment of AC joint cyst is the excision associated with the lateral clavicle resection and the rotator cuff repair, if it is possible. In cases of cuff tear arthropathy, reverse shoulder prosthesis is indicated in addition to cyst excision.
- Regarding aspiration of a voluminous cyst in ASA 3–4 patients, our data indicate that the aspirated mass recurs in 2–3 weeks and rapidly reaches the same size it had before aspiration. Our patients have had only a temporary decrease in skin tension and a transitory pain reduction. Therefore, we believe that aspiration is a useless practice. However, it is still a motive for discussion if the reduced suffering of the skin overlying the cyst after the aspiration has avoided, or simply postponed, an imminent complication.

Differential Diagnosis

Cervical Radiculopathy

The causes of shoulder pain are often difficult to interpret. The reason is that pain may originate from the shoulder (degenerative diseases and articular instability, tendonitis, etc.), or it may radiate to the shoulder from distant organs and structures (see Chap. 22), and particularly, from the cervical spine and from nerve roots that emerge from it [49–51]. The clinical evaluation is also more difficult when a shoulder disorder coexists with a cervical disease and it frequently occurs in the elderly patients [52, 53]. Generally, patients with cervical disease refer pain that is exacerbated by extending or tilting the head on the affected side because such positions increase compression on the nerve root [53, 54]. Three clinical tests are commonly performed to assess the presence of a cervical pathology: the Spurling maneuver [53, 55–59],

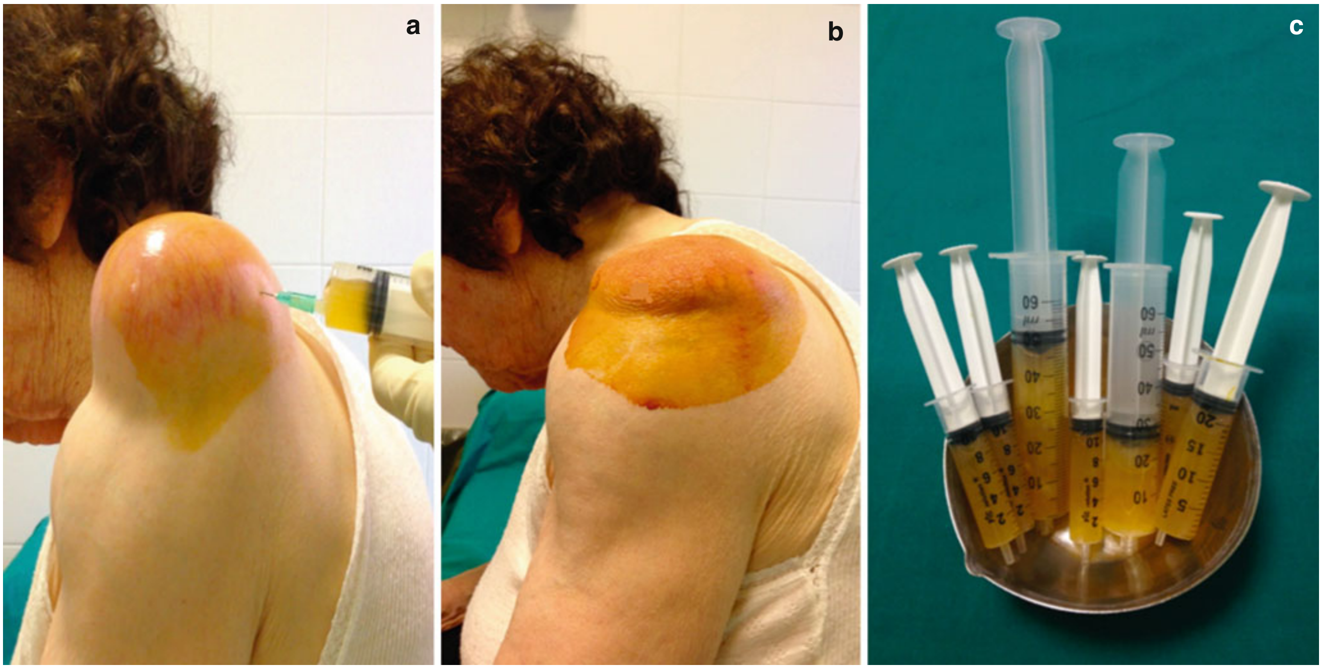

Fig. 16 (**a**) Aspiration of the cyst through the posterior via. (**b**) AC joint cyst at the end of the aspiration. (**c**) We were able to aspirate 150 ml of yellow joint fluid

Fig. 17 Cyst recurrence after 30 days

the test of shoulder abduction [57, 58, 60], and the upper limb tension test [61].

To perform the *Spurling maneuver*, the examiner stands behind the sitting patient and exerts a downward pressure on the head while it is inclined from the affected side. The maneuver is considered positive if it reproduces or exacerbates shoulder pain along the entire upper limb (Fig. 18).

The *shoulder abduction test* is positive if pain increases when patient places the palm of the affected side on the apex of the head (Fig. 19).

The *upper limb tension test* is performed in several steps. Initially, patient lies in a supine position. The examiner passively abducts the limb that is then flexed and pronated at forearm. Subsequently, the forearm is supinated and extended, and finally, patient's wrist is extended. The test is considered as positive when pain intensity becomes higher at each stage [61].

Ghasemi et al. [62] compared the diagnostic validity of these three clinical tests. According to the authors, the Spurling and abduction tests had the higher specificity (85 %), while that with higher sensitivity was the upper limb tension test (60 % for acute and 35 % for chronic pathologies). Finally, the abduction test was the one with the highest positive and negative predictive values. Based on their data, the authors recommend performing the upper limb tension test for screening, and the other two tests to confirm the clinical suspicion.

Patients with cervical radiculopathy usually refer pain beyond the elbow; painful irradiation to forearm is instead present only rarely in patients with rotator cuff tear

Table 4 Constant scores registered at each follow up

			Constant score			
Case	Sex	Age	T0	T1	T2	T3
#1	F	78	35	36	36	35
#2	M	82	37	37	36	34
#3	F	85	33	34	33	35
#4	F	87	38	40	38	35

T0 aspiration, *T1* 14 days after aspiration, *T2* 30 days after aspiration, *T3* 1 year after aspiration

Table 5 Pain intensity registered at each follow up

			VAS			
Case	Sex	Age	T0	T1	T2	T3
#1	F	78	7	6	6	7.5
#2	M	82	6	6	5	6.5
#3	F	85	7	5	7	7
#4	F	87	5	3	5	6

T0: aspiration, *T1* 14 days after aspiration, *T2* 30 days after aspiration, *T3* 1 year after aspiration

Fig. 18 Spurling maneuver. The examiner stands behind the patient and exerts a downward pressure on the head while it is inclined from the affected side. The maneuver is considered positive if it reproduces or exacerbates pain on the shoulder and/or along the upper limb

(see Chap. 20). Moreover, in contrast to cuff tear, patients may have paresthesias along the whole upper limb until the fingers; loss of strength in the muscles innervated by C5-C8 roots; alteration of biceps, triceps, radial osteotendinous reflexes (reduction or absence); hypoesthesia or anesthesia of specific dermatomes; but above all an *arm squeeze test* positive [63] (Fig. 20). This test, of our design, is considered as positive when the squeezing carried out by the examiner on the middle third of arm (area of the biceps and triceps brachii) is able to generate pain. The anatomical explanation of the test is that at the middle third of the arm, the musculocutaneous nerve (nerve roots C5-C7), the radial nerve (C5-T1), the ulnar nerve (C7-T1), and the median nerve (C5-T1) are relatively shallow, so it is easy to obtain a pain caused by a moderate compression of the skin, the subcutaneous tissue and muscle. In our series, the test was positive in 295/305 (96 %) of patients with cervical root (C5-T1) compression. In control subjects and in patients with cuff tears, adhesive capsulitis, acromioclavicular arthropathy, calcific tendinitis arthropathy, and glenohumeral joint, the test was positive in 4 %, 4 %, 2 %, 0 %, 2 %, 8 %, respectively (Table 6).

Acromioclavicular Joint Arthropathy

In my experience, a detailed history collection is enough for the diagnosis of painful acromioclavicular joint arthropathy. Asked to indicate the painful site, patients with arthropathy, usually put the index of the contralateral limb on acromioclavicular articulation, while patients with cuff tear cover with the palm of their hand the whole region anterior-lateral

Fig. 19 Shoulder abduction test. Pain increases when patient places the palm of the affected side on the apex of the head

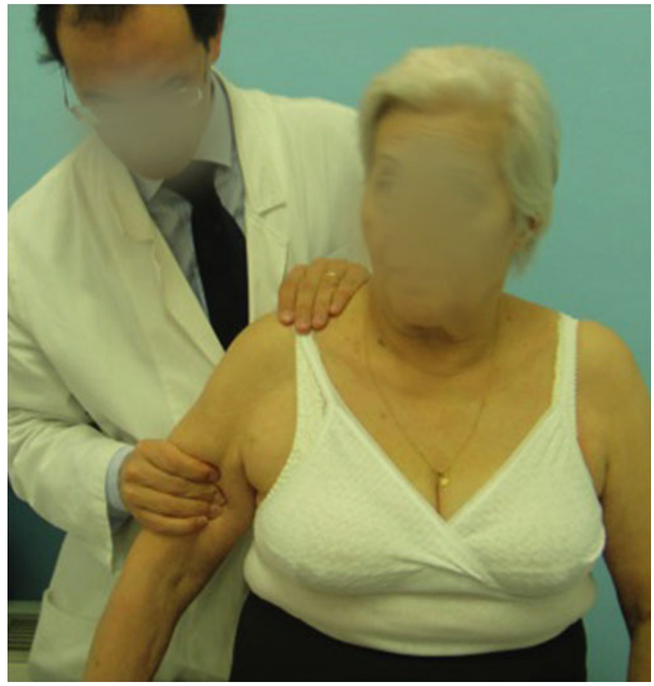

Fig. 20 Arm squeeze test. The squeezing carried out by the examiner on the middle third of arm is able to generate pain

of deltoid. In many cases, the acromioclavicular joint arthropathy is completely asymptomatic. In fact, it is common to hear from patient that pain appears after physical activity (work or sports).

Direct pressure on the acromioclavicular joint awakens or increases pain. The pain can also increase with the *grind test* [64]. The examiner still maintains the acromion with two fingers and with the other hand makes slightest movements of the clavicle in anterio-posterior direction (Fig. 21). The *O'Brien* or *Active compression test* [65] is another test commonly used for the diagnosis of a painful arthropathy or a synovitis of the acromioclavicular joint. Patient's arm is flexed to 90°, adducted to 10–15°, and completely internally rotated (thumb is directed downward). Patient is then instructed to resist the strength that the examiner applies downward. The maneuver is then repeated with the arm fully supinated. The test is considered as positive when pain appears or is exacerbated during the first part of the test and decreases or disappears during the second one. The O'Brien test creators believed that it has a sensitivity of 100 %, specificity of 96 %, and a positive and negative predictive values of 89 % and 100 %, respectively [65].

The *cross-body adduction stress test* is performed with the limb flexed to 90° and maximally adducted on the horizontal plane. It is considered as positive if it causes pain on the tip of the shoulder, near the acromio-clavicular joint [66]. The *Bell-van Riet test* (BvR) [67] is a variant of this test. As for the cross body, the BvR is performed with the elbow extended and the arm in internal rotation. The shoulder is flexed to 90° and adducted on the horizontal plane. The patient is then asked to resist the strength applied on his/her forearm and directed downward.

The *test of the extension against resistance* has been described by Jacob and Sallay [68]. The shoulder and the elbow of the patient are flexed to 90°, and the limb is in internal rotation. Patient is then asked to extend the limb against resistance. The maneuver is positive when the pain appears on the acromioclavicular joint.

The *infiltration of a mix of steroids and anesthetics* in the acromioclavicular joint can relieve or defeat pain. The test is difficult to perform, especially for the less experienced, due to the anatomical variability of the joint and the difficulty to reach it in people with abundant adipose tissue. A retrospective study [68] has shown that infiltration determines a clinical improvement in 93 % of cases, but the comfort lasts only for 20 days and in no case there is an interruption of the natural progression of the disease.

Chronopoulos et al. [69] have evaluated the diagnostic values of the cross-body extension against resistance and O'Brien tests have found that the cross-body has the highest sensitivity (77 %), while the O'Brien test has the lowest one (41 %). The latter test, however, has the highest value

Table 6 Diagnostic values of the arm squeeze test in patients with cervical radicular compression compared to asymptomatic controls and patients with various shoulder diseases (95 % CI)

Arm squeeze test	Value					
	Controls	RCT	Adhesive capsulitis	AC Artrop.	Calcific tendinitis	GO Artrop.
Sensibility	0.96 (0.85–0.99)					
Specificity	0.96 (0.87 a 0.99)	0.96 (0.86 a 0.98)	0.98 (0.88 a 1)	1 (0.95 a 1)	0.98 (0.87 a 0.99)	0.91 (0.8 a 0.95)
Positive predictive value	0.95 (0.87 a 0.97)	0.89 (0.83 a 0.92)	0.98 (0.88 a 1)	1 (0.96 a 1)	0.99 (0.89 a 1)	0.98 (0.87 a 0.99)
Negative predictive value	0.99 (0.9 a 1)	0.98 (0.89 a 0.99)	0.93 (0.84 a 0.96)	0.9 (0.96 a 1)	0.84 (0.8 a 0.91)	0.81 (0.75 a 0.99)
Likelihood ratio for negative result	24 (6.5 a 99)	24 (6.07 a 99)	– (7.08 a –)	– (24 a –)	48 (7.38 a 96)	10.6 (4.8 a 19.2)
Likelihood ratio for positive result	0.04 (0.01 a 0.17)	0.04 (0.01 a 0.17)	0.04 (0.01 a 0.17)	– (0.04 a –)	0.04 (0.04 a 0.044)	0.44 (0.2 a 0.8)

of specificity (95 %). Moreover, the three tests have a high negative predictive value (94 %), but a low positive predictive value (30 %). The O'Brien test is the one with the greatest accuracy (92 %) while the cross-body is the one with the lowest (79 %).

A similar study was conducted by van Riet and Bell [67]. The authors concluded stating (by stating or the statement) that their test (BvR) is the one with the highest value of sensitivity (98 %).

Biceps Pathology

The history and physical examination may be sufficient for the diagnosis of subcutaneous tear of the long head tendon of the biceps. The forearm flexion on the arm, even better against resistance, makes the deformity of the biceps profile (*Popeye's sign*) more obvious. It is more difficult to diagnose a tendinitis or a partial detachment of the biceps anchor (insertion) (SLAP lesions), because these conditions are often the result of more complex diseases. In these cases, many clinical tests are positive, so their interpretation is particularly difficult.

The *O'Brien test* [65], already described for the differential diagnosis of acromioclavicular joint disorders, has a sensitivity for SLAP lesions (biceps anchor avulsion from anterior to posterior) of 100 %, specificity of 98 %, a positive predictive value of 94 %, and negative predictive value of 100 %.

The patient maintains throughout the *Yergason test* [70] the elbow flexed at 90° and adherent to the chest, the forearm is pronated. The examiner is opposed to the attempt to supination and external rotation. The test is considered positive if it triggers pain along the bicipital groove or, in addition to pain, even causes a medial dislocation of the biceps, due to a sudden loss of function of the limb.

The *Speed's test* [71] is performed with the shoulder flexed to 90°, the elbow extended, and the forearm supinated. The examiner contrasts arm flexion; if positive, the test causes pain along the bicipital groove.

To perform the *belly press test* [72], the patient is asked to place and press the hand of the affected limb against the abdomen, internally rotating the shoulder. In case of positivity (lesion of the subscapularis with probable instability of the long head tendon of the biceps), the patient is not able to maintain the limb abducted and the elbow forward.

In the first phase of the *upper cut test* [73], the patient keeps the arm in a neutral position, the elbow flexed to 90°, the forearm supinated, and the hand closed. The examiner opposes, by placing his/her hand over the closed hand of the patient, the attempt of movement similar to one that the boxer does when delivers a "hook". The test is considered as positive if, in the second phase, it provokes pain along the frontal surface of the arm (Fig. 22).

The *bear-hug* [17] and *O'Brien* [65] tests, already described for the evaluation of the anterior rotator cuff and for the differential diagnosis of acromioclavicular joint diseases, respectively, may show positive results even in the case of inflammatory or traumatic diseases of the long head tendon of the biceps.

To perform the *anterior slide test* [74] patient should stand with the hand of the affected side to the abdomen (the thumb looks backward). The examiner places a hand on patient's shoulder and the other hand on the elbow and exerts an axial pressure with anterior-superior direction from the elbow to the shoulder. The test is positive if provokes pain or articular click.

Kibler et al. [73] compared the diagnostic values of the tests for the biceps and they observed that the bear-hug and the upper cut are the most sensitive, while the belly-press and Speed's tests are the most specific. The upper cut is also

Fig. 21 Grind test. The examiner maintains the acromion with two fingers and with the other hand makes slightest movements of the clavicle in anterio-posterior direction

Fig. 22 Upper cut test. The examiner opposes, by placing his/her hand over the patient's closed hand, the attempt of a movement similar to one that the boxer does when delivers a "hook". The test is considered as positive if, in the second phase, it provokes pain along the frontal surface of the arm

the most accurate. The authors also found out that the combined positivity of "upper cut" and "Speed's test" reveals, more than the other combinations, a biceps lesion.

Glenohumeral Instability

The glenohumeral instability (traumatic or not, from overuse or congenital anatomical abnormalities) is usually a common disease among adolescent and young-adult patients. Those found in senile-adult age are often associated with a cuff tear [75]. It is debated whether the instability is the result of tendon tear, or if tendon tear is the result of excessive pathological offsets due to the shoulder instability. The elderly patient with instability clearly reports not having the normal control of the shoulder or episodes of dislocation, which are spontaneously resolved.

In my experience, in elderly patients a few tests to verify joint stability are sufficient: the drawer test, the relocation test, and the apprehension test to passive abduction and external rotation movement [76]. Tests to verify laxity is often unnecessary because such constitutional property tends to disappear over time because of physiological rigidity of the periarticular tissues.

During the execution of drawer test [77] the patient is sitting. The examiner, placed behind the patient, stabilizes the scapula with one hand (the left one when looking at the right shoulder) blocking the acromion, and the other hand moves the humeral head anteriorly and posteriorly. This test is difficult to interpret because in cases of marked forward instability, the humeral head may already be anteriorly dislocated; therefore, the excessive posterior translation is only the reduction of a chronic dislocation.

The *relocation test for anterior instability* [78] is performed with the patient in the supine position. The limb is moved passively in abduction and external rotation (elbow flexed to 90°). This position may cause apprehension and/or pain. Both apprehension and pain disappear if the examiner moves the humeral head posteriorly by exerting a pressure on the shoulder in the antero-posterior direction. The apprehension and/or pain reappear when the examiner stops the pressure. The apprehension test is more evident when it is performed with the patient in the sitting position.

In cases of multidirectional instability, the *sulcus sign* is positive. It consists of a depression, greater than the one in the stable shoulder, which is present between the acromion and the humeral head when the limb of the patient is simultaneously pulled downward and externally rotated. However, in cases of elderly patients with subcutaneous fat and inelastic skin, the interpretation of the examination can be difficult.

In conclusion, for clinical diagnosis of cuff tears, only few and focused tests are sufficient, especially when patients are very old. The range of motion should be evaluated first and then clinical tests should be performed by focusing on those less painful. Clinical history should be accurate. Patients, with their story, often provide elements that will enable the examiner to perform precise tests. Furthermore, the examiner's willingness to listen carefully to the patients will increase the trust they have already placed in their examiner.

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Differential Diagnosis

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Many patients affected by shoulder pain refer to an orthopaedic specialist suspecting a rotator cuff abnormality; most of them actually suffer other musculoskeletal disorders which may cause shoulder pain (Table 1, Fig. 1–3), but in some cases extra-orthopaedic pathologies may clinically cause shoulder pain indeed. Orthopaedic specialists should always remember extra-orthopaedic etiopathogenesis of shoulder pain, in order to include important systemic diseases into a complete differential diagnosis approach.

The aim of this chapter is to focus on specific and extra-muculoskeletal types of shoulder pain due to pulmonary, gastrointestinal or cardiovascular diseases characterized by shoulder clinical involvement (Table 2, Fig. 4). For each of these fields, we analyze clinical, laboratory and instrumental means favouring a correct diagnostic process.

Visceral Causes of Shoulder Pain

'Referred' pain is pain perceived at a location other than the site where a painful stimulus actually acts. The gallstone disease, hepatic cancer and/or abscess, peritoneal diseases, some iatrogenic situations (laparoscopy, hepatic biopsy, radiofrequency hepatic ablation), spleen traumas and adrenal metastases are the most relevant visceral causes of referred shoulder pain. Hepatic infectious or neoplastic processes as well as biliary colic are often accompanied by pain at neck, shoulder, scapula, clavicle and upper arm [1]. In all these cases, pain is related to normal anatomical features of diaphragm innervation [2], as well explained in several historic scientific articles:

> The diaphragm will suffer more or less by contact with the inflamed organ and through the irritation carried to it along the phrenic twigs of the liver; and so the influence may pass up the trunk of the phrenic nerve to the brachial, and even the cervical plexus, and thus the subclavius nerve and others may be affected, which may account for pain about the clavicle, and partly for that in the side of the neck and even in the arm [3].

> In this contest, filaments of the phrenic nerve penetrate the diaphragm and communicate with the ganglia that lie around the coeliac artery; other filaments are distributed to the muscles about the shoulder, and in this way has been explained the fact that disease or irritation of the liver is very apt to be accompanied with pain in the shoulder [4].

Right shoulder pain may be a symptom of the gallstones passage in association to epigastric and right hypochondrial pain, either in absence of heartburn or independent from severity of visceral involvement [5, 6]. During biliary colic specific laboratory parameters change, all serum bilirubin, alkaline phosphatise, γ-glutamil transpeptidase and, sometimes, both aminotransferases increase. The gold instrumental standard for diagnosis of gallbladder and biliary tract lithiasis is ultrasonography.

Indeed, when associated to respiratory movements and progressive clinical deterioration (weight loss and fever), right shoulder pain may be a satellite of hepatic cancer or abscess [7].

Table 1 Orthopaedic causes of referred shoulder pain

Orthopaedic disease causing referred shoulder pain
Cervical spine radiculopathy
Cervical disc herniation (Fig. 1)
Cervical spine stenosis
Congenital abnormalities of the cervical spine
Supernumerary vertebra (Fig. 2)
Cervical spine vascular malformation
Cavernoma (Fig. 3)

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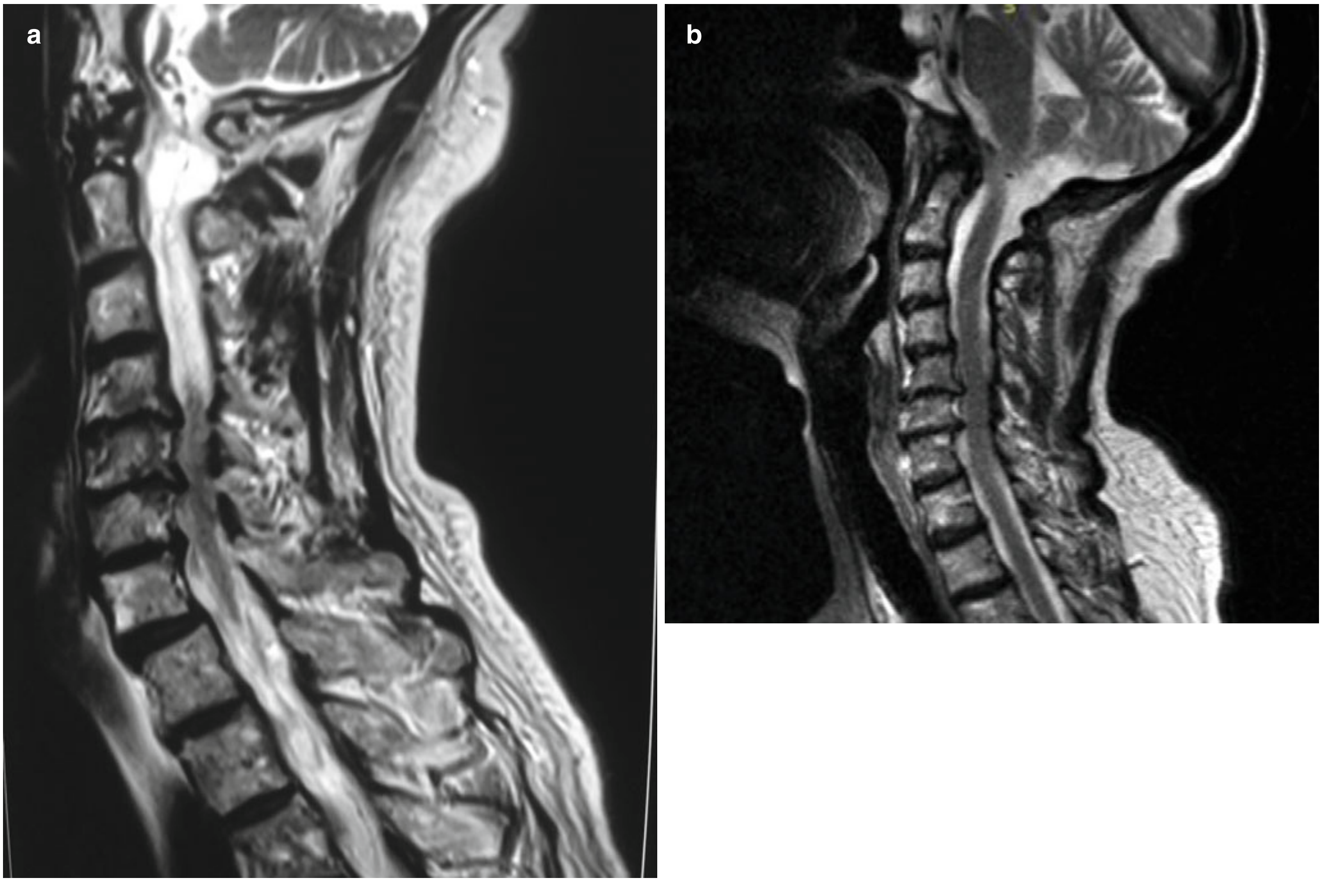

Fig. 1 (**a**, **b**) MRI (sagittal plane) of the cervical spine showing multiple disc herniations and osteophytes

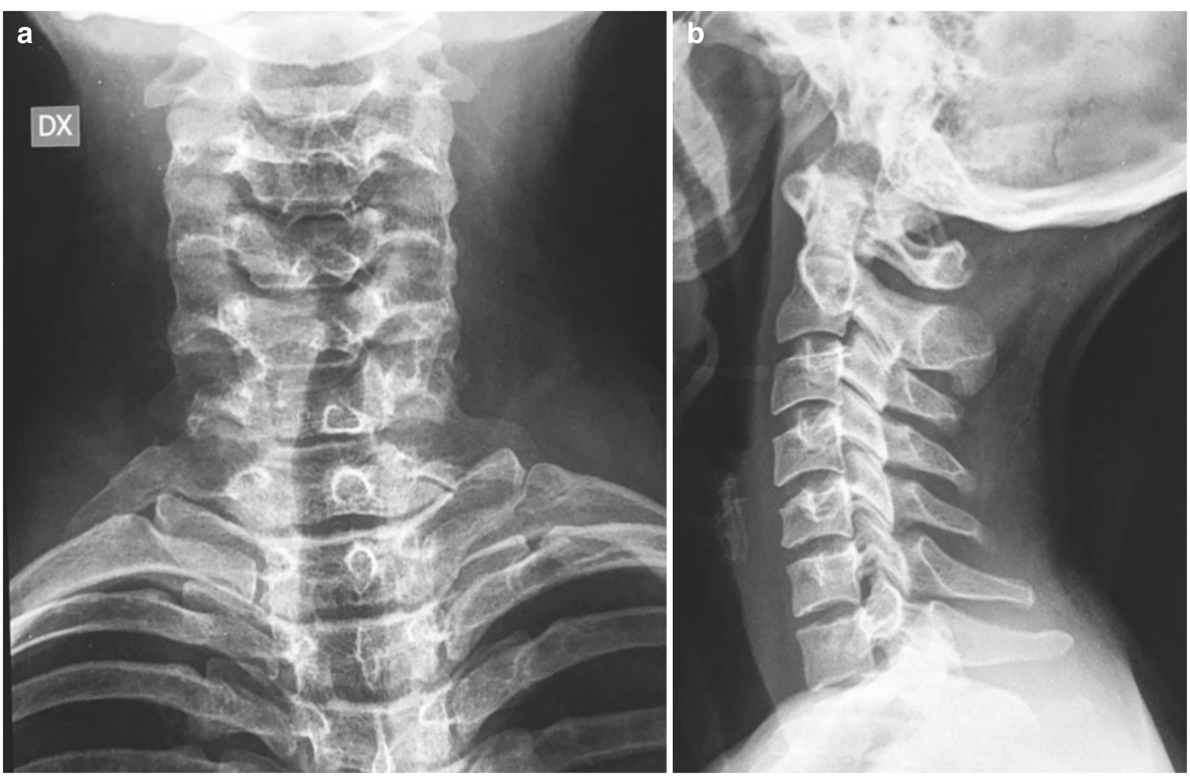

Fig. 2 X-ray of the cervical spine in antero-posterior (**a**) and lateral (**b**) views showing the presence of a supernumerary C7 vertebra

Fig. 3 MRI (sagittal plane) of the cervical spine showing a cervical cavernoma

Moreover, laparoscopic surgery (cholecystectomy in particular) often causes right shoulder scapular pain during postoperative period, accompanied by nausea, vomit and abdominal pain. Probably due to residual pneumoperitoneum, the mechanism that exactly determines this pain in not yet clear [8]: it may be caused by neck and shoulder irradiation of diaphragm irritation from CO_2 peritoneal conversion to carbonic acid (H_2CO_3) [9].

Pain is the more frequent complication of liver biopsy. It occurs at bioptic site as well as at right shoulder, so that the severity or the worsening of pain may be a spy of bleeding or subcapsular hematoma [10].

When hepatocellular carcinoma is treated by percutaneous radiofrequency ablation, such a procedure may be complicated by diaphragmatic oedema and thickness with consequent referred shoulder pain [11].

Spleen traumatic breakage should be suspected when left hypochondrial pain is irradiated to homolateral shoulder (Kehr's sign) [12]. As well, such a symptom may relate to haematological spontaneous rupture of spleen [13, 14].

For all the above-mentioned abdominal visceral situations (hepatic bleeding, residual pneumoperitoneum or splenic rupture), the integration between instrumental (abdominal ultrasonography and CT) and laboratory exams often provides diagnostic information so as to dispatch the patient to the specialist as soon as possible [15].

Table 2 Extra-orthopaedics causes of referred shoulder pain

Visceral diseases
Diaphragmatic irritation from:
Biliary disease
Blood or gas in peritoneal or pleural cavity
Splenic trauma
Adrenal metastases
Cardiovascular diseases
Angina pectoris/myocardial infarction, or both
Pericarditis
Aortic dissection
Pulmonary embolism
Pulmonary diseases
Apical lung cancer (Pancoast's syndrome)

Cardiovascular Causes of Shoulder Pain

Irradiation of cardiac pain to upper arms and shoulders is a typical example of referred pain [16]. Several physiopathological mechanisms have been purposed in order to explain this phenomenon, but no conclusive consensus has been obtained yet. Locating their cell bodies into the dorsal thoracic ganglia T1-T5, cardiac visceral sensory fibres follow the dorsal sympathetic chain. The central nervous system receives sensory cardiac pain information from thoracic somatic spinal cord segments between T1 and T5. Nevertheless, dermatomers of chest wall and upper arm are coupled to fibres having their cell body into the same dorsal ganglia (T1-T5) whose sensory cardiac fibres synapse. As a consequence, the central nervous system is not capable to clearly recognize if stimulus comes from body wall rather than viscera and perceives painful information from substernal region, left upper arm and/or jaw.

The most common cardiological causes of shoulder pain are myocardial ischemia [17, 18], pericarditis, aortic dissection and pulmonary embolism. Among them, the first is surely the most important.

When associated to myocardial ischemia, pain is usually perceived in the middle of chest and substernal, even if every zone between epigastrium and lower jaw or teeth. It usually radiates to neck, interscapular region or left shoulder/upper arm (sometimes bilaterally, especially to ulnar surface). The patient describes it as oppressing, thick, sometimes constricting and burning. Pain intensity varies among patients, either potentially absent (elderly patient or diabetes) or substituted by fatigue, dyspnoea or syncope. In case of stable angina, pain is usually brief (less than 20 min, typically 5–10 min), follows emotional or physical stress and promptly relieves

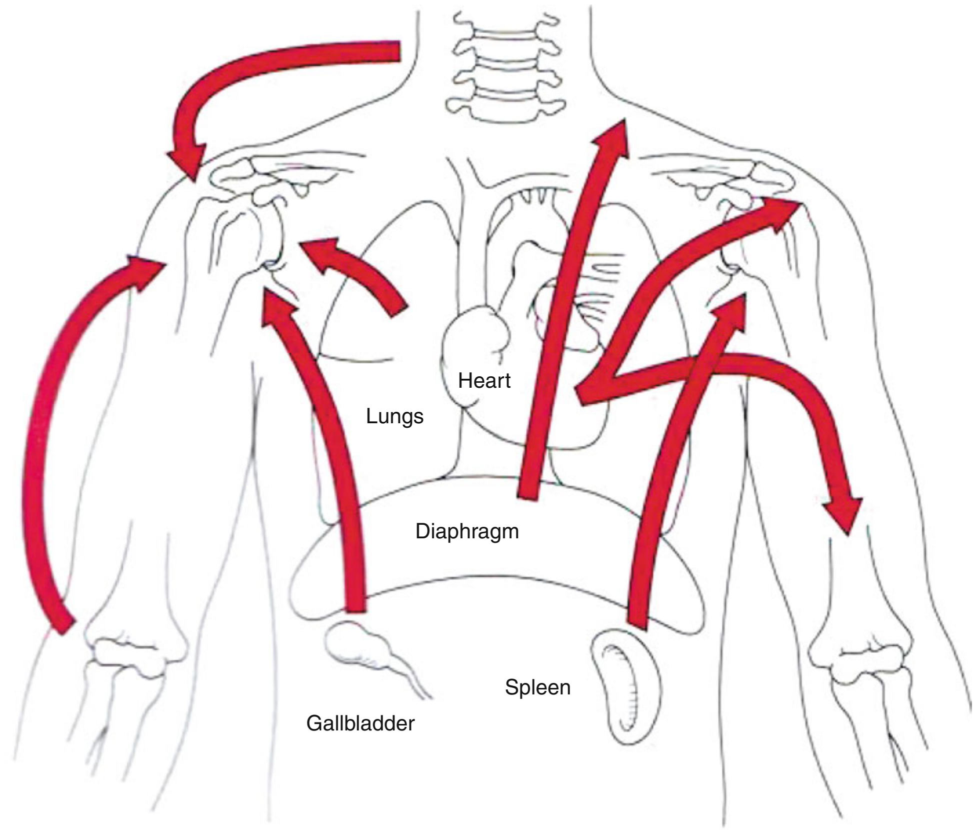

Fig. 4 Sites of referred visceral shoulder pain

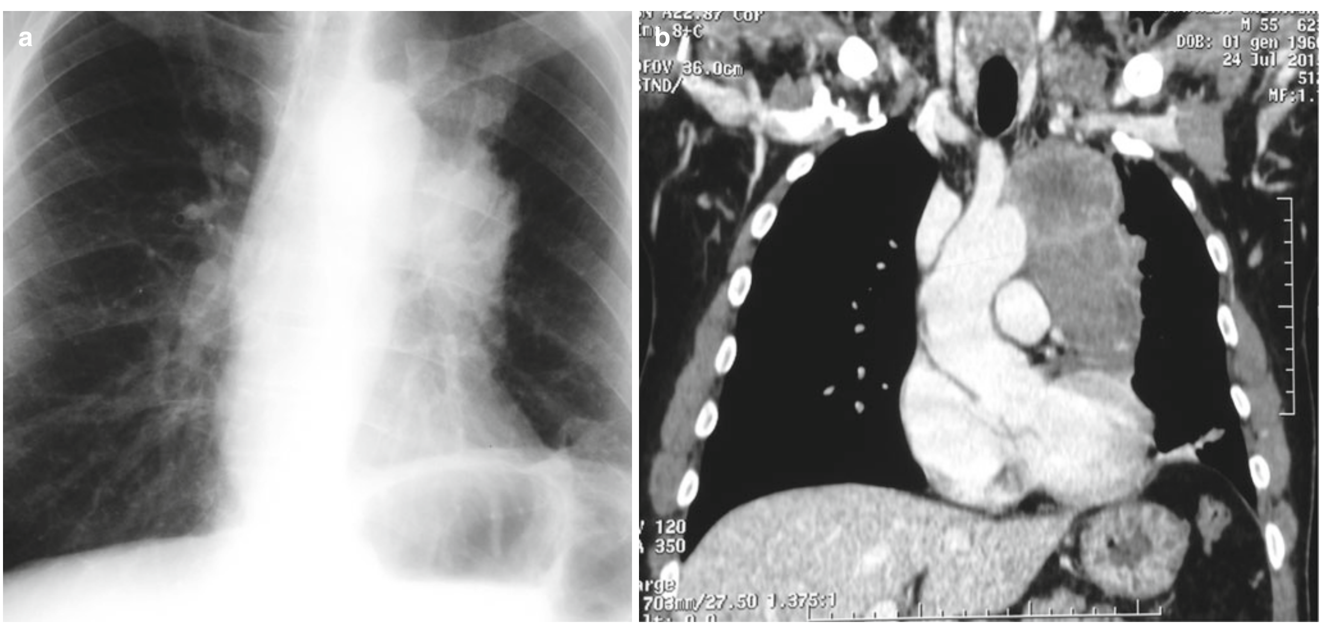

Fig. 5 X-ray in AP view (**a**) and CT (**b**) of the chest showing a left Pancoast's tumour

with rest or nitrates assumption. Pain of angina appears to be not influenced by arm movements, posture or respiration.

In acute coronary syndrome (ACS) from instable angina and/or myocardial infarction, pain increases at rest, lasts more than 20 min (intermittent or persistent) and does not relieve by nitrates; it is often accompanied by autonomic signs/symptoms (sweating and nausea/vomit) or death sensation. Diagnosis of myocardial ischemia is corroborated by the co-

Fig. 6 A 46-year-old female with right Horner's syndrome (ptosis, miosis and anhidrosis)

existence of risk clinical factors (diabetes, renal insufficiency, coronaropathy, peripheral vascular diseases) and confirmed by electrocardiogram (ECG), echo-cardiogram and specific laboratory tests (T troponine, CPK), resulting the submission to a cardiologist always mandatory in all these cases.

In pericarditis, chest pain is typically exacerbated by inspiration and particular postures (supine or left lateral decubitus); clinical setting often includes fever, leucocitosis, increase of PCR, VES and cardiac enzymes. ECG shows specific alterations.

In aortic dissection, pain is acute, stinging and moves along with dissection; retrosternal in proxymal dissections, pain becomes interscapular or dorsal in distal dissections.

Thoracic pain of pulmonary embolism may be due to pleural irritation by occlusion of peripheral arterial branches, or angina-like retrosternal. Dyspnoea, hypoxiemic tachypnoea, cough, hemoptysis and clinical signs of deep venous thrombosis usually define the clinical setting.

Pulmonary Causes of Shoulder Pain

Pancoast syndrome has many inflammatory and neoplastic causes, due to the expansion of pathological tissue into the pulmonary apex (superior sulcus tumours) (Fig. 5a, b); the classic presentation is pain along the C8–T2 dermatomes, weakness and atrophy of the intrinsic muscles of the hand and Horner's syndrome (ptosis, miosis and anhidrosis) (Fig. 6).

These tumours are mostly non-small-cell lung carcinomas (NSCLC), with adenocarcinomas slightly more common than squamous carcinomas. Pancoast tumours are rare, and constitute less than 5 % of NSCLCs. Notably, a wide variety of other entities can also cause Pancoast syndrome, including aspergillosis, tuberculosis and lymphoma. In some patients, the diagnosis of Pancoast syndrome is determined by intense shoulder pain associated to history of smoking, weight loss and subsequent neurophysiological evidence of lower brachial plexopathy. Although Horner's syndrome is classically considered a hallmark of Pancoast syndrome, it should be remembered that its prevalence in published case series is quite variable, ranging from 4 to 64 %. Conversely, shoulder pain and arm pain or 'brachialgia' can be relatively common presenting complaints, ranging from 19 to 65 % in the same series. As such, many patients have exhaustive rheumatological and orthopaedic evaluation and present confounding symptoms, leading to delays in diagnosis of up to 7.5 months. Red flags for a more sinister process included the lack of an inciting trauma, the progressive nature of the pain and muscular atrophy and the persistence of pain despite numerous interventions. It is highly likely that part of shoulder pain is due to referred irritation of the parietal pleura and that the subsequent brachial plexopathy merely represent progression of the Pancoast tumour instead of being its true original presentation. MRI remains the imaging modality of choice for diagnosing a superior sulcus tumour. Data on the diagnostic utility of EMG/NCS in Pancoast syndrome are less exhaustive: the EMG/NCS findings coupled with the patient's clinical symptoms often provide clear evidence of a lower brachial plexopathy.

Far from being exhaustive, this chapter may be an attempt to remind the orthopaedic surgeons that some patients may consult them in a potentially wrong clinical overview. Each possible cause of shoulder pain must be known by the expert, especially when clinical setting appears not to be promptly clear.

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Instrumental Evaluation: X-Rays, MRI

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Using diagnostic imaging for the evaluation of the rotators cuff disorders is crucial to the assessment of the clinical conditions of the patient.

Among the different exams, traditional radiology and MRI have a fundamental role in the identification of problems to the rotators cuff [1].

Traditional radiology gives an indirect evaluation of the rotators cuff tear, according to radiopacity of the soft tissue inserted between the bone structures and gives us the possibility to highlight the skeletal characteristics of the joints that characterize the tendinous sliding space.

In particular, the radiological exam defines morphology and surface characteristics of the acromion: tilt, ratio with the other structures of scapula and humeral head, and gives us the possibility to assess the osteoarthritis degree [2, 3] (Fig. 1).

In fact, we all know that a reduction of the joint space between acromion and humeral head and between acromioclavicular joint and humerus causes an impingement of the soft tissues creating a mechanical insult, most of the time responsible of the tendinous tear.

Traditional radiology allows us to evaluate the tissue characteristics of soft tissues, including the presence of possible calcifications and the characteristics of the skeletal district we are examining, and especially the aspect of the acromion, the bone tuberosity of the humeral head, the sclerosis of the greater tuberosity of the humerus and its following curvature (supraspinatus weakness that allows the head to go back up), the identification of vacuolar degenerating cists, the return of the humerus head, and concurrent acromioclavicular arthritic deformation [4].

The evaluation of morphology and skeletal characteristics is given by an adequate radiological exam.

There are many different projections able to define the bone characteristics of the shoulder, but the most valuable and substantial for the assessment of the rotators cuff pathology, included in the radiological protocol of the shoulder, are mainly 4:three anteroposteriors and one outlet view.

In the anteroposterior projection, it is very important to abide by the position of the patient and the upper limb.

In fact, in the starting anteroposterior projection, defined as real anteroposterior or else "zero starting position" (ZSP), the upper limb of the patient lays along the side [5].

This is how we acquire the real AP (anteroposterior) projection, valuable in the detection of all the angles.

The anteroposterior radiogram acquisition technique in orthostatic ZSP provides for:

The incidence ray that must fall about 2 cm away from the coracoid process with a craniocaudal tilting angle of 20–30° (depending from the anatomy of the patient), by the glenohumeral joint line spacing.

The patient is then turned by a 45° angle with the scapula leaning against the radiographic coil (Fig. 1).

This radiogram must include the proximal third humerus, the glenohumeral joint, the coracoid, the clavicle, and the acromial-clavicle joint.

In this position, without any changes in the patient as well, we also carry out the following intra- (Fig. 2a) and extra-rotation projections (Fig. 2b) of the upper limb, with the movement of the upper limb alone, in abduction as well as in adduction.

Such projections better define the characteristics of the radiologic semeiotic of the humeral tuberosity of both tubercles and the glenoid and acromion outline and allow the assessment of possible calcifications that lie on the bone surface of the humeral head.

The fourth projection used in the assessment of a suspect rotators cuff lesion is the outlet view projection, which is able to better show the tendinous sliding space of the cuff itself and the morphological characteristics of the acromion [6].

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The outlet view projection helps also to better assess the skeletal characteristics of the joints in the acromioclavicular glenohumeral space (Fig. 2c).

We obtain it in orthostatic position with the patient standing by the radiologic table in a slanting anterior position with the involved limb laying against the radiological table in a 45° angle and a craniocaudal incidence of about 15–20° of the incidence beam. The central incidental beam must point on the passing area of the supraspinatus tendon "defilè", under the acromion process.

Fig. 1 X-ray of a left shoulder in true AP view. Oblique glenohumeral radiogram in indifferent position of the limb – zero starting position (ZSP). Normal position of the acromion. District radiopacity of the great tubercle of the humerus

The arm of the patient lies along the side of the body, in neutral position.

This way, we create a "y" with the bone base made of the glenohumeral joint, the roof made of the acromioclavicular joint and medially by the coracoid (Fig. 3).

The radiological assessment highlights the bone characteristics of the district under examination, and especially the humeral bone tuberosity, the acromion surface, and the real extent of the sliding space of the rotators cuff, normally ranging between 12 and 14 mm [7].

In fact, the causes of impingement are often associated with a skeletal deformation and the morphology of joints.

Traditional radiology cannot define the extent of a total or partial lesion of the rotators cuff, nor can it give information on the extent of degeneration, but it certainly is fundamental in defining the tendon's sliding space, the presence of calcifications or osseous calcified metaplasia and the extent of any bone deformation, often associated with phenomena of bone degeneration. In international literature, they speak of a high incidence of total lesions in the elderly caused by the high degree of arthritic bone deformation [4].

A minor bone damage is associated, instead, with partial lesions of the rotators cuff.

Among the crucial skeletal factors able to help the assessment of a tendinous degeneration that could induce partial or total lesion for the rotators cuff, three are considered responsible: the acromion, the humerus head and its tuberosity, the deformation of acromion clavicle joint on its humeral plane.

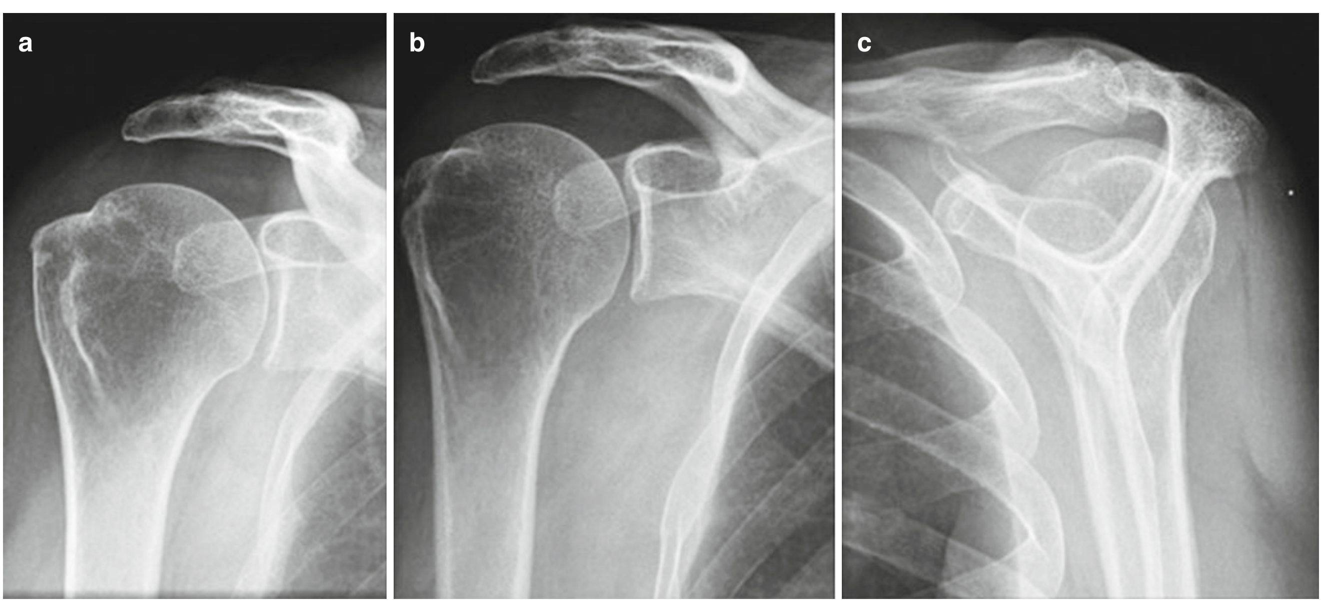

Fig. 2 X-rays of a right shoulder: (**a**) AP in intra-rotation of the limb with the beam etching on the glenoid surface. (**b**) AP view obtained with the arm in external rotation position. (**c**) Outlet view. The X-ray shows the reduction of space between acromion, humeral surface, and the acromioclavicular joint

Important role have also the characteristics of the acromion, such as shape, slope, anomalies of the joint surface on the glenohumeral side (rough undersurface of the acromion).

Up to now, international literature acknowledges Bigliani classification as fundamental in the evaluation of acromial morphology [7, 8]:

1. Flat
2. Curved
   Parallel to the humeral head with concave undersurface (considered most common type [3])
3. Hooked
   Most anterior portion of the acromion has a hooked shape. This form is considered associated with increased incidence of shoulder impingement.

According to the acromion slope against the glenoid, different authors give different possible measurements that could predict a partial or total lesion of the rotators cuff, according to the value obtained [6, 9].

Among them all, we will take into consideration, according to the most recent international literature, the acromial index (AI) and the critical angle [10–12].

Fig. 3 Outlet view: the X-ray of a right shoulder shows a good profile of acromion surface and Y shape

Such measurements have been taken radiologically either in the real AP projection or in the ZSP.

Some authors have suggested using the same measures taken with the magnetic resonance imaging (MRI) on the coronal plane and with the CT scan, on the reconstruction coronal plane [13, 14].

Parallel studies have confirmed that these offer a major radiological accuracy, compared with the other two radiological techniques.

The AI measurement represents a radiological index that evaluated the lateral extension of the maximum acromial profile, responsible for the impingement and following lesion of the rotators cuff.

Authors such as Nyffeler et al. agree that if Ai value is greater than 0.7 a cuff tear is present. Higher the index is, more complex the rupture will be (Fig. 4).

AI absolute value is obtained calculating the difference between glenoid and acromial lateral tip, obtained drawing

Fig. 4 True AP, zero starting position (ZSP) X-ray of a left shoulder. Evaluation of the acromion index (*AI*) by perpendicular lines of the shoulder, through the distance from the joint surface of the glenoid and the lateral edge of the acromion (*GA*) divided by the distance between the glenoid and the maximum lateral edge of the greater tubercle of the humerus (*GH*). In this case, the value >0.7 suggests a tear

Fig. 5 True AP, zero starting position (*ZSP*) X-ray of a left shoulder. The value of the acromial index (*AI*) is <0.7 meaning negative condition for a cuff tear

one perpendicular line on the glenoid and one parallel to the first and perpendicular to the acromial tip, defined as GA [11].

The value obtained is then divided by another absolute value calculated in the distance between the line perpendicular to the glenoid and an equal parallel line, perpendicular to the lateral border of the greater tuberosity of the humerus, defined GH.

The difference between GA/GH gives the value AI which, if >0.7, preannounces a higher risk of lesion of the rotators cuff (Fig. 4 and 5).

Lately, however, we started to prefer another measurement, which certainly means the rapture of the rotators cuff.

And this, also, is calculated on the real AP or ZSP radiograms.

We are talking of the critical shoulder angle CSA, acknowledged as a valuable evaluation of a possible tendency to a tendinous lesion of the rotators cuff, against a more external position of the acromion and the slope of the glenoid.

The measurement is taken drawing a line perpendicular to the glenoid and a second one starting from the lower edge of the glenoid and ending to the farthest sideline of the acromion, creating an angle defined CSA, where the values higher than 35° suggest a greater incidence of rotators cuff rapture (Fig. 6). Instead, values lower than 30° (Fig. 7) are more common in presence of osteoarthritis of the glenohumeral joint [12, 14].

Such value is always associated to greater AI values.

Bouaicha et al. suggested comparing CT scans and X-rays to define such values and have demonstrated that there is a strong correlation between the values obtained with the CT scan and those calculated through a real AP of the CSA [12].

A third measurement is the lateral tilt of the acromion (LTA) or the lateral acromial angle (LAA).

Banas et al. believe that the most external position of the acromion is connected to the insertion of the deltoid, which can tend to give a more cranial position of the humeral head, with a greater incidence of reduction in the acromial humeral distance and an increase of impingement in the abduction movements of the arm. The same author has also suggested measuring the lateral tilt on the slanting coronal plane in an MRI [12].

As the majority of authors, we prefer the LTA measures taken on the ZSP radiogram [14] as well.

Such value is calculated drawing a line perpendicular to the glenoid and another one parallel to the humeral surface of the acromion, creating a lateral tilt angle, where values lower than 75° mean higher tendency to the rapture of the rotators cuff (Fig. 8a, b).

Such value is also always associated to a higher AI value.

Fig. 6 X-ray in zero starting position (ZSP) of a left shoulder. The critical shoulder angle (CSA) is a valuable indicator of the degenerative rotator cuff disease. The measurement is obtained drawing a line parallel to the glenoid surface and another one starting from the lower edge of the glenoid bone and going to the maximum lateral extension of the acromion. The value >30–35° is indicative of rotator cuff degeneration/tear

A LAA lower than 70°, a more lateral extension of the acromion, and a CA higher than 30–35°, a high AI value, connected to a more external position of the acromion, are associated to a higher possibility of impingement and lesion of the rotator cuff.

MRI

Magnetic resonance imaging (MRI) is an assessing technique on the matter based on the processing of the spin of protons of other nuclei presenting a magnetic moment, when they undergo a magnetic field. It was discovered independently in 1946 by the physicists Felix Bloch and Edward Purcell who received the Nobel Prize in 1952 for it. Studies were carried on by Paul Lauterbur and Peter Mansfield to develop the technique, and for this reason, they also received the Nobel Prize in 2003. The fields of application of the magnetic resonance are many: medicine, chemistry, petrophysics, etc. In the medical field, it is mainly used for diagnostics. The density signal is given by the atomic nucleus of the element under examination.

Fig. 7 X-ray in true AP view of a right shoulder. The critical shoulder angle (CSA) in a young athlete with pain on his right shoulder is <30°

The multi-parametric effect of the MRI allows the direct characterization of tissue, while the multiple plane effect allows the direct visualization of an anatomic segment on different planes.

The main application of MRI in traumas of the shoulder and upper limbs is the assessment of lesions to the soft tissues and of joint and intraspongious damages. There are many causes to shoulder pain, and most of them start from pathology of the rotators cuff or instability [15–17].

The most common indication of MRI in the painful scapulohumeral pathology is the study of patients with a suspect tear of the rotators cuff or presenting an impingement [18–23].

The rotators cuff gives 33–50 % of the muscle strength needed for the abduction, and 80–90 % of the one needed for the external rotation [24, 25]. Zlatkin [20] classified the etiology of rotators cuff tears as extrinsic (impingement, impingement with instability, subcoracoid impingement) and as primary degeneration of the cuff, which can also have an ischemic nature. Bone anomalies or anatomic variations of the coracoacromial arch,

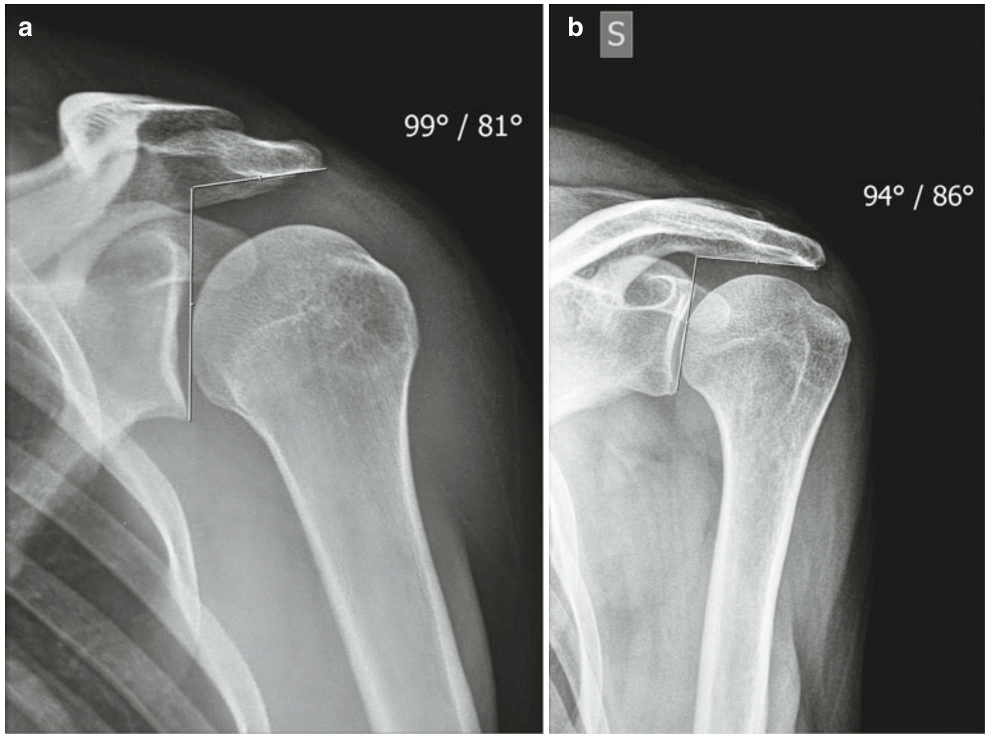

Fig. 8 (**a**, **b**) X-rays in true AP view of a left shoulder for lateral tilt angle. Lines are drawn on the inferior acromial surface and on the joint surface of the glenoid bone

ligaments or soft tissue anomalies inside the arch can determine impingement. Even traumas can be associated to the tear of the rotators cuff.

The majority of tears of the rotators cuff starts from the anterior portion of the supraspinous by the insertion of the great tuberosity of the tendon of the long head of biceps [26]. In the more wide or extensive tears, other components of the rotators cuff can have a major role. The tears of the rotators cuff increase with aging [27].

The rotators cuff tears can be classified as partial or total. The criterion that specifies a partial lesion from a complete one is the presence or absence of communication between the subacromial-subdeltoid bursa and the glenohumeral joint. The majority of tears of the rotators cuff interest the supraspinatus muscle tendon: more than 89 % of the partial tears and 47 % of the full thickness ones [28].

Many studies showed that fast spin-echo sequences (or turbo spin-echo) [FSE (or TSE)] are equivalent to conventional spin-echo. Sonin et al. demonstrated a 100 % correlation between the sequences T2-weighted and T2-weighted TSEs in the evaluation of rotator cuff integrity, as well as an increase in the signal to noise ratio in TSE sequences. They also showed sensitivity higher than 89 %, a specificity of 94 %, and an accuracy of 92 % in diagnosing rotator cuff full thickness lesions [28]. It is possible to obtain TSE sequences images with thinner layers in order to obtain less motion artifact and finally reduce acquisition time compared to conventional IF sequences [29]. Fat suppression or saturation signal (FAT-SAT) improves the contrast of soft tissues because it eliminates the artifacts from chemical shift taking place at fat–water interface and reduces artifacts from breathing. Singson et al. [32] have shown in the diagnosis of full-thickness rotator cuff injuries that the use of FSE T2-weighted sequences has optimal results both with and without fat suppression signal, while partial tears are better demonstrated using fat suppression sequences. Some authors have proposed a sequence of short Tau inversion recovery (STIR) with an inversion time reduced from 110 to 150 ms, which allows a more homogeneous (non-selective) fat suppression signal and improved signal/noise ratio [30, 31]. Kijowski et al. [33] showed equivalence between STIR and FAT-SAT FSE T2-weighted sequences in assessing rotator cuff integrity.

Studying suspect tears of the rotators cuff, we need to evaluate cuff's damage and the surrounding structures; MRI should analyze the extent of the tear, the degree of damage of the tendon, the tendon's edges, the muscle withering and the bone's alterations (the kind of acromion, the presence or absence of the acromial bone, the degeneration of the acromial-clavicle joint).

Partial Thickness Tears

The partial tears of the rotators cuff have been classified with the MRI [15] according to the depth or vertical thickness of the affected tendon as: (a) I degree (<3 mm in depth), II degree (between 3 and 6 mm in depth), and III degree (>6 mm in depth). It is important noticing that the thickness (craniocaudal diameter) of the supraspinous tendon is about

12 mm. Furthermore, the partial lesions can be divided according to the site of interest in: (a) superficial lesions (28 %) (which interest only the bursal plane) (Fig. 9) intralaminar (or intratendinous) (Fig. 10a, b) (more than 50 % of the partial lesions) characterized by the complete absence of communication with the joint or bursal plane (33 %) (Fig. 11) (c) when they interest the joint surface (Fig. 12) and (d) when they interest both joint and bursal surfaces (39 %) [31].

Conventional MRI is less perceptive and less accurate in the assessment of partial tears [32–34] ultrasound (US) and conventional MRI have pretty much the same usefulness in the identification of partial tears [35].

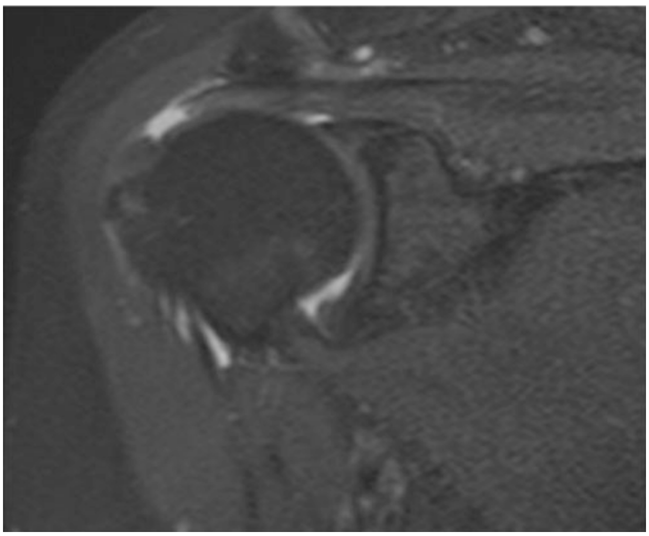

Fig. 9 MRI image in coronal STIR showing a partial lesion of the supraspinatus tendon on the bursal side

The MRI study of the scapulohumeral joint uses a protocol that includes multiple plane T1-weighted sequences, for the better spatial resolution needed to characterize anatomy and T2-weighted sequences both with and without fat suppression signal for the better tissue contrast resolution between the signal of solid structures and fluids; the weighted sequences in protonic density (PD) show the soft tissue under examination as an intermediate signal intensity

Fig. 11 MRI image in coronal STIR: the *red arrow* shows a complete lesion of the supraspinatus tendon with retraction of the proximal belly and pseudo-osteoarthritis (stage III)

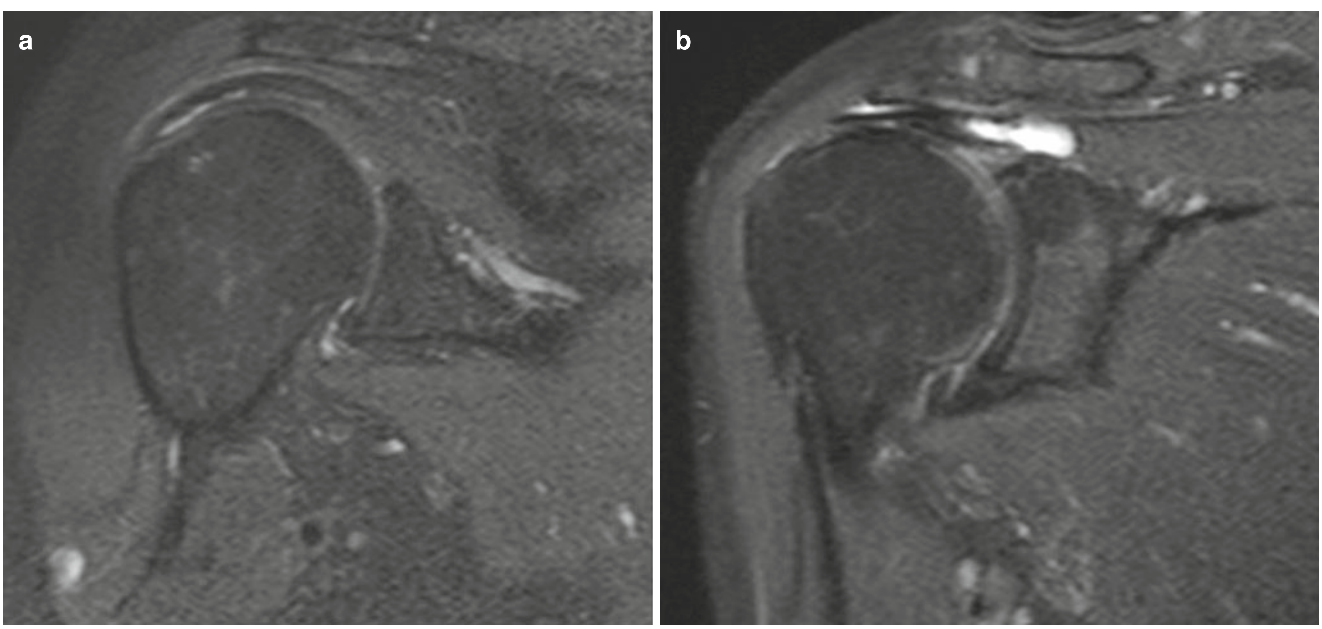

Fig. 10 Intralaminar lesion of the supraspinatus tendon. (**a**) MRI (coronal STIR) image; (**b**) pseudo-cyst in the myotendinous junction secondary to the intralaminar lesion of the supraspinatus tendon

between the sequences T1 and T2-weighted; weighted sequences in gradient-echo (GE), instead, seem to be very useful in the study of the chondral planes [36].

Despite the multiple parameters used in the MRI study, the diagnosis of tendons' lesions is still complex, especially if it presents poor joint spill, granulation tissue, or scars in the tear site [37, 38].

Tears extending onto the articular surface appear as focal intermediate signal intensity areas in proton density (PD) sequences, showing an increase of signal intensity on T2-weighted sequences. TSE sequences with signal suppression in STIR sequences or T2-weighted fat make it a much more obvious injury. However, the diagnosis is more difficult if there is a low amount of joint effusion or otherwise granulation tissue or scar at the site of rupture.

The MRI is the technique chosen if we suspect a diagnosis of possible partial tears that could extend to the joint surface [39–41]. Recent studies, in fact, have demonstrated the use of this acquisition in abduction and external rotation (ABER). Such acquisition mode of the exam allows a better identification of the joint portion of the rotators cuff, a better view and grading of the partial supraspinous tendon's lesions on the joint plane, in some cases negative to the exam carried out with a standard MRI [42].

The partial bursal tears can be difficult to diagnose if there are no fluids in the subacromial bursa.

In the images T2-weighted with fat suppression signal, they present the same characteristics of the tears that extend to the joint plane (Fig. 12) [42].

Intralaminar tears that do not communicate with the tendon's surface appear as linear images with a high-intensity signal that increases from the PD images to the T2-weighted. The intratendinous partial lesions appear as well defined hyper signal linear areas in the images T2 and T2 fat suppressed, without any communication with the joint and bursal space.

Rafii et al. [43] reported a sensitivity of 84 and 89 %, a specificity of 85 % for the diagnosis of partial lesions with conventional MRI. Reinus et al. [44] demonstrated a lack of sensitivity of MRI in the diagnosis of partial lesions (from 19 to 57 %) and has also shown that there is little interobserver agreement in the diagnosis of partial lesions or tendinosis/tendinopathy [38, 45–48].

The reason for poor results in the identification of partial lesions by MRI is not yet clear, reflecting its inability in distinguishing areas of increased signal due to tendonitis/tendinitis arising from partial tears [49]. Rafii et al. pointed out a lack of signal hyperintensity in T2-weighted sequences at the level of injury in 50 % of partial tears.

Authors noted that the lesions of bursal surface were often superficial and could be interpreted as partial tendon degeneration or as lesions, while partial intralaminar lesions can appear as fissures within a tendon degenerated or infiltrated areas or replaced by connective tissue, demonstrating intermediate signal intensity [50].

The different results obtained in literature on the identification of partial lesions by MRI can, in part, be attributed to the different criteria used in various studies. Information regarding the horizontal component of partial lesions is useful for determining the extent of injuries and the surgical plan [51].

Full Thickness Tears

In the complete or full thickness tears, the subacromial-subdeltoid bursa and the glenohumeral joint cavity communicate [52, 53]. These tears include 10 % of all the lesions of the rotators cuff. According to the localization, they can be divided into: (a) lesion of the free margin of the tendon, in contact with the tendon of the long head of brachial biceps (lhbt); (b) intratendinous; and (c) massive. Furthermore, there are many different classifications of the full thickness tears, according to dimensions (or extent) [53] as: (a) small or I degree (<2 cm) (Fig. 13), big or II degree (between 2 and

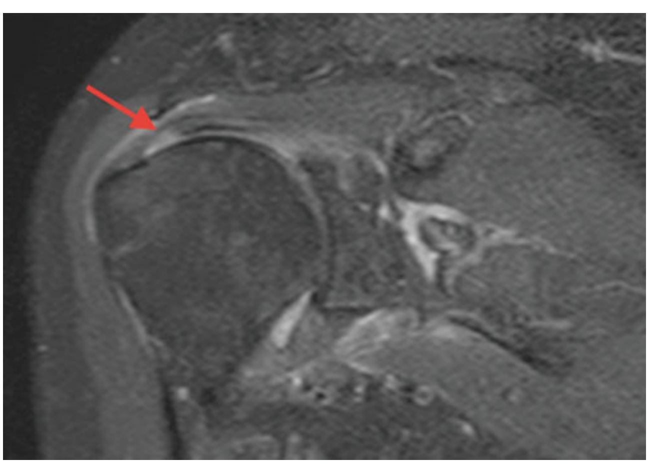

Fig. 12 MRI image in coronal STIR showing an Ellman II degree lesion on the articular side of the supraspinatus tendon (*red arrow*)

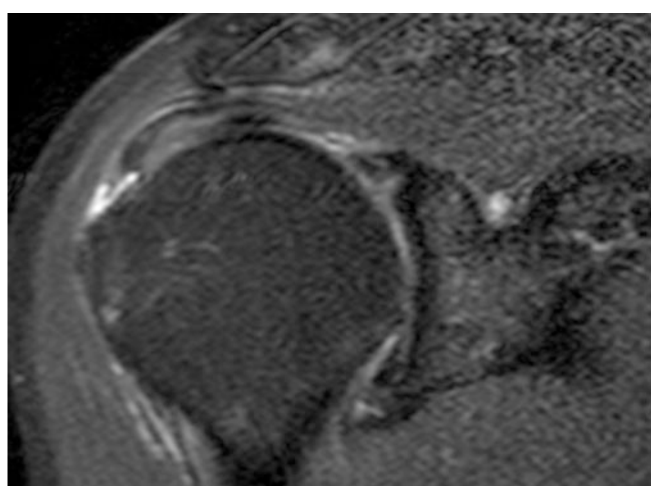

Fig. 13 Coronal STIR image of a I degree complete lesion of the supraspinatus tendon

4 cm) (Fig. 14 and 15), massive or III degree (>5 cm) (Fig. 16), and IV grade, when they determine secondary arthropathy (Fig. 17).

The size of full thickness tear can be measured by T2 images in fat suppression on the coronal and sagittal planes.

Besides the extent of the lesion, in complete tears it is important defining also the entity of the tendinous retraction. The retraction degree of the supraspinous tendon can be assessed on the oblique coronal plane. According to the degree of tendinous retraction, the tear of the rotators cuff can be classified in stage (or level) I, when the retracted tendon is inside the tear site, stage II, when the retracted tendon is by the humeral head and stage III, when it is by the glenoid (Fig. 18a–c) [54].

The conventional MRI is able to diagnose the majority of full thickness tears of the rotators cuff. The axial images (T1 and T2 weighted) and oblique coronal (TSE weighted with fat suppression PD and T2) allow the identification and classification of the rotators cuff tears. Usually, the ABER projection is not necessary for medium large or large full thickness tears.

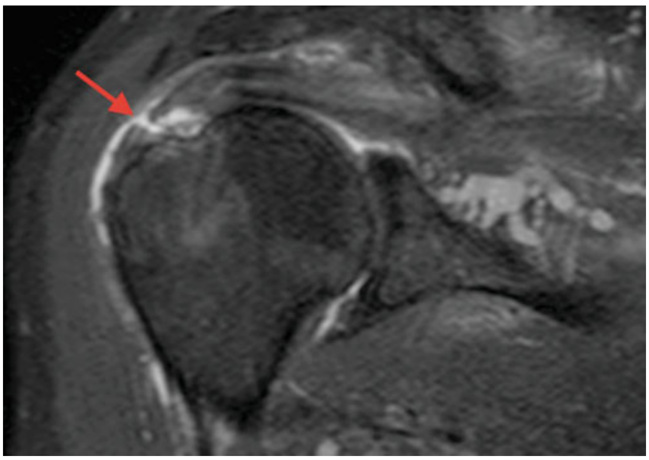

Fig. 14 Coronal STIR image of a II degree complete lesion of the supraspinatus tendon (*red arrow*) with bursal effusion

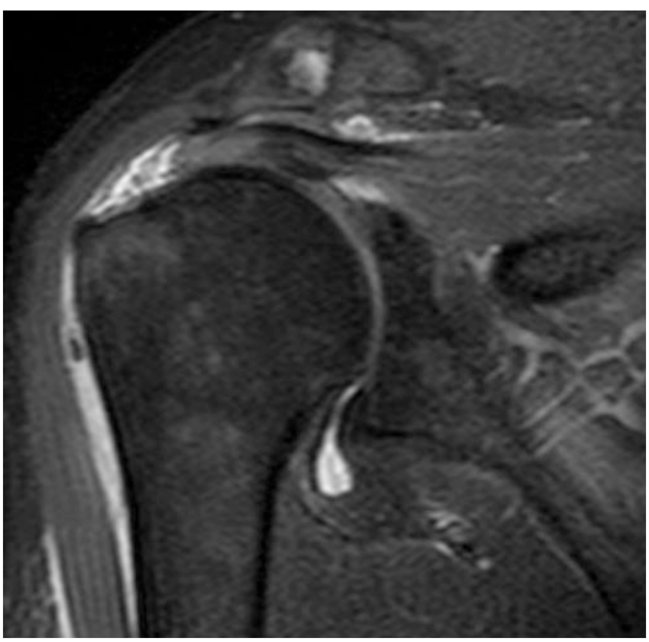

Fig. 15 Coronal STIR image of a III degree complete lesion of the supraspinatus tendon with bursal and articular effusion; the tendon is thickened and hyperintense, as for degenerative tendinosis

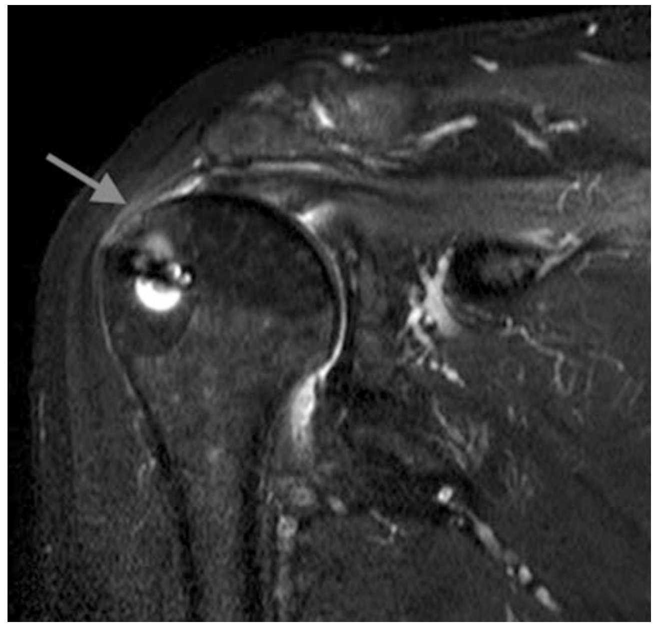

Fig. 16 MRI image showing massive lesion of the supraspinatus tendon after surgical repair with proximal retraction (*gray arrow*)

Fig. 17 Massive cuff lesion with osteoarthritis (*red arrow*) between humerus and acromion

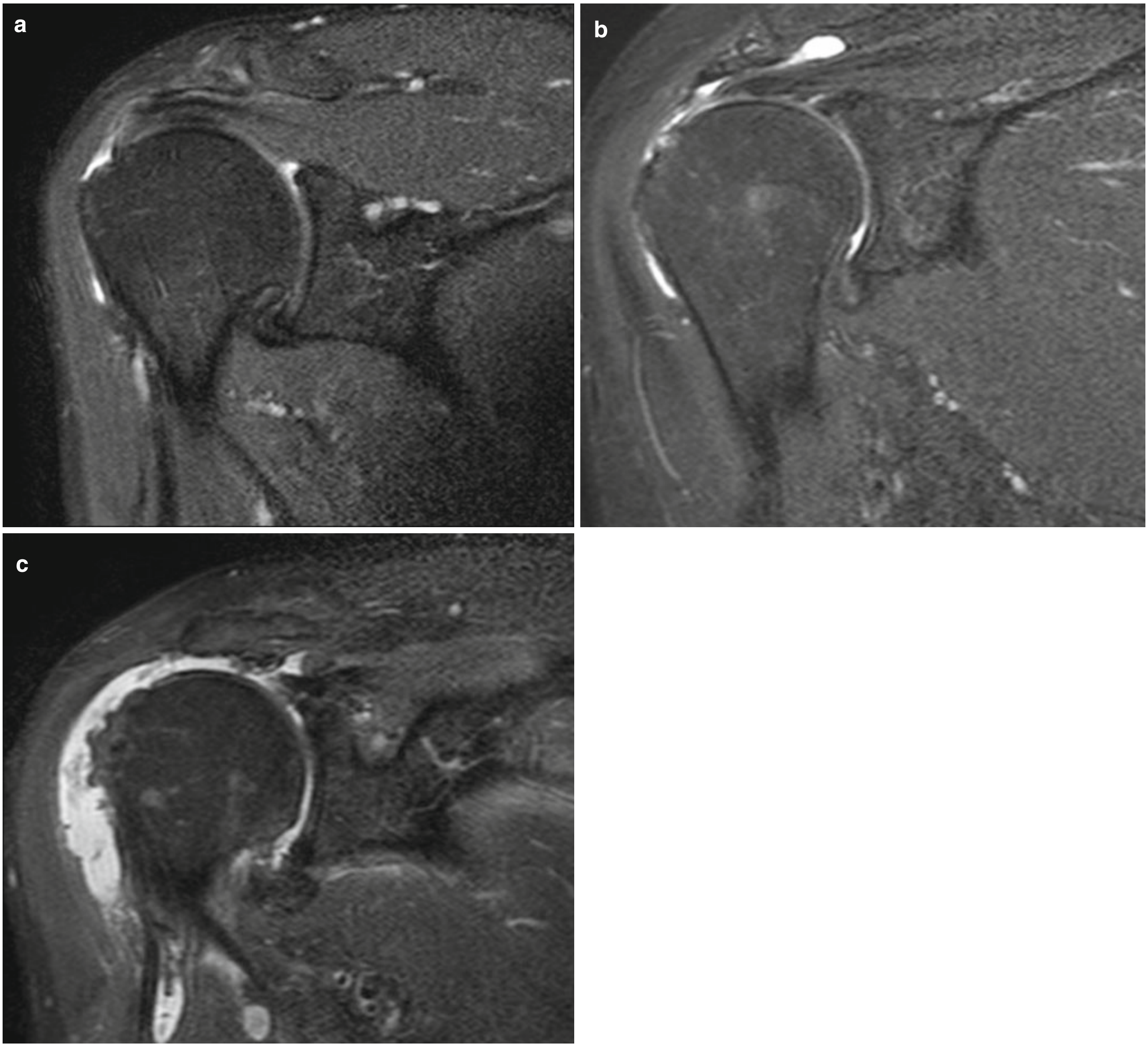

Fig. 18 Proximal retraction of the supraspinatus tendon; (**a**) retraction at insertional level; (**b**) retraction at humeral convexity level; (**c**) retraction at glenohumeral joint level

In these patients, the high definition images allow us to obtain the grading of the lesion, so that we integrate it with an MRI arthrography only if we need to diagnose small full thickness tears.

The most important evidence found in the conventional MRI images is the presence of an intense signal for the water present throughout the tendon [55–57]. Tendon retraction is also important and is the most common confirmation of more massive tears. Farley et al. [48] have demonstrated that a regular myotendinous junction should not be further than 15° away from a line passing at 12 h, by the humeral head. However, we must remember that can also be anatomic variations and that the position of the arm can modify the localization of the myotendinous junction. Sometimes, in chronic tears, the lesion can cicatrize causing a thinning of the tendon, keeping a low-intensity signal in the T2-weighted sequences. In such cases, the retraction of the myotendinous junction is a very important MRI evidence.

The conventional MRI has also shown other secondary signs of the rotators cuff tear. The reduction of the acromion-humeral space to 7 mm or less in the AP radiogram with the humerus in external rotation shows a tear of the rotators cuff [50–52]. The disappearance of the bursal fat plane, together with the presence of fluids inside the bursa, is valuable in 92–94 % of patients with a complete rotators cuff tear [53, 54]. Even though the presence of fluids in the bursa is MRI

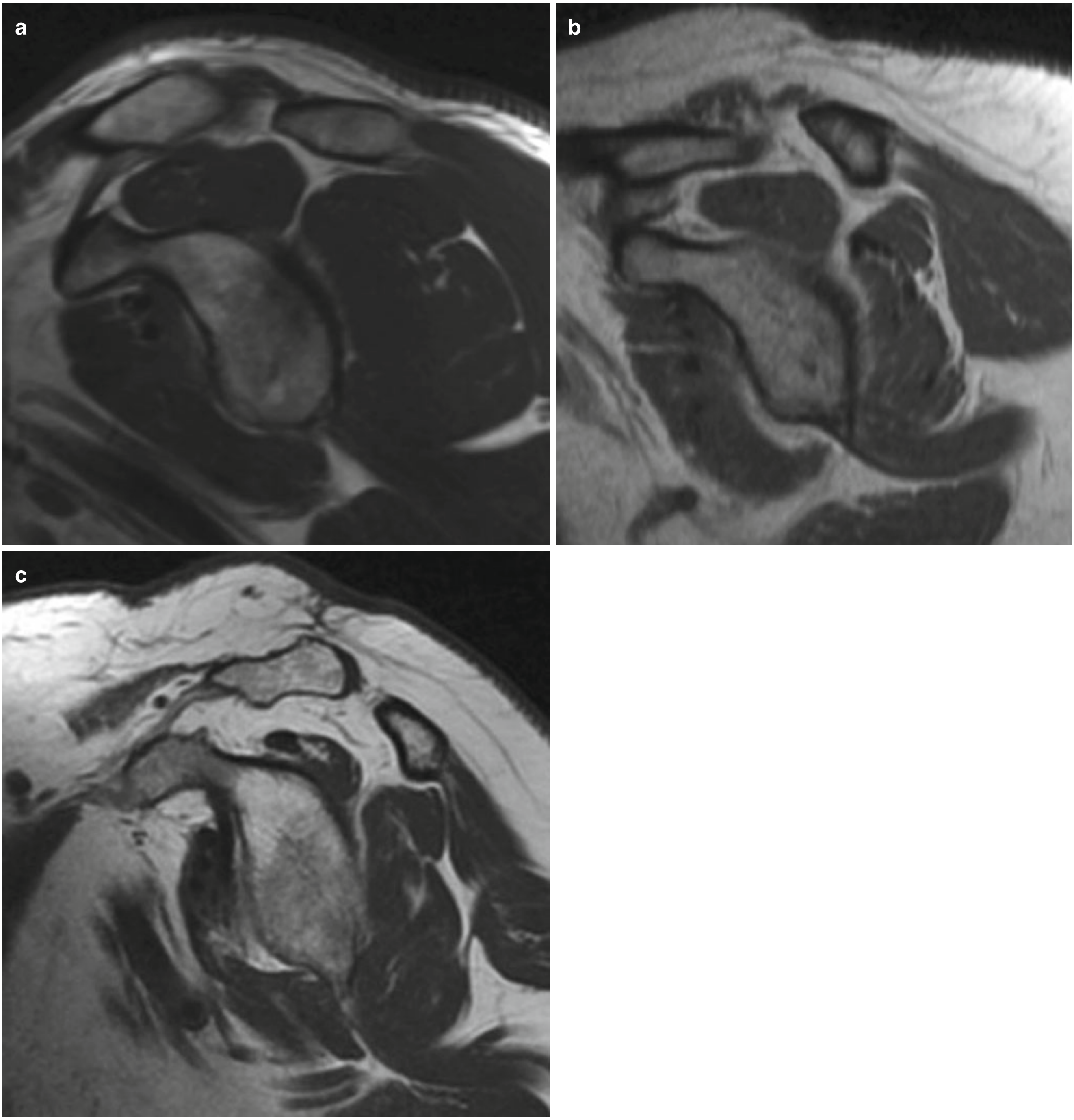

Fig. 19 T1-weighted image with fatty involution of the supraspinatus muscle in oblique sagittal, according to Fuchs et al. [57]. (**a**) Grade I: some fatty streaks. (**b**) Grade II: less than 50 % fatty muscle atrophy. Grade III: 50 % fatty muscle atrophy. (**c**) Grade IV: greater than 50 % fatty muscle atrophy

sensitive evidence (93 %), tendinous discontinuity is still a more specific sign (96 %) of the complete tear of the rotators cuff [55–57]. In patients suffering from painful shoulders, there can be fluids inside the bursa, secondary to the impingement (43 %), anomalies of the glenoid lip with an instability condition (29 %), bursitis (19 %), and tendinitis (14 %) [55].

Muscle atrophy is frequent in complete tears of the rotators cuff and can involve also many muscles of the supraspinatus. Muscle atrophy is typical of chronic large tears. This, together with a tendinous retraction, is very important for the orthopedic surgeon. The degree of muscle atrophy can be assessed with an MRI. Thomazeau et al. [56] and Fuchs et al. [57] have quantified muscle atrophy for the supraspinatus in three and five degrees, respectively, using the "index of occupancy" of the supraspinous fossa through the supraspinous muscle, thanks to an analysis carried on the oblique sagittal

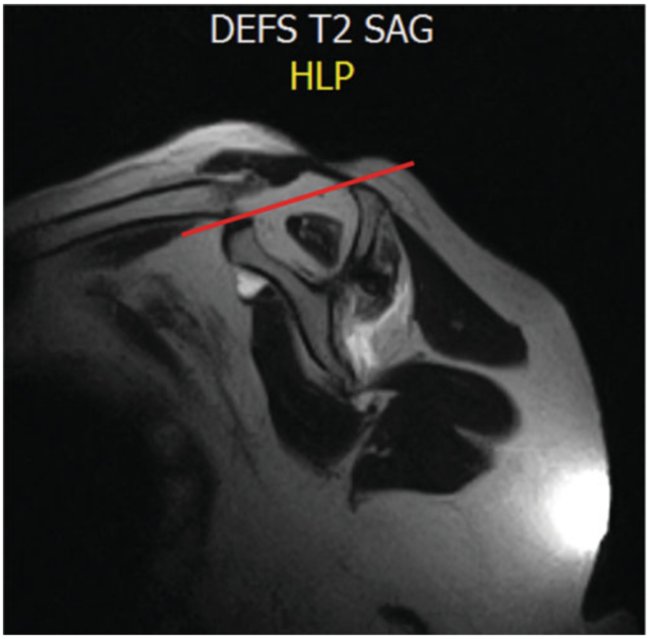

Fig. 20 Tangent sign, measured on the sagittal plane, showing the supraspinatus muscle below the level of a line tangent to the coracoid process and the scapula spine; the finding suggests muscular atrophy

images on the site where the scapula looks like a "Y" because of the union of the spine with the base of the coracoid process. According to Thomazeau et al. [56], the I degree means absence of atrophy, the II degree moderate atrophy, and the III degree means severe atrophy. Fuchs' classification is represented in Fig. 19a–c. Furthermore, in the same study, they demonstrated that the degree of atrophy seems increasing with the increment of the anteroposterior extension of the tear and retraction of the tendon on the coronal plane [55]. The authors have also observed that the degree of muscle atrophy of the supraspinous is the most important anatomic factor to predict a relapse of the lesion after surgery.

Zanetti et al. have described an evaluation qualitative method, using the tangent sign [44, 58]; it is positive, that is pathologic, if the line drawn from the upper margin of the scapular spine to the upper margin of the coracoid process does not cut the supraspinous muscle (Fig. 20).

In the full thickness tears of the rotators cuff, communication has been found with the acromial-clavicle joint and muscle cyst alterations. Continuity is appreciated between the glenohumeral joint and between bursa and the acromial-clavicle joint [59].

The MRI is an excellent diagnostic means to identify the lesions of the subscapular tendon (Fig. 21a–c) and especially its connections with the tendon of the long head of biceps (lhbt). It presents a good sensitivity in identifying both low degree lesions of the subscapular (Fig. 22) and the high degree lesions with medial dislocation of the lhbt (Fig. 22a–c).

The same diagnostic accuracy can be seen in the lesions of the infraspinatus tendon (Fig. 23a–b).

In history, many studies have been carried out, in order to evaluate the accuracy of conventional MRI in the tears of the rotators cuff. Authors have compared impulse sequences, surgical and arthroscopic evidence, and conventional MRI images with the MRI arthrography ones [49–53].

The MRI has shown a sensitivity degree of 80 %, a specificity of 94 %, and an accuracy of 89 % for complete tears of the rotators cuff. When they included both complete and partial tears, sensitivity went down to 69 % and specificity remained at 94 %, but accuracy dropped to 84 % [52].

Tuite et al. [26] have evaluated the sequence SE T2-weighted and the sequences GRE T2*-weighted assessing a sensitivity of 91 % and a specificity of 95 %, against the 75–87 % assessed for partial tears. The technique of sequences T2-weighted with fat suppression signal increased accuracy in the identification of both complete and partial tears [55].

Therefore, to identify with great accuracy the entity of a lesion of the rotators cuff, it is crucial the choice of "dedicated" sequences. In particular, the use of techniques in fat suppression signal increases accuracy and helps differentiate the contrast of the peribursal fat [59].

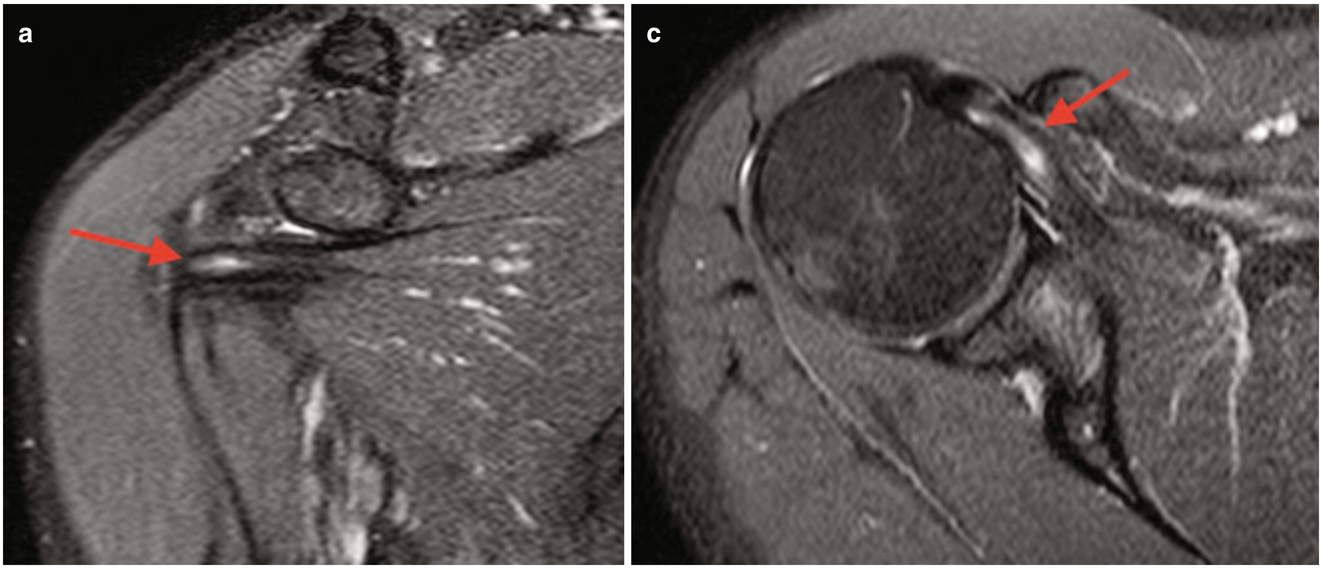

Fig. 21 MRI of a right shoulder showing intralaminar lesion of subscapularis tendon (*red arrow*). (**a**) Coronal view; (**b**) axial view

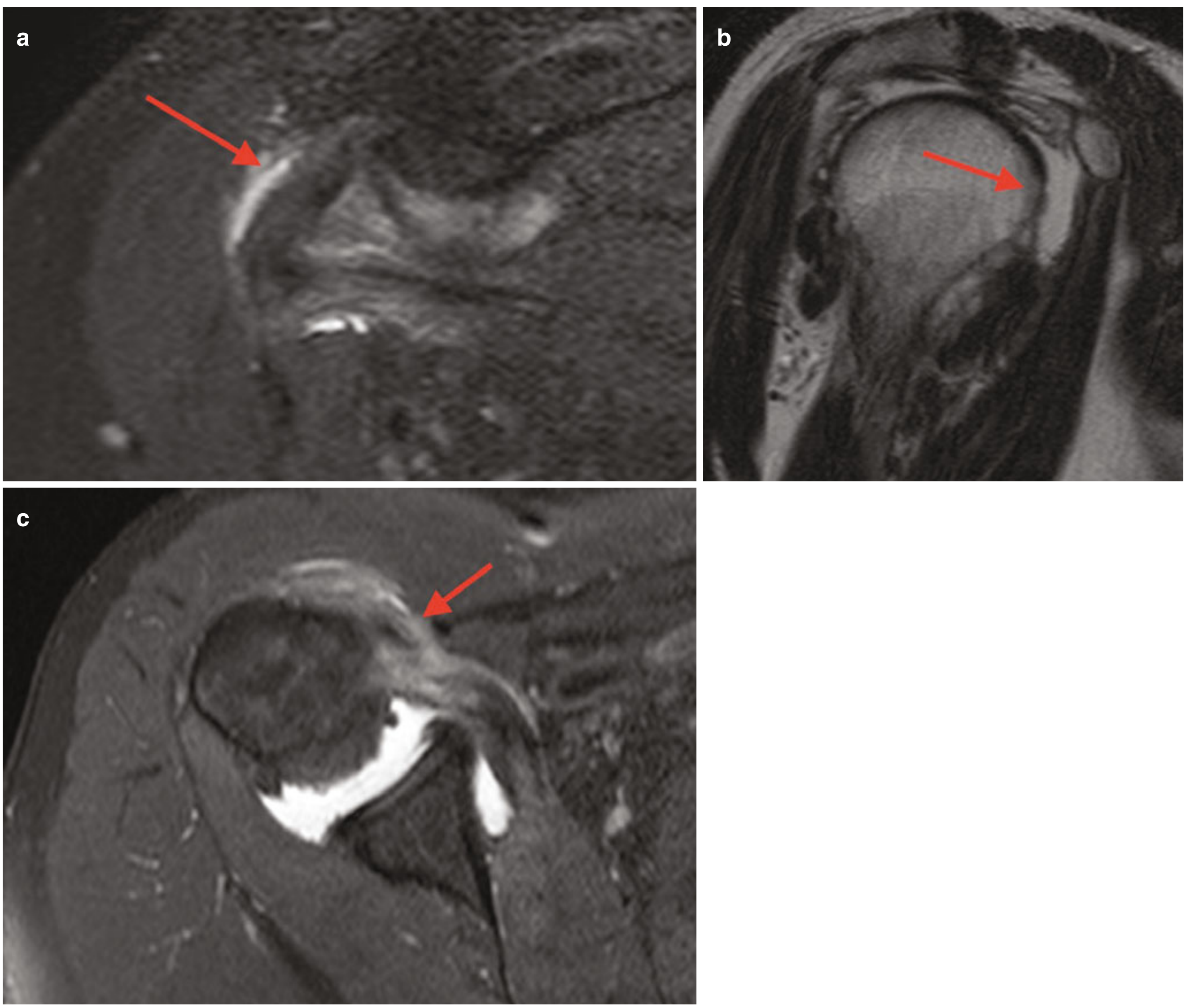

Fig. 22 MRI showing complete lesion of the subscapularis tendon with medial dislocation of the long head biceps tendon (LHBT) (*red arrow*); (**a**) coronal view; (**b**) sagittal view; (**c**) axial view

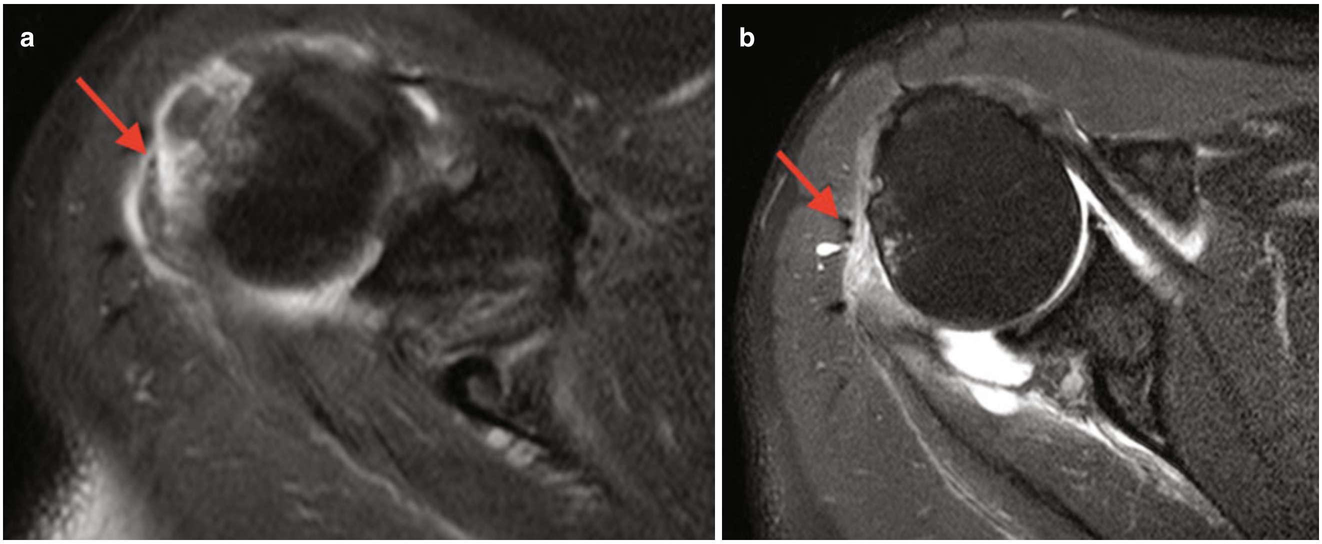

Fig. 23 MRI showing complete lesion of the infraspinatus tendon with retraction (*red arrow*). (**a**) Lesion at tendon's insertion; (**b**) retraction of the tendinous belly (*red arrow*)

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CT and CT Arthrography (CTA)

Arnaldo Conchiglia and Lorenzo Maria Gregori

The investigation of shoulder through CT and CT arthrography (CTA) plays a crucial role in evaluating rotator cuff injuries.

Over recent years, the spreading of magnetic resonance imaging has reduced the use of this diagnostic tool; however, CT scan is still a reliable technique in the evaluation of rotator cuff tendon injuries.

Even though CT guarantees a lower contrast resolution to scan soft tissues, thus promoting the major role of MRI, its characteristics make it a very useful tool for presurgical planning.

When compared to MRI, CT is a more reliable tool to evaluate the bone; moreover, it is able to clearly distinguish between muscle and adipose tissue, thus allowing, as described below, a quantitative evaluation of muscle belly degeneration (damage).

Moreover, sometimes it is necessary to use CT scan because of contraindications for MRI scan.

Today, the growing use of metal or electronic devices is giving prominence to this technique in the investigation of rotator cuff.

The indications for CT as a sole investigation tool are as follows:

- Claustrophobic patients. CT is better tolerated by claustrophobic patients due both to its very fast execution – images are acquired in a few seconds, and to the larger, opened shape of its gantry.
- Patients with contraindications to arthro-MRI (pacemaker or other metallic devices that are not compatible with magnetic resonance imaging).
- Postoperative evaluation in patients with intra-articular or periarticular metal fixation (screws or suture anchors). At present, MRI highly suffers the presence of metals, even though imaging sequences able to reduce ferromagnetic artifacts are being developed. Anyway, postoperative evaluation at the moment is far more simple with CT scan.
- Excessive movement of the patient. CT evaluation is quicker, in particular multi-slice CT systems which allow to investigate the shoulder in less than 1 s. This makes this method very useful in case of pain or other pathological conditions, which can cause the excessive movement of the patient.
- Obese patients. The investigation of the shoulder in obese patients is invalidated by the difficulty to correctly position the patient inside the MRI scanner and by the resulting lower imaging quality. For this reason, it is more advisable to use CT, which has a larger gantry and whose results are less dependent on both size and positioning of the patient.

Secondary indication for CT and ARTHRO-CT of the shoulder:

- Evaluation of articular calcified structures. When compared to MRI, CT allows to better discriminate the density of possible intra-articular or tendinous fragments or deposits.

Tendon calcifications can frequently cause intense shoulder pain, and even though they do not constitute an indication for a CT scan, being a pathological condition of ultrasound or radiographic concern, they can be better evaluated through a tomodensitometry than through MRI scan.

- Joint instability and bone incongruity.

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Technique

The patient is in supine position on CT scanner table, with the limb under examination either in indifferent position or in slight extra-rotation and fixed with a bag. It can be necessary to immobilize the arms with some strips. The laser beam is centered in the area under the chin, hence performing a scanogram until the half of humerus.

The scanner is prepared in axial scanning setup including acromioclavicular joint up to the inferior angle of the scapula.

Thickness 1 mm
Multiplanar reformation (MPR) coronal and sagittal scan
3D reconstruction

In the CT scan, bone is hyperdense while fat, air, and joint fluid are hypodense. Musculature, cartilage, and fibrocartilage are isodense without a good differentiation among different tissues.

The use of multidetector CT scanner allows to acquire submillimeter layers with isotropic voxel image, thus allowing multiplanar reformats with high resolution. In this way, it is possible to obtain sagittal and coronal reconstruction without artifacts.

After the illustration of the procedure and the subsequent signature of an informed consent by the patient, the procedure begins with the preparation of the patient; we disinfect the skin access site, then we proceed to skin puncture using 20–22G needle. The procedure is performed in a fluoroscopic room or under ultrasound guidance. When the tactile feedback or when the images suggest that the needle is in articulation (Fig. 1), we inject the solution composed of 2–3 ml of soluble contrast and 10–20 ml of filtered sterile air in according to the double contrast technique. The contrast flows rapidly from the tip of the needle and spreads in articulation. When there is a resistance to the contrast introduction, due to an increase pressure, or when the images show a uniform intra-articular filling, it is possible to stop the procedure.

The fluoroscopic monitoring is not required throughout the entire injection, and can be stopped after seeing that the needle is well positioned. It is not recommendable to inject much contrast in the shoulder because it may cause an extravasation especially at the level of the subscapularis recess. The images are acquired with the arm in neutral position or slight internal rotation, then they are reconstructed in coronal, sagittal, and oblique sagittal planes. In recent years, another acquisition in ABER position has been added (abduction 90° and maximum external rotation), as in arthro-MRI. The patient places the palm of his hand under his head turning the shoulder externally; this position determines the contact between the deep surface of the rotator cuff and the postero-superior portion of the glenoid labrum.

Fig. 1 Coronal CT showing the 22G needle in articulation so that the solution composed of 2–3 ml of soluble contrast and 10–20 ml of filtered sterile air can be injected

CT and CT Arthrography (CTA) in the Evaluation of Cuff Tears (Fig. 2a, b)

The evaluation of the rotator cuff tendons by arthro-CT is considered a secondary instrumental examination, although the use of multidetector scanners with very thin volumes of acquisition and multiplanar reconstructions on three floors allows a good evaluation of cuff tendons.

The arthro-CT has shown a good sensitivity in the diagnosis of rotator cuff ruptures. The tears of the articular surface of the tendon can be diagnosed by recognizing the contrast agent inside the rotator cuff, but through it without a full thickness or by detection of a small lesion on the surface of synovial bag. Also the intratendinous rotator cuff lesions can be showed with the arthro-CT, but only if they communicate with the joint cavity. The lesions, which do not communicate, and the partial lesions of the bursal surface cannot be viewed with this method. Intrabursal subdeltoid/subacromial injection has minimum efficiency in the study of partial lesions of the tendon bursal surface by displaying accumulation of contrast agent in the lesion of the tendon.

The sensitivity and specificity of CT are comparable to those of MR, especially if CT is performed with intra-articular

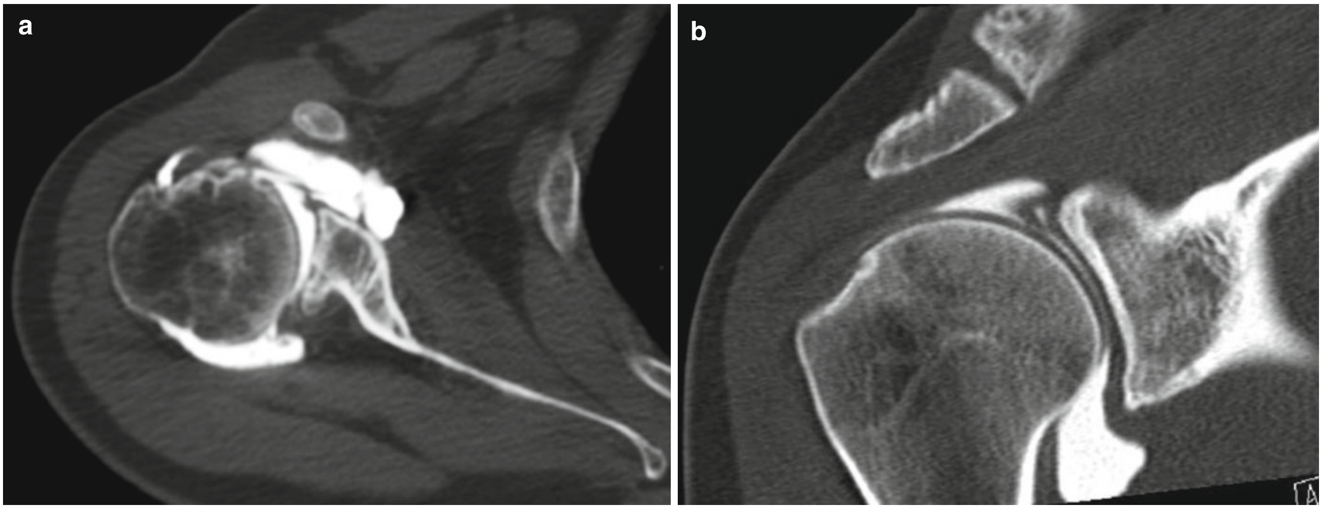

Fig. 2 Computed arthrotomography shows the humeral head and glenoid region of the scapula and soft tissue structures. Axial (**a**) and coronal (**b**) views. Distension of the glenohumeral joint allows identification of glenohumeral ligaments and sites of capsular insertion. The anterior capsular insertion varies somewhat in appearance: the capsule may insert in or near the labrum (type 1), medially or more medially along the scapular neck (types 2 or 3). Accurate analysis of glenoid labrum; variations in labral morphology (sublabral foramen and Buford complex) or tears. Evaluation of coracoacromial arch. Acromion shapes. Evaluation of long head biceps tendon. Evaluation of rotator cuff tear

injection of the contrast agent. CT arthrography showed a sensitivity of 99 % and a specificity of 100 % in the diagnosis of tears of supraspinatus. As for infraspinatus tears, these figures were 97.44 % and 99.52 %, respectively; as for subscapularis, 64.71 and 98.17 %. In case of lesions of the long head of the biceps, the sensitivity was 45.76 % and the specificity was 99.57 % [1].

CT allows the same evaluations performed by MRI in case of rotator cuff lesions, yet the capacity to discriminate the different tissues is much lower due to the poorer resolution of CT with respect to MRI, the latter being the gold-standard method in the evaluation and classification of cuff lesions.

With such limitations, CT allows to evaluate:

The location of the tendon lesions, in particular by CTA. The location influences the choice of the treatment to follow. CT allows to discriminate efficiently a lesion of the insertion footprint from a lesion in a critical location or in other regions. In addition, yet less efficiently in comparison to MR, it is possible to detect partial lesions, especially on the articular side, which appear clearly in presence of the contrast agent (Fig. 3).

Intraparenchymal lesions and bursal-side lesions, on the contrary, significantly suffer contrast's low resolution, or the possibility to distinguish different tissues. As for these lesions, intra-articular contrast is not useful because they do not communicate with the joint, so they can be misrecognized both with and without contrast agent. In these cases, the use of MRI is certainly more accurate.

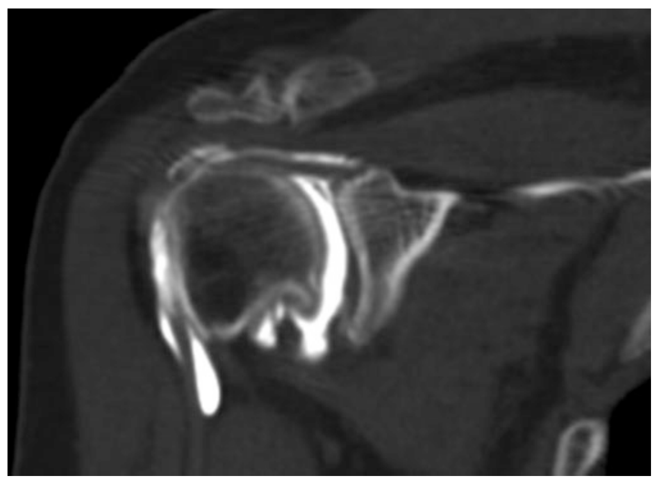

Fig. 3 Coronal CT arthrogram showing partial-thickness articular surface tear of supraspinatus tendon in a patient affected by glenohumeral arthritis. The deep fibers of the tendon are interrupted, but not retracted, and this explains the linear (contrast-white) appearance of the tear. This lesion communicates with the joint. Tears of bursal surface of the supraspinatus tendon cannot be examined at arthro-CT, which permits opacification only of the joint surface

Full-thickness lesions are usually well detectable both with and without intra-articular contrast agent, but in the first case the tears appear more clearly. In case of full-thickness lesions the contrast agent passes through the tendons and joins the bursa due to the new channel that has been created [1, 2] (Fig. 4).

As for lesions of the long head of the biceps as well, CT has shown to be as reliable as MRI [3].

Fig. 4 Coronal CT arthrogram in a patient with a full thickness rotator cuff tear, evidenced by a large amount of contrast in the subacromial/subdeltoid bursa

- Coronal extension of the lesion. The possibility to obtain coronal reconstructions without artifacts with isotropic voxel allows evaluating with accuracy the extension of the lesion, or the possible retraction of the torn tendon. This information is essential to the correct choice of the surgical treatment.

As well as in case of evaluation with MRI, the lesions can be then categorized on the basis of their extension.

On a coronal plane, it is possible to evaluate the extension of the insertional lesion according to Habermayer's classification criteria: type 1: small tear within transition zone from cartilage to bone, type 2: extension of tear up to center of footprint, type 3: extension of tear up to greater tuberosity.

It is cautiously possible to evaluate through CT the different classifications that have been studied both for MRI and for arthroscopy, in particular the most unrefined ones, as topographical classifications like Cofield's, who classified tears as small when less than 1 cm, medium between 1 and 3 cm, large 3–5 cm, and massive if the tear was more than 5 cm in length.

On a sagittal plane, it is possible to identify three kinds of supraspinatus tendon lesions, which can be distinguished on the basis of their location in anterior, posterior, or complete tear, depending on the portion of tendon involved (anterior, posterior, or the whole tendon, respectively). Concerning other components of the rotator cuff, as infraspinatus or subscapularis, tears were either limited to cleavage, the upper third (upper-third tears), or affected more than this called complete tear.

In case of tears of the long head of the biceps, it is possible to evaluate four different lesions through CT: The tendon can be intact, hypertrophic, partially damaged, or completely torn. Moreover, it is possible to evaluate its stability by verifying the possible dislocation of the tendon over the lesser tubercle of humerus.

Evaluation of Fatty Degeneration and Muscle Atrophy

Presurgical evaluation in a patient with rotator cuff lesion needs to take into account the evaluation of the conditions of both the tendon and the injured muscle.

The suture of a severely injured tendon entails a high risk of a relapse of further ruptures during the postoperative period. To quantify this possibility, several scores have been proposed. The most followed score is Goutallier's [4], which is based on the CT evaluation of the degree of the fat degeneration of rotator cuff components. This scoring has been conceived to evaluate CT scans, but it has been widely discussed and partially modified in order to be used in case of MRI images as well.

CT distinguishes the different tissues on the basis of their density. The adipose tissue has far lower density when compared to muscle or to tendons.

In the first grades of Goutallier scale, the muscle shows scarce fatty infiltration. At these grades of lesion, the tissues are able to resist to the surgical treatment, thus allowing an indication for surgery. At higher grades, the fatty degeneration undermines the structure of the muscle, with moderate to severe alterations of mechanical abilities.

According to an extensive literature, the degree of fatty degeneration affects in a significant way the success of the surgical treatment.

The evaluation of the degree of fatty degeneration can be made on a single muscle belly, or, more correctly, on every component of rotator cuff; the average score will produce a new result which is more strictly associated, according to new scientific evidence, to the risk of relapse of ruptures during the postoperative period.

The intratendinous fatty degeneration is related not only to the degree of the lesion, but also to other factors such as patient's age and possible concurrent pathologies.

By analyzing CT scans, it is possible to judge the degree of degeneration with a 1–4 scoring scale, where 0 indicates a normal condition and 4 the highest degree of fatty degeneration (Fig. 5a–d).

Grade 0: normal muscle, no fat
Grade 1: streaks of fat
Grade 2: more muscle than fat
Grade 3: equal muscle and fat
Grade 4: more fat than muscle

Other possible evaluations through CT scan involve muscle atrophy. Thomazeau's classification [5] evaluates in MRI the degree of muscle atrophy on a sagittal plane. This classification can be stretched to CT evaluation as well, on oblique sagittal plane, even if the ability to distinguish the different tissues is less accurate; nevertheless, it is possible to evaluate both muscle and adipose tissue (Fig. 6a–e).

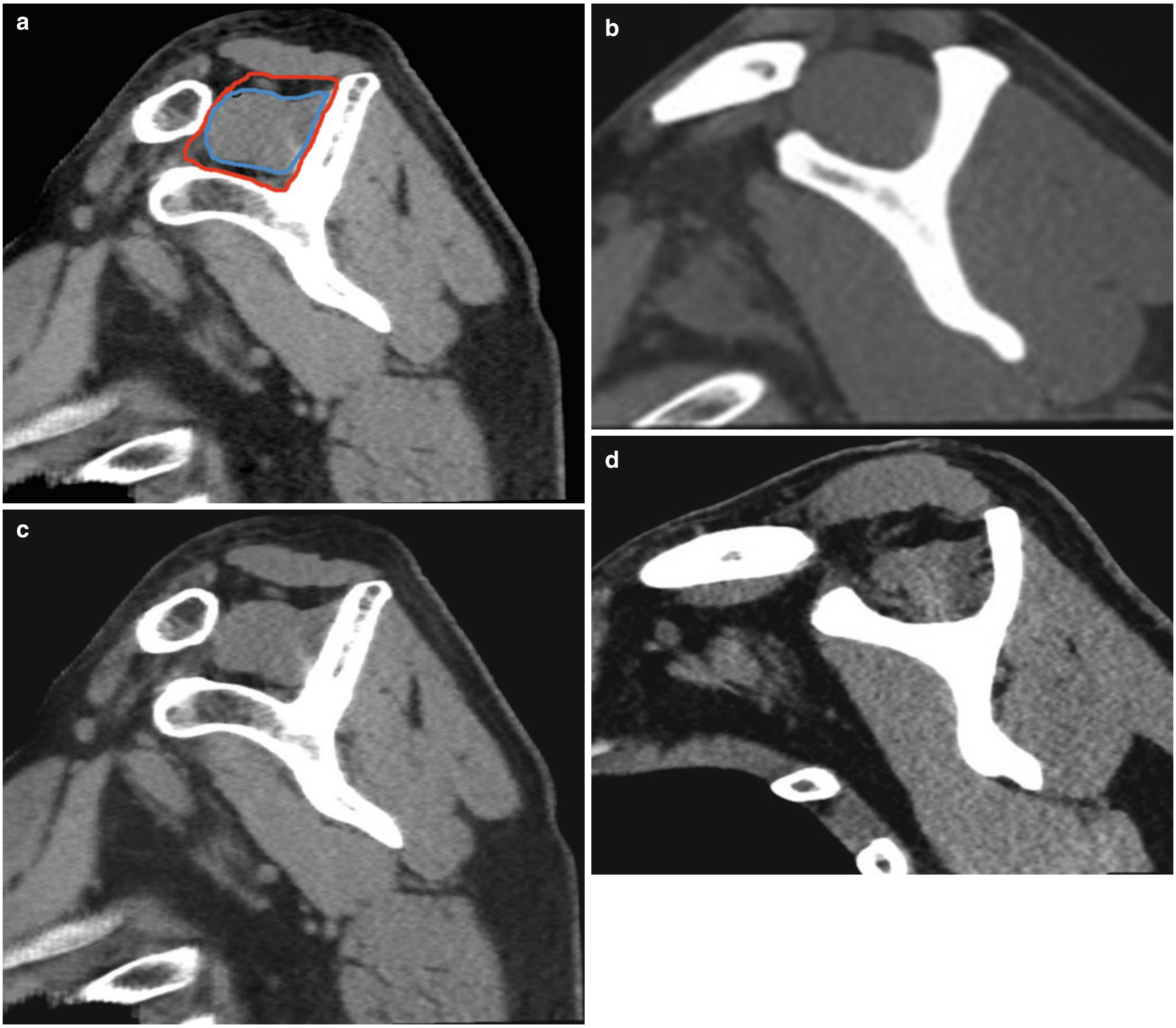

Fig. 5 Assessment of supraspinatus muscle atrophy: Thomazeau classification. Occupation ratio (R) = surface of supraspinatus muscle (S1) (*blue*)/surface of entire supraspinatus fossa (*red*) (S2) (**a**). Stage 1: normal/slight atrophy. Occupation ratio (1.00–.60) (**b**). Stage 2: moderate atrophy. Occupation ratio (0.60–0.40) (**c**). Stage 3: severe atrophy. Occupation ratio (<0.40) (**d**)

Fig. 6 Fatty degeneration of cuff muscles: Goutallier's classification. Stage 0 – normal muscle (**a**). Stage 1 – some fatty streaks (**b**). Stage 2 – less than 50 % fatty muscle atrophy (**c**). Stage 3 – 50 % fatty muscle atrophy (**d**). Stage 4 – greater than 50 % fatty muscle atrophy (**e**)

Both CT and arthro-CT are excellent alternatives in patients who present absolute or relative contraindications to MRI examination; thanks to CT multidetector, it is possible to obtain high spatial resolution and isotropic volume that offers the possibility to reconstruct high-quality images.

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Ultrasound Evaluation

Luca di Sante, Federica Alviti, and Valter Santilli

Ultrasonography (US) has been established as an effective imaging method in the evaluation of the rotator cuff. Specific US criteria have been used to correctly diagnose rotator cuff tears [1–4]. Several advantages of ultrasound include its availability, cost-effectiveness, and patient preference for ultrasound evaluation over MRI [5]. In recent years, thanks to technological developments, ultrasound has begun to play a key role in the study of tendons and has perhaps become even more accurate than magnetic resonance imaging (MRI) [5, 6]. However, ultrasound depends very much on technicians, and thorough training of technicians is essential to guarantee reliability and specificity of the diagnostic information obtained. US imaging is not expensive, so it possible to compare the affected and the contralateral shoulder and to perform a dynamic study, which can in some cases provide information indicating a tendinous conflict and full-thickness tears. Partial-thickness tears are more frequent (18.5 %) than full-thickness tears (11.7 %) and they can be painful [7]. Supraspinatus tendon abnormalities were detected during arthroscopy and classified according to the Snyder classification as "A" (articular), "B" (bursal), or "C" (full-thickness or complete tear) [8]. A complete routine shoulder examination involves an assessment of rotator cuff and surrounding structures [9].

However, there is a spectrum of non-rotator cuff abnormalities that can also be detected by US examination, including instability of the biceps tendon, glenohumeral joint, and acromioclavicular joint; arthropathies and bursites (inflammatory diseases, degenerative and infiltrative disorders, infections); nerve entrapment syndromes; and space-occupying lesions.

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Shoulder Ultrasound: Normal Ultrasound Anatomy and Scanning Technique

Multifrequency linear probes (9–12 MHz) make it possible to examine both superficial and deep structures of the shoulder. Doppler techniques, such as power and color Doppler, allow for the identification of active inflammation. The examination should include both longitudinal and transverse scanning planes, followed by bilateral and dynamic evaluations. The knowledge of the bone landmarks is fundamental in assisting transducer positioning; the ones generally used are the bicipital groove, the lateral end of clavicle, the acromion and coracoid process. US examination of the shoulder usually starts with the biceps.

Long Head Biceps Tendon

The long head biceps tendon (LHBT) evaluation is performed with the arm in neutral position while the patient is sitting, with elbow joint flexed at 90°. The patient's arm should be placed upright (in a supine position) on the patient's thigh. The recommended starting point of shoulder ultrasound examination involves the probe placed axially at the anterior aspect of the shoulder. The first part of the tendon usually studied is the extra-articular portion; this is performed by looking for the bicipital groove (Fig. 1a, b). In the transverse view, the LHBT appears as an ovalar hyperechoic structure within the groove that is surrounded by a small amount of fluid in the sheath (thickness less than 2 mm). Rotating about 90° the distal edge of the probe, from the bicipital groove, on the longitudinal plane the LHBT should be visualized: It has a narrow, striated fibrillar pattern. Shifting the probe distally should make the musculotendinous junction visible (Fig. 1c, d). Dynamic assessment with internal and external rotation is recommended in cases of biceps tendon subluxation and dislocation. Another dynamic assessment should be performed during active flexion and extension of the patient's elbow against resistance.

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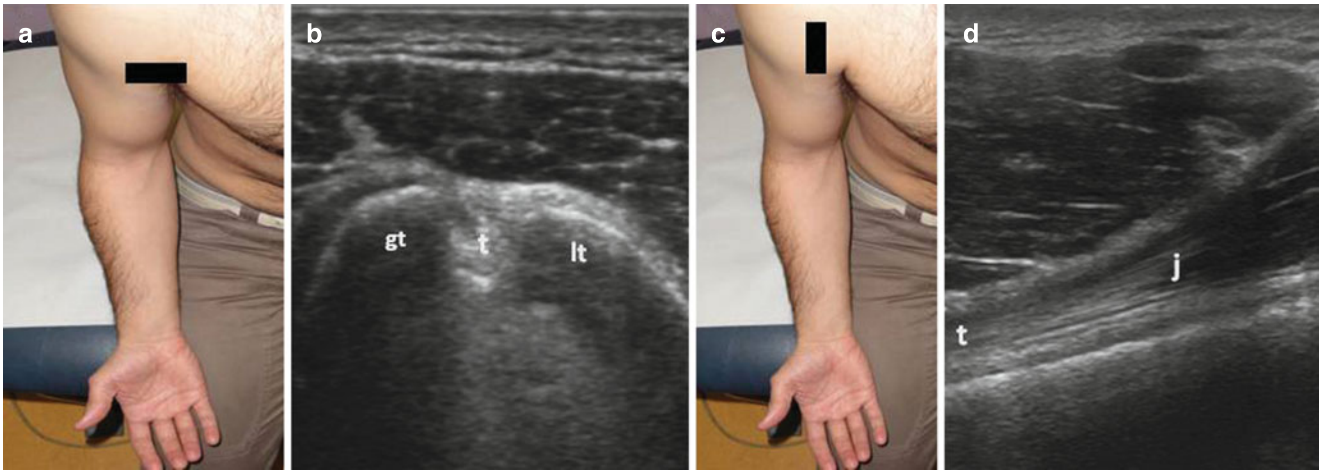

Fig. 1 Probe transverse across superior aspect of bicipital groove. Adducted arm and supinated hand (**a**). Biceps tendon groove (**b**). Schematical illustration shows how the biceps tendon (*t*) is located between the greater tuberosity (*gt*) and the lesser tuberosity (*lt*). Probe longitudinal to long head of biceps tendon. Adducted arm and supinated hand (**c**). Dynamic examination for subluxation of the tendon using internal and external rotation of the glenohumeral joint. Long head of biceps tendon (**d**), biceps tendon (t) and muscle tendon junction (*j*)

Shifting the probe superiorly and medially from the groove, with the patient's arm in external rotation, makes it possible to evaluate the proximal intra-articular part of the LHBT. It enters the glenohumeral joint through the rotator cuff interval which is the free space between the subscapularis and supraspinatus tendons. The LHBT should be recognized between the subscapularis tendon medially and the supraspinatus tendon laterally.

Subscapularis Tendon

After LHBT examination, while maintaining the probe placed axially on the anterior aspect of the shoulder, move the probe medially until the coracoid image is visualized. The subscapularis tendon appears on the long-axis scan; it has a convex shape and a well-defined fibrillar echostructure, and it lies deep in the deltoid muscle and is superficial to the humeral head (Fig. 2a, b). To evaluate the muscular and tendon integrity, dynamic assessments during passive internal and external rotations, keeping the patient's arm adducted, should be performed. On the short-axis scan, the multipennate structure of the normal subscapularis tendon creates a series of hypoechoic clefts (Fig. 3a, b).

With the medial margin of the transducer on the coracoid process wheel and with the lateral edge of the probe upward and laterally positioned toward the acromion, the coracoacromial ligament and the anterior portion of the subacromial-subdeltoid bursa will be evaluated. From this position, the subscapularis recess and the subcoracoid bursa should be analyzed for effusion. External and internal rotations may also be used to demonstrate anteromedial impingement (the distance between coracoid process and lesser tuberosity measured in the internal rotation).

Supraspinatus Tendon

The US study starts by placing the probe on the coronal plane with its medial margin at the lateral margin of the acromion. The position of the supraspinatus tendon between the acromioclavicular arch and the humeral head makes it partially obscured by the overlying acromion process. This only makes it possible to examine its distal part in a standard neutral position (Fig. 4a, b). A better visualization of the supraspinatus tendon could be ensured using the complete internal rotation with the patient's arm extended posteriorly, elbow flexed and pointing directly posteriorly, and with the palm of patient's hand placed on the ipsilateral iliac wing. The long-axis and short-axis scans should be obtained. On the long-axis scan, the supraspinatus tendon is visualized as convex beak-shaped hyperechoic structure over the smooth hypoechoic band of the articular cartilage and the hyperechoic humeral cortex, ending into the great tuberosity. It lies under the layers of the subacromial subdeltoid bursa with hypoechoic fluid in it and under the hypoechoic deltoid muscle (Fig. 5a, b). On the short-axis scan, the supraspinatus tendon has a convex shape, and it consists of a homogeneous texture of medium-level echoes. A dynamic assessment is performed with passive abduction and adduction of the patient's arm (Fig. 6a, b).

Infraspinatus and Teres Minor Tendon

The infraspinatus and teres minor tendons are evaluated using a posterior approach, with positioning of the transducer on the glenohumeral joint. The patient's forearm is placed across his or her chest and the patient's palm is placed on his or her opposite shoulder. The transducer is then placed over the posterior part of the glenohumeral joint, and the spine of the

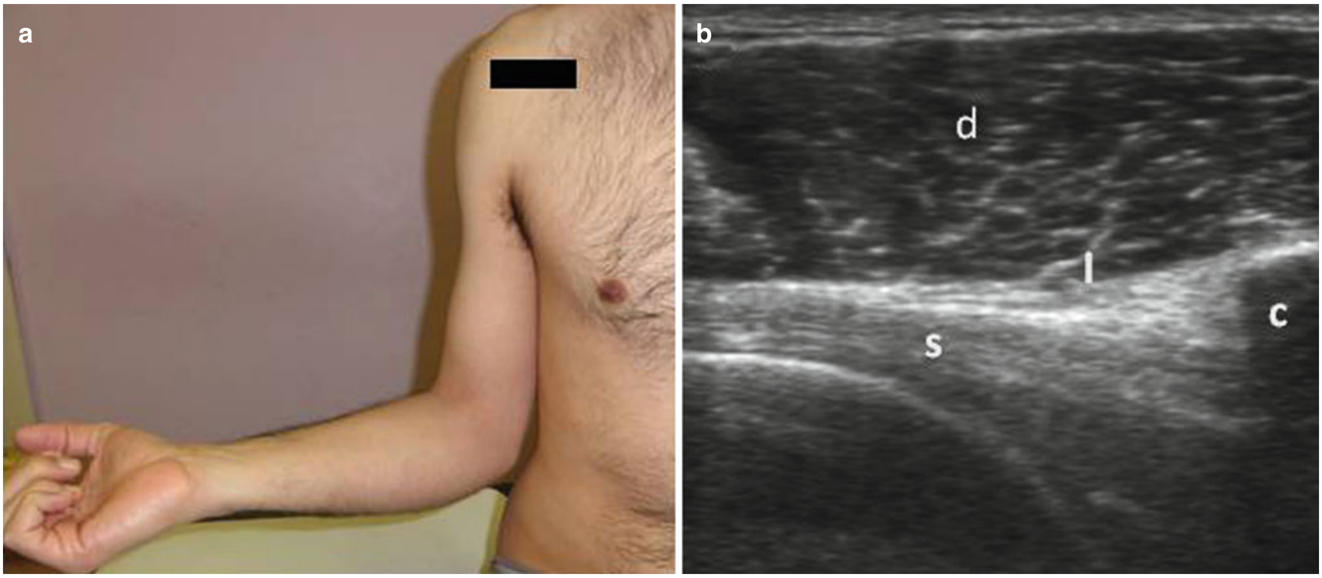

Fig. 2 Probe longitudinal to the subscapularis muscle (transverse to anterior shoulder). Dynamic examination using internal and external rotation of the glenohumeral joint (**a**). (**b**) Coracoid (*c*); subscapularis tendon (*s*); coracohumeral ligament (*l*); deltoid muscle (*d*)

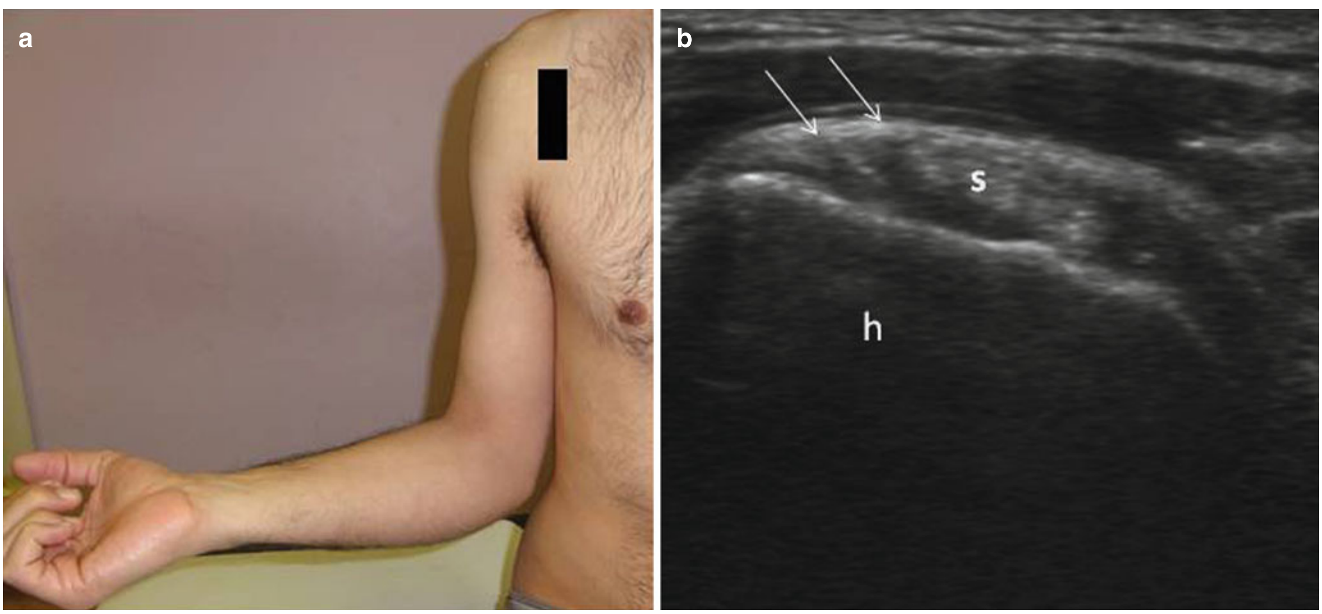

Fig. 3 Short-axis scan of subscapularis at level of the musculotendinous junction. The hypoechoic muscle (*arrows*) between the echogenic tendon slips is normal and should not be mistaken for tendinosis or tears. (**a**) Subscapularis tendon short axis scan tecnique; (**b**) Subscapularis tendon ultrasound image, humerus head (*h*); Subscapularis tendon (*s*); Muscle tissue interposed between tendon fascicles (*arrows*)

scapula is used as the landmark to distinguish the supraspinous fossa (transducer shifted up) from the infraspinous fossa (transducer shifted down) on the sagittal planes. The infraspinatus tendon is larger and longer than the teres minor tendon. On the long-axis scans, both of them have a fibrillar pattern. The infraspinatus tendon has a beak-shaped morphology, while the teres minor tendon appears to be a thin triangular-shaped structure. On the short-axis scans, they are visualized as convex-shaped layers with medium-level echogenicity. Dynamic assessment is performed by passive internal-external rotation, with the patient's arm in adduction.

With posterior transverse scans of the glenohumeral joint at the level of the infraspinatus tendon, the posterior labrum-capsular complex should also be evaluated and the posterior recess of the joint should be checked for effusion during scanning. In thin subjects, the posterior labrum can be seen clearly. The transducer should be moved medially to the labrum on transverse plane to visualize the spinoglenoid

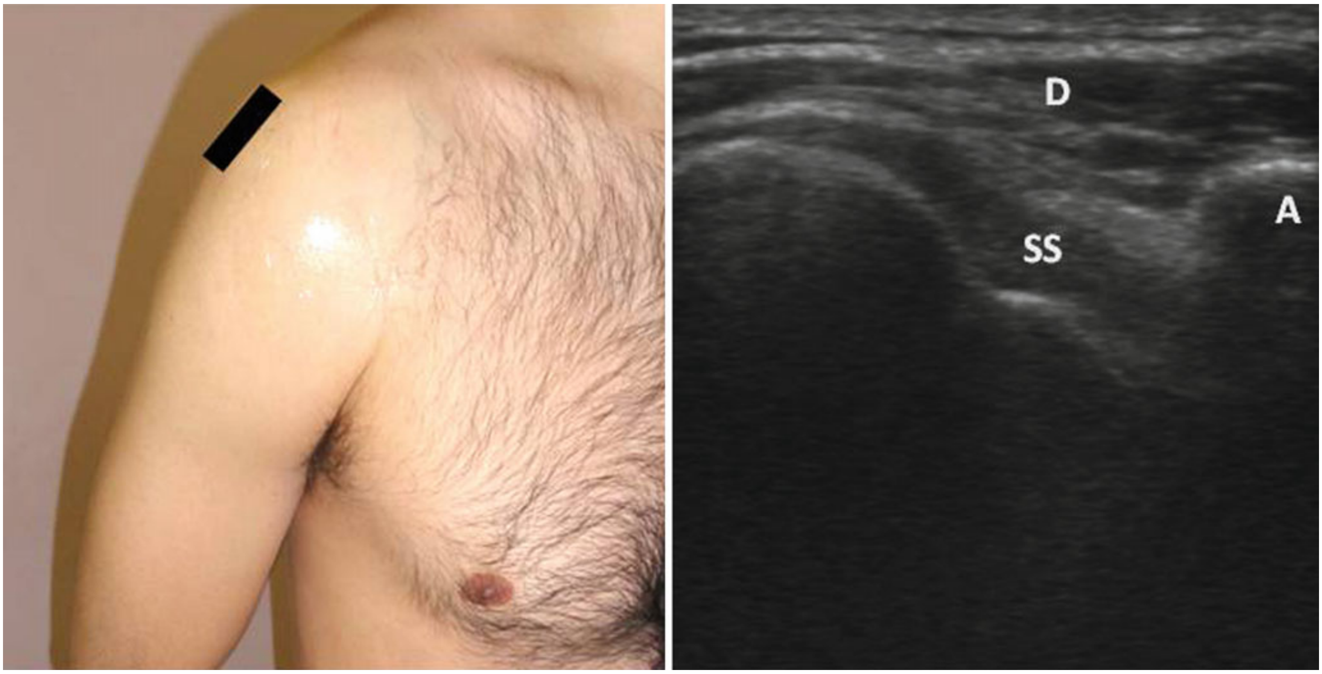

Fig. 4 (**a**) Probe longitudinal to supraspinatus tendon, with shoulder in neutral position. Long axis sovraspinatus tendon scan technique; (**b**) (*SS*) sovraspinatus tendon; Acromion (*A*); deltoid muscle (*D*)

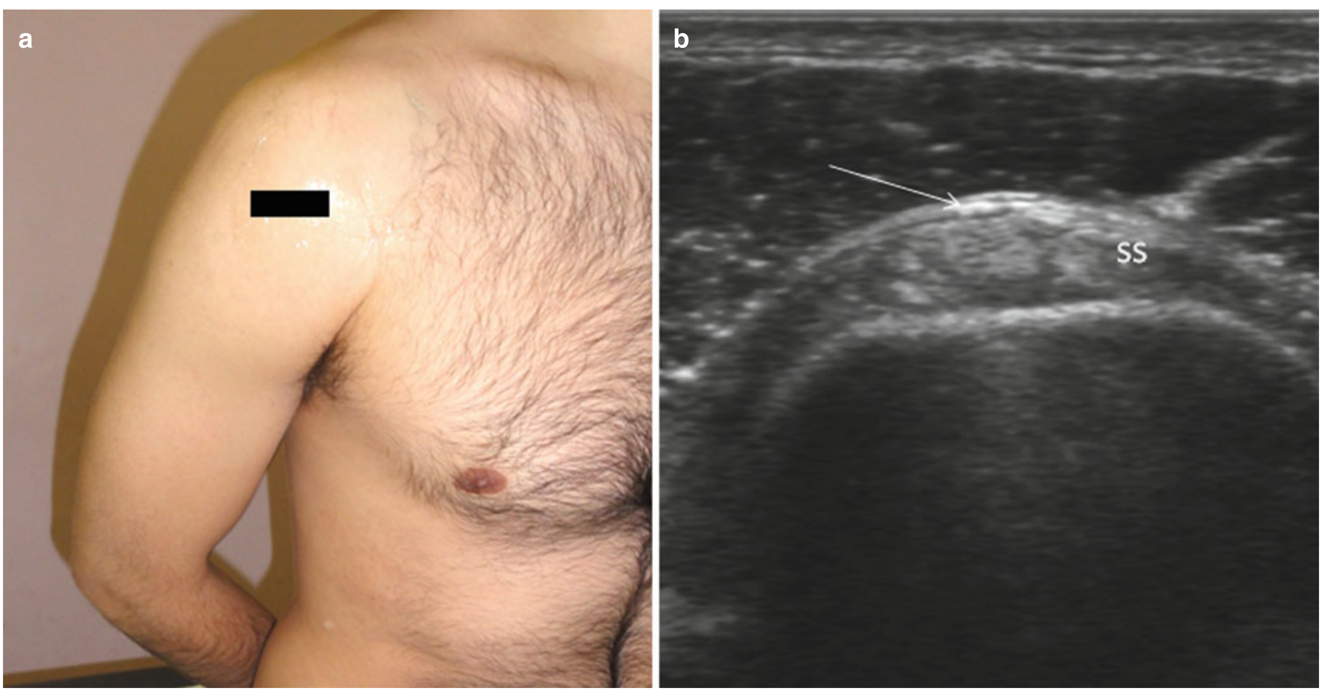

Fig. 5 Probe transverse to supraspinatus tendon, with shoulder extended and internally rotated. Shoulder extension with internal rotation is required for clear visualization (**a**). (**b**) Transverse scan of supraspintus showing the echogenic rotator cable (*ss*). The hypoechoic subdeltoid bursa (*arrow*) lies between the cuff and the deltoid muscle

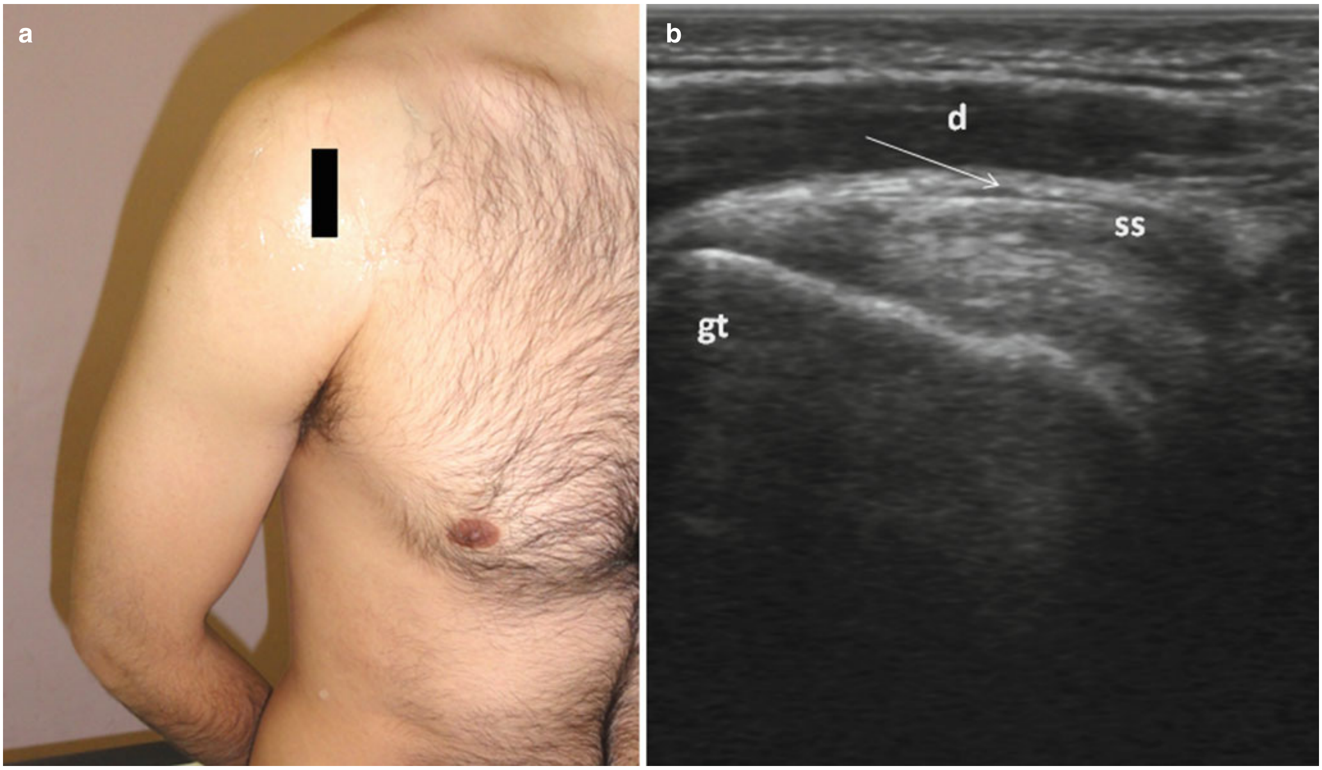

Fig. 6 (**a**) Dynamic assessment of supraspinatus can be useful in further evaluation of impingement and cuff tears. Probe over supraspinatus whilst abducting and adducting arm. Sovraspinatus tendons scan tecnique. (**b**) sovraspinatus tendon ultrasound image. Deltoid muscle (*d*); sovraspinatus tendon (*ss*); humerus great tuberosity (*gt*); subacromion deltoid bursa (*arrow*)

notch. It is often necessary to increase the depth of the field-of-view so as not to miss this area. It is worth checking for a paralabral cyst originating in this area. The fibrocartilaginous labrum can be visualized by US as a triangular, homogeneously hyperechoic structure that caps the bony rim of the glenoid. The anterior labrum is best scanned with curved-array transducers and low frequencies (as low as 5 MHz) with an anterior or axillary transverse approach performed either with the patient's arm in the adducted position or with the patient supine and his or her arm abducted at 90° with his or her elbow flexed (Fig. 7a, b).

Supraspinatus Full-Thickness Tears, Partial-Thickness Tears

Supraspinatus Full-Thickness Tears

Magnetic resonance (MR) and US have good diagnostic accuracy and both of these tests could be used indifferently to detect the full-thickness tears in people with shoulder pain when surgery is being considered. The diagnostic performance of MRI and US may be similar for the detection of any rotator cuff tears. However, both MRI and US may have poor sensitivity for detecting tears with moderate thickness, and the sensitivity of US in making such assessments may be much lower than that of MRI [10]. The full-thickness tears are divided into two types: (i) small to moderate sized tears and (ii) large or massive tears. The first sign of a full-thickness rotator cuff tear is a defect that extends from the joint side to the bursal side of the tendon. The space between the two heads, proximal and distal, is occupied by fluid that is anechoic or contains low-level echoes. If any doubts arise, it is always useful to make a comparative exam with the contralateral arm. Large or massive tears result in retraction of the tendon under the acromion and nonappearance of the cuff (Fig. 8). Tendon non-visualization is the single primary US finding that best predicts massive full-thickness tendon tear. Complex tears may be related: tendinosis, normal tendons with or without the presence of fluid in the subdeltoid bursa and glenohumeral joint (Fig. 9).

Supraspinatus Partial-Thickness Tears

US has an accuracy rate of 87 % in detecting partial-thickness tears; the corresponding value for MRI imaging is 90 % [11].

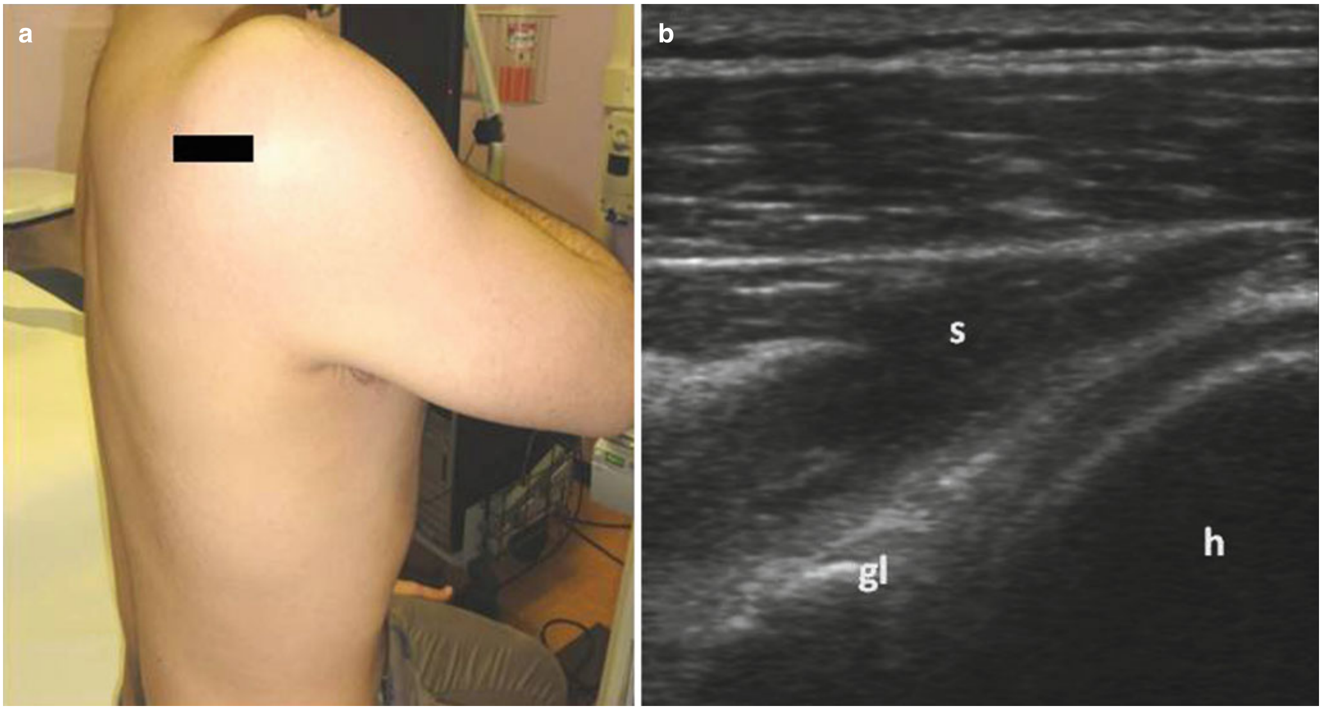

Fig. 7 Sonographic scanning technique to optimize visualization of the infraspinatus and teres minor tendon; the fibers of these tendons can be stretched. This is accomplished by bringing the patient's arm in front of the body. The arm is flexed and adducted with his or her hand resting on the contralateral shoulder. The transducer is placed on an axial plane dorsolaterally to the shoulder, just below the scapular spine and it is angled slightly inferiorly to better visualize these tendons (**a**). (**b**) Long-axis scan of infraspinatus muscle (*s*) as it runs toward the rotator cuff. The echogenic posterior glenoid labrum (*gl*) lies adjacent to the humeral head (*h*) and the spinoglenoid notch

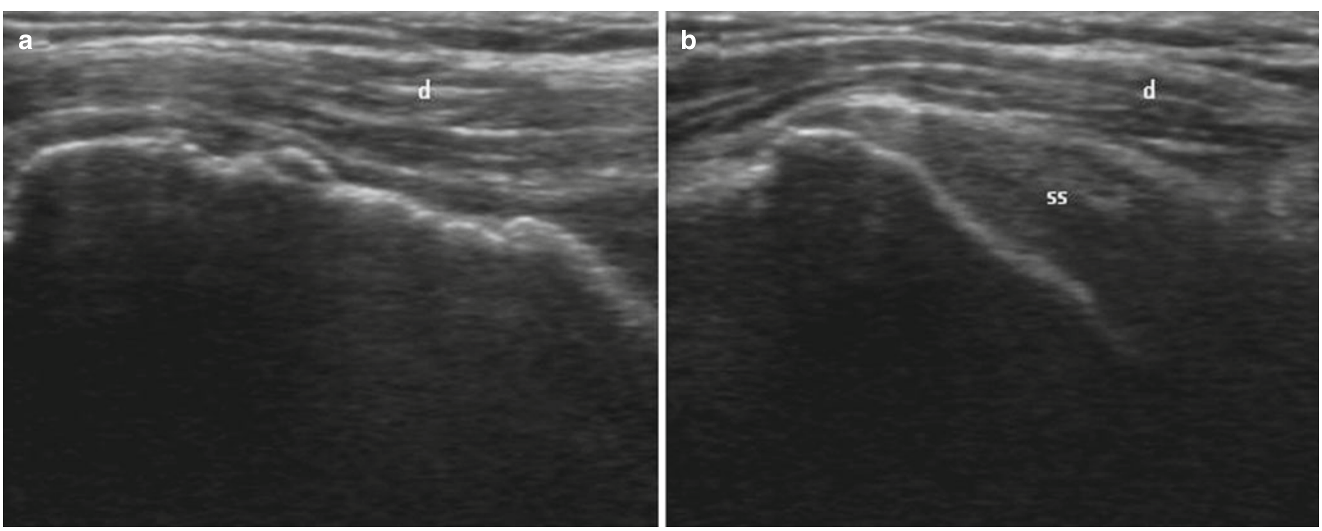

Fig. 8 Full-thickness supraspinatus tendon tear. (**a**) Longitudinal US images of the supraspinatus tendon show the non-visualization of the distal supraspinatus tendon and dipping of the deltoid muscle (*d*) into the tendon gap (**a**). (**b**) Normal ultasound image of the supraspinatus tendon. Supraspinatus tendon (*ss*); deltoid muscle (*d*)

Partial-thickness tears are diagnosed when there is a focal hypoechoic or anechoic defect in the tendon and this involves either the bursal or the articular surface and it is present on two perpendicular planes.

A partial-thickness supraspinatus tendon tear extends either to the articular or bursal surface of the tendon.

A bursal-side partial-thickness tearproduces a flattening of the bursal surface, and it is associated with a loss of the superior convexity of the tendon.

An articular-side partial-thickness tear appears as a distinct hypoechoic or mixed hyper-hypoechoic defect of the articular surface (Fig. 10).

Intra-tendinous tears not extending to the bursal or articular surface are unusual. It possible to measure the size of the tear in centimeters directly on freeze-frame images using the cursor software function.

Fig. 9 Supraspinatus tendon long axis view shows fluid-filled subdeltoid bursa (*b*) under the deltoid muscle (*d*). Over the humeral head, there is a hypertrophy of the synovium. Humerus head (*h*); sovraspinatus tendon (*s*)

Subscapularis and Infraspinatus Tendon Tears

Isolated tears of the infraspinatus and subscapularis are very uncommon. Tears within these tendons usually occur due to an extension of a tear of the supraspinatus tendon. The reported incidence of subscapularis tendon tears among rotator cuff tears ranges from 2.1 to 10.5 %. Isolated tearing of this tendon is rare. It usually occurs if the patient falls forward with his or her arm in an externally rotated position. It is more commonly torn in association with the supraspinatus tendon when the tear crosses the anterior interval (where the long head of biceps tendon, coracohumeral, superior glenohumeral, and transverse ligament meet) [12]. One of the primary symptoms involving a subscapularis tendon tear is general shoulder pain, which is often located more anteriorly than pain reported from patients with most rotator cuff tears (Fig. 11).

Rupture of the infraspinatus is not necessary for fatty changes to occur in the muscle; but when the tendon is torn, the progression of infiltration is more rapid and severe. The infraspinatus muscle is the main depressor of the humeral head, and fatty infiltration of the muscle can result in proximal migration of the humerus along with subacromial impingement and a loss of strength in external rotation and elevation [13]. Therefore, the infraspinatus muscle plays a vital role in shoulder function by statically and dynamically centering the humeral head within the glenoid. The insertion of the tendon into the greater tuberosity as well as the articular capsule remains intact in these cases; thus, there is no full-thickness tear of the rotator cuff in the arthrographic

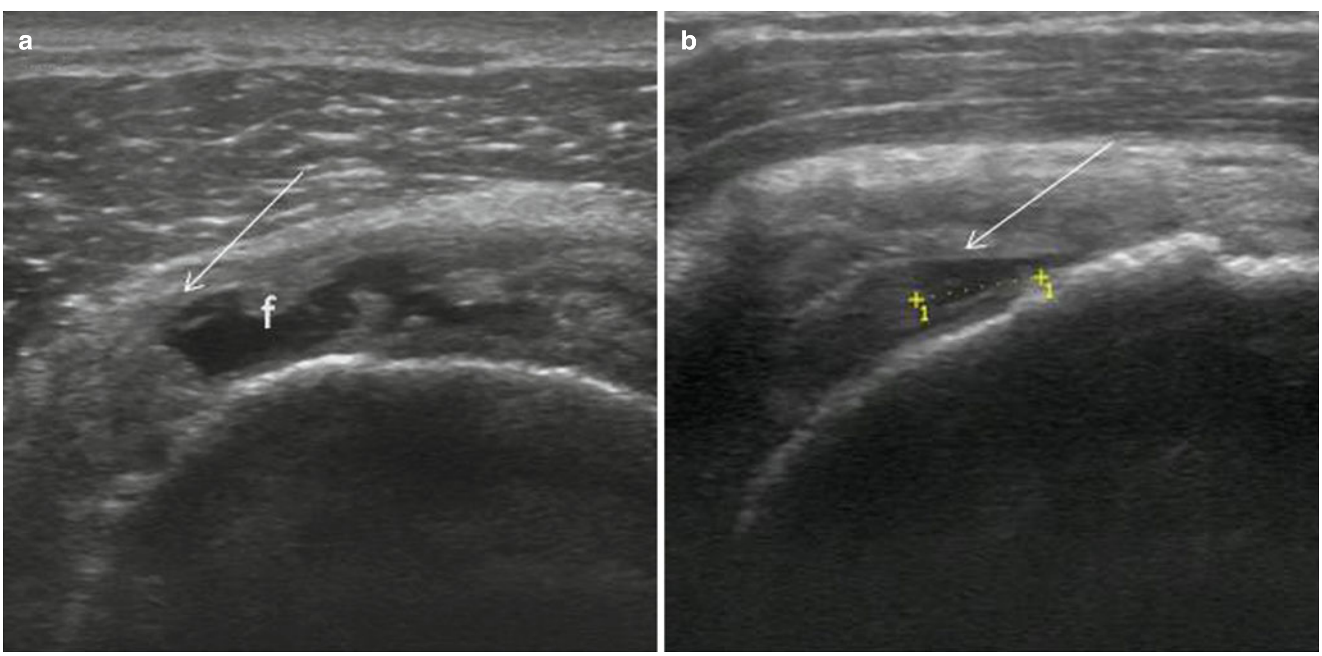

Fig. 10 Partial-thickness tear of the deep surface of the supraspinatus tendon. Transverse US scan (**a**) and longitudinal (**b**). The deep fibers of the tendon are disinserted and considerably retracted (*arrows*) causing a US pitfall. *The tendon shows fluid-filled* (*f*)

sense of the word. It is associated with an acute phase including a severe inflammatory reaction of the muscle and its retraction into the fossa. Several months later, severe fatty infiltration develops and replaces the initial muscular edema (Fig. 12).

Lower fatty infiltration of the supraspinatus and of the infraspinatus muscles suggests a good functional outcome while fatty atrophy indicates a poor prognosis. Fatty infiltration also results in increased echogenicity. This is best identified by comparing the echogenicity of the supraspinatus and the infraspinatus with the adjacent deltoid or trapezius muscles. Fatty infiltration is present if the supraspinatus or the infrapinatus are more echogenic than the deltoid or the trapezius. While the biological cause of fatty infiltration remains unclear, it has been shown that the loss of strength associated with fatty changes of the cuff musculature are not affected by a repair of the cuff tendon [14, 15].

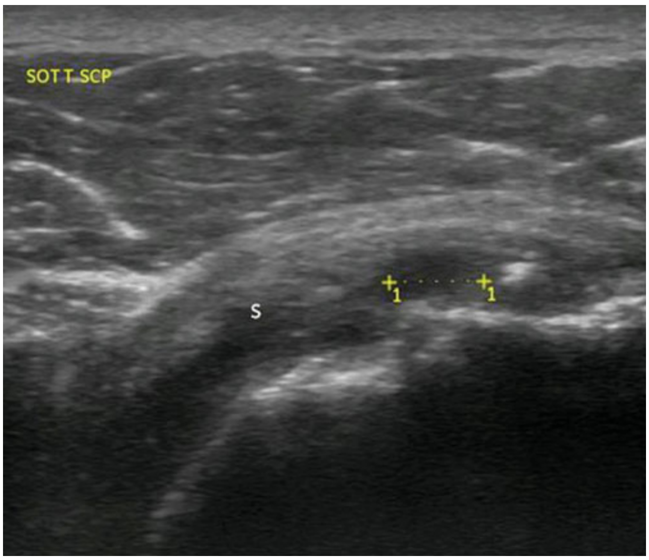

Fig. 11 The patient has to extrarotate his arm from the starting position while keeping his upper arm adducted and the elbow flexed at 90º. Longitudinal view scan. Signs of partial-thickness tears include focal anechoic or hypoechoic defects in the joint surface of the tendon; tendon fibers (*s*)

Limits

The limitation of US examination is related to the relevant hardware; the US machine must be new, good quality, and it must be equipped with a high-frequency probe. The physician must furthermore understand that this examination is difficult and that it requires years of experience and the acquisition of specific US techniques along with a good knowledge of the anatomy of the shoulder and its pathologies [16, 17]. Obesity is a considerable obstacle as the US beams are absorbed by adipose tissue. Obesity furthermore increases the distance between the probe and the anatomic structures under examination thus imposing a lower frequency and therefore a lower resolution of the probe. Also, decreased mobility of the shoulder, regardless of its cause (pain, capsular contracture, arthropathy) makes it difficult to study the cuff, if retropulsion of the shoulder and internal rotation of the arm is limited. It is less likely that anisotropy is a cause of abnormal tendon hypoechogenicity, as only tendon segments that are perpendicular to the ultrasound

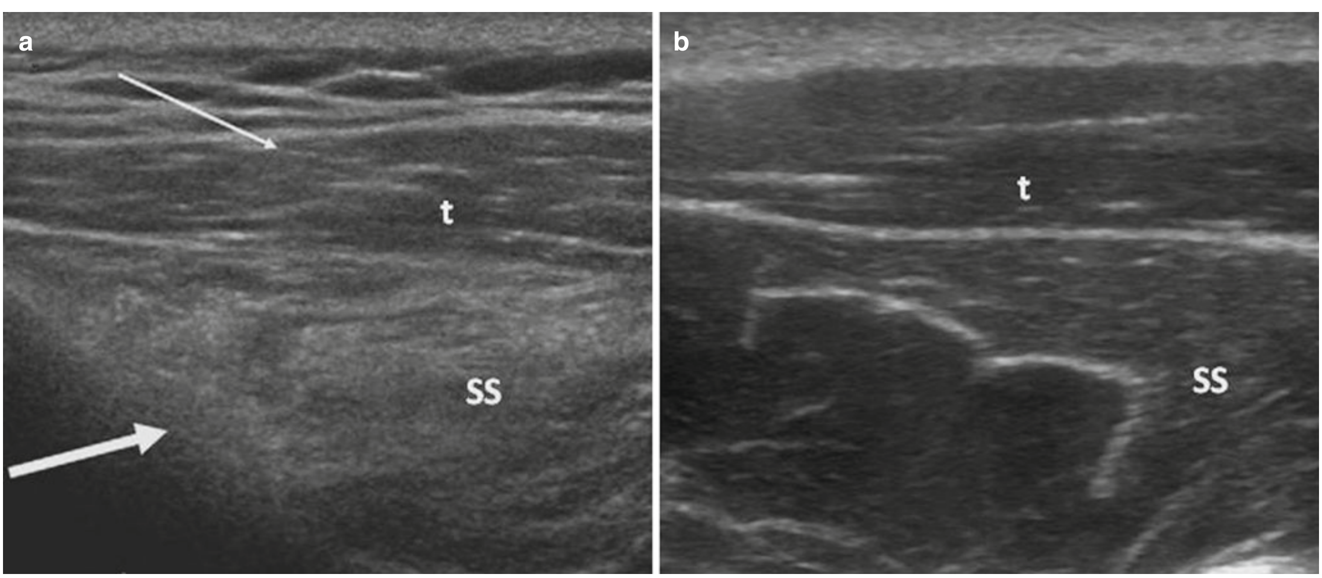

Fig. 12 (**a**) shoulder with cuff tear. Sagittal scan of infraspintus muscle showing advanced fatty infiltration. Infraspinatus (thick arrow) has lost its normal internal architecture and is diffusely echogenic compared with the overlying deltoid muscle (*thin arrow*). (**b**) Controlater healthy shoulder. Infraspintus muscle (*ss*); trapezius muscle (*t*)

beam are assessed for abnormality. The presence of bone structure like acromion could make it extremely difficult to visualize tendon retraction in the event of complete tears because the bone structure reflects all US and creates a black shape image.

Ultrasound Guided Injection

There are four major reasons for a glenohumeral joint injection: (i) osteoarthritis and adhesive capsulitis (frozen shoulder), (ii) rheumatoid arthritis, (iii) acute subacromial burisitis, and (iv) brachial bicipits tenosinovitis.

Although the glenohumeral joint may be accessed anteriorly or posteriorly, our preferred approach is the latter. This technique is used to instill either a corticosteroid for the management of frozen shoulder or to contrast medium for CT or MR shoulder arthrography.

The Posterior Approach An examination is performed on the axial plane to visualize musculotendinous junction of the infraspinatus muscle, just inferior to the scapular spine, with the posterior glenoid rim and posterior glenohumeral joint line centered in the field of view. The needle is introduced laterally on an axial plane and is advanced medially. The needle target is between the most posterior aspect of the humeral head and the posterior labrum (Fig. 13a, b). It is necessary to proceed with caution so as not to puncture the labrum or articular cartilage. With the correct and proper intra-articular placement, the drug will flow easily into the joint. If there is resistance to the injection, gently twirling the syringe or withdrawing the needle by 1–2 mm while continuing to inject a small amount of drug will often resolve the problem. A 25-G needle used for local anesthesia will suffice in accessing this joint with a single puncture. In some cases, the use of a longer 22-G spinal needle may be required (Fig. 14). Shoulder joint injection using a posterior approach

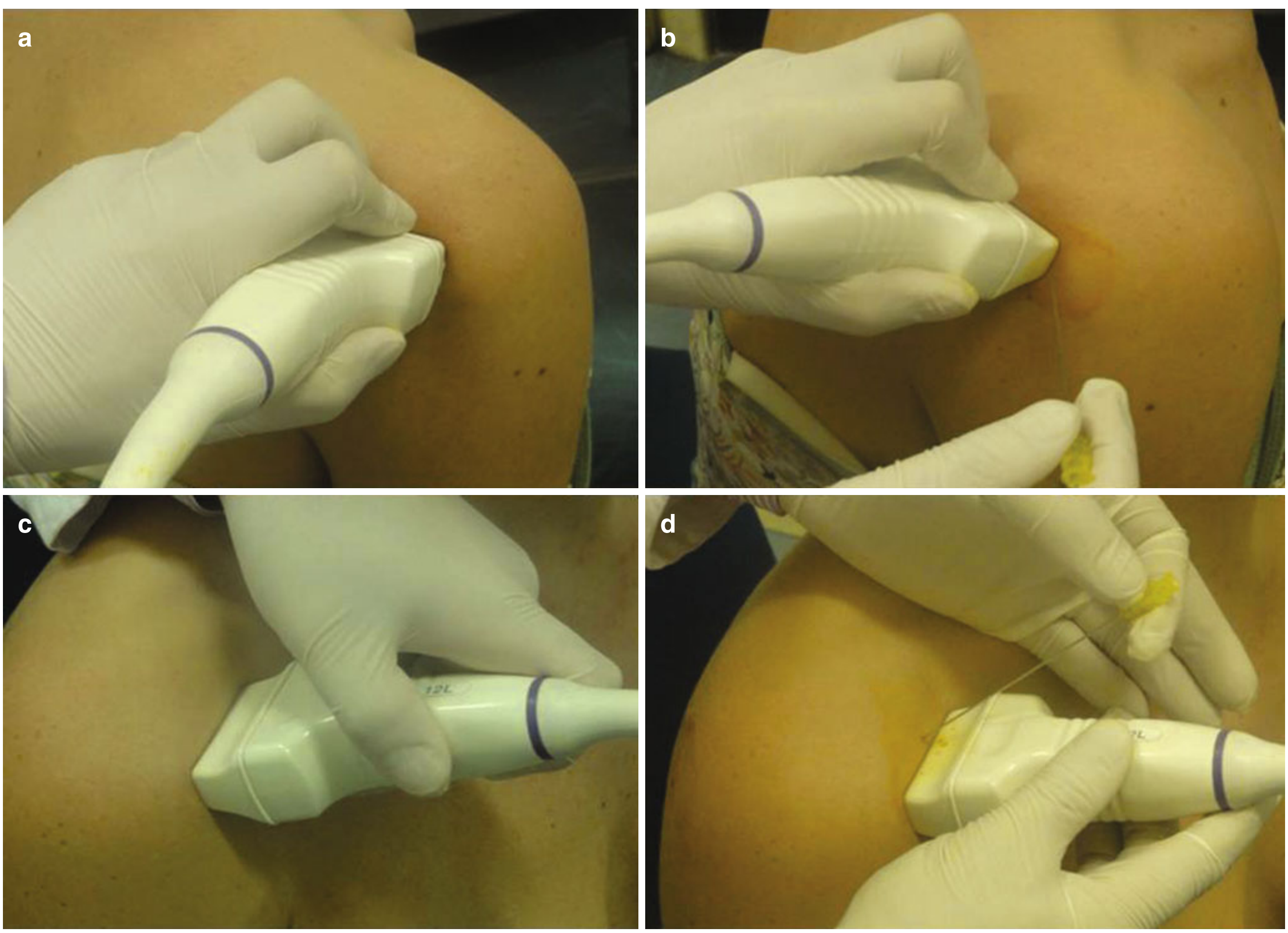

Fig. 13 Glenohumeral joint injection: posterior and anterior approaches. (**a**) Posterior ultrasound examination of the glenohumeral joint (**b**) and lateral needle introduction. Anterior ultrasound guided needle introduction into the joint, with needle between coracoid process and humeral head (**c**, **d**)

under sonographic guidance is tolerated quite well; this approach also completely eliminates the risk associated with an anterior approach of accidental puncture or injection of the major axillary neurovascular structures.

The Anterior Approach The patient should be placed in a supine position on an examination table with his or her extended arm externally rotated, or the patient could be seated with his or her arm in a neutral position (Fig. 13c, d). Axial slices in the anterior area of the shoulder are obtained to localize the coracoid process, the anteromedial portion of the humeral head, and the long axis of subscapular tendon. The coracoid process is identified as a hyperechogenic structure 1 cm wide, medial to the humeral head. The articular cartilage is a homogeneous hypoechogenic curvilinear band over a hyperechogenic layer that represents the subchondral bone of the humeral head. Once the anteromedial portion of the humeral head and the coracoid process are localized, a 21-gauge (0.8 × 40 mm) needle can be introduced at a 45° inclination angle to the limb and it may be inserted into the shoulder joint. This is always performed during an ultrasound. When the needle makes contact with the articular cartilage of the humeral head, the needle is tilted to position the point of the needle in the articular cavity. The intra-articular position of the needle and the complete distention of the shoulder joint are confirmed by sonography. It is necessary to closely examine the long portion of the biceps, glenoid cartilage, and vascular structures. Positioning the point of the needle requires careful attention. It is recommended that the beveled side of the needle is placed adjacent to the humeral head.

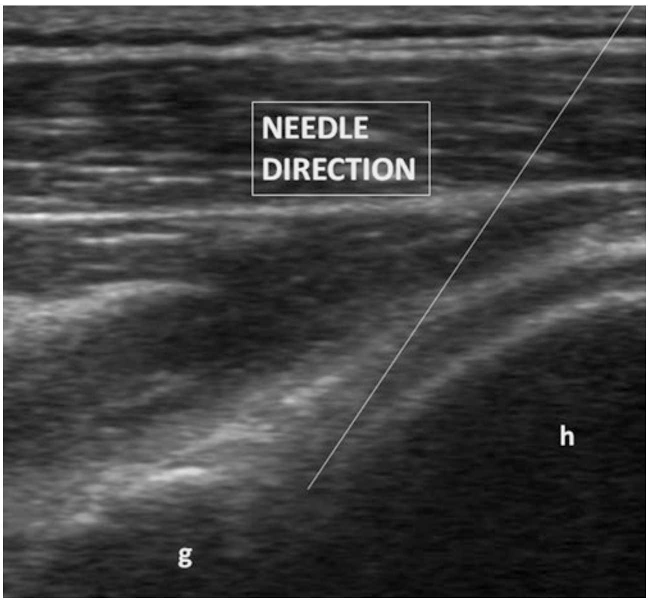

Fig. 14 Posterior approach with needle inserted between humeral head (*h*) and glenoid (*g*)

Intra-bursal Injection

US-guided injection is performed using a free hand technique. Patients lay supine on an examination table or sit upright facing the radiologist, keeping his or her arm in a neutral position and the palm of his or her hand facing upward. Once the bursa has been localized, a 21–23-gauge, 50 mm needle is inserted parallel to the transducer from the anterior aspect of the shoulder. The needle is advanced under real-time US control until the needle tip enters the bursa (Fig. 15). To optimize the visualization of the tip, it is inserted with the beveled side facing the transducer.

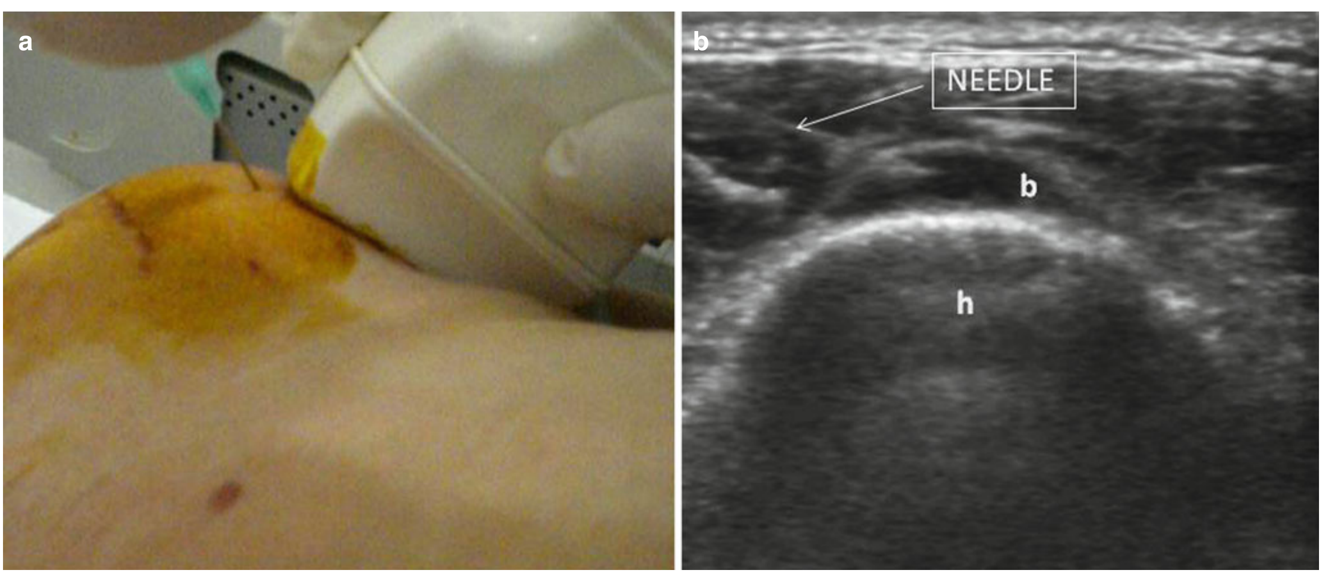

Fig. 15 (**a**) Ultrasound-guided intra-bursal injection from the anterior approach of the shoulder. The needle is inserted parallel to the transducer. (**b**) The needle (*arrow*) is guided into the bursa (*b*); humerus (*h*)

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Part IV

Cuff Tear Treatment

Natural History

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International literature has always shown more interest in the surgical treatment of the rotator cuff tear rather than in the medical or physiotherapy ones. However, the orthopedic surgeon should be able to propose, among the various treatment options, also the conservative treatment, as many tears can become asymptomatic over time. In addition, many patients with cuff tears are in their seventies and often carriers of chronic diseases that contraindicate surgery except for treatments closely related to patient survival.

The lack of information regarding tear's natural history puts the examiner in trouble when he must respond to specific questions on the possible evolution of the injury, pain and motion or about the possibility of spontaneous healing. In addition, the examiner should know the time in which irreversible histological changes occur, changes that may affect the result of an immediate treatment or lead to the choice of a more complex surgical treatment.

In this chapter, we summarized information obtained from recent studies on natural history of cuff tear, also enriched by the daily experience of the authors.

Asymptomatic Full-Thickness Rotator Cuff Tears

Many cuff tears are asymptomatic because they do not compromise the biomechanical balance determined by the action of external and internal rotator tendons [1]; because they are accompanied by poor or absent inflammatory bursal tissue [2]; or because they are not associated with tendinitis/tendinosis of biceps long head tendon [3].

Potentially, some of these lesions may become symptomatic over time. Yamaguchi et al. [4] have followed for a mean period of 5.5 years patients with a symptomatic tear on one side and an asymptomatic one on the other side, and observed that 51 % of asymptomatic tears became symptomatic after a mean of 2.8 years (Table 1).

Furthermore, 50 % of these new symptomatic lesions increased its size, while only 20 % of those that remained asymptomatic showed a progression. None of the patients belonging to this series presented spontaneous healing. In the series of Moosmayer et al. [3], among 50 patients with asymptomatic tear followed clinically for 3 years, with ultrasound and MRI, 18 (36 %) have become symptomatic. Mall et al. [5] have recently compared 34 patients who became symptomatic over time with 35 who remained asymptomatic. The authors noted that the symptoms appear after an average of 2 years from the initial assessment and they usually arise in those tears that increased in size ($p<0.01$). In fact, the extension of the lesion was more frequent in the group of patients who became symptomatic (23 %) than in the remaining asymptomatic group (4 %). In addition, the authors believe that the larger the size of the lesion, the higher the probability that cuff tear may become symptomatic in a short time.

Therefore, analysis of these data leads us to the following two observations: (a) cuff lesion has little or no capacity for self-repair, (b) the increase of tear size often makes it symptomatic.

In a ultrasound study performed on 588 patients with bilateral rotator cuff tear, Yamaguchi et al. [6] observed that asymptomatic lesions have an extension of 30 % less than the symptomatic ones. Therefore, a surgeon should always suspect an increase of the lesion every time that an asymptomatic patient becomes symptomatic.

It is possible that tear extension leads to the onset of pain because: (a) it alters the normal glenohumeral kinematics [1], (b) it results in a gradual upward migration of the humeral head [7, 8], and (c) it causes a greater activation of muscle-tendon units involved in the lesion (overcompensation), compared to the activation of the healthy units [9].

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Table 1 FAQ of patients with full-thickness rotator cuff tear

Full-thickness tears	How many tears become symptomatic from asymptomatic?	Probably 50 %, after 5 years
	How many tears become asymptomatic from symptomatic?	60–70 % after 2.5–7 years However, only half of them are correlated with good functional scores
	Among cuff lesions, how many tears increase in size?	Probably after 3 years: 50 % of symptomatic 20 % of asymptomatic
	How many tears heal spontaneously or at least regress?	Conflicting data: 0–37 % Authors' thought: 0 %
	What are the lesions most likely to progress?	The symptomatic and the wider ones and those belonging to older patients (over 65 years)
	Is tear progression constant?	Initially it is slow (first 2 years), then it is faster, especially in older patients
	Is pain considered a negative prognostic factor?	Yes; pain is a sign of tear progression Symptomatic tears have a mean extension greater than the asymptomatic ones

Symptomatic Full-Thickness Rotator Cuff Tears

Surgeons who are interested in the treatment of shoulder disorders are well aware that many patients with symptomatic rotator cuff tear report, over time, that shoulder pain has lessened or even disappeared.

Goldberg et al. [10] evaluated, with the simple shoulder test (SST), subjective symptoms of 46 patients with symptomatic lesion conservatively treated. The assessments were made every 6 months and for a period of 2.5 years. Fifty-nine percent of patients in this series had an improvement in symptoms that was maintained throughout the follow-up period. Bokor et al. [11] have re-evaluated 53 patients with symptomatic rupture after a mean period of 7.6 years; among these, 74 % reported having no pain or have only mild discomfort; but only 56 % had a satisfactory "UCLA score." A similar result was observed by Hawkins and Dunlop [12]. In their series, consisting of 33 patients, 58 % had achieved an improvement in terms of pain and range of motion after an average period of 3.8 years.

Maman et al. [13] evaluated 33 patients with symptomatic tear and observed that, at a median follow-up of 2 years, the lesion had increased in size in 52 % of cases and that the increase occurred predominantly after 18 months (50 %) and rarely before this time (19 %). Obviously, tear progression was also correlated with patient age and state of muscles fatty degeneration of the respective broken tendons. Safran et al. [14], followed over time (mean follow-up 29 months), 51 symptomatic patients. Also in this series, 49 % of cuff tears became larger. Forty-three percent of the lesions had no significant changes, while in 8 % of tears a reduction of its initial size was present. On the other side, in 24 % of initially healthy shoulders, a cuff injury was diagnosed. Mall et al. [5] report that patients with symptomatic rupture have a higher probability that their lesion size may increase (18 %) than the asymptomatic patients (5 %). The analysis of these data leads to the assumption that: (a) approximately half of the patients with symptomatic rotator cuff tear undergo a progressive increase in the size of the lesion and that (b) this increase occurs after a mean period of 2 years.

In contrast with from Maman et al. [13] and Safran et al. [14], Fucentese et al. [15] observed that, at a mean follow-up of 3.5 years, in only 25 % of 24 symptomatic patients (mean age 54 years) with a tear less than 1.6 cm, conservatively treated, a progression of the lesion occurred. In addition, in the cases of a progression, it did not compromise the tear repairability.

Therefore, these data suggest that young, symptomatic, and with a small tear patients can initially be treated conservatively as the risk that a progression of the lesion occurs is still low.

Zingg et al. [16] examined clinically, with RX and RM, 19 patients with a massive tear, mean age of 64 years, with mild symptoms and poor functional claims. Four years after the first observation, patients maintained a satisfactory functional status although they presented greater degenerative joint changes.

Asymptomatic and Symptomatic Partial-Thickness Tears

Natural history of symptomatic and asymptomatic partial tears has been studied by Mall et al. [5]. The authors followed over time (mean follow-up: 2 years) 30 patients with asymptomatic partial lesion; 20 of them were asymptomatic, the others started to have pain. During ultrasound examination, none of partial tears had become full-thickness ones, while the worsening had occurred in 40 % of the lesions which became symptomatic. Pain, as for full-thickness lesions, appeared closely related to the increase of tear size.

Maman et al. [13] re-evaluated, after 2 years, 30 patients with symptomatic partial-thickness lesion diagnosed by MRI. In this series, only 10 % of the lesions increased in size (>5 mm); this data is significantly lower than the one reported for full-thickness lesions (50 %). No difference was found between progression of the partial tear on bursal side compared to that on the articular side.

These data suggest that partial-thickness tears have low tendency to progress in the first 2 years; therefore, especially at the beginning, the best treatment of patients with this type of lesion should be conservative. However, as it is possible that these lesions remain asymptomatic for a long time, and therefore undetected, in front of an occasional diagnosis it is incorrect to state that they cannot become full-thickness tears in the short period.

Spontaneous Healing

Some authors [17–19] studied the possibility of a spontaneous healing of rotator cuff tendons in animal models. These studies provide histological information on the reparative tissue, but may be altered by the fact that the shoulder of laboratory animals is subject to load and that the tendon tissue may, as in humans, have different degrees of individual degeneration that largely depend on age, but also on heredity, metabolic disorders, peripheral microcirculation disorders, and anatomical variations. Therefore, to reduce the possibility that results may be influenced by individual factors, the animals should be taken from the same farrow.

In the study by Hirose et al. [17] carried out on 4 rabbits, no spontaneous healing of supraspinatus tear, of about 12 mm, was found after 3 weeks. On other 16 rabbits, a lesion of 5 mm was then practiced. The macroscopic and histological examination at 1, 2, 3, and 4 weeks (performed for each interval of tie on 4 rabbits) showed the presence of reparative tissue in increasing proportion.

Carpenter et al. [18], in a study conducted on mice, produced a 2 mm^2 tear of the supraspinatus tendon on both shoulders. Furthermore, tendon tissue adjacent to the lesion on the left shoulder was subjected to refrigeration so that it had a reduced capacity to repair. Twelve mice were sacrificed at 3 weeks and an equal number, at 6 and 12 weeks. At the last follow-up, 78 % of the animals still had the tendon defect; furthermore, the mechanical strength properties of the repaired tissue were lower than those of the healthy one.

In another study on mice, Gimbel et al. [19] studied the repair tissue present after 12 weeks from the detachment of the supraspinatus tendon. In all the samples, only scar tissue was observed.

Clinical studies on humans provide conflicting results. Yamaguchi et al. [4] observed that none of the patients with symptomatic or asymptomatic lesion had a reduction in the size of the lesion after an average period of 5 years.

Weber [20] performed an arthroscopic or open debridement, associated with an acromioplasty, on 55 patients with a partial-thickness rotator cuff tear. Tendon healing has never been observed at a second arthroscopic evaluation carried out after 2–7 years. In a study conducted by Kartus et al. [21], there was no healing at a mean follow-up of 101 months in patients treated with arthroscopic acromioplasty for a partial-thickness rotator cuff tear.

Similarly, Massound et al. [22] performed an acromioplasty and an arthroscopic debridement in 114 patients with a small full-thickness lesion. At the follow-up (2–5 years), none of the 25 patients who underwent reoperation because of the beginning of pain had a healing or a reduction in tear size.

Among 40 patients re-evaluated after 14 months with arthrography by Yamanaka and Matsumoto [23] suffering for a symptomatic partial tear of the articular side, 4 (10 %) had experienced a healing and other 4 (10 %) a reduction in tear size.

In the series of Safran et al. [14], consisting of patients with lesions larger than 5 mm, 8 % of them, re-evaluated by ultrasound after a mean follow-up of 29 months, showed a smaller lesion. Fucentese et al. [15], however, have evaluated with MRI, and after 2 years, 24 patients with a small cuff lesion conservatively treated. Of the 24 patients, 9 (37.5 %) had experienced a reduction in tear size.

Gumina et al. [2] performed a study on the role of a pro-inflammatory cytokines transcription factor (NFkB), present on the edges of cuff tear. The authors found that NFkB concentration increases with the increase of the lesion size. As one of the recognized NFkB roles is the opposition to natural apoptosis [24–27], it is possible that its activation is induced by the tissue itself in order to limit the evolution of the degenerative process, which is, in turn, the main factor predisposing to tendon rupture. However, as the biggest concentration of activated factor was recovered in massive tears, it is conceivable that NFkB is not able to cope with the natural progression of tendon degeneration. Furthermore, the depletion cell (fibroblasts/fibrocytes) also leads to an alteration of collagen metabolism, which in turn leads to tissue degeneration [28]. Finally, it is known that massive tears are poorly covered by bursal tissue, from which should start the biochemical stimuli to the tissue repair (NFkB).

Taking all this into account, these data suggest that the degenerative process, which characterizes the histology of the tissue adjacent to the tendon tear, is irreversible. Therefore, the possibility that a spontaneous tendon healing (with new tendon tissue) may occur seems highly unlikely; instead, it is more plausible that the lesion gradually increases in size.

Fatty Infiltration and Muscle Atrophy

The tear of one or more cuff tendons is followed by a progressive retraction of the tendon itself and the relative muscle belly. The retraction leads to a change on "pennature" muscle angle compared to the raphe. Gerber et al. [29] believe that this change will allow fat tissue to infiltrate the muscle. Analyzing the axial CT scans, Goutallier et al. [30] were the first to quantify the degree of muscle degeneration in patients with rotator cuff tear. Authors believed that it occurs mainly in large and massive lesions and in older ones (never earlier than 6 months after the injury).

Since then, the degree of fatty infiltration was considered an important negative prognostic factor for tendon healing and for final outcome. In fact, a significant tendon retraction with severe fatty infiltration is correlated to a low possibility of muscle mobilization and tendon repair [31–33]. Fuchs et al. [34], Jost et al. [35], and Liem et al. [36] have independently verified that fatty infiltration does not regress after surgical repair, but rather continues in its evolution. Despite the importance given to muscle infiltration in order to estimate the possibility of healing and to obtain a good result, few studies are present in the literature about: factors predisposing to fatty infiltration; the quickness of fatty infiltration progresses; and the correlation between fatty infiltration and atrophy. By analyzing CT scans and MRI, Melis et al. [37] observed that a moderate (state Goutallier 2) or marked (state Goutallier 3–4) fatty infiltration of the supraspinatus appear after an average of 3–5 years after the onset of symptoms, respectively. The authors also indirectly measured the degree of supraspinatus atrophy using the "tangent sign" described by Zanetti et al. [38]. This method is applied on the CT scan or MRI of the more lateral sagittal plane. A healthy muscle should cross the line from the top edge of the coracoid to the top edge of the spine of the scapula (the line is called "kickback"). The "sign" is positive when the muscle does not cross the tangent. According to the authors, the sign becomes positive after an average of 4.5 years from the onset of symptoms. Based on the results that were obtained, Melis et al. [37] suggested to perform surgery on a patient with a supraspinatus tear before he has developed a moderate fatty infiltration or a positive "tangent sign."

The same author [39] has also extended the study on the natural history of infraspinatus fatty infiltration. This muscle is the main depressor of the humeral head (see Chapter "Rotator Cuff Biomechanics"), so its inefficiency leads to an impingement syndrome and to a loss of strength in flexion and external rotation [40]. Furthermore, the achievement of a stage 3 or 4 of Goutallier involves a significant loss of strength in flexion and external rotation, with a consequent "drop sign" positivization [41] (if supraspinatus and infraspinatus are involved by the tear) and the "horn blower sign" [42] (if lesion involves also the teres minor). The study showed that the wider and older tears and those belonging to older patients are the ones that most frequently develop a fatty infiltration of muscle. Stage 2 of Goutallier would appear, according to the Authors, after a mean period of 2 years and a half after the onset of symptoms. In addition, fatty infiltration of the infraspinatus can also occur in lesions that do not directly involve this muscle.

Maman et al. [13] consider that, after two years from the onset of a full-thickness lesion, only a quarter of patients develop fatty infiltration and that in these patients tear progression occurs faster. According to the authors, fatty infiltration is not present in partial-thickness tears (Table 2).

Fucentese et al. [15] followed, for more than 3 years, patients with a small full-thickness tear of the supraspinatus and observed, at the end of the follow-up, a mean increase in fatty infiltration, which, however, did not exceed the Goutallier 2 stage.

Zingg et al. [16] showed that all of the 19 patients with low functional demands and massive cuff tear had an increase of at least one Goutallier stage of the affected muscles after a mean follow-up of 4.5 years.

Table 2 FAQ of patients with partial-thickness tear

Partial-thickness tear	How many tears become symptomatic from asymptomatic?	Probably 30 %, after 2 years
	Among partial lesions, how many tears increase in size?	Probably, after 2–3 years: 10–40 % of symptomatic 0 % of asymptomatic
	How many tears heal spontaneously or at least regress?	Conflicting data: 0–37 % Authors' thought: 0 %
	What are the most likely to progress lesions?	The symptomatic ones and those belonging to older patients (over 65 years)
	Is pain considered a negative prognostic factor?	Yes; pain is a sign of tear progression

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The Possible Role of the Transcription Factor NF-kB on Evolution of Rotator Cuff Tear and on Mechanisms of Cuff Tendon Healing

Stefano Gumina

NF-kB (nuclear factor kappa beta) is a transcription factor that has an important role in the immune system [1–3]. It regulates the expression of inducible nitric oxide synthase, cytokines, cyclo-oxgenase 2 (COX-2), growth factors, and effector enzymes [1–3]. It also has a role in the development and the activity of a number of tissues including the central nervous system [4]. Moreover, pathological dysregulation of NF-kB is linked to inflammatory and autoimmune diseases as well as cancer [1].

NFkB family is composed of five related transcription factors (p50, p52, RelA (p65), c-Rel, and RelB). They are related by means of an N-terminal, 300 aminoacids, DNA binding/dimerization domain through which they can form homodimers and heterodimers that bind to 9–10 base pair DNA sites in the promoters and enhancer region of genes, thereby modulating gene expression [3].

NFkB is activated following stimulation of cells with pro-inflammatory ligands including cytokines, antigens, and bacterial products [5]. Furthermore, during chronic inflammation, decreased tissue perfusion and increased energy demand causes hypoxia. Cytokine levels promote inflammation through activation of the canonical (IkB kinase complex) NF-kB pathway; simultaneously hypoxia facilitates this response by decreasing hydroxylase activity which serves to de-repress NF-kB signalling [6–8].

Tang et al. [9] have demonstrated that expression of NF-kB genes is promoted manifestly by basic fibroblast growth factor (bFGF) and that NF-kB may play a pivotal role during in vivo healing of the flexor tendons of the hand.

Therefore, we have recently verified [10] if NF-kB, whose activation has been demonstrated on samples of transacted and repaired flexor digitorum profundus tendons of the long toes of white leghorn [11] and during in vitro stimulation of tenocite culture with beta fibroblast growth factor (bFGF) [9], is present on the margins of the rotator cuff tears. Since it was also demonstrated that NF-kB is a regulator of anti-apoptotic gene expression [8] and that it has a role in neoangiogenesis stimulation [12, 13], we have hypothesized that NF-kB might have a role on evolution of rotator cuff tear and on possible mechanisms of cuff tendon healing.

Therefore, 63 consecutive patients (35M and 28F) with non-traumatic rotator cuff tears were recruited and enrolled the study. The mean age at the time of operation was 64 years (range 52–74). All patients underwent arthroscopic treatment of the lesion. The Southern California Orthopaedic Institute's (SCOI) classification of complete rotator cuff tears was used to classify tendon tears intraoperatively as small, large, or massive tears according to SCOI classification [14]. Obviously, patients who assumed anti-inflammatory drugs during the 2 months before surgery were excluded from the study. Other exclusion criteria were V-shaped or L-shaped lesions, glenohumeral arthritis, diabetes, and rheumatologic diseases, prior surgery.

The average elapsed time with shoulder pain before surgery was 8 months (range 2–12 months).

Samples from anterior and posterior edges of the tear and medial portion of subacromial bursa were excised during the arthroscopic surgical treatment. Furthermore, samples of uninjured subscapularis tendon from the same patients were collected in 29 cases and used as control.

Removed tissues were immediately fixed in 10 % neutral-buffered formalin and then paraffin-embedded. Serial sections were cut (3-μm) and either stained with hematoxylin and eosin for morphologic evaluation or used for immunohistochemical analysis with nuclear factor kappa B p65 antibody (NF-kB p65) (Fig. 1).

Neoangiogenesis evaluation was scored as absent or present (multifocal or diffuse).

NF-kB p65 immunostaining was either cytoplasmic (not activated protein) or nuclear with or without cytoplasmic staining (activated protein). The specific immunoreactivity was investigated in endothelial cells, tendon fibroblasts, and synoviocytes. A semiquantitative assessment of immunostaining

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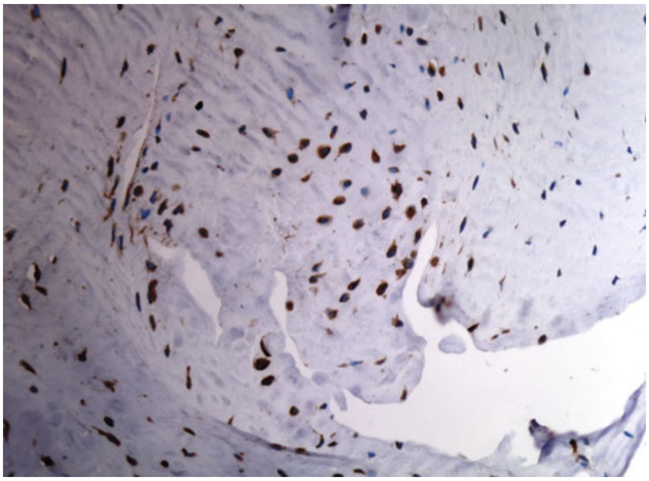

Fig. 1 Immunohistochemical analysis with nuclear factor kappa B p65 antibody. Anterior margin of a massive rotator cuff tear. Activated tenocytes. 20×

was expressed as: score 0 (not activated protein); score 1 (nuclear with or without cytoplasmic staining). In case of adulterated sample, the result was not considered; therefore, some cases were missing.

A quantitative assessment of immunostaining was also executed and was expressed as: not assessable, absent, unifocal, multifocal, widespread. However, we decided not to analyze these results because sample size is not large enough to permit an analysis at such a level of detail and because the expression of the p65 may vary in the same section, making the quantification of p65 difficult. Because no other studies were performed with the aim of establishing if NF-kB is present on rotator cuff tear margins, we considered more appropriate to focus our study on NF-kB localization rather than on a quantitative analysis, such as PCR.

Data were submitted to statistical analysis.

The results of our study are summarized in Figs. 2 and 3. These figures show the frequency of positive and negative responses to p65 and to angiogenesis, respectively, for each type of cuff tear (small, large, and massive) and in the different tissues analyzed (margins of rupture, bursa, or healthy tendon).

Figure 4 refers to the percentages of the positive responses to p65 factor. It shows that the presence of the activated p65 increases with the increasing of the tear size. This tendency was observed in the anterior and posterior margin of the cuff tear and in the subacromial bursa. Furthermore, the activated p65 factor was not present in the subscapularis tendon of patients with small cuff tear, but its presence progressively increased in the tendons of patients with large and massive cuff tears.

Analogously, we observed that neoangiogenesis grows with the increasing of the cuff tear size and that this tendency occurs in the anterior and posterior margins of the cuff tear and in the bursa (Figs. 5 and 6a, b). Unlike as it was registered for the presence of the activated p65 factor, in the subscapularis tendon the neoangiogenesis resulted equally present in the different sized cuff tears.

Although results point out that the percentage of positive responses to p65 activated factor grows as the seriousness of the cuff tear increases, there was no statistically significant difference between small, large, and massive tears, if we consider separately the anterior (chi square $=2.77$, $p=0.250$) and the posterior margin of the rupture (chi square $=5.24$, $p=0.073$). However, when we globally analyzed the results obtained for both margins, without distinguishing the anterior and posterior margin, the difference was significant (chi square $=7.66$, $p=0.02$).

For the bursae and the healthy tissue, the chi squared test may not be valid because cell frequencies were too small even though the differences that emerged among small, large, and massive tears relative to presence of the activated p65 resulted significant (bursae: chi square $=7.03$, $p=0.03$; healthy tissue: chi square $=9.2$, $p=0.01$).

The difference in angiogenesis observed in three types of cuff tears resulted statistically significant for the anterior margin (chi square $=6.17$, $p=0.046$) but not for the posterior margin (chi square $=2.39$, $p=0.3$). Again, when we globally analyzed the results obtained for both margins, without distinguishing the anterior and posterior margin, the difference was significant (chi square $=8.03$, $p=0.02$).

For the bursae and the healthy tissue, the chi square test, used to investigate the difference relative to angiogenesis in the three sizes of cuff tear, may not be valid for the same reasons explained above; however, in this case, the test was not significant (bursae: chi square $=4.4$, $p=0.11$; healthy tissue: chi square $=0.03$, $p=0.98$).

The Spearman test indicates that p65 and neoangiogenesis are correlated in spite of the dimension of the cuff tear. The correlation was present when we globally considered the results emerged by all the examined tissues ($\rho=0.299$, $p=0.0001$) and also in the case when we only considered the anterior and posterior margins of the tears ($\rho=0.236$, $p=0.009$) or the bursae ($\rho=0.429$, $p=0.0006$).

Two main results emerged from our study: (1) the presence of the activated p65 factor (one of the five transcription factors that compose the NFkB) on the margins of the tendinous rupture increased with the increasing of the rotator cuff tear size; (2) activated p65 and neoangiogenesis were correlated in spite of the dimension of the cuff tear.

Three hypotheses could explain the first result:

1. *NFkB activation induced by tissue apoptosis*. Strong support for a protective role for NFkB in apoptosis came from some studies [15–18]. Apoptosis, or programmed cell death, is a physiological process that contributes to control cell population [19]. Excessive apoptosis was

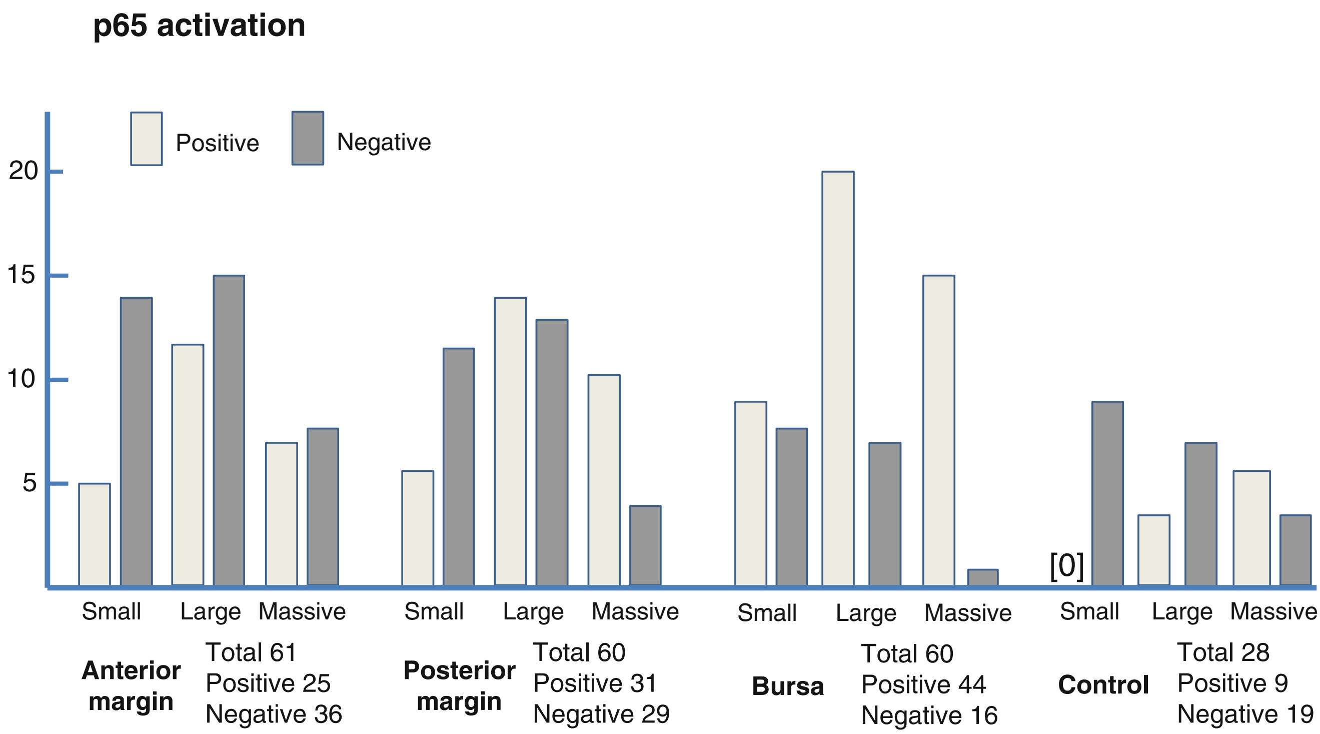

Fig. 2 Graphs representation of frequency of positive and negative responses to p65

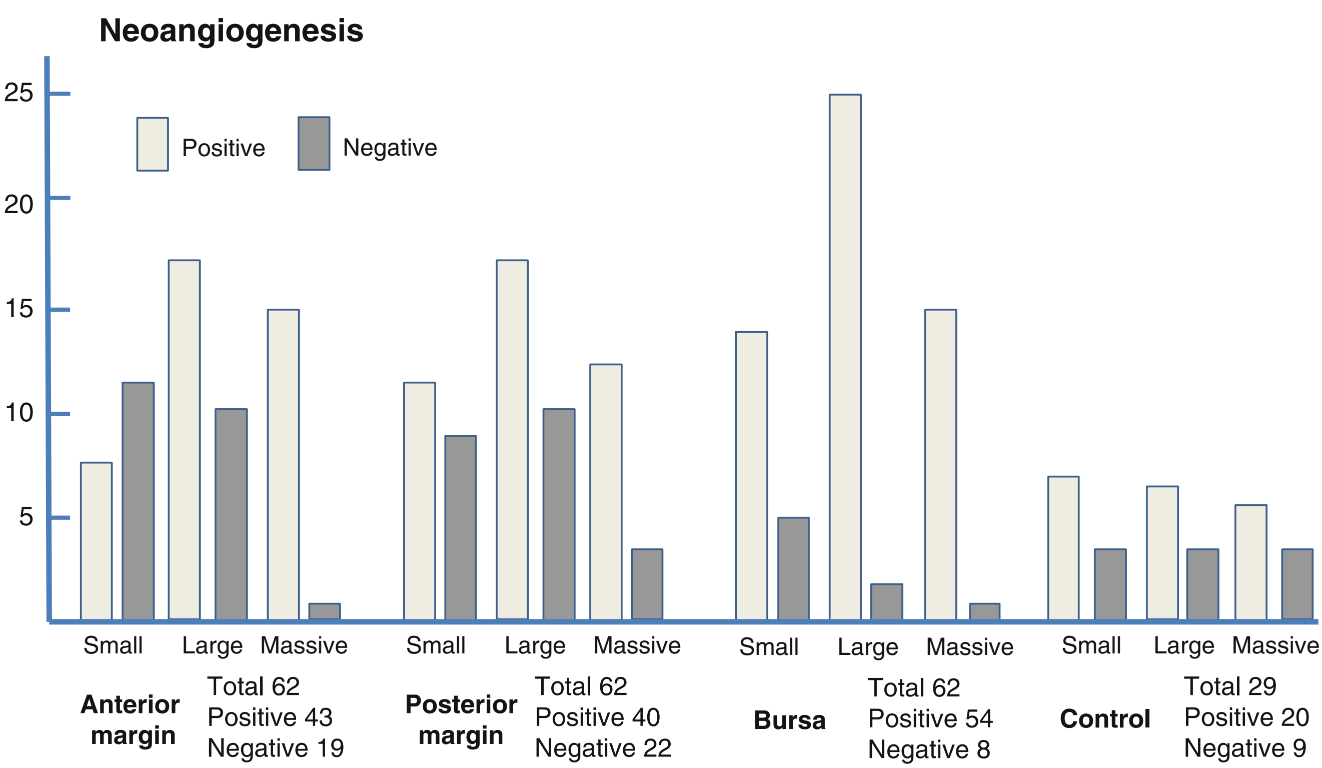

Fig. 3 Graphs representation of frequency of positive and negative responses to angiogenesis

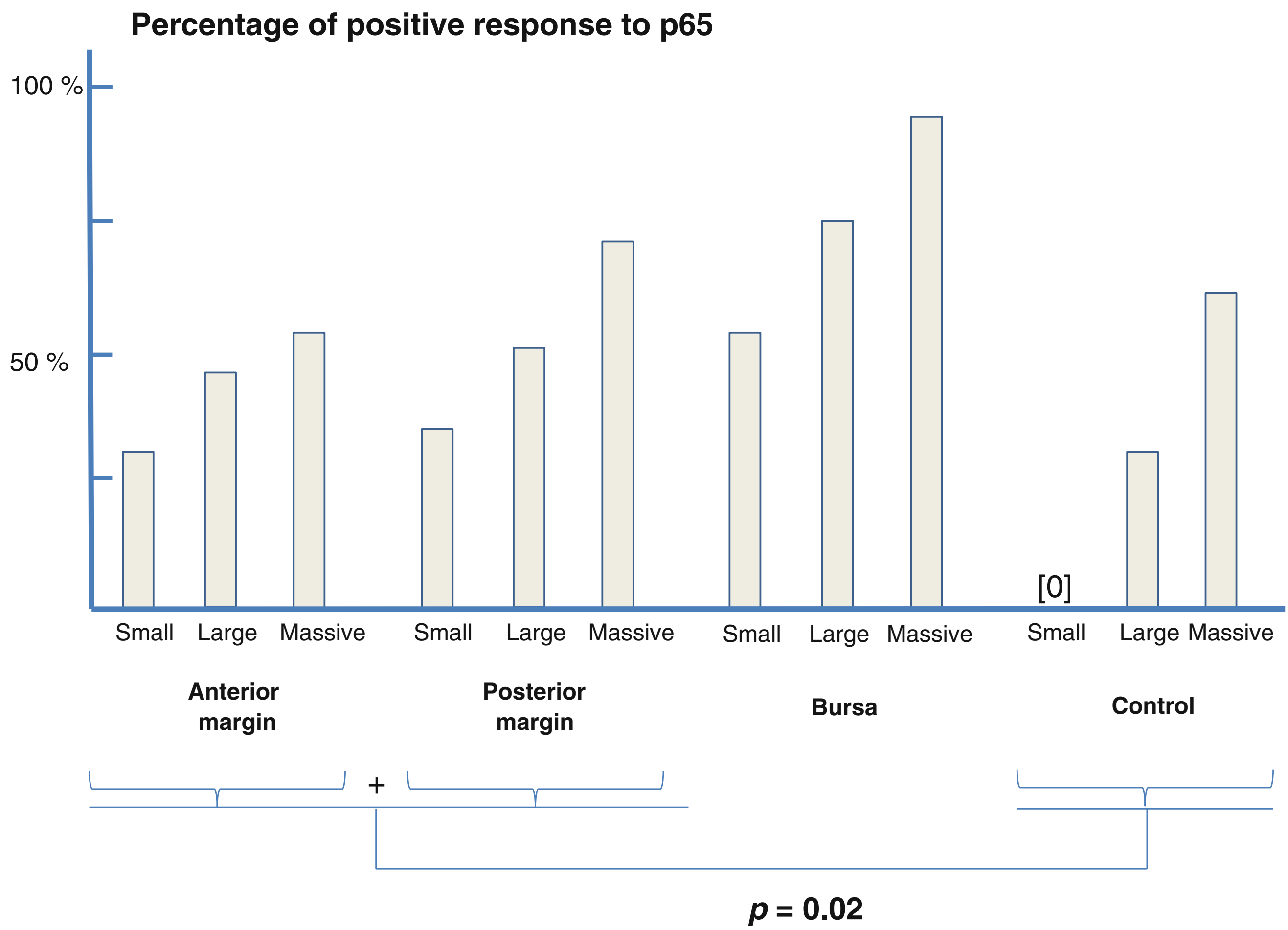

Fig. 4 Percentages of the positive responses to p65 factor. Differences obtained collapsing percentages of the anterior margin to those of posterior margin, respect to controls, resulted statistically significant (chi square = 7.66, $p = 0.02$)

observed in degenerative changes of joints [20] and in rheumatoid arthritis [21]. This phenomenon has been attributed to tissue ischemia [22, 23], hypoxia [24], free radical generation [25, 26], and nutritional imbalances [27]. However, it may be possible that the mechanism responsible for the beginning of the apoptosis is a combination of factors [28]. Therefore, our hypothesis was that NFkB may lessen, above all in massive rotator cuff tears, progression of tendinous degeneration keeping the other tendinous cells from death. In fact, Rylei et al. [5] have stated that loss of cellular activity and decreased extracellular matrix synthesis are causes of tendon degeneration. Similarly, Yuan et al. [28] believe that the reduced number of functional fibroblast/fibrocytes may contribute to impaired collagen metabolism culminating in rotator cuff degeneration. The authors have also observed that the percentage of apoptotic cells in the superior cuff tear (34 %) was significantly higher than that revealed in the controls (13 %). Furthermore, they added that there was no correlation between the proportion of apoptotic cells and the size of rotator cuff tear. This affirmation seems to be in contrast with our study because we have observed that NFkB on the margins of the tendinous rupture increases with the increasing of the rotator cuff tear size. However, the same authors considered the possibility that their results were not significant because of the relatively small number of patients (only 25). Furthermore, cuff tears size was not mentioned.

2. *Role of the subacromial bursa* (*SB*). Tang et al. [9], studying tenocyte proliferation in a vitro model, have demonstrated that expression of a series of genes along the NFkB pathway was remarkably promoted by basic fibroblast growth factor (bFGF). The effects were proportionate to in vitro cell proliferation rate. They concluded that activation of a series of genes along the NFkB pathway might play a pivot role in initiating cell proliferation during the healing process of intrasynovial tendons. Sakai et al. [29] have demonstrated that bFGF is expressed in cytoplasm of fibroblast in SB more frequently in patients with rotator cuff tear (86 %) compared to those with anterior instability (33 %).

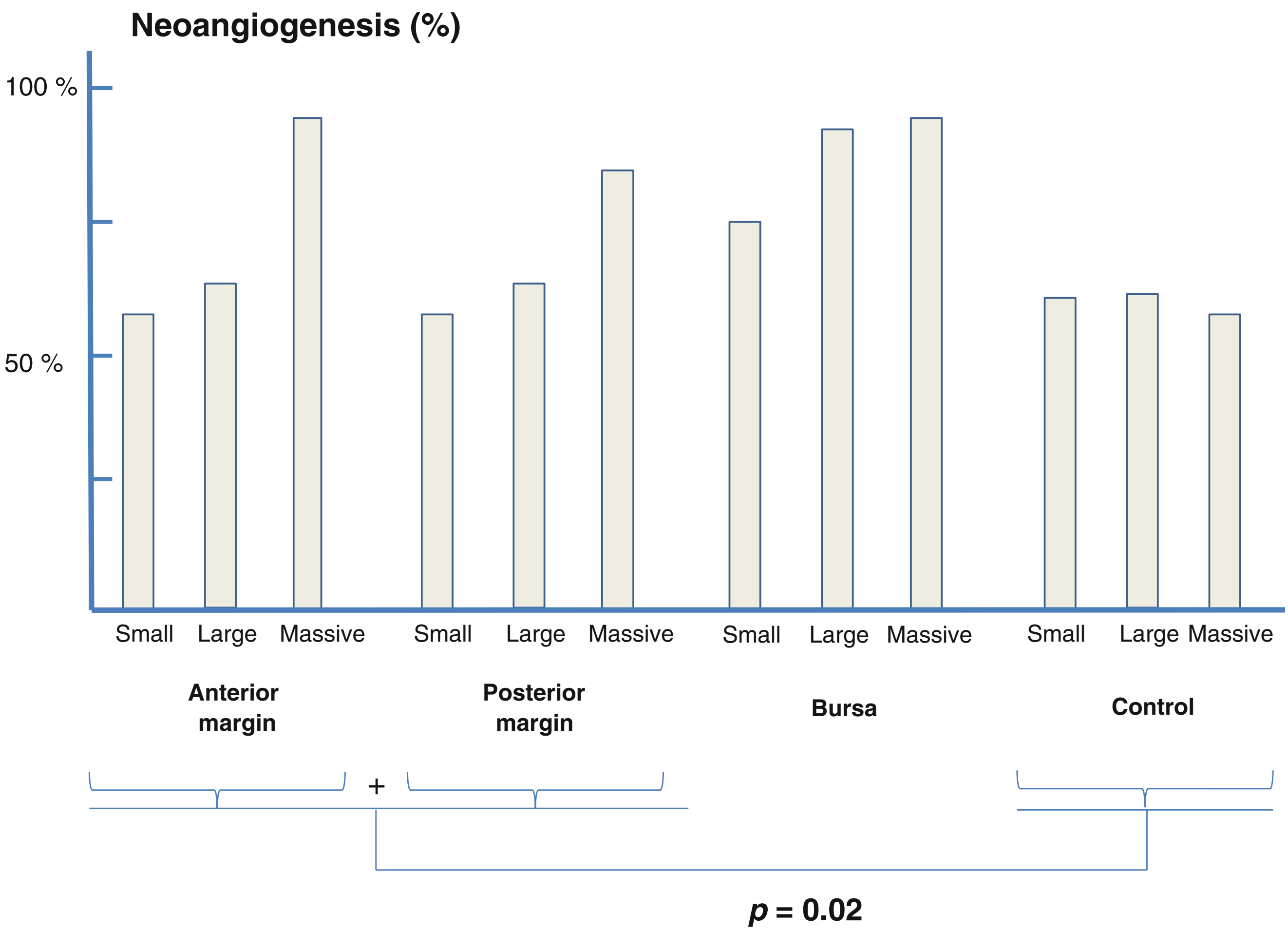

Fig. 5 Percentages of the positive responses to angiogenesis. Differences obtained collapsing percentages of the anterior margin to those of posterior margin, respect to controls, resulted statistically significant (chi square = 8.03, $p = 0.02$)

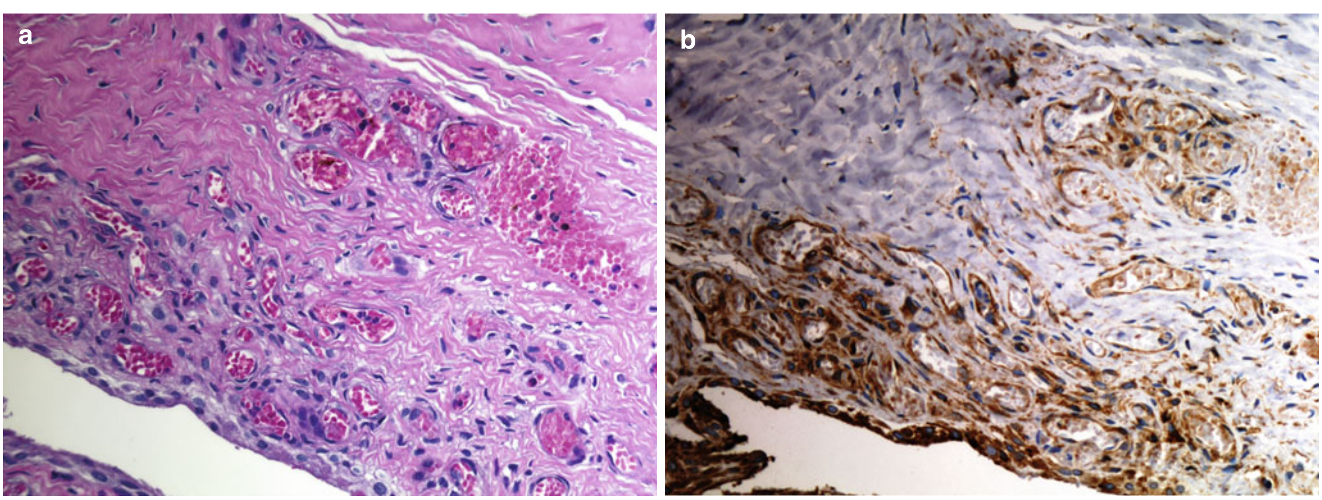

Fig. 6 Neoangiogenesis in an anterior margin of a massive rotator cuff tear; HE 20× (**a**) and immunohistochemical analysis with nuclear factor kappa B p65 antibody; 20× (**b**)

Sakai et al. [29] and Voloshin et al. [30] observed that staining grade for IL-1 and TNF-α was significantly more pronounced in the SB of patients with rotator cuff tear than that of patients with instability. Therefore, a dominant role of the cytokines and growth factors, usually present into the inflamed SB, in NFkB activation seems to be confirmed by literature. Unfortunately, this hypothesis is not supported by our data. In fact, we should have a wider NFkB activation above all in tendon tissue belonging to small cuff tear that is often completely covered by a hypertrophic bursa, and a scarce activation in massive cuff tear where usually the SB is scarcely present. Instead, our data show the contrary.

3. *Hypoxia causes the activation of NFkB*. Cellular hypoxia occurred when the request for molecular oxygen necessary to generate ATP levels sufficient to sustain physiologic function exceeds the vascular supply [7]. Many studies have demonstrated that hypoxia causes the activation of NFkB [6–8, 12]. Kannus and Jozsa [31] evaluated specimens obtained from the biopsy of spontaneously ruptured tendons of the upper and lower limbs in 891 patients. They observed narrowing or obliteration of the lumina of the arteries and arterioles due to hypertrophy of the intima and media of the vessel walls. Longo et al. [32], using a semiquantitative assessment of the tendinous lesions, observed a markedly abnormal increased vascularity in 0 % and 60 % of the healthy tendon (controls) and of the supraspinatus tears, respectively. These observations support the hypothesis that the degenerated tendons live a hypoxia status that would be responsible for the activation of the NFkB. However, it is not well elucidated if tendon degeneration increases with the increasing of cuff tear size. Therefore, further studies will be needed for establishing if the hypoxia is the dominant factor that stimulates activation of NFkB.

In addition, further studies are needed for verify whether the NFkB activation persists during time. In fact, in old and presumably massive cuff tears, the activated cells increase in number (accumulation effect). Many of the remaining cuff cells (fibroblast or fibroblast-like cells) and the new-formed endothelial cells and synoviocytes might remain activated during time in order to regulate the expression of cytokines and growth factors. Again, it should be still elucidated if cells activate themselves in order to stimulate inflammation and neoangiogenesis because massive tears are usually scarcely covered by the bursa and consequently the retracted tendon does not receive reparative biochemical stimuli.

A motive for further discussion is why the subscapularis tendon of patients with postero-superior rotator cuff tear resulted positive to the activated p65 and why its presence progressively increased in the tendons of patients with large and massive cuff tears. It may be plausible that subscapularis tendon reacts in the same way as the supraspinatus tendon also because both tendons fuse into one structure at or near their insertion into the humeral tuberosities [33, 34]. This hypothesis seems to be confirmed by Yuan et al's study [28] who observed that percentage of apoptotic cells in the healthy subscapularis tendon of patients with postero-superior cuff tear was significantly higher (21 %) than that registered in the healthy subscapularis tendon of the controls (13 %).

We observed that p65 and neoangiogenesis are correlated in spite of the dimension of the cuff tear. It is still not clear whether this is a direct or an indirect relationship. Koolwijk et al. [35] and Kroon et al. [12] have observed that in vitro human microvascular endothelial cells form capillary-like tubules after stimulation with fibroblast growth factor in presence of TNF- α or hypoxia, respectively. Therefore, two possible hypotheses could explain the increase of neoangiogenesis in the margins of the rotator cuff tears: (1) activated p65 directly stimulates neoangiogenesis; (2) the same factors responsible for p65 activation also act as neoangiogenesis inductors. However, unlike as it was registered for the activated p65 factor, the fact that the neoangiogenesis in the subscapularis tendon resulted equally present in the different sized cuff tears suggests that the second hypothesis is more plausible.

Conclusion

We identified the association between activated NF-kB and RCT. The presence of the activated p65 factor on the margins of rotator cuff tear increases with the increase of the tear size. We hypothesized possible causes for NF-kB activation in RCT; of these, we believe that the cause having the major role in activation is tissue hypoxia. Activated p65 directly stimulates neoangiogenesis; furthermore, our data suggest that the same factors that regulate NF-kB activation also act as neoangiogenesis inductors.

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Indications for Conservative Treatment

Stefano Gumina, Filippo Camerota, and Claudia Celletti

The rotator cuff tear can cause pain, functional limitation, and loss of strength; it may compromise life quality and affect working or sport activities; however, it does not jeopardize patient survival. Therefore, when a patient asks me if she/he must necessarily undergo a surgery due to cuff tear, my answer varies as it derives from many notions and by the same number of uncertainties.

When I have to express my opinion on the type of treatment to be performed, initially I try to determine whether the lesion is reparable. In this regard, clinical evaluation provides useful information. Usually, a marked muscle hypotrophy and a loss of strength and movement give evidence of an irreparable tear. X-ray images and MRI are able to resolve any doubts about reparability.

Frequently, I observe patients with small or large tears who had shoulder pain but that, at the time of visit, are completely asymptomatic. In these cases, I recommend a surgical repair only in young patients, in order to preserve the shoulder by the progressive evolution of the cuff tear and by the possible degenerative changes of the glenohumeral joint consequent to the altered biomechanics.

Reparable Tears

Partial lesions can generate pain and functional limitation, but, as well as for the full-thickness tears, they may become asymptomatic and be so for a long period. Before proposing a surgical repair (arthroscopic tear completion and repair or transtendinous repair), especially in an over 50-year-old patient, it is necessary that the conservative treatment, continued for at least six months, have failed.

In my opinion, there are general and local factors that may contraindicate the arthroscopic or open repair of a full-thickness cuff tendon tear.

General Factors

The ensuing factors may definitively or temporarily contraindicate the surgical treatment.

Age The age range to be considered the borderline for the choice of treatment is between 70 and 72 years (Fig. 1). Usually, surgical indication for older patients is not recommendable. The choice is motivated by the fact that elderly patients have one or more general or local factors that contraindicate surgery. The preceding indication does not change even for >72 year-old patients who are biologically young and are sportspeople.

Comorbidities Only rarely does rotator cuff tear depend on extrinsic factors (hooked acromion, acromioclavicular spurs, acromial anti-tilting); most frequently, the tendon lesion is the result of tissue degeneration caused by systemic diseases that alter the peripheral microcirculation. Therefore, all those diseases that reduce the arterioles and capillaries caliber, and that consequently decrease the normal vascular supply, can represent a contraindication for the repair.

According to consistent observation, patients with large or massive rotator cuff tear and with: (a) insulin-dependent or not well-controlled diabetes; (b) poorly manageable blood hypertension; and (c) uncontrolled hypercholesterolemia are candidates to the conservative treatment. In fact, possibility that patients may experience a postoperative early recurrence of the lesion is very high. For the same reason, doubts arise when operating on patients with BMI ≥30. These patients often suffer from one or more of the

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Fig. 1 A 77-year-old male patient with massive reparable rotator cuff tear of both shoulders (forward flection and abduction: 135°; external rotation: 25°; internal rotation T12). Bilateral muscular hypotrophy. He has a slight bilateral shoulder pain and his daily activity is only scarcely compromised. A conservative treatment was suggested

abovementioned diseases (Fig. 2). In addition, the arms of the obese are very heavy. This increases the difficulties they have in raising the involved upper limb during the assisted and/or self-managed rehabilitation program. All of abovementioned facts expose the patient to develop a stiff shoulder.

Paradoxically, even excessively skinny patients (BMI ≤20) may be candidates to conservative treatment. In my experience, the patients with poorly represented musculature, for example, adult patients with anorexia, have enormous difficulties following a proper rehabilitation program and not only for psychological disorders (Fig. 3). Even in these cases, the percentage of postsurgical shoulder stiffness is very high.

The patients who are heavy smokers (>20 cigarettes per day for more than 10 years), older than 55 years, cannot be considered candidates for surgical repair. Not only does cigarette smoking predispose to cuff tear (peripheral microcirculation disorders) [1], but it also affects the cuff tear size [2]. Similar considerations may be done for alcoholics [3]. Preemptive patient information on the choice of conservative treatment is justified by the high percentage of re-rupture after surgery.

Obviously, the surgical treatment is not recommendable in patients with severe heart or lung disease, with cancer, recent sepsis, coagulation diseases, and in patients with neurological deficits resulting from brain disorders. During the clinical evaluation, the patients are always asked if they are smokers, have a cough, and if they have recently noted change of voice. In doubtful cases, a chest X-ray should be prescribed, and the

Fig. 2 Prototype of a patient to which a conservative treatment should be proposed: BMI >30; alcoholic, smoker, with hypercholesterolemia, blood hypertension, and diabetes

patient is sent to a respiratory physician, especially if an exophthalmos occurred.

During my practice, I often visit patients who are erroneously addressed to my shoulder surgery office although they suffer from a radiculopathy due to compression (cervical disc herniation) (Fig. 4) or to intrinsic causes (e.g., herpetic radiculopathy). In rare cases, patients may be at the same time suffering from radiculopathy and cuff tear. In these cases, it is extremely difficult to determine to which, of the two diseases, shoulder pain has to be attributed.

However, the focus should firstly be directed to the cervical root problem in order to avoid that pain persists during the immobilization period and the shoulder becomes stiff during rehabilitation. Therefore, when a radiculopathy is suspected and when contraindications are absent, steroid treatment, electromyography, and an MRI of the cervical spine should be advised.

When I listen to patient history, to which I devote more time than to clinical evaluation, I try to understand what motivates the patient to the treatment, his/her

Fig. 3 A 56-year-old patient with a large rotator cuff tear of his left shoulder. He was considered excessively skinny. Furthermore, a pacemaker was applied on the same side of the involved shoulder. A conservative treatment was proposed

Fig. 4 MRI of the cervical spine showing a C6 cervical root compression due to articular spur and C5–C6 disc herniation. Physiological cervical lordosis is reduced

expectations, and the possible compliance during the rehabilitation program. Patients with psychological disorders (marked depression, panic attacks, schizophrenia), socially marginalized (homeless), and untreated drug addicts and alcoholics, with little care for personal hygiene, are not candidates for surgery.

Local Factors

Concentric Arthropathy

Patients with slight concentric shoulder arthropathy (Samilson Prieto I–II) might also have a rotator cuff tear (Fig. 5). In such cases, the cuff repair is contraindicated for two reasons: (a) pain could persist after repair; (b) patient with shoulder arthropathy easily undergoes shoulder stiffness. In these cases, patients should be informed that, because of a developing arthrosis, a conservative approach to managing pain is initially indicated and the implantation of a reverse prosthesis is likely within a few years. The acromion-clavicular joint arthropathy is not considered a contraindication as it may be simultaneously treated with the cuff tear.

Stiffness Shoulder I never recommend an immediate surgical treatment in patients with a rotator cuff tear and shoulder stiffness (capsulitis) (Fig. 6). The immobilization subsequent to the repair might increase the stiffness. Postoperative course of patients with stiffness shoulder who have been submitted to cuff repair shows unsatisfactory results as stiffness persists even after surgery or attempts to mobilize the shoulder with the aim of recovering the movement.

Dermatological Diseases Pyodermia (e.g., erysipelas) and mycosis (e.g., tinea corporis) represent some of the contraindications to the surgical treatment for the cuff tear. The skin disease should be healed for at least 2 months before proposing a surgical treatment and, in any case, the dermatologist should be consulted over the possibility of surgical intervention even in the absence of macroscopic lesions.

Pacemaker The arthroscopic portals are far away from the possible course of the electrocatheter introduced through the right subclavian artery or left brachiocephalic vein and conducted in the cardiac cavities even in patients

Fig. 5 X-ray radiogram of the right shoulder of a 62-year-old gentleman with a large rotator cuff tear. Radiogram shows a concentric glenohumeral arthropathy. Shoulder mobility was maintained and shoulder pain was subjectively considered as slight. A conservative treatment was suggested

Fig. 6 A 67-year-old lady with a small rotator cuff tear and an adhesive capsulitis of the right shoulder. A rehabilitation treatment for recovering the movement was recommended

with cuff tear to whom an excessive supero-lateral placed pacemaker was implanted; however, the arthroscopic fluid distributed into the pectoral region could displace the electrocatheter (especially if the implant is recent) and/or raise the stimulator. Furthermore, the pocket created for the positioning of the pacemaker may contain germs capable of infecting the operated shoulder. If the surgical repair of cuff tear is necessary, a cardiologist; the expert in pacemaker implants, should be present in the operating room.

Scapular Dyskinesis It may be the consequence of many diseases (neurological, traumatic, infective) [4–6]. In turn, dyskinesia may be responsible for a subacromial impingement [4, 5]. Therefore, the association between scapular dyskinesis and rotator cuff pathology is not uncommon. Dyskinesis is characterized by the asynchronism of the shoulder joint. Therefore, it can be argued that cuff tear should not be repaired when the shoulder joint rhythm is altered (Fig. 7a, b). Since dyskinesia may spontaneously regress following a careful rehabilitation program [7], it is appropriate that the patient is monitored over time, and surgery is performed when dyskinesis is healed.

Minagawa and colleagues (cited by Tanaka) [8] observed that patients with a restricted range of motion in external rotation and a large cuff tear do not have satisfactory results after the conservative treatment.

Irreparable Tears

In case of irreparable cuff tears, a few surgical treatments may be proposed with the aim of relieving pain (arthroscopic debridement); restoring the center of rotation recentering the humeral head into the glenoid cavity (partial repair; musculotendinous transfer); or/and replacing the arthritic joint with a reverse prosthesis. According to evidence, partial repairs or capsular shift, performed to reinsert the tendon stump to the greater tuberosity, should not be proposed if the MRI showed a fatty degeneration of the respective muscles (Grade 4 of

Fig. 7 A 69-year-old (**a**) and a 72-year-old (**b**) gentlemen with a large rotator cuff tear and scapular dyskinesis on the right and left shoulder, respectively. Initially, a rehabilitation program was suggested. The patients were surgically treated for the cuff tear 6 months later when the dyskinesis was almost completely resolved

the Goutallier scale). This is for two reasons: (a) if the repair is too tight, the risk of recurrence of the tear is high; (b) there is a risk of making a tenodesis and not a tendon repair because the degenerated muscle is not functioning [9].

As well as for the reparable tears, there are general and local factors that contraindicate surgical treatment.

General Factors

Age Usually, shoulder arthroplasty should not be recommended in patients older than 85 years because this treatment can provide a benefit in terms of pain and mobility, but also affect the general healthy status, above all when it is in a very precarious balance. The exceptions are patients with arthropathy and a markedly painful and swollen shoulder.

Comorbidity As for the reparable tears, I do not suggest a surgical treatment in patients with severe heart disease, with cancer, recent sepsis, and neurological deficits resulting from brain disorders.

Local Factors

Patients without arthropathy, with slight shoulder pain, chronic rupture of the long head biceps tendon, and preserved shoulder movement (functional shoulders) should be followed over time, but they do not have to be surgically treated. Patients without osteoarthritis, with forward flexion between 90° and 120°, subscapularis tear, subacromial space <5 mm are not candidates for a musculotendinous unit transfer [10, 11]; nor for arthroscopic debridement if they already have a chronic rupture of the long head biceps tendon (Fig. 8).

Indication to reversed arthroplasty should be carefully evaluated in patients with pacemakers.

Any shoulder surgery should be discouraged or postponed in case of pyoderma or local or nearby mycosis.

(Table 1) summarizes the indications for conservative treatment.

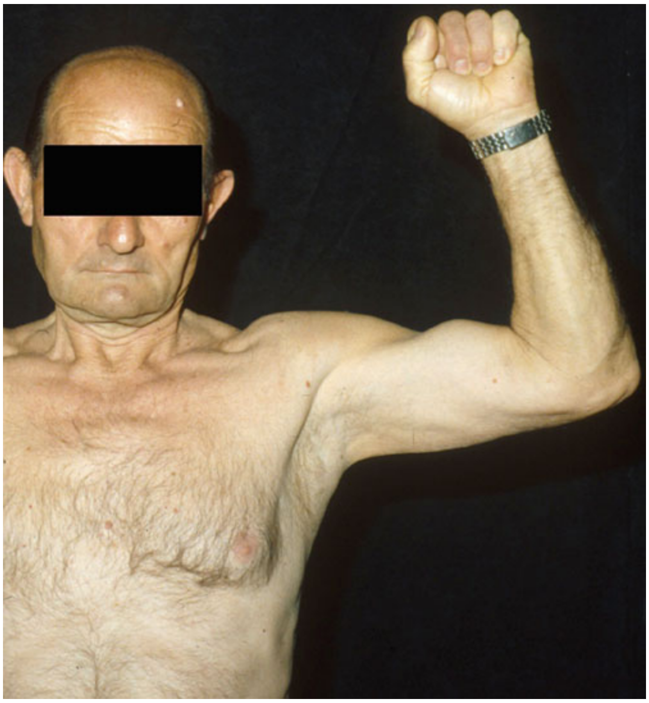

Fig. 8 A 68-year-old male patient with irreparable massive cuff tear of the left shoulder. Subscapularis tendon was also involved and range of motion was considerably compromised. For these reasons, latissimus dorsi transfer was not indicated. Arthroscopic debridement was not proposed because the rupture of the long head biceps tendon was already present

Table 1 Indications for conservative treatment

Reparable tears	General factors	Age > 72 years
		Insulin-dependent diabetes
		Poorly controlled hypertension longtime hypercholesterolemia
		Smoking habit
		Alcoholic patients
		BMI ≥30 and ≤ 20
		Cancer
		Severe heart and lung diseases
		Recent sepsis
		Coagulation diseases
		Neurological deficits resulting from brain disorders
	Local factors	Concentric shoulder arthropathy
		Scapular dyskinesis
		Stiff shoulder
		Supero-laterally inserted pace maker
		Local dermatological diseases
Irreparable tears	General factors	Age >85 years (see general factors for reparable tears)
	Local factors	Patients without arthropathy, scarce shoulder pain, with chronic rupture of the LHBT and preserved shoulder movement
		Supero-laterally inserted pace maker
		Local dermatological diseases

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Operating Room Setting

Paolo Albino, Stefano Gumina, and Valerio Arceri

Basic Equipment

In order to be able to perform rotator cuff repair correctly, some basic equipment is required in the orthopaedic operating theatre:

Instrument Table

This is the working surface on which surgical instruments are laid out. The table is composed of a stainless-steel base and a tubular support whose height can be adjusted by means of an oleodynamic pump.

Operating Table

For cuff repair procedures, a state-of-the-art operating table is critical to the operation's success. It has to ensure that the patient can be positioned easily, it has to be stable and it has to take up as little space as possible. It is made up of two main parts: the column and the surgical table.

The column has to sustain the load. It can be fixed (with a base that is either built into or lies on the floor) or be partially or totally movable. The movable type allows the table to be placed in any position within the theatre by means of a specific integrated or removable truck. The electric supply is either provided by the cells placed in the movable columns or integrated in the fixed columns.

Surgical tables require high-precision settings for procedures, optimal radio-translucency, flexible configuration and modular structure for maximum access and easy adjustment. The modularity is provided by the 10-block partition of the table (Fig. 1a–c). Depending on the anatomical district involved, each block is removable, thus facilitating access to the surgical site. Positioning is guaranteed by an electric motor. The remote control of the table allows gentle mobilization of the seatback as well as of the limb supports. The table is also equipped with specific accessories such as extension devices and head and arm rests (the latter can also be motorized). In shoulder arthroscopy, being able to move the arm during the procedure without involving the surgeon is helpful.

Scialytic Lamps

The word 'scialytic' comes from the Greek words σκιά «shadow» and *-lityc* «producing lysis». This light source is in fact also known as 'shadowless lamp'.

The surgeon needs to be able to see the anatomical structures being operated upon perfectly (especially for deep planes), and homogeneous illumination serves this purpose. The most important characteristic in surgical illumination is shadow dispersion, an effect obtained through the intersection of multiple light beams.

Furthermore, the light is filtered in such a way as to only transmit the radiations of the visible spectrum, thereby eliminating the infrared radiation responsible for the thermal effects that may damage tissues. State-of-the-art lamps use LED technology as a light source and do not need any filter.

The scialytic lamp may be installed on the ceiling or the wall of the theatre. The theatre is usually equipped with a main light source and multiple satellites, both of which are attached to mechanical adjustable arms that allow them to be pointed at the surgical field. The characteristics of the scialytic lamp (as recommended by the Illuminating Engineering Society) are:

- Light intensity: between 25,000 and 100,000 lux
- Colour temperature: between 3,500 and 6,700 K (in order to avoid colour distortion)

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Fig. 1 Operating room. (**a**) Lateral view of the surgical table placed in beach chair position; the column is visible at the foot of the table; (**b**) View from behind; (**c**) the patient is placed in beach chair position

Specific Equipment for Shoulder Arthroscopy

Arthroscopic Column

The Shoulder Arthroscopy Instrument Set

Arthroscopic shoulder surgery should be performed in operating rooms specifically equipped for this purpose. Even though surgical procedures are carried out through arthroscopy, in which tissue exposure is extremely limited, the risk of infection should be taken into account.

Equipment Set-Up

After positioning the patient, the equipment needs to be set up. The video and shaver equipment is placed on either a movable video cart or a ceiling-mounted arm, on the anterior side of the table and facing the surgeon. The basic equipment includes: 32″ high-definition video monitor connected to the camera control through a RGB line, camera box, light source, shaver power source, videotape recorder and irrigation pump (Fig. 2). Fluid management and dynamics are essential for the performance of advanced arthroscopic procedures.

Fig. 2 Arthroscopic column assembled

(a) *Videotape*. Optional equipment: DVD video recorder, video printer and Zip drive or CD-ROM recorder for image-capture (Fig. 3). It is used to capture, print and store information and/or pictures in permanent digital format and subsequently used them to enhance operative reports.
(b) *Camera*. Currently the best cameras are characterized by high-definition technology (HD-vision 1080 pixel), LED lighting (solid state Xenon Bright light source) based on 30,000 h of bulb life, image management based on a video system that streams live to any authorized remote viewer, HD still capture and HD video recording (Fig. 4).
(c) *Shaver*. The arthroscopic shaver system is a software-based tool that provides aggressive tissue resection and rapid bone debridement. This easy-to-use system is ideal for all arthroscopic procedures (Fig. 5). The rotation speed of the blades ranges from 100 to 8000 revolutions per minute. Engagement of the blades occurs automatically when the minimum and maximum speed are adjusted.
(d) *Radio Frequency Ablation* (Fig. 6). The electrosurgical system is capable of controlling a host of different instruments, including disposable arthroscopic ablation probes, disposable monopolar arthroscopic electrodes, reusable

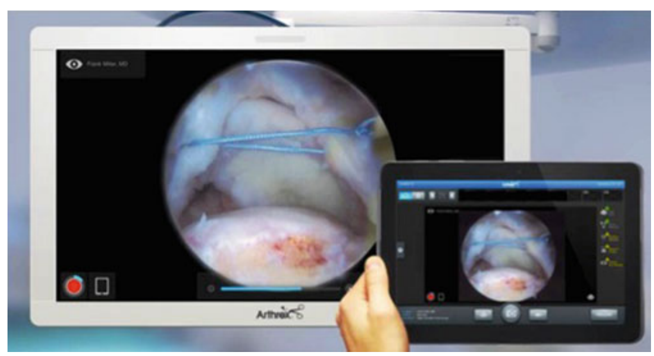

Fig. 3 32″ High-definition video monitor

Fig. 4 Optic system with high-definition technology (HD-vision 1080 pixel)

Fig. 5 Arthroscopic shaver system. The motor allows a rotation speed of the blades from 100 up to 8000 revolutions per minute

Fig. 6 The electrosurgical system for radiofrequency ablation

and disposable monopolar open procedure pencils and tips, and reusable bipolar forceps. In addition to its standard cut, coagulation and bipolar modes, the electrosurgical generator is equipped with ten blend modes that can be incrementally adjusted to allow precise tissue ablation or cutting with the right amount of haemostasis. This system was designed with patient safety as its highest priority. As the tissue impedance varies, the power is adjusted to deliver a consistent clinical effect. Overall, this technology allows the electrosurgical generator to cut or ablate tissue more efficiently with lower power levels within safe temperature ranges in either the open or arthroscopic environment.

(e) *Fluid management*. The arthroscopy pump is an integrated inflow (40 mmHg) and outflow (100 mmHg) fluid management system that may also be used as a simple inflow-only arthroscopy pump (Fig. 7). It is a safe, reliable, user-friendly system that maintains constant, non-pulsed control of intra-articular rinsing and distension pressure throughout an arthroscopic surgical procedure. It is designed to provide continuous pulse-free flow that reacts immediately to changes in intra-articular pressure, thus ensuring that joint distension is sustained even under high shaver extraction volumes or secondary outflow. The user-defined settings for inflow pressure and outflow rates are adjustable through controls located on the touch panel screen or on the remote control.

Fig. 7 Fluid management system. Arthroscopy pump with integrated inflow and outflow control

Instruments

Arthroscope

This is a fibre-optic modular instrument, surgically inserted through an incision. It is used to visually expand and examine the joint interior.

It is composed of:

The Trocar A surgical instrument with a triangular sharp-pointed or smooth end. It is used within the cannula in order to create a path to the articulation (Fig. 8).

The Operative Cannula Assembled with the trocar (see above) or an irrigation extender (used to introduce the optic and control the liquid flow).

The Irrigation Extender Sheath A crosswise system with bilateral valves useful to control both inflow and outflow in the articulation. Valves are matched up with the aspiration and irrigation systems (Fig. 8).

The Optic The image acquisition system that is located inside the *sheath* (Fig. 8). Optics can differ depending on the diameter, focal length and lens angle. A wider diameter confers stiffness to the system and thus avoids bowing, which may compromise the image resolution and alter light conduction. A smaller diameter instead allows great manageability within the articulation. Increased focal length allows a lower visual depth as well as an enlargement of the images. The lens angle is measured by drawing two lines from the distal optic extremity to the two opposite points of an object. The wider the angle, the wider the visual field, but the greater the image distortion.

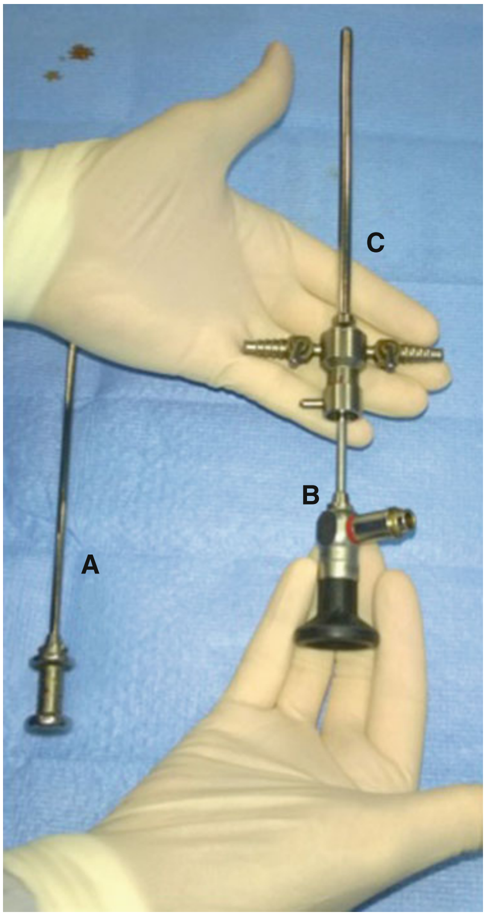

Fig. 8 Arthroscope. (**A**) Trocar: used with the sheath to create a path to the articulation. (**B**) Optic: used with the sheath and the camera system to obtain images from the articulation. (**C**) Sheath: a crosswise system with bilateral valves matched up with the aspiration and irrigation systems

The optic used in shoulder arthroscopy has a 4 mm diameter, 30° angle and 160 mm length, which allows a 115° line of sight. Occasionally, a 70° optic can be used, especially in case of subscapularis tendon tear.

The light source entry is on the side of the optic. As the system used in arthroscopy for image visualization is digital, the light source plays a fundamental role in image quality. The most important characteristics required to achieve good light conduction are intensity and transverse section area of the optical fibres.

Cannula

Cannulae are used to preserve the path between the articulation and the outside (Fig. 9). They are important insofar as they prevent intra-tissutal run-off and facilitate the introduction of surgical instruments, thereby minimizing soft tissue damage. The presence of an anti-reflux membrane, on the inside of the cannula, is essential to keep endoarticular pressure stable, reduce bleeding and allow the correct distension of anatomical structures; the lateral valve is used to calibrate both inflow and outflow. Cannulae can have different diameters (from 5.5 to 9 mm) and lengths, and be opaque or transparent, smooth or shaped. We prefer to use transparent cannulae because they afford direct visualization of the surgical instruments and knots, thereby limiting the risk of 'twisting' during the sliding. To prevent the cannula from accidentally dropping out during arthroscopy (anti-fallout characteristics), cannulae are available with a distal anti-sliding ring, lateral stop or screw-shape. The screw-shaped cannula provides a homogeneous full-length grip on soft tissues, while the cannula with an anti-sliding ring only provides distal tightness.

Fig. 9 Transparent operative cannula. *1*, Anti-reflux membrane: allows the insertion of the instrumentation while maintaining endoarticular pression stable. *2*, Lateral valve: used to calibrate inflow and outflow. *3*, Anti-fallout system: screw-shaped cannula allows homogeneous grip on soft tissues

Probe (Hook)

The hook is used to evaluate the integrity of anatomical structures. It can be used to assess the consistency and tension of tendons and ligaments, as well as to evaluate cartilage uniformity or degeneration. It is irreplaceable for expert surgeons because it reveals lesions that have escaped detection and strengthens the preoperative diagnosis. Its systematic use leads to a complete and dynamic analysis of articular tissues (Fig. 10).

Arthroscopic Rasp

Arthroscopic version of the common open-surgery instrument. Mostly employed during gleno-humeral instability surgery to mobilize the glenoid labrum (Fig. 11).

Grasper

It is used to grasp and pull soft tissues in order to evaluate consistency, mobility and reducibility. It is also used to remove endoarticular loose bodies. A wide range of graspers with specific functional and ergonomic characteristics are available. Depending on the type of handle, they may be subdivided in: self-blocking, continuous pressure, straight or inverted (retrograde) handhold. The surgical specificity of each instrument increases according to the different diameters, angles and beak shapes (Fig. 12).

Basket and Scissors

Simple scissors can be used to cut the wire after the suture knot has been tied (Fig. 13). Their blades may be either straight or curved. Basket scissors take their name from the shape of their ends (biconcave with sharp edges). They are used to cut and remove tissues in one step. The wide range of angles and shaft shapes increase the specificity of the instrument, allowing direct access to anatomical structures that cannot be reached otherwise.

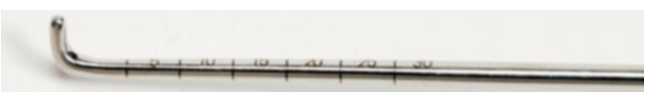

Fig. 10 Probe. Its hooked end is used to evaluate the integrity of anatomical structures during the first phases of arthroscopy

Fig. 11 Rasp. Mostly employed during gleno-humeral instability surgery to mobilize the glenoid labrum

Suture Passer

Used to perform arthroscopic sutures. Suture passers can be either direct or indirect (the latter need a transport wire to pass through soft tissues). The choice of the instrument depends on the surgeon's needs (i.e. surgical lesion treated and technique adopted). Some cases require hybrid passages that require the use of both methods.

Direct Suture Passer Used during rotator cuff tear repair. It has a sharpened end, for tissue perforation, and an opening curved device designed to pass the suture wire through

Fig. 12 Grasper. Detail of the operative end of two different graspers. The different shape allows the management of tissues of different consistencies

Fig. 13 Semi-automatic scissors. Used to cut the wire after tying the suture knot. The suture wire is used as a guide to slide the instrument to the cut point

the tissue (Fig. 14a). The mechanism in some models is automatic, which allows the surgeon to load the passer with the suture wire outside the articulation and then perforate and pass the suture in one surgical step (Fig. 15a, b). This kind of passer usually has a safety block designed to prevent accidental openings during the introduction or extraction of the wire.

Indirect Suture Passer This type of passer may prove useful during capsulolabral complex repairs. It allows the suture to be modified depending on the surgeon's needs and the technique being used. The wide range of angles, curves and sizes available enhance the surgical manageability and versatility. Moreover, each instrument varies according to the type of wire exit, which may be straight, needlepoint or double-free. A transport wire (monofilament, PDS) or a Shuttle-Relay suture passer is needed to be able to use the indirect suture passer (Fig. 14b).

Suture Retriever

This instrument may be shaped like a hook or grasper, have or not have a hole, and be disposable or reusable. Its most important function is to retrieve the suture wire atraumatically in order to preserve the suture and avoid any residues, which are difficult to remove from the articulation (Fig. 16).

Knot Pusher

It is used to slide the knot, which is tied on the outside, through the cannula into the articulation and to tighten the suture. There are various types of knot pushers: standard single-hole, cannulated single-hole, standard double-hole or double-hole mechanical spreader.

Anchors

They are designed to keeping soft tissue and bone tight until integration and biological healing are complete. There are two types of anchor: one designed to perforate and remain in the bone (Fig. 17) (real anchor), another that contains the suture wires required to stitch soft tissues. Differences in the materials and functional characteristics of each of these anchors yield varying biological and mechanical system properties.

The fixation system has evolved over the years, which means a wide range of different positioning systems (screw-shaped or 'hit') and materials (reabsorbable, peek or titanium) are now available.

Despite its widespread use, reabsorbable material still has to be perfected. Indeed, not only does it appear to be more fragile during implantation and less resistant to pull-out, but it may also lead to secondary reactive or inflammatory phenomena due to the presence of polylactic or polyglycolic

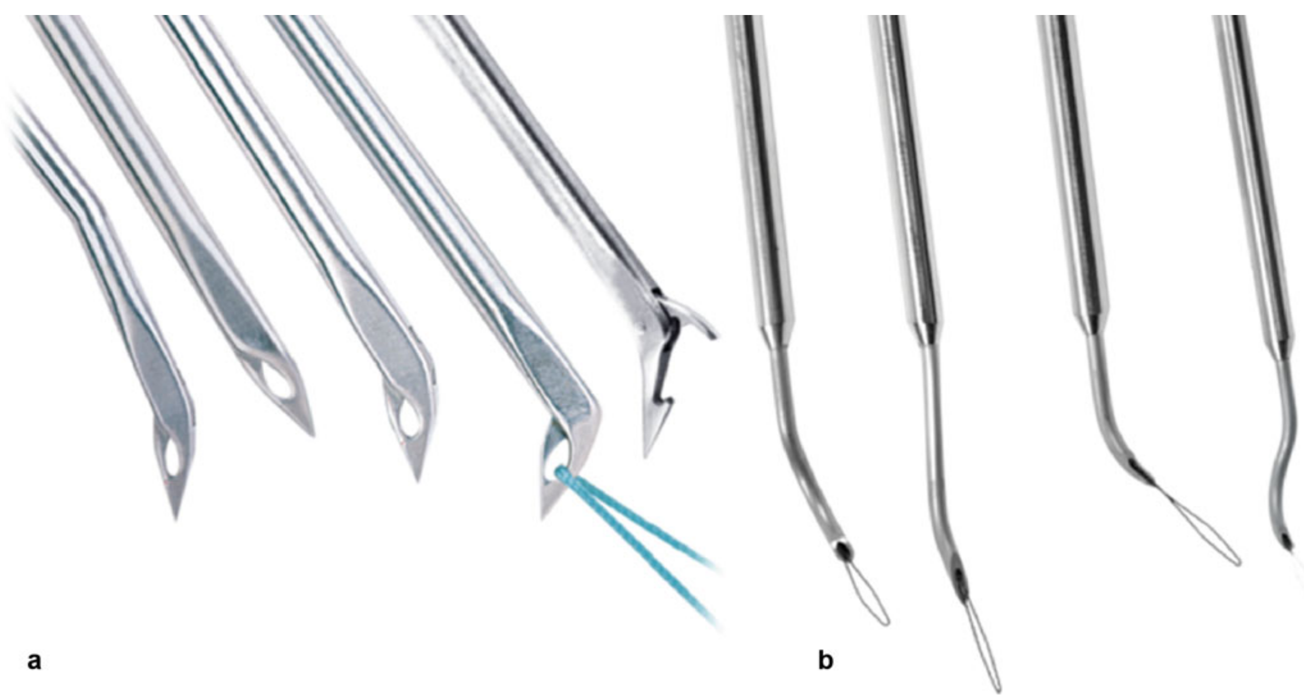

Fig. 14 Suture passers. (**a**) Direct suture passer with a detail of the operative end. (**b**) Indirect suture passer. The transport wire, visible at its end, is used to retrieve the suture wire through the tissues

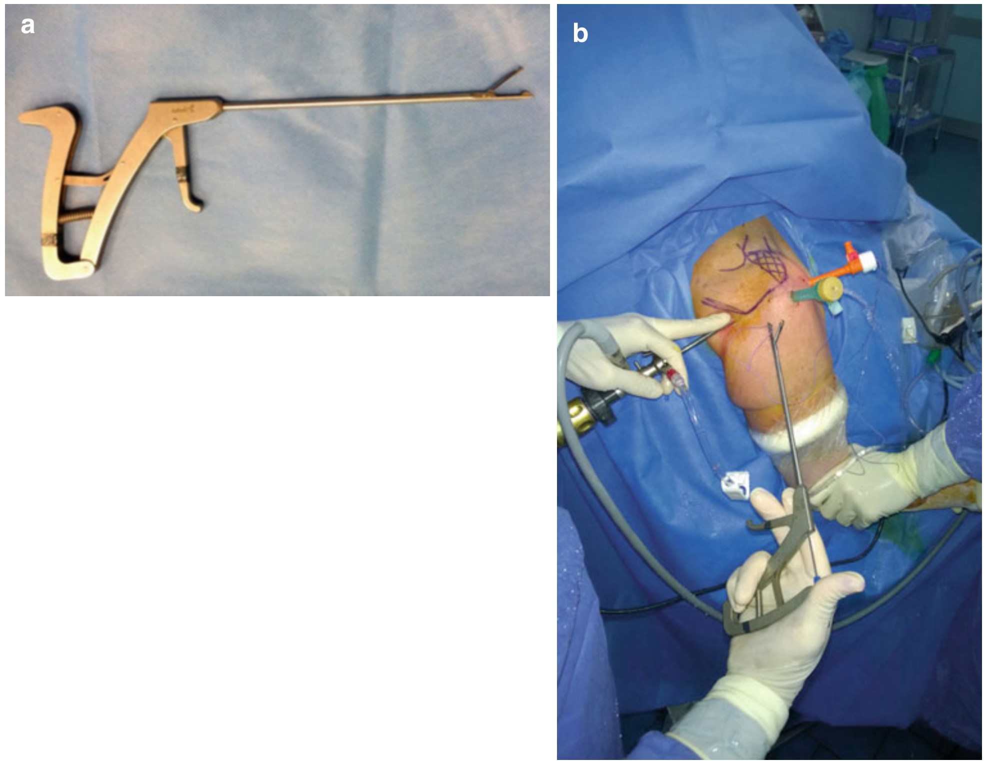

Fig. 15 (**a**, **b**) Automatic direct suture passer with ergonomic handle. Squeezing the handle, the needle exits from the operative end of the suture passer

Fig. 16 Suture retriever. Detail of the operative end of the instrument

Fig. 17 5 mm anchor designed to perforate and remain in the bone

acid. The advantage of reabsorbable material is its high initial resistance and complete demise of the device once biological healing has been achieved.

PGA (polyglycolic acid); Fast demise (50 % in the first 2 weeks), 8 % of tissue reaction; PLA (polylactic acid); Slow demise (90 % in 12 weeks), minimal tissue reaction.

Suture wires may be preloaded or free. Preloaded suture wires may prove useful to tie the soft tissues tightly to the bone, while free suture wires can also be used to perform a side-to-side suture and penches

Ethibond

Polyester that is covered in polybutylate, woven, non-reabsorbable, and provides good sliding and knot tightness.

Panacryl

Copolymer 95 % lactic acid, 5 % glycolic acid, very slow reabsorption (1–2.5 years), greater tightness and sliding than ethibond.

Fibre Wire

Polyester and polyethylene, woven, higher resistance to abrasion.

PDS

Polydioxanone, monofilament, used as transport wire during arthroscopic suture or penches

Positioning in Shoulder Arthroscopy

We prefer to perform shoulder arthroscopy with the patient in a beach chair position. The patient is seated on the surgical table (trunk 60° flexed, lower limbs 40° flexed), with the shoulder being operated on slightly outside the backseat and the corresponding block removed. Even when the patient appears to find this position comfortable, care must be taken to prevent secondary iatrogenic injuries due to high pressure points. We usually place a silicone pillow underneath the knees to prevent lesions of the peroneal nerve/artery. Two cotton, ring-shaped strips are placed underneath the heels to prevent possible bedsores. We use a lateral support and a soft belt to keep the patient still throughout the surgical procedure. To maximize surgeon mobility, a 6-cm separator can also be used to detach the shoulder from the backseat (we usually use a folded drape sheet).

The arthroscopic column is located near the patient's feet. The monitor must be placed in front of the surgeon, while the motorized shaver, burr and aspirator are placed over the patient's abdomen. The surgeon's assistant stays by his/her side, while the scrub nurse and instrument table are placed directly behind the surgeons so as to provide prompt support to both.

The advantages of the beach chair position are easy preparation, good visualization of the anatomical structures during any kind of arthroscopic procedure, easy shift to open surgery (if required) and, last but not least, prevention of possible injuries of the brachial plexus secondary to traction.

An alternative used by other authors is the bean bag position: the patient lies on his/her back on the surgical table, with the arm being operated on elevated to 90° and fastened to a traction device with a 7-kg weight. Although the presence of the traction system, usually placed at the end of the surgical table, means the arm can be maintained in a stretched and stable position without the need for the assistant, traction may lead to the aforementioned complications. The bean bag position does not affect the stability of the either the instrument table or column.

Anesthesiological Techniques

Fabrizio Fattorini and Alessandro Rocco

Collaboration and agreement between orthopedic surgeons and anesthetists are necessary to perform each intervention, in order to guarantee safety for patients and satisfaction of operators' needs, as well. The collaboration is important for open surgery, but it becomes essential for the arthroscopic technique.

In our opinion, integrated anesthesia, i.e. the association of general "light" anesthesia and the peripheral brachial plexus block, is the most suitable anesthesiological technique both for patients' needs and shoulder surgeon requirements [1]. Loco-regional anesthesia potentially allows the surgical intervention by itself, but its application is likely to be limited by several factors [2]. First, the intraoperative position assumed by patient – beach chair or lateral – associated with a prolonged surgical procedure often causes a discomfort that can sometimes require the switch to general anesthesia during intervention [3]. Second, arthroscopic procedures require a reduced bleeding that can be obtain only by applying controlled hypotension (maximum arterial systolic pressure 80–90 mmHg), which is usually poorly tolerated.

General anesthesia for shoulder surgical interventions is not different from that adopted in other types of surgery: therefore, only loco-regional anesthesiological procedures will be described in this chapter.

Loco Regional Anesthesia

In the last decades, loco-regional anesthesia underwent a progressive development, especially in orthopedic surgery: a better safety and analgesia are improved, especially during surgical interventions performed in day surgery setting. Several clinical studies demonstrate the efficacy of peripheral blocks not only for their effective control of intra and postoperative acute pain but also for their use during the rehabilitation and functional recovery. It is in fact possible to prolong the analgesic effect of peripheral block during postoperative period (continuous nervous blocks) by continuous perineural infusion of local anesthetics. Furthermore, the introduction of ultrasonography to identify nerves makes the peripheral blocks more selective and safer.

Background on Neuroanatomy

Knowledge of anatomy is crucial to plan and perform anesthesia, regardless the use of ultrasounds. Motor functions of shoulder are controlled by the brachial plexus, while sensitive functions receive an important contribution from cervical plexus through suvraclavear nerves (C3–C4) that reach suvraclavear skin, the lateral extremity of shoulder, and forward the first two intercostal spaces [4].

The control of postoperative pain requires an anesthetic block of structures that innervate capsule and articular surfaces, periosteum, ligaments, and muscular-cordial-tendon units [5, 6]. Terminal branches of brachial plexus that innervate shoulders are the suprascapular and axillary nerves. In addition, a modest contribution is given by musculocutaneous and subscapular nerves. More specifically, the acromioclavear articulation is innervated by the suprascapular nerve, that reaches also the gleno-omeral articulation. The lower part of capsule is prevalently innervated by the axillary nerve.

Fundamental of Loco Regional Anesthesia

Loco-regional anesthesia is based on the pharmacological action of specific drugs (local anesthetics) able to temporarily block the conduction of nervous impulse. This effect can be obtained in each region of the body in which nerves can be reached by percutaneous injection. In orthopedic surgery, loco-regional anesthesia is widely used, as it guarantees both

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intra-operative anesthesia and postoperative analgesia. Before performing any loco regional technique, the patient must be evaluated with the same accuracy that is used for general anesthesia. Any absolute contraindication (documented allergy to topical anesthetics, infection in the treated region) must be excluded, and any relative contraindication (hemorrhagic diathesis, systemic clinically stable neurological diseases, and local nervous damage) must be carefully considered in terms of risk/benefit ratio. Lastly, an informed consent concerning the planned anesthesiological technique must be signed by the patient.

Techniques for Nerves Localization

During the history of loco-regional anesthesia, a number of anatomical approaches to nervous structures have been developed. Initially, nerves were identified with paresthetic evocation or by locating fascial clicks; alternatively, perivascular or trans-arterial injection were performed. However, these approaches were often associated with side effects (nervous lesions) and risk of failures. In the 1980s, the introduction of the electroneurostimulator (ENS) allowed a wide diffusion of locoregional anesthesia, for two main reasons. Firstly, ENS permits to easily perform nervous blocks, also profound, which were not previously feasible. Secondly, nerve location is safely performed, with a low risk of complications.

Electroneurostimulator

The electroneurostimulator (ENS) is a direct current generator that permits to localize a nerve by releasing tunable current, applied to an exploratory needle. ENS determines the depolarization of the motor component of afferent muscles (mioclonic) when the needle is near to the nervous fiber. Maximal muscle contraction obtained with minimal current intensity indicates the maximal proximity between nerve and needle.

ENS allows:

(a) Low risk of nervous lesions
(b) Reduced amount of required local anesthetic
(c) Performing selective blocks
(d) Performing blocks on not-collaborative patients

The introduction of ENS made the peripheral block techniques easy to perform and safe and usable. However, it should be considered that searching nerves with ENS is a blind technique that is error-prone and may cause neurological damages. Indeed, the electroneurostimulation sometimes results in false negatives: the needle is correctly located in the perineural space without eliciting muscle contraction. This results in a useless needle redirection, with an increased risk of nerve lesions and discomfort for patient.

Echography

Loco-regional anesthesia of the superior arm has been profoundly influenced by the use of ultrasounds [7, 8]. Beyond showing nerves, echography shows also vessels, muscles, pleura, and all the structures that have to be identified to perform blocks. Moreover, the echography shows anatomical individual variations – not assessed by ENS alone – that could make difficult performing blocks [9]. Echography (or ultrasonography) is an extremely user-friendly procedure since it does not use ionizing radiations, is not invasive, is repeatable, and allows a real-time imaging of anatomical structures closely following the diagnostic and therapeutic procedures [10–12].

The echography is based on the reflections (echo) that an ultrasound pulse of given characteristics undergoes when it passes through biological tissues. Ultrasounds are acoustic waves with frequency higher than 20000 cycles/s (Hz) that are not detected by humans. In medicine, waves with frequency ranging from 1 to 20 MHz (1 MHz = 1.000.000 Hz) are used.

Ultrasounds are produced by using the properties of given materials that vibrate at high frequency when excited by an electric pulse. The propagation of ultrasounds occurs only in a solid medium as a wave motion that generates alternated bands of compression and rarefaction. The propagation is subjected to the intrinsic resistance of the medium, defined as acoustic impendence that has different values in each tissue.

Transducers or probes generate and receive ultrasounds and, then, transform electrical energy to mechanical energy at high frequency. Probes are constituted by one or more elements of piezoelectric materials that generate ultrasounds when excited by an electrical pulse. Ultrasound waves are directed into the human body when the probe is in direct contact with skin and mucosal tissues. At interfaces between different tissues, the acoustic impendence changes. A portion of ultrasounds is transmitted to below tissues, while another part is reflected as echoes, toward the emitting crystal. This emission is, then, elaborated into images or echographic trace.

The probes can be classified at high (10–15 MHz), median (5–10 MHz), or low frequency (<5 MHz). The selection of the probe depends on the type of examination and anatomical structures that are to be investigated. The frequency (energy) is inversely correlated with the depth of the tissue. Probes at high frequency produce an image at high resolution but have only a superficial penetration if compared with those at low frequency. Linear high frequency probes can be used for imaging superficial structures, such as in the interscalenic, supraclavear, and axillary approaches to brachial plexus. Curvilinear low frequency transducers (convex probes) are preferable when the structure are deeper than 4 cm, e.g. in the infraclavear block.

The propagation of sound waves shows different echogenicity in relation to density of tissue that encounters. Therefore, the higher is the intensity of reflection, the higher is the brightness (hyperechogenicity). On the other hand, the higher the absorbance by tissues, the lower the brightness of echo on the screen (hypoechogenicity). A structure totally lacking of echoes is defined as anechogenic.

At roots (e.g. brachial plexus), nerves are hypoechogenic. When nerves progressively approaches periphery, they become hyperechogenic ("aspect of honeycomb") due to a higher level of myelination.

The anatomy of involved structures (nerves, blood vessels) can be studied by two levels of scanning: longitudinal (long axis) and transversal (short axis). The relationship between visualized anatomic structures and the exploratory needle is function of the reciprocal position of the probe and the needle. This latter is entirely visible if it is parallel to the long axis of the probe (IN-PLANE technique); on the other hand, only the tip is visible if the needle is introduced perpendicularly to probe (OUT-OF-PLANE technique).

Echography brought a revolution in loco-regional anesthetic procedures, since it permits to:

- Directly visualize various nerves, also those exclusively sensitive
- Follow the needle movement, thus reducing the risk of nervous lesions
- Observe the spread of the anesthetic around the nerve, thus minimizing the risk of intravascular and/or pneumothorax injection
- Guide the positioning of perineural catheter
- Have a quicker *onset time* and a longer duration of action
- Perform the block without pain due to muscle contraction (particularly discomforting when fractures are present)
- Reduce the dose and volume of local anesthetics (30–40 % less than those with ENS technique), thus reducing the risk of adverse reactions
- Reduce the incidence of complications and increase the number of success
- Perform the block also in presence of serious anatomic abnormalities

However, we think that echography does not substitute neurostimulation, but rather integrates it and helps to increase both success rate and safety [21, 22]. For these reasons, these two techniques of nerves localization are presented for each type of block described.

Blocks for Shoulder Surgery

Interscalene Block

The interscalene brachial plexus block represents the gold standard of shoulder anesthesia, since it involves the lateral two-thirds of the clavicle, proximal humerus, and glenoomeral joint [13, 14]. With this procedure, the brachial plexus is reached in correspondence of its roots, thus delivering the local anesthetic to C5–C6 or the superior trunk. Depending on the amount of anesthetic used, also the roots of C7 and C8 can be involved, while ulnar roots are mainly saved (C8 and T1) [15, 16]. The block can be performed by a single injection (single shot) or continuous block, both assisted by ENS or ecograph.

Interscalene Block with ENS

The patient is positioned supine with the head extended and slightly rotated contra-laterally to the side of the block (Fig. 1) [23]. Superficial positioning points are represented by:

Fig. 1 Interscalene block with eletcroneurostimulator (ENS). Superficial positioning points are represented by the posterior edge of sternocleidomastoid muscle and the superior edge of the cricoid cartilage and the left clavicle body

- Interscalene groove (between anterior and medium scalene muscle), located back to the posterior edge of sternocleidomastoid muscle
- Superior edge of the cricoid cartilage (transversal process of C6)

To better identify these points, it can be useful to flex patient's head.

The needle, 50 mm long, should be inserted into the interscalene groove at the level of superior edge of cricoid cartilage and should be directed downward, medially, and backward. The needle encounters the nervous fibers at 2.5–3.5 cm deep from cutaneous plain.

Contractions to be evoked:

- Bend of forearm towards arm (musculocutaneous nerve)
- Shoulder abduction (axillary nerve)

Interscalene Block according to Alemanno with ENS

The patient is positioned supine, with the head extended and slightly rotated contralaterally to the side of the block [23]. Superficial positioning points are represented by:

- Median point of the clavicle
- Supraclavicular pulse of the subclavian artery

The needle (50 mm long), connected to the ENS, is introduced 0.5 cm laterally to the above-mentioned points and is then moved in posterior-medial direction, toward the spinous process, arch and C7 body, in order to induce a motor stimulation.

Ecoguided Interscalene Block

The patient is positioned supine with the head rotated contralaterally to the side of the block and the arm in neutral position along the body (Fig. 2a, b) [23]. An echographic probe at high frequency regulated at 12–18 MHz and stimulating 50 mm needles (22 G) are used.

The brachial plexus can be easily visualized by ultrasounds in correspondence of the posterior interscalene space (Fig. 3). The search for the brachial plexus starts laterally to the larynx, passing through the thyroid, carotid artery, and internal jugular vein. Then, moving the probe more externally and downward along the lateral edge of the sternocleidomastoid muscle, the nervous structures become visible in transversal vision as oval or circular hypoechogenic areas delimited by the anterior and medium scalene muscles.

The roots of brachial plexus (C5, C6 e C7) are located immediately behind the anterior scalene muscle and appear as round hypoechogenic structures, sometimes "traffic light-shaped". By ultrasonography, both the needle movement through the interscalene space and the diffusion of the local anesthetic can be monitored (Fig. 3).

Most complications associated with the block of brachial plexus, continuous or not, are transient and do not have any consequence; however, extreme caution should be given during the procedure due to the proximity between the exploratory needle and neurovascular structures [17, 18].

Common complications of the interscalene brachial plexus block include the block of homolateral phrenic nervous (consensual hemi-diaphragmatic paralysis), Horner's syndrome due to the block of stellate ganglion (exophthalmos, palpebral ptosis), recurrent block of laryngeal nerve (dysphonia), and vascular cut (hematomas). Rare complications, but potentially severe, are carotid and intervertebral cuts, pneumothorax, subaracnoidal or intraforaminal cut (cause of spinal anesthesia and cervical epidural, respectively), and direct nervous lesion. In continuous, blocks perineural catheters can infect, kneel, tie, or become imprisoned [19, 20].

Supraclavear Block

The use of ultrasounds allows to easily perform anesthetic procedures which were associated with a high risk up to date. This is the case of supraclavear block that was progressively neglected in clinical practice due to the high incidence of pneumothorax dependent on close relationship between neurovascular structures and lung. The introduction of echography has drastically reduced those risks, making this block feasible also in pediatric patients.

In patients who are not eligible to general anesthesia – even if light – the association of supraclavear and interscalene blocks allows the intervention on shoulder in totally conscious patient.

The patient is positioned supine with the head rotated contralaterally to the side of the block and the arm in neutral position along the body. An echographic probe at high frequency set between 12 and 18 MHz is positioned into the supraclavear groove, in parallel to the third medium of clavicle and with the ultrasound beam in caudal direction.

Then, the probe is laterally and medially slid to search for the subclavian artery that will appear, over the short axis, as a hypoechogenic and pulsatile structure [23]; color Doppler can be used to confirm the vascular nature (especially when the anatomy is abnormal). The subclavian vein is more superficial and medially located with respect to the artery [23]. Behind the artery, the surface of the first rib will appear as a hyperechogenic line with an underlying hypoanechogenic shadow, since the bone surface totally reflects ultrasounds. The first rib and its posterior shadow interrupt the continuity of an underlying hyperechogenic

Fig. 2 (**a**, **b**) Ecoguided interscalene block

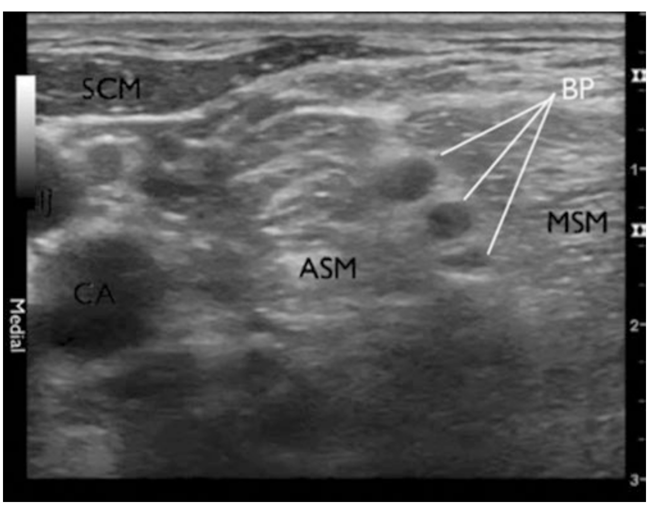

Fig. 3 Soundanatomy of interscalene groove: *ASM* anterior scalene muscle, *MSM* medium scalene muscle, *BP* brachial plexus

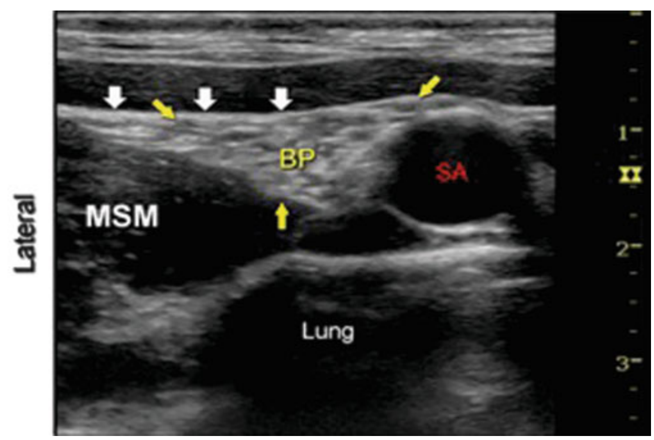

Fig. 4 Soundgraphic image of supraclavear region. *SA* subclavian artery, *MSM* medium scalene muscles, *BP* brachial plexus. White arrow heads: Prevertebral fascia. Yellow arrow heads: Brachial plexus

line which represents the parietal pleura that, – unlike the rib – is passed by ultrasounds, thus generating reflection artifacts. These artifacts, defined as "comet tail", are typical of the tissue-air interface that represents pulmonary parenchyma (Fig. 4) [23].

The patient may be asked to take a deep breath in order to show the sliding of layers of parietal and visceral pleura [23]. In most patients, the distance skin-pleura at supraclavear level is far less than 3 cm.

The plexus is identified laterally, behind, and in cephalic position with respect to the artery. When it is visualized over the short axis, it appears as a complex of hypoechogenic, round and oval structures in a number ranging 2–12 (according to patients characteristics and the level of analysis). The most superficial nerves usually innervate the proximal extremity of superior limb (shoulder and proximal part of arm), while the deepest nerves, near to the first rib, innervate the distal part (elbow, forearm, hand). A lateral-medial approach is usually preferred over medial-lateral approaches, since with this approach it is possible to avoid the subclavian vein that alternatively could collapse because of probe pressure and lead to a missing identification of the intravascular injection. In our opinion, for a supraclavear block the *in-plane* approach is more suitable, thanks to its safety (the needle should be always followed to reduce the risk of pneumothorax).

After skin disinfection, the probe is positioned to the image of the artery in the center of the screen. Then, the needle is inserted using the *in-plane* approach and slowly moves to contact the sheath that envelops nerves. After this, the band is pierced by slightly pressing the needle. In this way, it is possible to enter into the virtual space that hosts nervous structures. When the desired location is reached, the needle can be connected to the ENS in order to have a further confirmation of its exact position. After aspiration, a local anesthetic solution is injected, and its diffusion around nervous structures is observed (Fig. 5).

When the diffusion of the anesthetic cannot be observed, the procedure should be suspended and the needle repositioned. The correct position is confirmed by the anesthetic spread around the nerve (sign of "ring-shaped cake") [23].

Comparison Between Echographic and ENS Approaches

Echography provides an anatomical visualization, reduces complications, increases the success rate of blocks, and limits anesthetic doses. However, interscalene block performed by ENS is an established technique, with high success rate, low complication rate, more rapid, and less expensive than echography.

In a prospective randomized study on 230 patients, Liu [21] demonstrated that ENS reduces the duration of the anesthetic procedure and the onset of the block. Moreover, no difference was shown between the two techniques with respect to the incidence of block failure, patient satisfaction, or severity of postoperative neurological symptoms. In a similar trial on 160 patients, Kapral [22] reported a surgical anesthetic rate of 99 %, in echo-guided group in comparison to the 91 % reported in the ENS group ($p < 0.01$). Sensitive and motor extension appears higher in the first group.

According to available evidence and our experience, the gold standard approach to perineural blocks is represented by echographic imaging with the exploratory needle connected to ENS and a parallel evocation of muscle twitch.

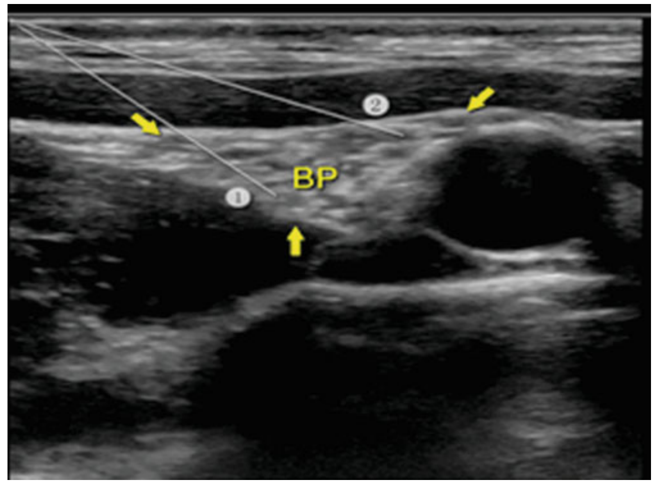

Fig. 5 Needle position inside the sheath that contains nervous roots; *BP* brachial plexus. Yellow arrow heads: Brachial plexus. Labels 1,2: Two possible needle positions used to inject local anesthetic

Local Anesthetics

Several local anesthetics are currently available; each drug presents advantages and disadvantages due to its specific pharmacokinetic and pharmacodynamic characteristics. In our experience, we usually associate two molecules, one with a short onset of action (and a shorter duration of action, as well) and one with longer onset, but with prolonged duration of action, in order to take advantage of their characteristics. For a single shot block of brachial plexus (interscalene or supraclavear), we use a combination in equal volume of mepivacain 1.5 % + ropivacain 0.75 % or mepivacain 1.5 % + levobupivacain 0.5 %: dose 0.3–0.4 ml/kg. For a continuous block, we use only local anesthetics with long-term action: levobupivacain 0.125 % or ropivacain 0.2 %, both at dose of 5 ml/min.

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Treatment of the Partial Tear

Stefano Gumina, Alessandro Castagna, and Mario Borroni

Partial-thickness rotator cuff tear was described by Codman [1] as "rim rents" in 1934, but Ellman was the first author to present a classification system that included partial rotator cuff tear [2]. The classification was based on arthroscopic findings and on the location of the tear (A, articular; B, bursal; C, intratendinous) as well as on the depth of the tear (grade 1, <3 mm; grade 2, 3–6 mm; grade 3>6 mm). In 1991, Snyder introduced his classification with four different grades of severity based on the size of the defect by its superficial extension [3]. Snyder also coined the acronym PASTA lesion (partial articular supraspinatus tendon avulsion) as a special form of a type A III or A IV tear with a traumatic etiology, which established a relationship to a tear at the tendon insertion without considering the extension of the tear as well as the exact location of the partial-thickness tear [4–6].

Gerber et al. [7] retain that partially torn supraspinatus tendon can be functionally incompetent, leading to a biomechanical deformation of the musculotendinous unit that is not different from that of a unit with a full-thickness tendon tear.

The approach to the patient with a suspected partial thickness rotator cuff tear should not differ from that in any patient presenting with complaints of shoulder pain or dysfunction. Patients will often report pain and stiffness of the affected shoulder. Nocturnal pain and pain exacerbated by overhead activity are common but not specific for partial-thickness tearing. The physical examination will often elicit a painful arc, positive impingement signs and real or apparent weakness with rotator cuff strength testing. MRI exam may contribute to formulate a correct diagnosis (Fig. 1).

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Histologic studies showed that partial-thickness tears have essentially no ability to heal themselves over time [8]. Yamanaka and Matsumoto showed a 80 % tear progression in 40 partial-sided tear (28 % to full thickness) followed for 2 years [9].

Most authors recommend repair of tears involving 50 % or more of the tendon thickness even if it is always difficult to evaluate the depth of the tear because of the variability of the tendon thickness.

Some surgeons prefer to complete the tear and perform a more traditional repair via arthroscopic or open approaches [10–14]. Itoi performed a retrospective review on 38 shoulders having partial-thickness tear treated with completion and open repair. At 5 years, good or excellent results were maintained in 82 %, with no differences noted with the addition of acromioplasty [12].

Intratendinous repair techniques have been described with good results and biomechanical properties [11, 15–18]. Ide et al. reported on 17 patients with grade 3A tears who underwent an arthroscopic transtendinous repairs and showed excellent improvement at a minimum follow-up of 25 months. Six overhead athletes were included in this series; two were able to return to the same level of competition, whereas three returned at a lower level (the outcome of the sixth patient is unknown) [17].

Conservative Treatment

Patients with a suspected partial tear should be initially treated in the standard manner for patients with impingement syndrome. Inflammation of the subacromial bursa is controlled through activity modification, nonsteroidal medication, and the judicious use of injectable corticosteroid. Physical therapy is advanced as inflammation diminishes and pain subsides. Therapy should be first directed at eliminating capsular contractures and regaining full motion. Progressive stretching in adduction and internal rotation and horizontal adduction exercises (cross body) may improve

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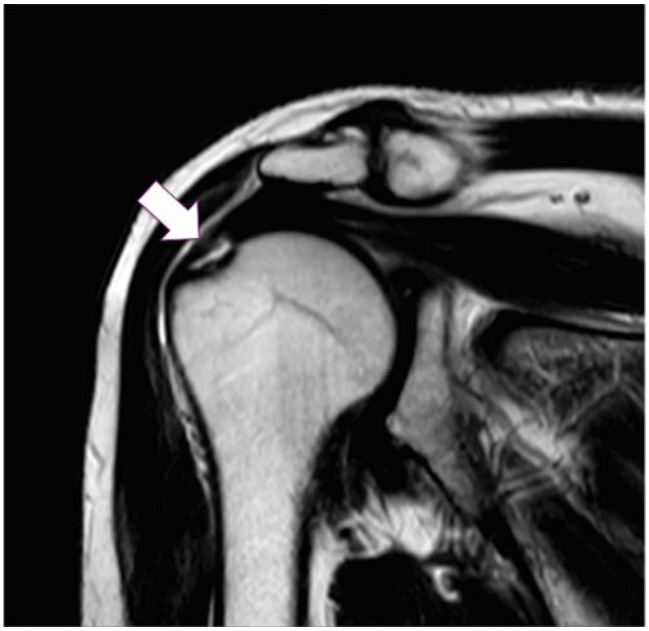

Fig. 1 MRI image. The *arrow* shows a partial tear

contracture of the posterior capsule. Rehabilitation of the periscapular musculature may contribute to restore normal scapulothoracic mechanics and minimize dynamic impingement secondary to scapulothoracic dyskinesis. Restoration of proper shoulder mechanics is especially important in overhead athletes.

Wolff et al. [19] retain that conservative treatment is successful in most patients. They will improve with conservative measures over 6 months and that some of them continue to improve for up to 18 months.

Debridement

In a systematic review, Strauss et al. [20] identified seven studies [3, 14, 21–25] using operative debridement, with or without concomitant subacromial decompression, for partial rotator cuff tears that comprised less than 50 % of the tendon's thickness and were Ellman grade II or less. Good to excellent results as measured by validated shoulder scoring system were obtained with this procedure [22–25]. Kartus et al. [23] referred that outcomes obtained with debridement may not remain in optimal range over the long term, noting that the Constant score fell nearly 20 points below with respect to the contralateral normal shoulder at longer follow-up. Acromioplasty did not significantly affect the overall outcome of patients submitted to debridement; in fact, satisfactory results were reported in studies that did not use this adjunct [3, 13, 21]. Return to high-level athletic activity was variable when debridement was used. Raynolds et al. [13] reported 45 % rate of return to play at the same or higher level before the rotator partial tear. Of about 57 % of Budoff's [21] patients were able to return to preoperative levels of sport activity; 22 % were unable to participate because of persistent shoulder discomfort; while 20 % had shoulder pain with this activities. Andrews reported good or excellent results, at short-term follow-up, in 85 % of overhead athletes suffering of partial rotator cuff tear treated with debridement alone [10]. In a later series, the author noted that the 76 % of professional pitcher was able to return to competitive pitching; however, only 55 % returned to the same or a higher level of competition [13].

Considering these data, partial tears of less than 50 % of Ellman grade II or less can be successfully treated with debridement alone without acromioplasty.

Arthroscopic Tear Completion and Repair

Initially, an intra-articular diagnostic arthroscopy is performed. The thickness of the lesion is measured off the footprint. Average thickness of the rotator cuff footprint has previously been determined by Ruotolo et al. [26]. Authors retain that it corresponds to 14 mm. If the tear is >7 mm, it is judged to be >50 % thickness (Fig. 2a, b). Once the patient is determined to be a partial thickness rotator cuff tear, a marking suture is placed (using a 18 gauge spinal needle as a guide) (Fig. 3a, b) and the arthroscope is moved to the subacromial space. Subacromial decompression is performed only if an impingement lesion, defined by observable fraying and abrasion on the undersurface of the coracoacromial ligament with or without a kissing abrasive lesion on the superior aspect of the rotator cuff, is visualized (Fig. 3c). Bursectomy is performed, by using a shaver and radio frequencies, taking care not to damage the marking suture (Fig. 4a, b). The cuff is then evaluated around the marking suture (Fig. 4c, d). Once the lesion was localized, the tear is completed utilizing a shaver or radio frequency (Fig. 4e, f). The tear edges are freshened. The footprint is cleared of soft tissue and cortical bone left intact. A single row anchors is placed in an anatomical position, as determined by reducing the torn rotator cuff to the greater tuberosity and noting the repair location that allowed anatomic recreation of supraspinatus tendon direction and tension and the cuff sutured. If adequate tissue remained, the repair is extended laterally with additional suture beyond the original anchor, using a second row of anchors.

Patients are treated post-operatively in an internal rotation shoulder immobilizer for 25 days, coming out of the sling for passive range of motion. Active motion is initiated at 4 weeks, with no resistive rotator cuff exercises until 12 weeks and return to normal activities at 6 months.

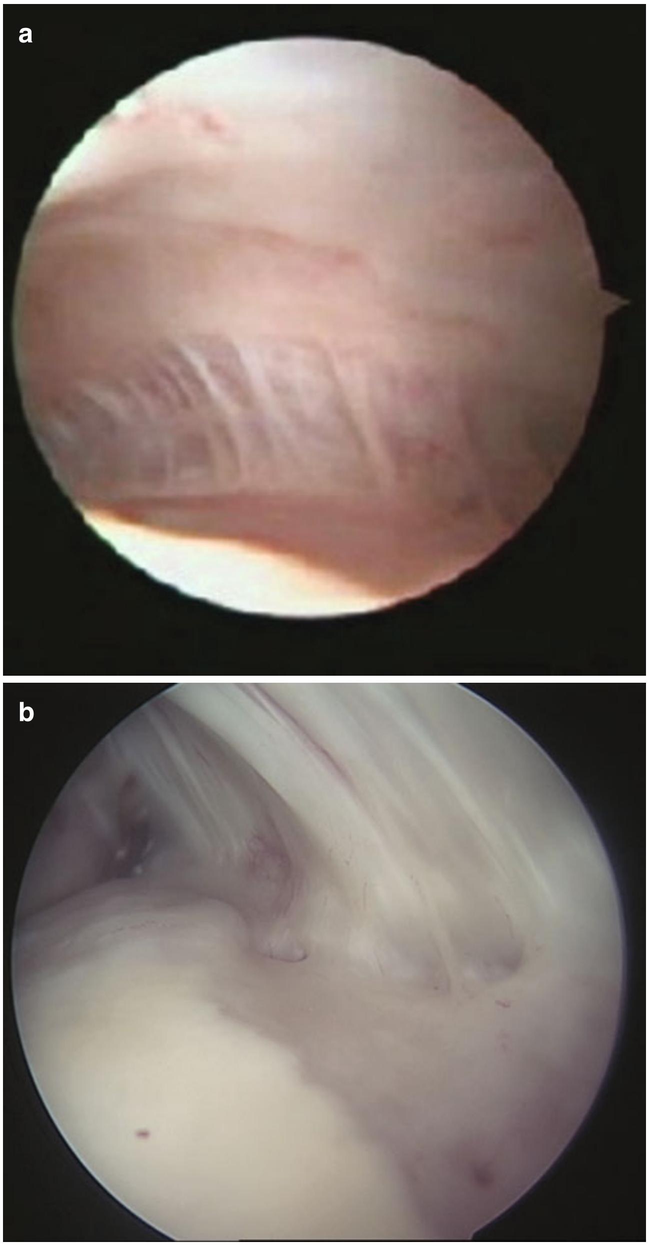

Fig. 2 (**a**, **b**). Arthroscopic intraarticular posterior portal view of two different right shoulders. In both cases, thickness of the rotator cuff footprint is >7 mm

Transtendon Arthroscopic Repair

In order to accurately describe the technique as proposed by the authors, we used fragments extracted from the original work [18]. Diagnostic gleno-humeral arthroscopy is performed. Partial thickness rotator cuff tear will reveal degeneration and fraying of a portion of the cuff insertion. After debridement, the medial aspect of the footprint will be observable. Before repairing the tear, scope is moved into subacromial space; bursectomy and acromioplasty, if necessary, are done. Attempting to debride the bursa after anchor replacement can easily lead to inadvertent damage to or resection of the sutures [18]. The presence of an eventual and concomital bursal-sided tear has to be verified. To allow correlation of the articular surface tear to the bursal side, a suture marker is used to help locate the lesion on the bursal surface. If a concomitant bursal tear is present, tear is completed and a standard repair is performed. After bursectomy, scope is reintroduced into the gleno-humeral joint. Foot print is carefully abraded with an acromionizer. To place transtendon anchors, a 18-gauge spinal needle has to be used. The angle of insertion is usually directly adjacent to the lateral aspect of the acromion, allowing the anchor to be placed at the dead man's angle of 45° or less into the medial margin of the rotator cuff footprint [18–27]. In some cases, adducting the arm can improve the dead man's angle for anchor insertion. A percutaneous incision parallel to the spinal needle is done; by maintaining the same angle of the needle, a suture anchor is the placed transtendon into the abraded foot print. If the tear involves <1.5 cm of the foot print (in an anterior to posterior direction), 1 anchor for the repair is sufficient; however, if the tear involves >1.5 cm of the footprint, then 2 anchors are employed.

For a 1 anchor repair (Fig. 5), because the suture limbs all pass through the same puncture (used for anchor insertion) in the rotator cuff, one must create a bridge of tissue to compress against the bone bed. A Shuttle Relay (Fig. 6a–c) or a bird beak suture passer may be used to pass one limb of each suture retrograde through a more posterior area of the tear. The sutures can be tied in a routine fashion in the subacromial space (Fig. 7a–c).

For a 2 anchor repair, one limb of suture of the same color from each anchor is grasped and retrieved through the lateral portal. These sutures are then tied together over a probe (or another instrument). By pulling the opposite limbs of the same sutures (same color), the tied knot will be drawn through the cannula, into the joint, and over the top of the rotator cuff. In this manner, the eyelet of the two anchors are used as pulleys to draw the tied knot into the joint, creating a bridge of suture over the rotator cuff that compress it against the abraded footprint. To secure this construct, the free limbs of the suture pair that were previously tied are retrieved through the lateral portal for tying. A nonsliding knot must be tied because sliding has been precluded by the previously placed knot in the suture pair. The other sutures (different color) are similarly tied extracorporeally first, pulled into the joint and then tied again (the opposite limbs). A final evaluation of the construct is performed both subacromially and intraarticularly.

The postoperative rehabilitation program is similar to that previously described for arthroscopic tear completion and repair.

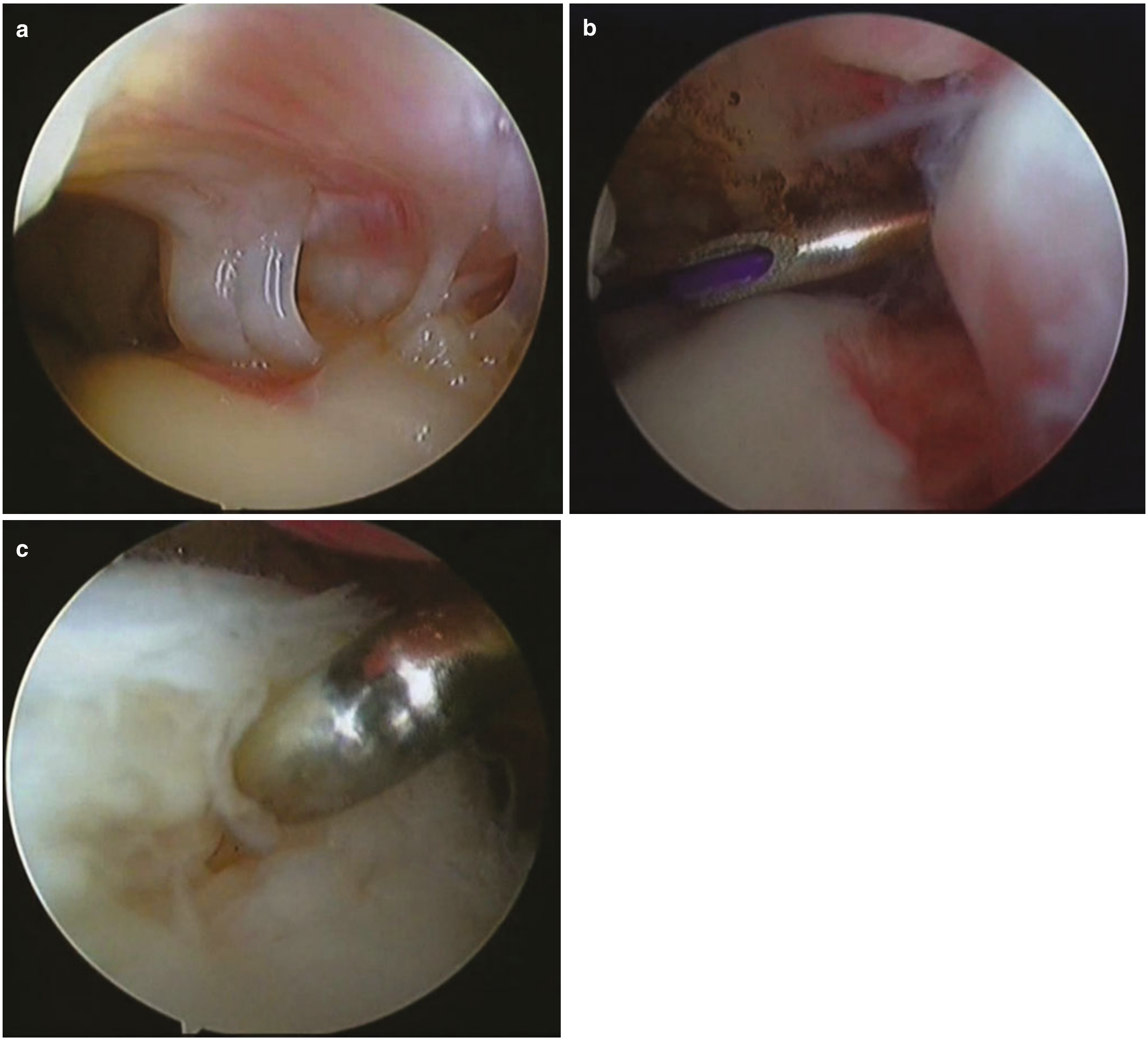

Fig. 3 Partial articular supraspinatus tendon avulsion of a right shoulder (**a**). A marking suture is placed using a 18-gauge spinal needle as a guide (**b**). A partial bursal lesion. The probe penetrates into the cuff thickness (**c**)

Transosseous Arthroscopic Repair

In 2008, Tauber et al. [28] described the transosseous arthroscopic repair of partial articular-surface supraspinatus tendon tears (Fig. 8a, b). To accurately describe the technique as proposed by the authors, we used fragments extracted from the original work [28].

Diagnostic shoulder arthroscopy is performed, as for the other three techniques. Before beginning tendon repair, the arthroscope is moved into the subacromial space for bursectomy. An accurate soft tissue shaving extended 2 cm distal at the lateral wall of the greater tuberosity is mandatory for a clear overview of the tendon structures in terms of not missing a concomitant bursal-sided tear and to provide sufficient space for tendon repair and knot-positioning. Subsequently, the arthroscope is reinserted into the gleno-humeral joint and the cortex at the medial aspect of the altered footprint is exposed and resected. A special curved sharp-cut cannulated hollow needle with a diameter of 2.5 mm at its curvature (TransOsteoNeedle®, Arthrex, FL, USA) is introduced through the skin at the anterolateral edge of the acromion. Previously, a spinal needle may be inserted percutaneously to locate the proper point of entry for the needle. Under intra-articular view, the anterior entry point through the partial lesion is carefully detected by palpation with the point of the hollow needle avoiding tendon perforation. Just after localization of the correct point of entrance, which should be directly at the border between intact and debrided tendon tissue, the sharp-hooked needle is stuck through the tendon and pressed into the cancellous bone at the anterior aspect of the

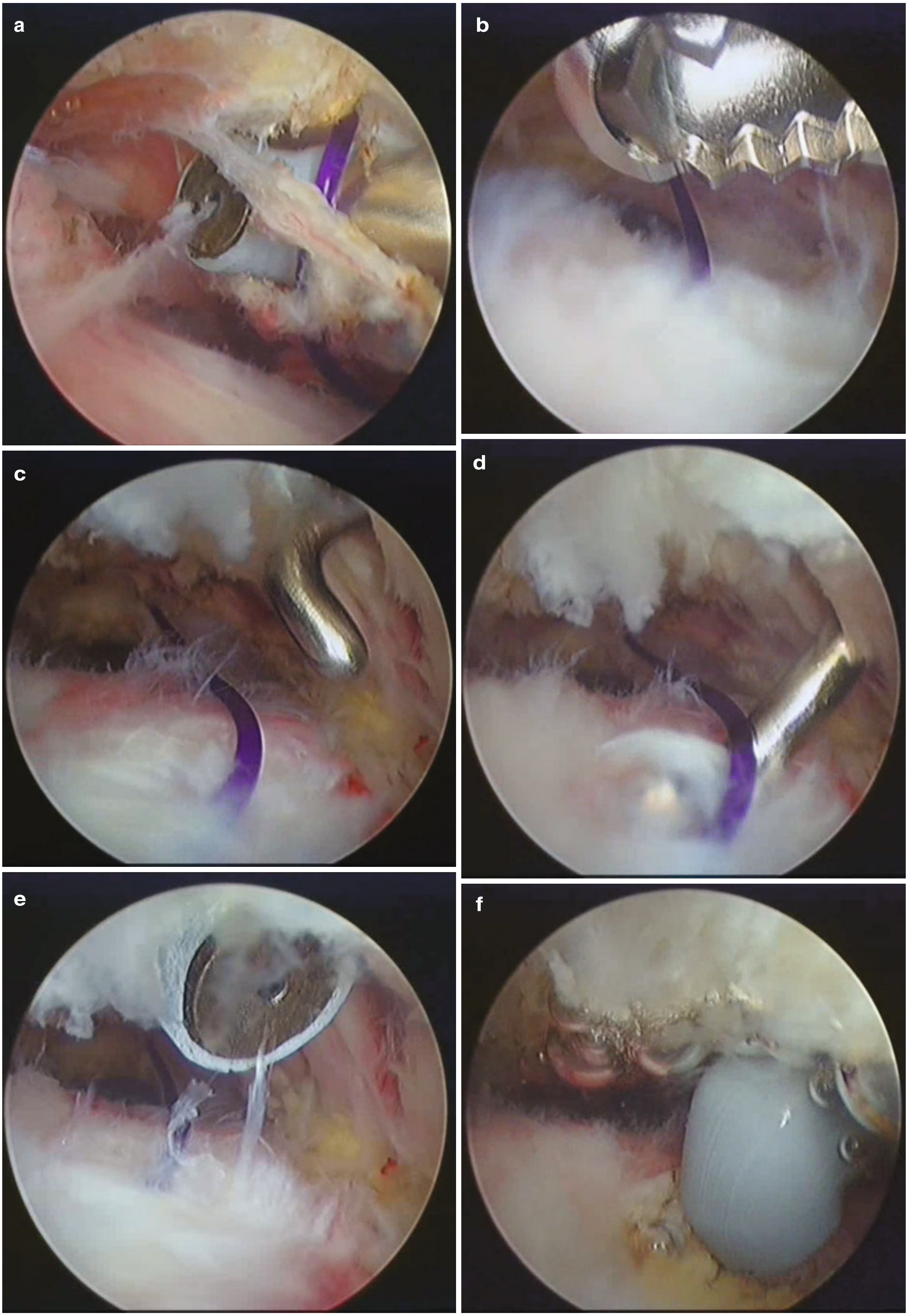

Fig. 4 Bursectomy is performed, by using radio frequencies and shaver (**a**, **b**), taking care not to damage the marking suture (**c**, **d**). The tear is completed utilizing a shaver or radio frequency (**e**, **f**)

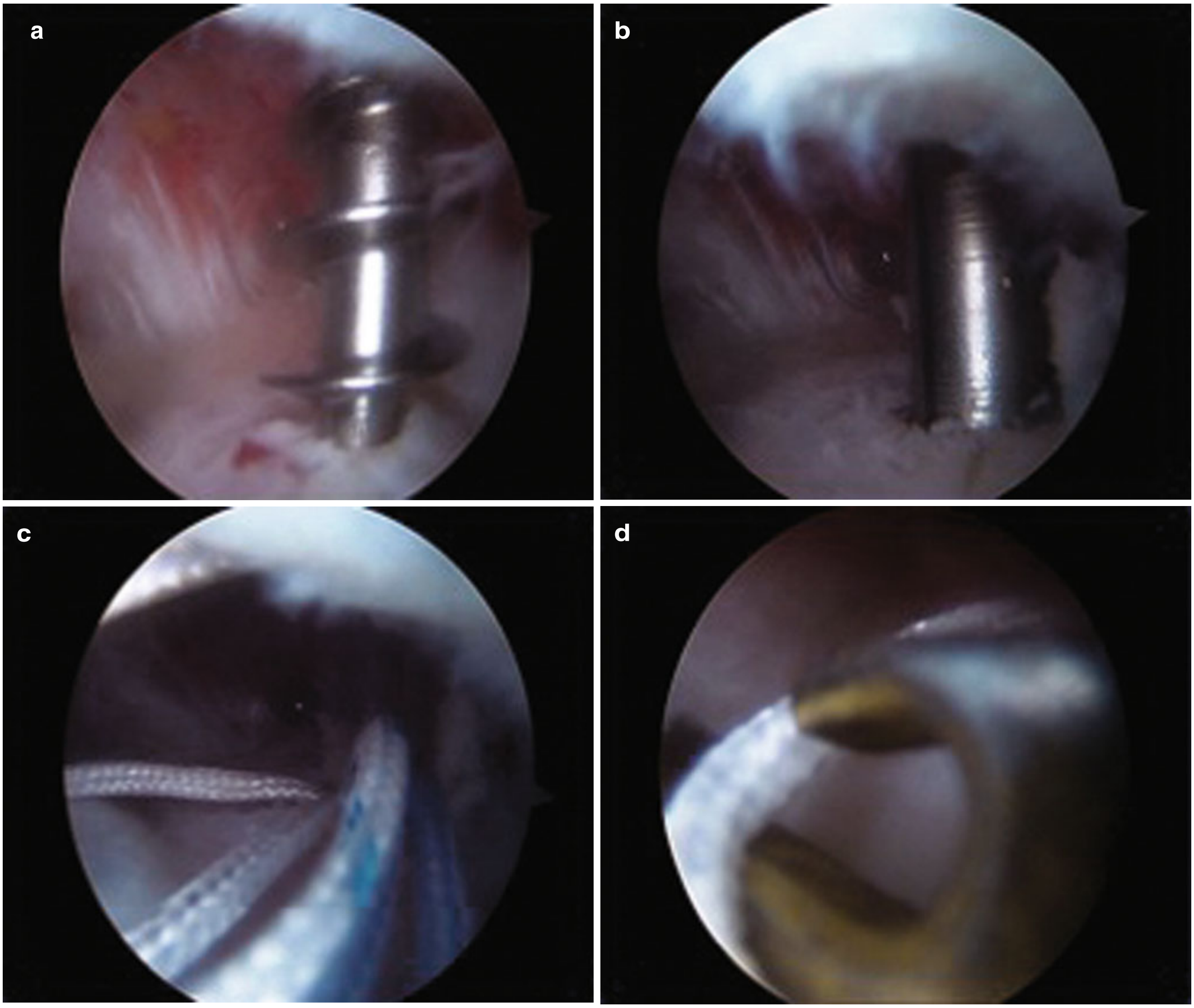

Fig. 5 Anchor introduction (**a**, **b**). Suture are momentaneously transferred in the anterolateral portal (**c**, **d**)

footprint by gentle turning movements. The entry point of the needle at the footprint should be close to the lateral edge of the humeral head cartilage. The needle is guided into a lateral direction to then perforate the lateral cortex of the greater tuberosity using careful taps with a hammer. The exit point is approximately 1.5 distal from the level of the greater tuberosity. When the acromion is laterally extended, it is advisable to place the entry point directly at the anterolateral edge of the acromion and to create an acceptable angulation by rotation and retroversion of the arm. The trocar of the cannulated needle is removed and an eyelet shuttle loaded with a No. 5 fiber wire (Arthrex) is inserted through the needle perforating the skin at the lateral deltoideal region. The shuttle is secured with a clamp and the needle is removed into a superior direction leaving the eyelet in situ. Then a working cannula is placed at the lateral portal, through which a hooked suture grasper is introduced grasping the eyelet at the lateral wall of the greater tuberosity. For this step, the arthroscope must to be switched into the subacromial space. Pulling out laterally the shuttle, the loaded fiber wire lies in the hook of the suture grasper and can easily be guided out through the lateral portal. During this maneuver, it is important to hold the hooked suture grasper under slight pull, in order not to loose the fiber wire. To avoid suture manipulation, the superior end of the fiber wire perforating the skin at the lateral edge of the acromion is grasper and pulled out through the lateral working cannula as well. Thus, both wire ends of the first transosseous suture run out through the lateral working cannula.

The second eyelet shuttle is placed in an identical manner to the first one using the same skin perforation for the curved hollow needle. However, depending on the antero-posterior extension of the partial-thickness tear, the entry point of the

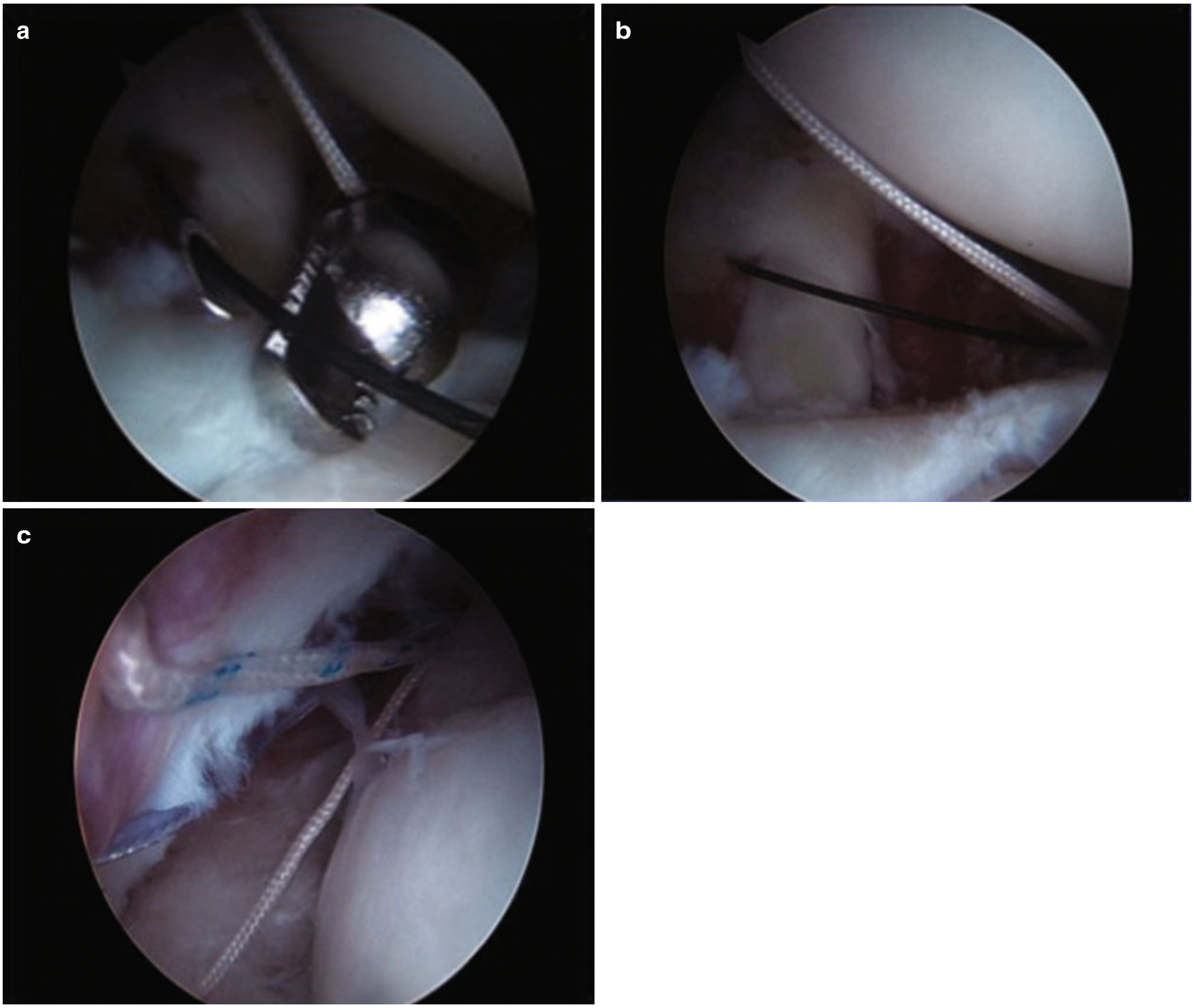

Fig. 6 (**a**) Insertion of the Shuttle-Relay beyond the tendon using a spinal needle. Pass the suture beyond the tendon using the Shuttle-Relay (**b**). The step is repeated for all the sutures (**c**)

curved needle in the tendon and footprint is placed at the posterior end of the partial lesion creating an adequate bridge of suture. After transosseous positioning of the curved needle at the footprint of the greater tuberosity, the eyelet shuttle is introduced after removal of the trocar and secured with a clamp at the lateral deltoid area after skin perforation. After that TransOsteoNeedle® is drawn back in proximal direction. Notice that this second shuttle is not loaded with any wire. Then, the hooked suture grasper is led in a subacromial direction over a groove drilled at the top along the shuttle through the skin and the deltoid muscle. The gliding groove should help avoid soft tissue interposing between the grasper and the eyelet wire. Now, the proximal wire end of the first suture running out the lateral working cannula is grasped and guided out proximally along the eyelet wire. In this manner, a transosseous mattress suture is performed, when the eyelet shuttle is then loaded with this suture wire end pulled out laterally. Before pulling out the shuttle, the hooked suture grasper has to be inserted through the lateral working cannula and grasp the wire in order to catch the loaded Fiber wire. The latter is guided out through the lateral working cannula as well, and the mattress suture is completed after tying with an arthroscopic sliding knot at the lateral wall of the greater tuberosity. Thus, transosseous arthroscopic repair of the partial lesion is concluded.

Immobilization is recommended for 6 weeks; during this period, only passive exercises are permitted.

Biomechanical study comparing transtendon in situ repair and tear completion with repair for high-grade, partial, articular-sided supraspinatus tendon tear of the rotator cuff showed that in situ transtendon repair was biomechanically superior [11].

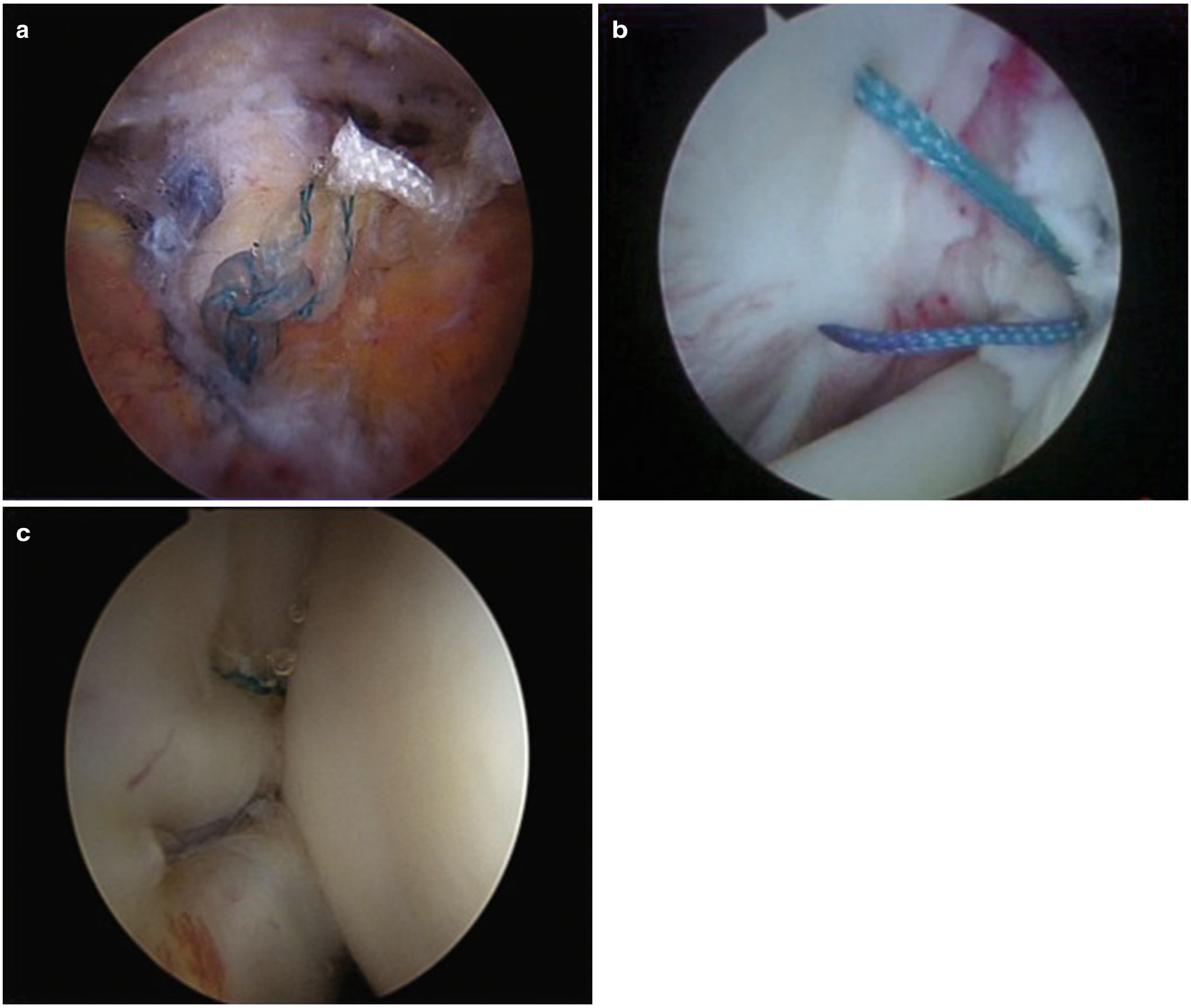

Fig. 7 Tying the knots in the subacromial space. Final result (**a**). One double loaded titanium anchor suture (**b**, **c**)

A prospective randomized study that compared the clinical outcomes of patients who underwent partial-thickness articular sided rotator cuff repair by tear completion or transtendon repair was performed by Shin [29]. He observed that arthroscopic repair of partial lesion provides satisfactory functional improvements and pain relief regardless of the repair technique. Although repair after completion to a full thickness tear showed less postoperative morbidity, tendon integrity is of primary concern after repair. However, the transtendon repair resulted in complete tendon integrity but slower functional recovery.

Strauss et al. [20], after a systematic review of the literature, concluded that there is no evidence to suggest a differential in outcome for tear completion and repair versus transtendon repair of these lesions because both methods have been shown to result in favorable outcomes.

Yamakado [30] observed that over 90 % of the macroscopically intact residual tendon tissue of the PASTA lesions showed moderate histopathologic degeneration. Degenerative changes were evident in 28 of 30 cases, including features of myxoid degeneration, hyalinization, chondroid metaplasia, rounding of tenocyte nuclei, vascular proliferation, and disorientation of the fibers (these features were present either individually or in combination). Therefore, transtendon technique leaves not only degenerative but also potentially thin fibers at the repair site, which may compromise the repair site. Based on this data, the completion into a full-thickness tear followed by classical repair should be the best choice.

In 2012, we performed a study in order to evaluate, in a randomized clinical trial, the difference in clinical outcomes between transtendon repair and the complete repair technique in a group of patients suffering of partial articular-sided

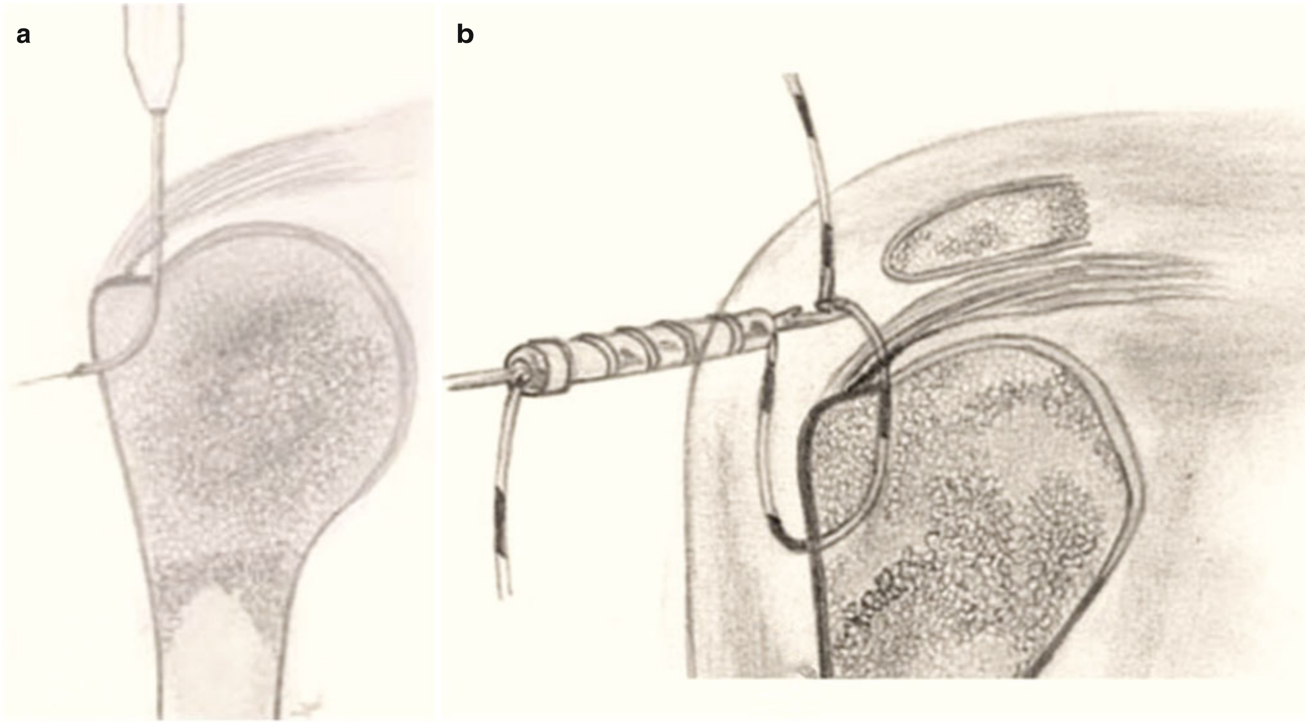

Fig. 8 The curved needle perforates the medial edge of the tendon lesion and the anterior aspect of the foot print close to the articular cartilage of the humeral head (**a**). By means of a hook grasper, suture wires (shuttle relay) are pulled out through the lateral portal (**b**). Successively, suture can be passed using the shuttle relay (Modified from Tauber et al. [28])

supraspinatus tear [31]. This was a prospective multicenter (2 institutes), randomized, nonstratified, double-blind study. In the period between 2006 and 2009, 2658 patients underwent an arthroscopic rotator cuff repair operation in two different institutes. Of these, 74 patients with a mean age of 51 years (21–68) were prospectively enrolled in this study. The inclusion criteria were as follows: (a) all adults aged 18 or over (b) in whom during arthroscopic examination we noted the presence of a significant articular side supraspinatus tear (footprint exposed more than 5.5 mm). The exclusion criteria were patients with (a) long head of biceps lesions, (b) chondral lesions, (c) associated bursal supraspinatus tear, and (d) subacromial impingement. Avulsion from the footprint was measured using a 5.5-mm shaver blade [16]. All the surgical procedures started with a diagnostic arthroscopy in lateral decubitus with traction of 4 kg. Evaluation was performed using two traditional posterior and anterior portals. According to Randelli's randomization criteria [32], 37 patients with an average age of 54 years (21–68) were treated with a transtendinous technique (Group A) and 37 patients with an average age of 47 years (33–64) were treated with a tear completion and a suture anchor repair (Group B). Particularly, the randomization method was a "block randomization" using a dedicated software (StatsDirect, StatsDirect Ltd., Ceshire, England) and it was done during the surgical procedure, after that the presence of a partial articular tear was proven and after the inclusion/exclusion criteria were satisfied. In Group A, to place the transtendinous anchor, we initially used an 18-gauge spinal needle as guide. Placing the anchors at the medial margin of the rotator cuff footprint just lateral to the articular surface is crucial to restoring the rotator cuff footprint. A 5.0-mm Fastin anchors (Mitek) double-loaded with No. 2 Orthocord (Ethicon, Somerville, NJ) were used. Definitive sutures were passed through the tendon using a spinal needle percutaneously [16]. In Group B after the intra-articular examination, the scope was moved in the subacromial space. The tear was completed with using a shaver and then, after debridement at footprint level, the tear was repaired with the traditional suture anchor repair technique, with the same anchor used in Group A and with two simple stitches [33]. Surgeon who made the operation does not examined patient before surgery, neither at postoperative time. Patient just signed before the operation an informed consent to undergo an arthroscopic cuff repair, so he was blinded too respect to the type of surgical procedure. No additional treatment such as subacromial decompression or biceps tenotomy was performed in either group. All patients were immobilized in a 20° abduction sling for 4 weeks when they then started a normal rehabilitation protocol for 4 months. All the patients were evaluated pre- and postoperatively at a minimum follow-up of 2 years with Visual Analogic Scale (VAS) and with Constant score (analyzing the total value and its four subgroups) by two independent physicians, blinded about the surgical procedure.

Passive and active range of motion in each plane was evaluated with a goniometer; the strength measurement was done with a Lafayette Manual Muscle Test Dynamometer (Lafayette Instruments, San Diego, USA). Each measurement was done three times, and the mean of the three measurements was choice as the measure.

Statistical analysis. Assuming a standard deviation of 15, a sample size of 37 per group was necessary to detect a Constant score difference of eight (that is, about half the standard deviation) between the pre-and the post-situation within each group, with a power of 90 % and a type I error of 5 %. Pearson's Chi-squared tests were used to compare categorical data, and Student's t tests to compare continuous variables, or Wilcoxon rank sum test whether the hypothesis of normality was rejected. All the analyses were done using TIBCO Spotfire S 8.1 for Windows, TIBCO, TIBCO Software Inc., Palo Alto, CA.

Both groups showed statistically significant improvement in the scores. There were no statistically significant differences of the pre-op Constant score relating to age (n.s), sex (n.s.), and dominancy of the arm (n.s.). The post-op Constant tends to decrease with age (−0.2 per year, n.s.). In Group A, the Constant score improved by a mean value of 25.1 (SD 5.8) ($p<0.0001$) and VAS score by a mean value of 3.4 (SD 1.2); ($p<0.0001$) while in Group B, Constant's score improved by a mean value of 29 (SD 6.2) ($p<0.0001$) and VAS score by a mean value of 3.6 (SD 1.7) ($p<0.0001$).

No statistically significant differences were found when comparing results between the two centers or between the two different techniques neither in Constant's score (n.s.) nor in VAS score (n.s.).

The most important finding of the present study was that the two examined techniques to treat deep partial supraspinatus tear both provide good results in terms of function and pain. No differences were found relating to age, sex, or arm dominancy, and when analyzing the Constant score subgroup, it is noteworthy from a percentage point of view that improvement in the Constant score was greater in Group B than in Group A (50 and 40 %, respectively) and the greatest improvement of both groups was related to the score for ADL (74 % in Group A and 90 % in Group B). It is important, however, to note that there were no differences between results obtained in the two centers meaning that results relate solely to the technique and not to the surgeon. No statistically significant differences were found when comparing the two techniques leading us to conclude that both procedures examined are effective in the treatment of this pathology. The study, however, had some limitations: for example, different surgeons in different institutes may lead to a subjective evaluation of the size of the lesion, even if the method of measurement was well understood.

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Treatment of the Reparable Postero-Superior Lesions: Single and Double-Row Repair

Stefano Gumina and Vittorio Candela

The number of rotator cuff arthroscopic repairs is increased by 600 % in the next decade to 1996 [1]. Actually, the number of open repairs too is increased during the same period, but only by 34 %. According to a survey conducted in 2005 among orthopedists of the American Academy, 62 %, of the 167 interrogated colleagues, routinely arthroscopically repaired a small rotator cuff tear [2]. This finding is surprising when compared with 14.5 % that was the rate extrapolated 3 years earlier from a Dunn et al. [3] study.

The goals of cuff repair are to restore footprint anatomy with biomechanically secure, tension-free construct that promotes biologic healing at the tendon-to-bone interface. Regardless of the used surgical technique, some “steps” of the repair remain constant: (a) assessment of the size, shape, and elasticity of the lesion; (b) assessment of the degree of tear retraction; (c) assessment of thickness and fraying (delamination) of tear edge; (d) preparation of a bloody footprint or of holes in the greater tuberosity to allow bone marrow diffusion; (e) suture (with different techniques) with high-resistance nonabsorbable sutures of the cuff tear edges; (f) secure knots with low tendency to failure; and (g) the evaluation of the possible effectiveness of acromioplasty in order to (1) provide for a further park and postoperative bleeding and/or to (2) preserve the made sutures.

The optimal repair construct has been outlined by many authors in attempts to restore the kinematics of the glenohumeral joint [4–6].

Single-Row Repair

I perform the arthroscopic rotator cuff repair with patient in beach chair position (Fig. 1), regardless of the used technique. I draw the outline of the acromion, the spine of the scapula, the clavicle, the acromioclavicular joint, and coracoid using a sterile dermographic pencil on the sterilized shoulder (Fig. 2a–c).

The portals commonly used are the posterior (located approximately 2–3 cm inferior and 1 cm medial to the posterolateral corner of the acromion at the “soft” spots), the lateral (located approximately 1.5–3 cm lateral to the acromion in line with the posterior aspect of the clavicle), superolateral (percutaneous portal is located just lateral to

Fig. 1 Patient is placed in beach chair position for an arthroscopic rotator cuff repair of the right shoulder

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Fig. 2 The outline of the acromion, the spine of the scapula, the clavicle, the acromioclavicular joint, and coracoid are drawn using a sterile dermographic pencil on the sterilized shoulder. Posterior (**a**), lateral (**b**) and anterior (**c**) views

the edge of the acromion), and anterolateral (utility portal located midway along the anterolateral acromial corner and the tip of the coracoid). The mid-glenoid portal is required only if there is an intra-articular operative time (tenotomy/tenodesis of the long head of biceps; synovectomy, debridement of the labrum or insertion of the biceps tendon).

The anterior, anterolateral, and lateral portals are established after introduction, in the alleged right spot, of an 18-gauge spinal needle (pink needle) with out-in technique. For the lateral portal, the needle should be centered on the apex of the medial tendon injury in order to have easy access to both posterior and anterior edges of the tear. This access will be the one through which we will carry out the repair (for surgeons using only the posterior portal); that will be used alone or, alternatively, with the posterior portal, for the direct view of the lesion; for the introduction of the anchors (metallic or plastic resorbable material and nonresorbable one); for tear margins preparation and for the execution of the acromioplasty, if this surgical procedure is necessary. In the lateral portal, an 8-mm cannula is usually inserted. Instead, in the anterior one, a 5.5-mm cannula is inserted. It is used for suture threads recovery or for anchors positioning [7–9] (Fig. 3).

The instrumentation required for cuff repair with single-row technique is represented by a grasper used to test the mobility of the tissue and to retrieve the suture thread once passed in the tendon, a passing suture (as Scorpion, Elite, TruePass, suture hooks, etc), a crochet hook, (alternatively a clamp ring), and one knot pusher to carry out the sutures (Fig. 4).

Since my job is also to teach, I perform the operation with two young colleagues. The entire operation is registered in order to have a useful documentation for teaching.

Obviously, the first operation time is the intra-articular view with the arthroscope inserted through the posterior and anterior portals. I run the 15 common steps (changing the portals), as suggested by Snyder (Table 1) [10].

Fig. 3 In the lateral and in the anterior portals, a 8-mm (*green*) and a 5.5-mm (*orange*) cannula are inserted, respectively

The observation of these structures is firstly performed keeping the arm along the side and then performing abduction, flexion, internal, and external rotation movements in order to obtain a dynamic view of the same.

Subsequently, the arthroscope is inserted into the subacromial space. It is recommended that the optic is kept parallel to the inferior surface of the acromion to prevent that the liquid that flows from the portal impairs the vision. I run the bursectomy if necessary, with a radiofrequency ablator (Fig. 6) and a shaver.

Usually, I remove only the bursa that obstructs the view of the tear edges, exposing the same for at least 1.5 cm. The use of radiofrequencies reduces the risk of bleeding; therefore, they are preferred to the shaver; however, in case of subacromial bursa hypertrophy, radiofrequencies are not able to remove the exuberant tissue. The arthroscope is then moved to the lateral portal; it gives you a clearer idea of tear shape and extension. It is important to verify also the presence of a delamination of tendon edges.

I perform the single-row technique only in cases of type crescent tears.

The frayed edges of the rotator cuff tendon are debrided using a 4.2-mm shaver or a basket (Fig. 7). Successively I assess the pattern of the tear using a soft tissue grasper through the anterior and posterior portal and experiment with various options to reposition the tendon back to the footprint and for possible side-to-side sutures. To check the tightness of the suture, Gartsman [7] has recommended to pass a high-resistance No. 2 wire with a suture passer and then trying to mobilize the margin of tear; obviously a not repairable tissue is the one cut by the thread with no mobilization of the same.

I use a bur in order to prepare a suitable bleeding footprint having care not to remove an excessive quantity of bone since the holding of the anchors could then be compromised (Fig. 8). The length of the footprint will be equal to the length of the lesion from anterior to posterior.

Take care to avoid cutting out and damaging the articular cartilage. Single-row suture anchor techniques typically use a linear row anchors inserted approximately 5 mm lateral to the articular surface (Fig. 9a–d). I usually use titanium 5 mm anchor. In some young patients (<45 years), I used absorbable anchors of the same size.

The angle of incidence to the bone is crucial. Anchors are ideally placed with a deadman angle, as described by Burkhart [4, 11], of less than 45°. If the insertion angle is too vertical, it will enter the softer bone of the greater tuberosity rather than the dense subchondral bone of the humeral head, increasing the risk of anchor pullout. The metallic anchor should simply be screwed and not beaten. The absorbable anchors and those in peek may require the execution of a hole on the greater tuberosity (using a bone punch), within the anchor that is introduced. Once inserted, regardless of the material, it is right to verify its resistance to pullout and that the stitches slide freely in its hole.

Using double-loaded and/or triple-loaded suture anchor reduces the load at the suture-tendon interface and provides more secure fixation [11–13].

The anterior anchor is the first to be inserted; then, the arm is placed in external rotation to allow a better view of the anterior portion of the greater tuberosity. The sutures are retrieved by the assistant through the anterolateral portal (Fig. 10a, b). If more than an anchor is needed, the stitches of the first anchor are retained together with a Klemmer through the anterolateral portal, but outside the cannula (Fig. 11), so that in the latter only the sutures with which you are working are always present. In this way, the sutures from different anchors do not intertwine.

The sutures are passed through the tendon tissue through the use of suture passers (Fig. 12a–c) or suture hooks. The latter allows the pass in the tendon of a shuttle relay that is used as an entrainment wire for the suture.

Surgeon has to choose the appropriate suture hook that affords the best angle for passing the needle through the cuff. Shuttle has to be clamped near the tip of the needle, and while feeding it by turning the rubber wheel, located on the handle of the hook, carried it out the anterior or lateral portal. Successively, shuttle is loaded with the suture outside the cannula and carried

Fig. 4 The instrumentation required for the arthroscopic cuff repair with single-row technique

Table 1 Fifteen point anatomy review

Visualizing from the posterior portal
1. Biceps tendon and superior labrum
2. Posterior labrum and capsular recess
3. Inferior axillary recess and inferior capsular insertion to the humeral head
4. Inferior labrum and glenoid articular surface
5. Supraspinatus tendon of rotator cuff
6. Posterior rotator cuff insertion and bare area of the humeral head
7. Articular surface of the humeral head
8. Anterior superior labrum. Superior and middle GHL, and subscapularis tendon
9. Anterior inferior labrum
10. Anterior inferior GHL
Visualizing from the anterior portal
11. Posterior glenoid labrum and capsule insertion into the humeral head
12. Posterior rotator cuff
13. Anterior glenoid labrum and inferior GHL attachments to the humeral head
14. Subscapularis tendon and recess and middle GHL attachment to the labrum
15. Anterior surface of the humeral head with subscapularis attachment and pulley

back through the cuff from bottom to top and out the back. The partner limb of the sutures is retrieved out the lateral or anterior cannula with a crochet hook for knotting.

At the beginning of my arthroscopic career, I used a modified Caspari suture punch.

Usually I use an SMC knot (Fig. 13a–g). An important technical consideration when performing single-row repairs is to use mattress, Mason Allen, massive cuff stitch, or comparable suture configurations to improve the biomechanical strength of the repair [14–18].

Obviously, knotless anchors or like-chain, like-tape sutures, and other devices can be used.

When necessary, acromioplasty is performed using a bur (Fig. 14a–e).

Double-Row Repair

In 2001, Apreleva et al. [19] evaluated the three-dimensional rotator cuff footprint in the normal rotator cuff and after different methods of rotator cuff repair and determined that suture anchor repair constructs, using a single row of anchors, restored only 67 % of the original footprint of the rotator cuff. This value was significantly lesser compared with 85 % obtained performing a transosseous simple suture repair. Authors suggested that a larger footprint of repair might potentially improve the healing and mechanical strength of repaired tendons and that this could not be achieved using a single row of anchors.

Double-row suture anchor repair technique involves placing a medial row of anchors in proximity of the humeral head articular margin and a second row of anchors laterally on the footprint. The concept upon which this technique is based is that each anchor has to have an independent point of fixation. The technique was originally described by Lo and Burkhart [20] (Fig. 15) who used horizontal mattress sutures tied

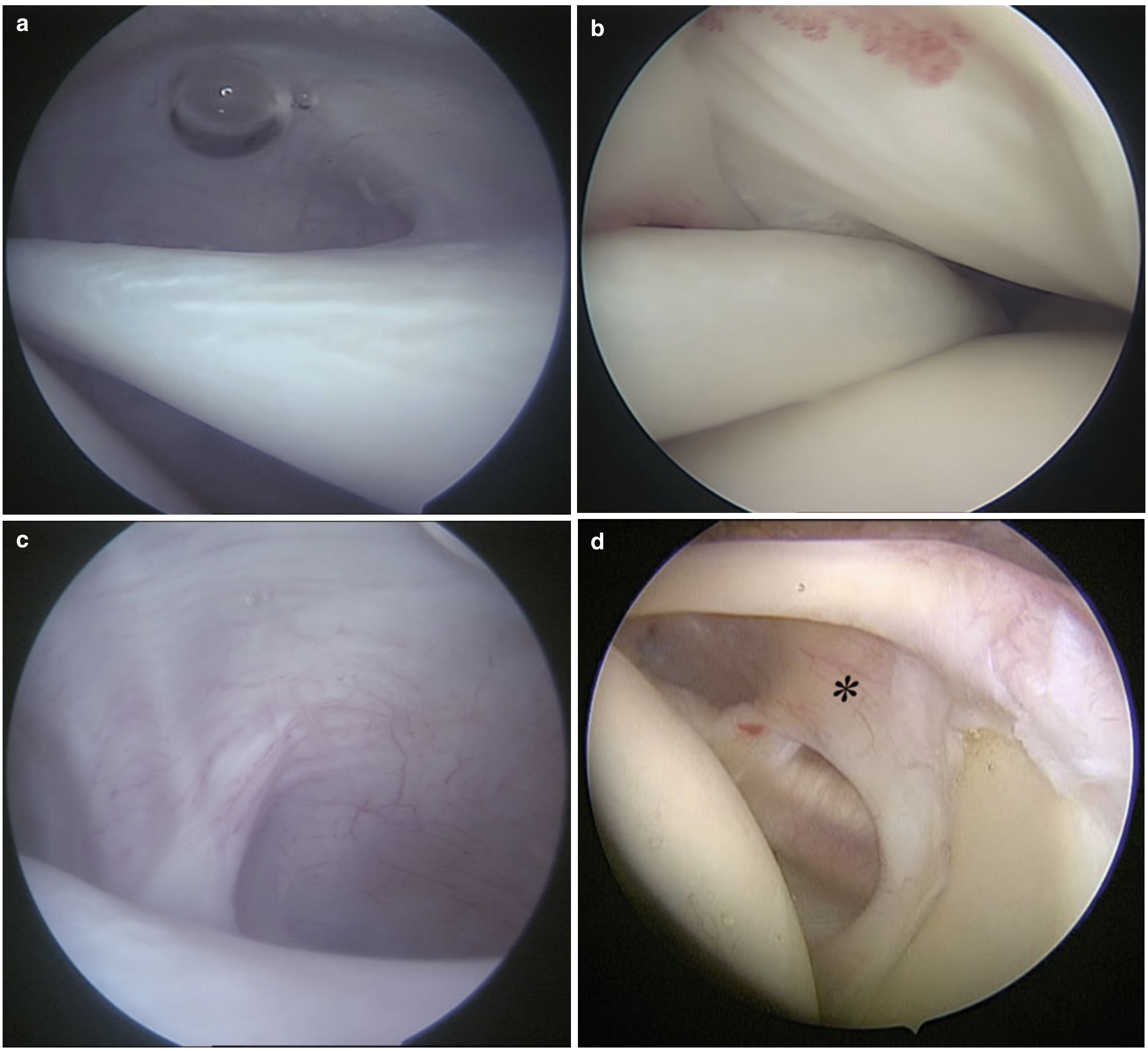

Fig. 5 Common steps, as suggested by Snyder [10], viewed with the arthroscope in the posterior portal. Long head biceps tendon near the proximal insertion (**a**); long head biceps tendon near its groove (**b**); superior glenohumeral ligament (**c**); medium glenohumeral ligament (*) (**d**); posterior rotator cuff insertion and bare area (**e**); inferior axillary recess and inferior capsular insertion to the humeral head (**f**); rotator cuff cable (**g**)

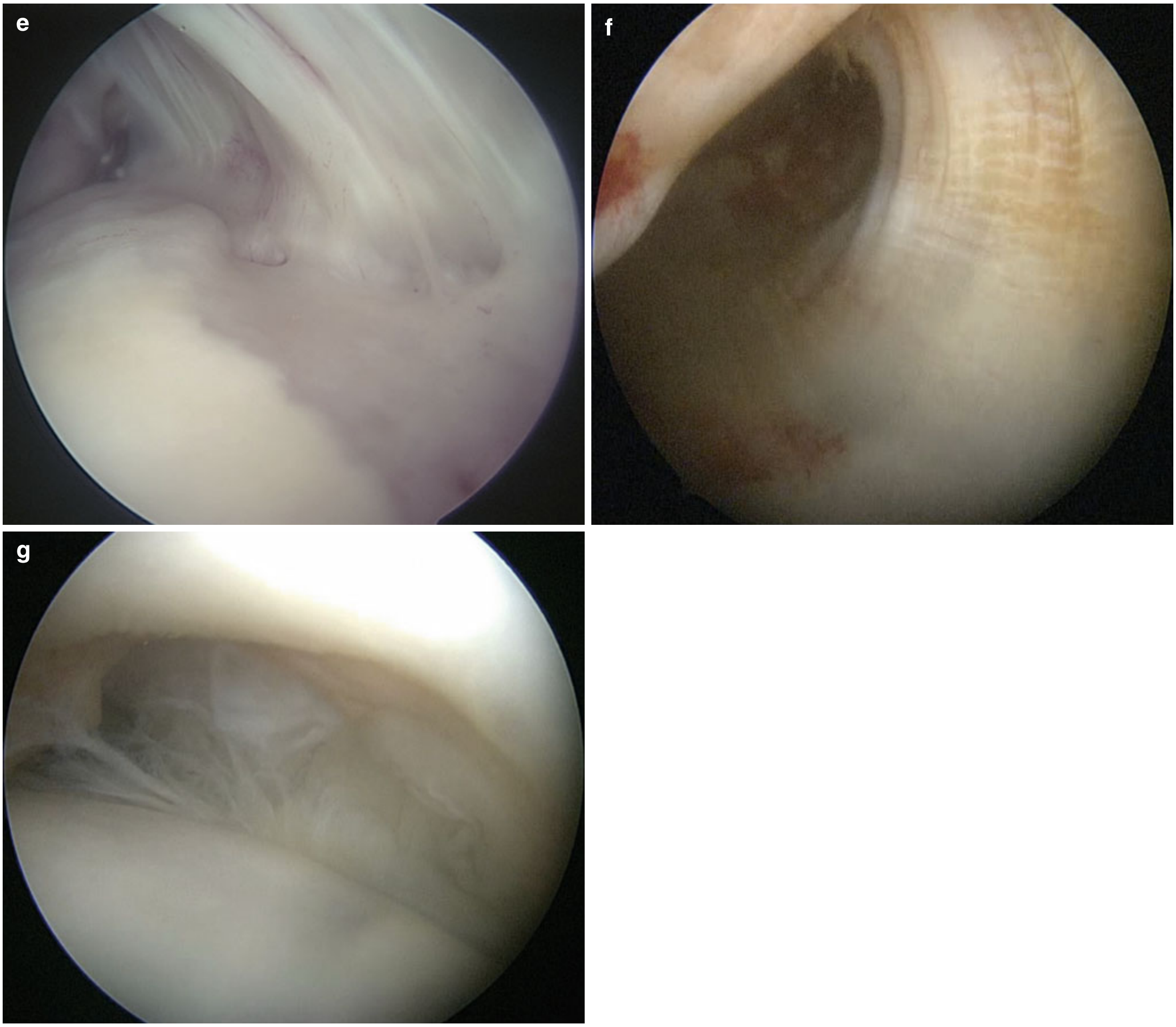

Fig. 5 (Continued)

medially and simple sutures tied laterally. Successively, other authors [21–23] supported the concept that double-row repair should better cover the foot print than single-row constructs and that the increased footprint coverage of double-row repairs theoretically should provide a greater surface area for tendon-to-bone healing.

According to Lo and Burkhart [24], most small to large crescent-shaped, U-shaped, and L-shaped tears (i.e. <5 cm) have sufficient mobility to allow a double-row repair. Massive, contracted, immobile rotator cuff tears are obviously not amenable to a double-row repair.

The medial row of anchors is placed first and is positioned just lateral to the articular surface of the humeral head. Usually, I use an 18-gauge needle as a guide for anchor placement and use implant metallic, double-loaded No. 2 high-resistance suture anchors. Each anchor is placed at a deadman's angle [11].

Lateral row of anchors may be placed on the lateral aspect of the bone bed just medial to the "drop-off" of the greater tuberosity. Lo and Burkhart [20] suggest placing lateral row after the medial sutures have been passed (mattress or more complex sutures), to make suture management easier. An adequate space between the first and second row has to be maintained to prevent lateral anchors have the same hole of the medial ones. Depending on the size of the tear, the medial and lateral row will each require one or two anchors.

In order to obtain a large tendon tissue to be reinserted, it must be that the sutures belonging to the first row of anchors are located very medially; Lo and Burkhart suggested a retrograde suture passage through a modified Neviaser portal [25]. It approximately correspond 2–3 cm posteromedial to the acromioclavicular joint in the soft spot bordered by the posterior clavicle, medial acromion, and scapular spine. A spinal needle as guide is used to localize the proper position of the new portal to allow a correct angle of approach to the central rotator cuff. Because the portal has to allow only a penetrator to be inserted, cannula is not necessary. The penetrator is walked down the needle and its entry into the subacromial space is visualized. Successively, the rotator cuff is penetrated and one limb of the suture is retrieved and withdrawn through the rotator cuff. The other sutures are passed with the same technique through the medial aspect of the cuff margin so that the sutures will be tied in a mattress fashion over a tendon "bridge" [20].

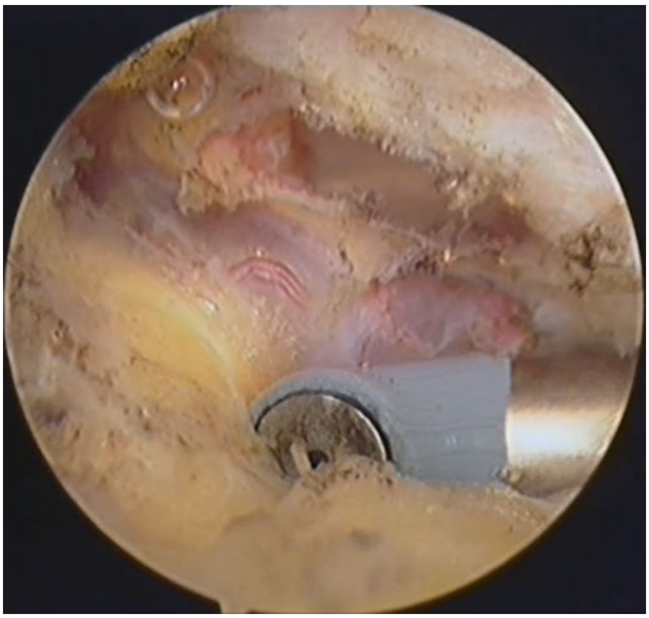

Fig. 6 Subacromial view from the posterior portal. Bursectomy is performed with a radiofrequency ablator

Recently, new suture passers with long bite have been introduced; they allow sutures belonged to the first row of anchors to pass very medially and therefore make useless the penetrator and, consequently, the accessory Neviaser portal. Furthermore, the diameter of the hole created by the suture passer needle in the cuff for passing the suture is smaller than that left by the penetrator.

The lateral row of anchors may now be inserted in the lateral aspect of the footprint. To pass sutures from the lateral anchor, a suture passer is useful. Sutures are passed through the rotator cuff tear margins in a simple suture fashion. Successively, sutures are retrieved through the lateral portal and tied.

A double-row technique may still be used also for U-shaped and L-shaped tear patterns. In these cases, Burkhart suggested side-to-side sutures (Fig. 16a, b), starting medially, to begin to converge the rotator cuff margin toward the bone bed until the "converged margin" is approximately 1 cm away from the bone bed itself [26, 27]. A suture anchor is then placed in the medial aspect of the prepared footprint. The sutures from the medial anchor are then passed to combine a side-to-side margin convergence suture with tendon

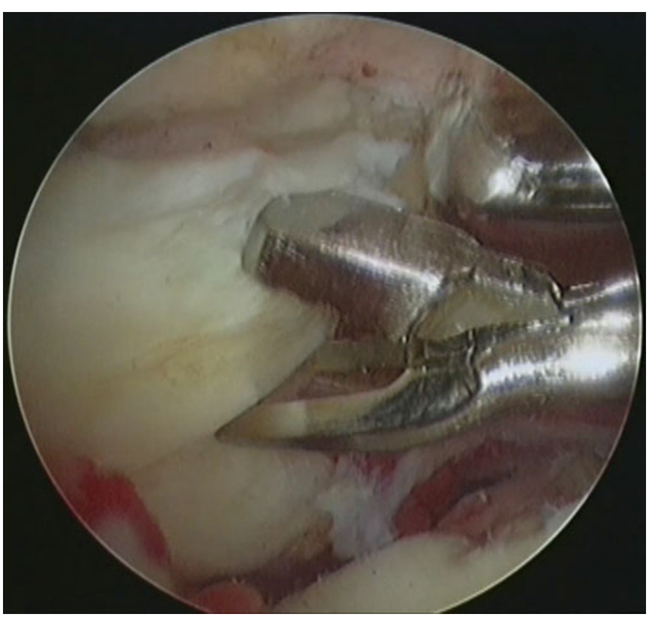

Fig. 7 Subacromial view from the posterior portal. The frayed edges of the rotator cuff tendon are debrided using a basket

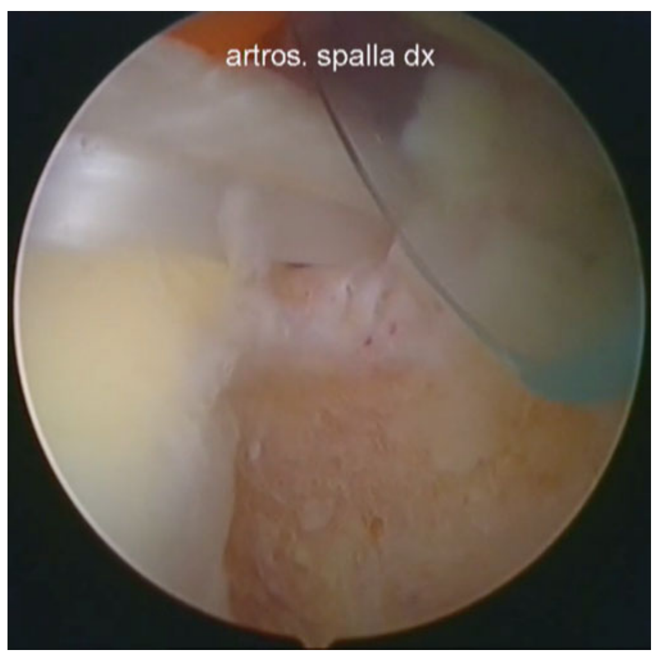

Fig. 8 Subacromial view from the posterior portal. A suitable bleeding footprint is prepared with a bur

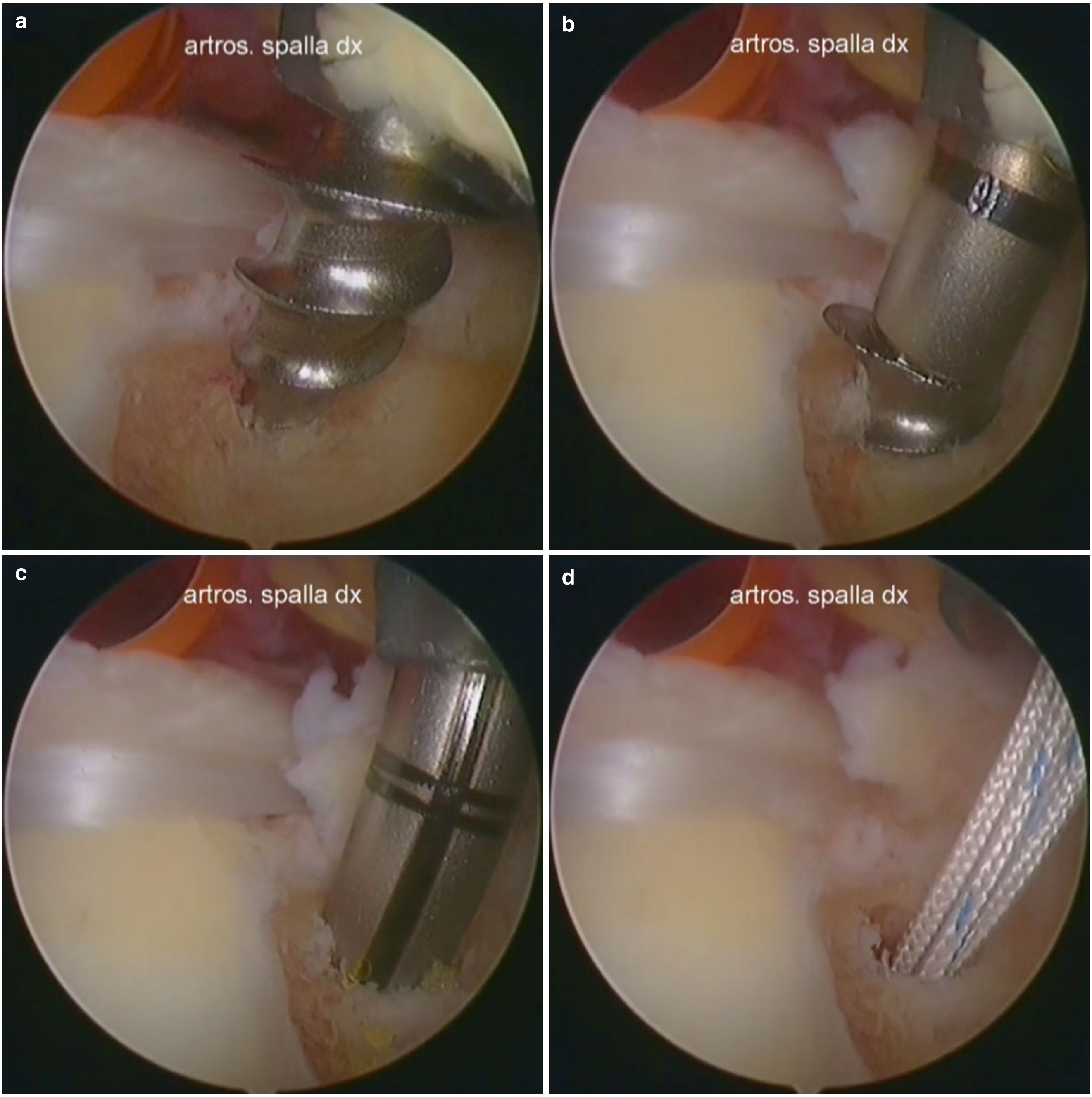

Fig. 9 (**a**–**d**) Subacromial view from the posterior portal. Phases of insertion of a titanium 5 mm anchor, approximately 5 mm lateral to the articular surface

fixation to the medial bone bed. To accomplish this, one limb of suture is passed through the anterior leaf and the other corresponding suture limb is passed through the posterior leaf. By doing this, a margin convergence side-to-side suture is passed through an anchor. The lateral row of anchors may be now implanted, and depending on the cuff tear shape, the sutures from the lateral row may be passed in a simple fashion or using side-to-side sutures.

In 2007, Charousset et al. [28] performed a prospective, nonrandomized, comparative study of double-row and single-row anchorage techniques with computed tomographic arthrography tendon healing assessment. Authors found no significant difference in clinical results, but tendon healing rates were better with the double-row anchorage.

In a prospective randomized study performed in the same year, Franceschi et al. [29] observed that single- and

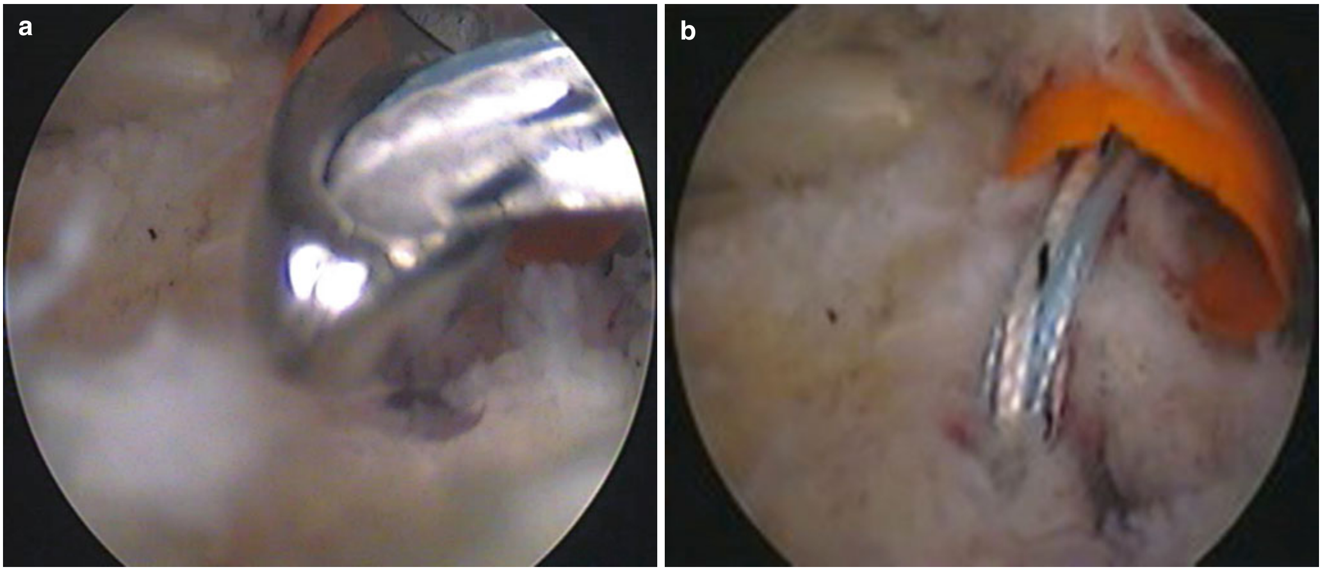

Fig. 10 (**a**, **b**) Subacromial view from the posterior portal. After the insertion of the anchor, the sutures are retrieved by the assistant through the anterolateral portal

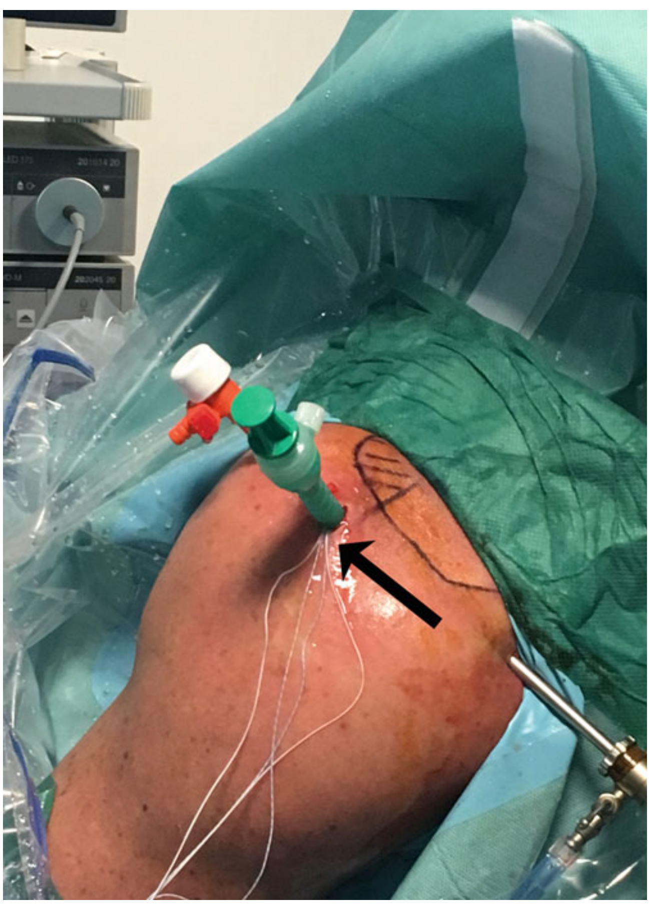

Fig. 11 The stitches of the first anchor are retained together through the lateral portal, but outside the cannula (*arrow*)

double-row techniques provide comparable clinical outcome at 2 years. However, double-row technique produced a mechanically superior construct compared with the single-row method in restoring the anatomical footprint of the rotator cuff, but these mechanical advantages did not translate into superior clinical performance. Using a bovine model, Mahar et al. [30] referred their skepticism towards double-row technique. In their hands, double-row repair did not show a biomechanical advantage compared with single-row repair.

In 2008, Milano et al. [31] carried out a brilliant biomechanical study and observed that double-row repair is significantly more resistant to cyclic displacement than single-row repair in both tension-free and tension repair; therefore, double-row repair can be primarily considered for large, unstable rotator cuff tears to improve mechanical strength of primary fixation of tendons to bone.

On the basis of their clinical results, Park et al. [32] suggested the single-row method for small to medium rotator cuff tears, while large to massive tears should be repaired with the double-row technique.

Ozbaydar et al. [33] compared time-dependent changes in the biomechanical properties of single- and double-row repair of a simulated acute tear of the rotator cuff in rabbits to determine the effect of the fixation techniques on the healing process. A total of ten intact contralateral shoulder joints were used as a control group. The mean load to failure in double-row group was greater than in single-row group, but both groups remained lower than the control group. Histological analysis showed similar healing in both groups,

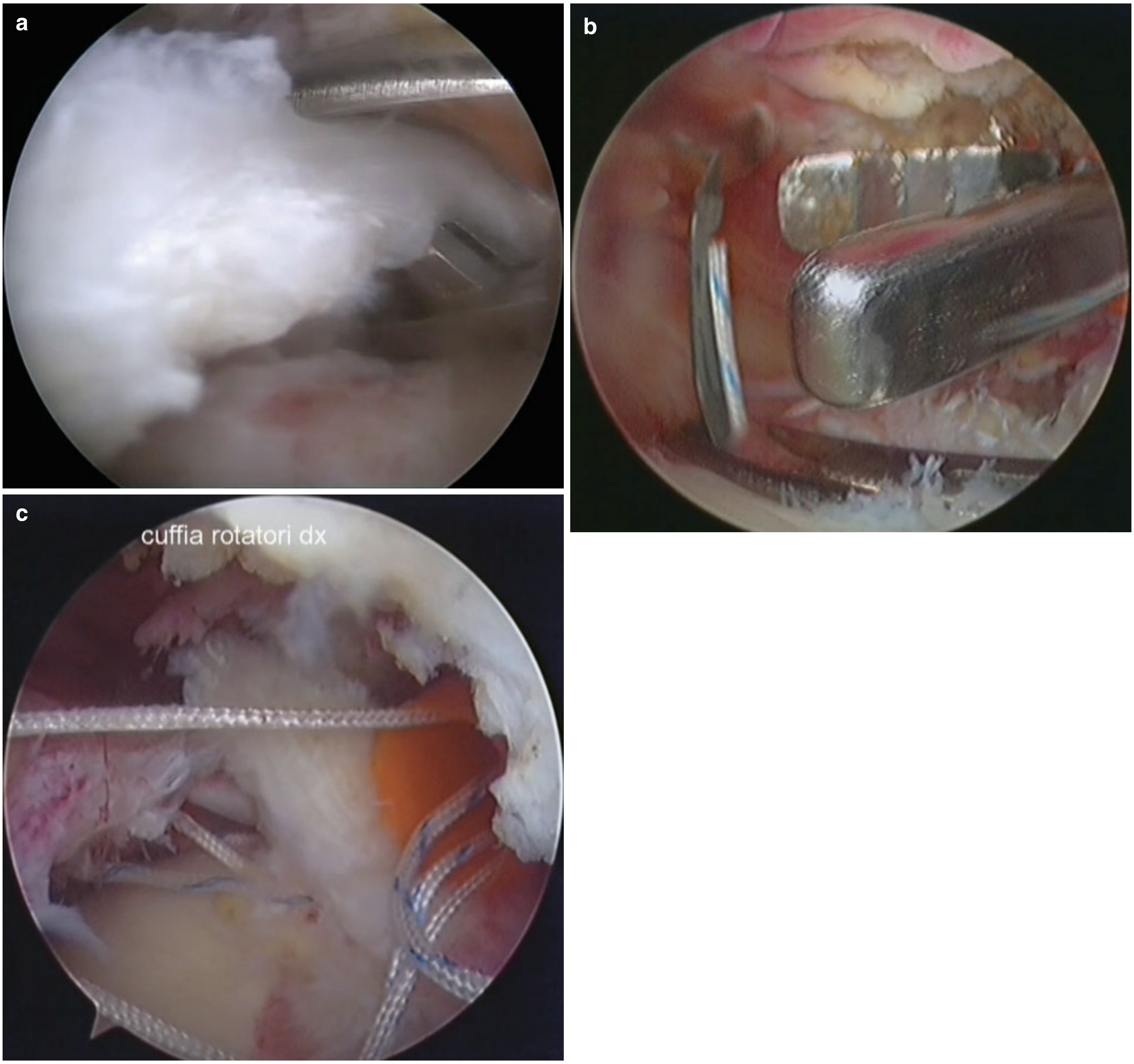

Fig. 12 (**a**, **b**) Subacromial view from the posterior portal. The sutures are passed through the tendon tissue through the use of suture passer (**a**, **b**); result during this procedure (**c**)

but a significantly larger number of healed tendon-bone interfaces were identified in double-row group than in single-row group at 8 weeks.

In a clinical study performed in 2009, Grasso et al. [34] observed that at short-term follow-up, arthroscopic rotator cuff repair with the double-row technique showed no significant difference compared with single-row repair; analogously, in the same year three studies observed no clinical [35–37] or MRI [35] differences between patients repaired with a single- or double-row technique.

In 2010 and in an additional clinical study and after a long-term follow-up, Aydin et al. [38] observed that arthroscopic rotator cuff repair with the double-row technique showed no significant difference in clinical outcome compared with single-row repair in small to medium tears. Comparing the two methods, Ji et al. [39] noted that double-row repair group showed better clinical results in recovering strength; however, no statistical clinical difference was found between the two methods. Although the relative short-term results, Pennington et al. [40] suggested that single-row Mason Allen configura-

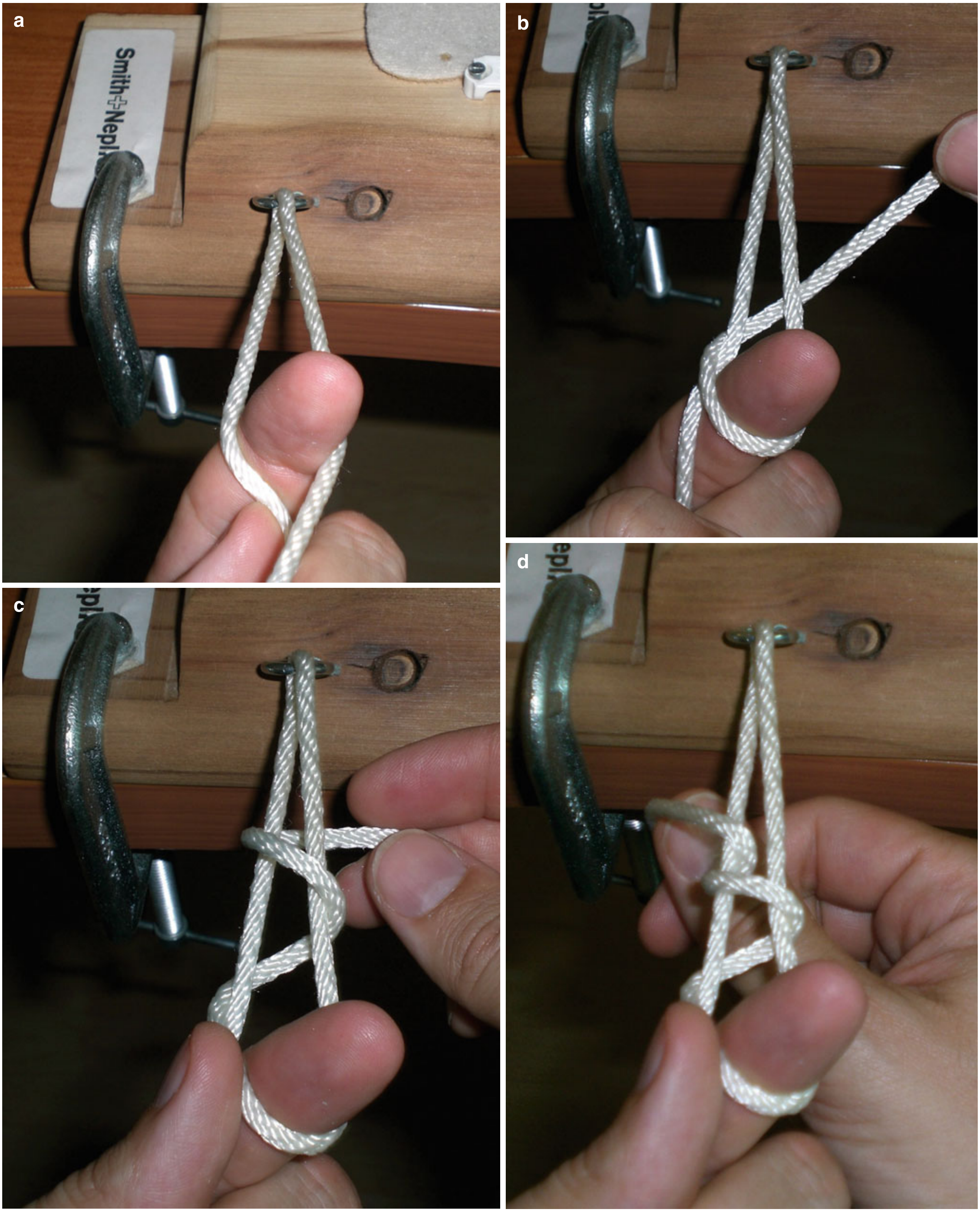

Fig. 13 (**a**–**g**) Steps to perform a SMC knot

Fig. 13 (Continued)

tion repair provided comparable clinical results to double-row repair. On the basis of the literature, Dines et al. [41] in 2010 concluded that further studies were needed to justify the potentially increased implant costs and surgical times associated with double-row rotator cuff repair.

In 2011, Kho et al. [42] performed a prospective randomized study on 71 patients with a 2- to 4-cm rotator cuff tear submitted to single- or double-row repair. At the follow-up, 62 (31 in each group) were available for clinical and MR evaluation. This study indicated that the clinical results and retear rates of double-row repair with one additional medial suture anchor were not significantly different from those of single-row repairs with two lateral suture anchors. In the same year, Perser et al. [43] reviewed (meta-analysis) clinical outcomes of single-row versus double-row rotator cuff repair with the hypothesis that double-row rotator cuff repair will result in better clinical and radiographic outcomes. Their conclusions were that double-row repair did not show statistically significant improvement in clinical outcome or radiographic healing with short-term follow-up. Prasathaporn et al. [44] reported that despite the fact that double-row repair shows a significantly higher rate of tendon healing and greater external rotation than does single-row repair, there is no significant improvement in shoulder function, muscle strength, forward flexion, internal rotation, patient satisfaction, or return to work.

In a prospective randomized trial conducted in 2012 [45], arthroscopic rotator cuff repair with double-row fixation

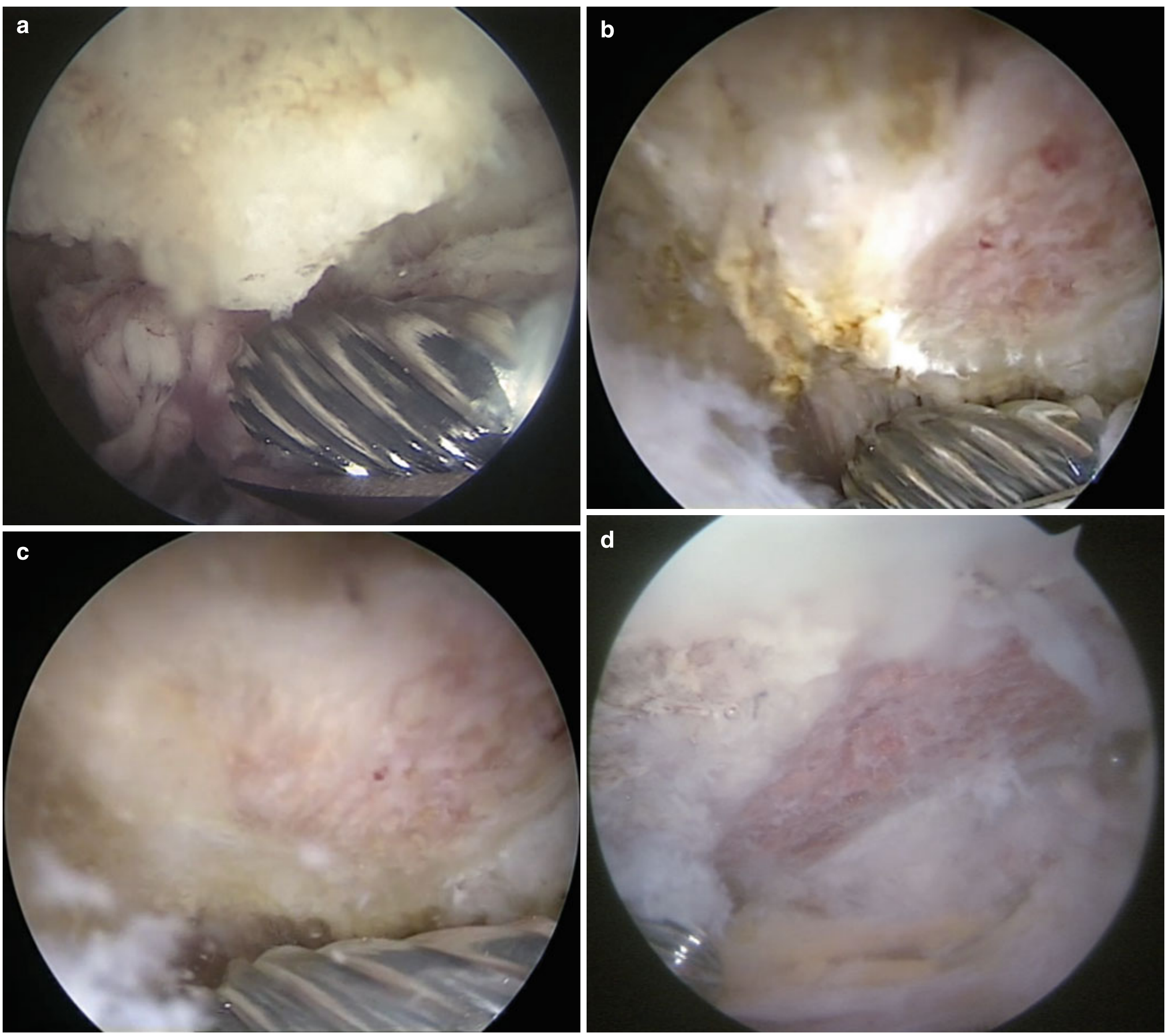

Fig. 14 Subacromial view from the posterior portal of a subacromial spur (**a**); acromioplasty is performed with a bur (**b**); result at the end of the acromioplasty from the posterior (**c**) and lateral (**d**) portals; view from the posterior portal of a bleeding acromion (**e**)

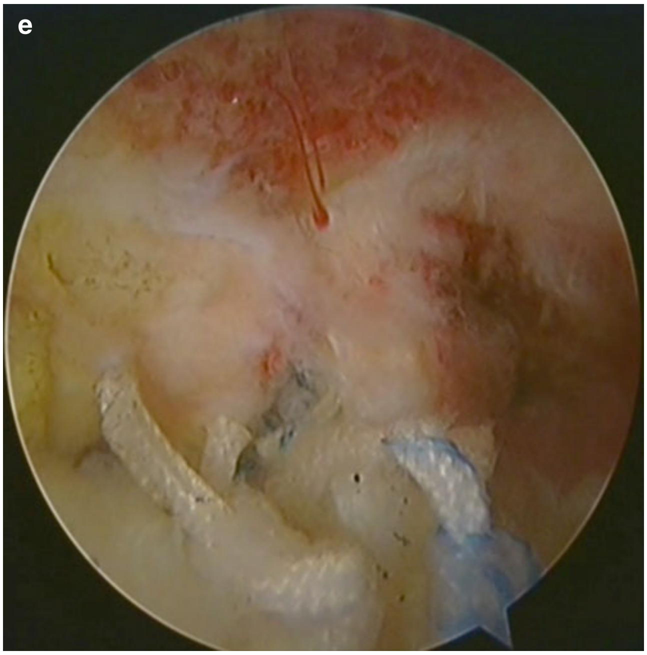

Fig. 14 (Continued)

showed better shoulder strength in patients with larger tear size (>3 cm) in comparison with single-row fixation. However, the imaging results showed no significant difference in cuff integrity in both groups in patients with any tear size at 6-month and minimum 2-year follow-up.

Considering the lack of statistically significant differences between the two techniques and that the double row was a high cost and a high surgical skill-dependent technique, Papalia et al. [46] suggested, in 2012, using the double-row technique only in strictly selected patients. In a systematic review published in the same year [47], the single-row repairs did not differ from the double-row repairs in functional outcome scores. The double-row repairs revealed a trend toward a lower radiographic-proven retear rate, although the data did not reach statistical significance.

In an in vivo sheep model study [48], it was observed that double-row enabled higher mechanical strength that was especially sustained during the early recovery period. In this study, an improved clinical outcome with the double row was also hypothesized.

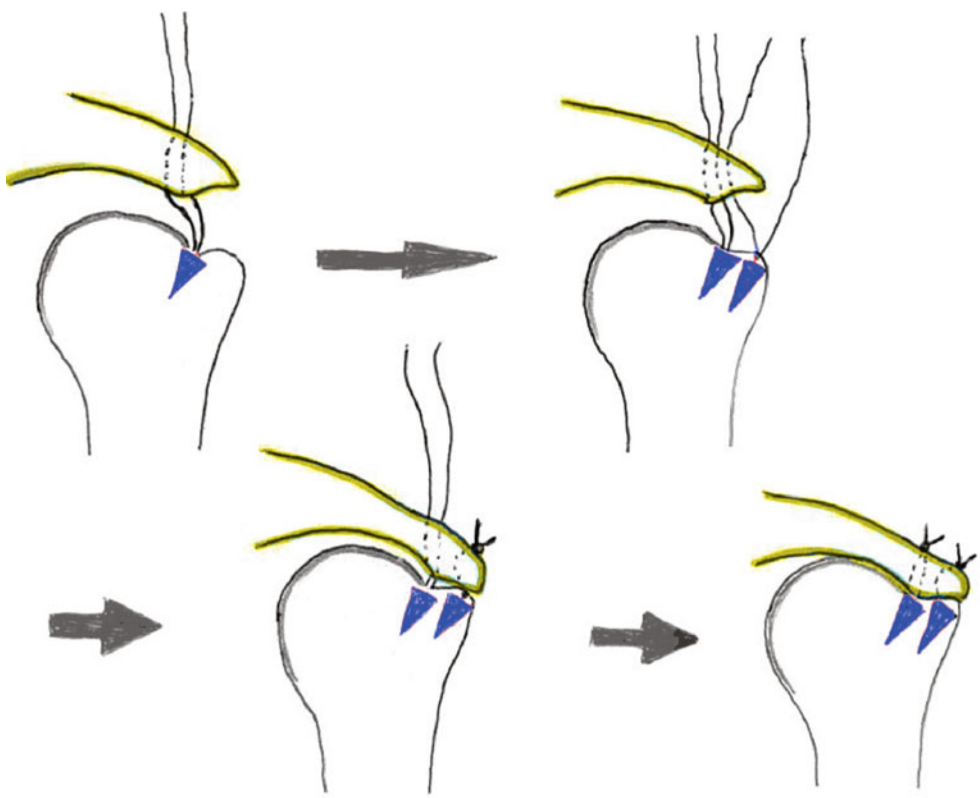

Fig. 15 Schematic drawings showing double row fixation technique. Sutures for the medial row are placed first in a mattress fashion; then, simple sutures for the lateral row are placed through the lateral margin of the cuff. Knot-tying for the lateral row is performed first, and then the repair is completed with the knot-tying for the medial row

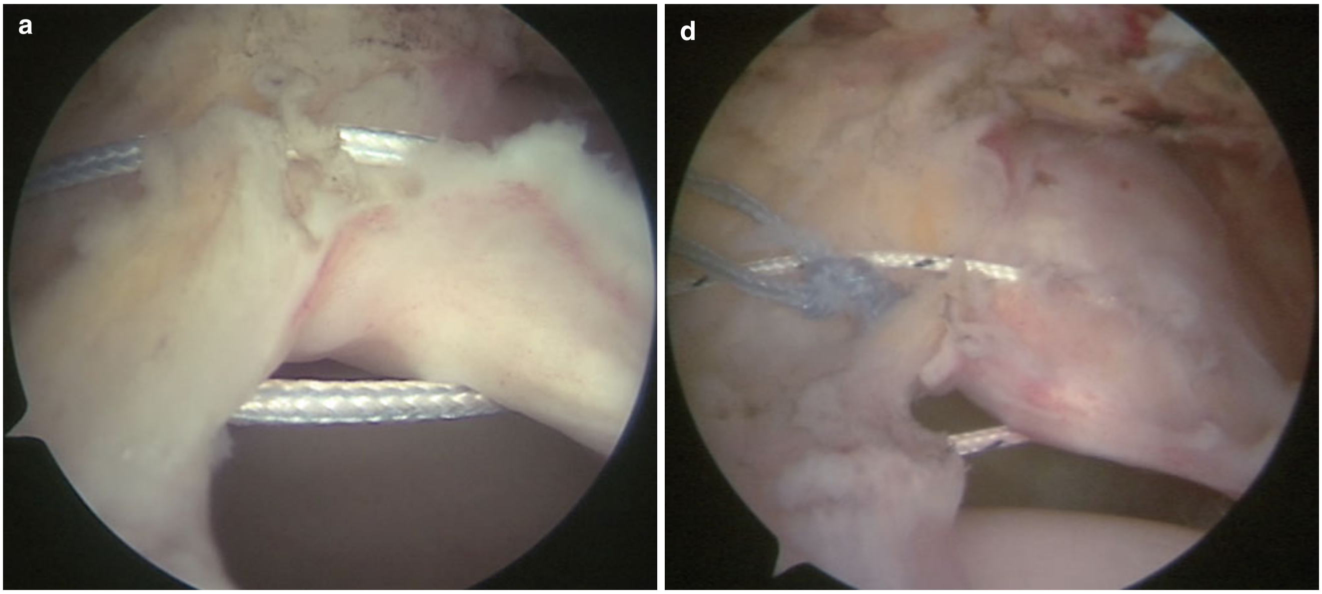

Fig. 16 V-shaped cuff tear viewed from the lateral portal. A side-to-side suture is performed starting from the medial side (**a**) to lateral one (**b**)

In a prospective randomized study, conducted by Carbonel et al. [49], double-row technique showed a significant difference in clinical outcome compared with single-row repair, and this was even more significative in over 30-mm tears. Instead, no MRI differences were observed. A multicenter randomized controlled trial [50], performed at the same time, identified no significant differences in functional or quality-of-life outcomes between single-row and double-row fixation techniques. However, a smaller initial tear size and a double-row fixation technique were associated with higher healing rates as assessed with ultrasonography or MRI. Genuario et al. [51] constructed a decision-analytic model to assess the cost-effectiveness of double-row arthroscopic rotator cuff repair compared with single-row repair on the basis of the cost per quality-adjusted life year gained and concluded that double-row rotator cuff repair is not cost-effective for any size rotator cuff tears.

Using a 3 Tesla MR arthrography, in 2013 Tudisco et al. [52] observed that double-row repair resulted in a statistically significant lower retear rate.

On the basis of their meta-analysis of the randomized clinical trials, Sheibani-Rad et al. [53] concluded that there were no significant differences in clinical outcomes between the two techniques.

In a nice sheep model study, Liem et al. [54] demonstrated that suture anchor repair leads to an intraoperative decrease in tendon blood flow regardless of the repair technique; however, a significant difference between single- and double-row repair was not found. These findings indicate that tendon blood flow should not be a factor to determine the use of either repair technique over the other. In a systematic review and meta-analysis conducted in 2013 by Chen et al. [55] emerged that double-row repair provides a significantly higher rate of intact tendon healing than does single-row repair, and this advantage was mainly reflected in patients with large or massive tears. However, this benefit did not translate into clinically confirmed functional improvement. In the same year, Zhang et al. [56] performed an analogous study; unfortunately, the conclusions were partially different. In fact they concluded that double-row fixation technique increases postoperative rotator cuff integrity and improves the clinical outcomes, especially for full-thickness rotator cuff tears larger than 3 cm. In an in vitro study of the same period [57], it was found that there is no significant difference between the kinematics of single- and double-row techniques in medium-sized rotator cuff repairs on glenohumeral joint.

In 2014, Xu et al. [58] performed a meta-analysis comparing the two techniques and observed that double-row repair has a significantly lower retear rate, higher ASES score, and greater range of motion of internal rotation compared with single-row repair techniques. Therefore, they recommend the double row especially in those rotator cuff tears with a size >3 cm. Millet et al. [59] conducted another meta-analysis and concluded that single-row repairs resulted in significantly higher retear rates compared with double-row repairs, especially with regard to partial-thickness retears. However, they observed that there were no detectable differences in improvement in outcome scores between single-row and double-row repairs.

Finally, Mascarenhas et al. [60] conducted a systematic review of meta-analyses comparing single- and double-row techniques to elucidate the cause of discordance and to determine which meta-analysis provides the current best available evidence. According to this brilliant study, the current highest level of evidence suggests that double-row repair provides superior structural healing to single-row repair.

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Suture Bridge and Transosseous Techniques

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Introduction

Over the past 40 years, rotator cuff tear repair techniques have undergone a notable evolution. The surgical approach has progressed from open to mini-open to arthroscopic techniques. Currently, the clinical results reported with arthroscopic procedures are equivalent to those reported for both open and mini-open techniques [1–3]. However, despite good clinical outcomes, structural healing of the tendon to bone interface remains problematic. Failure rates after rotator cuff repairs remain high with retear rates ranging from 10 % in small tears up to 90 % in large to massive tears [3–10]. Though controversial, several studies have documented that healed rotator cuff tears have improved functional outcomes compared with tears that have not healed after rotator cuff repair [11, 12]. As postulated by Gerber et al. [13], from a biomechanical perspective, the goal of the rotator cuff repair should reasonably be the achievement of tendon healing through high initial fixation strength, minimal gap formation, and mechanical stability. Therefore, several arthroscopic techniques have been developed in the last decades. Arthroscopic procedures evolved from single-row [14, 15] to double row [16, 17], and recently to transosseous equivalent techniques [18–20] in an attempt to more closely reproduce the normal rotator cuff footprint anatomy. Double row repair was created to increase the footprint contact area and distribute the stress over multiple fixation points [16]. Numerous studies reported superior biomechanical properties of traditional double-row when compared to single-row fixation techniques, in terms of loading conditions and gap formation at time zero, contact area, and restoration of the anatomic footprint [21–26]. Much controversy remains about clinical correlation with biomechanical findings. Nho et al. [27] showed no difference between healing in single-row and double-row techniques. In contrast, Duquin et al. [12] demonstrated superior healing in rotator cuff tears repaired with double-row compared with single-row techniques. The transosseous equivalent, or suture bridge technique, has been developed to increase the compressive forces between the tendon and the bone interface, mimicking an open transosseous tunnel technique [18–20]. Technically, the major differences between the transosseous equivalent and the traditional double row fixation techniques are the suture bridge over the tendon and the more distal fixation points for the lateral row. The suture bridge connects the medial and lateral rows, as well as the anterior and posterior rows, allowing compression throughout the entire footprint. Compared with the traditional double-row technique, biomechanical studies showed that the suture bridge technique provide improved contact area and pressure between rotator cuff tendon and insertion footprint [28, 29]. Currently, transosseous equivalent techniques have largely replaced traditional double row techniques and various suture bridge configurations have been developed [30–36].

With an increasing attention to healthcare costs, recent studies have shown that implantable devices, specifically suture anchors, could be responsible for rises in the costs of rotator cuff repair surgery [3, 37]. This has led to renewed interest in anchorless repair constructs that maintain the biomechanical advantages of a suture bridge construct. Arthroscopic anchorless transosseous repair techniques have been developed at a potentially lower cost.

In the following chapter, we will discuss operative techniques and technical pearls for two different suture bridge techniques: transosseous equivalent with suture anchors, and anchorless transosseous repair. Finally, a brief overview of biomechanical and clinical outcomes for each technique will be reviewed.

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Indications for Suture Bridge Fixation

According to recent literature data, suture bridge cuff repair techniques demonstrate good to excellent clinical outcome for partial tears [38] as well as small to large tears repairs under normal physiologic tension [39–44].

To determine the appropriate rotator cuff repair technique, the surgeon must consider tear size, retraction, tissue quality and repair tension. Whenever possible, our preference is to perform a suture bridge repair construct when a small to large cuff tear is present as long as tissue quality is adequate and the repair isn't under significant tension. A suture bridge repair technique is usually not recommended for a massive retracted tear with poor tissue quality and pliability. If a suture bridge repair technique will result in significant tension at the suture-tendon interface then it is likely to fail and we prefer a single row repair under normal physiologic tension. Small partial cuff tears are usually amenable to a single row repair.

Currently, a few clinical data are available on arthroscopic anchorless transosseous repairs. One study reported good clinical outcomes after the treatment of small and medium tears (1–3 cm) [45]. Recognized clinical concerns are suture cut-through the bone tunnel wall, especially in osteoporotic bone, or suture abrasion by scratching against the bone.

Surgical Technique

Patient Position

Rotator cuff repair can be performed in either beach chair or lateral decubitus position, according to the surgeon's preference.

Anesthesia

A combination of preoperative ultrasound-guided regional block and general endotracheal anesthesia is commonly utilized. The regional block will be helpful in the management of immediate postoperative pain.

Proper Portal Placement

After completing a diagnostic intra-articular arthroscopy, the arthroscope is placed into the subacromial space through a standard posterior viewing portal. A mid-lateral portal is established through an inside-out technique first with a spinal needle placed 1–2 cm below the lateral acromial edge in line with the posterior edge of the acromioclavicular joint. The shaver is introduced and a subacromial decompression is performed including bursectomy, release of the coracoacromial ligament, and release of the anterior and lateral subdeltoid space. Next the arthroscope is placed in the lateral portal and the shaver is placed through the posterior portal to complete the posterior subdeltoid space release. Once the subacromial space is well visualized and the subdeltoid space is released, an anterolateral working portal is established with a spinal needle located just off the anterior-lateral edge of the acromion. Care is taken to place this anterolateral portal in a position that will allow unimpeded access to the rotator cuff tear but not close enough to crowd the lateral viewing portal. A large diameter cannula is placed in the anterolateral portal (Fig. 1).

Tear Assessment and Decision Making

While viewing through the lateral portal, a grasper is then placed through the anterolateral portal to plan rotator cuff repair strategy by assessing the rotator cuff tendon integrity, by identifying the tear pattern (crescent, L shape, reverse L shape), and by attempting to reduce the tear to the greater tuberosity footprint. If needed, a careful mobilization of the tear will be performed (Fig. 2).

If the tear pattern is amenable to a suture bridge repair technique then the surgeon can perform a transosseous equivalent technique utilizing medial and lateral suture anchors, or a transosseous anchorless fixation technique.

Fig. 1 Patient position and portal locations for transosseous equivalent suture bridge repair technique. Beach chair position, standard posterior and anterior portals, mid-lateral viewing portal 2 cm from the acromial edge, anterolateral working portal immediately off the lateral acromion for large cannula. Anchor placements will be through percutaneous incisions just lateral to the acromial edge

Fig. 2 Lateral view. A grasper is placed through the anterolateral portal to assess tendon mobility, identify tear pattern, and attempt to reduce the tear to the footprint

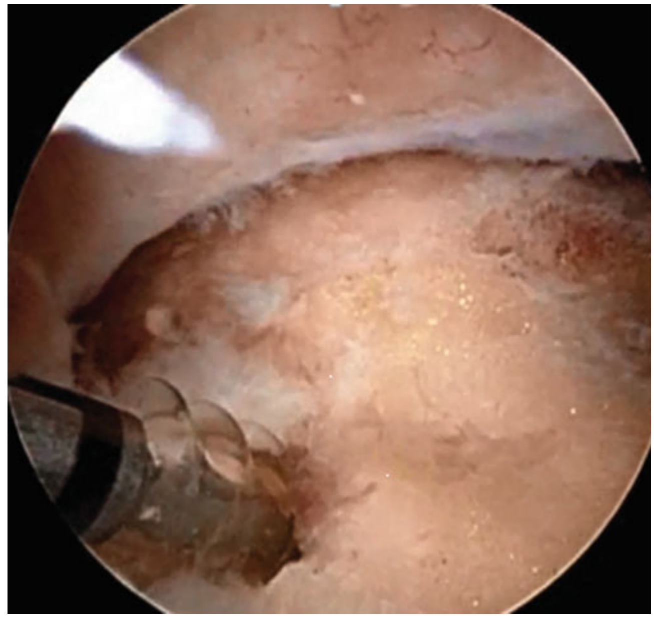

Fig. 3 The scope is into the lateral portal and a posterior medial anchor is placed through the posterolateral portal. Medial anchors should be placed close to the articular margin at a 45° dead's man angle

Transosseous Equivalent Repair Technique

It is our senior author's preference to perform a knotless "speed bridge" transosseous equivalent rotator cuff repair whenever possible in order to limit irritation of the subacromial space from prominent knots in either the medial or lateral row (Fig. 3). The knotless speed bridge technique is described here.

Footprint Preparation

The greater tuberosity footprint is prepared with a high-speed burr introduced through the anterolateral cannula. A cortical bone abrasion is carried out with the high-speed burr until bleeding cancellous bone is present in order to stimulate a biologic response and augment repair. Alternatively, a microfracture of the footprint can be performed either with an awl or commercially available marrow stimulation device.

Medial Anchor Placement

The medial row anchors are placed at the osteoarticular junction at a 45° "dead man's angle." The medial row anchors are typically placed percutaneously after localizing with a spinal needle. The number of medial row anchors is dictated by the tear size and configuration (Fig. 4). Depending on the patient age, bone quality, or surgeon preference, suture anchors made of either metal, PEEK, or PLLA biocomposite material may be used (Swivel Lock C™, Arthrex). When performing a knotless speed bridge technique, each medial row anchor is loaded with a 2 mm wide suture constructed of a multi-strand, long-chain ultra-high molecular weight

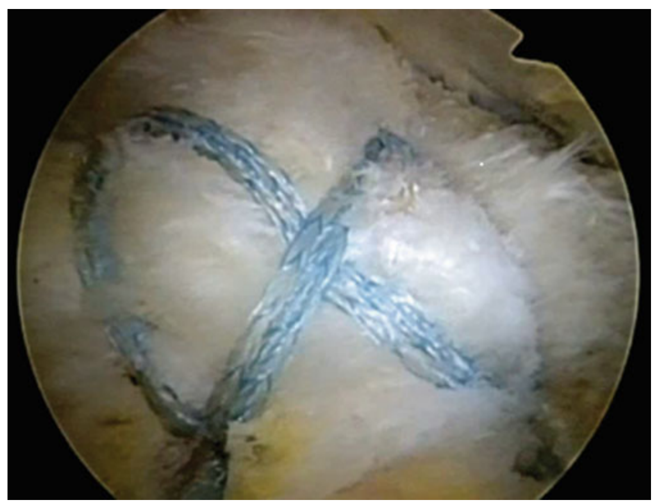

Fig. 4 Transosseous equivalent "speed bridge" knotless suture bridge

polyethylene (UHMWPE) core with a braided jacket of polyester and UHMWPE (FiberTape™, Arthrex). For a small or medium-sized tear, commonly two medial and two lateral anchors are required. Care must be taken to place each medial anchor at least 7 mm apart from the other in order to avoid contiguous tapping and/or loss of anchor fixation. Once the medial row anchors have been placed, the surgeon may proceed with suture passage. Many commercially available suture passage devices allow the surgeon to pass suture through a retrograde or antegrade fashion. Regardless of suture passage device used, each suture is carefully passed medial through the tendon but not too medial through the musculotendinous junction. The FiberTape™ suture limbs of each anchor can be passed together or individually in a horizontal mattress fashion through the rotator cuff tendon. Sutures passed through the cuff are then retrieved through the anterior or posterior portals. Alternatively, the medial row can then be tied at this moment and then the tied limbs are retrieved through the anterior or posterior portals (Fig. 5).

Lateral Anchor Placement

The proper location for the lateral row anchors is typically found 5–10 mm distal to the lateral edge of the footprint of the greater tuberosity. Careful debridement of the lateral row anchor site is necessary to visualize the anchor insertion site. Overaggressive debridement may injure the intact infraspinatus tendon, and therefore, it must be avoided. When incorporating the sutures from the medial row into the lateral row, there are many different possible suture configurations. When using two medial anchors and two lateral anchors, a single limb from each medial anchors is incorporated into each lateral anchor. Prior to incorporation of the medial row sutures into the lateral anchors, the surgeon may evaluate for potential "dog ears" that may form after lateral row fixation. If dog ears are likely to form, the surgeon has the option to pass cinch stitches through each dog ear and incorporate these sutures into the lateral row anchors to compress the dog ears. Prior to insertion of the lateral anchors into the bone, the slack on each of the sutures must be removed individually to compress the tendon onto the footprint equally and avoid "spot welds." Once the lateral anchors are placed, the free sutures ends may be cut at the anchor insertion site (Fig. 6).

Transosseous (Anchorless) Repair Technique

When performing a transosseous anchorless repair technique, the creation of six portals is often necessary. In addition to standard posterior and anterior portals, superior and inferior anterolateral portals are created in line with the anterior edge of the supraspinatus tendon. In addition, superior and inferior posterolateral portals are created. The transosseous repair will be performed through these four lateral portals. Once the subacromial space is prepared and the reparability of the rotator cuff is assessed, the transosseous repair is begun. Typically the footprint is not decorticated with the burr to avoid suture cut out of the cancellous bone. While viewing through the posterior portal, a specific drill guide is inserted through the anterior superior portal to create a 2.9-mm medial tunnel immediately adjacent to the articular

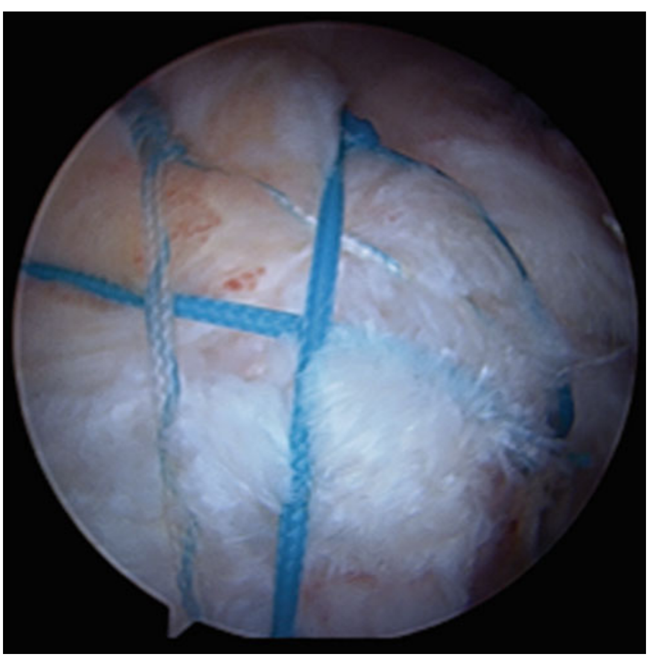

Fig. 5 Transosseous equivalent suture bridge with medial row knots

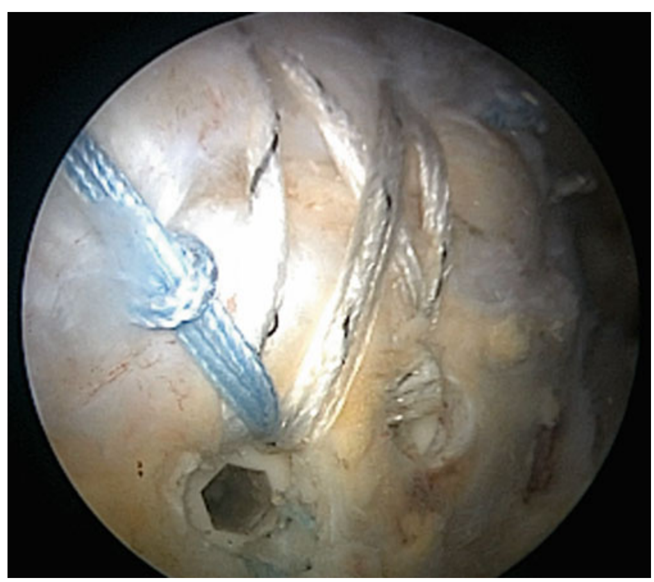

Fig. 6 Speed bridge with chinch stiches to compress the dog ears

surface. Next, through the inferior anterolateral portal, the device that allows the creation of an intersecting tunnel (ArthroTunneler, Tornier, Edina, MN, USA) is introduced. Through this inferior anterolateral portal, the lateral intersecting 2.5-mm tunnel is drilled. The position of the inferior anteriorlateral tunnel is approximately 1.5 cm below the superior tip of the greater tuberosity and can be localized under direct arthroscopic visualization. Next, a loaded suture inserter is introduced through the hole of the device. The loop is moved into the retrieval position, and the suture inserter is removed leaving the suture passed in a transosseous fashion through the greater tuberosity. Next, the device will retrieve the suture through the superior anterolateral portal thereby completing the transosseous suture passage. This suture can be used to complete the tendon repair or as a suture shuttle to pass 2 or 3 definitive sutures through the tunnel. All transosseous sutures are first placed in the bone and then passed through the cuff with different suture passing devices according to surgeon preference. The sutures are managed through the anterior portal. The same steps are taken to pass suture transosseously through the posterior aspect of the tear utilizing the posterolateral portals. Various suture configurations repair patterns are possible (Fig. 7a, b).

Postoperative Rehabilitation

Immobilization in a sling with an abduction pillow is recommended for 6 weeks. Only home pendulum exercises and elbow and wrist mobilization are allowed in the first week after surgery. From week 2 to 6, a physical therapist will help the patient to recover the passive range of motion in order to avoid scar formation and postoperative stiffness due to the immobilization. Subsequently, active assisted range of motion and active motion as tolerated will be allowed. Strengthening exercises will start after a full recovery of the active range of motion, usually 12 weeks after surgery. After that, the patient will be directed to a home exercise program or alternatively to a specific training sport-related exercise program. Return to competitive sport activities are usually allowed 6 months after surgery.

Literature Review

Many factors can contribute to an optimal repair. Biological factors, such as tendon quality, muscle atrophy, and fatty infiltration, as well as patient's related factors such as age, smoking, and osteoporosis have been reported to influence the tendon healing response [46–48]. Nevertheless, biomechanical factors play an important role, especially in the early stage of the healing process. Initial fixation strength and footprint coverage are essential in optimizing rotator cuff repair; therefore, numerous biomechanical studies have focused on clarifying the strongest devices, knots, and repair configurations [49]. Suture bridge fixation techniques have been shown to provide numerous biomechanical advantages when compared with previous arthroscopic repair techniques, including increased failure loads, improved footprint restoration and pressurized area as well as decreased gap formation [18, 19, 50, 51]. In an attempt to maximize the biomechanical properties of suture bridge techniques, different configurations have been described [38–44]. They can be

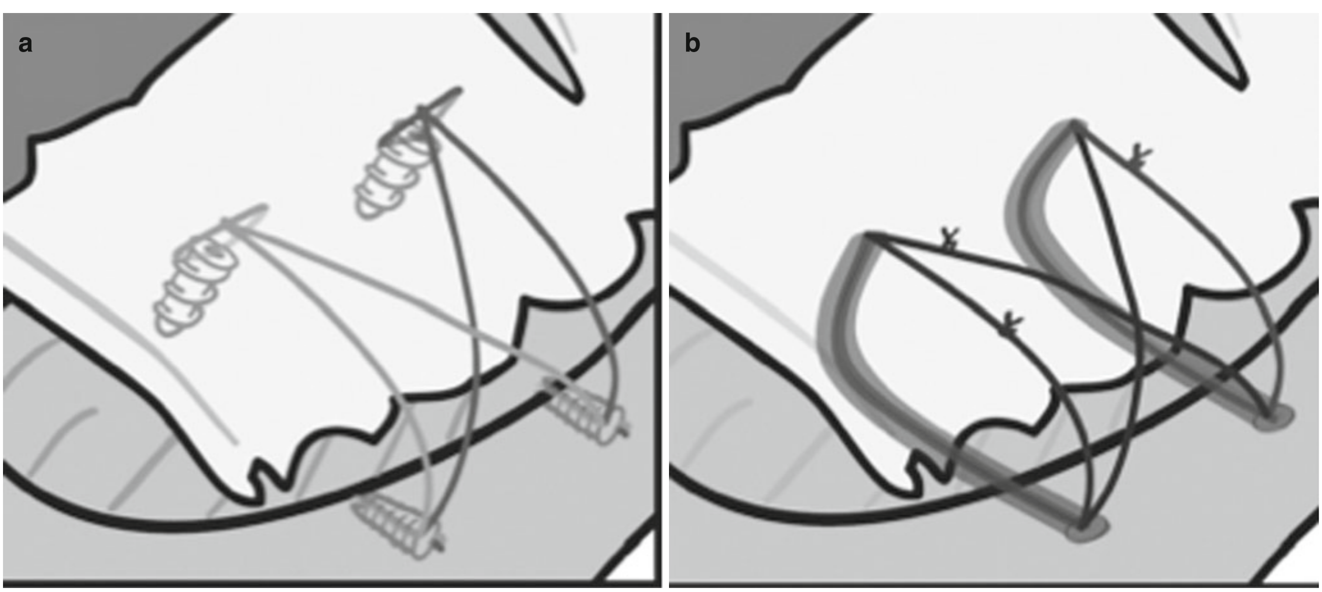

Fig. 7 (**a**) Represents transosseous equivalent suture bridge technique with "M" suture configuration. (**b**) Transosseous anchorless repair technique also with "M" suture configuration

generally divided between two main categories: those in which the medial row is tied and all-knotless repairs. Tying the medial knots can result in knot impingement and strangulation, which has been advocated as a possible explanation for the high number of medial row failure with double-row techniques [36, 51, 52]. Nevertheless, a recent systematic review [53] reported that biomechanical factors, such as ultimate load, stiffness, gap formation, and contact area, are significantly improved when medial knots are tied.

Tissue strangulation is one of the main concerns associated with a suture bridge configuration. It might be due not only to knots type but also to high contact pressure, multiple tendon perforations, and strong synthetic sutures [34]. Currently, only one study [54] showed a reduced but preserved blood flow in the tendon repair site after placing the second row. Therefore, excessive tensioning of the lateral row is not recommended, but further studies are needed to elucidate possible biological consequences in the healing process.

Transosseous equivalent configurations have been rapidly evolved. They were first based on two medial mattress sutures with four tied suture bridges fixed laterally by knotless anchors. Subsequently, an anterior augmentation through an additional lateral single stitch has been proposed to prevent gap formation at ultimate load in dynamic external rotation [28, 55]. Recently, the speed bridge technique has been developed. It combines quick arthroscopic application and eliminates medial and lateral knot impingement. As already described, speed bridge consists of a four strands, knotless construct with suture tapes of 2-mm width. Suture tapes should provide better high footprint coverage and compression between the tendon and bone to help promote healing. In addition, the theoretical risk of cut-through resistance on medial rows may have been reduced because this new construct is supposed to better distribute the pressure to the underlying tendon tissue [30, 41, 56]. Pauly et al. [52] compared four different Speed Bridge configurations with or without medial or lateral row reinforcement. The authors showed that double tendon perforation per anchor and additional medial mattress stitches significantly enhance biomechanical construct stability at time zero. Moreover, lateral addition of simple stitches reduces lateral “dog ear” deformities, but did not improve repair stability.

Besides biomechanical studies, several clinical studies evaluated repair integrity with regard to healing and functional outcomes after suture bridge techniques. Comparable or even better results than single and traditional double-row techniques have been reported. According to the recent literature, re-tear rates after suture bridge repairs vary between 9 and 29 % [38–42, 57].

Perhaps in an attempt to control implant costs, arthroscopic transosseous techniques have recently been revisited [45, 58, 59]. Open transosseous rotator cuff repair was first described by McLaughlin in 1944 [60] and it has been considered the gold standard for a long time. Transosseous sutures showed numerous biological and biomechanical advantages: allow reduction of the tendon bone gap formation; increase blood flow through the tunnel, maximizing the healing potential; improve footprint restoration, providing a more direct tendon to bone compression vector; and avoid the presence of implant devices in the footprint insertion, reducing the risk of anchor pullout and simplifying future revision surgeries [61, 62]. Currently, a few biomechanical studies have compared anchorless transosseous techniques with different transosseous equivalent suture anchor techniques. Nevertheless, a recent biomechanical study [Beherens 2012] showed comparable initial fixation strength between transosseous equivalent suture anchor fixation and traditional open transosseous anchorless technique. Two other studies [63, 64] showed equivalent biomechanical properties in regard to gap formation, ultimate load, and linear stiffness. One study [65] showed that suture anchor repair offers higher failure load than transosseous repair regardless of tunnel or suture configuration. Further biomechanical and clinical studies are needed to clarify potential clinically relevant differences.

Pearls

1. When compared to single-row repair or traditional double-row repair, a suture bridge repair technique has superior biomechanical properties but no difference in clinical outcomes to date.
2. Suture bridge technique is not appropriate for a cuff tear with significant retraction and poor tissue quality that will result in a high-tension repair.
3. Transosseous equivalent technique can be enhanced by using a wider suture.
4. Transosseous equivalent technique can be performed with medial row knots or a “speed bridge” knotless technique.
5. Dog ears can be compressed by passing cinch stitches through the dog ear and incorporating them into the lateral anchors.
6. Transosseous anchorless repair techniques have shown biomechanical excellent strength but poor, osteoporotic bone may result in suture cut out.

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Open-Surgery Technique

Stefano Gumina and Franco Postacchini

In my daily practice, I do not perform cuff repairs using this technique but prefer arthroscopic treatment. The main advantage of the latter is that it does not require dissection or detachment of the deltoid. In practical terms, this decreases the possibility of post-operative deltoid detachment, which represents a frequent and feared complication related to the open technique [1]. The arthroscopic technique also offers an aesthetic advantage; however, this factor is of scarce importance in the majority of patients who require cuff repair, being middle-aged or elderly. A further advantage is that the surgeon can explore the glenohumeral joint and identify pathological conditions, such as partial tear of the articular side, that cannot be diagnosed when applying the open technique. Finally, arthroscopic treatment results in less shoulder pain in the immediate post-operative period and allows patients to be discharged on the day of the operation itself.

The disadvantages of the arthroscopic method are the longer learning curve and the higher cost of the operation, associated with the use of disposable instruments. Arthroscopy using the so-called "mini-open" access consists in an arthroscopic evaluation of the glenohumeral joint and subacromial space followed by limited open access, permitting the cuff to be repaired.

Postero-superior Cuff

Positioning the Patient

On the day before surgery, the shoulder and axilla are shaved. Patient is placed in a semi-sitting position (beach-chair position). The entire limb, including the posterior region of the shoulder and the corresponding hemi-thorax, must be carefully washed, preoperatively, with iodine soap or chlorhexidine. Sterile laparotomies are used to dry the limb. Sterilization is carried out using iodine or alcoholic solutions if the patient is allergic to iodine. The axillary region is the last part of the limb to be sterilized. The operative field is bounded by three sterile drapes. The dressing of the field is completed with two large drapes: a "U" shaped one, fitting the armpit, and a normal drape for delimiting the shoulder from the neck. A sterile drape is used to cover the entire surgical field.

Incision of the Skin

A lateral, antero-superior, anterolateral, superior or deltopectoral incision may be performed. The choice depends on the surgeon's preference and location of the cuff tear, and on the dimension of the tear, above all on whether or not reparable rupture is suspected and a latissimus dorsi and/or teres major transfer is hypothesized.

The lateral incision may be horizontal or vertical. The first is made along the lateral border of the acromion (Fig. 1). Generally, it is easier to palpate the lateral acromion than the front edge. To facilitate detection of the bone margin, it is useful to request the assistant to lower the humerus. The lateral incision has the advantage of permitting better exposure of the posterior cuff and greater tuberosity, although it does not provide a good view of the medial acromion and, above all, of the acromio-clavicular joint.

To access these structures, the incision may be extended anteriorly along the anterior margin of the acromion.

The incision starts from the upper surface of the acromion, at the middle third, and goes down. This incision is suitable for a mini-open access, when the cuff tear is repaired after a preliminary arthroscopic phase, allowing diagnosis, debridement of soft tissue and acromioplasty. In this case, it meets the arthroscopic lateral portal in the distal portion (Fig. 2a, b).

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The superior, or saber, incision, starts from the upper surface of the acromion, slightly lateral to the acromioclavicular joint, and descends vertically, reaching 3 cm or more from the anterior margin of the acromion. The skin is retracted with a self-retaining or manual retractor. The length of the incision depends on the size of the cuff tear. This incision is less aesthetic than the lateral one. Moreover, it may be necessary to extend it in case of massive postero-superior cuff tears.

The delto-pectoral approach allows the surgeon to expose the subscapularis tendon, the lesser tuberosity and the rotator interval. To expose the supraspinatus properly, and, above all, the infraspinatus, the incision needs to be extended as far as 1 cm caudally with respect to the anterior margin of the acromion and extended laterally along the edge of the bone. Length varies according to the size of the postero-superior cuff tear.

Fig. 1 A horizontal lateral skin incision along the lateral margin of the acromion

Detachment or Split of the Deltoid

Deltoid Detachment Once the subcutaneous tissue has been dissected and the edge of the acromion has been identified, the deltoid is detached in close adherence to the bone margin. Detachment may be carried out through electrocautery. Complete detachment is often confirmed by spillage of a serous fluid from the subacromial space.

Extension of the deltoid detachment permits the cuff tear to be repaired. Post-operative recovery time is related to the degree of deltoid integrity. The extension may vary from 3 cm (for a small tear) to 6 cm (for a massive tear).

Deltoid Split Splitting is carried out following the direction of the muscle fibres. The longitudinal extension and size of the split depends on the location and size of the cuff tear and may vary from 2 to 5–6 cm. A transverse stitch is applied only if dissection is longer than 5 cm.

Evaluation of the Cuff Tear

Preliminary Assessment Once the subacromial space is exposed, the cuff tear needs to be identified. If the tear is not immediately observable, the humerus has to be rotated internally and externally so that the whole extension of the cuff may be evaluated. The initial inspection of the lesion allows the location and size of the tear to be assessed. The preliminary assessment also helps the surgeon to determine whether deltoid detachment or split should be enlarged posteriorly or anteriorly. Furthermore, this also makes it possible to determine whether or not the tear may be repaired.

Acromioplasty This may not be necessary when the subacromial space is wide, the anterior margin of the acromion

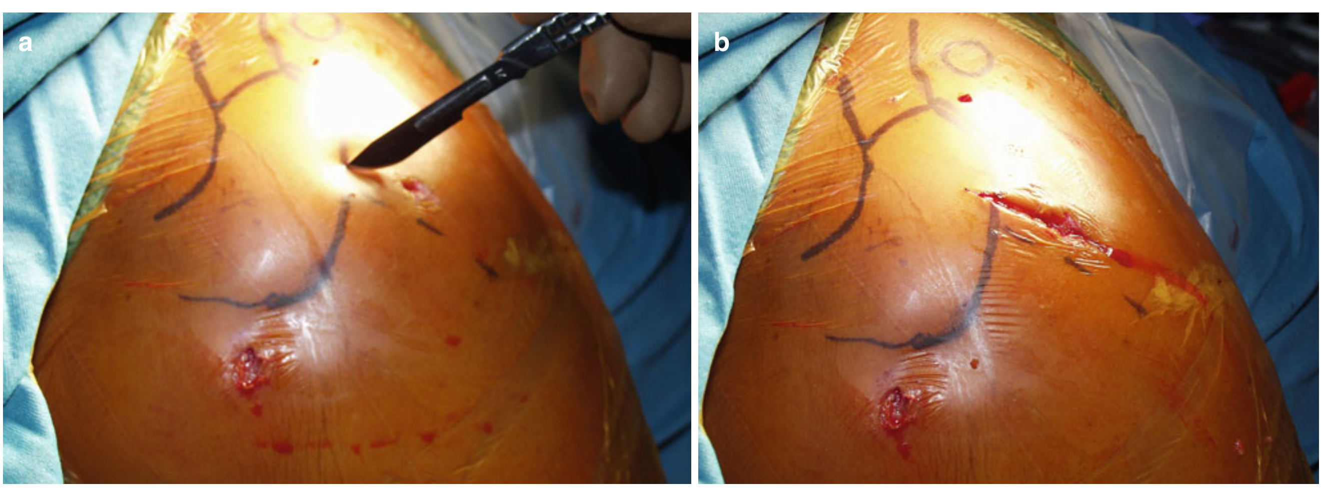

Fig. 2 A vertical lateral skin incision, performed after prior arthroscopy. The incision starts on the superior surface of the acromion near its lateral margin (**a**) and passes through the arthroscopic lateral portal (**b**)

thin and the cuff tear small. It is essential when the subacromial space is narrow, there is a large or massive tear, or when an acromial spur makes the tear difficult to repair or because it is responsible for subacromial impingement.

Acromioplasty may be performed before or after bursectomy. Before proceeding to bone resection, it may be useful to detach the bursa from the deep surface of the acromion, if it is adherent to the bone (Fig. 3). This is performed using a 1.5-cm-wide chisel. In massive rotator cuff tears, some surgeons save the coracoacromial ligament to prevent upward migration of the humeral head [2]; in this case, the ligament is detached from the acromion and may be reinserted later. Others believe that it should always be excised because it can be a cause of persistent post-operative impingement.

When the open-surgery phase is preceded by initial partial arthroscopic acromioplasty, the latter can be completed with a motorized bur, rather than an osteotome or a Luer.

Caudal acromio-clavicular joint osteophytes should be removed, if prominent. The removal can be performed using a Luer or a small rasp, or a motorized bur.

Bursectomy The subacromial bursa has to be removed to permit adequate exposure of the tendon lesion. When the bursa is thick, it may be difficult to distinguish it from tendon tissue. The distinction can be made on the basis of the colour, friability and thickness of the tissue. Generally, the bursa is pink in colour, while the tendon is whitish (Fig. 4). If the tissue receives a number of stitches and traction is applied, the bursa will tear while the tendon is generally resistant to slight traction.

A radical bursectomy is not necessary, especially if the bursa is thin. Preservation of the bursa may be useful as a source of fibrovascular tissue, which can facilitate repair of the tendon [3]. Once acromioplasty and bursectomy have been carried out, the characteristics of the lesion need to be carefully evaluated. In addition, the degree of degeneration of the tendon and the status of the long head biceps tendon have to be assessed.

Long Head Biceps Tendon The biceps tendon may be: (1) intact and in good health, or present a synovial sheath inflammation; (2) partially broken or detached from the scapula – SLAP lesion; (3) absent, because it is completely broken and distally retracted; (4) medially dislocated and located on the front of the subscapularis tendon or between the bundles of this tendon; (5) dislocated within the joint cavity, medially to the humeral head.

The long head biceps tendon is easily visible when the supraspinatus is completely involved in the tear (Fig. 5). When the tear involves the postero-superior portion of the cuff, the biceps tendon is not visible; therefore, it should be sought by retracting the tendon stump medially to expose the area of the biceps groove. This is necessary especially when, preoperatively, a clinical diagnosis of complete rupture

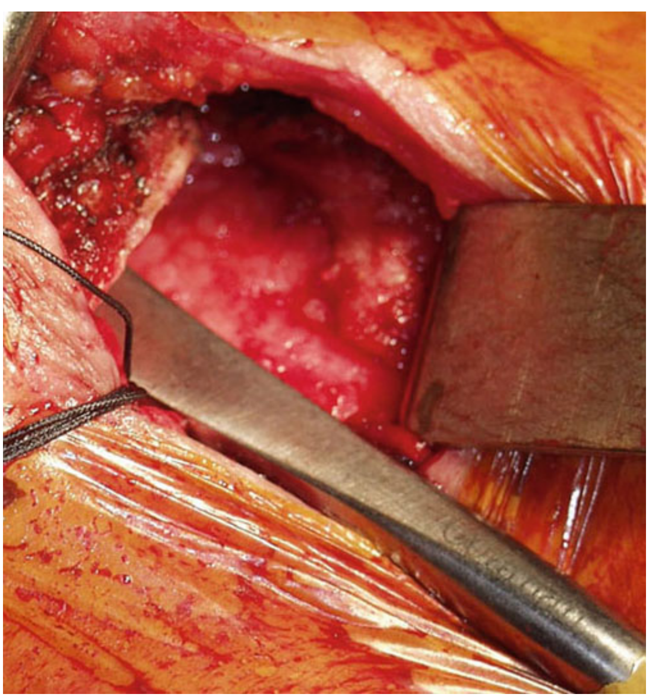

Fig. 3 A longitudinal section of the deltoid muscle bundles

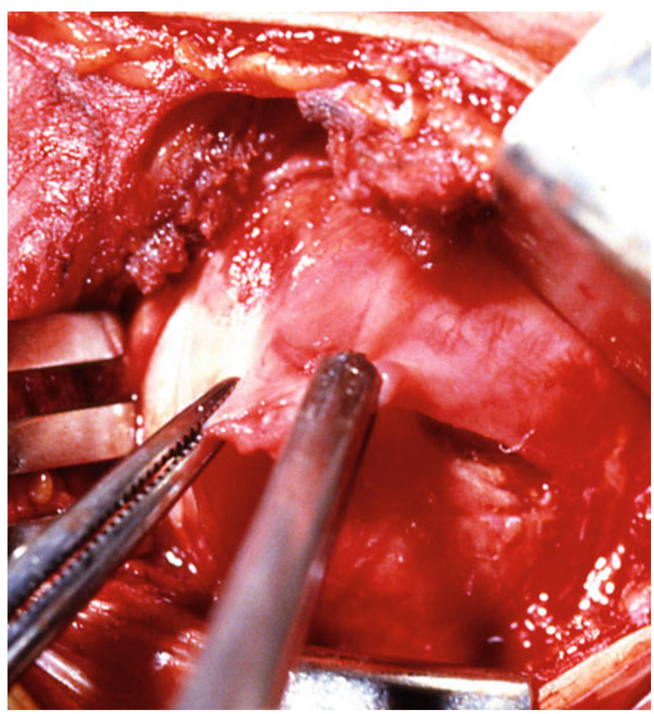

Fig. 4 A bursectomy is performed before the tendinous repair. The bursa is clearly distinguishable from the white tendon

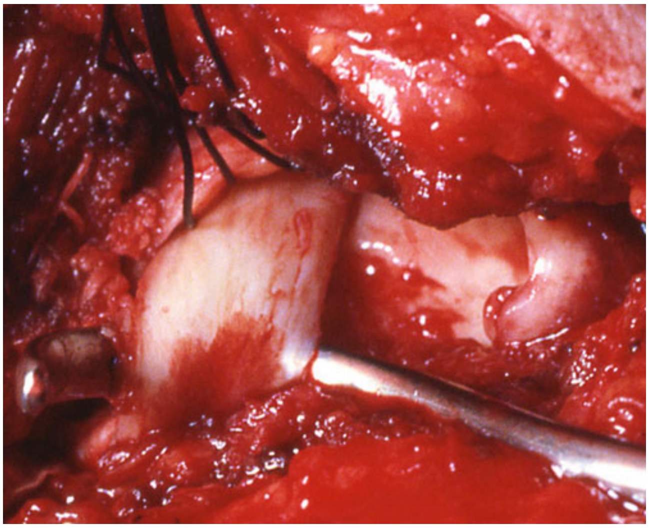

Fig. 5 A supraspinatus tendon tear and lesion of the rotator interval. The biceps tendon is lifted by a hook. The tendon sheath is partially flushed, but maintains its integrity

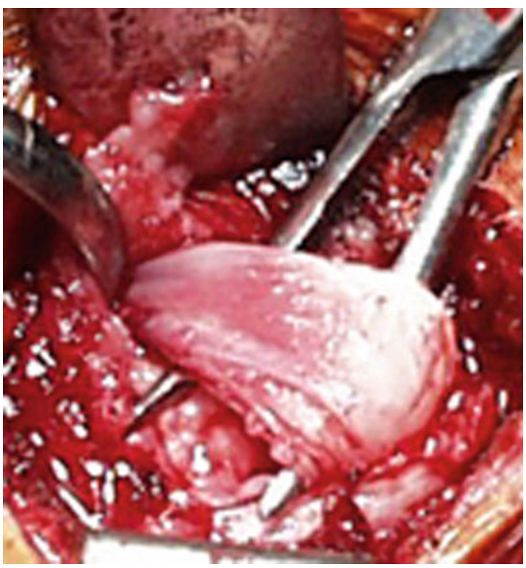

Fig. 6 A longitudinal tear and associated inflammation of the long head of the biceps tendon

of the biceps tendon has not been formulated. Exposure is important to determine if it is partially broken or dislocated; as well as to avoid it being gripped by the sutures used during cuff repair. When the tear is far from the biceps groove, exposure of the biceps is not necessary, especially in the absence of clinical data possible partial rupture or dislocation.

Tenotomy is recommended when the tendon is widened and/or fissured (Fig. 6). In young patients, bicipital groove tenodesis is performed. Some surgeons dissect the tendon in all elderly patients even when it does not show degenerative changes. Normally, tenodesis is not indicated in the case of elderly patients.

Repair of Postero-superior Cuff Tear

Partial Tears Usually, partial tears of the bursal side of the postero-superior cuff present small lesions not exceeding 1–2 cm in its larger diameter. Generally, they affect the supraspinatus and involve a small area of the tendon (Fig. 7).

Currently, it is anachronistic to treat these injuries using the open technique. However, if a surgeon, unfamiliar with arthroscopic technique, decides to treat the cuff tear traditionally, he needs to detect an oval-shaped portion of tissue in which the partial lesion is contained; afterwards, this tissue is removed and the margins of the lesion repaired. Sutures must be applied at a short distance from the edge of the tendon section to avoid creating salience of the tendon, which knocks against the deep surface of the acromion during shoulder movement. When the lesion is close to the insertion of the bone, a triangular or crescent-shaped portion of the tendon is removed. In the case of a triangular section, the two margins are sutured starting from the apex of the triangle to obtain a straight base, which is successively fixed to the greater tuberosity.

Full-Thickness Lesions

Mobilization of the Tendon Stumps This procedure is necessary in the case of large lesions, especially when the tears are

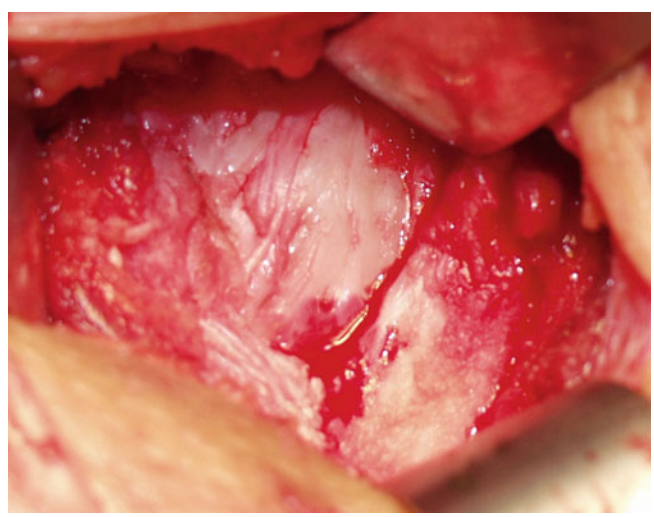

Fig. 7 A partial-thickness tear of the supraspinatus tendon on the bursal side

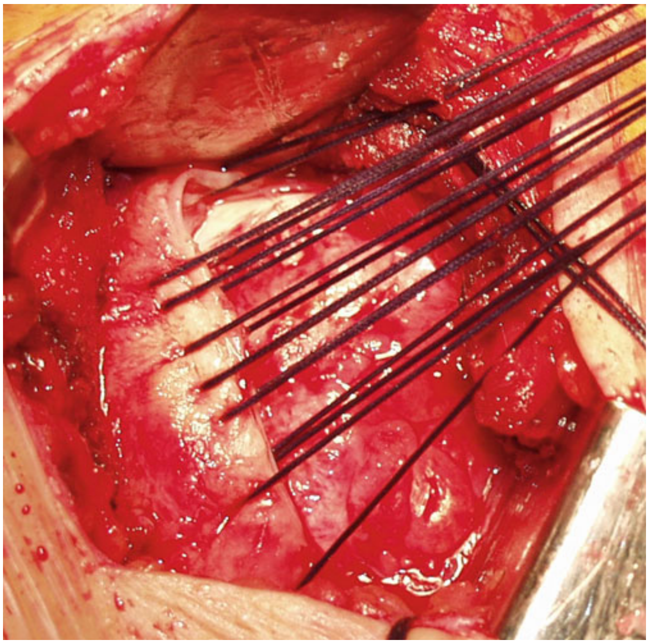

Fig. 8 Application of suture stitches on the medial-most margins of the cuff tear. These sutures must be applied in a healthy tissue to avoid laceration during mobilization of the cuff

massive. Mobilization can be achieved using arthroscopic grasping forceps or suture stitches. When strong traction is requested, suture stitches on the tear margins have to be applied starting with the most easily accessible portion of the tendon stumps. By pulling the suture stitches applied to this portion together, lateralization of the less accessible portion is facilitated. The internal or external rotation of the humerus or the downward traction of the limb may facilitate the application of suture stitches on the medial-most margins of the cuff tear. Sutures need to be applied on healthy tissue to avoid laceration during cuff mobilization (Fig. 8). Mobilization starts from the bursal side of the cuff, completing the phase already partially performed before acromioplasty. The cuff is detached from the lower surface of the postero-lateral portion of the acromion. The portion thus released is gradually fixed with sutures, continuing the procedure as far as it is necessary or possible. Subsequently, the articular side of the cuff has to be mobilized, because it is often adherent to the glenoid rim and to the base of the coracoid process (Fig. 9a).

If mobilization does not permit the cuff to be inserted into the greater tuberosity with a 20–30° humeral abduction, the rotator interval may be opened up (anterior interval slide) using scissors; starting from the bicipital groove region and proceeding medially and anteriorly as far as the coracoid base [4] (Fig. 9b).

This procedure may permit a lateral advance of some millimetres of the supraspinatus to be obtained. If this is not enough, an attempt to mobilize the infraspinatus further can be made; however, this manoeuvre might harm the suprascapular nerve. Alternatively, the so-called posterior interval slide might be performed (Fig. 9c).

This procedure permits both further mobilization of the postero-superior cuff, which may be advanced towards the greater tuberosity, and the reinsertion into a biomechanically more favourable position (Fig. 9d). The repair of the posterior cuff is important for restoration of an appropriate couple of force balances on the transverse plane, necessary to re-establish a normal glenohumeral fulcrum [5].

Debridement of the Tear Margins It is commonly thought that the marginal edges of the cuff tear should be removed, especially when they appear thickened and sclerotic. This is done to obtain a healthy and/or more vascularized tissue, capable of healing with the opposite side of the tendon (side-to-side repair in case of “V” shaped lesion) or with the bone. Debridement involves removal of 2–3 mm of the tear margin.

Cuff to Bone Repair Anchorage to the greater tuberosity by means of a trench is the most common method to fix the cuff tear to the bone. The trench is created in the anatomical neck of the humerus using an osteotome. The medial edge of the trench is smoothed with a Luer to avoid the tendon being damaged. Suture stitches are passed through the trench and knotted on the lateral face of the greater tuberosity (Fig. 10a, b).

Before making the trench, it may be useful to mark the chosen area using electrocautery. With the osteotome, two cuts may be performed: the first is medial and is carried out in a (30–40°) mediolateral direction; the second has a (10°) lateromedial direction. The width of the osteotome is approximately 2–3 cm. The depth of the trench is about 3–5 mm.

The medial edge of the trench, which borders on the articular cartilage of the humeral head, is smoothed using a Luer. The latter may also be used to make the trench deeper or wider, if required. The sagittal extension must be adequate to accommodate the free edge of the cuff in all its extension.

The two ends of a mattress suture, applied to the tendon, are inserted into the lateral side of the trench. They are passed so as to arrive approximately at 1 cm from the apex of the greater tuberosity (Fig. 11). The distance between the two holes of each suture must be of 5–7 mm. This distance prevents the second end of the suture from penetrating into the same hole as the first and, at the same time, leaving enough space for other sutures.

The transosseous hole may be made with a cylindrical curved needle, which, during the passage into the bone, is repeatedly swung to increase the size of the hole and provide the eye of the needle with easier passage. Two converging holes may be previously created using a Kirschner wire to

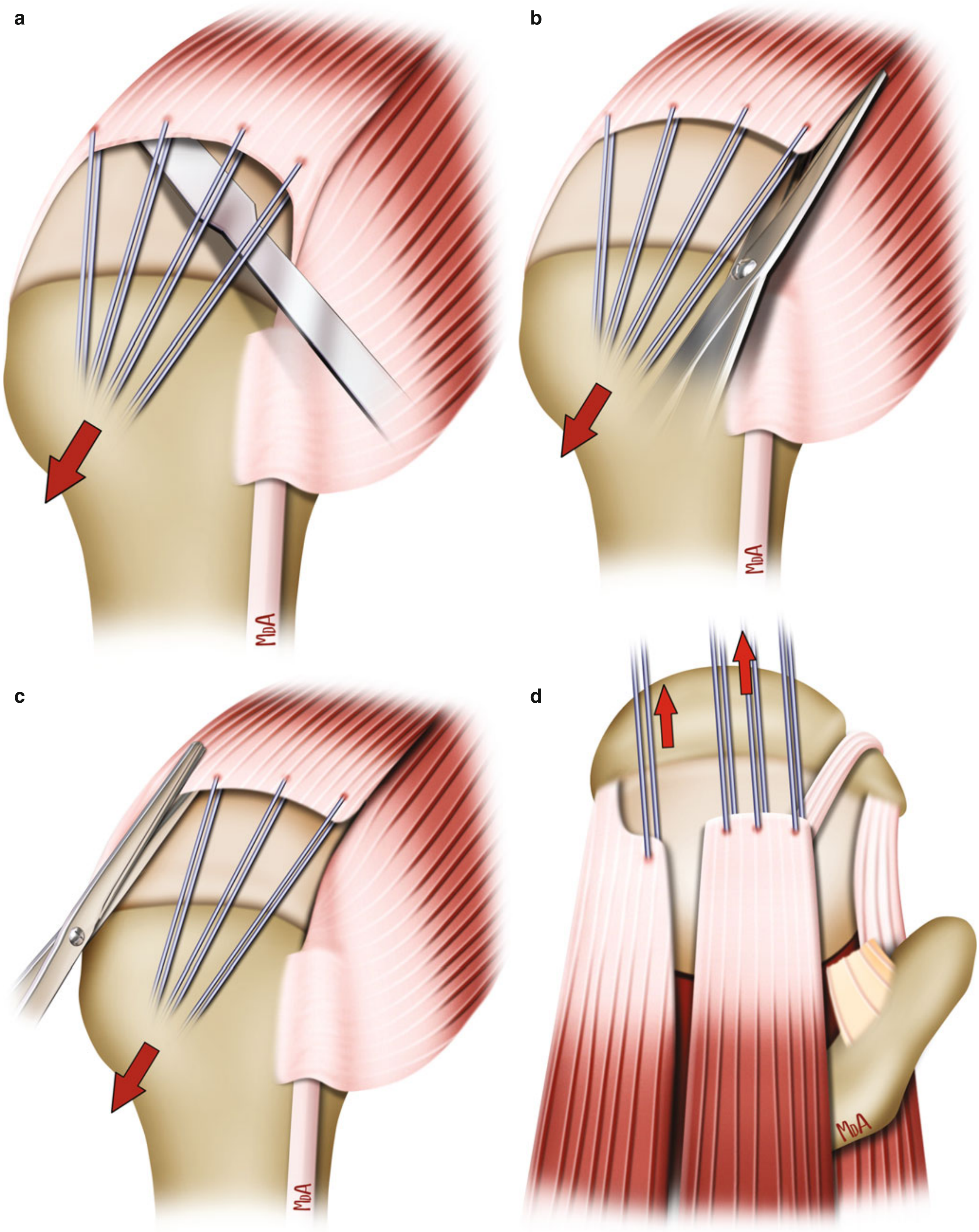

Fig. 9 Tear dissection and mobilization from the anterior and posterior glenoid rim using a periosteal elevator (**a**); a section of the rotator interval: anterior capsular slide (**b**); the section is then performed between the supraspinatus and infraspinatus tendons: posterior capsular shift (**c**); after the interval slides are performed, the supraspinatus and/or infraspinatus tendon can be easily mobilized by the greater tuberosity (**d**)

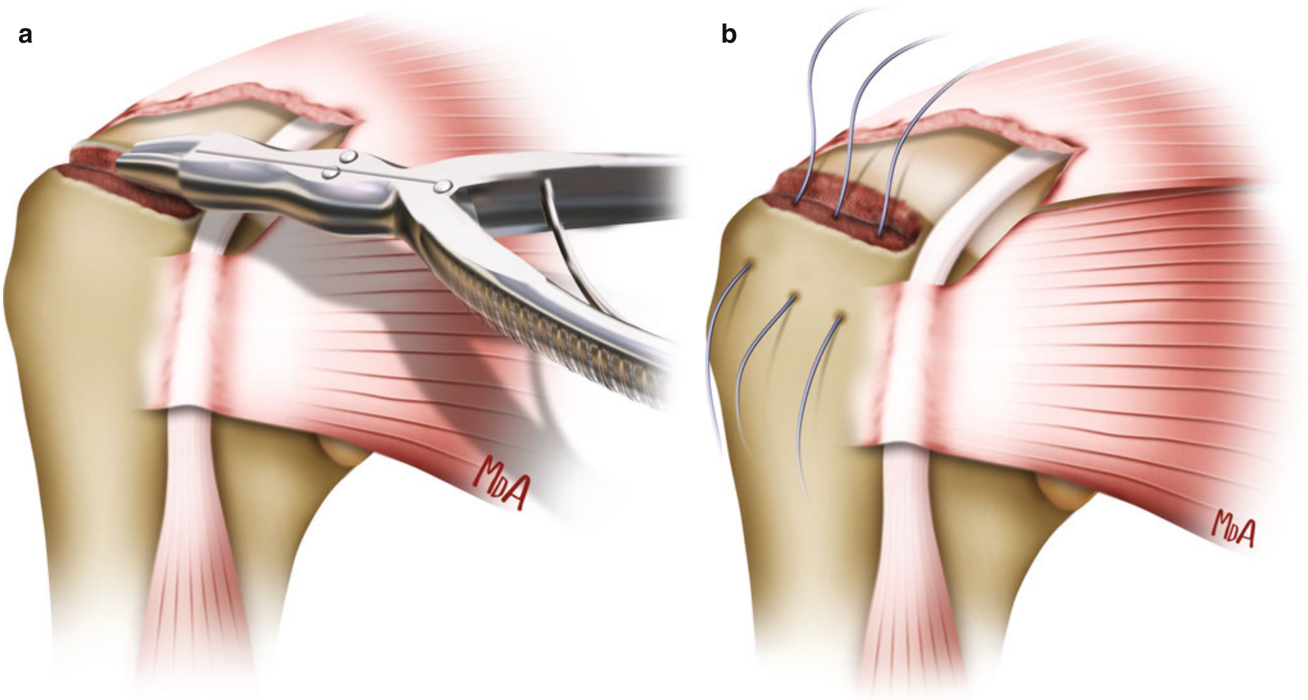

Fig. 10 Creating a trench in the anatomical neck of the humerus bone. Removing the crest of the medial wall of the trench (**a**); introduction of suture threads into the bottom of the trench (**b**)

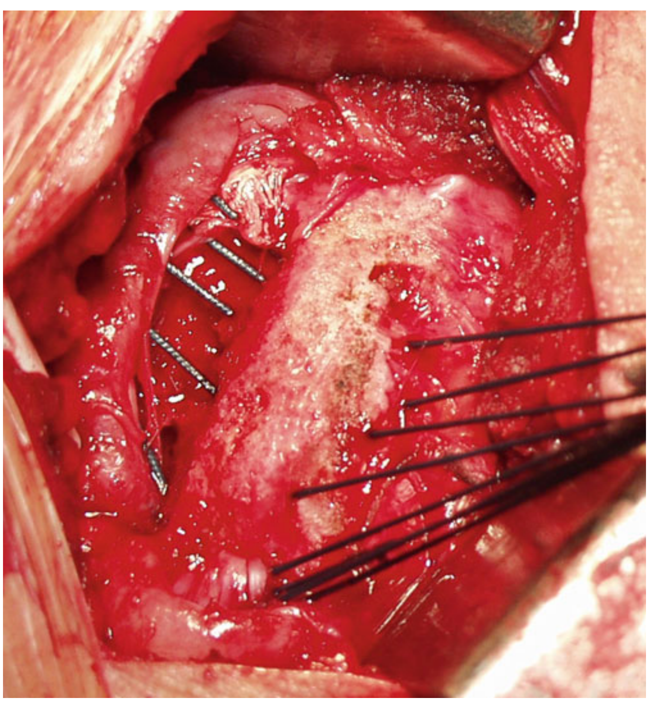

Fig. 11 The two ends of a mattress suture, applied to the tendon, are inserted into the side of the trench. They are passed in such a way that they emerge at approximately 1 cm from the apex of the greater tuberosity

permit the needle to pass with greater ease. The sutures are knotted while the arm is in the abduction, so that the tendon is in contact with the bottom of the trench (Fig. 12).

The tightness of the suture increases if the sutures are knotted together on a titanium or plastic plate (augmentation), placed on the outer face of the greater tuberosity [5–7]. The use of augmentation can be particularly useful in the case of osteoporotic patients.

Anchorage to the bone can be carried out using titanium or resorbable anchors. The anchors should be inserted into the greater tuberosity at an angle of 45° in the coronal direction. They should be spaced at 10 mm from each other, while the interposed bone surface must be abraded with a bur to promote tendon-to-bone adhesion. This should be done before inserting the anchor (Fig. 13a, b).

The use of anchors reduces surgery time; the disadvantages are the cost and the pull-out risk. This is higher in patients suffering from osteoporotic humeral head and when the cuff exerts a considerable traction.

"V" or "L" Shaped Tears In these cases, sutures are applied along the cuff edges starting from the most medial portion and proceeding laterally. By pulling the sutures, the margins of the tear are brought together (Fig. 14a). Generally, the first sutures to be knotted are those closest

to medial point; the knotting then proceeds using lateral sutures until the lesion is repaired (Fig. 14b, c). Care must be taken not to create a salient suture that may knock against the acromion during forward elevation. In the presence of an irregularly shaped cuff tear, the repair technique varies according to the shape of the lesion. Generally, knotting starts where the distance between the margins is least and proceeds to the area where the diastasis is greatest.

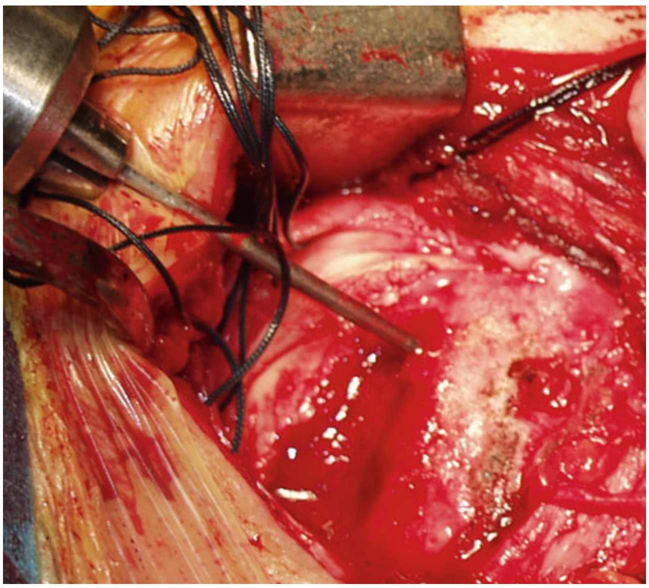

Fig. 12 The sutures are knotted keeping the arm in the abduction position, so that the tendon is in contact with the bottom of the trench

In "L" shaped lesions, knotting starts first along the sides of the triangle; the tendinous front obtained is then fixed to the transverse base of the lesion.

Massive Tears Massive lesions repair may require significant commitment and the implementation of different surgical strategies, depending on various factors, such the site, shape and width of the lesion; the degree of retraction of the tendons and the resistance of the tissue to traction forces. Usually, sutures are passed, first, through the free margins of the cuff. Successively, lateral tendon mobility needs to be assessed. Release of the lesion is often requested too.

Afterwards, the surgeon should assess whether cuff-to-bone repair is possible or whether side-to-side repair is necessary. Further evaluation should establish whether the entire lesion, or only a portion of it (biomechanically useful partial repair), may be repaired.

Non-absorbable # 2 sutures should be preferred. They may be applied to the tendon in various ways. Simple, U, mattress, Kessler [6] or the Mason-Allen sutures may be used (Fig. 15a–c).

When possible, cuff reinsertion should be performed with the arm in adduction or in a 10° abduction position. In the case of some massive tears, this is absolutely impossible. In these cases, reinsertion may be performed with the arm in abduction; successively, the arm is cautiously returned to the trunk to assess the resistance of cuff-to-bone repair. If the latter is not possible, even at 45° of abduction, a trench may

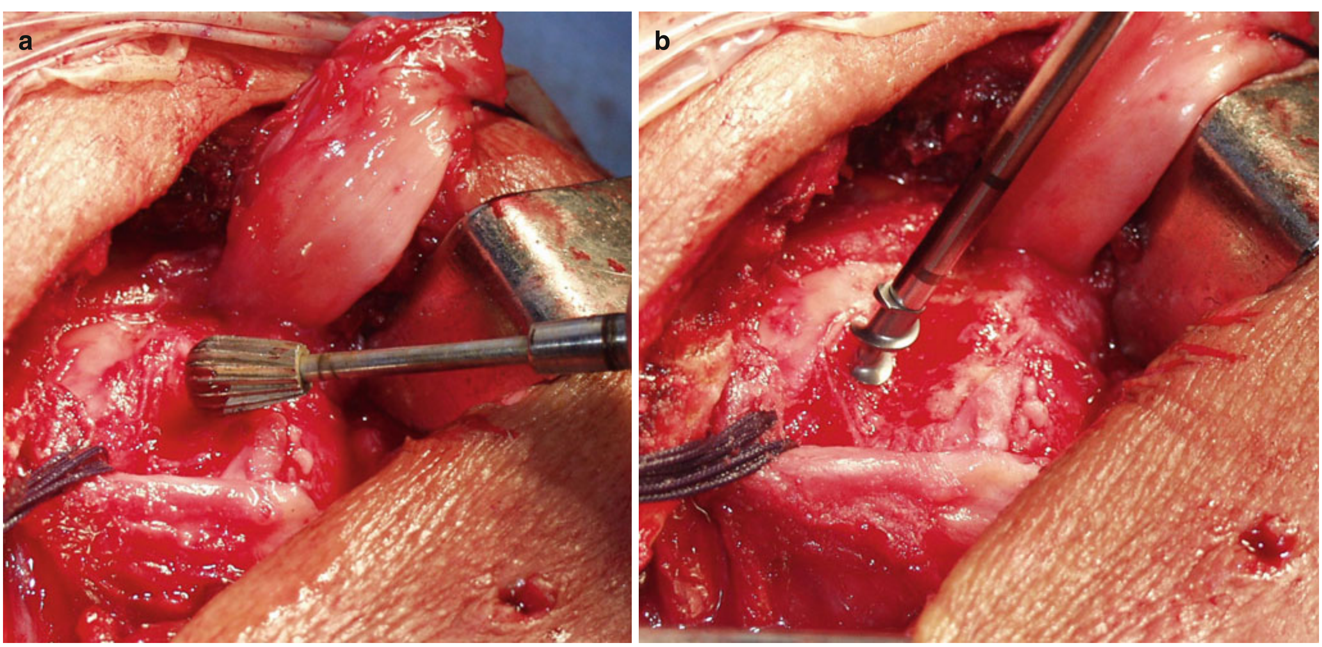

Fig. 13 Preparation of a bleeding footprint before anchor implant (**a**); implant of a suture anchor; the anchor should be inserted into the greater tuberosity at an oblique angle of 45° in the coronal direction (**b**)

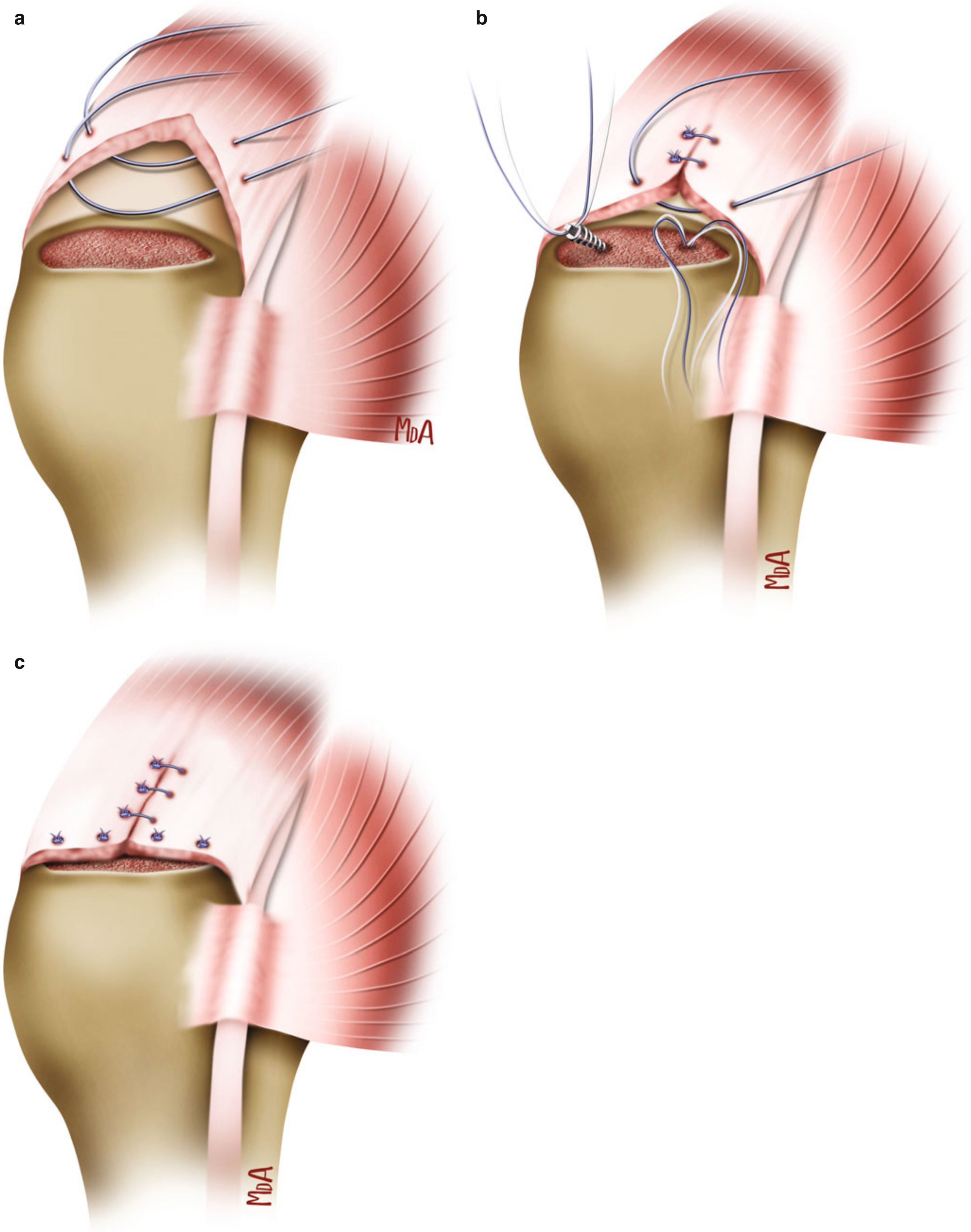

Fig. 14 Repair scheme of a triangular tear. (**a**) At first, a side-to-side repair was performed. (**b**) Then the sutures were tied and two anchors were included in the bleeding footprint. (**c**) The suture anchors fixed the tendon to the footprint on the greater tuberosity

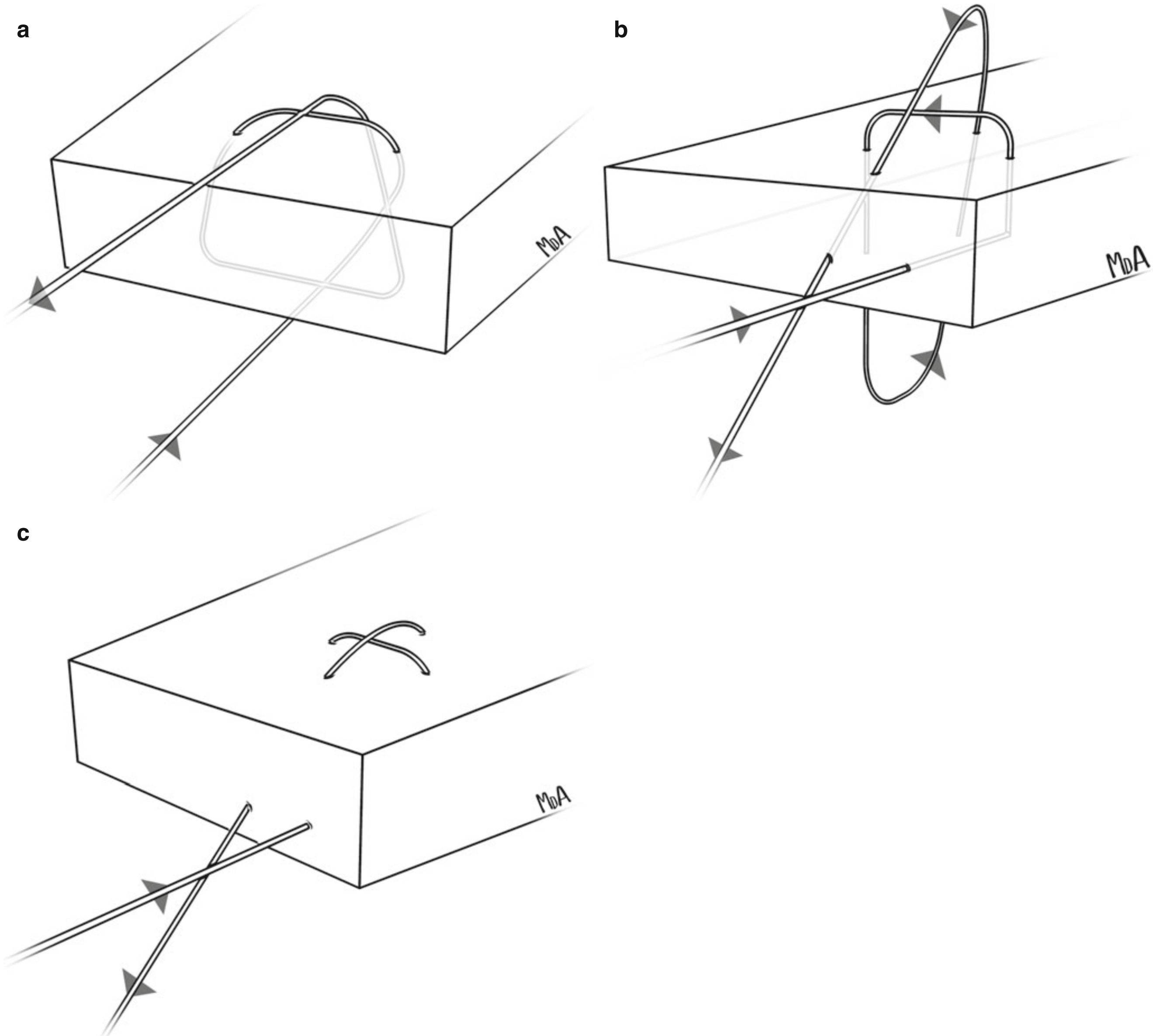

Fig. 15 The Mason-Allen suture technique: the stitches are passed outside of the tendon (**a**); the modified Mason-Allen technique: the stitches are passed through the tendon (**b**). Final aspect (**c**)

be prepared 1 cm medially to the anatomical neck of the humerus (medialized repair).

When it proves impossible to repair the superior cuff, despite all possible efforts, it may be left unrepaired (Fig. 16). This is in agreement with Burkhart's theory of the suspension bridge [8], according to which the subscapularis and infraspinatus-teres minor generate a couple of opposing forces that balance and allow movement of the arm to be carried out. If the superior cuff remains unrepaired, the reinsertion of the coracoacromial ligament into the acromion is recommended.

Deltoid Reinsertion This is a strategic phase of surgery, since the detachment of the deltoid is one of the causes of the failure of cuff tear treatment when using the open-surgery technique. In a retrospective study carried out in 2008, Gumina et al. [1] observed that of the 112 patients who underwent massive tear repair using open-surgery technique, 9 (8 %) experienced detachment of the deltoid. In all cases, detachment occurred in the immediate post-operative period (within 3 months).

It is recommended that deltoid reinsertion into the acromion edge be performed with 4–6 non-resorbable suture stitches. Needle penetration through the antero-lateral margin of the acromion can be difficult. Therefore, it may be useful to make some holes at a distance of 5–7 mm from the lateral margin of the acromion using a thin Kirschner wire. Holes

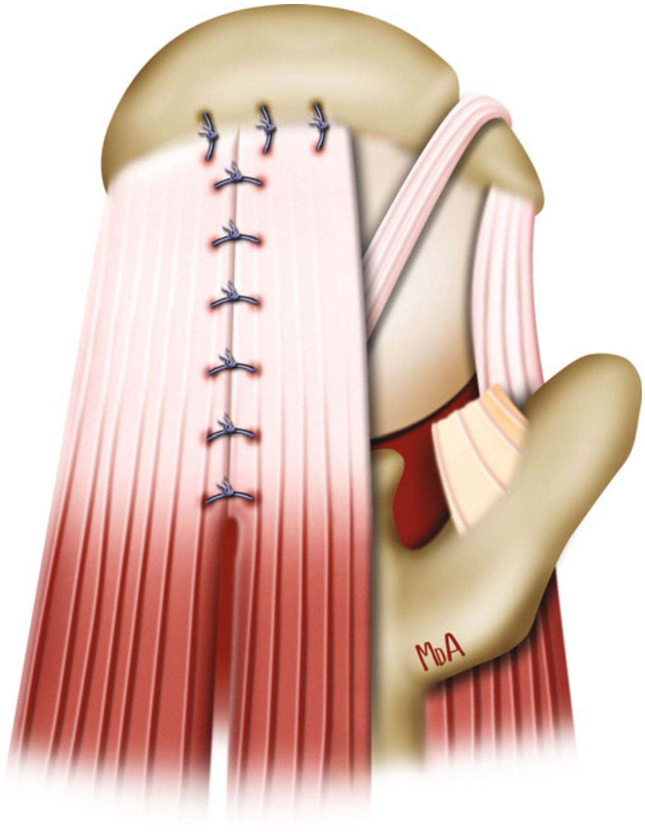

Fig. 16 Schematic drawing showing the upper portion of the cuff left unrepaired when sufficient tendon tissue is unavailable

facilitate the passage of the needle. The suture should include the deep fascia of the deltoid. Simple sutures should be avoided as they facilitate the detachment of the deltoid. Therefore, mattress or Mason-Allen sutures should be preferred.

Tears in Patients with os Acromialis To find os acromialis is a relatively rare occurrence. It is not easy to diagnose preoperatively, especially if it involves the anterior portion of the acromion (preacromion). An axillary view radiograph can be helpful to confirm any suspicion suggested by the antero-posterior view.

In the presence of os acromiale, different surgical strategies may be implemented. Mudge et al. [9] removed acromial bone spurs of different sizes in six patients, obtaining satisfactory functional outcomes in most cases.

In the case of a stable mesoacromion, this should be left in place after a slight acromioplasty [10]. The latter treatment should be carried out very carefully, using a bur. If the fragment is unstable, internal fixation may be indicated, after that the nonunion tissue is removed, the opposite bone surfaces are abraded and the gap filled with autologous bone graft. Internal fixation can be performed using a thin cannulated metallic cerclage.

Repair of the Subscapularis

Tears of the subscapularis tendon may be isolated or combined with postero-superior cuff tears. The isolated lesion is the most typical and most common. Associated lesions of the subscapularis and supraspinatus, which cause the antero-superior tears, are not frequent, and, in any case, rarer than postero-superior tears. The reason for this difference, in terms of prevalence, is probably due to the rotator interval, which is interposed between the supraspinatus and the subscapularis and which represents a kind of "barrier" opposing extension of the lesion from the superior to the anterior cuff and vice versa. Usually, in full thickness supraspinatus tears extending to the subscapularis, the latter presents small lesions of the cranial portion. Similarly, in full thickness subscapularis tears, the supraspinatus is usually interested only in the portion closest to the bicipital groove.

Sometimes, tendon can be injured in the proximity of the lesser tuberosity to which it remains adherent by means of a thin tendon stump. Much more often, the tendon is detached from the bone insertion in the proximal half or three-quarters area, or is completely detached. In not recent lesions, which represent the vast majority, the tendon is medially retracted and the interval between the tendon stump and the lesser tuberosity filled by a fibrous scar lamina, which may easily be confused with the tendon. The long head biceps tendon is often medially dislocated or subluxated below the lamina, or partially or completely broken.

In case of rupture, tendon stump can be found in the bicipital groove; sometimes the groove may be empty for the distal retraction of the tendon.

A delto-pectoral approach is normally utilized. The deltoid is laterally retracted together with the cephalic vein; conjoint tendons are medially retracted to expose the bicipital groove, the lesser tuberosity and the subscapularis tendon stump. The latter is found in depth with respect to the conjoint tendons. The biceps tendon is tenodesized.

Some stitches inserted on the most medial portion of the subscapularis tendon, which are used both as a landmark and subsequently to pull the musculotendinous unit towards the lesser tuberosity. The capsule is left adherent to the deep surface of the subscapularis.

After that, adhesions between the subscapularis and the lower surface of the coracoid process are removed, the coracohumeral ligament is dissected and the rotator interval opened. The s muscle is moved away from the homonymous fossa to allow the muscle-tendinous unit to be brought forward sufficiently.

A trench in the lesser tuberosity is created, to the bottom of which the subscapularis tendon is fixed by means of transosseous non-absorbable sutures. However, it has become much more common to use one or more 5-mm-thickness

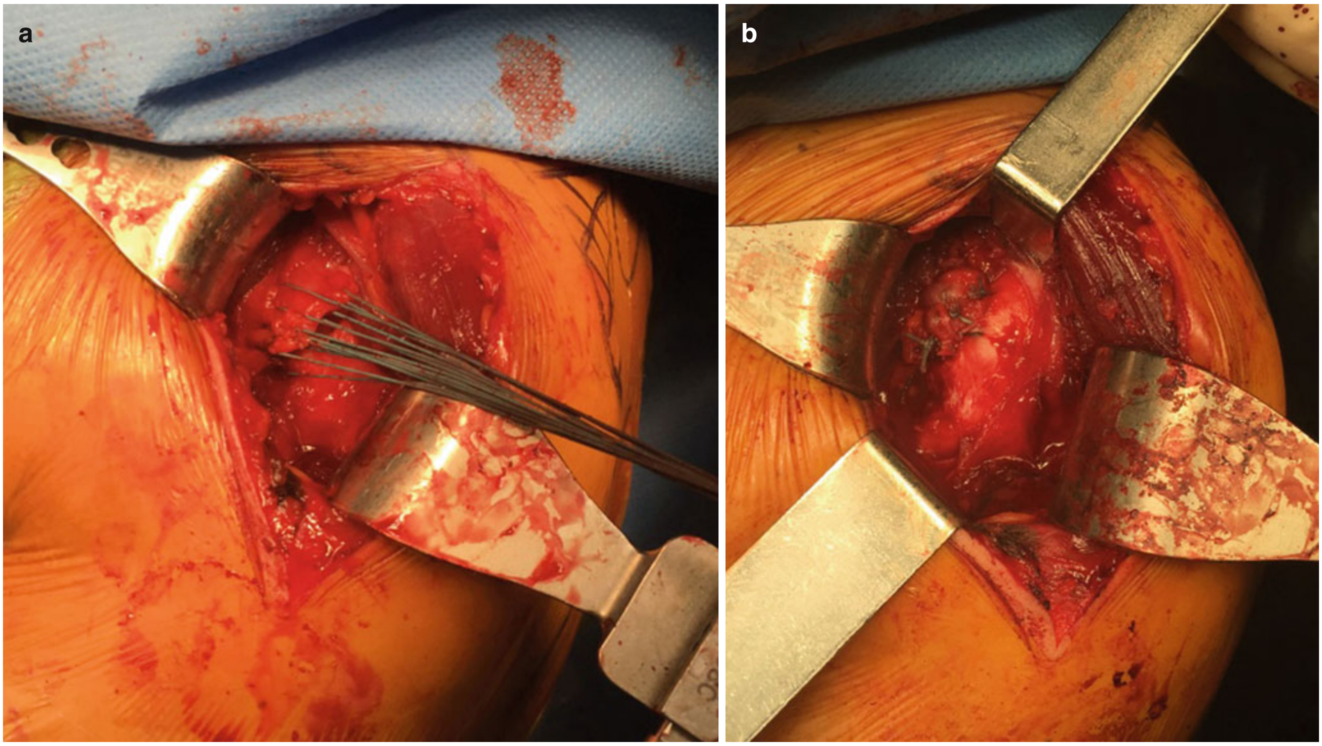

Fig. 17 Subscapularis open repair. Stitches inserted on the most medial portion of the tendon (**a**); repair with two 5-mm anchors is completed (**b**)

anchors, which are screwed into the native area of the tendon insertion (Fig. 17a, b). Finally, the supraspinatus tendon needs to be evaluated to assess the presence of a tendon tear or of a subacromial impingement.

Complications of the Open Technique

Detachment of the deltoid. Detachment of the deltoid (Fig. 18a, b) and infections (Fig. 19) are the most frequent complications after open-surgery cuff repair. Detachment occurs if reconnection to the acromion is improperly performed or if excessive and sudden traction occurs on the suture causing a detachment of one or more transosseous stitches, with consequent retraction of a more or less extensive portion of the muscle. Rarely, detachment of a small portion of the acromion occurs.

Usually, detachment occurs 3–6 weeks after surgery, during the active rehabilitation program of the shoulder. In the case of large defects, it may cause, in addition to a cosmetic defect, a decrease in the range of motion. Detachments of a small portion of the muscle may rarely determine functional deficits and usually do not require re-operation. In the presence of gaps that exceeding 3 cm, it is appropriate to reattach the deltoid to the acromion in the shortest possible time, since it can be difficult to obtain a functional reinsertion of the muscle in cases of inveterate lesions.

In a retrospective study of ours [1], we observed that patients who undergo detachment of the deltoid achieved an average increase in Constant score of 5 points compared to the 17 points obtained by those who had no post-operative complications.

Superficial infections are not uncommon and are easy to diagnose. Usually, they are no cause for concern, although in a few cases they may require vigorous antibiotic treatment.

Deep infections are rarer. In these cases, the patient unusually complains of a sharp pain and the skin wound is reddened and edematous. After 8–12 days, a fistula tends to form, and may leak purulent material.

When a *deep infection* occurs, the surgeon should avoid administering antibiotics before carrying out a bacterial culture and susceptibility tests. If the test is negative, high intravenous doses of broad-spectrum antibiotics and specific antibiotics for Propionibacterium acnes should be administered, because this is the most common germ responsible for post-operative shoulder infections. At the same time, rehabilitation of the shoulder should be suspended. If no tendency towards improvement occurs after 1 week following the antibiotic treatment, the surgeon should proceed to surgical revision of the wound.

Neurological Lesions An axillary nerve injury may occur due to a longitudinal dissection of the deltoid greater than 6 cm. In this case, there is functional loss of the muscular portion innervated by the interested branches. The lesion

Fig. 18 Deltoid detachment after open rotator cuff repair using both horizontal (**a**) and vertical skin incision (**b**)

Fig. 19 Superficial infection that occurred 30 days after an open rotator cuff repair

may also occur during the dissection of the subscapularis musclular-tendon unit when it is necessary to mobilize it. The axillary nerve may also be damaged in the quadrilateral space during latissimus dorsi and/or teres major transfer performed because of an irreparable postero-superior cuff tear.

Musculocutaneous nerve injuries are rare. They are often due to excessive medial traction of the conjoint tendons or are the result of direct trauma during transfer of the pectoralis major performed due to an irreparable tear of the subscapularis tendon.

The radial nerve may be injured during latissimus dorsi and/or teres major transfer, when tendons are exposed near the humeral insertion. Lesions are usually due to excessive traction or may also occur when tendons are detached from the humerus, if the operation is carried out without an adequate control of the tendon insertion.

The suprascapular nerve may be injured, near the base of the scapular spine, during attempts to mobilize the supraspinatus tendon during the interval slide procedure [11].

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Treatments for Irreparable Tears

Stefano Gumina and Eugenio Savarese

When the rotator cuff tear cannot be repaired and patient functional demand is low, a conservative treatment may be proposed with the purpose of mitigating the pain, and, consequently, completely or partially recovering the shoulder motion. This treatment consists of following a rehabilitation programme, taking medication for reduce shoulder pain or undergoing subacromial injections using steroids, hyaluronic acid or PRP. In some patients this treatment is effective; although, it is possible that the attenuation or the disappearance of pain is simply due to rest and/or to the natural history of the cuff tear.

Other patients do not get any benefits from the conservative treatment or refer they have gone through a relative pain-free period only for few weeks. In these cases, and only if the general health status does not contra-indicate a surgical solution, an arthroscopic treatment may be proposed in order to mitigate the shoulder pain and/or restore a couple of forces able to improve shoulder biomechanics.

Cuff Debridement

Debridement consists in:

Synovectomy

Synovectomy in the cases of synovitis has mainly to be performed close to the rotator interval (anterior capsule), trying to expose the subscapularis tendon and the biceps insertion that are often surrounded by hyperemic villi.

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Long Head Biceps Tendon Tenotomy

Patients with a massive cuff tear often have a degenerated, frayed and flattened biceps tendon. When this occurs, patient usually suffers from an intense anterior lateral pain and semiological tests for biceps tendinitis are often positive. Walch [1] observed that many patients with chronic rotator cuff tears had pain relief after spontaneous rupture of the biceps tendon. Therefore, he hypothesized that selected patients with irreparable cuff tears, or unwilling to undergo rehabilitation, may benefit from the long head biceps tendon tenotomy. He observed a significant improvement in mean Constant score from 49 to 68 after biceps tenotomy; furthermore, 87 % of patients were satisfied or very satisfied with their result.

Tenotomy may be carried out close to the insertion on the glenoid with a basket or with radio frequencies (Fig. 1a–c). Some colleagues prefer to perform the tenotomy where the tendon is flattened, so that with tendon retraction, the tenotomized biceps will remain “stuck” at the entrance of the bicipital groove. When it occurs, the decalage of the biceps muscle does not verify and Popeye sign continues to be negative. The proximal tendon stump must be regularized so that it does not interpose between the humerus and the glenoid during shoulder movements.

Bursectomy

The subacromial bursa contains algogenic substances and inflammatory cytokines; therefore, it is believed that bursa removal would decrease symptoms (Fig. 2). Unfortunately, in the subacromial space of shoulder with massive tear, especially if the lesion is not recent, bursa is scarcely represented; therefore, shoulder pain is only in part due to the inflamed bursa. Its removal only marginally affects shoulder pain.

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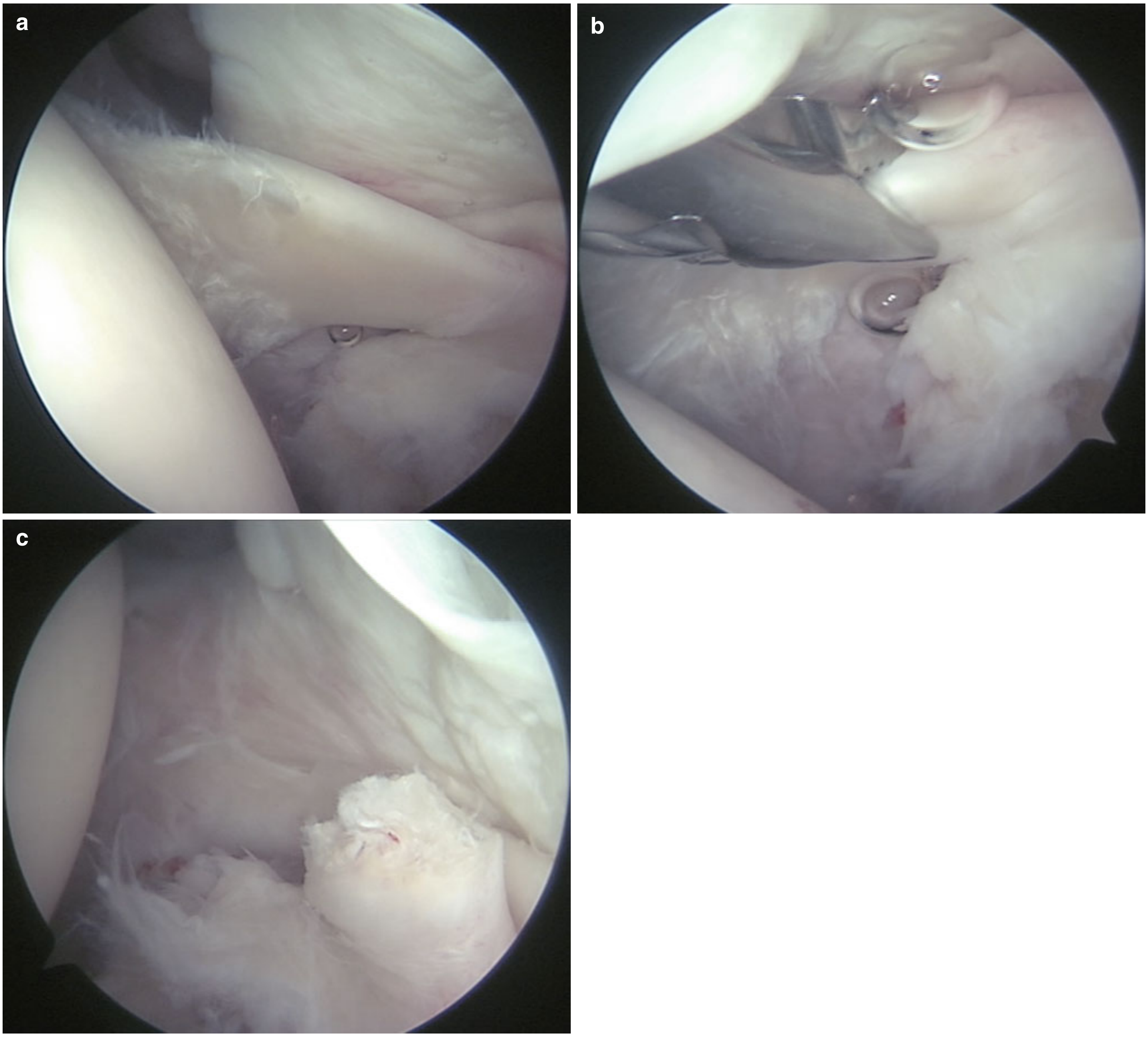

Fig. 1 Intra-articular view from the arthroscopic posterior portal. Long head biceps tendon is degenerated (**a**), so the tenotomy is performed with a basket (**b**). The procedure is completed (**c**)

Debridement of Tear Margins

The tear margins are represented by a chronic inflammatory infiltrate, consisting of synovial-like cells, lymphocytes, macrophages, plasmacytes and young fibrocytes. Dystrophic calcifications have occasionally been observed. Adjacent to the inflammatory infiltrate, the tendon appears hypocellular and disorganized, with micro-fragmentation of the normal collagenous architecture. Areas with myxoid or fatty degeneration were often observed [2]. Therefore, it is believed that removal of this tissue may determine pain decrease (Fig. 3a, b).

Acromioplasty

Acromioplasty is not a standard procedure of the arthroscopic debridement because inevitably it will cause the disruption of the coracoacromial ligament and an incentive for the upper ward migration of the humeral head.

Resection of the Distal Clavicle

Resection of the distal clavicle (arthroscopic Mumford) (Fig. 4a, b) is not routinely recommended.

Post-operatively, patients' shoulder is immobilized in a sling for 1 or 2 days; successively, they are allowed immediate active and passive mobilization as tolerated.

Advantages of this technique include: (a) a short operative time; (b) low risk of complications compared with the common cuff repair procedures; (c) uncomplicated rehabilitation protocol.

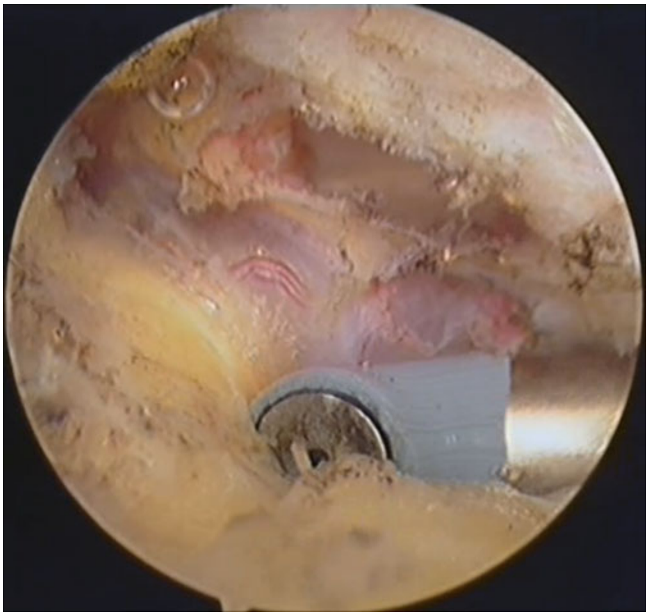

Fig. 2 Subacromial view of a right shoulder from the arthroscopic posterior portal. A massive cuff tear is associated to the presence of a great subacromial inflamed bursa. In this case, bursectomy is recommended

Patient has to be informed that the main purpose of this procedure is pain relief; shoulder function or strength could only scarcely increase.

In 1991, Burhart [3] attempted arthroscopic cuff debridement and acromioplasty in six patients with massive tear, following strict biomechanical, anatomic and preoperative patient selection guidelines. Five of the six patients had near-normal preoperative active motion, with one having adhesive capsulitis. Pain relief was 90–100 % in all cases. Wiley described superior humeral head migration as a complication of rotator cuff debridement and bursal decompression and concluded that debridement alone may lead to upward migration of the humeral head and an increase in disability [4]. Ogilvie-Harris and Demaziere [5], in 1993, observed that 22 % of patients had moderate loss of function at follow-up after cuff repair but that greater than 64 % had similar loss after arthroscopic debridement. In the same year, Ellman et al. [6] stated that arthroscopic subacromial decompression and debridement of rotator cuff tears has a valuable, but limited, role in selected patients. They noted that patients with irreparable tears did not regain strength or range of motion, but did have significant pain relief. The year after, Zvijac et al. [7] reported on the 3–6-year long-term follow-up of 25 patients treated with arthroscopic debridement associated to acromioplasty alone for full thickness repairs of the rotator cuff. They observed a trend of further deterioration of results with time. There was a significant decrease in rating

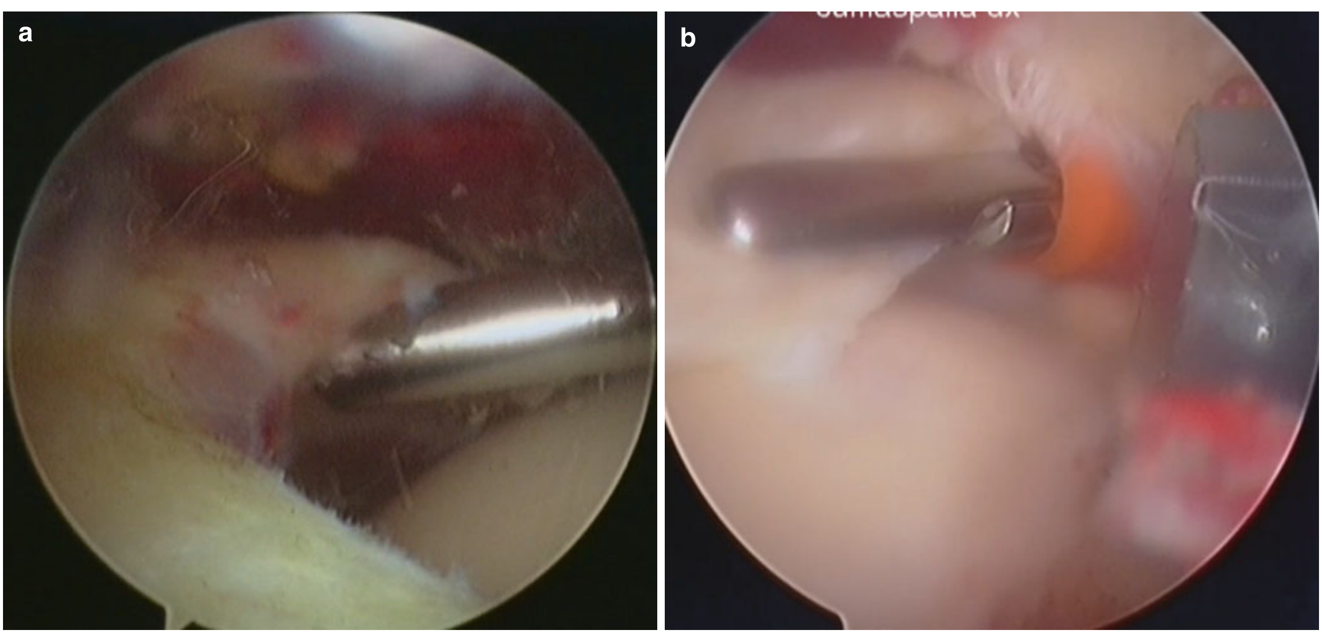

Fig. 3 Subacromial view of a right shoulder from the arthroscopic posterior portal. Debridement of a massive tear margins may be performed with a shaver (**a**) or a basket (**b**)

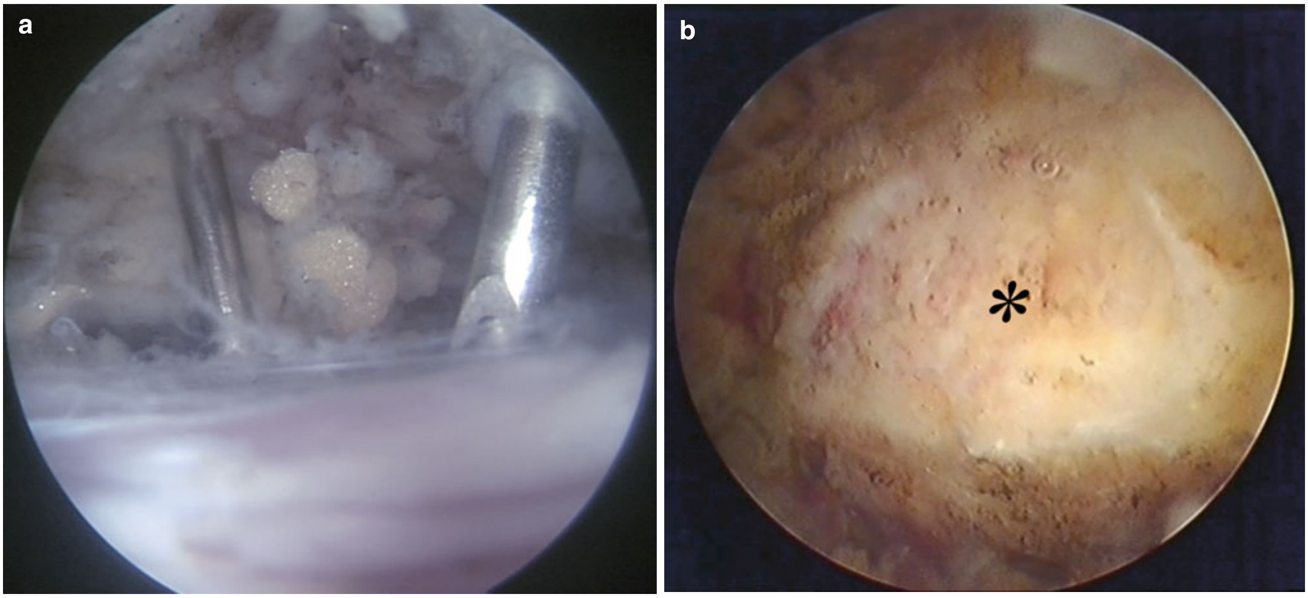

Fig. 4 Arthroscopic resection of the third lateral of the clavicle (Mumford procedure) of a right shoulder. Two landmark needle for the acromio clavicular joint are introduced (**a**); resection is completed (*) (**b**)

regarding shoulder pain and function compared with no deterioration with regard to motion and strength. Montgomery et al. [8] submitted 19 patients to arthroscopic debridement and concluded that this procedure, associated with subacromial decompression, was inferior to rotator cuff repair. Furthermore, five of the 19 patients went on to develop cuff tear arthropathy and were treated with hemiarthroplasty.

Rockwood et al. [9], in 1995, proposed the open debridement associated with acromioplasty. After surgery, 50 patients (53 shoulders) were followed (mean follow-up: 6.5 years); out of these, 83 % had satisfactory functional results, with a significant decrease in pain and an average increase of 35° of shoulder forward flexion. Two years later, Gartsman [10] reported similarly encouraging results with open debridement; however, the author a decrease in strength and suggested that this weakness might be due to the incompetent coracoacromial ligament and the loss of superior humeral head containment. The author further demonstrated that irreparable subscapularis or teres minor tendon tear, or both, and superior migration of the humeral head were negative prognostic factors for this procedure. In the same year of Gartsman's publication, Melillo et al. [11] observed that only 8 % of their patients who were submitted to debridement had had a satisfactory result. Twenty-three of the 25 patients who underwent debridement required additional surgery. Furthermore, in nine of the 25 patients, degenerative changes developed, compared within two of 27 patients submitted to cuff repair. In 1999, Kempf et al. [12] performed a multicentre study of 210 rotator cuff tears treated by arthroscopic acromioplasty. The preoperative Constant score was 38.2 points (41 % were supraspinatus tears, 40.2 % were supra- and infraspinatus tears, 10.5 % were three-tendon tears and 8.1 % were supraspinatus and subscapularis tears). Acromioplasty was associated to tear debridement in 183 cases (88 %) and to a tenotomy of the long head biceps tendon in 38 cases. Global objective results shown by the corrected Constant score reached 79.7 % and were satisfying in 73 % of cases. Preoperative shoulder stiffness, post-operative painful crises, worker compensation, a preoperative history longer than 4 years, and young age were considered as poor clinical factors; while osteoarthritis, a lesion of the acromioclavicular joint or of the biceps tendon were considered as poor anatomic factors.

Klinger et al. [13], in a nice paper published in 2005, said that arthroscopic debridement of massive and irreparable tears provides reliable expectation for improvement in function, decrease in pain and improvement in shoulder score for most patients. Additional tenotomy of the long head biceps tendon did not significantly influence the post-operative results at the latest follow-up.

In 2008, Liem et al. [14] retrospectively reviewed 31 patients after arthroscopic debridement of an irreparable rotator cuff tear (mean follow-up: 4 years). They observed that the mean ASES score significantly improved from 24 points preoperatively to 70 points at follow-up. Scores for pain were reduced from 8 to 3 points on a visual analog scale ranging from 0 to 10 points.

Barth et al. [15] compared the functional results of arthroscopic debridement with those obtained after partial repair. In their series, consisting of 42 patients, both groups had good or satisfactory results after rotator cuff surgery. Regardless of high rates of structural failures of partial rotator cuff repair, determined using ultrasonographic evaluation, the results of arthroscopic partial rotator cuff repair demonstrated slightly better functional outcome than debridement. A similar study was conducted in 2012 by Franceschi et al. [16]. Authors, after evaluating 68 patients, concluded that both techniques are effective in reducing patients' symptoms, with higher functional outcomes for partial repair. In particular, those who underwent debridement did not show any increase in strength, maintaining the same preoperative values.

Although a variety of studies have shown that this remains a viable option in the elderly and low-demand patient, it does not slow the progression of osteoarthritis [17]. However, satisfactory results are mostly likely to be achieved in elderly and low-demand patients for whom pain relief is the priority and in patients in whom the integrity of the deltoid is preserved and who have good external rotation strength preoperatively, indicating an intact posterior cuff.

Margin Convergence

In 2001, Burkhart [18] coined the idiom "margin convergence" to indicate side-to-side closure of massive, U-shaped cuff tears (Fig. 5). The author observed that most apparently irreparable ruptures are not retracted but are L-shaped tears with a vertical split from medial to lateral, which take on a U-shape because of the elasticity of the muscle-tendon unit. Burkhart added that attempts at mobilization of tear margins lead to failure of repair because of tension overload at the apex of the tear, whereas side-to-side repair determines a mechanical advantage because of a biomechanical principle called margin convergence. This technique requires that free margin of the tear converges towards the greater tuberosity as side-to-side repair progresses. As the margin converges, the strain at the free edge of the cuff is reduced significantly, leaving an almost tension-free converged cuff margin overlying the humeral bone bed for repair. Side-to-side repair of two-thirds of a U-shaped tear reduces the strain at the cuff margin to one-sixth of the strain that existed at the pre-converged cuff margin. This surgical approach furnishes a lower probability of failure of fixation to bone, either by anchor or transosseous repair. If a partial defect persists on the superior cuff after margin convergence, it can be repaired to bone using one or two anchors.

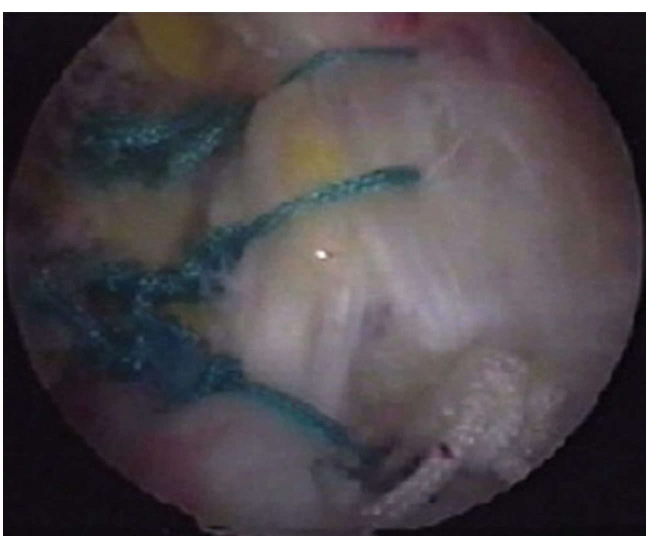

Fig. 5 Arthroscopic view of a right shoulder from the lateral portal. The margin convergence procedure of a massive, U-shaped cuff tear has been performed

Mazzocca and colleagues [19] believe that margin convergence decreases the size of the tear gap and reduces strain with minimal effect on glenohumeral translation and intrinsic tendon strain during knot tying.

Interval Slide

In non-mobile tears, an interval slide as described by Tauro [20] may allow an additional 1–2 cm of lateral excursion of a supraspinatus tendon and permit a greater degree of partial repair. The technique requires that the adhesions between the cuff and the superior capsule have to be released with an arthroscopic elevator. Successively, the mobility of the cuff is checked with a grasper inserted through the lateral portal. The interval slide is performed by introducing a basket punch through the lateral portal and through the rotator cuff tear. The capsular attachment to the supraspinatus tendon has to be released. The release is performed from lateral to medial until the articular surface of the glenoid until the tendon is completely detached from the rotator interval capsule (Fig. 6). Tauro suggests performing the release while viewing from the posterior intra-articular portal. In the cases where the biceps tendon is ruptured, the exact position of capsular division must be approximated at the anterior-superior corner of the glenoid. Usually, supraspinatus mobility is greatly improved after the interval slide. A side-to-side repair of the supraspinatus to the infraspinatus is an integral part of the repair. The tendon is then repaired back to the greater tuberosity using the suture anchor technique. If adequate mobilization cannot be achieved, a decision to proceed with debridement or partial repair has to be made.

Concerns regarding this technique include re-vascularization of the superior cuff and de-functioning of an already impaired muscle tendon unit from the interval slide [21].

The advantages of this technique are thought to be a more anatomical and reliable repair. However, studies comparing the results of partial repair with interval slide found no significant difference in outcomes [21, 22].

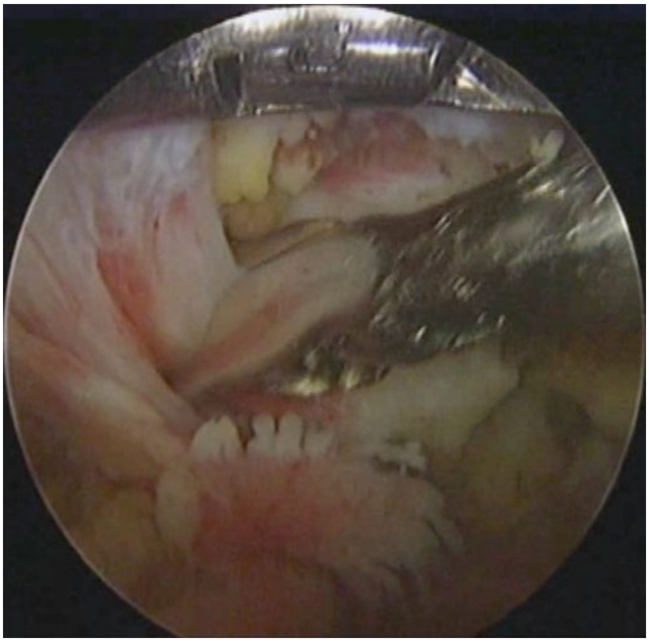

Fig. 6 Arthroscopic view of a right shoulder from the posterior portal. The interval slide procedure of a non-mobile tear is performed

Partial Repair

Burkhart et al. [23], in 1993, first introduced the biomechanical concept of the "suspension bridge" in the rotator cuff. This theory has led to the hypothesis of the functional rotator cuff and furnished a rationale for partial repair of the cuff tear. This procedure involves the restoration of the cables involved in force transmission as well as force couples around the shoulder. The rotator cables have been defined anatomically at the level of the biceps tendon above supraspinatus anteriorly and the lower border of infraspinatus posteriorly. The vast majority of the irreparable tears have an anterior and/or posterior extension that affects the transverse couples. The concept that the balance between the transverse couples (consisting of subscapularis and infraspinatus-teres minor complex) must be restored has been strongly stressed.

After removal of the subacromial bursa, which is often scarcely represented, the mobility of the residual cuff is tested by grasping the edges of the tendons with a clamp and trying to pull it laterally to the footprint. Repair has to include all of subscapularis as well as the inferior half of infraspinatus as a minimum. If this is possible, the transverse force couples and a stable fulcrum for physiologic shoulder kinematics are restored. The supraspinatus footprint may be flattened with a bur. Tenotomy of the biceps tendon and acromioplasty are usually performed before the partial repair.

Using this technique, Burkhart obtained an improvement in forward flexion (from 60° to 150°), strength (from 2.1 to 4.4 in a 0–5 scale). The UCLA score improved from 9.8 to 27.6. All but one of his series of 14 patients obtained satisfactory results. In their series, Duralde and Bair [24], in 2005, had similar results and a significant improvement of the ASES score. Of 24 patients, 11 (46 %) had excellent results; five (21 %) good; seven (29 %) fair and one (4 %) poor. Despite residual defects in the rotator cuff tendon that averaged 1 × 3 cm, patients with a partial repair demonstrated impressive improvements in strength and range of motion at a mean follow-up of 21 months (Burkhart e Duralde). Porcellini et al. [25] observed that the Constant score of their patients improved from 44 to 73 points and the Simple Shoulder Test from 4.6 to 9. The acromion humeral distance increased from 6.1 to 9.1 mm. They stated that "partial" functional repair of the infraspinatus, leaving the greater tuberosity uncovered, gives good results in terms of patient satisfaction and in restoring the acromion humeral distance. Furthermore, they added that complications were rare and in line with the usual sequelae of a rotator cuff repair.

Subacromial Biodegradable Spacer

The deployment of a balloon biodegradable spacer (OrthoSpace, Kfar Saba, Israel), implanted between the acromion and the humeral head, should reduce subacromial friction during shoulder abduction by lowering the head of the humerus and facilitating humeral gliding against the acromion during movement. A balloon implantation technique was previously described by Sartoretti et al. [26] for the ankle joint. The InSpace system contains an introducer and a preshaped spacer made of poly (L-lactide-co-ε-caprolactone), which is a copolymer of poly-lactide and ε-caprolactone, a biodegradable and widely used material that biodegrades over a period of 12 months [27, 28]. To enable insertion, the balloon is folded into a cylinder-shaped insertion tube, which is removed once the spacer is inserted into the subacromial space.

The device is contraindicated for patients with known allergy to device material or patients having active or latent infection or signs of tissue necrosis in the subacromial area.

As with any other implantable material, the expected risks after implantation may include foreign body response, local irritation at the wound site, local infection, inflammation, and tissue necrosis. Moreover, device displacement may occur and increase pain. All mentioned adverse effects are relatively rare and can be treated by routine medications such as antibiotics and/or injectable steroids. Alternatively, the implant can be punctured or removed by an arthroscopic procedure.

Debridement and/or bursectomy is performed to define the dimension of rotator cuff tear. The soft tissue over the glenoid rim and the rotator cuff muscle stump is cleaned in order to insert the spacer in an accurate position. The InSpace subacromial spacer is available in three different sizes: small (40 × 50 mm), medium (50 × 60 mm) and large (60 × 70 mm).

To select the appropriate spacer size, measurements are made with an arthroscopic probe with marked lines, where the medial point is defined 1 cm medial to the superior glenoid rim and the lateral point is the lateral border of the acromion. If there is doubt about the size of the spacer to be inserted, the larger spacer size is used to ensure proper positioning and to minimize the likelihood of implant displacement. The biodegradable spacer is introduced through the lateral port. The system should be placed approximately 1 cm over the glenoid rim and the rotator cuff tendon stump, inside the medial point. In some cases a stabilization and placement assistance with a probe through the anterior portals may be required. Once correct positioning of the spacer is achieved, the protective sheath is withdrawn to reveal the spacer. The extension tubing is connected to the distal side of the Luer-lock connector, and the spacer is inflated to its maximal volume depending on the spacer size. The valve should remain open to permit backflow of saline solution into the syringe until the recommended volume is achieved that allows a full range of motion of the shoulder [29]. It is important to maintain the recommended volume because spacer overinflation may result in excessive tension in the deltoid muscle with pain, as well as an increased likelihood of device displacement over time. The spacer is sealed and secured in situ by firmly grasping the deployer and withdrawing the connecting syringe. Successively, the delivery system is removed, and the shoulder is passively moved through a full range of movement to verify that the spacer is accurately placed, is stable and does not interfere with shoulder function (Fig. 7a–e).

Senekovic et al. [30] implanted the subacromial spacer in 20 cases. The mean Constant score increased from 33 to 65 points at 3 years. There was an improvement of 6.5 points in subjective pain score. Also, activities of daily living and motion commenced improvement by 9.4 and 7.7 points, respectively.

The spacer degrades within 12 months, which is a period that conforms well to the rehabilitation time frame after any arthroscopic procedure performed on the rotator cuff. It is unclear, however, how long the spacer remains inflated, and it is not understood why pain and functional scores continue to improve beyond the period of spacer disintegration.

Tuberoplasty

In 2002, Fenlin et al. [31] introduced a new surgical open procedure for the treatment of massive irreparable rotator cuff tears. This procedure, described as tuberoplasty, consists in removing the exuberant lateral margin of the greater tuberosity, until you get to cancellous bone, to create a smooth congruent acromiohumeral articulation. The technique does not require the removal of the coracoacromial ligament nor acromioplasty. Nowadays, the removal of the exuberant bone is arthroscopically carried out with a bur (Fig. 8a–c). What remains of the greater tuberosity should have a curved shape that well fits with the lateral curvature of the acromion. The investigators reported on 20 patients (average age 63 years; range 44–82) with a minimum of 27 months follow-up (7–58 months), all of whom had disabling shoulder pain before tuberoplasty. The acromion and coracoacromial ligament were left intact. There were 12 excellent results, six good and one fair (UCLA score from 9.3 to 27.7 with 95 % satisfactory results). Sixty-eight percent of patients were totally pain-free and no patient had night pain post-operatively. In this series, all cases had residual external rotation weakness.

Scheibel et al. [32] presented an arthroscopic approach to this procedure 2 years later described as reversed arthroscopic subacromial decompression. Authors studied 23 patients with an average age of 69 years (range 60–81) at a mean follow-up of 40 months (range 20–58). The mean weighted Constant score improved from 65.9 to 90.6 %, with significant improvements in pain, activities of daily living and range of motion. A progression of osteoarthritis was observed, although it did not interfere with clinical result. Successively, Verhelst et al. [33] and Lee et al. [34] performed an arthroscopic tuberoplasty on 33 (with acromioplasty) (average age 70 years; FU: 38 months) and 32 patients (without acromioplasty) (average age 62; FU: 40 months), respectively. Both studies showed a significant improvement in range of motion and decrease in pain following surgery with 84 and 81 % patients reporting excellent or good results. No significant differences were observed in the improvement related to gender, age and preoperative range of motion. These studies concluded that tuberoplasty has to be considered an excellent treatment option in patients with irreparable tears.

Suprascapular Nerve in Association with Irreparable Tears

Recently, there has been a great interest in the suprascapular nerve course and on the potential effect on the nerve successively to the muscular-tendon unit retraction, such as that which occurs during a massive, chronic and irreparable cuff tear.

It is possible that the resorption of the lateral margin of the tear, the reduced elasticity of the muscle consequent to the fatty infiltration, and the possible adhesions related to the scar tissue, can cause damage on the suprascapular nerve when the tear margins are laterally tractioned in an attempt to repair the lesion. It was shown that the maximum lateral advancement of the cuff that is permitted by the neurovascular structures is 3 cm [35], which is less than what is usually required for repair of massive tears of the rotator cuff.

The suprascapular nerve (SSN) originates from the upper trunk of the brachial plexus (C5 and C6). It inner-

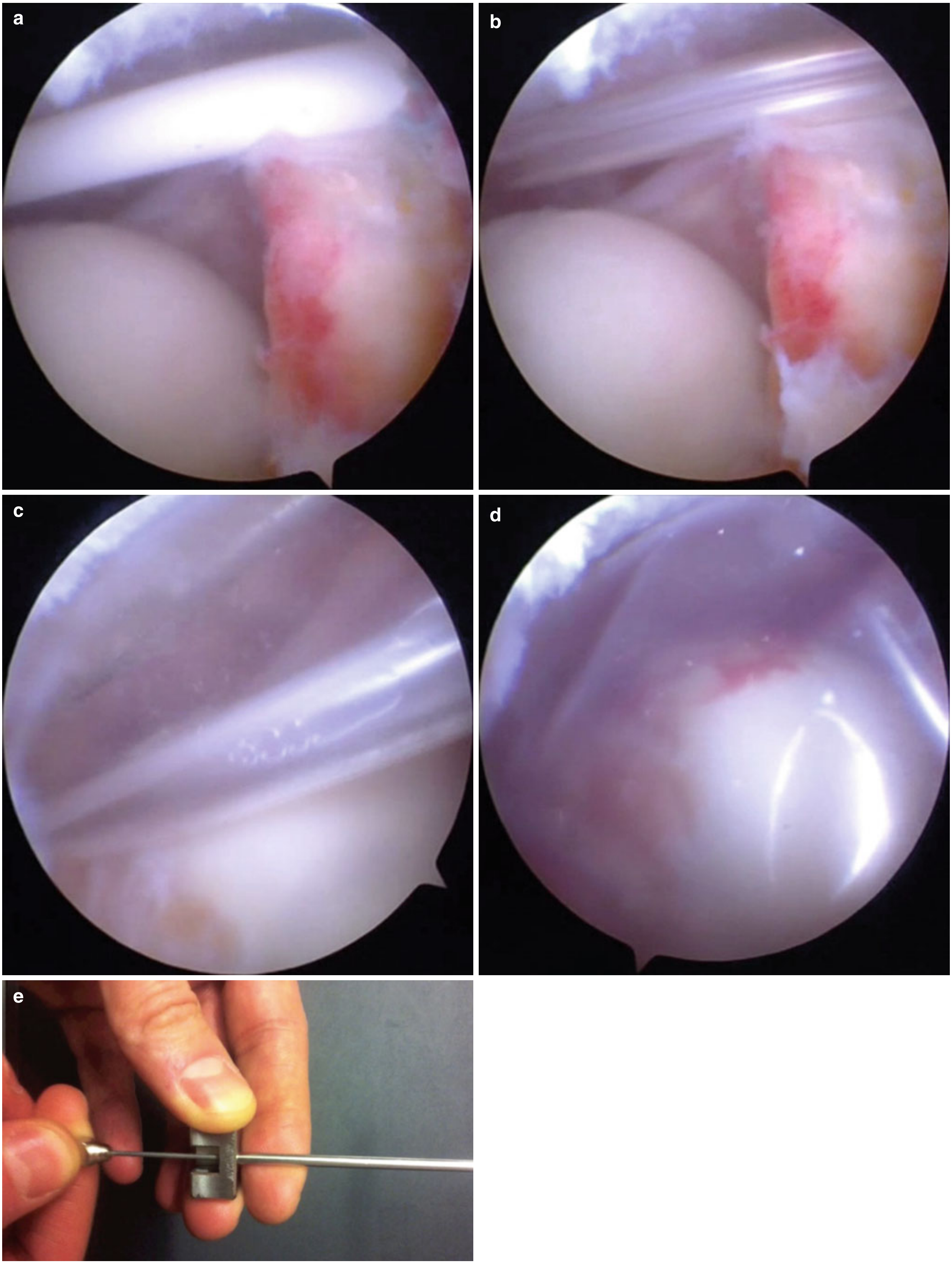

Fig. 7 Arthroscopic procedure for the "InSpace subacromial spacer" introduction. The biodegradable spacer is introduced from the lateral portal (**a**) and, when correctly positioned (**b**), is partially inflated (**c**). When completely inflated (**d**), it is sealed and secured in situ by firmly grasping the deployer and withdrawing the connecting syringe (**e**)

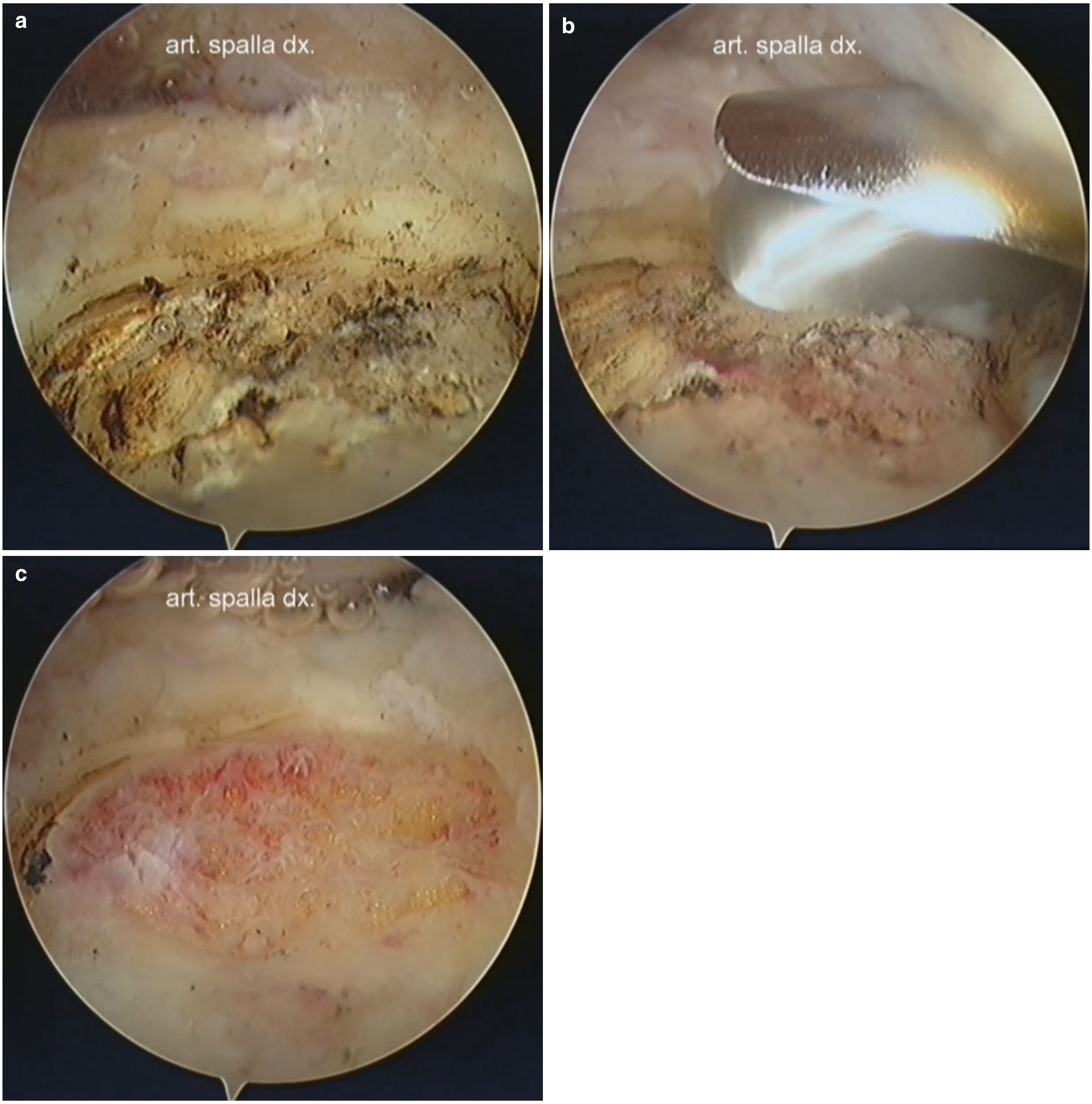

Fig. 8 Arthroscopic tuberoplasty of a right shoulder. At first, the area of the greater tuberosity is prepared (**a**), then tuberoplasty is performed with a shaver (**b**). The procedure is completed (**c**)

vates supraspinatus and infraspinatus and supplies sensory fibres to the coracoacromial and coracohumeral ligaments, the subacromial bursa, and the glenohumeral and acromioclavicular joints [36]. After branching from the plexus, the nerve goes inferiorly in the posterior triangle of the neck, deep to the trapezius muscle, and then through the suprascapular notch medial to the base of the coracoid. The nerve divides into a large branch that traverses the supraspinatus fossa beneath the supraspinatus muscle, through the spinoglenoid notch to supply infraspinatus, and one or more smaller branches that traverse a short distance and enter the muscle belly of supraspinatus directly. At its superior margin, the notch is covered by the short, thick transverse scapular ligament. The suprascapular artery and vein pass into the supraspinatus fossa directly above the ligament.

MRI is the preferred modality to evaluate atrophy of the cuff muscles as well as assess potential causes of suprascapular nerve compression. Electromyography and nerve conduction velocity studies remain the gold standard for formulation of the diagnosis of suprascapular neuropathy; however, nerve pain may occur even in the setting of a negative electromyography [37]. Initially, the treatment is usually non-operative [38], consisting of shoulder rest, physical therapy, and anti-inflammatory drugs. Surgical treatment is considered for patients with nerve compression by an external source or for symptoms refractory to conservative measures. Retraction of a detached supraspinatus muscle and tendon causes traction on the nerve within the supraspinatus notch, where it lies beneath the transverse scapular ligament [39]. Compression of the nerve at the spinoglenoid notch is less common and is seen in association with spinoglenoid cysts from labral pathology. However, a ganglion cyst is not necessary to produce SSN compression at the spinoglenoid notch.

A matter of debate exists about whether incision of the transverse ligament is necessary once stretch and traction on the nerve have been relieved by repairing the cuff.

The SSN can be visualized and released posteriorly [40, 41] or anteriorly [42] to the coracoclavicular ligaments. Posterior visualization is achieved by inserting the arthroscope and instruments through the subacromial space and dissecting medially along the anterior border of the supraspinatus muscle. Anterior visualization is through medial and inferior portals, and the notch is viewed on the medial side of the base of the coracoid process.

Lafosse et al. [41] observed that for a standard suprascapular nerve release, the nerve can be easily visualized through the subacromial space as it exits the suprascapular notch posteriorly and descends into the supraspinatus fossa, beneath the muscle belly of supraspinatus. To observe the nerve here, the medial subacromial bursa is opened at the anterior border of the supraspinatus muscle. With the arthroscope and shaver inserted through lateral and anterolateral portals, the muscle is used as a guide and followed medially. The shaver is used to open the bursa and remove loose connective tissue as the dissection progresses medially to the base of the coracoclavicular ligaments. Lafosse [41] protects the nerve from the shaver by the superior transverse scapular ligament; however, the suprascapular artery (transverse scapular artery) passes from anterior to posterior over the ligament, so debridement should stop once the dissection has reached the region posterior to the coracoclavicular ligaments. The authors suggest creating a new portal (G portal) on the same line of the coracoid, but just posteriorly to the lateral aspect of the clavicle. It is created under direct vision, using a needle to identify the exact location of the portal. Triangulation of the tip of the needle and view from the arthroscope is assisted if you ensure that the 30° scope is looking directly inferior. The needle is then introduced in line with the arthroscope, directly over the ligament at the anterior border of the supraspinatus muscle. The shaver is left in position and released from the surgeon's hand. The weight of the shaver acts as a retractor on the trapezius muscle to improve visualization in the area.

A blunt trocar is then introduced through the G portal and used to dissect the remaining connective tissue in line with transverse ligament, from the coracoclavicular ligaments posteromedially. The suprascapular artery and two accompanying veins lie on top of the ligament and are gently displaced medially with the trocar. Occasionally, an aberrant branch of the artery is found beneath the transverse ligament and is protected along with the nerve when cutting the ligament. The SSN supplies the supraspinatus muscle through a very short branch that exits the notch and enters the muscle belly directly behind the notch. Dissection with the blunt trocar is performed very gently and without excessive distraction of the muscle belly to avoid avulsing the nerve from the muscle belly.

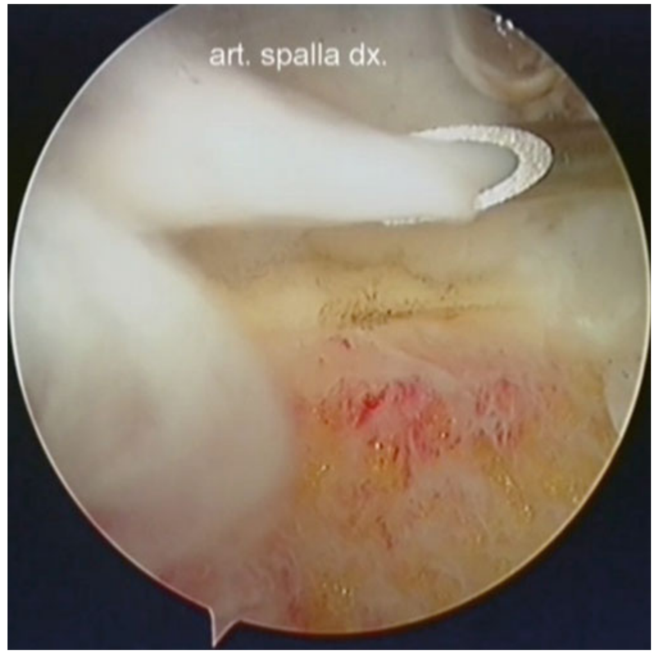

Fig. 9 Arthroscopic intra-articular steroid infiltration of a right shoulder

The ligament can be divided with arthroscopic scissors introduced through a second stab incision adjacent to the G portal. Once the ligament is removed, the nerve can be visualized in the notch.

Intra-articular Steroid Infiltration

At the end of the procedure, an intra-articular steroid infiltration may be performed with the aim of removing the residual inflammatory process (Fig. 9). It will also reduce postoperative pain.

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Failure of Arthroscopic Rotator Cuff Repair

Stefano Gumina

Shoulder arthroscopy presents increased risk of complications over knee arthroscopy in regard to vascular and neurologic injury, fluid extravasation, stiffness, iatrogenic tendon injury and equipment failure [1].

In 2012, Randelli et al. [2] performed a superb literature review investigating patients with rotator cuff tears, managed by a completely arthroscopic repair technique; complications were meticulously reported. These were classified into general and specific complications. Of the 2,890 studied patients, 414 had had a complication. Re-rupture was the most frequently encountered complication (Fig. 1a, b). Stiffness and hardware-related complications were observed in 74 and 12 patients, respectively. Eleven less common complications were also reported: five neurovascular, three septic, two thromboembolic events and one anaesthesiological complication.

In the series of Brislin et al. [3], published in 2007, the most common complication was recognized as persistent stiffness; failure of healing, infection, reflex sympathetic dystrophy, deep venous thrombosis and death were considered as less frequent complications.

The failure rate, reported in the literature, after rotator cuff repair varies from 13 % [4] to 94 % [5]. These figures are important because they highlight the problem, but raise questions about their actual value because they are strongly affected by: (a) number of examined patients, (b) original size of the lesion, (c) patient age, (d) fatty degeneration of their muscles, (e) acromio-humeral distance, (f) patient habits, (g) gleno-humeral arthritis [6–10].

In 2011, Chung et al. [11] stated that bone mineral density, as well as fatty infiltration of the infraspinatus and amount of retraction, was an independent determining factor affecting post-operative rotator cuff healing.

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In the past, many patients underwent surgical cuff repair although they had important predisposing factors to tear and consequently to re-tear (advanced age, diabetes, hypercholesterolemia, metabolic syndrome, smoking and alcohol habit). For these patients, failure is almost the rule. Therefore, error does not consist in the used surgical technique for repair, but in the indication for surgery.

In 2013, Iannotti et al. [12] observed that re-tears primarily occur between 6 and 26 weeks after arthroscopic rotator cuff repair, and few additional tears occur thereafter. A substantial number of re-tears occur between 12 and 26 weeks after repair. Two years before, Miller et al. [13] had reached the same conclusions, although they had examined a lesser number of patients.

At the beginning of the learning curve, the re-tear can be the consequence of a wrong repair technique: (a) incorrect repair construct/procedure, (b) not tensioned knot, (c) incorrect number of used anchors, (d) reduced distance between two anchors resulting in the possibility to create a single large hole in the greater tuberosity that reduces the tightness of both anchors.

An incorrect positioning of the anchor may be the cause of subsequent failure. The angle of incidence to the bone is crucial. Anchors are ideally placed with a deadman angle, as described by Burkhart [14, 15], of less than 45°. If the insertion angle is too vertical, it will enter the softer bone of the greater tuberosity rather than the dense subchondral bone of the humeral head, increasing the risk of anchor pull-out (Fig. 2a–c). Instead, if the insertion angle is too horizontal (Fig. 3a–d) there is the possibility that the anchor protrudes from the articular surface and the suture is significantly weak. Benson et al. [16] believe that there is a minimal risk of suture anchor pull-out in small- to medium-sized tears; however, this risk increases with larger tear sizes. According to Kirchhoff et al. [17], placement of suture anchors in a medialized way at the border to the articular surface might guarantee a better structural bone stock.

Many patients over 60 years of age have dystrophic changes or pseudo-tumours in subcortical bone of the greater

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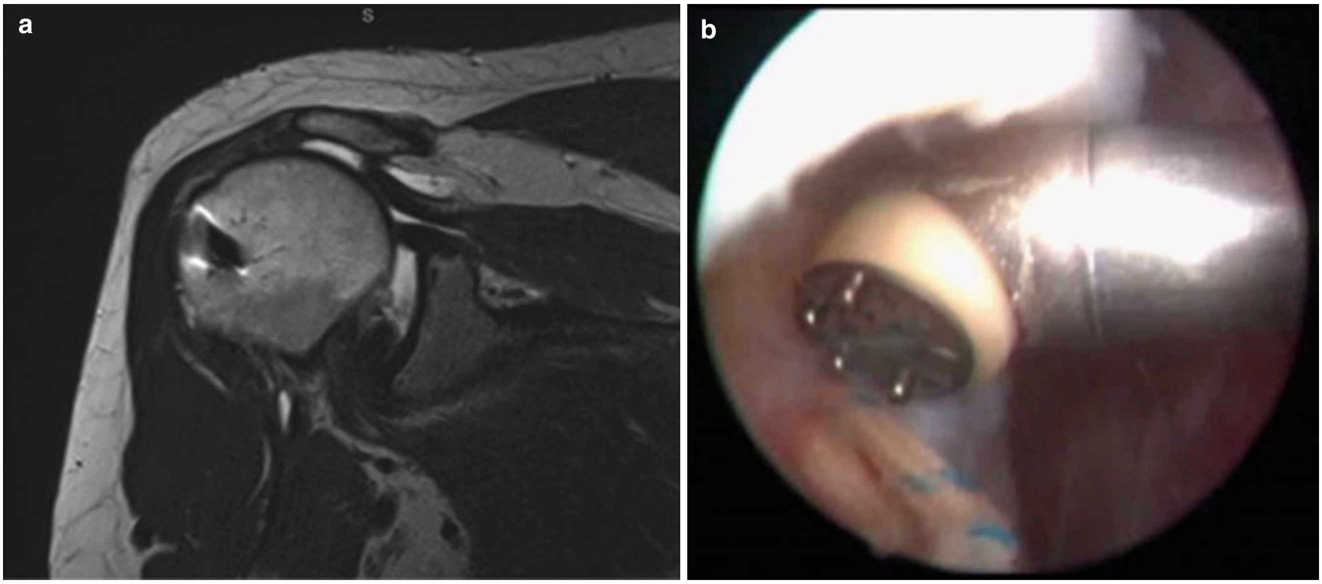

Fig. 1 Right shoulder of a 67-year-old gentleman. MRI scan (**a**) and arthroscopic view (from the posterior portal) (**b**) showing a rotator cuff repair failure

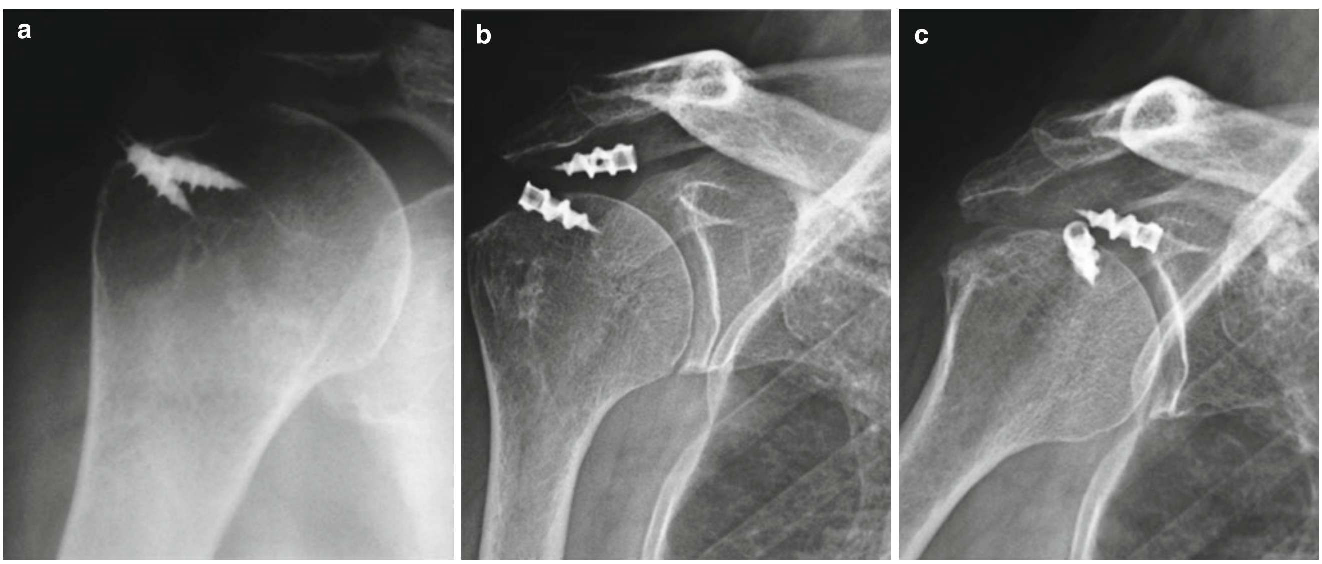

Fig. 2 Radiograms (AP views) of two patients with a cuff re-tear. In both cases, anchor pull-out strengths partially (**a**) or totally (**b**, **c**) failed

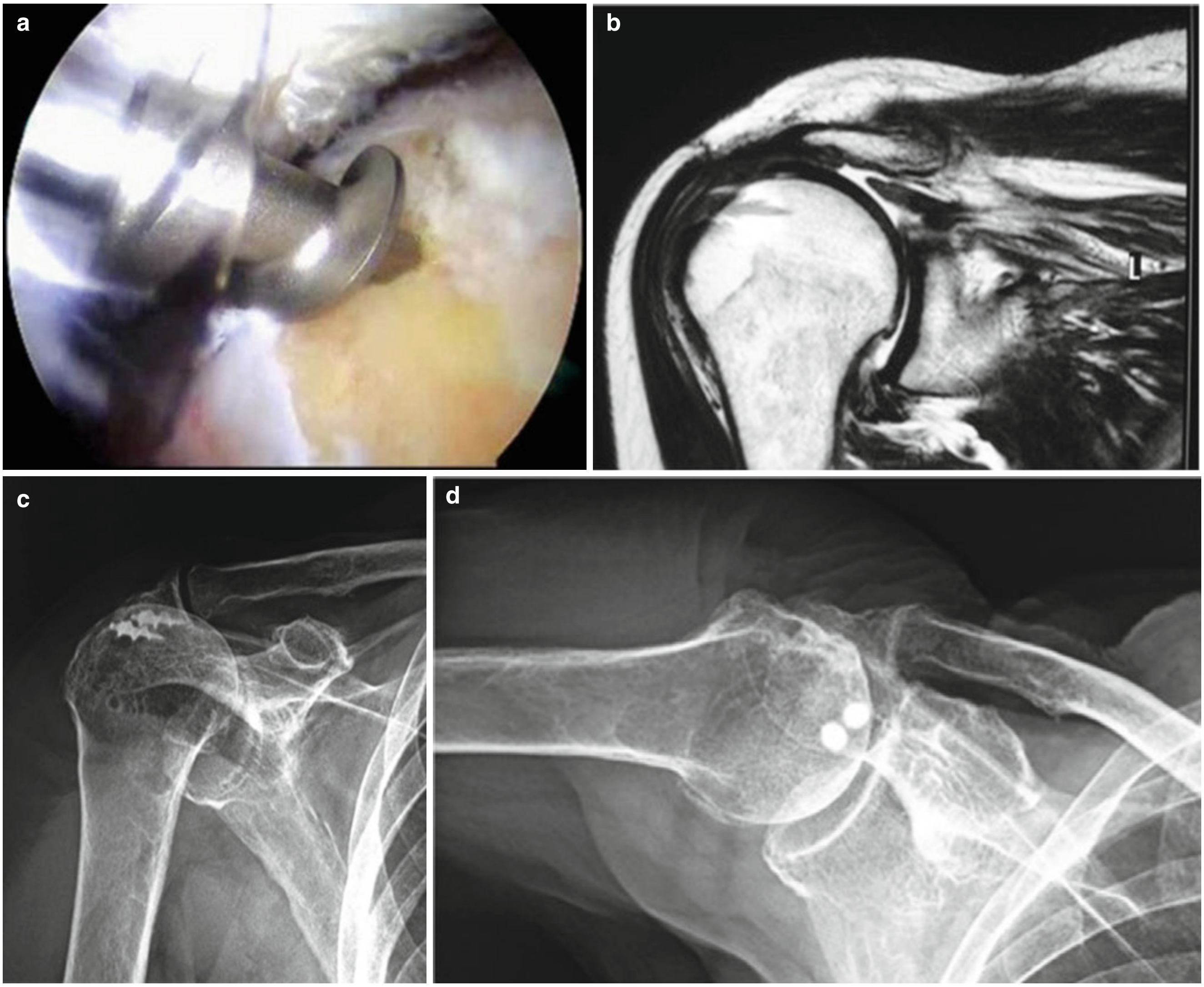

Fig. 3 Anchors horizontally inserted (**a**) might predispose to cuff re-tears. MR scan (**b**) and radiograms (**c**, **d**), relative to a patient with a cuff repair failure

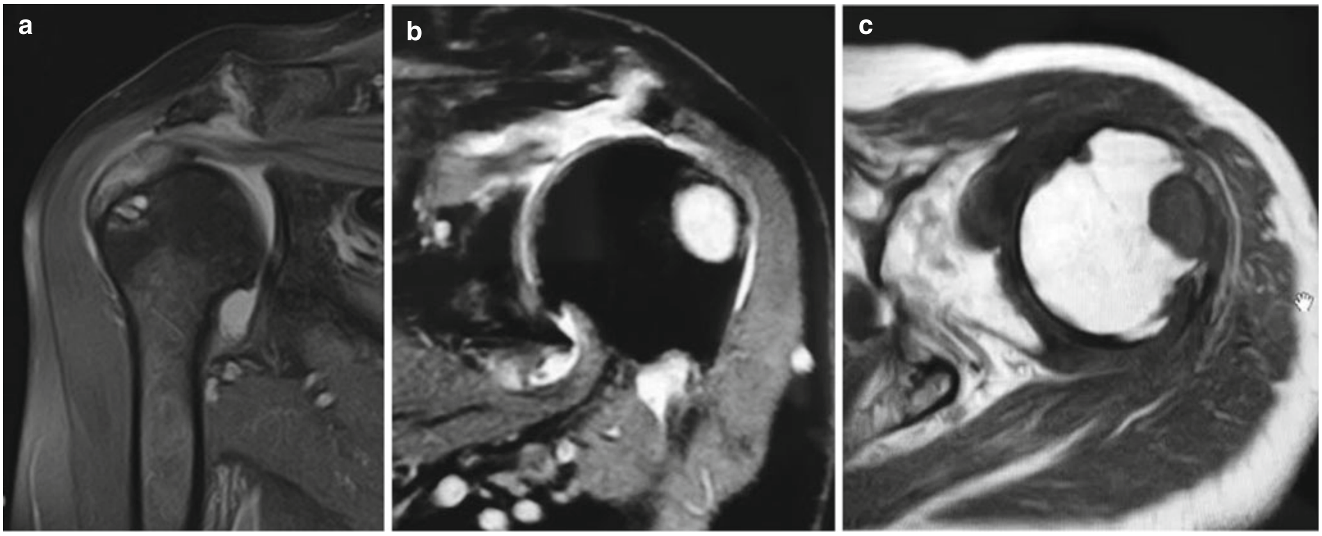

Fig. 4 Dystrophic changes (**a**) or pseudo-tumours (**b**, **c**) in subcortical bone of the greater tuberosity reduce the anchor pull-out strengths

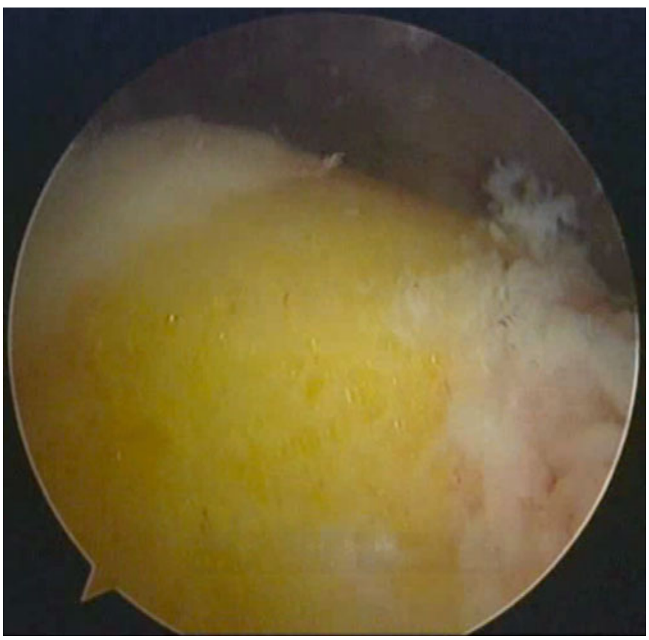

Fig. 5 Medialization of the footprint may reduce tension of the repaired cuff. Arthroscopic view (from the posterior portal) of a foot print created removing 3 mm of the articular cartilage

tuberosity (Fig. 4a–c). Obviously, in this area the holding capacity of the infixed anchor is decreased and the possibility of a pull-out in the intra-operative or in the immediate post-operative period is high.

In case of markedly degenerated tendon tissue, the suture thread used for the repair could cut the tendon itself. Therefore, it would be appropriate to pass the thread medially to the tendon edges in order to avoid the likely failure of the repair, or to perform more complex types of sutures, like the Mason-Allen type, so that the traction is exerted on the handle side of the suture and not directly on the degenerated tendon.

Massive lesions repair sutured in excessive tightness have a high risk to undergo failure. Also in this case, sutures might cut the degenerated tissue. It is advisable to perform an additional debridement in order to eliminate any remaining adhesions between cuff tendons, subacromial bursa and acromion. Moreover, the possibility of performing a single or a double interval slide to further mobilize the tissue should be considered.

The removing of 3 mm of lateral articular cartilage and therefore the medialization of the footprint is another option to consider (Fig. 5).

When the tear involves a single tendon, the quality of the neighbouring apparently healthy tissue should be checked. The check should be done especially on the articular side of the cuff tendon. In the case of partial lesion, near to the full-thickness one, I extend the repair even to the partial tear (arthroscopic tear completion and repair). Once the lesion is localized, the tear is completed utilizing a shaver. The tear edges are freshened.

Recently, the number of surgeons who systematically perform acromioplasty during a rotator cuff repair is significantly reduced. It is because the results after small or large tear repairs performed with or without acromioplasty are similar. Therefore, if acromioplasty is not routinely performed, it is important to check in the preoperative period or during surgery, the acromio-humeral distance. In fact, risk of leaving type III acromion or acromio-clavicular spurs (consequent to AC joint degenerative changes) that may lead to a damage of the performed sutures and then to a re-tear is high.

A risk category for re-tears is also represented by elderly patients with acquired dorsal kyphosis (by multiple fractures of the vertebral bodies). In fact, the kyphosis causes a more

Fig. 6 A 64-year-old lady with a partial deltoid detachment in proximity of the lateral portal previously used for repairing a rotator cuff tear of the right shoulder. Unfortunately, she underwent cuff repair failure. Deltoid detachment might compromise the clinical result after a further cuff repair

horizontal position of the scapula on the chest resulting in an acromial ante-tilting. In this case the acromio-humeral distance decreases and tends to decrease with the worsening of the kyphosis.

Revision rotator cuff repair is made technically more difficult by poor tissue quality, tissue adhesions, and retained suture and suture anchor material. Historically, open revision rotator cuff repair yields inferior results compared with primary rotator cuff repair; however, more recent studies show 52–69 % satisfactory results in small-sized or medium-sized tears. Arthroscopic revision rotator cuff repair yields greater than 60 % good or excellent results [18]. Ideal candidates for revision rotator cuff repair have minimal muscle atrophy, minimal tendon retracted, preoperative forward elevation of greater than 90°, a functioning deltoid (Fig. 6) and no evidence of cuff tear arthropathy.

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Augmentation with Patches

Alessandro Castagna, Marco Conti, Eugenio Cesari, and Raffaele Garofalo

Introduction

There is an increasing demand for repair of rotator cuff tears. However, despite many improvements in repair techniques and materials such as high-strength sutures and strong anchors, and despite our understanding of the factors affecting surgical outcomes, the rates of failure of cuff repairs ranges from 11 to 94 % depending on the size of the tear, level of tendon degeneration, fatty infiltration, the age of patient, delamination and retraction of tendon, and the chronicity of tear [20, 33]. Failure has been considered as retear, but in many of these cases, it can be the effect of missed healing of tendon. Revision procedures repeatedly demonstrate the site of failure at tendon suture interface and despite modifications of suture configuration and orientation, and modification of surgical technique to reduce the tensioning of rotator cuff during repair (such as placing the anchors along the articular margin), the tendon suture interface failure remains a significant problem [9]. Historically, it was thought that good clinical outcomes could be achieved despite the persistence of a rotator cuff defect. However, clinical studies show that patients with failed repairs have inferior clinical outcomes compared with those with intact repairs [6]. In order to overcome the limitations of traditional direct reparative surgery, techniques of regenerative medicine have been under investigation in recent years. The aim is to enhance and stimulate the formation of a tendon tissue with histological and mechanical properties resembling those of the native tendon. Considering an appropriate biologic treatment to improve the healing for rotator cuff repair and then the shoulder function, it is very important to understand the etiology of rotator cuff tear and process of healing. When we look at the biology of the rotator cuff healing, there are two main critical points in the repair process: the quality of tendon tissue itself, and the reestablishment of the tendon to bone junction.

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Patches

Mechanical augmentation of a rotator cuff repair is emerging as an important tool in the treatment of large and chronic degenerative tears. The patches used for rotator cuff could be synthetic or biologic.

Synthetic Patch for Rotator Cuff Repair

The rationale for the use of synthetic patches is related to the concept that they could give a mechanical strength to stabilize the repair construct until host tissue healing can occur. Different synthetic patches could be used in case of rotator cuff repair including polyurethaneurea or Poly-L-Lactide or polycarbonate. Synthetic patches generally are very strong, easy to handle, and cut and shape to soft tissue. For synthetic scaffolds, the sequence of host response commences with an acute inflammatory reaction, followed by chronic inflammation, and if the biomaterial is nondegradable, granulation tissue and fibrous capsule formation. The duration and intensity of the host response are determined by its biomaterial composition and morphology [23]. A study on animal showed that rotator cuff repair augmented with woven poly-L lactide device increased cross-sectional area of cuff repair [11]; however, in this study fibrous tissue ingrowth and an occasional presence of macrophages and foreign body giant cells were observed. Ozaki et al. [28] were the first to report the use of polyester as well as Teflon (polytetrafluoroethylene) grafts in the repair of massive rotator cuff tear showing good tolerance and improved functionality in 23 out of 25 patients. Another clinical study on ten patients in whom a polycarbonate polyurethane patch was used, revealed a 10 % of retear at

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1 year of follow-up. The patch was well tolerated and no reactions were reported [13]. Additionally, Hirooka et al. [16] and Audenaert et al. [2], both reported good clinical outcomes using synthetic scaffolds in large retears. A more recent study on the use of polypropylene patch augmentation showed at 3 years of follow-up a significant improvement in terms of strength, function, and retear with respect to only rotator cuff repair or repair and biologic augmentation [10]. However, concern associated with implantation of nondegradable materials still remains. Another concern is the occurrence of infections, which often require a revision operation to remove the implant [25]. Furthermore, the loss of integrity in the long term is another possible complication of synthetic patches.

Biologic Patches for Rotator Cuff Repair

Different biologic patches such as autograft biceps tendon, fascia lata [26, 5] and allograft freeze-dried rotator cuff [27], or patellar tendon [24] have been used in the past with mixed results. Recently, biological matrices have been developed to improve rotator cuff repair. Commonly, the most common method to biologically enhance the healing of rotator cuff repair is the use of extracellular matrices (ECMs). An ECM is a complex structure comprised of structural proteins (collagen), specialized proteins (fibrillin, fibronectin), and various proteoglycans. The rationale is to use these different ECMs as patches to reinforce soft tissue repair during rotator cuff surgery. On the other hand, the final elegant idea is that these ECMs resembling the native structure of human body can function as scaffolds and provide a conducive chemical and structural environment for repair healing and remodeling. Scaffolds, in fact, can provide a geometrical space for construction and act as a tissue bridge between tendon and bone.

Requirements for scaffolding include biocompatibility, hemocompatability, and the use of nontoxic materials that are durable, functional, and able to support cell growth. Since ECM scaffolds are retrieved from different species and tissues, there is concern about the in vivo host response. The removal of cells and cellular remnants from the ECM is thought to be crucial for a favorable host response.

In this sense, rotator cuff ECMs patches have been engineered to contain purified collagen, primarily type I, as scaffold from a variety of human (Allograft) or animal (Xenograft) sources. Some concerns with the use of processed human and animal collagen, about infection (viral) transmission and inflammatory reaction still exist; however, the problem of graft rejection has been minimized using acellular material. At this moment, however, there are no xenograft-associated disease-transmission issues for ECMs.

An ideal rotator cuff scaffold should have the following features:

1. A negligible risk of disease transfer or rejection
2. Minimal inflammatory response
3. Robust initial strength, mechanical properties sufficient to provide reinforcement of repair
4. Support biological incorporation and remodeling of the matrix itself into host tissue during the healing process
5. Moderate elastic nature-stress shielding
6. Favorable handling characteristics
7. Not very expensive
8. Rapidly repopulated and appropriate host cells
9. Rapidly available as a freeze-dried graft
10. Suitable to arthroscopic insertion

With any implanted allograft or xenograft tissue, there is concern regarding inflammatory reaction, tissue reorganization, and safety. All the ECMs scaffolds, in fact, are associated with host cellular immune response and the amount of acceptable inflammation after ECM implant is unknown. The process of chemical (usually glutaraldehyde or paracetic acid) cross-linking seems to have an important role in the antigenicity and soft tissue reaction. In fact, a chemical cross-linking diminishing the surface recognition of epitopes and other cell burden, and the subsequent graft degradation by the host environment, allows the tissue to be somewhat immunoprivileged [4]. Differently, ECM scaffolds that have not been cross-linked underwent a more rapid tissue degradation secondary to a very important host immune response. However, the chemistry of a given scaffold material also influences the rate and degree of degradation and remodeling. In fact, scaffolds derived from non-cross-linked small intestine submucosa (SIS) are rapidly remodeled and replaced by new host tissue, whereas scaffolds derived from dermis appear to undergo slower remodeling and may be incorporated by the host to some extent rather than completely replaced.

Allograft

Acellular Non-cross-linked Human Dermal Matrix

The acellular non-cross-linked human dermal matrix (GJA, *GRAFJACKET* Matrix, Wright Medical Technology, Inc, Arlington, TN) is a decellularized and freeze-dried human dermal tissue, processed using a patented technique to remove epidermidis and to maintain an intact collagen structure while avoiding intentional artificial cross-linking. Collagen types I, III, IV, and VII, are retained. Beyond the collagen, this ECM contains elastin and proteoglycan. It requires rehydration prior to use. The material is a single layer and is provided in a variety of thickness (0.5–2 mm) and size for different surgical indications. The GJA has been well studied in terms of rotator cuff repair augmentation. Fini et al. [14] compared the effect of tenocytes on SIS and

GJA and demonstrated that the GJA was able to support ECM synthesis better by maintaining higher level of TGF-ß1, matrix proliferation, and lower inflammatory cell counts compared with SIS. Adams et al. [1] studied the use of GJA in a canine model for full-thickness infraspinatus tear. He noted at 6 weeks, chronic inflammation consistent with surgery and repair. By 6 months, the tendon-bone interface contained Sharpey's fibers, and a robust, remodeled tendon-like structure that contained elastin was present. Ide et al. [18] found that rotator cuff tears repaired with GJA augmentation had higher tendon maturing scores than an untreated control defect group. Bond et al. [7] reported the preliminary results on 16 patients with massive rotator cuff tears treated arthroscopically with GJA augmentation. At a mean follow-up of 26.8 months, 13 patients had full incorporation of the graft into native tissue as documented on 1 year MRI.

Dopirak et al. [12] reported on the use of GJA as an interpositional graft in 16 patients with massive, contracted, immobile rotator cuff tears. At more than 2 years after treatment, the 75 % of patients were satisfied with their result. MRIs at 3 and 12 months indicated three failures, two occurring in the first 3 months. There were no reported complications. Burkhead evaluated 17 patients treated with the GJA graft augmentation in massive rotator cuff tears greater than 5 cm in size and involving 2, 3, or 4 tendons. After an average of 1.2 years, three smaller recurrent tears were noted from 11 postoperative MRIs and a computed tomography arthrogram. Overall, 14 of the 17 patients were satisfied with their results [8].

Xenograft

Small Intestine Submucosa (SIS)

SIS is derived from the tunica submucosa of porcine jejunum and constitutes an acellular, collagen-based, resorbable biomaterial. The heterogenic nature of SIS is due to the different areas of intestinal graft harvest, and this factor limits the graft homogenicity. Some studies have shown that not all SIS harvest sites were the same and in consequence also the biomechanical properties are different. For example, distal samples of intestine are more elastic and less permeable than proximal samples. Schlegel [30] performed full-width infraspinatus injury and repair in sheep. They placed a patch of SIS over the superficial aspect of the repaired tissue. The control was tendon repair without a graft. The investigators did not report on the extent to which there was a biomechanical benefit of using the graft devices at time zero; however, at 3 months, repairs augmented with SIS were significantly stiffer (39 %) than nonaugmented repairs, and stiffness was 40 % of a normal tendon. Zalavras [36] similarly examined SIS's regenerative capabilities in a rat model. In 40 rats, a supraspinatus midsubstance tendon defect was created. Twenty were repaired with an SIS patch and the others were left unrepaired to evaluate the spontaneous healing capacity of large defects as a control. Rats were sacrificed at 6 and 16 weeks for histologic and biomechanical analysis. The regenerated tendons exhibited neovascularization and fibroblasts oriented along lines of mechanical stress. Foreign-body reactions did not occur in the rats. Mechanically, the regenerated tendons had higher tensile strength and stiffness compared with the full defects but only reached approximately 75 % of the normal tendon. SIS is available through several manufacturers, each with a proprietary processing and sterilization process.

The *RESTORE* (Ortobiologic Soft Tissue Implant; Depuy Orthopaedics, Inc, Warsaw IN) is composed of ten *non-cross-linked* layers of SIS processed with paracetic acid and ethanol to free them from cellular or immunologic DNA components. This device contains predominately type I collagen, fibronectin, chondrointin sulfate, heparin, hyaluronate, and some growth factors. The implant is terminally sterilized using electron beam radiation, and is packaged dry. It requires rehydration prior to implantation. The use of xenograft ECM in rotator cuff repairs yielded mixed results in clinical trials. Malcarney [21] published their experiences in 25 patients. In four patients, an overt inflammatory reaction required debridement and removal of the graft was reported. Zheng [37] reported similar noninfectious swelling and painful inflammatory response. Iannotti [17] performed a randomized controlled trial designed to compare SIS augmentation against no augmentation in two groups of two tendon cuff tears. The results were striking; four of 15 augmented shoulders healed in the SIS group compared with nine of the 15 in the control group. Moreover, in the augmentation group, there were three cases of adverse reactions. Metcalf [22] also investigated the clinical efficacy of using Restore as augmentation for massive chronic rotator cuff tears. Postoperative MRI showed significant thickening of the cuff tendon with the incorporation of the SIS graft in 11 patients. There was no evidence of local or systemic rejection or infection in any patient. Sclamberg [29] evaluated the use of Restore in 11 patients undergoing open repair of large or massive rotator cuff tears. The device was used as an augmentation graft in four patients and as an interpositional graft in seven patients. Follow-up MRI scans showed that ten of the 11 patients exhibited large retears. Walton [35] started a prospective study comparing Restore with a nonaugmented control. This study was stopped when four of 19 patients treated with SIS endured inflammatory response. Because of all these concerns, the American Academy of Orthopedic surgeons currently does not recommend the use of non-cross-linked porcine SIS (Restore) for the treatment of rotator cuff tear in humans.

The *CuffPatch* (Bioengineered Soft Tissue Reinforcement; Arthrotek, Biomet Sports Medicine, Inc, Warsaw, IN) is an eight-layer acellular, *cross-linked* SIS device. A nondetergent, nonenzymatic chemical cleaning protocol removes cells and cellular debris without damaging the native collagen structure. The implant is packaged hydrated and is terminally sterilized by gamma irradiation. CuffPatch is approximately 0.6 mm thick. Valentin [34], in a histologic study comparing different xenograft and allograft used to augment rotator cuff repairs, demonstrated that rotator cuff repaired with CuffPatch experienced substantial inflammation when compared to other grafts.

Bovine Dermis

The acellular, nondenatured, *not cross-linked* collagen membrane (*TissueMend*, Soft Tissue Repair Matrix, Stryker Corporation, Mahwah, NJ) is a single layer of fetal bovine dermis processed to remove cells, lipids, and carbohydrates and terminally sterilized with ethylene oxide. The device is approximately 1 mm thick, and is composed primarily of type I and type II collagen. It is lyophilized and packaged dry. To date, there is little clinical information using this implant. A study comparing rotator cuff repairs augmented with patches, however, demonstrated TissueMend had higher levels of DNA embedded in the ECM when compared to other xenograft materials [11]

Porcine Dermal Collagen

Porcine dermal collagen (Zimmer Collagen Repair Patch: Zimmer Inc, Warsaw, IN) marketed as *Permacol* (Tissue Science Laboratories, PLC, Aldershot, Hampshire, UK) is an acellular, cross-linked, porcine dermal collagen. Organic and enzymatic extractions are used to remove fat, cellular materials, and proteins. This scaffold is resistant to enzymatic degradation. It is one layer 1.5 mm thick. It is packaged hydrated and terminally sterilized via gamma irradiation. In preclinical studies Permacol was reported to be a well tolerated implant with an absence of cellular infiltration and limited vascular ingrowth of the scaffold. Gilbert [15], in one study comparing the different commercially available biologic ECMs, noted that Permacol has no detectable DNA in its matrix. With regard to clinical studies, Badhe [3] reported on a prospective study of ten patients with a 4.5-year follow-up after augmented repair of posterosuperior rotator cuff using Permacol. Imaging (MRI and ultrasound) identified intact grafts in eight patients and graft disruption in two patients. The authors did not note any adverse side effects during the study period.

In contrast, Soler [32] investigated the use of Permacol as a bridging device to repair massive rotator cuff defects. In all four patients, the graft device failed within 6 months of treatment. All the four bridging cases had signs of inflammation.

The *Conexa* (Tornier Edina MN) is an acellular, *not cross-linked*, porcine dermal collagen. It is prepared by removal of all the cellular components and alfa galactose (α-Gal) residues to minimize human immunologic reaction. Both primates and humans in fact, have preexisting antibodies to the α-Gal antigen. The reduction of the α-Gal antigen can minimize the primate immune response to xenograft tissues. Conexa is ready to use after a 2 min rinse. This device is available in two different thicknesses (1 and 2 mm) and various sizes. In a laboratory study performed to evaluate the response of human tenocytes in culture to seven commercially available ECM patches, it was noted that Conexa and secondarily GJA evoked the most favorable responses from the human tenocytes [31]. To date, however, there is no published clinical study on the use of Conexa device.

The *Biotape* (Wright Medical Technology, Inc, Arlington, TN) is a terminally sterile acellular porcine dermal matrix. Collagen scaffold is preserved intact during processing and is *not cross-linked*. To date, there are no clinical studies reporting the results of the use of Biotape.

Equine Pericardium

The *OrthADAPT* trademark bioimplant (Pegasus Biologics, Irvine, CA) is an ECM derived from native equine pericardium. It is a decellularized, *cross-linked*, terminally sterilized type I collagen matrix. It is a very thin (<1 mm) pliable scaffold. The OrthADAPTtrade has three subtypes that differ in the degree of cross-linking of collagen strands. The three products are named as FX, PX, and MX in the order of the degree of collagen cross-linking, with FX most dense in cross-linking and hence most durable. A recent biomechanical study found that in tensile strength and suture pullout strength tests, the products FX and MX had mechanical properties that were comparable with CuffPatch, while the mechanical strength of PX was significantly inferior to FX and CuffPatch in tensile strength test [19]. To date, however, there have been no clinical reports using this material in rotator cuff.

Table 1 summarizes the main features of the current biological scaffold available for rotator cuff surgery.

Indication for the Use of Patches in Rotator Cuff Repair

Commonly, the use of patches in the rotator cuff surgery can be identified in two different settings: augmentation of repair or as gap-spanning devices. We prefer to use patches for augmentation only, particularly in case of large to massive tears with degenerative tendons that may be less likely to heal. In cases where the tear appears irreparable, retracted, and associated with a severe (grade IV) muscle atrophy, the use of

Table 1 The main features of the biological scaffold are summarized

Product Name	Manufacturer	Material source	Cross-link	Sterilization	Size
GraftJacket (Allograft)	Wright Medical Technology, Inc	Human dermis	No	Aseptic processing	Multiple
Restore (Xenograft)	Ortobiologic Soft Tissue Implant; Depuy Orthopedics	Small intestine submcosa	No	E-beam	6 × 2 cm
CuffPatch (Xenograft)	Arthrotek, Biomet Sports Medicine, Inc	Small intestine submcosa	Yes	Gamma irradiation	6.5 × 9 cm
TissueMend (Xenograft)	Stryker Corporation	Fetal bovine dermis	No	Gamma irradiation	5 × 6 cm
Permacol ZCR Patch (Xenograft)	Zimmer Inc	Porcine dermal collagen	Yes	Gamma irradiation	5 × 5 cm
Conexa (Xenograft)	Tornier Inc	Porcine dermal collagen	No	Patented technique	Multiple
Biotape (Xenograft)	Wright Medical Technology, Inc	Porcine dermal collagen	No	Terminally sterile	4 × 7 cm 6 × 8 cm
OrthADAPT (Xenograft)	Pegasus Biologics, Inc	Native equine pericardium	Yes	Terminally sterile	Multiple

ZCR zimmer collagen repair, *PGA* polyglicolic acid, *PLLA* poly-l-lactic acid

patch as bridging in our view is not suitable because there are problems related to securing the graft to the native patient's tissue, and moreover it is not likely that it can be repopulated and function as muscle-tendon unit.

We also prefer to augment with patches in the setting of revision repairs in cases without a severe grade of muscle atrophy.

We use biological patches because we believe that it could be able to increase early strength of repair, provide a biological network for cellular ingowth, and not induce a foreign-body reaction, thereby not interfering with the healing process.

Advanced glenohumeral osteoarthritis/rotator cuff tear arthropathy is a relative contraindication because these patients may get significant stiffness and inadequate pain relief.

Surgical Technique

We use the augmentation patch associated with the suture anchors technique for rotator cuff repair. Patients are under general anaesthesia and positioned in a lateral decubitus position. The arm is prepped and draped sterilely. A standard posterior portal to the glenohumeral joint is established, and diagnostic arthroscopy is done. Then an anterior and two lateral portals are made. Associated lesions, if detected, are treated simultaneously, after which attention is turned to the rotator cuff. The stump of tendon is identified and debrided minimally, then it is pulled with a grasper toward the greater tuberosity to assess if a direct repair is possible. Sometimes, in case of massive retracted V-shape tear, marginal convergence sutures could be necessary as first step. The tendons are mobilised enough to bring the edge back to the native footprint on the greater tuberosity. Then we start the repair. We use a single row repair with triple loaded suture anchors. According to the size of tear, two or three anchors are inserted on the greater tuberosity at a distance where the repairing cuff is not overtensioned. Two of three sutures of anchors are passed directly through the tendon, then arthroscopic knots are tied to secure the tendon to the greater tuberosity (Fig. 1). The strands of these sutures are cut. One limb of suture that remains from each anchor is retrieved outside the lateral cannula and passed through the lateral margin of the patch. The size of patch is then measured, and the graft is cut and prepared on the back table. Medially on the rotator cuff three sutures are passed – one anteromedial, one in the middle, and one posteromedial – and retrieved from anterior cannula, percutaneously through the Neviaser portal and from posterior cannula, respectively. One limb of these three sutures is retrieved from lateral cannula and passed through the medial margin of the patch. The limbs coming from each suture are knotted with a Mulberry knot over the surface of the patch. Different suture colors can help during these steps. Once all the sutures are passed through the patch, the patch is pushed gently through the lateral cannula and the other limb of sutures (that outside the anterior cannula, Neviaser portal, posterior cannula and the other two sutures coming through the anchors that remain all the time outside the skin) are pulled by an assistant so that the patch is introduced in the subacromial space and on the cuff. In this phase, any twist of suture should be avoided (Fig. 2a–e). Once the patch is on the cuff, any single suture is retrieved from lateral, anterior or posterior cannula and are tied (Figs. 3 and 4).

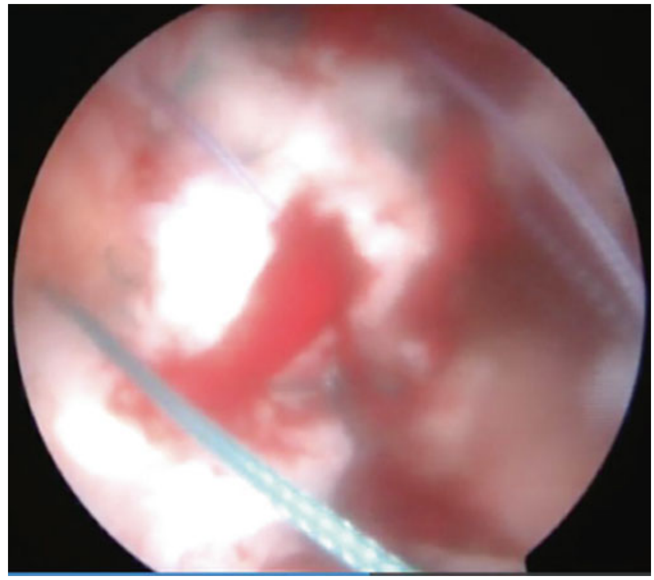

Fig. 1 Right shoulder observed through a posterior portal. Once the rotator cuff is sutured to the bone, a series of sutures are passed to be used as carrier for the patch

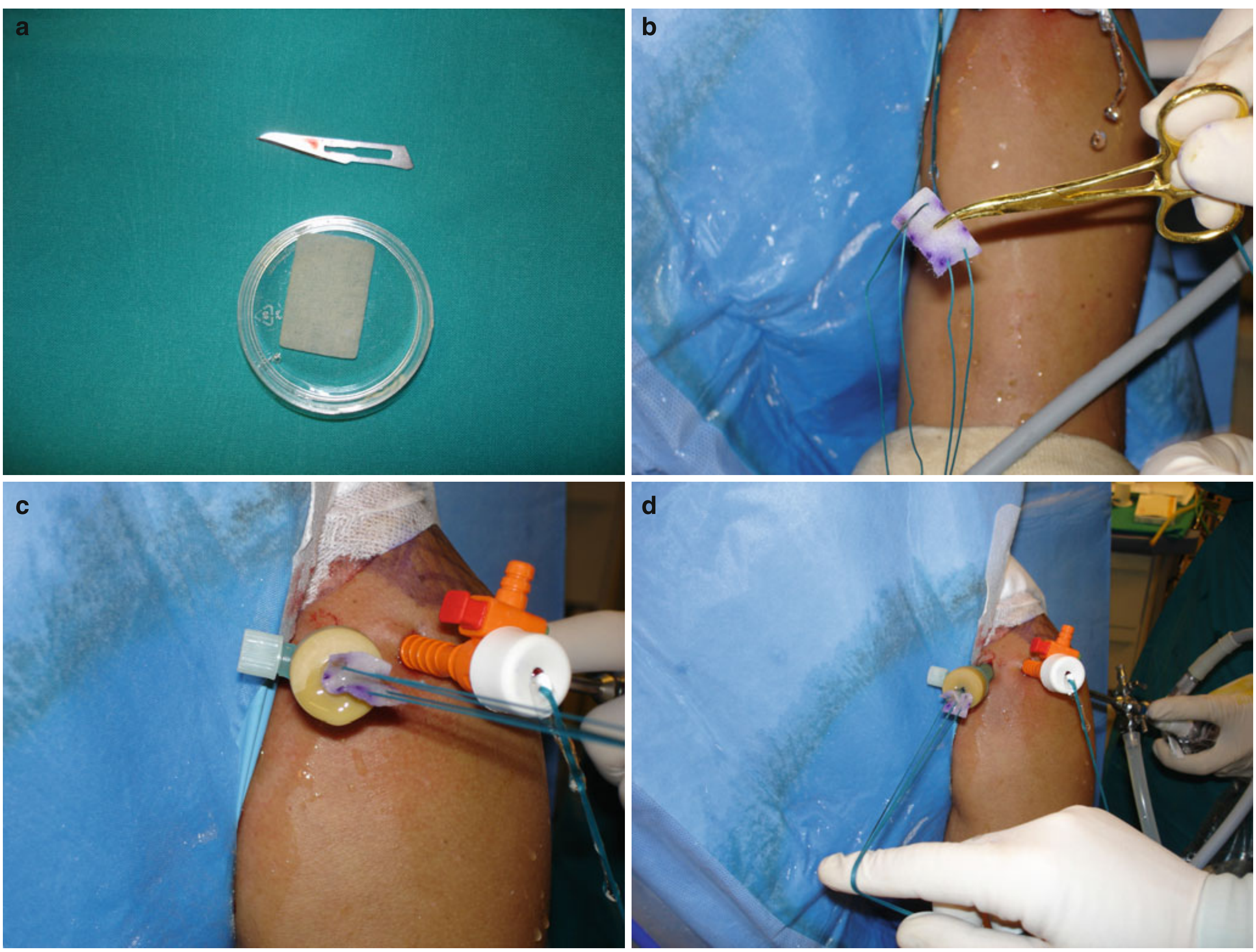

Fig. 2 (**a**–**e**) Chondrotissue patch (**a**); intraoperative phases (**b**–**e**)

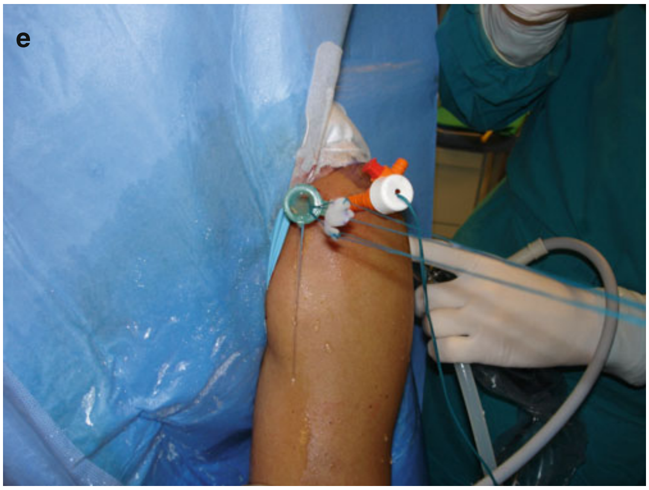

Fig. 2 (continued)

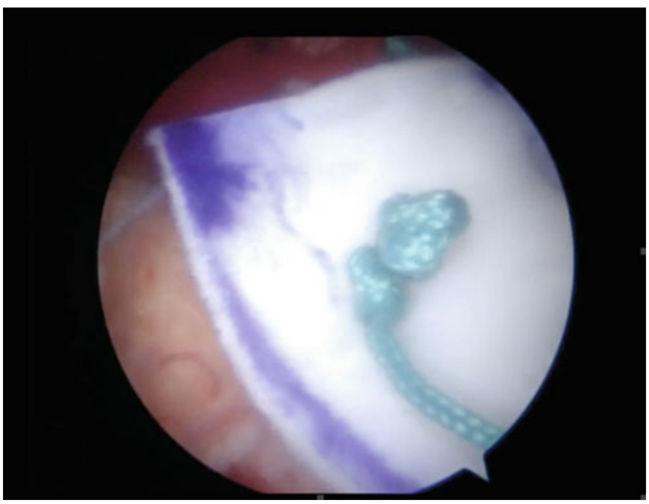

Fig. 3 Right shoulder observed through a posterior portal. The patch has been delivered through the lateral cannula using sutures as a shuttle. The mulberry knot on the surface of the patch is showed

Conclusions

The use of patches in the treatment of rotator cuff tear continues to expand. Synthetic materials are improving and show less adverse reaction compared to early materials. With regard to biological patches, porcine SIS, while once promising, has been exposed as a poor material for scaffold development. Dermal matrix (ECMs) seems to support better results in term of reduced adverse reaction and improved clinical outcome. A contemporary technical challenge for the use of ECM patches is that rotator cuff repairs are commonly being done arthroscopically. Placing and securing the patch graft arthroscopically would be technically difficult for most surgeons. The added operative time and swelling from arthroscopic fluid extravasation might add additional morbidity for the patient without a well-defined clinical benefit. Another crucial point concerns patients with a large irreparable rotator cuff tear with an associated severe muscle tissue fat infiltration. The repair of this tendon also with ECM patch cannot reverse the muscular atrophy and consequently this repair cannot reestablish the muscle-tendon function.

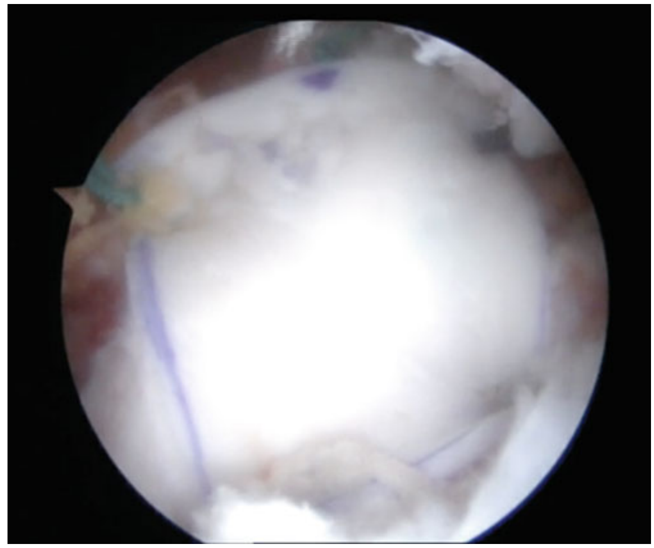

Fig. 4 Final view from the lateral subacromial portal. All the sutures are tied and the patch is now seated on the repaired rotator cuff

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Latissimus Dorsi Transfer for Primary Treatment of Irreparable Rotator Cuff Tears

Stefano Gumina, Roberto Castricini, Massimo De Benedetto, and Nicola Orlando

Introduction

The definition of irreparable tear of the rotator cuff is still controversial. We consider as irreparable those tears in which, after extensive mobilization of the residual tendon cuff, no reinsertion to the humeral tuberosities or to the nearest portion of the anatomical neck of the humerus appears to be possible. This usually occurs when no identifiable tendon tissue is found over the humeral head or when the tendon stumps are so retracted, and often so frayed and friable, that no stitches can be applied to bring the stumps to the area of insertion. In these cases, a transfer of a distant musculotendinous unit is indicated for middle-aged or early elderly patients, when surgery is aimed at restoring a satisfactory active range of shoulder motion and strength, and there appears to be enough compliance by the patient with a long postoperative rehabilitation program.

Most of the massive tears can be repaired with the arm at the patient's side or by abducting the arm 30–60°. Patients with truly irreparable cuff tears may be exceedingly difficult to manage, particularly when the irreparability of the lesion has not been diagnosed or suspected before surgery. In fact, in few cases, it might be difficult, before surgery, to determine whether a massive tear of the rotator cuff can be repaired, even when excellent MRI studies are available. In these cases, patient should be informed that the distant musculotendinous transfer may possibly be done and the operating table should be adequately positioned in order to perform the transfer if necessary.

There are several surgical options in patients with an irreparable cuff tear. These include arthroscopic debridement, hemiarthroplasty or inverse shoulder prosthesis, the use of flaps of deltoid or trapezius muscles, and the transfer of a distant musculotendinous unit, such as the latissimus dorsi or the teres major. The lone open decompression leads to deterioration of shoulder function after surgery [1].

Arthroscopic debridement, associated or not with biceps tendon tenotomy [2], may relieve pain, but no significant improvement in active shoulder motion can be expected when functional inability is related to loss of muscle function rather than pain [3]. Hemiarthroplasty may lead to satisfactory results in terms of pain relief, but in most cases it improves moderately the active shoulder motion [4–6]. Reverse total shoulder prosthesis may give satisfactory results with regard to both pain and shoulder function [7, 8]. However, reverse prostheses, as well as any type of arthroplasty, are indicated for elderly patients, particularly in the presence of cuff arthropathy. Conflicting results have been reported with the use of muscle flaps of deltoid [9] or trapezius [10, 11]; furthermore, flaps of these muscles cannot be usually used in truly irreparable cuff tears because in these cases there are no, or not sufficiently healthy tendon stumps to which the muscle flaps can be anchored. The two distant musculotendinous units that are currently used for an irreparable tear of the superoinferior cuff are the teres major (Fig. 1a, b) and the latissimus dorsi. Celli et al. [12] reported the transfer of teres major muscle for infraspinatus in six patients with irreparable rotator cuff tear, associated, in one case, with a neurologic deltoid deficiency. Of their patients, one was very satisfied and five were satisfied with the results of surgery. The tendon of the latissimus dorsi, being wider and longer, can reach the greater tuberosity and cover a large portion of the humeral head; furthermore, it can be attached to a fairly large bone surface and be more easily sutured to residual tendons of the cuff. Although the functional role of the transferred latissimus dorsi is still unclear, it is conceivable that it acts not only as a passive restraint, but also as an active muscle unit which centers the humeral head in the glenoid, thus allowing the deltoid to exert its mechanical function. The fact that the transfer is functionally active is suggested by the increased range of active flexion and exter-

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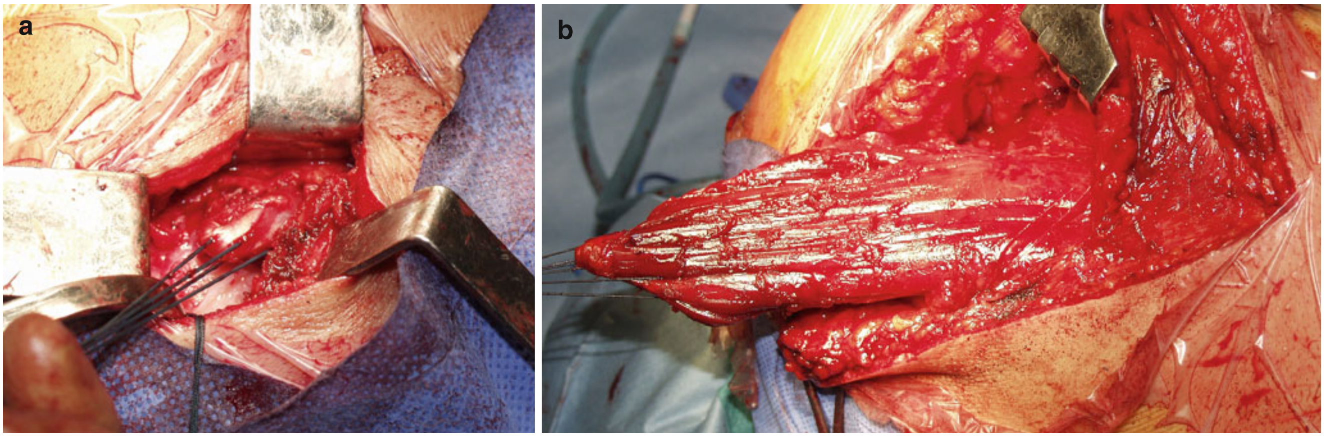

Fig. 1 (**a**, **b**) Teres major musculotendinous unit

nal rotation of the arm that was observed in previous series [13–16] as well as in most of our patients [17].

Transfer of the latissimus dorsi muscle was originally reported by Gerber et al. [13] in four patients with irreparable rotator cuff tears; subsequently, Gerber [14] evaluated the medium-term results after such a transfer in 15 patients who had no previous cuff surgery. Miniaci and MacLeod [15] reported the use of the latissimus dorsi in 17 patients who had repeated surgery after a failed operative treatment of a massive tear of the rotator cuff. Warner [11] and Aoki et al. [16] performed six and ten transfers, respectively, to reconstruct irreparable rotator cuff tears that had not been treated with prior surgery. Iannotti et al. [18] submitted 14 patients who had undergone latissimus dorsi transfer to electromyography. It demonstrated clear activity in the transferred latissimus muscle during humeral abduction in all 14 patients, some electrical activity with active forward elevation in only one patient and some electrical activity with active external rotation in six of the nine patients with good clinical result. None of the patients with a poor clinical result demonstrated electrical activity of the transferred muscle with active forward flexion of external rotation.

In 1934, L'Episcopo [19] described a combined teres major and latissimus dorsi transfer by using his technique in obstetric paralysis, changing their function from internal to external rotators.

Buijze et al. [20] performed an anatomical study on 62 cadaveric shoulders with the aim to give a description of the morphology of teres major and latissimus dorsi with particular regard to their suitability for use in transfer. They observed that the mean length of teres major was 13.7 cm at its superior edge; the distance from the muscle origin to the greater tuberosity was 19.2 cm; the tendon length, width, and thickness, respectively, of 1.5 cm, 3.4 cm, and 1.3 mm. The mean length of the latissimus dorsi was 26.0 cm and the distance from its origin to the greater tuberosity was 32.9 cm. The mean length, width, and thickness of the tendon were, respectively, 5.2 cm, 2.9 cm, and 1 mm. The authors concluded that both muscles could easily reach the greater tuberosity; however, tension of the neurovascular bundle is more probable with latissimus dorsi because it enters the muscle relatively closer to the tendon. Problems with regard to reattachment might be more likely to occur with the teres major because of its short tendon.

Warner and Pearson [21] observed that latissimus dorsi transfer for revision surgery results in more limited gains in patient satisfaction and functional scores than primary transfer. Irlenbusch et al. [22] detected a slight decrease in the values of Constant scores in the revision group and in the presence of an additional subscapularis lesion. Costouros et al. [23] reported nearly comparable improvements in pain relief and function following transfer in either primary or revision surgery. Subscapularis integrity has been shown to be relevant for latissimus dorsi transfer (Gerber and Maquiera [14]; Aoky [16]). Finally, Costouros et al. [23] observed that fatty infiltration of the teres minor significantly influenced the results of latissimus dorsi transfer; whereas the presence or absence of tendon tear did not. In particular, stage 2 fatty infiltration was associated with worse preoperative and postoperative pain and function scores, as well as limited active external rotation and flexion.

Operative Technique

When the preoperative clinical or imaging findings led to suspect that the cuff tear was irreparable, the patient was placed in the lateral decubitus position on the operating table with 20° anti-Trendelenburg inclination (Fig. 2). This position allows the musculotendinous unit of the latissimus dorsi to be exposed and transferred to the greater tuberosity if the cuff lesion is irreparable.

The subacromial space is exposed through an anterolateral or superolateral approach. The deltoid was detached from the anterolateral border of the acromion using cutting current diathermy and split up vertically for approximately 5 cm in the middle part of the exposed portion. After horizontal acromioplasty, the rotator cuff was inspected to assess tear size and tissue degeneration. If the subscapularis tendon cannot be repaired, then the latissimus dorsi transfer should not be done without performing also a pectoralis muscle transfer. If the biceps tendon shows any signs of wear, the tendon can be tenodesed in the bicipital groove to prevent pain postoperatively. The greater tuberosity is debrided of soft tissue and osseous prominences. Skin incision was temporarily closed with clamps and the second incision was done to expose the latissimus dorsi muscle (Fig. 3). Posterior skin incision along the anterior border of the latissimus dorsi to the posterior axillary fold, curving proximally to be perpendicular to the humeral shaft is performed. Careful attention is made to avoid crossing a skin crease without changing the direction of the incision and so to avoid scar contracture at the skin crease. Deltoid, long head of triceps, and latissimus dorsi are identified.

The latissimus dorsi is easily recognized as the large muscle crossing, with an oblique direction, the distal portion of the scapula. There is no large muscle inferior to the latissimus dorsi and, if one is found, then the surgeon may have mistaken the teres major for the latissimus dorsi muscle. Latissimus dorsi is followed laterally toward the humeral insertion and progressively dissected from the teres major. The neurovascular bundle, running on the undersurface of the muscle, is identified and carefully preserved. By blunt dissection, proceeding along the dorsal surface of the muscle, the tendon of the latissimus dorsi is palpated with the finger and exposed as far as its insertion on the humerus, while placing the arm in adduction and internal rotation. The axillary nerve is superior to the teres major tendon. The brachial plexus is deep and anterior. The radial nerve, lying deep to the tendon, is rarely exposed, but its presence is taken into consideration to avoid neural damage. The tendon is detached as close as possible to the bone surface, using scissors under direct vision of the anatomical structures (Fig. 4). If the latissimus dorsi tendon does not seem long enough or broad enough to cover the greater tuberosity after it has been dissected free from the humerus, teres major tendon transferring has to be considered, too. Teres major must be attached to the greater tuberosity separately because the length and tension relationship of each muscle is different and the tendon length of the teres major is shorter than the latissimus dorsi one. While retracting the detached tendon medially and

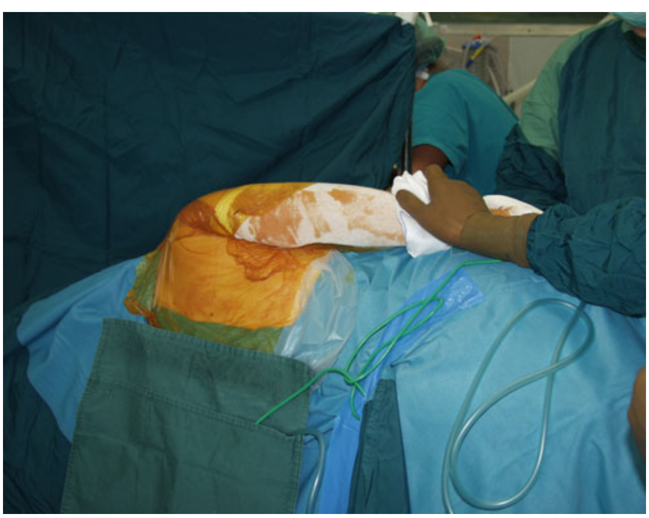

Fig. 2 Patient in lateral decubitus position (*left*) for a right latissimus dorsi tendon transfer

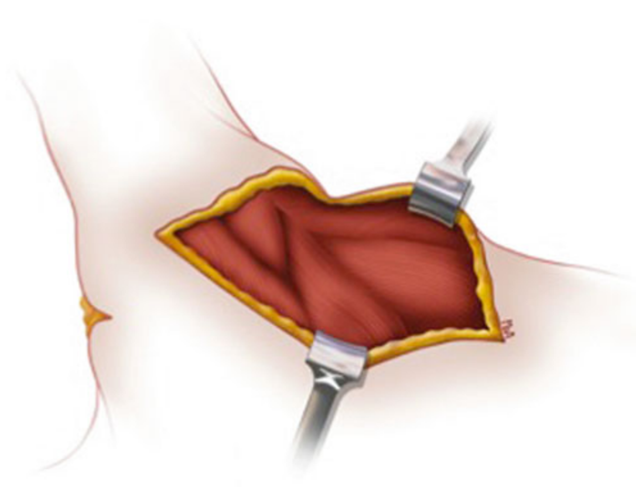

Fig. 3 Drawing showing the double-skin incision for the surgical procedure

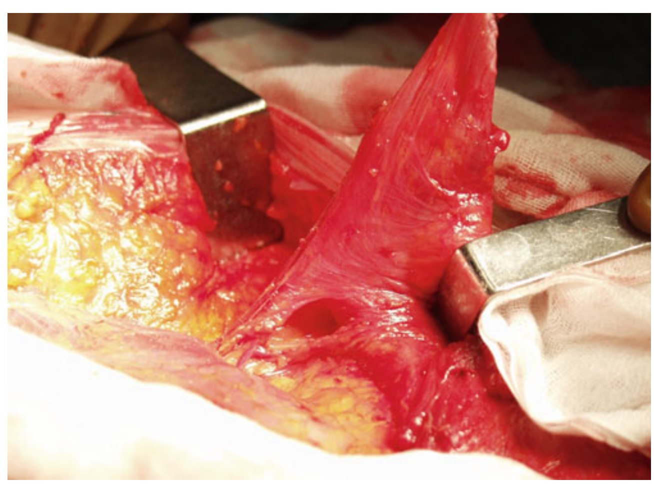

Fig. 4 Latissimus dorsi musculotendinous unit with its neurovascular bundle

distally, the dissection of the undersurface of the muscle is completed, avoiding tearing and stretching of the neurovascular bundle. It is identified and mobilized with scissors to allow complete excursion of the tendon out of the wound and above the acromion. The tendon is prepared by weaving a No 2 Fiber wire or equivalent suture with locking Krackow technique along each of its edges so that two suture strands can be used for attachment to the superior aspect of the subscapularis tendon (Fig. 5). The undersurface of the posterior portion of the deltoid is separated from the triceps tendon by blunt dissection and a clamp is inserted deeply to the deltoid with a craniocaudal direction to grasp the sutures in the latissimus dorsi and bring them above the humeral head (Fig. 6). Often the tunnel needs to be enlarged inferiorly to accommodate the large muscle belly and to avoid excessive tension on the tendon or the neurovascular bundle. The tendon of the latissimus dorsi is advanced as far as possible toward the greater tuberosity by both pulling the sutures and pushing upward the muscle belly with the hands.

A bone trough is created in the region of the greater tuberosity, where the latissimus dorsi tendon is anchored with nonabsorbable transosseous sutures (Fig. 7a, b). On the basis of electromyographic studies, Codsi et al. [24] believe that the latissimus dorsi acts primarily as a passive humeral head depressor. Therefore, they repair the latissimus tendon over the top of the humeral head. The residual free margins of the latissimus dorsi tendon may be sutured to the subscapularis tendon. Postacchini et al. [17], in very few patients, sutured the latissimus dorsi tendon to the long biceps tendon, after anchoring the distal portion of the latter to the bicipital groove. The medial edge of the tendon is secured to the edge of the remaining portions of the supraspinatus and infraspinatus tendons. If the teres major tendon is transferred as well, it can be secured more laterally and posteriorly on the humeral head than the latissimus dorsi tendon. If the tendon does not have at least 2 cm^2 of coverage over the humerus, the healing potential will be compromised and the surgeon should consider using a graft to augment the tendon. In these cases, Codsi et al. [24] use a fascia lata graft. The humeral head could be completely covered with tendon tissue in many cases.

The deltoid is reattached with transosseous sutures to the acromion and the deltopectoral fascia is closed. A drain is placed in the latissimus dorsi muscle bed if needed, and the skin is closed without closing the deep fascia. A brace is applied to hold the arm in neutral rotation and 20° of abduction.

Postoperative Regimen

The shoulder is immobilized 35 days after surgery. Passive elevation in neutral rotation is done twice a day for the first 4 weeks. A rehabilitation program of active motion in flexion, abduction, and external rotation was initiated 6 weeks after operation and continued for 8 weeks. Afterward, strengthening exercises started and usually continued for 4–8 weeks.

Our Experience

We report our experience with the transfer of the latissimus dorsi muscle in patients with irreparable rotator cuff tears who had no previous surgery for cuff defect.

We were able to follow 41 patients who underwent a primary transfer of latissimus dorsi musculotendinous unit for

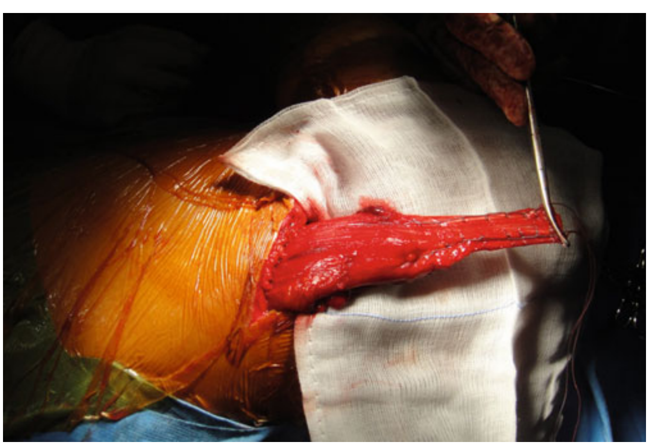

Fig. 5 Latissimus dorsi tendon is prepared with a Krackow-type suture

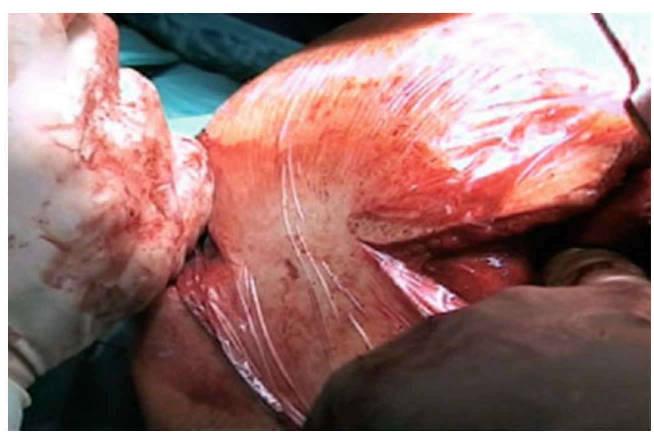

Fig. 6 Latissimus dorsi musculotendinous unit is brought above the humeral head using a clamp, which is inserted deeply to the deltoid with a craniocaudal direction to grasp the sutures

an irreparable posterosuperior rotator cuff tear. There were 28 men and 13 women, aged 46–69 years (mean, 59). The right, dominant shoulder was involved in 34 cases and the left, nondominant shoulder, in 7. All patients had shoulder pain lasting 6–24 months at the time of surgery. The active range of motion was limited in all cases, though to a variable extent.

Seven patients had a positive Lift-off, Bear and Napoleon tests, indicating a tear of the subscapularis tendon.

In no patient did plain radiographs show evidence of cuff arthropathy. The acromiohumeral interval was less than 7 mm in 28 cases. Diagnosis of cuff tear was made by magnetic resonance imaging (MRI) in all cases. MR scans showed a massive lesion in all patients, with a varying degree of degeneration of the cuff muscles, as evaluated by the Goutallier and Fuchs grading system [25, 26].

The patients were examined monthly in the first 5 months after surgery. The latest follow-up was carried out a mean of 24 months after surgery (range, 7–34 months). The results of surgery were evaluated using the Constant and Murley system [27].

All patients had a considerable to complete relief of shoulder pain. Twenty-nine patients had an almost complete active range of motion in flexion, abduction, and internal rotation (Fig. 8a–e). However, the strength in abduction and external rotation was decreased, on average, by one-fourth to one-third, compared with the contralateral side.

Ten patients had a mild improvement of active motion and strength. At surgery, seven of these patients were found to have disinsertion of the upper portion of the subscapularis tendon from the lesser tuberosity, as well as a complete rupture of the biceps tendon. The latissimus dorsi tendon, after attachment to the greater tuberosity, could not be anchored to the subscapularis, but it was sutured to a few degenerate remnants of the infraspinatus tendon.

The average postoperative Constant and Murley score was 65 points, with an increase by 24 points compared with the preoperative score.

Arthroscopic Technique

Gervasi and colleagues [28] described a variant of Gerber's [29] original LDT-T (latissimus dorsi tendon transfer) technique where improved patient outcomes are provided by performing part of the procedure by arthroscopy, thus limiting the surgical trauma to the deltoid. Our group has been applying it since 2008.

We will describe our procedure that is modified by the changes and adjustments that we have introduced over the years.

The procedure is carried out under general anesthesia and interscalene block, with the patient in lateral decubitus and the arm under longitudinal traction for routine arthroscopy. The armrest allows the switch to open surgery with the shoulder in 90° of abduction, to enable internal rotation and facilitate LDT harvesting (Fig. 9). In the initial phase, diagnostic arthroscopy enables lesion identification and classification through standard posterior, anterior, and lateral portals.

Any associated lesions in the joint space are assessed and treated arthroscopically: LHB tendinopathy is managed by tenotomy and any subscapularis lesions are identified and repaired as appropriate. Bursectomy is performed from the subacromial space and the amenability of the cuff tear to repair is evaluated both from the posterior and the lateral portal. If the indication for LDT-T is confirmed, a bleeding

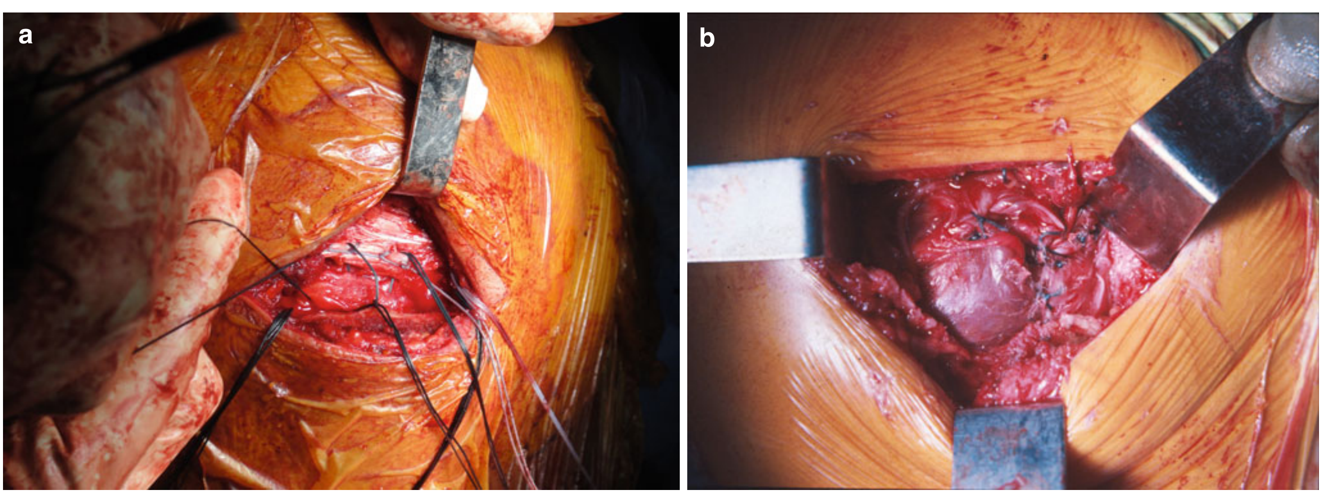

Fig. 7 Latissimus dorsi tendon is anchored with nonabsorbable transosseous sutures on the greater tuberosity (**a**); final result (**b**)

Fig. 8 A 5-year-old male patient submitted to latissimus dorsi tendon transfer. (**a**) Surgical scar; shoulder active range of motion: (**b**) flexion, (**c**) abduction, (**d**) external rotation, (**e**) internal rotation

bone bed is created in the greater tuberosity using a motorized burr. The optics is passed through the lateral portal to find the space between the deltoid and the posterior cuff (residual infraspinatus and teres minor) to pass the transposed tendon and identify the axillary nerve. The traction is then removed for the switch to the open procedure. The LDT is harvested with the arm abducted and the elbow flexed to 90°. A curved anteriorly concave incision measuring 6–8 cm is made in the axillary cavity anterior to the posterior axillary fold, along the LDT course (Fig. 10).

The muscle belly and the LDT are found immediately below the subcutaneous layer. A cleavage plane is found

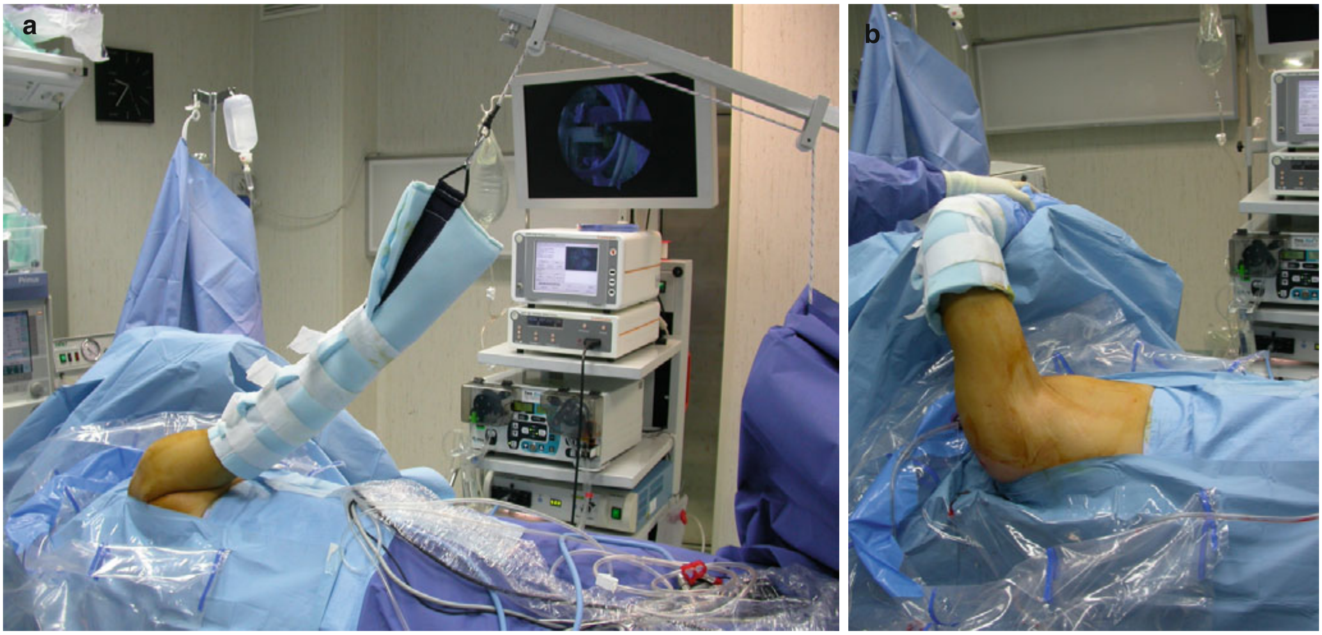

Fig. 9 (**a**) Patient in lateral decubitus position with the arm under traction for the arthroscopic procedure, (**b**) in the open procedure the arm lies on an armrest

between the LDT and the underlying teres major muscle. In patients where the proximal end of the LDT is fused with the teres major LDT, harvesting is more complex. In such cases, after identification of the cleavage plane at the level of the muscle belly, and carefully avoiding damaging the LDT, it is necessary to proceed in proximal direction and dissect the LDT up to its humeral insertion. Internal rotation of the arm maximizes visualization; a bent Hohmann retractor placed in contact with bone anterior to the LDT protects the radial nerve, ensuring safe tenotomy. As much of the LDT as possible is released (Fig. 11). After tenotomy, the stump is stitched with #2-0 nonabsorbable suture threads of different colors (suture length, 3–4 cm) to ensure safe transfer. The proximal end of the tendon (humeral insertion) will correspond with the lateral portion of the transposed LDT and the distal end with the medial portion.

Distal dissection and mobilization of the muscle belly is helped by pulling on the suture threads. The thoracodorsal nerve and the thoracodorsal vein and artery, which are found ventrally at a distance of about 13 cm from the free end, are then identified (Fig. 12).

The final length of the tendon is assessed by passing it over the acromion with the arm in adduction: transfer requires the tendon to be longer than the posterior border of the acromion by at least 2 cm (Fig. 13).

To find a route to pass the tendon from the axillary cavity to the subacromial space, the teres major muscle is

Fig. 10 Right shoulder: cutaneous incision at the level of the LDT course

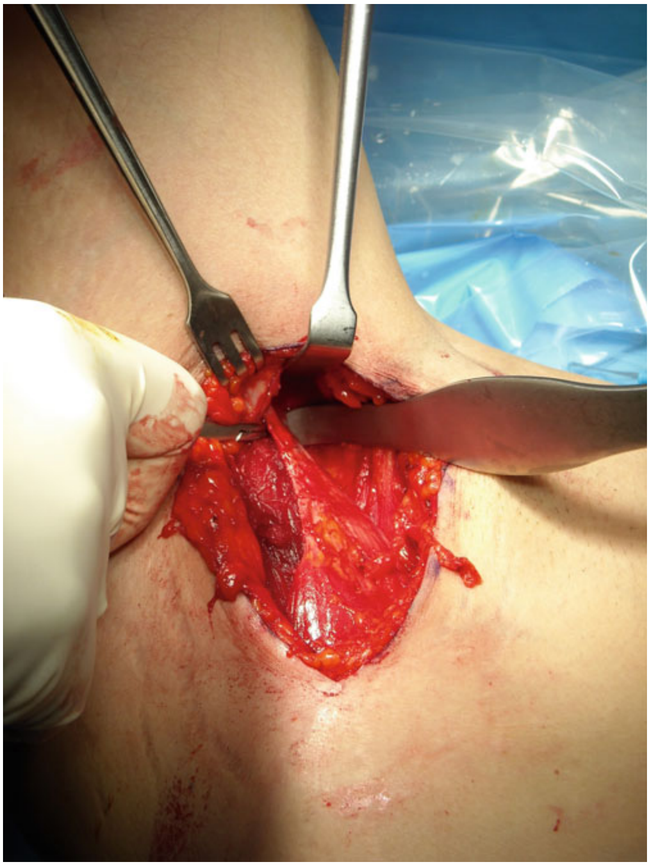

Fig. 11 LDT harvesting

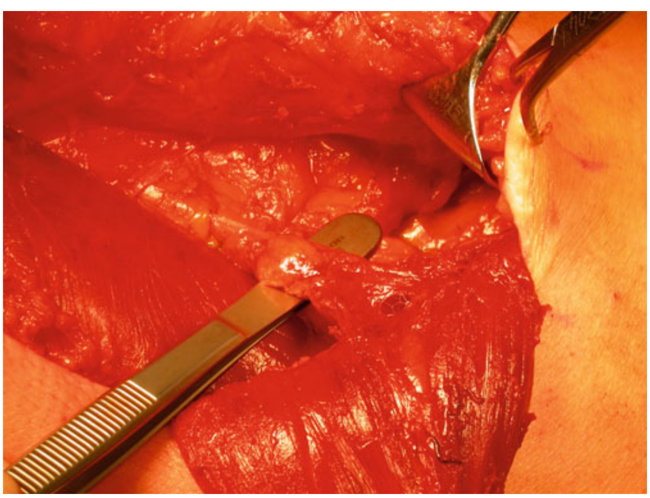

Fig. 12 Thoracodorsal nerve and thoracodorsal vein and artery

mobilized anteriorly and a pathway is identified between deltoid and brachial triceps tendon.

At this stage, the arthroscopic procedure is resumed and the optics is introduced into the subacromial space through

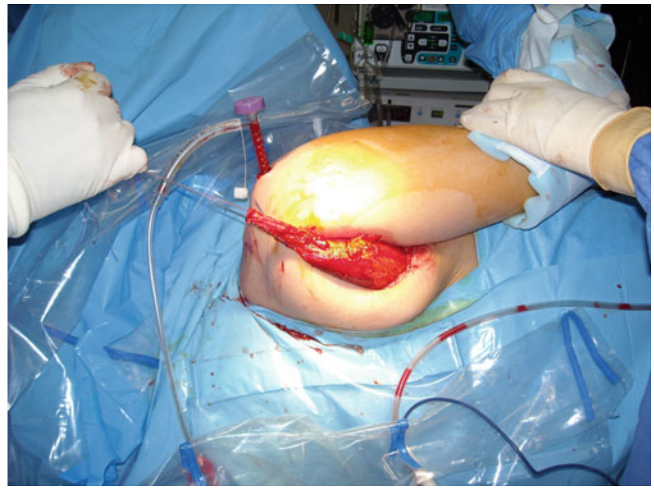

Fig. 13 Assessment of the length of the harvested tendon

Fig. 14 Preparation of tendon transfer

the lateral portal. A Wissinger rod is inserted through the posterior portal and slid downward between the deltoid and the teres minor until it emerges into the space between the deltoid and the triceps identified previously. At this point, the rod is introduced into a Hegar dilator, modified by two holes bored at the blunt end (Fig. 14).

The dilator is pushed back up, and then the Wissinger rod is withdrawn. The colored suture threads are passed through the Hegar dilator, which is slid upward, pulling the LDT into the subacromial space. The different colors ensure correct transposition. The threads are recovered from the anterior portal using a suture retriever and the dilator is removed (Fig. 15).

The LDT is slid as far as the humeral tuberosity through the subacromial space by pulling on the suture threads; it is then fixed to it by two knotless anchors placed on the superior edge of the subscapularis through one or two ante-

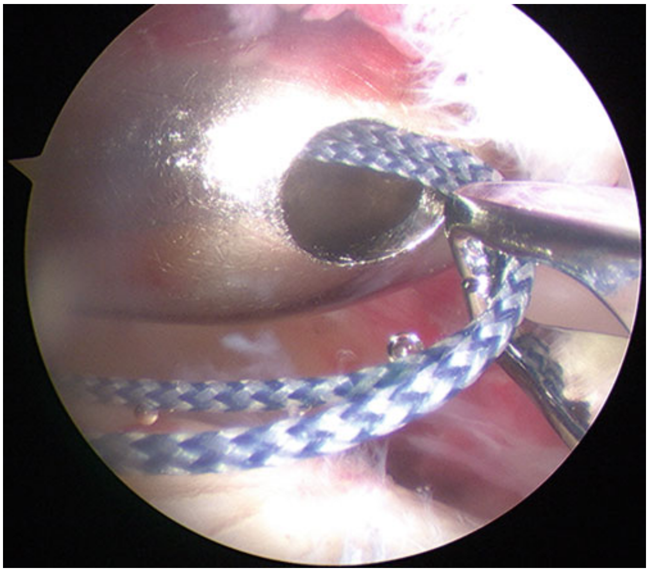

Fig. 15 Recovery of the medial thread

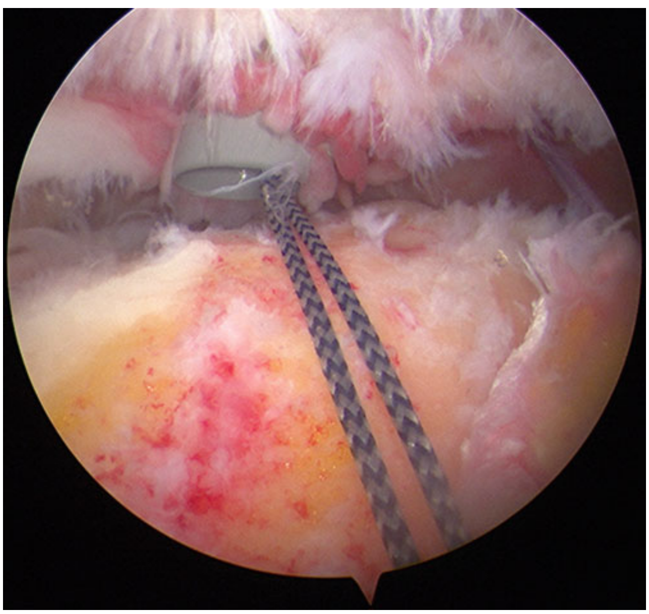

Fig. 16 The tendon is slid through the subacromial space; note the braided blue and white thread (medial end) and the purple thread (lateral end)

rior accessory portals made by the outside-in technique (Fig. 16).

The medial anchor is placed on the anterior aspect of the greater tuberosity near the bicipital groove along the cartilage boundary (Fig. 17).

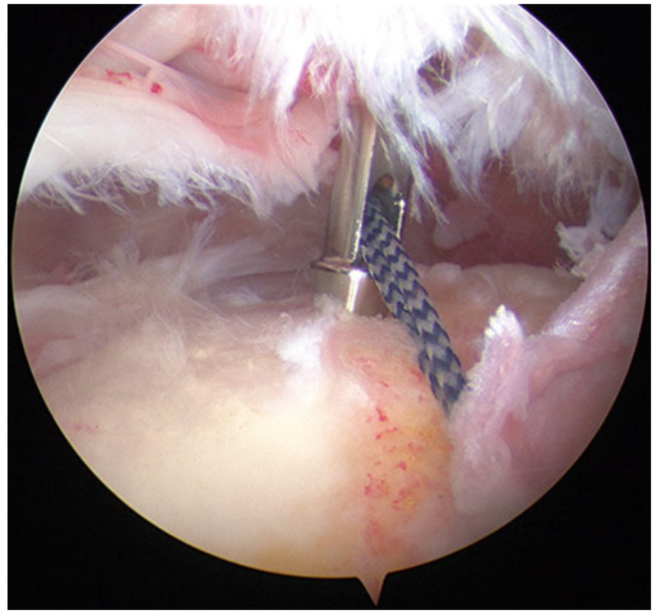

Fig. 17 Fixation of the medial end of the tendon

The other anchor is inserted lateral to it, attaching the LDT to the greater tuberosity and ensuring that it lies completely on the bleeding bony bed (Fig. 18).

A suction drain is placed in the axillary cavity, the wound is sutured, and a brace applied.

Rehabilitation Protocol

Patients follow a standard postoperative rehabilitation program.

The arm is kept in the brace in 15° of abduction for 4 weeks. Only passive forward flexion is allowed (5–10 times a day) beginning on the first postoperative day. Assisted passive mobilization is begun in the fourth week. Active exercises are allowed as soon as full passive ROM has been regained. The active and strengthening phase can then be started in association with scapulothoracic exercises. Proprioceptive exercises begin in 8–12 weeks.

The average duration of rehabilitation is 3–5 months.

LDT-T is a useful technique that restores shoulder function and provides pain relief in patients with irreparable infraspinatus and supraspinatus tears and no significant glenohumeral arthritis.

Gerber's original technique, entailing a double incision, has generated several variants including the combined arthroscopic-open technique devised by Gervasi and colleagues. The technical advances have been accompanied

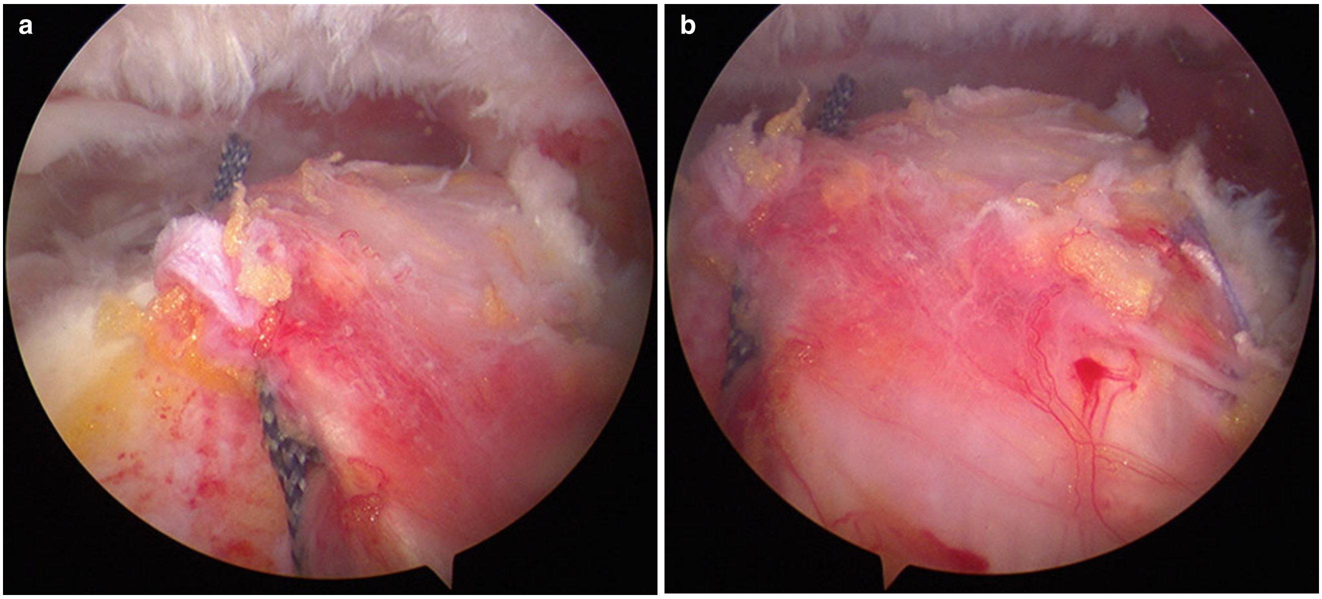

Fig. 18 (**a**, **b**) View from the posterior portal after tendon fixation with two knotless anchors

by a change of view regarding the action and function of the transposed tendon, which some consider more useful as an external rotator and others as a means to lower and center the humeral head in the glenoid (tenodesis effect). This has prompted the development of different surgical approaches to achieve such different goals; the technique described herein has been devised to reach the latter goal.

The short-term outcomes of our combined arthroscopic-open LDT-T technique, which we have described in a recent report, show significant improvement in terms of Constant score, pain, strength, and ROM, and poorer Constant scores when the operation was not a primary procedure [30].

Gerber and colleagues [29] obtained improved age- and gender-matched Constant-Murley scores (from 55 to 73 %) and improved active forward elevation (from 104° to 123°), abduction (from 101° to 119°), and active external rotation (from 22° to 29°) in their studied group operated on with the original two-incision procedure.

Nov'e-Josserand and colleagues [31] reported higher Constant scores (from 62 to 91) in 26 patients operated on with Gerber's original technique.

Habermeyer and colleagues [32], and [18] found significantly improved Constant-Murley scores in patients operated on with a single-incision technique.

In a long-term study of 55 patients (mean follow-up, 147 months), Gerber and coworkers [33] found an increase in the relative Constant score from 56 to 80 % and an increment of the subjective shoulder value from 29 to 70 %, with significant and lasting improvements in terms of both function and pain. The degree of teres minor fatty degeneration and the state of the subscapularis seemed to be the major factors affecting patient outcomes.

The procedure is demanding and not risk-free. According to a recent review, the overall complication rate is 9.5 % due to wound infection, nerve injury, tearing of the transferred tendon, failure of deltoid repair, hematoma, and wound dehiscence.

The overall rate of reoperation is 6.9 %, which includes revision repair of the transferred LDT, reverse total shoulder arthroplasty, shoulder arthrodesis, subscapularis repair, distal clavicle excision, deltoid muscle repair, rotator cuff debridement without infection, wound revision, and irrigation and debridement for infection [34].

In conclusion, arthroscopic LDT-T is an effective therapeutic option providing improved outcomes compared with the original open technique and enabling treatment of painful irreparable posterosuperior cuff tears refractory to conservative management.

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Pectoralis Major Transfer for Isolated Subscapularis Tear

Herbert Resch, Stefano Carbone, and Stefano Gumina

Isolated subscapularis tendon tears have been described as uncommon injuries, and they are usually detected early because of their typically traumatic causes [1, 2]. Anterosuperior cuff tears, with an associated supraspinatus-subscapularis tendon tears, are more common, and they are usually the result of degenerative causes in patients older than 40 years [3]. In such degenerative cases, the subscapularis rupture diagnosis can be delayed and it may result in a major time-lapse before the repair is attempted. This delay may lead to an impossibility of the surgical repair of the lesion, with important consequences to the biomechanics of the shoulder. Apart from its function in rotating, abducting, and flexing the shoulder, the subscapularis acts as the most important tendon in stabilizing the shoulder joint. [2, 4] If this balance is compromised by a subscapularis tendon tear, pain, weakness, and anterior instability may be observed [4].

In cases of long-standing tears with high fatty degeneration (Goutallier stage ≥ 2) [5], big defect, tendon retraction and muscular atrophy, direct repair is not possible, with retear rate between 50 and 70 % when it is attempted [6]. In patients with an irreparable tear of the subscapularis tendon, the superior one-half to two-thirds of the tendon of the pectoralis major muscle has been described as a substitute muscle-tendon unit [7]. This has been proposed as a salvage procedure that provides satisfactory results for pain and function [7, 8]. This tendon transfer was firstly proposed by Resch et al. [7] in 2000, with the tendon stump routed behind the conjoined tendon of the coracobrachialis muscle and the short head of the biceps to the lesser tuberosity, in order to adapt the orientation of the transferred muscle to that of the subscapularis.

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Operative Technique (According to Resch et al. [7])

General anesthesia is initiated and the patients are placed in the beach chair position. The arm is draped flexibly.

Using a deltopectoral approach, the clavipectoral fascia is opened and the deltoid muscle is bluntly separated from the pectoralis major muscle until the humeral insertion of the pectoralis is exposed. Directly at the insertion, a horizontal split of the upper two-thirds and the lower third of the tendon is created and the upper two-thirds of the tendon are harvested together with a bone chip taken from the humeral corticalis. In order to do so, a superficial dent around the tendon insertion is performed inferiorly, laterally, and superiorly using a chisel. Then, the undersurface of the tendon is exposed using Hohmann retractors and the bone chip is harvested performing a tangential osteotomy starting medially from the insertion of the proximal two-thirds of the tendon (modified fixation technique) [9]. Alternatively, the tendon can be sharply detached with a scalpel (standard technique). Two traction sutures are applied to the free end of the tendon and the corresponding muscle fibers are separated from the remainder of the pectoralis muscle for a length of about 10 cm (Fig. 1a, b). Next, the conjoint tendon is exposed from lateral as well as from medial, paying attention to the musculocutaneous nerve running close to the conjoint tendon on the medial side within fatty tissue. It is highly recommended to clearly envision the nerve before performing the transfer in order to avoid entrapment of the nerve. Once the subcoracoid space is freed, a finger is used to bluntly pass the subcoracoid space from lateral to medial underneath the conjoint tendon, preventing any neurovascular entrapment. Using the finger as guide, the tendon transfer can be executed (Fig. 2). The bursa and capsule above the lesser tuberosity are removed, and the former footprint area of the subscapularis tendon is exposed. A superficial crevice of 2 cm length, 5 mm width, and 2 mm depth is created in the area of the lesser tuberosity in order to form an insertion site for the bone chip attached to the tendon. If the length of the transfer

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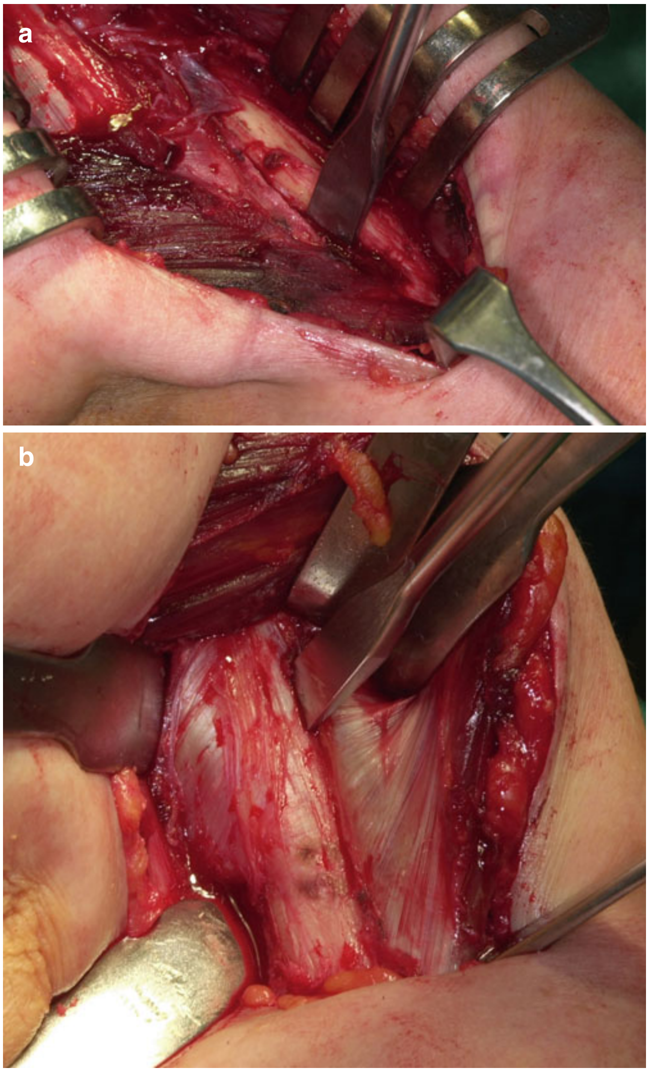

Fig. 1 Bony tendon harvesting from the bottom (**a**); Bony tendon harvesting from the top (**b**)

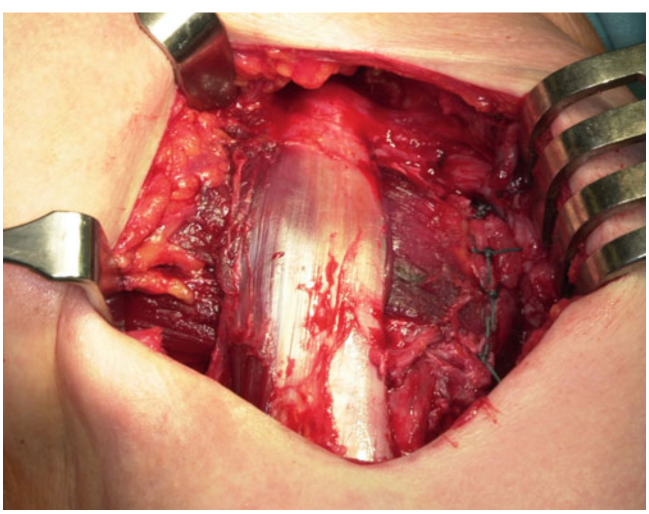

Fig. 2 Subcoracoid passage of the tendon

is insufficient to reach the lesser tuberosity, further mobilization of the muscle needs to be performed. If the transfer is too long, the insertion site should be slightly moved toward lateral to avoid under-tensioning. The insertion is performed transosseously with nonabsorbable suture material firmly attaching the bone chip to its insertion site. While rotating the arm, the stability and right pre-tension of the transfer can be checked. At the end of surgery, a drainage should be positioned to avoid hematoma and possible secondary neurovascular lesion. After skin closure, usually performed with nonabsorbable sutures, the arm is positioned in a 15° abduction pillow.

Postoperative Rehabilitation

Passive range of motion exercises are started the third day after surgery and limited to 30 degrees of flexion and 80 degrees of internal rotation for 6 weeks, with progressive increase in range of motion in each week. External rotation is permitted until neutral position. Then, after 6 weeks, active range of motion is allowed, including external rotation. At 3 months after surgery, strengthening of rotator cuff muscles is started, with a minimum of additional 2 months of rehabilitation.

The proposed technique, with the two alternative fixation methods (with and without bone chips), are suitable for irreparable ruptures of the subscapularis muscle as well as for anterosuperior defects of the cuff (Bateman III-IV, AB Patte) [10, 11]. In literature, reported results show satisfactory results in terms of improvement of function and reduction of pain, especially in those cases with isolated subscapularis rupture [7, 8, 12]. The pectoralis tendon transfer certainly provides a safe and promising method for the treatment of irreparable ruptures of the subscapularis tendon. A secure method of fixation that avoids secondary ruptures is of high importance. Jost et al. [8] reported that patients with pain localized in the insertion area (60 %) could have an insufficient insertion, and for this reason, the authors changed their fixation method from suture anchor to transosseus. The fixation method is of essential importance because the pectoralis muscle exhibits a high level of traction. The alternative technique with bony fixation was proposed to address it, with osseous healing more stable and predictable. This is supported by the finding that lesser tuberosity osteotomy compared to subscapularis tenotomy has lower rate of tear and higher functional scores [13, 14].

Another point of debate is the pathway of the transferred tendon. A recent biomechanical investigation has shown that rerouting the conjoined tendon is a good way to imitate the natural force vector and function of an intact subscapularis tendon [15]. Specifically, a transfer underneath the conjoint tendon better mimics glenohumeral kinematics (the maximum abduction angle as well as the external rotation angle and humeral translations at maximum abduction) that are closer to those in the intact shoulder than a transfer above the conjoint tendon.

The main reported complication of the pectoralis major tendon transfer is injury to the musculocutaneous nerve [8, 16]. In a recent study, it is shown that the anatomical variation in the musculocutaneous nerve branches may compromise the nerve integrity and function in approximately half of cases when a subcoracobrachialis pectoralis major transfer is performed [17]. Moreover, in 21 % of cases, there is not even enough space between the coracoid and the nerve branches to accommodate the transferred sternal portion of the pectoralis major muscle [17]. Authors of the latter study conclude that it might be unsafe to perform a subcoracobrachialis transfer in many shoulders [17]. To avoid iatrogenic injuries to the nerve, it is essential that the musculocutaneous nerve and its branches are identified since local variations may produce undesired contact between the transferred muscle and the nerve.

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Biceps Tenodesis Augmenting Repair

Jeffrey S. Abrams

The massive rotator cuff tear is a challenging problem for the shoulder surgeon [1–3]. Large and massive tears include multiple rotator cuff tendons with varying degrees of retraction [4]. Treatment of multitendon tears may result in a residual defect following arthroscopic or open repair [5–7].

The tear crosses the rotator cuff interval and commonly includes the long head of the biceps and the supporting pulleys [8]. Symptoms resulting from a torn or unstable biceps can be disabling [9, 10]. Several authors have suggested tenotomy, and other have performed tenodesis for the painful shoulder cuff tear associated with a biceps tendon that has not ruptured [10, 11]. Both tenodesis and tenotomy have reduced the painful symptoms in patients with a massive tear. These procedures, however, have not improved the functional deficits [12].

The goals of arthroscopic rotator cuff repair include closure of the defect and correct other painful lesions within the shoulder. At times, the entire defect cannot be closed due to tissue attrition and retraction. In these cases, partial closures have been performed with decrease in pain, but shoulder weakness can persist [13]. An option proposed by open surgeons [1, 14, 15] and more recently by Castagna [16] was to arthroscopically incorporate the biceps tenodesis into the residual defect of the cuff repair. This chapter will present the techniques used to surgically repair a massive rotator cuff tear and perform a biceps tenodesis, reinforcing the retracted supraspinatus tendon.

Patient Selection

Preoperative evaluation includes shoulder range of motion and stability. Patients often present following a traumatic event that has created painful restricted range of motion or reduction in the ability to lift the arm due to pain and weakness (Fig. 1). Common complaints include difficulty sleeping at night, painful daily activities, and weakness when using the arm away from their torso. Many try a period of physical therapy and there may be a reduction in pain, but the weakness and loss of sleep can persist.

The examination is used to distinguish active and passive ranges of motion. Some shoulders develop stiffness after a traumatic anterosuperior tear [17]. Most will have a near to normal passive range of motion. Weakness during attempts at elevation, external rotation, and belly-press signs are common in shoulders with multitendon tears. The examiner should evaluate internal rotation weakness with liftoff, belly-press, and bear-hug signs [4]. External rotation weakness can be assessed and compared to the uninjured side (Fig. 2). Reduction of elevation can be the result of pain, and can be altered with an injection. True anterosuperior glenohumeral escape, when chronic, may require a different approach, and a soft tissue repair may be inadequate to improve the functional loss.

Imaging studies should include radiographs in an upright patient. Maintenance of the acromiohumeral interval and a normal-appearing acromion are important features of a shoulder that has maintained the humeral head concentric position. Advanced glenohumeral arthritis may require an arthroplasty to reduce the articular symptoms of incongruity of the surfaces to improve pain and function.

Additional imaging studies include magnetic resonance imaging or computerized technology with or without articular contrast. Changes in the muscle trophicity may indicate the chronicity of muscle changes and influence the ability to improve the shoulder following a repair.

The ideal candidate for surgical repair is one that has been functioning well with little or no shoulder pain, and is injured acutely, changing their shoulder function. Their exam would demonstrate a multitendon deficit, in an otherwise stable shoulder. Imaging studies would demonstrate minimal or no glenohumeral arthritis and minimal superior humeral head migration. The MRI would demonstrate a multitendon tear with supraspi-

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natus retraction, an intact biceps tendon, and grade I or II muscle changes as presented by Goutallier [18, 19].

Technique

The shoulder is examined under anesthesia. A full range of motion can be demonstrated and if not, gentle manipulation will reverse any adhesions that may restrict motion. The patient is then positioned for arthroscopic repair in either the beach chair or lateral decubitus position.

A posterior portal is created 2 cm inferior to the junction of the spine of the scapula and posterior extension of the acromion. After irrigation of the articulation, an anterior portal is created inferior to the acromioclavicular joint, entering into the rotator interval. After achieving satisfactory flow, a systematic examination of the glenohumeral joint is performed.

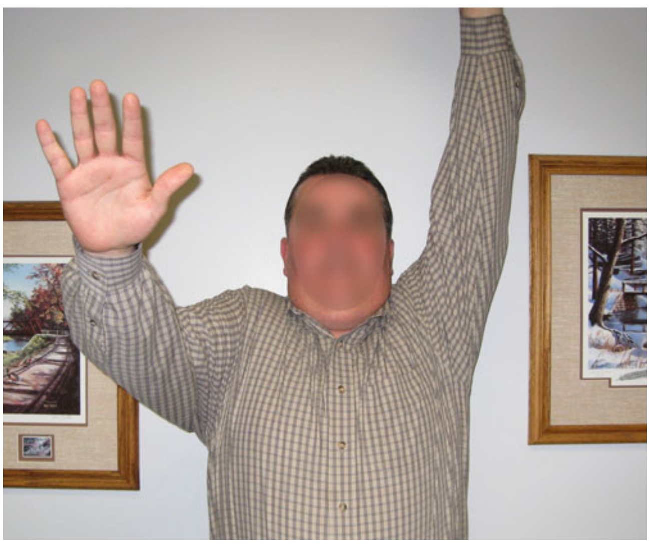

Fig. 1 Traumatic injury to right shoulder with inability to forward flex

The superior border of the subscapularis is visualized and its relationship to the long head of the biceps. The medial pulley is often detached and can retract toward the glenoid edge, creating a "comma sign" (Fig. 3). The middle capsular ligaments may remain intact, hiding a retracted subscapularis tendon. The supraspinatus tear is confirmed, and the footprint and articular margin are identified.

The scope is then switched to the anterior portal and the posterior extension of the tear is revealed. A posterior capsulotomy can be performed, which extends inferiorly, allowing improved internal rotation. Further inspection of the subscapularis can visualize the lesser tuberosity footprint and amount of retraction.

The arthroscope is placed within the subacromial bursa and a brief debridement is performed to understand the tear pattern and muscle and tendon quality. A lateral portal, 3 cm lateral to the anterior margin of the acromion, is created.

Once the diagnostic arthroscopy is completed, the arthroscope is placed in the posterior articular portal. A suture is placed in the long head of the biceps and a tenotomy at this junction of the superior labrum is performed (Fig. 4).

An arthroscopic subscapularis repair is completed using both the articular and bursal viewing portals. Any medialization or tendon retraction should be reduced without complete division to the pulley and the coracohumeral ligaments. This additional tissue can provide additional length to reduce the tension of the repair. At the completion of the repair, the surgeon should confirm a safe interval between the repair and the coracoid process and short head of the biceps and brachioradialis. Gentle rotation will confirm this interval.

The arthroscope is now placed in the posterior portal, entering within the subacromial space. There is often a partial reduction of the supraspinatus tear following the

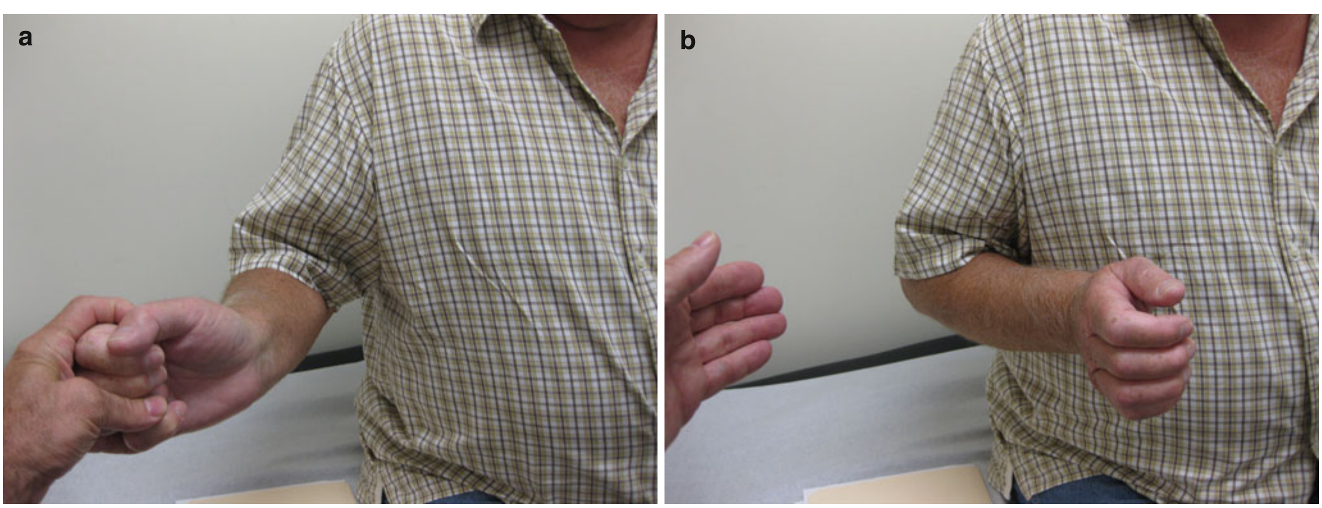

Fig. 2 External rotation lag sign. (**a**) Passive assist external rotation. (**b**) After releasing, the arm returns to internal rotated position

subscapularis repair. Posterior medial retraction is common, and the multiple delaminations within the infraspinatus can often be seen from a lateral viewing portal. Anteriorly, additional bursal releases can be performed adjacent to the coracoid's lateral border. A modified acromial decompression is performed without complete detachment or resection of the coracoacromial ligament. Any significant osteophytes from the anterior margin of the acromion or clavicle are resected with a burr. Preservation of the coracoacromial ligament insertion may be important in providing stability to the anterior aspect of the humeral head. Following debridement and decompression, additional viewing space allows instrumentation and tissue mobilization. Preparation of the greater tuberosity includes a gentle debridement of devitalized tissue.

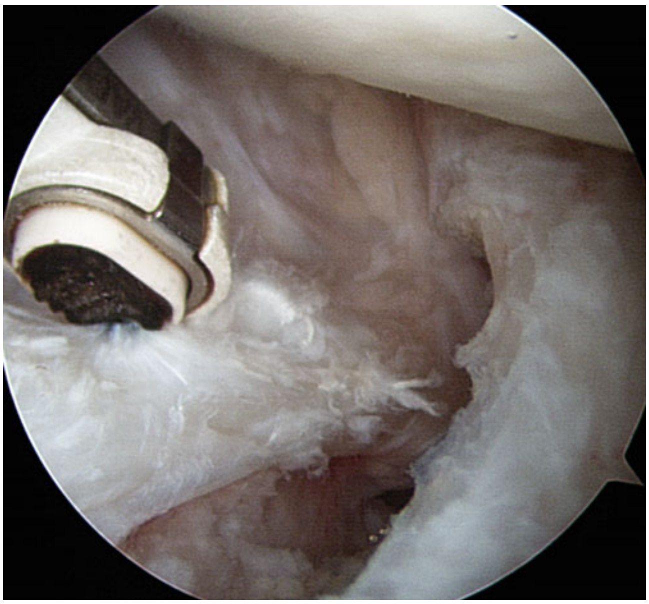

Fig. 3 Retracted subscapularis tear with connected pulley capsular ligaments creating a comma sign

A percutaneous placed posterior anchor is used to reduce multiple layers and reattach the infraspinatus and posterior margin of the supraspinatus with multiple mattress sutures (Fig. 5). When multistitch anchors are used, a stitch is retracted for biceps reattachment. A second anchor is placed anteriorly on medial margin of the greater tuberosity. Sutures are passed through the supraspinatus as simple, mattress, or combination for optimal security. The posterior sutures are tied first to confirm proper tension, followed by the anterior sutures.

The long head of the biceps is then aligned transversely as the anterior anchor stitch is placed approximately 3–4 cm from the cut edge. As this suture is tied, the biceps will no longer retract and is fixed at this point. The posterior anchor free stitch is passed through the biceps approximately 1.5 cm from the end and tied. The free edge of the biceps is sewn into the infraspinatus tendon, providing additional strength of the repair (Fig. 6). In patients with incomplete repair of the supraspinatus, the defect is often covered by the transferred biceps that has been tenodesed (Fig. 7). For patients with a thin repair, the supraspinatus tendon can be augmented or reinforced adjacent to the footprint attachment (Fig. 8).

Postoperatively, patients are placed in a neutralized shoulder splint and allowed to perform pendulum exercises. I add an Ace wrap to the upper arm for support and comfort (Fig. 9). No active elevation or passive terminal movements are allowed for 5 weeks. Physical therapy will begin after

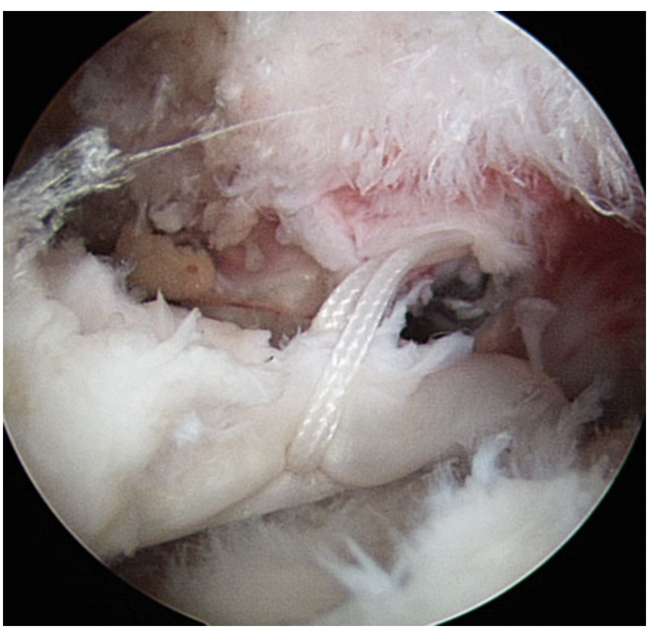

Fig. 4 A suture is placed through the long head of the biceps prior to tenotomy

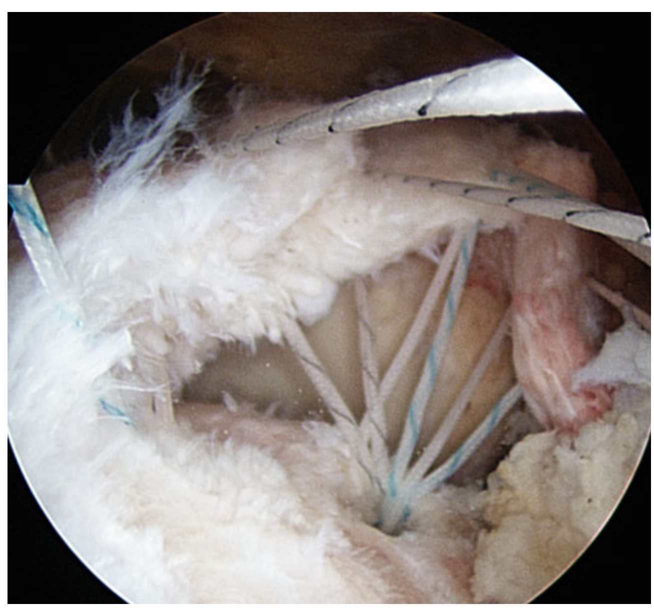

Fig. 5 Lateral arthroscopic view of repair of delaminated infraspinatus tendon

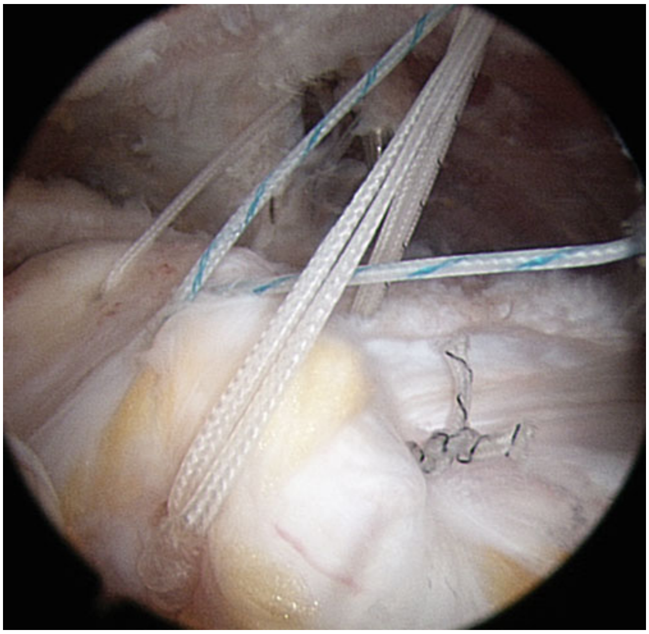

Fig. 6 After suture anchor fixation, the free edge of the biceps is attached to the infraspinatus

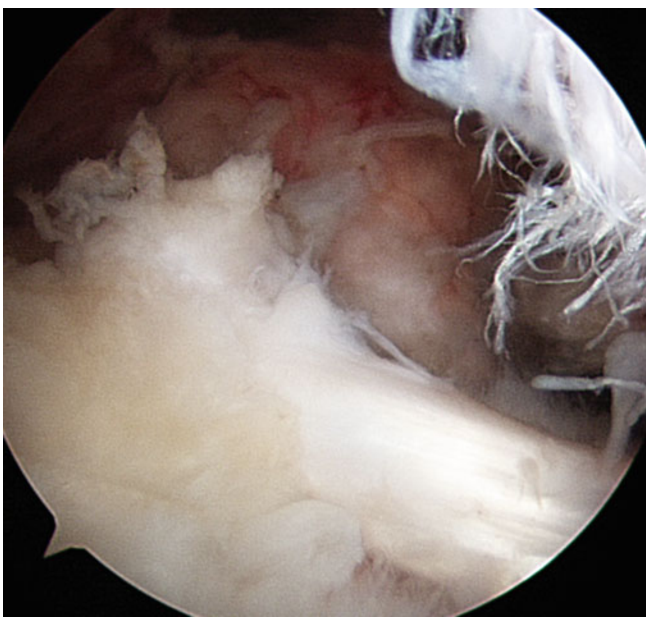

Fig. 7 In patients with incomplete repair of the supraspinatus, the biceps can be used to bridge the cuff defect

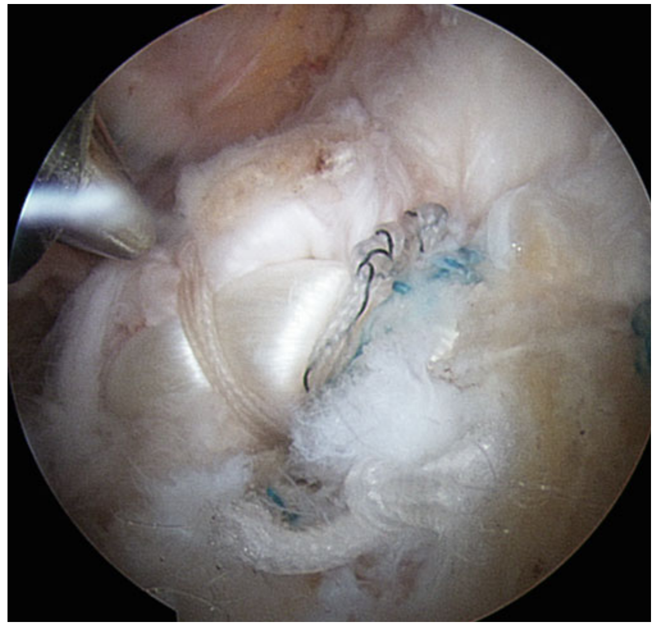

Fig. 8 In patients with a thin repair, the biceps tenodesis can be incorporated into the anchors for an augmented repair

Fig. 9 Postoperative protection with a supportive Ace wrap following biceps tenodesis

sling removal and supine passive flexion; table slides and continued pendulums will begin the gradual progression. Resistive exercises are delayed for 10–12 weeks.

Results

Fifty-three shoulders were arthroscopically repaired using the described technique. Forty-eight of the shoulders had a complete repair of the supraspinatus prior to transfer, and five had incomplete repair of the supraspinatus and the transferred biceps was used as a graft to close the defect. Of these shoulders, 12 were revision cases that followed failed prior attempts at repair. The average age was 61 years, ranging from 45 to 76 years old.

The satisfaction rate was 85 %, with most returning to an active lifestyle. Range of motion was improved in 78 %, and active elevation was regained in 23 shoulders of 27 that could not flex above 90° before surgery. There was one biceps deformity, in a patient with satisfactory pain relief and returned to function. Two patients, both with workmen's compensation claims, had persistent pain and underwent repeat MRI studies and had recurrent defects. Both patients felt that there had been improvement, but continued symptoms did not allow a return to full activity. Night pain was improved in most shoulders, particularly if there was minimal joint degeneration.

There were no infections and patients did not require treatment for persistent stiffness. Two patients underwent a reverse shoulder arthroplasty for anterosuperior escape and continued pseudoparalysis. In both of these patients, the choice of soft tissue repair was noted to have risk of failure but patients were considered too young for the arthroplasty alternative at the time of their initial consultation. The arthroplasty stabilized their shoulder and improved their forward flexion. External rotation lag signs persisted in these complex shoulder deficits.

Conclusions

The massive rotator cuff tear has several components that make this difficult to treat. There is often a chronic component that is extended with additional injury. As a result, there is often a retracted shortened supraspinatus muscle tendon unit. Over time, the biceps may degenerate or hypertrophy to compensate. Repairing the upper portion of the subscapularis and infraspinatus can reestablish the superior stability to the humeral head. A persistent defect or a thinned repair of the supraspinatus may be a likely result following arthroscopic repair.

The option of incorporating the long head of the biceps can be applied to the deficient supraspinatus tendon after securing at the upper aspect of the bicipital groove should be considered. This can be utilized in patients with massive rotator cuff tears that can be repaired with concern of thin tissue, or used in patients with partially reparable massive tears that benefit from a bridge covering the defect. This can be accomplished with a combination of stabilization with the medially placed anchors and soft tissue repair to the infraspinatus. Complete coverage of the superior and posterior articular surfaces can be accomplished, leaving an open rotator interval defect lateral to the coracoid. Symptomatic and functional improvement is common. It is not known how long the improvement will be present, and there is a possibility that reverse arthroplasty is a potential surgery in these patients' futures. Due to age, activity demands, patients informed selection, and reduced risk of infection, this has become a favorable option for some patients with a massive rotator cuff tear. It is possible, as noted by some authors, that biceps tenotomy or tenodesis without attempting repair would improve symptoms [11]. Active rotation is best treated with repair of the anterior and posterior components of the rotator cuff deficiency.

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Subscapularis Tear: Intraoperative Evaluation and Treatment

Raffaele Garofalo, Brody F. Flanagin, Alessandro Castagna, and Sumant G. Krishnan

Introduction

The subscapularis represent the anterior portion of rotator cuff and it is very important to stabilize the shoulder on the coronal and on the transverse plane. Balancing the coronal and transverse plane force couple is essential in providing a stable fulcrum for glenohumeral joint motion [1]. In a cadaveric study, some authors noted that when an anterosuperior rotator cuff tear extends into the upper subscapularis, glenohumeral joint kinematics start to be altered [2]. Conversely, glenohumeral kinematics were not altered in presence of an isolated tear of the middle portion of supraspinatus tendon. The upper part of the subscapularis tendon, in fact, is the zone where the fibers of subscapularis fuse with the most anterior fibers of supraspinatus tendon forming the anterior cable. Subscapularis tears usually originate proximally in the upper band and tend to propagate distally to the lower band. An EMG study showed, however, that the lower subscapularis has significantly higher muscle activity during shoulder elevation and this reflect its greater role as a humeral head depressor and anterior stabilizer [3]. A recent clinical paper confirmed this evidence, and furthermore showed that a dysfunction of the entire subscapularis (upper and lower part) and supraspinatus was associated with the loss of active elevation and was a risk factor to develop a pseudoparalytic shoulder [4].

A subscapularis tendon tear can be isolated or more usually associated with other rotator cuff tendons tear. If we think about the function of the subascapularis, we can understand how a failure to identify and treat an injury of this tendon can lead to a disabiliting shoulder.

Shoulder arthroscopy offers the surgeon the possibility to better evaluate subscapularis pathology. Bennett et al. reported a 27 % rate of subscapularis pathology in a series of 165 patients with a shoulder pathology treated arthroscopically [5]. A completely torn subscapularis tendon is prone to retraction and the development of irreversible changes of the muscle. After a delay of several months or longer, repair of the retracted tendon can be difficult or impossible.

Anatomy and Pathology

The subscapularis muscle is the largest and most powerful of the four rotator cuff muscle. The muscle originates from the anterior surface of the scapula and typically is split into the upper two thirds and lower third. The subscapularis insertion area has been described as trapezoidal; it is widest superiorly and gently tapers as it extends inferiorly. The superior-to-inferior footprint length is approximately 25 mm, and the average width is approximately 17 mm superiorly and 3 mm inferiorly [6]. The upper two thirds insert on the lesser tuberosity, whether the lower, muscular part wing onto the humeral metaphysis. The upper tendinous portion is what can be visualized arthroscopically. The upper portion of the subscapularis tendon interdigitates with the anterior fibers of the supraspinatus tendon and contribute together with coracohumeral ligament to form the anterior part of rotator cuff cable. From the intra-articular point of view, the insertion of upper part of subscapularis is at the same level of superior glenohumeral ligament, which contributes to form the medial sling of pulley system of LHBT.

Most subscapularis lesions involve the superior lateral insertion of the tendon at its insertion on the lesser tuberosity. When the ligamentous pulley complex is intact, this lesion is not visible during gross inspection of rotator cuff. When the pulley system is divided, subscapularis lesion is identified as a bare area of bone at the superior aspect of the

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lesser tuberosity [7]. Most part of these tears, in fact, are deep or articular sided, partial, and degenerative [8]. These lesions could be observed by an accurate intrarticular arthroscopic view. In case of complete tear of subascapularis tendon, the lesion could be easily observed also with a gross inspection of rotator cuff.

Isolated subscapularis tears are relatively uncommon and, however, when isolated, are more commonly associated with trauma in comparison to other types of rotator cuff injuries. Isolated tears are associated with a trauma in a forced external rotation in an adducted arm [9] or abducted arm [10]. Subscapularis tears more often are associated with degenerative tear of other rotator cuff tendons and tend to progress in a medial and inferior direction. A lesion of the subascapularis can cause inflammation and distension of the ligamentous pulley and bicipital sheath, ultimately destabilizing the biceps (LHBT) within its groove. The superior insertion of the subscapularis may be the most important restraint keeping the LHBT in place. Anatomical studies showed that the most upper part of subscapularis tendon is the zone where the superior glenohumeral ligament and the medial head of the coracohumeral ligament inserted to form a part of the complex pulley system (Fig. 1). The reported prevalence of LHBT lesions associated with subscapularis tears ranged from 63 to 85 % [11].

Different age groups often present with a different injury pattern of the subscapularis tendon (Fig. 2). Middle-aged athletes may sustain a traumatic isolated subscapularis tear or an anterosuperior cuff tear, which can range from articular-sided partial tears with instability of long head of biceps to large tears combined with pain and stiffness (Fig. 3).

Elderly peoples, on the other hand, may present with a massive tear that is often the result of an acute extension of a prior minimally symptomatic chronic tear (acute on chronic tear), leading to instability and possible pseudoparalytic shoulder sometimes associated with an anterosuperior escape (Fig. 4). Often, in these patients, the trauma consisted in an anterior shoulder dislocation.

Classification

Different classification has been proposed for subscapularis tear classification. Generally, the subscapularis tears could be classified as partial or complete, retracted, and no retracted. The more recent classification of Lafosse classification distinguishes subascapularis tears into five types: type I tear is a simple erosion of the upper third of the tendon without any disconnection to the bone; type II is a complete lesion of the superior one-third of the tendon; a type III lesion is characterized by involvement of all the insertion of the tendon without detachment of the lower third of the muscular portion. In type IV tears, the subscapularis tendon is completely detached from the lesser tuberosity and the humeral head is centered within the joint, and fatty degeneration less than or equal to stage 3. In a type V lesion, the lesion is complete, the humeral head is translated anteriorly and superiorly, with coracoid impingement and fatty degeneration of the muscle fibers of the subscapularis more than stage 3 [12].

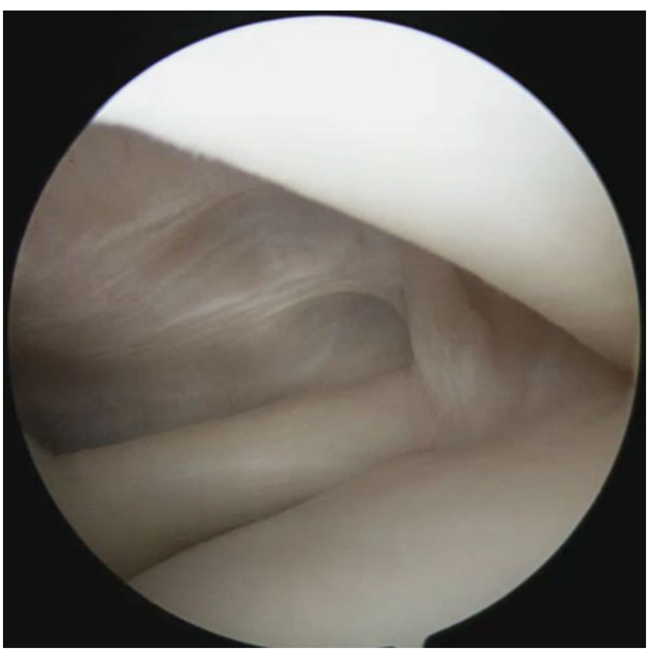

Fig. 1 Right shoulder. Intra-articular view from the posterior portal. The superior border of subscapularis tendon is intact and creates the foundation supporting the medial pulley to the long head biceps tendon (LHBT)

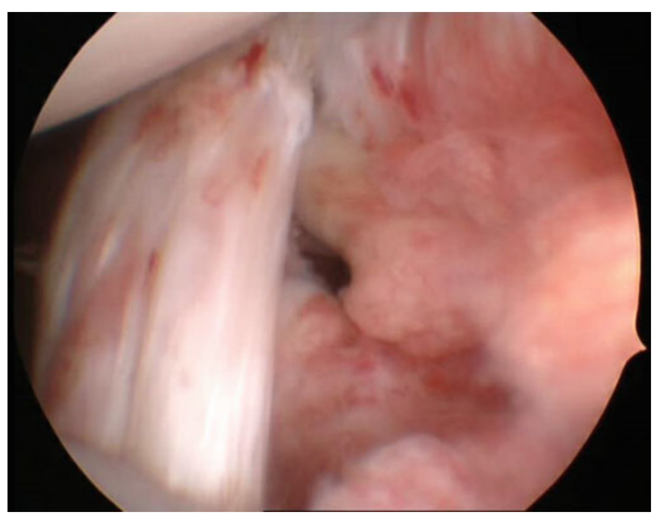

Fig. 2 Left shoulder observed through a posterior portal. A degenerative tear of the upper part of the subscapularis tendon at insertion on lesser tuberosity could be observed

Clinical Evaluation and Imaging

The clinical presentation for injury of the subscapularis tendon are extremely variable, particularly because the injury could be acute and traumatic versus degenerative.

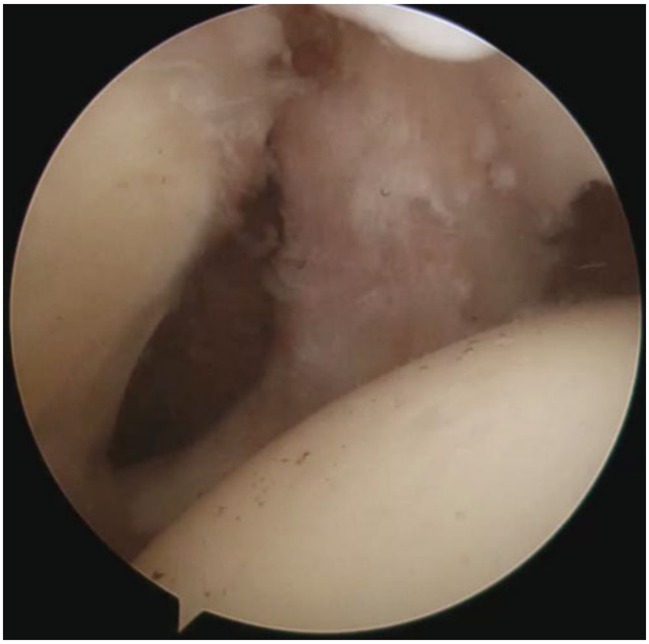

Fig. 3 Right shoulder observed through a posterior portal. An antero-superior large tear could be observed. Glenoid on the *left*, humeral head on the *right*. Subscapularis tear with interval slide in continuity and supraspinatus tear on the *upper right side* is noted

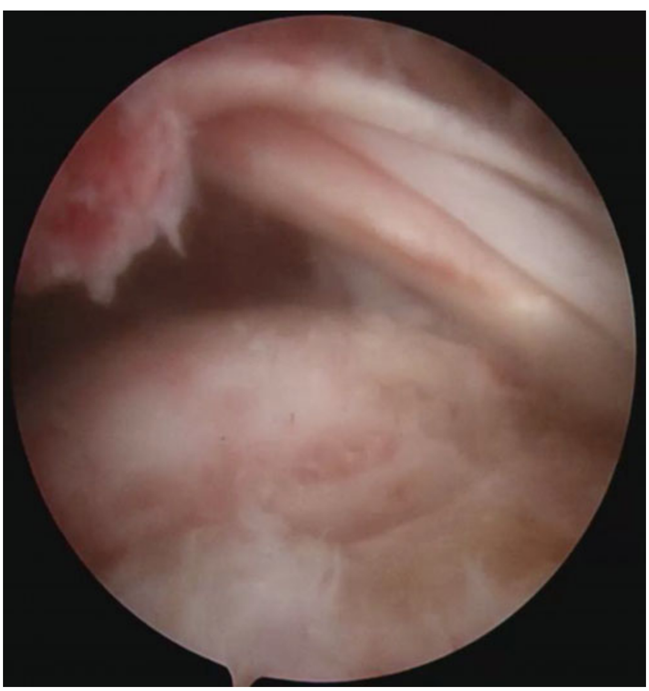

Fig. 4 Subacromial view of a right shoulder. A massive rotator cuff tear involving the subscapularis tendon too. The LHBT is visible. Acute on chronic tear

Patients with tears of the subscapularis may complain of achy, anterior shoulder pain as well as weakness with abduction and internal rotation. Tenderness in the anterior region over the bicipital groove and lesser tuberosity is very common, particularly in acute cases. In chronic cases, this could be confounding just because symptoms related to LHBT are commonly associated with cuff pathology. Tucking one's shirt in the back may be particularly troublesome as this requires coupled internal rotation and extension. Since the proximal LHBT derives medial stability from the subscapularis tendon insertion, biceps tendon symptoms may be present with a subscapularis tendon tear.

Examination findings include increased passive external rotation, especially in adduction, as well as loss of internal rotation strength. The "Belly-Press" test (or Napoleon test), where upon the patient attempts to apply pressure to the abdomen while maintaining a straight wrist, has been shown to be reasonably sensitive for subscapularis tears. A decrease in the ability to maintain a forward position of the elbow compared with contralateral side is also considered positive for insufficiency of subscapularis tendon. This test and lift-off test has been described by Gerber et al. [9]. A prerequisite to perform the lift-off test is that patient should have a minimal pain with motion and should be able to internally rotate the arm. A positive test occurs when the patient is unable to lift or maintain the hand away from the back.

The "Bear-Hug" test, first described by Barth et al. [13] has been shown by Chao and Thomas et al. [14] to be perhaps the best test for detecting upper subscapularis tendon tears. To perform this maneuver, the examiner asks the patient to place the involved side hand on the contralateral shoulder with the elbow in 45° of forward flexion and the fingers extended. The patient then attempts to resist an external force by trying to pull the hand away from the shoulder in a perpendicular fashion. The test is positive when the patient is unable to put the hand on the opposite shoulder or shows weakness compared with contralateral shoulder. The bear-hug test is particularly sensitive and specific for tears of the upper subscapularis. Sometimes this test could be only painful, but this is not sensitive for a subscapularis tear.

About the imaging, plain radiographs (X-ray) are the initial studies required for patients with a suspected rotator cuff tear. X-rays normally are negative and do not give direct information of a subscapularis tear. In case of long-standing massive rotator cuff tear, a superior migration of humeral head could be observed, or in case of subscapularis chronic tear, a reduction of the coracohumeral distance can also be observed. Additional studies, however, are necessary to evaluate subscapularis, including magnetic resonance imaging (MRI), MRI with intrarticular contrast injection (arthro-MRI), CT arthrography (CTA), and ultrasonography (US).

The US could be able to detect a tear of subscapularis and allows dynamic evaluation of the tendon and LHBT. However, it does not have any ability to show fatty infiltration, muscle

Fig. 5 MRI of a right shoulder. Axial view. Detachment of the subscapularis tendon (*arrow*)

atrophy, and grade of tendon retraction. The presence of fatty infiltration and muscle atrophy has been correlated with a bad prognosis after repair. According to some authors [7], CT scan with or without arthrography is very useful to diagnose the injury of anterosuperior rotator cuff. About the MRI, Tung et al. reported that only 31 % of subscapularis tears confirmed at arthroscopy were detected at preoperative time on standard MRI [15] (Fig. 5). In particular, the small tears were frequently missed, whereas tears involving 50 % or more of the tendon insertion were more readily detected. Another study confirmed these findings, even when arthro-MRI was used. In this study, subscapularis tears were identified in 40 shoulders at the time of arthroscopy, whereas a lesion was identified in only 15 shoulders in a preoperative MRI. These findings indicate that sensitivity to identify subscapularis tears does not dramatically increase even with the use of arthrography, particularly in case of smaller partial thickness tear [16].

Treatment

Different considerations should be done before to discuss the options of treatment. First of all, as with the other tendons of rotator cuff, in cases with a small, degenerative tear in low-demand patients, a conservative treatment could be attempted. No steroidal anti-inflammatory drugs, injections, and physical therapy to improve pain and function are the mainstay of this treatment. On the other hand, an acute traumatic tear of the subscapularis muscle more typically should be repaired surgically as soon as possible. This tendon, in fact, is prone to retraction and early irreversible changes of the muscle. Inferior clinical results have been reported with delayed repair of subscapularis tear, and, in many cases, the subscapularis was found not repairable at the time of surgery [17]. As discussed before, the anterosuperior tear often results by a traumatic event. Often, these patients come to our attention because of pain, loss of function, and stiffness after a trauma. Stiffness could be probably related to the proximity of LHBT and rotator interval. These patients could be treated with physical therapy and planned repair. During surgery, a release of rotator interval should be done. Some authors believe that, given the critical role of the subscapularis in glenohumeral kinematics, even in the presence of a complete long-standing tear with a substantial fatty infiltration, an attempt to repair the subscapularis also for its tenodesis effect should be done [18, 19]. Other authors, however, think that patients with evidence of fatty degenerated subscapularis tendon, associated massive posterior rotator cuff tear, or with a static anterior subluxation of humeral head should not undergo a repair operation.

The biomechanical rationale to repair the subscapularis becomes most important in case of an anterosuperior rotator cuff tear. The anterior part of supraspinatus and superior part of subscapularis are connected by a comma-shaped arc of tissue called the comma sign. The comma sign is very helpful to find the subscapularis tendon, particularly in chronic cases when the subscapularis retract medially to the glenoid (Fig. 5). The comma sign represents the superior glenohumeral ligament and the medial segment of the coracohumeral ligament that are torn off the humerus at the upper border of the subscapularis footprint [20, 21]. Repairing the upper part of subscapularis together with comma system restores a part of the anterior attachment of the rotator cable.

For the repair of subscapularis tendon, arthroscopic and open techniques have been described.

Open technique could be a good option in rare case of isolated traumatic tear of subscapularis tendon, particularly when the lesion involves all the length of the subscapularis (tendon and muscular portion). Open surgery is also indicated for the management of extra-articular lesions or tears involving the myotendineous portion.

The subscapularis can be arthroscopically repaired with the patient in a beach chair or lateral decubitus position. We use four portals to work around the shoulder. Posterior, anterosuperior, and two subacromial portals (Fig. 6). We use a 30° arthroscopy during the entire procedure. Proper manipulation of the arm can be useful for visualizing the subscapularis. Bringing the arm into forward and internal rotation could be useful to examine the tendon.

In the lateral decubitus, the so-called posterior lever push, in which the assistant applies a lever from anterior to posterior associated with an internal rotation, could help to better visualize the tendon and the extent of the lesion.

Once the lesion is identified, we start to prepare and repair.

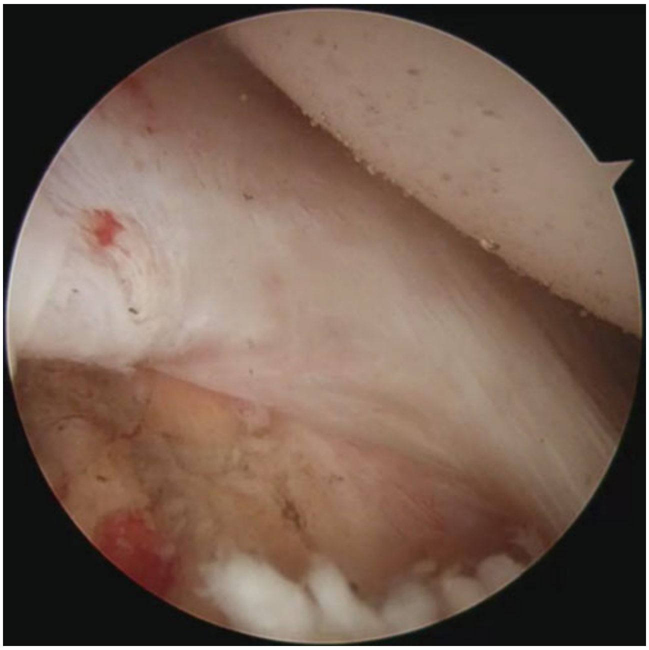

Fig. 6 Intra-articular view of a right shoulder. The subscapularis tendon is torn and retracted and the comma sign is evident. The comma sign is a combination of medial pulley, coracohumeral ligament, and interval capsule

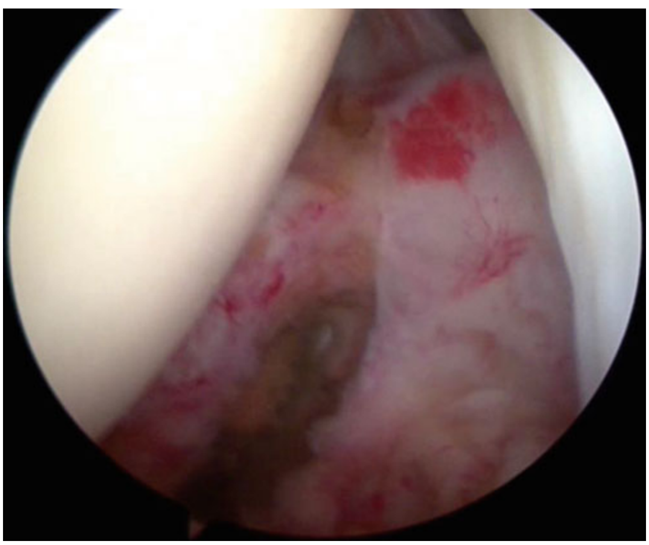

Fig. 7 Intra-articular view of a left shoulder. The subscapularis tendon is torn, the associated detachment of superior glenohumeral ligament is seen (comma sign). The LHBT is unstable

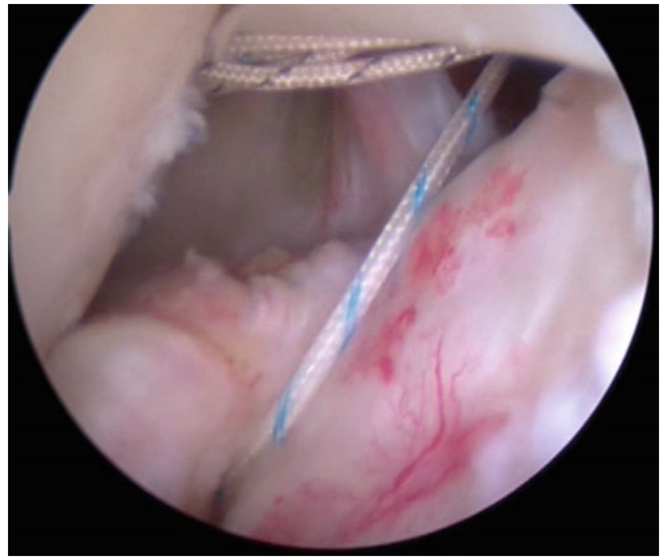

Fig. 8 Intra-articular view of a left shoulder from the posterior portal. A single triple-loaded anchor is inserted at the level of footprint and repair of subscapularis tendon is started

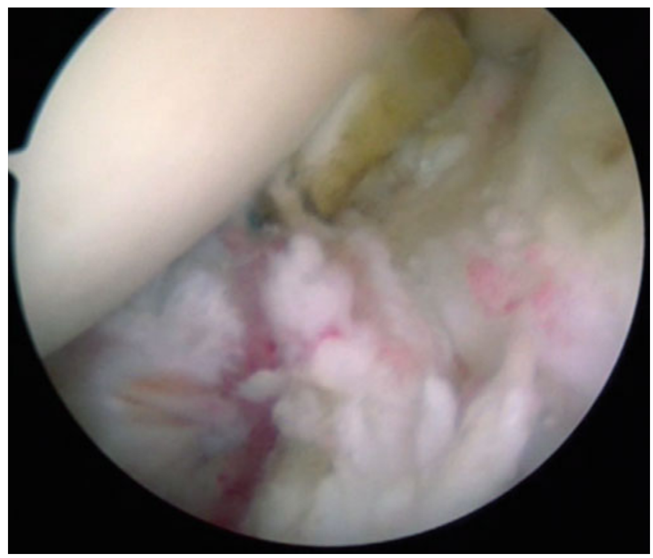

Fig. 9 Intra-articular view of a left shoulder from the posterior portal. The final repair of subscapularis tendon is shown with an associated tenodesis of LHBT

In case of isolated tear of subscapularis tendon, many authors suggest to treat this tear and associated LHBT pathology (fraying/tearing, instability, or tenosynovitis) through an intrarticular approach using the suture anchor technique (Fig. 7). One posterior and one anterosuperior portal could be enough to treat this tear. One or two triple-loaded suture anchors using a mattress stitch associated with two simple stitches could be used (Fig. 8). Suture could be passed with different tools according to the preference of the surgeon. In general, one anchor per linear centimeter of torn tendon should be used. When using anchors, most subscapularis tears could be repaired with a single-row technique with good results [22]. There is a high correlation between subscapularis tear and LHBT pathology, and often the LHBT pathology should be treated at the same time the subscapularis tendon pathology. If the LHBT is altered in the groove, a tenotomy or an associated tenodesis (subpectoral tenodesis) with a screw could be done

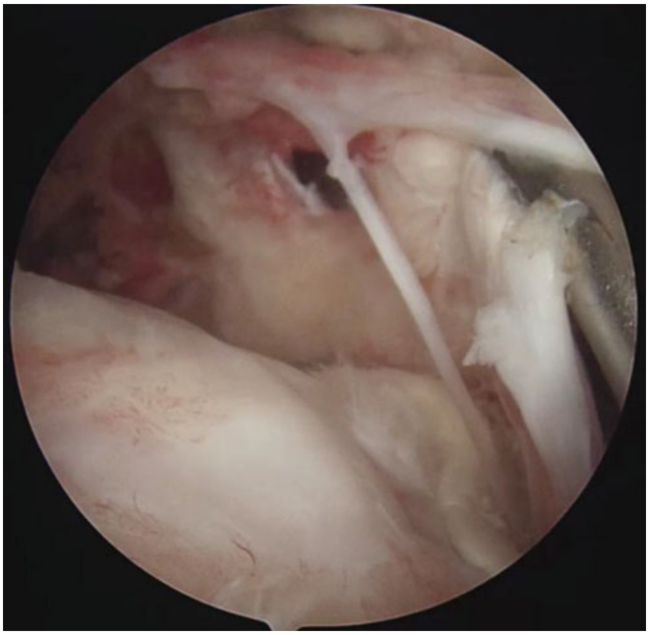

Fig. 10 Right shoulder: The scope is on the posterolateral portal. A grasper is inserted from anterolateral portal. Subscapularis tear with interval slide in continuity is shown

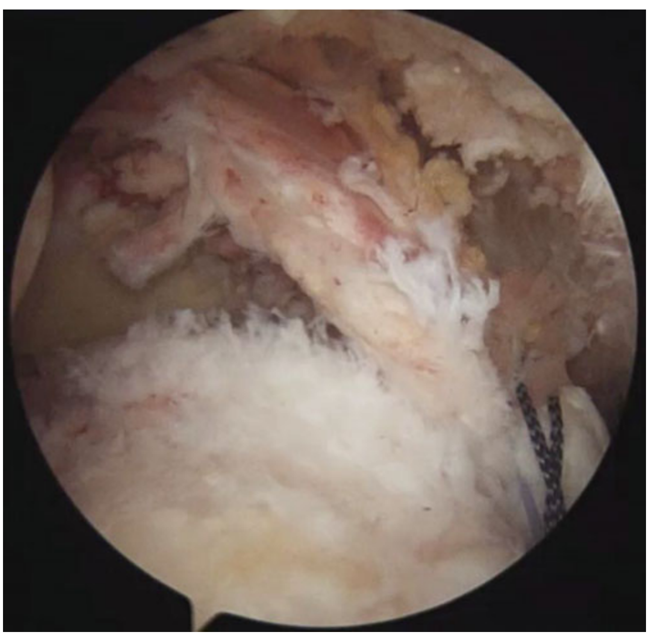

Fig. 11 Right shoulder: The scope is on the posterolateral portal. Subscapularis tear repaired with three transosseous sutures with interval slide in continuity is shown

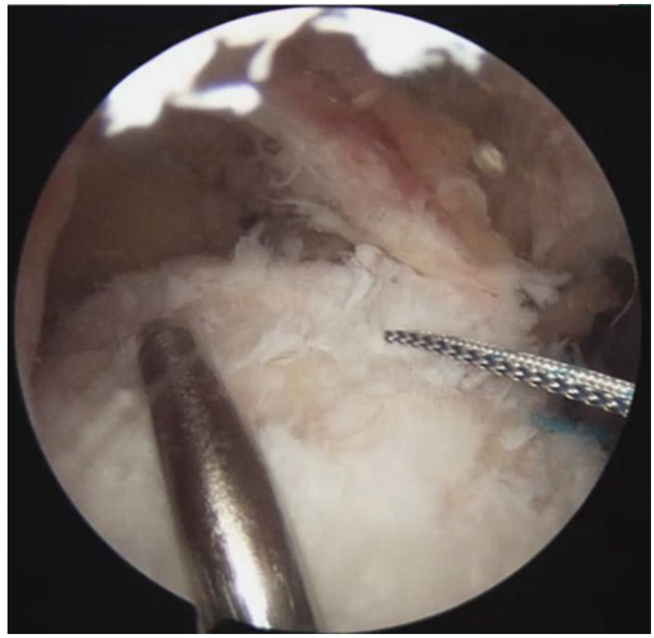

Fig. 12 Right shoulder: The scope is on the posterolateral portal. Once anterosuperior part is repaired, other tunnels can be repaired in case of massive rotator cuff tear

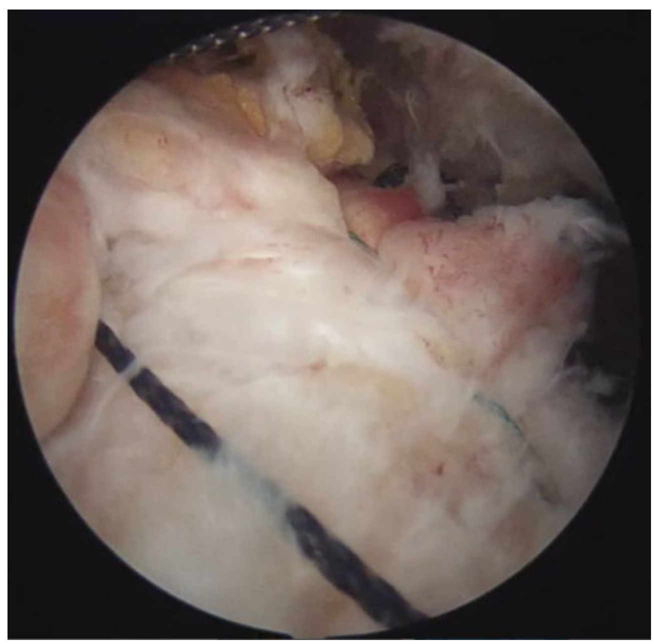

Fig. 13 Right shoulder: The scope is on the posterolateral portal. Final view of massive rotator cuff repaired with nine transosseous sutures

working once the subscapularis tendon is repaired, on the anterior space of shoulder. In case in which the LHBT is just unstable without any pathology, an associated tenodesis with the anchor used to repair the subscapularis tendon is carried out (Fig. 9).

Our preference is to repair the subscapularis tear with arthroscopic transosseous (anchorless) technique. This technique could be very difficult to use in case of isolated subscapularis tear. However, also, in this case, it is possible to use this technique but the repair should be done not intrarticularly but through the subacromial subcoracoid space. Certainly, this technique is more easy to perform when the subscapularis tear is associated with a tear or superior rotator cuff. In this case, we start the tissue mobilization during the articular phase of arthroscopy. If the subscapularis is very retracted in this phase, a traction stitch is used to assist in the reduction. Then, the scope is moved into subacromial space (Fig. 10). The space is cleaned and the superior cuff is freed from adhesions. The footprint of tendon is prepared. Different tunnels could be made, according to the size of tear, using the ArthroTunneler™ (Tornier, Edina, MN) device [23]. We perform the repair with the scope in posterolateral portal and using as working portal the anterolateral, anterior, and posterior portals. In case of anterosuperior tear with the interval in continuity, we prefer to not disrupt the margin between the supraspinatus and subscapularis, and we pass the anterior sutures so as to repair the most anterior superior part of the tear all together. This technique of repair is more easy and fast to do. Furthermore, this allows to reapproximate the superior cuff (Fig. 11). However, some authors showed that there are not different outcomes in continuity vs. disruption of subscapularis–supraspinatus margin [24]. Once the subscapularis and most superior part of rotator cuff is repaired, then infraspinatus and supraspinatus repair is carried out (Fig. 12), in case of massive rotator cuff tear (Fig. 13).

The overall results of arthroscopic subscapularis repair are promising; however, early recognition and treatment of tear improve prognosis after repair. Younger age of patients, less degree of tissue retraction, and less fatty infiltration lead to better clinical results.

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Stem Cells in Rotator Cuff Healing

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Introduction

Rotator cuff (RC) tears represent the vast majority of shoulder injuries in adult patients and are a common contributing factor to shoulder pain and occupational disability, and their prevalence in the population is rising. Although surgical procedures to repair have evolved and improved over the past decades, a high rate of failure, which may require additional therapy or re-intervention, thus decreasing the patient's quality of life, has been observed after RC repair.

In order to enhance tendon healing after arthroscopic repair, several biological strategies are being investigated. There is increasing interest in the application of stem cells to enhance tendon healing.

This chapter will examine current literature regarding the application of mesenchymal stem cells to improve tendon healing in animals and in a clinical setting.

Definition

Stem cells are defined as unspecialized cells that provide a self-renewing population and have the potential to differentiate into various adult cell types.

They serve as a repair system by being able to divide without limit to replenish other cells.

Types of Stem Cells

Stem cells can be classified by the extent to which they can differentiate into different cell types (potency):

- Totipotent stem cells
- Pluripotent stem cells
- Multipotent stem cells
- Unipotent stem cells

Totipotent stem cells (such as a fertilized egg) have the ability to generate all of the cell types in the body, as well as all of the cell types that make up the extra-embryonic tissues such as the placenta. Pluripotent stem cells (such as embryonic stem cells) develop about 4 days after fertilization. Pluripotent stem cells can generate all of the different cell types from all three germ layers, that is, ectoderm, mesoderm, and endoderm. Multipotent stem cells (such as hematopoietic stem cells) have the ability to develop into more than one specialized cell type, but they cannot make all tissues in the body. Unipotent stem cells, also known as progenitor cells, (such as epithelial stem cells), can only produce one cell type.

A number of sources exist for obtaining stem cells and thus stem cells can also be classified based upon their tissue of origin:

- Embryonic stem cells
- Fetal stem cells
- Umbilical cord stem cells
- Adult stem cells

Some believe that adult and fetal stem cells evolved from embryonic stem cells and the few stem cells observed in adult organs are the remnants of original embryonic stem cells that gave up in the race to differentiate into developing organs or remained in cell niches in the organs, which are called upon for repair during tissue injury.

The most common stem cell sources are adult stem cells and embryonic stem (ES) cells.

ES cells are derived from the inner cell mass of the developing embryo during the blastocyst stage. They have the ability to renew themselves indefinitely and are truly pluripotent, that is, they are able to differentiate into all derivatives of the three primary germ layers: ectoderm, endoderm, and mesoderm. Their use, however, is very controversial because

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of ethical concerns, current regulatory issues regarding their use, and the difficulty of cell acquisition.

In contrast to ES cells, multipotent adult stem cells are characterized by their capacity for self-renewal and differentiation potential limited to tissues of one germ layer. If they have the potential to differentiate into various forms of mesenchymal tissue (i.e., bone, tendon, cartilage, and muscle), they are termed mesenchymal stem cells (MSCs).

A more novel source of stem cells is induced pluripotent stem (iPS) cells, which are initially mature adult stem cells that have undergone in vitro modulation and obtained the characteristics of adult stem cells.

The majority of clinical related stem cells research to date has focused upon adult stem cells rather than embryonic stem cells, as the latter are associated with numerous regulatory and ethical constraints. iPS cells are a relatively new field that has generated a great deal of interest.

MSCs

MSCs are a subset of adult stem cells that may be particularly useful for stem cell-based therapies for three reasons. First, MSCs have been isolated from a variety of mesenchymal tissues, including bone marrow, muscle, circulating blood, blood vessels, and fat, thus making them abundant and readily available [1]. Second, MSCs can differentiate into a wide array of cell types, including osteoblasts, chondrocytes, and adipocytes [2]. This suggests that MSCs may have broader therapeutic applications compared to other adult stem cells. Third, MSCs exert potent paracrine effects, enhancing the ability of injured tissue to repair itself. In fact, animal studies suggest that this may be the predominant mechanism by which MSCs promote tissue repair.

Source of MSC

The principal source for MSCs for RC healing has been autologous bone marrow, for which extraction and culture technique, as well as conditions for propagation have been extensively defined.

The iliac crest is the most common site for MSC harvesting, although a number of other sources have been recently identified. Recently, Mazzocca et al. [3, 4] showed that proximal humerus is a source of MSCs, which can be safely accessible during arthroscopic procedures. Authors characterized the harvested cells as MSCs and induced differentiation in tenocyte-like cells after treatment with insulin. Furthermore, Beizel et al. [5] have shown that arthroscopic aspiration of bone marrow from the proximal humerus is a reproducible technique and yields reliable concentrations of MSCs. These studies demonstrate that MSCs can be harvested avoiding an additional surgical site for aspiration (i.e., iliac crest) or a second operative procedure, making easy future use of MSCs in arthroscopic RC surgery.

MSCs can also be derived from other sources such as accessible adipose tissue, which can also be relatively easily accessible, although these cells have an apparently reduced ability to differentiate compared to bone marrow-derived MSCs [6].

Tendon-derived stem cells (TDSCs) are considered of extreme interest in RC repair enhancement, based on an assumption that these cells would be more appropriate for tendon repair.

Existence of tendon-derived stem cells has been first proved in murine patellar tendons and human hamstrings by Bi et al. [7]. More recent *ex vivo* studies confirmed TDSCs isolation from animal and human RC tissues. Tsai et al. [8] showed on five patients that cells harvested from the RC tendon could be successfully isolated and differentiated into cells with MSCs characteristics. In 2013, Randelli et al. [9] confirmed the existence of stem cell populations in shoulder tissues; samples from human supraspinatus tendon and human long head of the biceps tendon were collected during arthroscopic RC repairs from 26 patients. Morphology, self-renewal capacity, immunophenotype, gene and protein expression profiles, and differentiation capacity were evaluated, and resulted in characterization of two new types of human stem cells. In the same year, Utsunomiya et al. [10] isolated and characterized MSCs from four shoulder tissues: synovium of glenohumeral joint, subacromial bursa, RC tendon and enthesis at greater tuberosity, obtained from 19 patients undergoing arthroscopic RC repair, suggesting that subacromial bursa is a good candidate for the source of MSCs in RC tears.

Recently, Song et al. [11] isolated MSCs from bursa tissue associated with RC tendons from five patients undergoing RC surgery and characterized them for multilineage differentiation in vitro and in vivo. The results showed that the cells isolated from bursa tissue exhibited MSCs characteristics and high proliferative capacity, and differentiated toward cells of mesenchymal lineages (osteoblasts, tenocytes, and fibrochondrocytes) with high efficiency suggesting that bursa, a tissue usually discarded during RC tear repairs, is a new abundant source of MSCs with a high potential for application of these cells in tendon repair in animal models.

Animal Studies

Gulotta et al. [12] in 2009 harvested BMSCs from long bones of ten rats and injected them on a repaired rat supraspinatus tendon. No significant differences were observed with the control group, in which the RC repair was not followed by stem cells injection. This study raised concerns regarding the isolated use of MSCs by showing that the application of MSCs alone was not sufficient to improve tendon healing, and suggesting that MSC activity must be supported by appropriate molecular signals.

Therefore, in later studies, Gulotta et al. [13, 14] examined various types of transduced MSCs for augmentation of supraspinatus tendon repairs. Three controlled laboratory studies showed that transducing cells with scleraxis or membrane type 1-matrix metalloproteinase improved histological quality and biomechanical strength as early as 4 weeks after repair, whereas transducing the cells with BMP-13 did not achieve favorable results.

Yokoya et al. [15] studied the implantation of a polyglycolic acid sheet seeded with cultured autologous BMSCs in a complete infraspinatus lesion created in a rabbit model. Sixteen weeks after the implantation, an increased production of type I collagen and an increment of the mechanical strength was seen as compared with both a non-augmented control and a non-loaded scaffold group.

Kim et al. [16] harvested BMSCs from the iliac crest of two rabbits, cultured and seeded them on a tridimensional open-cell polylactic acid scaffold. A similar scaffold without stem cells was implanted on the contralateral shoulder as control. This study showed that BMSCs survived for 2, 4, and 6 weeks within the scaffold and type I collagen expression was increased in the MSC group as compared with control.

Shen et al. [17] developed a knitted silk-collagen scaffold, loaded with allogeneic Achilles tendons stem cells, and used it to augment a RC repair in rabbits and compared these with repairs augmented with a non-loaded scaffold. No reject reactions were observed, and increased fibroblastic cell ingrowth and reduced infiltration of lymphocytes within the implantation site was observed in the treatment group after 4 and 8 weeks. Morphological evaluation performed after 12 weeks showed an improvement of the structural and mechanical proprieties, as compared with control.

Clinical Studies

Up to now, only one cohort study has evaluated the safety of clinical application of MSCs in shoulder surgery. In this study, Ellera Gomes et al. [18] suggested bone marrow mononuclear cells (BMMCs) are a safe and promising alternative to other biological approaches to enhance tissue quality in affected tendons.

Prior to surgery, 100 ml of bone marrow aspirate was obtained from the posterior iliac crest. BMMCs fractions were obtained in aseptic conditions, and then resuspended in saline solution enriched with 10 % autologous serum to a final volume of 10 ml, which was injected on the site of the repair to enhance tendon regeneration. Clinically, promising outcomes were recorded when compared with historical data available for patients undergoing the same surgical procedure without the addition of stem cells. At 12 months after surgery, the most valuable findings were an average increase of 19 points in term of UCLA score and the evidence of newly formed healthy tendon tissue at MRI examinations on the site of cells injection.

Discussion

Poor regeneration of tendons following damage and degeneration has encouraged the search for biological therapies to augment tendon healing. Stem cell-based therapies to augment RC healing are attractive because they provide a renewable source of pluripotent cells that can contribute to the healing environment. Therefore, stem cells therapies are an exciting new area of research.

A number of regulatory, ethical, and safety concerns have limited the use of stem cells to MSCs rather than more promising embryonic stem cells, although induced pluripotent stem cells are also being investigated.

Clinical research regarding the use of MSCs in shoulder surgery is very limited.

In vitro studies demonstrate that stem cell populations that can be easily isolated, maintained, and expanded in culture to provide the large numbers needed to be therapeutically useful, and induced to differentiate toward several cell types, indicating their intrinsically appropriate cell plasticity [3–5].

Results of in vivo animal studies suggest that MSCs may have the potential to improve the strength and histology of tendon-to-bone healing in RC surgery. However, the limited existing literature has to be considered critically [15–17].

MSCs can be harvested from various areas of the human body. They have traditionally been obtained through isolation of bone marrow aspirated from the iliac crest. The harvesting of MSCs from intra-articular tissue such as the subacromial bursa or the RC tendon as recently described by several authors [9–11] is an interesting approach that requires tissue digestion and cell culturing under laboratory conditions. These techniques allow for cell harvesting without the use of an additional surgical site (i.e., iliac crest). Studies in vivo in animal models are required to avoid the possible lethal complications of this type of therapy.

Other methods for obtaining MSCs from concentrated bone marrow of the proximal humerus have the advantage of being practical for the real-time setting of the operating room [5].

Whereas bone marrow grafting has been widely used in orthopedic medicine, the application of isolated MSCs is relatively new and ideal methods for procurement and application have yet to be adequately determined.

Application of stem cells into the RC repair usually can demand a specific carrier to keep the cells on site. In vivo animal studies that evaluated the effect of MSC augmentation on RC repairs have showed a successful improvement in RC regeneration through the use of fibrin carrier [12] or scaffold (spongy collagen and silk, open-cell polylactic acid, gel alginate, artificial with polyglycolic acid) [15–17] seeded with stem cells, suggesting that this is a promising treatment for the clinical application of tissue-engineered tendon in the near future. However, the high variability of studies does not permit to establish the effect of the carrier and the appropriate method of cell harvesting.

The effect of MSCs on tendon healing may be improved through an appropriate modulation of the healing environment (growth factors, cytokines, cell concentration, and mechanical stimulus). In effect, it is possible that the application of stem cells alone is insufficient, and that a signal must also be provided that can induce regeneration. A number of such potential approaches are currently under investigation. Methods such as genetic transduction, which involves the use of viral vectors to condition cells for therapeutic use, have also shown promising results in animal studies. Gulotta et al. [13, 14] showed in their studies that MSCs transduced with scleraxis or membrane type 1-matrix metalloproteinase resulted in improved healing after re-fixation of the supraspinatus in their rat model.

The repair site may lack the cellular and/or molecular signals necessary to induce appropriate differentiation of the transplanted cells, suggesting that cell-based strategies may need to be combined with appropriate growth and differentiation factors to be effective. In that scenario, the stem cells serve as the raw materials for regeneration, while the signal serves as the impetus toward that goal.

Current literature regarding therapeutic use of MSCs in shoulder surgery is limited. Although in vivo animal studies have shown some promising approaches to enhance tendon-to-bone healing, the use of MSCs for shoulder surgery should still be regarded as an experimental technique.

Further basic and clinical research will allow to study the potential role of stem cell-based therapies in RC pathology and their possible application in tissue engineering, so that a procedure can be defined for the routine use of these cells in shoulder surgery.

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PRP in Rotator Cuff Healing

Stefano Gumina

Rotator cuff retears may occur after open or arthroscopic repair. Galatz et al. [1] reported a retear rate as high as 94 %. Failures have been attributed to different causes: poor quality of repaired tendon, pullout of the suture anchors, suture breakage, precocious, and inappropriate rehabilitation program [2, 3]. Liem et al. [4] observed that higher degrees of muscular atrophy and fatty infiltration preoperatively are associated with recurrence of the tear as well as progression of fatty infiltration and an inferior clinical result.

The use of an autologous platelet-leukocyte gel or membrane is a new method, which might stimulate and accelerate soft tissue and bone healing [5–9]. Platelets can be retrieved and isolated from autologously drawn fresh whole blood. Point-of-care devices fractionate the blood into platelet-poor plasma, platelet-leukocytes-rich-plasma (P-LRP), and red blood cells [10]. Successively, P-LRP can be activated by autologous thrombin to create a viscous solution termed "platelet-leukocyte membrane." This may be exogenously applied, as a mass, to stimulate tissue healing. The reason for applying the membrane is the delivery of platelet growth factors that contribute to mimic and accelerate physiological wound healing and reparative tissue process [11, 12].

Inside the platelet cytoplasm, α granules and dense granules have been found. The α granules contain many platelet growth factors such as transforming growth factor β (TGF-β), basic fibroblast growth factor (bFGF), platelet-derived growth factor (PDGF-AB), epidermal growth factor (EGF), vascular endothelial growth factor (VEGF), and connective tissue growth factors (CTGF). Except for bFGF and PDGF, all the mentioned growth factors stimulate and increase angiogenesis; furthermore, almost all stimulate undifferentiated mesenchymal cell proliferation and stimulate or regulate mitosis in fibroblasts [13].

Platelet-leukocyte gel has already been utilized for treatment of tendon disease. Mishra and Pavelko [7] used the gel and obtained excellent results, in terms of pain and function, in the treatment of chronic elbow tendonitis. Aspenberg and Virchenko [6] used the gel in an Achilles tendon injury rat model and have observed an approximately 30 % increase in tensile strength and stiffness after the first week when compared to control animals. Everts et al. [14] have hypothesized that advanced healing due to platelet-leukocyte gel might be explained by higher concentration of VEGF, which is released from platelets and stimulates and promotes angiogenesis. This hypothesis agrees with Anitua et al.'s [15] idea; in fact, the authors have affirmed that blood supply to the injured tendon has improved.

We used the platelet-leukocyte membrane to facilitate tendon healing to the footprint area of the greater tuberosity where bleeding was previously induced in a group of consecutive patients with a full-thickness large postero-superior rotator cuff tear.

Platelet-rich plasma (PRP) was obtained from 10 cc of peripheral blood after slow centrifugation (120 RCF for 10 min; RCF = Relative Centrifugal Force g's) (Regen® Lab en Budron B2 1052, Le Mont-Sur-Lausanne, CH). This PRP was added to gluconate calcium and batroxobine, and the mix was centrifugated "high speed" (at least 1500 RCF) for 20–30 min to obtain a round membrane with a diameter of 13 mm and a thickness of 3–4 mm (Fig. 1). This membrane is thin, elastic, malleable, deformable thanks to its fibrin matrix. Platelets and leukocytes are trapped in fibrin matrix: for this reason, growth factors are gradually released "in situ" to ensure a higher therapeutic effect. In our previous ultrastructural study (unpublished data) on the membrane (whose dimensions were equal to those of the membranes utilized in this study), we observed that it contains a great number of white blood cells, $7 \times 10^3/mm^3$, mainly represented by lymphomonocytes, and more than $400 \times 10^3/mm^3$ platelets (1.7 times greater than normal whole blood level).

When the membrane was used, we introduced the post suture inside the membrane before the passage of the suture throughout the lateral edge of the tendon. In all cases, in order to facilitate the passage of the membrane inside the

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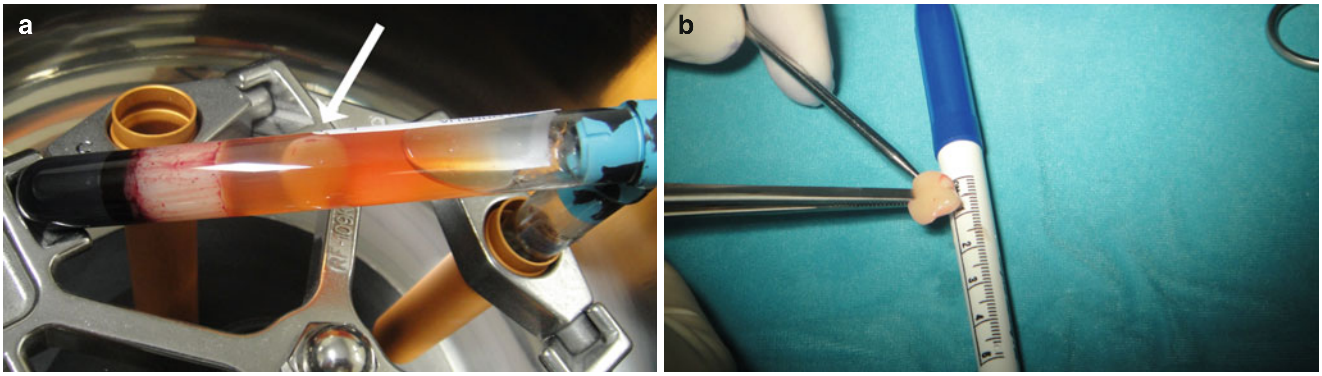

Fig. 1 (**a**) The *arrow* shows the platelet-leukocyte membrane into the test tube. (**b**) The membrane as it appears before its use

Fig. 2 The membrane is passed with the post suture and inserted, through the 8 mm cannula, in the subacromial space

cannula, we momentarily removed the rubber diaphragm of the 8 mm cannula and stopped the pump (Fig. 2). In this manner, the membrane was positioned between the abraded foot print area and the lateral edge of the cuff so that it could not be displaced or moved during the successive phases of the rotator cuff suture (Fig. 3). When the membrane was used, we utilized one membrane per each anchor.

Our results are summarized in Table 1 and 2.

In our study, the use of the platelet-leukocyte membrane improved repair integrity compared with single-row technique without membrane. Although our follow-up is not long, no cases of rerupture were registered in the group where the membrane was used. We were surprised to verify such a low incidence of rotator cuff retears. However, we believe that this could be attributed to the short follow-up period and to the fact that in our study we did not consider patients with massive tears. This improvement does not seem to carry a better functional effect. In fact, the Constant scores, calculated in the two groups, were similar when deprived of the shoulder pain component. This specification is fair because the intensity of the pain resulted statistically higher in the Group II even before the arthroscopic treatment. We believe that clinical results are not influenced by age, although it resulted statistically different between the two groups. Yian et al. [16] have in fact demonstrated that shoulder painless subjects, aged between 50 and 70 years, have similar Constant score.

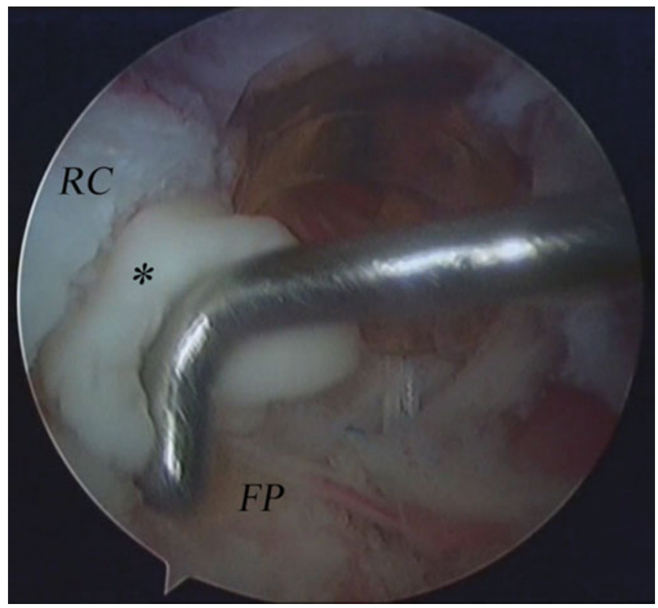

Fig. 3 A probe helps the membrane to be placed between the foot print and the tendon, before the cuff suture is done. *RC* rotator cuff, *FP* foot print, *platelet-leukocyte membrane

Recently, Castricini et al. [17] performed a randomized study on the use of the PRP augmentation for arthroscopic rotator cuff repair and observed that there was no statistically significant difference in total Constant score when comparing the results of cuff repair where the membrane was used with those where it was not. Furthermore, between the two groups, there was no difference in tendon thickness and in size of the supraspinatus footprint tendon thickness. The only difference was noted studying the alterations of MRI tendon signal intensity. In fact, patients belonging to the group where the membrane was not used had a higher percentage of alterations. The authors' conclusion was that the study does not support the use of the platelet-rich fibrin

Table 1 Comparison between Groups for independent variables

Variable		Group I	Group II	P value
Age (yrs)		60 (4.4)	63 (5.9)	0.02
Gender				0.63
	Male	20	21	
	Female	19	16	
Dominance				0.34
	Yes	28	30	
	No	11	7	
Fatty degeneration				0.74
	Grade 0	3	4	
	Grade 1	23	22	
	Grade 2	12	11	
	Grade 3	1	0	
	Grade 4	0	0	
Tenotomy of LHBT				0.50
	No	32	28	
	Yes	7	9	
Constant score				
	Pre-op	54.3 (4.1)	50.1 (3.7)	<0.01
	Post-op	77.9 (5.7)	74.2 (6.1)	0.01
SST				
	Pre-op	3.7 (1.0)	3.4 (1.0)	0.24
	Post-op	10.5 (0.8)	10.1 (1.0)	0.07

For the qualitative variables (age, CS, and SST), the values given are the means. Standard deviation is given in parenthesis. For the quantitative variables (gender, dominance, tenotomy of the long head biceps tendon, and fatty degeneration), the values given correspond to the number of patients. The p-value was set at $p=0.05$

Table 2 Repair integrity in Groups

Repair integrity	Group I	Group II
Type I	23 pts (59.0 %)	13 pts (35.1 %)
Type II	11 pts (28.2 %)	11 pts (29.7 %)
Type III	5 pts (12.8 %)	10 pts (27.0 %)
Type IV (retears)	0 pts (0 %)	1 pt (2.7 %)
Type V (retears)	0 pts (0 %)	2 pts (5.4 %)

The values are given as the number of patients with the percentage in parenthesis. The p-value was set at $p=0.05$
Repair integrity shows a significant difference between the two groups (chi square = 6.29, df = 2, $p=0.04$)

matrix for augmentation of repair of cuff tear to improve the healing of the rotator cuff. However, Castricini et al.'s study differs from ours for the following aspects: (1) in their series there are many patients with a small (<1 cm) tear; (2) only one membrane was used for each patient (also for those who had a medium rotator cuff tear); (3) in all cases the rotator cuff was repaired with a double-row technique; and (4) time of immobilization after surgery was shorter. Of all these aspects, we believe that the first two represent the main differences between the two studies.

Analogously to our study and concerning the repair integrity, Randelli et al. [18] obtained similar results using PRP – in combination with an autologous thrombin component – in patients with different types of rotator cuff tear. The spray applicator kit loaded with syringes of PRP and thrombin was positioned in between the bone and the repaired rotator cuff. The study showed autologous PRP reduced pain in the first postoperative months and suggested that it positively affected cuff rotator healing also when the tear exposed the humeral head but did not retract to the glenoid articular surface. Therefore, Randelli's and our study suggest that PRP might help rotator cuff healing, but there are no differences if it is applied in form of spray or membrane.

In conclusion, the use of platelet-leukocyte membrane seems to improve repair integrity of large rotator cuff tear, even if this improvement does not seem to determine a better functional effect. However, many aspects still have to be elucidated: (1) whether and in how much time the membrane is absorbed; (2) whether the membrane only slows down time of a possible rotator cuff retear; and (3) if it is sufficient to pass the post suture through the membrane and cover it with the cuff in order to maintain the membrane "in situ."

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The Impact of Nanomedicine on Rotator Cuff Lesions: A Future Outlook

Alessio Giuliani, Iva Chianella, and Stefano Gumina

Introduction

The scientific area of nanotechnology, which finds its origin in Professor Feynman's speech 'There is plenty of room at the bottom' given in 1959 [1], has nowadays a profound impact in many other scientific areas including medicine. Nanotechnology includes the development, characterisation and application of structures, devices and systems with dimensions of 1–100 nm. At the nanometric scale, materials possess unique chemical, physical and biological properties, which are totally different to those of the same materials in a greater scale. Among some of the phenomena responsible for such properties are the very high ratio between superficial areas and volume, the electromagnetic forces and the predominance of interfacial phenomena. These features vary not only among different materials, but also for the same material on the bases to its dimension [2]. For example, the high reactivity of nanoparticles, their tendency to auto-assembly and their peculiar behaviours make them particularly useful to a great variety of applications including those for the clinical area.

The application of nanotechnology in medicine for diseases prevention, diagnosis and therapy is called Nanomedicine. The possibility to intervene on the human body at a nanometric level, in which the majority of the cellular and biological processes take place, has been a dream for many medical doctors. Nowadays the existence of nanomaterials and their increase use for diagnosis and therapy are beginning to realise the doctors' dream.

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Nanomedicine is a wide scientific area, which includes the use of nanomaterials such as carbon nanotubes (and nanohorns) [3], polymeric nanofibres [4] and nanoparticles, from the natural ones such a liposomes [5], to silica nanoparticles [6], to those metallic such as gold nanoparticles [7], quantum dots [8] and magnetic nanoparticles [9]. Carbon nanotubes and nanoparticles are used for drug delivery and diagnostics (Imaging and biosensors) and also to develop novel devices (lab-on-a-chip [10] and Micro Electro mechanical System or MEMS [11]) mainly for diagnostics. Nanofibres are used both for drug delivery [4] and tissues and nerves regeneration and generally to repair the extracellular matrix [4, 12].

Another interesting application of nanomaterials in the medical field involves their use to develop implantable biosensors for continuous monitoring of the metabolism. In fact several clinical trials have demonstrated that continuous monitoring of the metabolism can help in the early diagnosis of several diseases. Continuous monitoring could be obtained with implantable and miniaturised biosensors capable of monitoring the metabolism without intervention by the patient and regardless of his/her physiological state (rest, sleep, exercise etc.) [13]. Among the challenges that still need overcoming and are currently hampering, the full development of implantable biosensors is the foreign body response (where the biosensor is seen as a foreign body), the biofouling and sensors drifts (loss of calibration in time). Coating biosensors with a layer of carbon nanotubes [14–17] or silica nanoparticles [18] has demonstrated to both reduce the foreign body response and to slow down biofouling, increasing considerably the life of the implanted devices. Carbon nanotubes have been also used as nanoelectrodes to develop miniaturised implantable biosensors [19].

Despite the promising examples reported so far on the use of nanomedicine for clinical applications, there are still several drawbacks that need resolving for a real impact of nanotechnology in the medical field. Currently the majority of the nanomaterials described up to now are under investigation to

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evaluate their toxicity. Unfortunately the nanometric dimensions and the high ratio between surface area and volume, accountable for the high reactivity and the peculiar chemical and physical characteristics of nanomaterials, are also responsible for their unpredictable interactions with the organisms and therefore for their toxicity. Nanomaterials such quantum dots [20], carbon nanotubes [21], gold nanoparticles [22] and magnetic nanoparticles [23] have demonstrated a certain level of toxicity. Several different measures have being taken to address such toxicity, such as coating with biocompatible materials (polyethylene glycol, PEG) which produces reduction of cytotoxicity. Unfortunately natural and biocompatible nanoparticles such as liposomes can also become cytotoxic once functionalised with other nanomaterials such as quantum dots, gold nanoparticles or magnetic nanoparticles.

In addition to all this, another aspect of nanomaterials that needs to be taken into account and accurately studied is their distribution inside the organisms and their biodegradability. In fact whereas many nanomaterials do not seem to have immediate toxicity (within hours or days), their permanence in the human body requires investigation to understand how and when they are excreted by the organism. This is because the time of permanence inside the body and the mechanism of excretion can influence the long-term toxicity with consequences not immediately observable.

There are several studies reported in literature on toxicity and biodegradability of nanomaterials. The results obtained so far are however inconclusive. This is due to the vast variety of nanomaterials tested, also within the same type of nanomaterial (e.g. gold nanoparticles with different forms, dimensions and functionalisations). Another important problem observed in the studies carried out so far is the lack of standard protocols for *in vitro* and *in vivo* tests. Experimental conditions such as the type of cells, the length of the experiments (e.g. incubation times *in vitro* and *in vivo*), the range of concentrations studied vary between different studies. Therefore, even though two laboratories might have tested the same nanomaterials, the results obtained can be totally different and in many cases contradictory [22, 24, 25]. Both the EU and the USA are currently investing money and resources to standardise nanomaterials testing to finally obtain conclusive results.

Despite all this, it is impossible to ignore the enormous potential that nanotechnology has to revolutionise medicine with a positive impact. Once the toxicity of nanomaterials has been fully investigated and totally resolved, there will not be any more obstacles for a successful development of nanomedicine. Maybe, in a near future, Dr Kurzweil nanorobots (Fig. 1), which are miniaturised devices with the dimensions of red cells capable of intervening in the organism at a cellular level, repairing tissues and prolonging human life [26], will no longer be sci-fiction but reality.

Nanofibres and Tendons Regenerations

Collagen is the most abundant constituent of tendons. For this reason, it has been widely employed to develop scaffolds for tissue engineering in the past. Collagen facilitates the healing process of tendons, but its clinical use is associated with some clinical problems that need still to be resolved. In particular, the large-scale production of collagen is very complex due to the poor repeatability of the industrial processes that are usually employed for its production. Collagen is characterised by a mechanical resistance that is lower than the one of other bio-polymers. In addition, it is a natural polymer and therefore could cause antigenic and immuno-reactions.

In order to improve the mechanical properties, some authors [27] combined collagen with the polyglyconate copolymer. They obtained a gel-like product which was even better than the natural tendons in terms of their physicochemical characteristics.

Nanotechnologies and nanomaterials (NMs) offer very interesting alternatives to improve the biocompatibility of scaffolds. In particular, due to the high surface-to-volume ratio, nanofibres (NFs) are characterised by unique physicochemical properties that make them excellent candidates for tissue-engineering applications [28–30].

Electrospinning is the most frequently used technique to produce NMs. The technological process is very straightforward. An electrical field is applied on a charged solution of a certain polymer. The polymer flows into very small channels, reaches a collector and is eventually ejected. The jet deposits on an external surface and after drying, takes a nonwoven mat form.

During the travel to the collector, the polymer is subjected to many looping and spiralling motions. In order to minimise the instability caused by the electrical field, the polymer stretches plastically. This produces a significant reduction of the NFs diameters, ranging from few micrometres to few nanometres [31].

Polymer NFs can successfully be employed to develop high porous scaffolds. Such pores have obviously dimensions at the nanometre scale and are interconnected. This increases the surface of the scaffold available for osteoblast adhesion and nourishments exchange.

The nanometre structure of these scaffolds can have a strong influence on cytoskeleton proteins orientation [32–34], facilitating the organization and morphogenesis of cells [35].

Many polymers could be processed through the electrospinning technology and then employed to repair tendons. It is worth mentioning polyglycolic acid (PGA), polycaprolactone (PCL), polyurethan (TPU), chitosan and collagen [36, 37].

The PGA-PCL copolymer (PLAGA) is characterised by excellent mechanical properties and a very good biocompatibility. If produced in form of microfibres, it is also able to

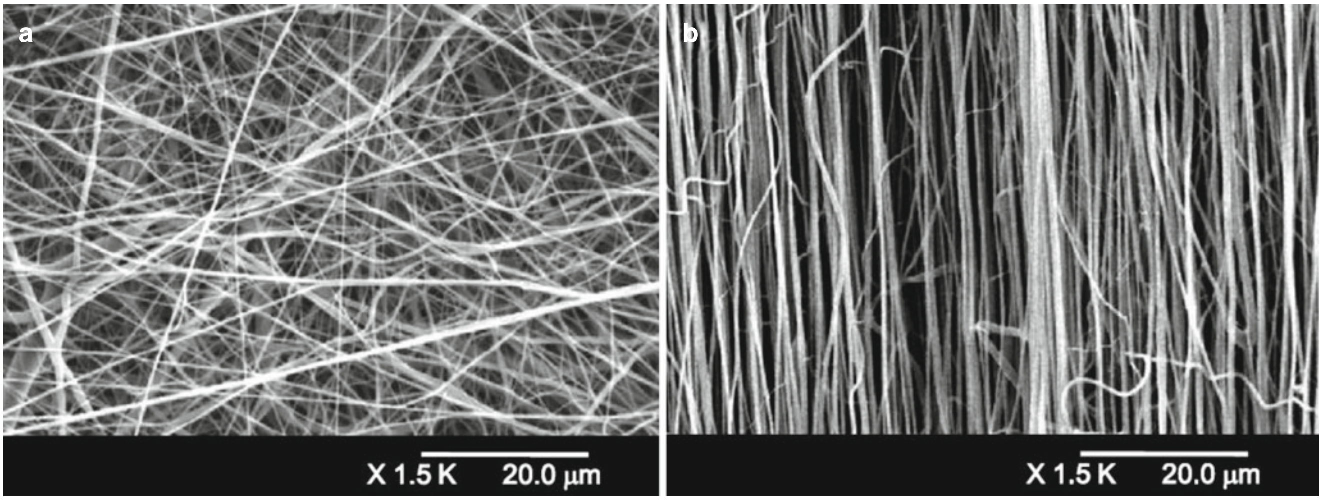

Fig. 1 Randomly oriented NFs (**a**). Aligned NFs (**b**) (Adapted with permission from Chen et al. [43])

stimulate the collagen production which makes it very useful from an histological point of view [38].

Some authors developed a mixture of electrospun PLAGA nano and micro-tubes [39]. In this way they reproduced the fascicular arrangement of collagen I. They cultured, on this NFs-based scaffold, adipose mesenchymal stem cells taken from rats.

This substrate showed a very high biocompatibility. In particular, the cells penetrated the porous structure reaching a depth of 200 nm.

Surface topography has a huge influence on biological response. In fact, some authors [39] showed that electrospun matrix systems were able to produce a significant increase in the proliferation and differentiation of cells.

The addition of the GDF-5 growth factor, with a concentration of 100 ng/mL, produced an increased Collagen type I gene expression. Higher concentrations of this protein could inhibit the Extra Cellular Matrix (ECM) formation and Scleraxis (Scx) gene expression. The latter is responsible for the stromal cells differentiation into mature tenocytes [40].

Obtaining a good mechanical resistance is not the only objective to achieve for the development of a nanostructured scaffold. It is also very important to mimic the ECM as more accurately as possible [41, 42].

For this reason, the fibres arrangement should have a specific architecture to guide the cellular growth and tissue regeneration. For example, if aligned (Fig. 1), these fibres cause the cytoskeletons and nuclei elongation which stimulates the cellular migration [43, 44].

Fibres alignment has also a positive influence on collagen production. In fact, some studies showed that it is more abundant on aligned NFs-based scaffolds than on matrixes made of randomly assembled NFs [45, 46].

NFs parallelism can also produce a positive effect on cellular differentiation. It increases the expressions of the Scx gene and collagen XIV immediately after scaffold implantation [47].

The above results show the importance of surface nanotopography in terms of improved cellular behaviour.

One of the most critical weak points of current tissue engineering techniques applied to tendons is the regeneration of the tendon-bone transition zone [44, 48]. NMs could represent the major breakthrough towards this problem resolution. For example, Li et al. [49] developed a collector that imitated the collagen fibres organization that could be seen at the tendon-bone transition site. It comprised both aligned and randomly oriented NFs that imitated the structure of the collagen fibres in tendons and bones, respectively [50].

In order to repair a tendon, it is necessary to regenerate the sheath it glides into. It should be made of two walls, one external with anti-adhesion properties and one internal with a lubricated surface. For this reason, some researchers [45] developed a nanostructured membrane comprising a mixture of PCL and hydroxyapatite (HA) NFs internally and only PCL NFs externally (Fig. 2). They employed the electrospinning technique.

The HA on these NFs mimicked the one which was on tendons and stimulated the tissue regenerative process as well.

Some adherence areas were identified on the control group, while they were completely absent on the HA-based NFs.

In order to obtain an effective tendon repair, NFs could also be combined with some specific bio-molecules. For example, Sahoo et al. [51] developed a PLGA NFs-based scaffold onto which they applied a micrometre mesh reproducing the ECM structure. The researchers cultured rabbit-derived mesenchymal stem cells and showed that the combination of micro and nano features stimulated the collagen I and III production.

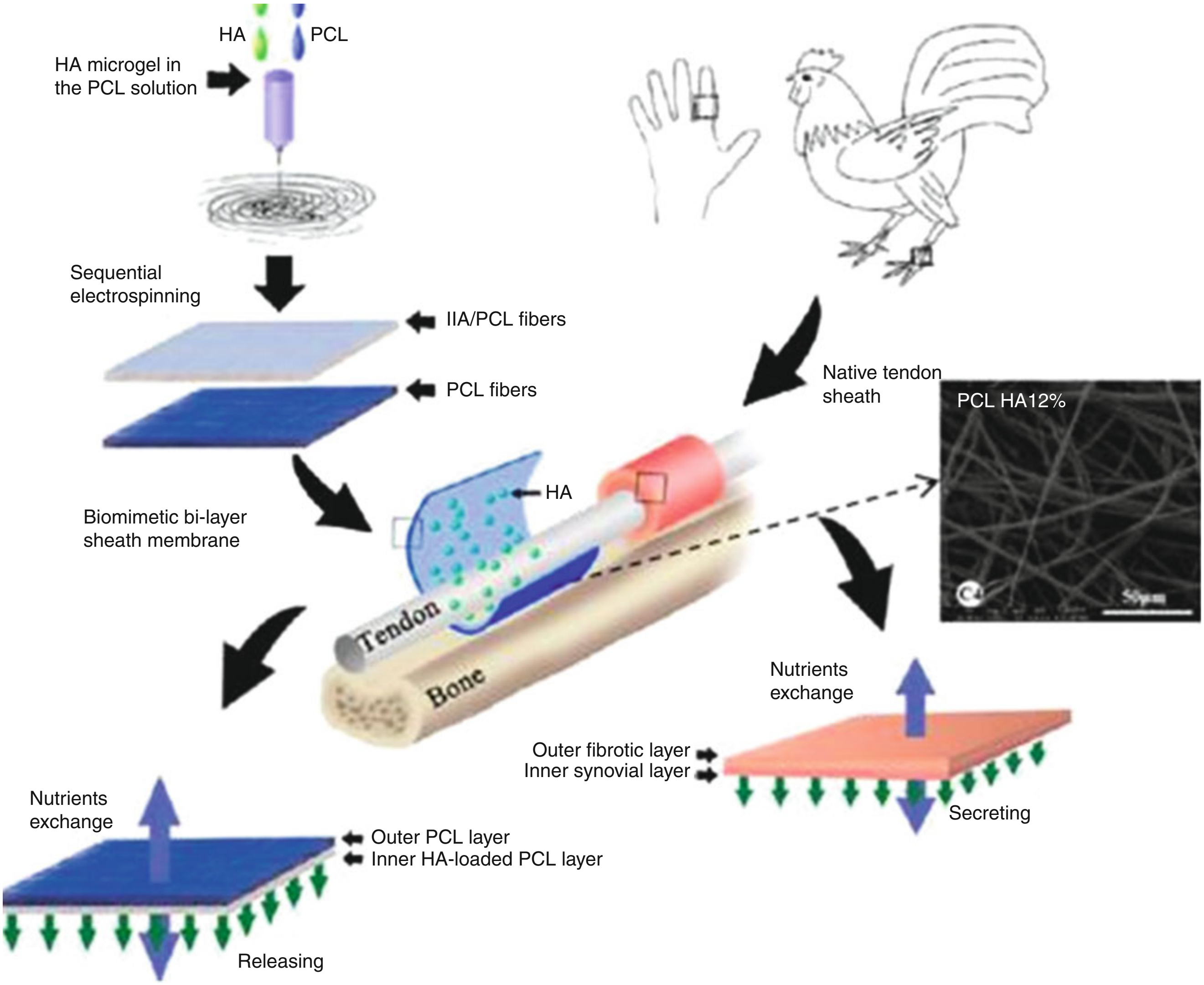

Fig. 2 NFs-based sheath for tendons repair (Adapted with permission from Liu et al. [45]. Copyright (2012) American Chemical Society)

The tendon healing process is characterised by an increase in the beta-transforming growth factor (TGF-β) production. TGF-β_1 is one of its isoforms and causes the formation of fibrous tissues and adhesions areas [52]. In order to reduce the concentration of this protein, some specific antibodies could be employed. However, their half-life is very short and may cause a reduced clinical efficacy [53–55].

Alternatively, the concentration of these proteins could be varied by sending micro-RNA segments directly into the tendinous cells. Viruses are among the most largely experimented vectors [16, 17, 56, 57]. They showed high transfection values but were also characterised by a considerable toxicity. Since they may cause very dangerous immunologic and oncogenic responses [58, 59], they are not still ready for an in vivo clinical application.

This obviously stimulated the research on non-viral vectors. In this sense, nanoparticles (NPs) played a very important role [60, 61]. In fact, thanks to their tiny dimensions, they proved to be able to pass through the cellular membranes by the endocytosis mechanism [62, 63].

In order to further reduce the TGF-β_1 expression, other researchers [64] inserted micro-RNA filaments into plasmids and encapsulated this system into PLGA NPs. Plasmids release was dependent on pH and extended over a long time period. The researchers showed that the PLGA NPs–plasmids–micro-RNAs complex were able to penetrate the tendinous cellular membranes more deeply than the other non-viral vectors. However, this depended on the tendon area under study. In fact NPs penetration was very high in the injection site while their diffusion reduced as the thickness of the tissue increased.

Collagen NFs-based scaffolds for rotator cuff repair are partly already available on the market. Although they showed a satisfactory biological response on animal studies, their mechanical properties were insufficient to allow their clinical use [65, 66]. For example, Derwin et al. [67] compared

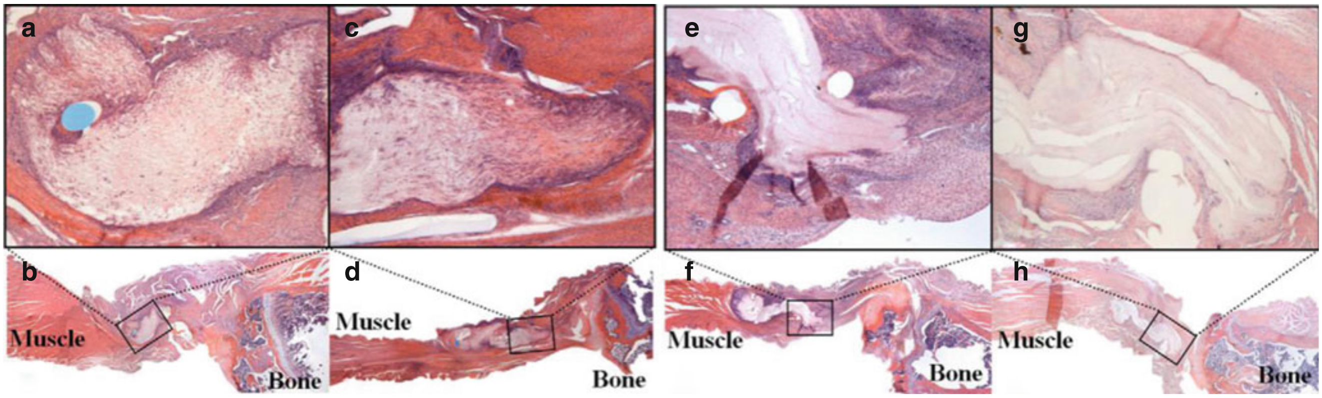

Fig. 3 Cellular infiltration and colonisation on PCL NFs-based scaffolds after 4 weeks (**a**, **b**) and 8 weeks (**c**, **d**). Cellular infiltration and colonisation on PCL and PEO NFs after 4 weeks (**e**, **f**) and 8 weeks (**g**, **h**) (Reprinted with permission from Beason et al. [70])

four different types of scaffolds and showed that the porcine one was affected by a very rapid reabsorption.

Another important problem to deal with is the cellular penetration of the substrate. To resolve this issue, some researchers showed that soluble NFs could be employed to fix the poor infiltration of cells into the scaffold [68, 69]. In this case, the NFs arrangement did not influence the substrate permeability.

Other authors [70], by employing the electrospinning technology, developed a PCL NFs-based scaffold. They also produced a second hybrid scaffold made of poly-ε caprolactone (PCL) and polyethylene oxide (PEO) (Fig. 3). They aimed at finding out a more effective solution to repair rotator cuff tendons. The above NFs were combined and then studied on a rat model. Animals were sacrificed after 4 and 8 weeks. No postoperative problems were noticed. Histologic analyses revealed that PCL NFs-based scaffolds allowed a better cellular infiltration and colonisation. It is worth noting that these results were less significant if a percentage of the fibres were sacrificial. In fact, the fibres removal reduced the space available for the scaffold and therefore the cellular colonisation. However, this result was in contradiction with other studies [68], showing that the removal of part of the NFs produced an improved biological response in vitro and in sub-cutaneous implants.

Other researchers developed PLLA NFs-based scaffolds and cultured fibroblast obtained from the Long Head of the Biceps Tendon [71], onto their surface. Articular instability, tendon inflammation or its complete rupture were the main inclusion criteria of the study. The polymer showed hydrophobic character which reduced the cellular adhesion [72]. Same results were also obtained when mesenchymal stem cells were cultured on PLLA NFs combined with collagen and gelatin [73, 74].

The researchers paid a lot of attention to the ECM regeneration. They aimed at creating a substrate able to stimulate collage type I production [75–77].

Tendon-derived fibroblasts were cultured on the combination of PLLA and collagen type I NFs. The researchers observed that the genic expression and collagen type I production increased more on the combination of these NFs than on the PLLA NFs alone [71].

With respect to the fibroblasts that were cultured on PLLA/Collagen I NFs, researchers found out that the FAK, PYK and PI3K genes expressions were higher than the ones observed on glass and PLLA NFs. The results depended on the scaffold chemical composition and the physical properties were influenced by the nano-topography of the device's surface.

The chemical interaction with integrins was the main responsible for the increased production of collagen type I. This result was also observed when osteoblasts and mesenchymal stem cells were cultured on different kinds of NFs [78]. The composite PLLA/Collagen I NFs were also able to stimulate the production of collagen type III. This protein along with collagen type X has a huge influence on the tendon healing process [79, 80].

Although the above studies look to be very encouraging, further investigations are still needed. In particular, researchers should check out whether the collagen type III and X influences the collagen type I production or not. Collagen type I is one of the most important constituents of the tendon as it provides the tissue with the mechanical resistance needed to resist to the external loads it is subjected to.

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Rehabilitation After Rotator Cuff Repair

Marco Paoloni, Andrea Bernetti, Valter Santilli,
and Stefano Gumina

Introduction

Rotator cuff repair represents the most common shoulder condition for which patients need postsurgical rehabilitation [1]. Two key factors for successful tendon healing and satisfactory functional outcome are a skillful surgical technique and a well-programmed rehabilitation protocol. Although the final outcome of surgical procedures for rotator cuff repair is, in fact, generally satisfactory, patients have to be carefully assisted in their postoperative period in order to guarantee a good final clinical outcome.

The continuous advances in the knowledge of the biological phenomena underlying healing and reparative mechanisms, the more exhaustive awareness of the natural history of rotator cuff pathologies, with and without surgery, as well as the improvement of surgical techniques and procedures, have made the process of postsurgical rehabilitation of rotator cuff a complex scenario, in which rehabilitation professionals should continuously interface with both the surgeon and the patient to obtain the best achievable results.

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Phase 0: Evaluation of Factors Affecting Outcome Results

Which Patients Have the Greater Risk of Unsuccessful Healing?

Before the rehabilitation program starts, the rehabilitative team should carefully consider a number of intrinsic and extrinsic risk factors that have been associated with recurrent tearing following rotator cuff repair. These include age, sex, smoking, medical comorbidities, and characteristics of the rotator cuff and the tear [2].

Age represents one of the most relevant risk factor for healing failure [3, 4], with patients aged more than 65 years generally showing greater risk for failed tendon healing [5], probably as a consequence of a worse microcirculation in the supraspinatus muscle-tendon junction [6].

Smoking habit influences the size of the tear [7] and this, together with the reduction in microcirculation, can explain why smokers are considered at risk for healing failure after rotator cuff repair [8].

A number of clinical conditions must be identified as they represent independent risk factors for healing failure. These include low bone mineral density and osteoporosis [9], which decreases the strength of the suture anchors, and poor glycemic control in patients with diabetes [10]. Cardiovascular comorbidities can also influence the healing process. The typical body habitus of individuals with metabolic syndrome (i.e., increased waist circumference or an increased waist-to-hip ratio) may impair healing capacity and predispose patients to increased intra-musculotendinous lipid deposition [11]. Hypertensive subjects are two to four times more likely to develop large-to-massive cuff tears [12].

The risk factor that has the greatest influence on the structural success of the repair, however, is the nature (i.e., the size and morphology) of the tear prior to the operation (Fig. 1). Larger tears are associated with the highest rates of failed repair [1], as well as multi-tendon tears, when compared with single-tendon ones [6]. Physiological changes

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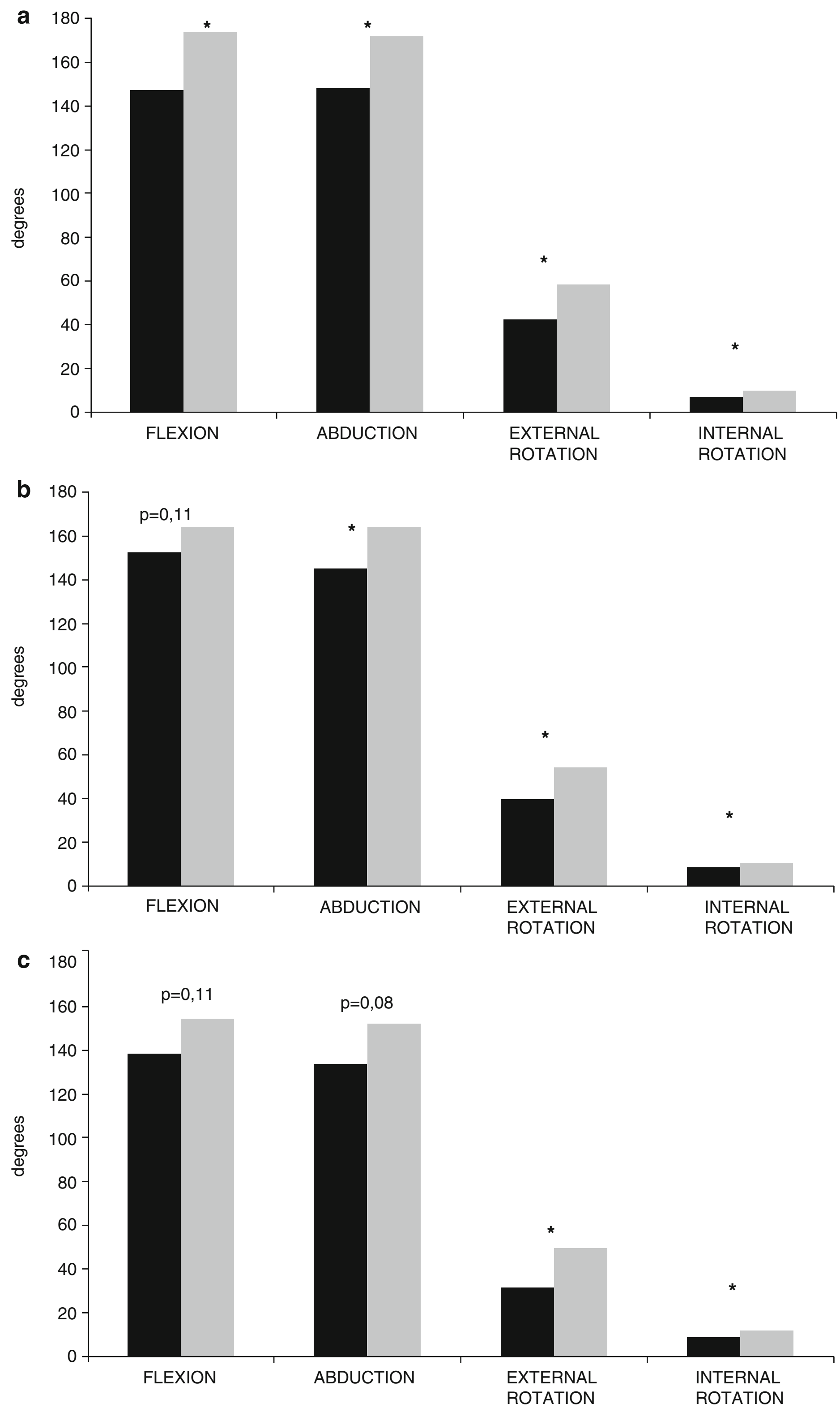

Fig. 1 Recovery of shoulder range of motions according to the size of the tear prior to the operation. Data from three groups of 30 patients each with small (**a**), large (**b**), and massive reparable lesions (**c**) [according to the Southern California Orthopedic Institute (SCOI) classification]. The *black columns* represent the mean preoperative values, and the *grey columns* represent the mean values three months after surgery of shoulder flexion, abduction, external rotation, and internal rotation. In the small lesions group, a significant improvement has been noted after surgery for all the range of motions. In the large lesions group, all the range of motions but not the flexion improved after surgery. In the massive reparable lesions group, only external and internal rotation significantly improved after surgery. [*: $p<0.05$] (Courtesy of Prof. S. Gumina)

occurring after full-thickness tears, including atrophy, fat infiltration, retraction, and fibrous contraction, are all associated with low healing rates.

Which Patients Have the Greater Risk to Develop Postoperative Stiffness?

Although conservative immobilization protocols are suggested after rotator cuff repair (see below), the rehabilitative team should be aware of those patients who are at high risk to develop postoperative stiffness.

Specific risk factors for postoperative stiffness include age more than 50 years, workers' compensation payer class, adhesive capsulitis or calcific tendinitis at the time of the operation, partial articular-side tendon avulsions or single-tendon tear defects, and concurrent capsule-labral surgical repairs [1, 13].

Particular attention should be given to the conditions of compensation claims. Patients with workers' compensation claims, in fact, tend to have poor outcomes after rotator cuff repair, which are mostly due to a very low compliance rate to postoperative immobilization and physical therapy program [14]. In this case, therefore, the risk of postoperative stiffness seems to be linked more to ineffective postoperative strategies than to intrinsic factors.

It should also be considered that "stiff" patients often display persistent postoperative pain, which might further impair functional results [15].

Obviously, the extent of stiffness varies among patients, and transitory conditions that respond to treatment must be differentiated from contractures that are resistant to multiple rehabilitation strategies, which may require surgery to restore mobility. Soft tissue mobilization and articular manual therapy represent the most important interventions for restoring mobility [16]. Moreover, attention to cervicothoracic and scapulothoracic mobility in the early phase of rehabilitation is safe and beneficial to the reestablishment of overhead mobility.

Which Patients Have the Greater Risk to Develop Postoperative Strength Deficit?

Recovery of the strength should be an important goal of postoperative rehabilitation of the rotator cuff. A functional shoulder, in fact, requires a good level of strength in the rotator cuff muscles. Approximately, it has been estimated that patients should expect 90 % of strength recovery after 12 months [17]. Noticeably, those patients who are at risk for unsuccessful healing should not be admitted to excessive load strengthening programs, thereby showing potential delays in strength gain. Risk factors for postoperative weakness are large tears [18], preoperative strength deficits in external rotation and abduction, and superior migration of the humeral head [19].

Phase I: Management of Immediate Postsurgery Period

As stated above, we actually do not have any level I evidence of which is the best rehabilitative treatment in the immediate postoperative period. The dilemma is, obviously, represented by the ratio between immobilization versus mobilization strategies to adopt, in order to obtain an optimal healing and avoid stiffness. The consequences of an increased postoperative stiffness are mainly represented by functional limitations, especially in shoulder forward flexion and rotations, which may, therefore, could be seen as "complications" of shoulder surgery. On the contrary, an incomplete or inadequate healing might determine the risk of a re-rupture of the rotator cuff, representing thus a "failure" [20]. With this concept in mind, and with the exact knowledge of the biology of the healing process and of the factors affecting it, the immobilization period should be carefully scheduled in each patient to achieve healing with reasonable safety.

Parsons and colleagues [21] retrospectively evaluated 43 patients operated for arthroscopic repair of full-thickness rotator cuff tears, who underwent a 6-week full-time sling immobilization period after surgery. Despite they found ten stiff patients after surgery, at 1-year follow-up, no differences between "stiff" and "non-stiff" subjects were found in the functional outcomes measures.

In a recent prospective randomized controlled trial [22], 105 patients who underwent arthroscopic repair for small to medium-sized full-thickness rotator cuff tears were randomized to two groups, early passive motion (starting at 1st postoperative day) versus delayed immobilization (4–5 weeks postsurgery, depending on tear size). Interestingly, the authors did not find any differences at 1-year follow-up between groups in shoulder range of motion, pain, and function. They suggest that early passive motion after arthroscopic cuff repair does not guarantee early gain of range of motion or pain relief, but also does not negatively affect cuff healing, and so it should not be considered as mandatory.

Lee and colleagues (2012) compared range of motion and healing rates between an aggressive and a limited early passive exercises protocol of postoperative rehabilitation in 64 patients who received arthroscopic rotator cuff repair for the treatment of full-thickness rotator cuff tears. They concluded that, 1 year after surgery, pain, range of motion, muscle strength, and function improved in both groups, regardless of the rehabilitation protocol used. However, in the aggressive group, they could see a trend toward an increased rate of anatomic failure of the repaired cuff [23].

Therefore, it seems reasonable to avoid too aggressive mobilization strategies in the early postoperative period, in order to accomplish a good healing process. This is particularly true in the era of arthroscopic repair of rotator cuff tears, which strongly limits surgical trauma, thereby reducing the risk of postoperative stiffness.

Early postoperative mobilization, nevertheless, could be useful for certain categories of patients presenting one or more risk factors for developing shoulder stiffness [24]. In these patients, the physiatrist and the physical therapist have to interface with the surgeon to choose the best possible rehabilitation strategy. Once again, therefore, the principle of treating as necessary, according to the patient's needs, appears to be the most rational and effective.

Hence, according to the size of the lesion, the immobilization period may last for 2–6 weeks.

The patient is usually positioned in a sling which maintains the shoulder in internal rotation. Because extreme adduction degrees worsen the microcirculation of the rotator cuff and increase the mechanical stress on tendons, a slight degree of shoulder abduction (30–40°) with neutral rotation may also be adopted, especially with those patients whose reconstruction was made applying more tension on sutured structures. The abduction position, in fact, represents the position which allows the most efficient vascularization of the rotator cuff structures, as well as the less biomechanical stress on the reconstructed tendons [25].

During this time period, passive and active exercises may be conducted to mobilize the elbow, the wrist, and the hand of the operated side, while shoulder motion exercise should not be considered as necessary. Because of the extreme frailty of the reparative tissue, during the first 4–6 weeks postsurgery, active exercise of shoulder musculature is not permitted.

Phase II: Recovery of Passive Range of Movement

When the immobilization period ends (after 25–28 days), the phase II of rehabilitative intervention may start. The patient has been restrained and only slow and limited movements of the surrounding joints have been allowed in the previous phase, so it is from this point in time that shoulder joint begins to be mobilized. The specific goal of this phase is to recover the passive range of movement of the shoulder, without compensations of scapular movements.

Although it varies from patient to patient, in consideration of the risk factors seen above, this phase approximately starts from the 4th week to the 6th week and lasts until the 12th. From a biological perspective, in this period of time, the progression of the healing process begins to be sufficient to allow the introduction of active movements with a minimum load [25].

Passive exercises should be performed with the aid of a physical therapist, who will gradually mobilize the shoulder, possibly with the patients lying supine in order to avoid scapular movements (Figs. 2 and 3a, b).

Active mobilization exercises are generally introduced starting from the 6th week to the 8th week. Tendon repairing process foresees, at this moment, the proliferative phase, in which unorganized collagen fibers constitute the reparative tissue. The small loading forces acting on repaired tendons during active exercises are useful to determine, through a gentle mechanical stimulation, a functional orientation of the fibers, that enhances the tensile strength of the repair [26]. The first step should be constituted by active-assisted exercises, including supine glenohumeral external and internal rotation as well as supine flexion with the aid of a physical therapist or of the contralateral limb (Fig. 4). Active exercises could also be introduced at this time, especially if performed in water, thereby annulling gravity. Exercises should be performed slowly (30°/s) and in the scapular plane to lessen the contraction of rotator cuff muscles [27].

A particular emphasis should be reserved in this phase to the function of the scapulothoracic joint. If the kinematics of this joint is not correctly restored, in fact, there might be the risk of development of iatrogenous subacromial impingement syndrome. Controlled mobilizations, as well as decoaptation of the humeral head, have to be used (Fig. 5). Rhomboids and trapezius muscles should gradually be reinforced, e.g., by the use of scapular retraction/

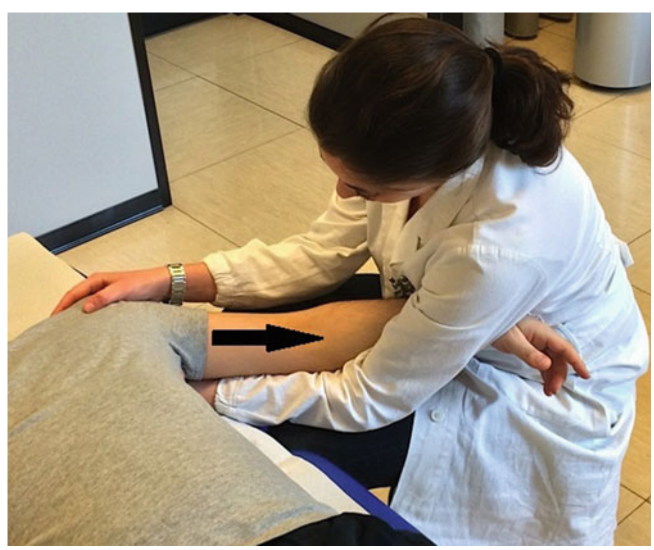

Fig. 2 Physiotherapist performing a passive gentle traction (the *black arrow* indicates the direction of traction) on the left shoulder ("pompage")

Fig. 3 Physiotherapist aids the patient to perform an external (**a**) and an internal (**b**) rotation of the left shoulder in supine position

Fig. 4 Active-assisted glenohumeral flexion in a supine position

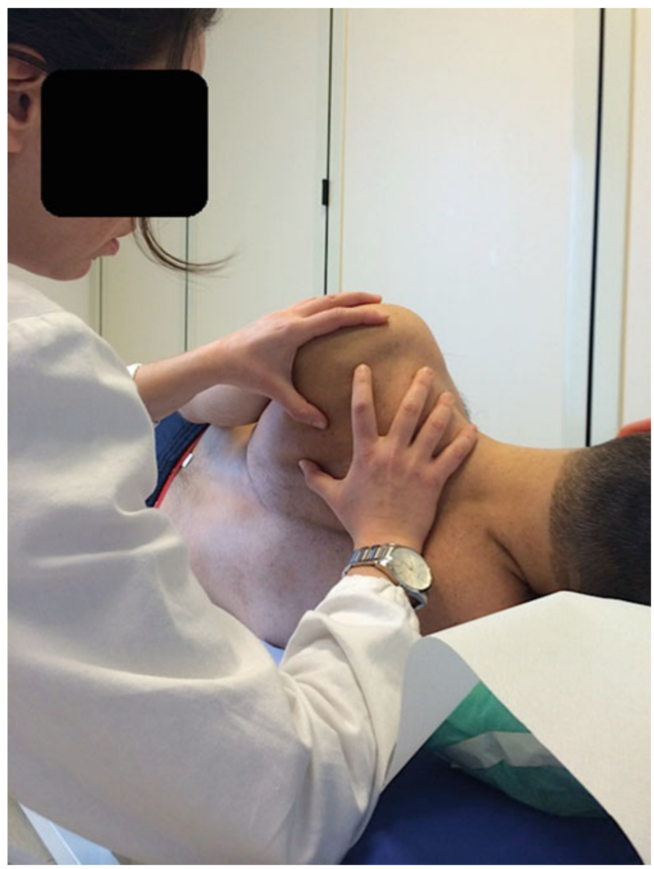

Fig. 5 Physiotherapist performing a passive mobilization of the scapula

depression exercises (Fig. 6). Serratus anterior may be trained by protracting the scapula from 90° of glenohumeral joint flexion.

During this phase, the rehabilitation program is not made up only of the part guided and assisted by the therapist but also of a part that includes a series of exercises performed by the patient alone, properly instructed (Fig. 7a–j). Moreover, attention has to be given to cervicothoracic and scapulothoracic rehabilitation in the early phase in order to reestablish overhead mobility.

At the end of this phase, before progressing to rotator cuff strengthening, it is important that a full glenohumeral range of motion, without pain and without scapular dyskinesia, has been achieved.

Fig. 6 Active exercise for rhomboids reinforcement

Phase III: Recovery of Rotator Cuff Strength

When the patient is able to achieve a full glenohumeral active and passive range of motion, the strengthening phase of rehabilitation can be started. The specific goals of this phase, generally lasting from the 8th week to the 12th week until the 16th week, are to progressively recover the muscular tone and strength of the shoulder muscles. Because the strengthening exercises might determine an excessive stress on the sutured structures of the rotator cuff, the beginning of this phase should be properly scheduled on an individual basis. Factors affecting tendon healing should be, once again, carefully checked before planning strengthening exercises.

To allow a correct reinforcement of the target muscles, it is important to consider the pain, as well as the correct execution of selected movements [25].

Isometric exercises are generally performed first, because they determine low stress levels on sutured tendons.

Isometric reinforcement is followed by isotonic exercises, which could be performed with the use of elastic bands, and that should initially involve only concentric contractions (Figs. 8 and 9). Open kinetic chain exercises are usually performed first, while the progression to closed kinetic chain exercises, which involve more important proprioceptive control systems, is reserved to advanced rehabilitative stages.

In this phase, it is important to perform specific exercises aimed to enhance full proprioceptive recovery (Fig. 10).

Phase IV: Advanced Strengthening and Full Recovery

This phase can be initiated starting from 16 weeks after surgical repair and generally continues until the 6th month. The goal of this phase is to allow functional recovery, which will be obviously different according to the patients' characteristics.

Every patient should obtain a complete recovery of the normal activities of daily life, which may also include, in case of athletes and young patients, participation in sports activities.

Physical Therapies

The rehabilitative program after rotator cuff repair, might benefit from the use of physical therapies, in order to manage pain, to improve range of motion, ato reduce stiffness, thereby allowing physical therapists and patients themselves to work better on shoulder motion and functionality.

Absolute contraindications in using any kind of physical therapies are represented by the presence of a pacemaker, recent neoplastic processes, and pregnancy. Particular attention should be also given to those patients with acute infective diseases, severe arrhythmias, seizures, and coagulation disorders, according to the physical modality employed.

Transcutaneous Electrical Nerve Stimulation (TENS)

Transcutaneous electrical nerve stimulation (TENS) is a technique used to relieve pain in an injured or diseased part of the body in which electrodes applied to the skin deliver intermittent electrical stimulation to surface nerves and block the transmission of pain signals.

The two most commonly used TENS in clinical practice are represented by the high-frequency, low-intensity (conventional) TENS (HF-TENS) and by the low-frequency, high-intensity (acupuncture-like) TENS (AL-TENS) [28]. The analgesic action of TENS is mediated by the peripheral nervous system and by both the spinal and supraspinal central nervous system mechanisms [29].

TENS could be used in the immobilization phase, acting as a valid support in pain management for their proved action on pain control. The advantages of TENS include noninvasiveness and ease to use. TENS can also be indicated as a first-line treatment in patients suffering from peripheral pain. Kocyigit et al. [30] suggest that a one-session low-frequency TENS may

Fig. 7 Patient is standing in front of the wall; from the starting position (**a**, **b**) is invited to flex both shoulders resting his/her palms against the wall. Once he/she reaches the sore point (**c**), it is required to maintain that position for about 10 s before returning slowly, and with opposite movements, to the starting position.

Patient is standing perpendicularly to the wall; from the starting position (**d**, **e**) is asked to abduct the affected shoulder with the palm of the hand on the wall. Once he/she reaches the sore point (**f**), it is required to maintain this position for about 10 s before returning slowly, and with opposite movement, to the starting position.

Patient grasps the top of the rope/towel/robe cord, with the hand of the healthy side, while the lower part with that of the operated one (thumbs up) (**g**). It is asked to extend the elbow of the healthy side thus increasing the internal rotation of the operated shoulder. Once he/she reaches the sore point (**h**), it is required to maintain this position for about 10 s before returning slowly, and with opposite movement, to the starting position.

Patient grasps the door handle or a fixed support with the hand of the operated side, keeping the elbow 90° flexed and the arm adducted (**i**). It is invited to turn out his/her feet and so to external rotate the operated shoulder while keeping the elbow flexed and arm adducted. Once he/she reaches the sore point (**j**), it is required to maintain this position for about 10 s before returning slowly, and with opposite movement, to the starting position

Fig. 7 (continued)

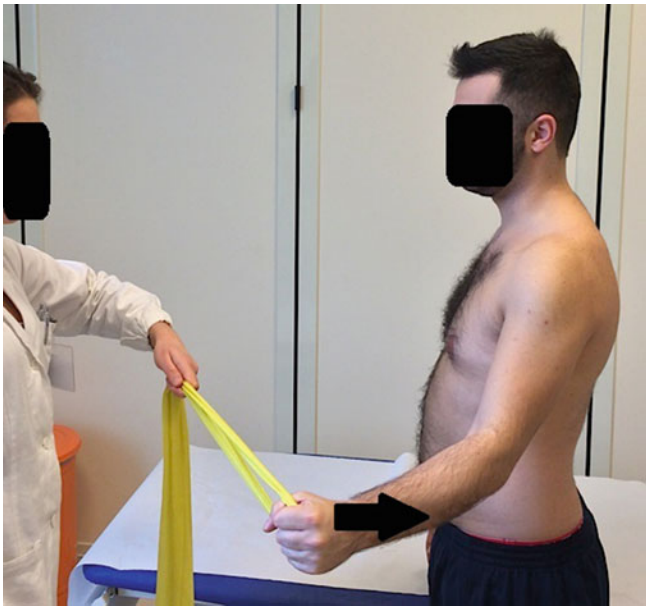

Fig. 8 Active reinforcement of the movement of external rotation of the shoulder with the aid of an elastic band

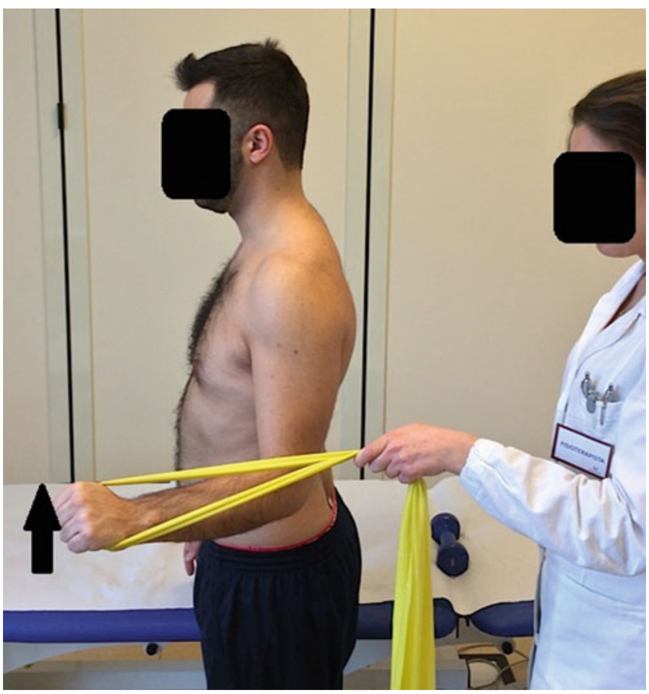

Fig. 9 Active reinforcement of the movement of internal rotation of the shoulder with the aid of an elastic band

induce analgesic effect through modulation of discriminative, affective, and motor aspects of central pain perception.

The most commonly used electrodes are of the reusable, nonsterile type, which can be made from a variety of materials. Carbonized rubber electrodes and siliconized carbon rubber electrodes are among the most commonly used.

Fig. 10 Proprioception exercise in a supine position

Sterile, disposable electrodes of various sizes and shapes are available for postoperative conditions in which infection of the surgical wound is likely.

Three basic electrode placement modalities are described in literature [31]. These may be represented as follows:

1. Over and around the painful area
2. Along the dermatomes corresponding to the painful area
3. Over specific body points

Over and Around the Painful Area

This is the most common electrode placement observed in the literature. The rationale for this placement is that the electrical field within the electrodes will depolarize nerve fibers anatomically associated with the site of injury, or with the injured soft tissues. This placement allows the stimulation of the nerve fibers entering the same spinal segment as the nerve fibers associated with the origin of the pain.

Along the Dermatomes Corresponding to the Painful Area

The rationale of this electrode placement is that the electrical field within the electrodes will depolarize nociceptive fibers belonging to the dermatomes associated with the site of injury or with the injured soft tissues. This type of placement also allows the stimulation of the nociceptive fibers entering the same spinal dermatome segment of those nociceptive fibers associated with the origin of pain.

Over Specific Body Points

The third electrode placement is characterized by its application over specific body points identified as acupuncture and trigger points. This placement may or may not allow the stimulation of the nociceptive fibers entering the same spinal segment as those associated with the origin of the pain.

Laser Therapy

A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The term "laser" originated as an acronym for "light amplification by stimulated emission of radiation" [32]. Lasers differ from other sources of light because they emit light coherently. Spatial coherence allows a laser to be focused to a tight spot, enabling applications like laser cutting and lithography. Spatial coherence also allows a laser beam to stay narrow over long distances (collimation), enabling applications such as laser pointers. Lasers can also have high temporal coherence which allows them to have a very narrow spectrum, i.e., they only emit a single color of light. Temporal coherence can be used to produce pulses of light—as short as a femtosecond.

Laser treatment is noninvasive, painless, and can be easily administered in primary care settings for a wide range of conditions. It has been reported that the use of laser therapy significantly reduces pain levels in both acute and chronic conditions such as rheumatoid arthritis, chronic osteoarthritis, carpal tunnel syndrome, fibromyalgia, knee injury, shoulder pain, and postoperative pain. Although low-level laser therapy does not elevate tissue temperatures more than a few degrees, studies have found that the treatment has the potential to reduce inflammation and pain and improve function. Low-level laser therapy (LLLT) significantly increases microcirculation, activates angiogenesis, and stimulates immunological processes and nerve regeneration. Moreover, it has an analgesic effect through stimulating an increased production of endorphins [33–35].

Low-level laser therapy could be a valid physical therapy for its known action on the reduction of inflammation process and pain control. Eslamian et al. [36] showed how gallium-arsenide low-power laser combined with conventional physiotherapy provides better results in terms of pain reduction and functional improvement in patients with rotator cuff tendonitis.

In a recent randomized clinical trial, Yavuz et al. [37] concluded that low-level laser therapy may be considered as an effective alternative to ultrasound-based therapy in patients with subacromial impingement syndrome, especially if ultrasound-based therapy is contraindicated.

LLLT can be delivered using the continuous or pulsed mode [31]. Practitioners can choose between red-light gaseous (HeNe) and infrared-light diode or semiconductor (GaAs; GaAlAs) lasers. Infrared-light lasers are made of one or more diodes. Multidiode lasers offer a wider range of wavelengths. Infrared lasers are more penetrating than gaseous lasers. Single (handled) and cluster (mechanically mounted on the laser device) probes of different shapes and radiating beam areas may be used. Selection is based on the size of the treatment surface area; larger surface areas will require clusters probes in order to minimize the number of applications. LLLT may be administered using two methods: point by point and scanning. With the point by point method, a handheld single probe is used; this method has three different techniques of application: contact, noncontact, and grid. With the scanning method, either a single probe or clusters probes are used. Scanning of the treated area may be manual or automatic.

Pont by Point

This method refers to the application of a single diode over the surface overlying the pathological lesion. This single laser beam thus makes one point of contact with the skin. To treat a given surface area, the single probe is manually moved from one point to the next, hence the term point by point.

Contact Application

This technique involves making a light contact between the tip of the probe and the skin surface. Contact with and without pressure can be used. The probe is held perpendicularly to the skin surface. This technique eliminates photonic reflection of the skin surface and minimizes beam divergence because of the probe's proximity to the area that is being treated.

Noncontact Application

This technique consists in keeping a distance of few millimeters between the probe tip and the skin surface overlying the treatment area. The laser probe is held perpendicular to and within 2–4 mm of the skin surface to reduce wave reflection and beam divergence. This technique is recommended when patients cannot tolerate the pressure exerted by the laser probe on the surface of the area being treated.

Grid Technique

This technique consists in making a grid by mapping the entire treatment surface area with 1-cm^2 squares to guide point application. Each square centimeter corresponds to one point. The grid can be made either visually or with a plastic sheet and a pen. The application can be done with the probe in contact or further away from the skin.

Scanning

This method refers to the scanning of the entire treatment surface area. This scanning action may be done by manipulating the single probe so as to cover the entire treatment surface area. It can also be done automatically by means of robotic displacements of the diodes within the cluster probe, or of the cluster probe itself, over the treatment area.

Patients and clinicians must wear protective glasses which filter the wavelengths emitted by the laser device during therapy.

More recently, the pulsed neodymium-doped yttrium aluminum garnet (Nd:YAG) laser, a form of high-intensity laser therapy (HILT), was introduced to the field of physical therapy [38]. This laser works with high peak power (3 kW), and a wavelength of 1,064 nm, and is considered to be a nonpainful and noninvasive therapeutic modality. It is able to stimulate areas that are difficult to reach with the low-power laser, such as the large and/or deep joints. The use of the pulsed Nd:YAG laser has been increasing, with patients reporting significant pain reduction. Studies have documented the anti-inflammatory, antioedematous, and analgesic effects of the Nd:YAG laser, justifying its use in patients with pain issues [39]. The effect of HILT in patients with subacromial impingement syndrome in terms of pain reduction, improvement in joint functionality, and muscle strength has been demonstrated in a recent randomized control trial [40]. From these considerations, high-intensity laser therapy (HILT) could be a valid support in the rehabilitation program after rotator cuff repair.

Segmental Muscle Vibration

Segmental muscle vibration is a technique that applies a low-amplitude/high-frequency vibratory stimulus to a specific muscle using a mechanical device. It induces the generation of Ia inputs by activating muscle spindle primary endings. The Ia inputs activated by segmental muscle vibration can alter the excitability of the corticospinal pathway by modulating intracortical inhibitory and facilitatory inputs to the primary motor cortex. It is widely known that a vibratory stimulus applied directly to a muscle induces presynaptic inhibition of Ia afferents and it is likely to reduce transmitter release from the Ia afferents, thereby decreasing the monosynaptic reflex excitability. Vibration also reduces the stretch-related afferent input through a "busy-line" phenomenon, whereby the Ia discharge is locked to vibration and is consequently unable to faithfully transmit the stretch-induced volley owing to the high vibration frequency (>90 Hz) and the entrained action potentials in the Ia fibers. Indeed, the application of a 91-Hz vibratory stimulus to the spastic upper limb muscles of poststroke patients results in a significant and persistent (up to 30 min) reduction in muscle tone, accompanied by a reduction in F-wave amplitude and F/M ratio, both of which point to a reduction in motor-neuronal excitability. Moreover, vibration also reduces the H reflex, probably through mechanisms of postactivation depression and dendritic depolarization [41].

It is also known that vibration applied to muscles and tendons could act on the proprioception [42]. Muscle-tendon vibration has also shown to elicit motor cortex activation. A recent study with TMS has demonstrated its direct modulating effect on M1 excitability with a vibration intervention below the sensory illusion threshold [43].

A comparative analysis of brain activity with positron emission tomography showed that both the loci and levels of activation during tendon vibration did not match with those obtained during passive movement [44].

From these points of view, segmental muscle vibration could be used to improve muscle strength and proprioception, so it could be utilized in the late phases of the rehabilitation program after rotator cuff repair.

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Part V

Cuff Tear Arthropathy

Rotator Cuff Arthropathy. What Is It?

Stefano Gumina and Vittorio Candela

Definition and Historical Review

In the early 1980s, Neer et al. [1, 2] have coined the term "rotator cuff arthropathy" to indicate a nosological condition characterized by arthritic degeneration of the glenohumeral joint consequent to the massive – postero-superior rotator cuff tear. However, more than a century earlier, Adams [3], in his book on rheumatic gout, and Smith [4, 5] had described cases of shoulder arthropathy characterized by erosion of the upper portion of the humeral head, of the acromion, and of the distal third of the clavicle and rotator cuff tear. Codman [6], in his monograph published in 1934, had described the case of a woman, 51 years old, whose shoulder underwent rotator cuff tear, glenohumeral arthropathy, loose bodies, and swelling for the abundant articular synovial fluid.

Further papers have not been published until the end of the 1950s when Galmiche and Deshayes [7], Burman et al. [8], Banna and Hume [9], Shepard [10], and Snook [11] reported a total of thirty cases of shoulder arthropathies, some of them with the characteristics of cuff tear arthropathy.

In 1968, De Seze [12] described the hemorrhagic shoulder of three elderly women whose clinical (blood streaked recurrent effusion; rotator cuff tear) and radiographical (severe degenerative glenohumeral arthritis) characteristics suggested a rotator cuff arthropathy. One year later, Bauduin and Famaey [13] described an analogous case.

Jensen et al. [14], in a prestigious publication of 1999, described the three main clinical and radiographical characteristics of the cuff arthropathy: (a) massive tear of the rotator cuff, associated with shoulder pain, supra- and infraspinatus atrophy and loss of motion (Fig. 1a–c); (b) degenerative changes of the glenohumeral joint (Fig. 2a, b); and (c) upward migration of the humeral head observable on AP view (Fig. 3a). Humeral head collapse (Fig. 3b), erosive changes of superior glenoid or acromion, periarticular soft-tissue calcifications, and subdeltoid effusion are other possible features that may be present [15].

Etiopathogenesis

Mechanical Theory

Neer et al. [2] hypothesized that mechanical factors were at the origin of cuff arthropathy. According to this theory, loss of downward force performed by a healthy rotator cuff on the humeral head would result in a superior migration of the humerus. This might facilitate an erosion of the superior surface of the glenoid and of the antero-inferior aspect of the acromion. In addition, the upward migration of the humeral head could cause a joint instability, an eccentric work of the humeral head, and consequently, a premature wear of the articular cartilage in the areas of higher glenohumeral compression. Since 21 of the 26 patients cited in the paper had the rupture of the long head of the biceps tendon, Neer thought that this injury would help the upward migration of the humeral head.

Burkhart's hypothesis [16] seems to support the mechanical theory. The author believes that the healthy inferior portion of the rotator cuff (below the center of rotation) creates a moment that must balance the deltoid moment (force coupling). Furthermore, the subscapularis is anteriorly balanced against the infraspinatus and teres minor posteriorly. Uncoupling of the essential force couples results in anterior superior translation of the humeral head with attempted elevation of the shoulder.

In 1997, Collins and Harryman [17] hypothesized that cuff arthropathy was initially due to supraspinatus tear and later to the infraspinatus lesion; the complex tendon tear would cause the upward migration of the humeral head and, consequently, the contact of articular cartilage of the humeral head against the antero-inferior margin of the acromion. Cartilage fragmentation results in particulate debris, which causes synovial thickening and effusion as well as calcium phosphate crystal formation. The enzymatic response to the crystals furthers the damage of the articular surfaces.

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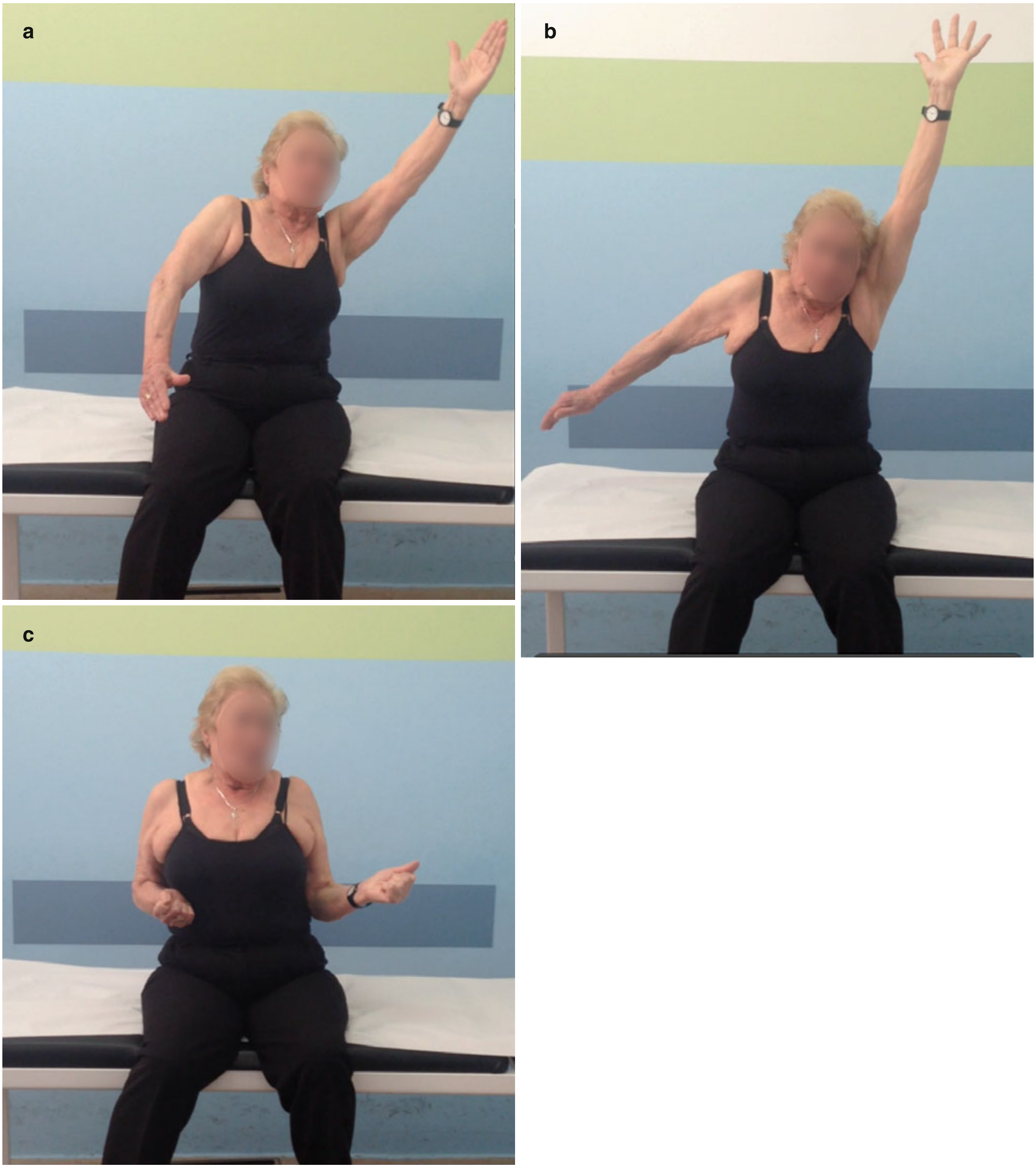

Fig. 1 (**a**–**c**) Decrease in range of motion in 75 female patient with cuff tear arthropathy

Concavity-compression mechanism, suggested by Hurov [18], further corroborates the mechanical theory. According to the author, the healthy cuff compresses the convexity of the humeral head against the pseudo-concavity of the glenoid; therefore, the cuff, with other periscapular muscles, would act as an important dynamic stabilizer of the joint. This action may be even more important in the presence of severe laxity of the static stabilizers of the shoulder (capsule, labrum, and glenohumeral ligaments).

Oh et al. [19] identified that critical tear sizes responsible for disrupted joint kinematics are those with full-thickness supraspinatus tears and 50 % detachment of the infraspinatus.

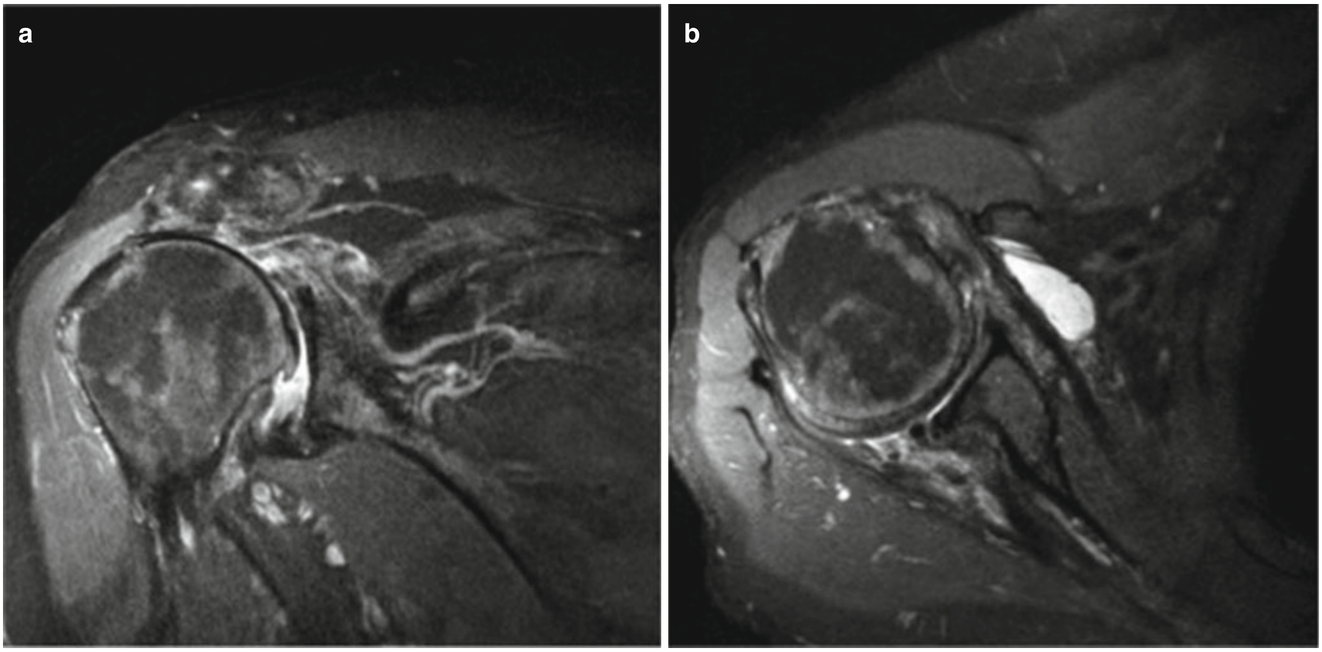

Fig. 2 MRI of a right shoulder of 77 male patients with Hamada 3 cuff tear arthropathy. (**a**) Coronal T2 fat suppressed FSE. Acromio-humerus distance <5 mm with acetabularization of acromion. (**b**) Axial PD fat suppressed FSE: Walch A1 glenoid morphology (humeral head centered with minimal erosion)

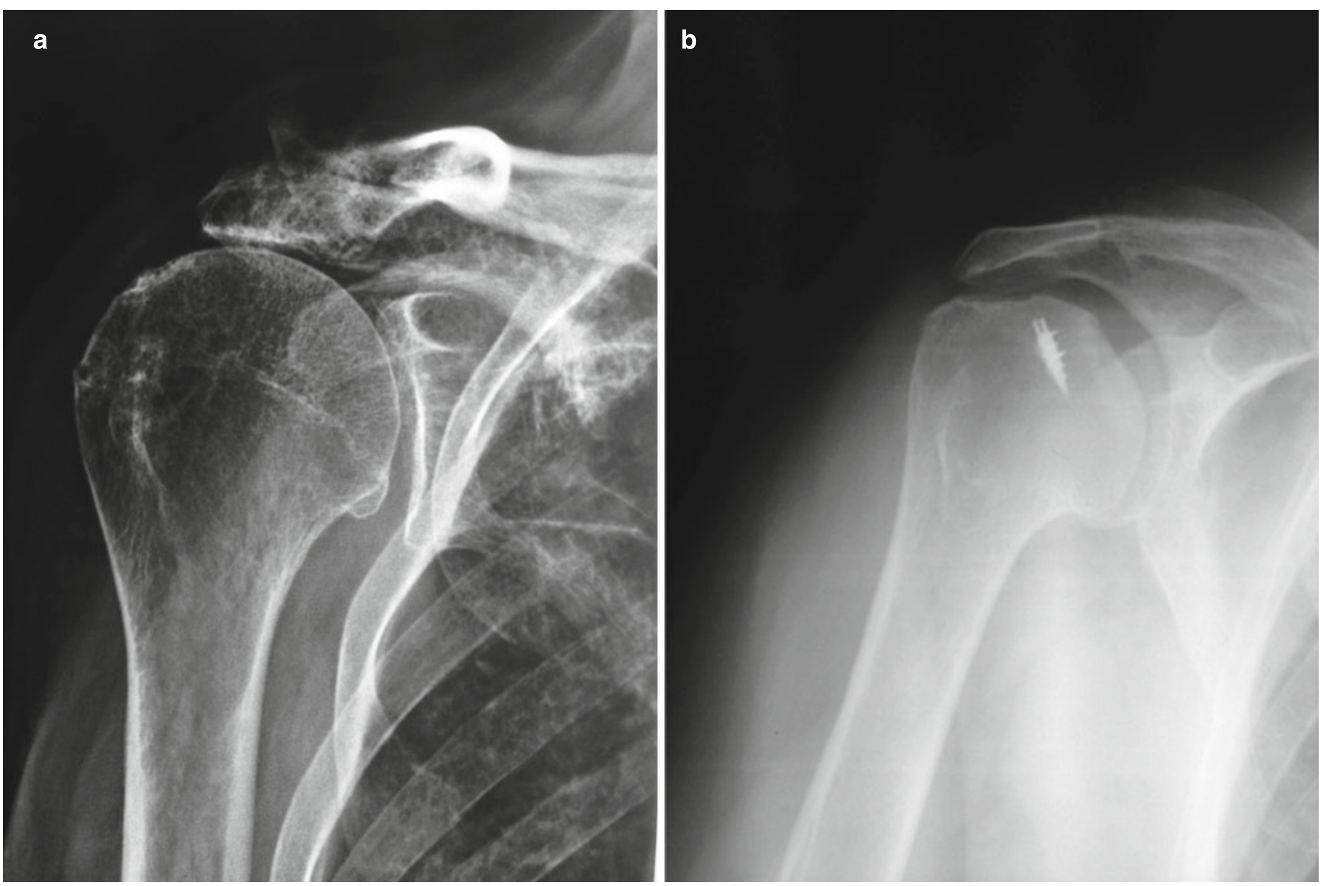

Fig. 3 (**a**) True AP X-ray view of a right shoulder: Hamada 3 cuff tear arthropathy. (**b**) AP X-ray view of a right shoulder: Hamada 5 cuff tear arthropathy, bony destruction – humeral head collapse after a cuff repair failure

Nutritional Theory

Neer et al. [1, 2] have also suggested that the osteoarthritis could depend on the loss of the "water tight" effect (loss of negative pressure normally existing inside the shoulder joint in normal conditions) due to the cuff tear.

This would cause dispersion of synovial fluid, normally contained in the joint, in the subacromial space. The dispersion would make the diffusion of synovial fluid into the joint cartilage difficult; consequently, the cartilage would be poorly nourished and would easily run into atrophy. Furthermore, diffusion of the fluid into the cartilage should be further hindered by the decrease in range of motion caused by the shoulder pain due to the cuff tear (loss of water and mucopolysaccharides content). In addition, decrease in mobility, resulting in pain, would lead the subchondral bone to be osteoporotic and more exposed to possible collapse.

It is known that cytokine and catabolic enzyme concentration increases in the early phases of osteoarthritis. Many studies have also proved that the rotator cuff tear leads to an increased production of interleukin 1β and TNF, which helps to explain the presence of pain and inflammation. It was also noted that the production of many cartilage matrix-specific matrix metalloproteinases (MMPs) increased, including MMP-1, MMP-2, MMP-3, MMP-8, and MMP-13 [20, 21]. The presence of MMP-3 is important because it is implicated in the proteolytic activation of the other MMPs. Yoshihara et al. [22] observed that there is a correlation between the concentration of these cytokines, collagenases, and aggrecanases and accelerated cartilage degeneration after a cuff tear.

These observations redimension the nutritional theory in the genesis of cuff tear arthropathy. In fact, with the evacuation of a part of the synovial fluid through the tendon lesion, inflammation factors and proteolytic enzymes should be removed and, thus, health status of articular cartilage should be preserved.

In 2012, Reuter et al. [23] sonographically assessed the articular surface of the glenohumeral joint in rats with a rotator cuff tear and observed a thickness decrease in the cartilage. Kramer et al. [24] histologically studied the glenohumeral cartilage of rats, respectively, submitted to detachment of the postero-superior rotator cuff and to suprascapular nerve root transection passing through the trapezoid (joint capsule was kept intact). The animals were killed 12 weeks after surgery. In the first case, if there had been degenerative changes of the cartilage, it would have been attributed, in accordance with the Neer's hypotheses [1, 2], to the altered mechanical loading and to the nutritional theory, instead, in the second case, only to the mechanical hypothesis. Surprisingly, the amount of cartilage degeneration was similar between the groups. This result suggests that aberrant mechanical forces are the primary causes of articular cartilage degeneration in the setting of cuff tear arthropathy.

Crystalline-Induced Arthritis of the Shoulder Theory

In orthopedic literature, almost simultaneously to Neer's hypotheses, a nosologic entity similar to the cuff arthropaty has been described: the "Milwaukee syndrome" [25]. Although it is responsible for a clinical condition similar to that of the cuff arthropaty, this disease has been attributed to the presence in the synovial fluid of basic calcium phosphate crystals encapsulated into microspheroids without apparent inflammatory cell response. Indeed, an altered capsular degenerated cartilage and synovium, possibly with a macrophage response and subsequent release of collagenase and neutral proteases, are associated with this condition, resulting in the attack and subsequent destruction of the joint.

In 1985, Dieppe and Watt [26] noted that basic calcium phosphate crystals could be found in arthritic and neuropathic joints and in apparently healthy joints of elderly subjects. In addition, the apatite crystals are found especially in the most destructive atrophic situations. Therefore, the authors hypothesized that the crystals are produced by the processes that are secondary to joint degeneration. This hypothesis redimensions the inflammatory theory and suggests that the syndrome is a form of cuff arthropathy.

Autoimmune Rheumatic Diseases

Cuff arthropathy could be considered an autoimmune rheumatic disease. As well as for scleroderma or systemic lupus erythematous, patients with cuff tear arthropathy are frequently females. No study has ever confirmed this hypothesis. We are conducting a study to verify the reliability of this hypothesis; however, available data do not allow us to formulate conclusions.

Idiopathic Theory

It is possible that the cuff arthropathy is the result of a fortuitous coincidence between rotator cuff tear, which is frequently found in elderly patients [27, 28], and idiopathic glenohumeral arthropathy. In other words, arthropathy would occur regardless of cuff tear.

Upward migration of the humeral head consequent to the cuff tear would only be responsible for the fast evolution of the arthritic process, and it would only cause a more precocious wear of the upper portion of the glenoid surface. If this hypothesis is correct, the cuff arthropathy should not have a clear preference for sex and patients should have an average age similar to that of patients with concentric arthropathy; instead, the cuff arthropathy is predominantly found in females and in older patients.

Theory Related to Joint Laxity

Since cuff tear arthropathy and youth joint laxity are significantly more frequent in females, we hypothesized that these two conditions are associated with each other. If the rotator cuff tear occurs in patients who have/had joint laxity, it is possible that the involved shoulder could develop a severe static instability that might be responsible for a premature wear of the cartilage of the superior glenoid. This assumption justifies the evident difference in the prevalence of cuff arthropathy due to gender.

In order to verify this theory, we are administering a questionnaire to patients with glenohumeral arthritis to detect joint hypermobility [29, 30]. The questionnaire investigates, using major and minor criteria, patient's ability to perform uncommon activities, the presence of joint diseases, or the tendency to dislocation.

From a preliminary analysis, performed on 38 patients [13 with concentric arthritis (6 M and 7 F; range 51–89 years) and 25 with eccentric arthritis (8 M and 17 F; range 64–85 years)], no significant difference was found between the groups regarding the association between joint hypermobility and concentric/eccentric glenohumeral arthritis ($p > 0.05$).

Clinical Presentation

Generally, patients with cuff tear arthropathy are older than 65. They refer shoulder pain; rarely pain intensity is marked. Patients typically are women with shoulder symptoms of long duration. The dominant side is most commonly affected. Usually, pain is distributed in the antero-lateral region of the shoulder, rarely at the neck base; it does not extend beyond the elbow; scapular region is not interested; pain is not accompanied by paresthesiae. The pain characteristically interferes with sleep and intensifies with activity.

Many patients experience audible crepitus. When these are present, it is easy to evocate them during the Jobe or the full can test maneuvers.

In thin patients, it is sometimes possible to observe shoulder profile deformity, because of the humeral head upward migration. Occasionally the shoulder is swollen by the presence of abundant synovial fluid that is spread in the subacromial space, glenohumeral, and acromio-clavicular joints.

Atrophy of infraspinatus and supraspinatus muscles is constantly observable. Weakness of the external rotators may be marked; generally full can test and Patt test are positive. Very often, the lag signs are also positive.

In the vast majority of patients, the active and passive range of motion is severely limited because of soft-tissue contractures or fixed glenohumeral subluxation [14]. Patients who maintain a stable core can keep mobility in flexion and abduction.

Differences Between Concentric and Eccentric Glenohumeral Arthritis

Histology

At our knowledge, no studies have been conducted regarding histological differences between shoulder arthropathy with or without cuff tear. Actually, the vast majority of the studies have considered histological and ultrastructural characteristics of the idiopathic arthritis, assuming that there were no differences between the two conditions. In both, articular cartilage layer is thinned or, as in the areas submitted to higher mechanical stress, has deep and broad splits or is completely absent, leaving wide exposition of the subchondral bone. In the most severe cases, cells are arranged in clusters in the deeper layer of the cartilage; sometimes chondrocyte lacunae are empty, surrounded by thickened collagen fibers [31]. The living cells are in intense activity and have well-developed cytoplasmin granules. They are enclosed in lacunae that contain numerous fibrils and mature collagen fibers. Matrix is represented by thickened collagen fibers, arranged in all directions, often perpendicularly disposed with respect to articular surface. Colloidal iron staining shows the presence of mucopolysaccarides around the living chondrocytes.

Neer [2] histologically described 26 shoulders with cuff arthropathy. Authors observed three consistent findings: areas with atrophic cartilage and osteoporotic subchondral bone in the humeral head; areas where cartilage is denuded and subchondral bone is sclerotic; and fragments of articular cartilage in the subsynovial layer. An histological study performed by Jensen et al. [14] on specimens of patients with cuff arthropathy revealed foci of calcific deposits in synovial microvilli.

Kramer et al. [24] performed an elegant study on rats whose cuff tendons were previously excised. The histological analysis was performed 12 months after surgery. Authors observed significant cartilage changes in the humeral head compared with the control side. Applying the modified Mankin score [32] (widely used for histologic evaluation of osteoarthritis), they obtained a value of 5.7 ± 1.9 in the involved shoulder and 2.0 ± 1.0 in the control side ($p < .001$). The score considers the structure, cellularity, safranin O staining, and tidemark integrity. Analogously, glenoid values were 5.1 ± 1.9 and 2.4 ± 0.8 ($p < .001$).

CT studies [33–35] have demonstrated that bone density, below the superficial cartilaginous layer of the glenoid, varies with the different forms of arthropathy. In particular, the calcified cartilage layer, which is deeper than the noncalcified layer, is thicker in cuff arthropathy with respect to the concentric arthropathy; instead, the subchondral bone is thinner [35].

Kekatpure et al. [36] submitted to histopathologic analysis the humeral head of nine women who underwent total

Table 1 Functional evaluation in patients with shoulder arthropathy

	Concentric arthropathy	Cuff tear arthropathy Data relative to 581 patients [46]
	Weighted average	Weighted average
Constant score	27.9 (57 patients) [40, 44]	
	26.8 (210 patients) [56]	30.5
	26.3 (41 patients) [57] 30.1 (41 patients) [57] 37.3 (62 patients) [58]	
ASES score	39.3 (635 patients) [37, 42, 43, 45]	31.8
SST	3.3 (57 patients) [42, 45]	1.8

Comparison between concentric arthropathy and cuff tear arthropathy

Table 2 Range of motion in patients with shoulder arthropathy

	Concentric arthropathy	Cuff tear arthropathy Data relative to 581 patients [46]
	Weighted average	Weighted average
Forward flexion	90.1° (771 patients) [37, 38, 42–45]	63.7°
Abduction	76.2° (488 patients) [43–45]	51.2°
External rotation	21.8° (771 patients) [37, 38, 42–45]	12.5°

Comparison between concentric arthropathy and cuff tear arthropathy

shoulder arthroplasty for a rapidly destructive arthrosis (rapid collapse of the humeral head with no evidence of other nonseptic articular arthropathy). Of the nine cases, seven had a rotator cuff tear (however, fatty infiltration of the rotator cuff muscles was not indicative of a chronic condition), whereas tendinosis in the supraspinatus tendons was found in two cases. Analysis showed absence of articular cartilage. In the subcondral zone, both fragmentation and regeneration of bone matrix, which represented fracture healing, were observed. There was no evidence of inflammatory changes, microorganisms, or crystal-induced arthropathy. Authors did not observe typical AVN findings in the marrow, medullary bone, and cortex.

Age and Gender

It is known that patients with cuff tear arthropathy usually are older than those with concentric arthropathy and are very often females. To check the reliability of these data, we reviewed all the scientific papers published in English from 2000 to date, relative to shoulder arthropathy without rotator cuff tear. We excluded all the papers conducted on patients with rheumatologic diseases, traumas, infections, previous surgical treatments, and cohorts of less than 20 patients. We were able to have demographic information on about 2761 patients with concentric arthropathy [37–45]. Data obtained were compared with those of a meta-analysis conducted by Samitier et al. [46] in 2015 relative to patients with cuff tear arthropathy. This cohort consisted of 581 patients. Data were not statistically analyzed. The weighted average age of the 2761 patients was 66.7 years, while that of patients with cuff arthropathy was 72.0 years. These differences reflect my personal experience. In fact, in my series, the mean age of cuff intact arthropathy patients was 70.1 years, while that of patients with cuff tear arthropathy was 75.6 years. The different age justifies a different etiology.

Analyzing the 2761 patients with concentric shoulder arthropathy, the weighted percentage of females was 48.8 % and that relative to cuff tear arthropathy was 74 %. In my series, the percentage values were 56 % and 70.3 %, respectively.

Literature data indicate that the prevalence of cuff tear does not vary between genders. These data reflect our experience. In our series of 586 patients with different sized cuff tear, males and females were, respectively, 280 and 306 [47]. Nevertheless, cuff tear arthropathy is much more common in females. Different hypotheses may be formulated to explain this sexual predisposition: (1) the percentage of females with joint hyperlaxity is higher than that of males [48–54]; therefore, in absence of cuff tendons and with less effective static stabilizers, shoulder could result excessively unstable. (2) Muscle mass in females is less represented [55]; also in this case, shoulder, in absence of cuff tendons, could be less stable. (3) Cuff tear arthropathy might be an autoimmune disease and therefore belong to those diseases that notoriously are more frequent in females. In this case, estrogens would play a primary role. In fact, estrogen receptors are present on cells of the immune system involved in the pathogenic mechanism of the autoimmune disease; (4) genetics; and (5) environmental factors and lifestyle.

Functional Evaluation

Absolute values of ASES and SST scores are lower in patients with cuff arthropathy than those reported for patients with concentric arthropathy (Table 1). This is partly due to the fact that patients with cuff arthropathy are older. However, the marked difference between the mean values of flexion, abduction, and external rotation recorded in the two groups of patients (Table 2) indicates an actual functional difference. In addition, patients with cuff arthropathy have a decrease in external rotation strength that further compromises shoulder function. Surprisingly, it shows no significant differences between the two groups when the shoulder function is evaluated with the Constant score.

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Reverse Shoulder Arthroplasty: Evolution in Design, Indications, Surgical Technique, and Associated Complications

Kamal I. Bohsali and Michael A. Wirth

Introduction

In the 1970s, the reverse ball and socket design was employed for use in the clinical scenario of glenohumeral arthrosis associated with a structurally or functionally deficient rotator cuff. Implant designs from this era demonstrated minimal success due to issues related to metallurgy, lateralized center of rotation, and fixed fulcrum kinematics. Complication rates regarding semi-constrained and constrained implants approached 90 %, resulting in abandonment of these implants [1, 2]. Current implant designs have focused on a medialized center of rotation, increased glenosphere radius of curvature, modularity of components, and improved baseplate fixation options. Indications for reverse shoulder arthroplasty have continued to evolve and currently include the treatment of proximal humerus fractures, failed unconstrained total shoulder arthroplasty, rheumatoid arthritis with irreparable rotator cuff tears, tumors, and massive rotator cuff tears without arthritis [3, 4]. Despite the current implant designs, surgical technique, and rehabilitation protocols, reverse shoulder arthroplasty has continued to demonstrate complication rates that exceed that of conventional total shoulder arthroplasty [5–7]. Even with its widespread use, there remains a paucity of long-term data regarding survivorship and functional outcomes.

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Patho-mechanics of Rotator Cuff Arthropathy

The glenohumeral joint is stabilized by both static and dynamics forces. Static restraints to motion include the glenoid labrum, glenohumeral ligaments, and negative intra-articular pressure. Dynamic restraints involve the rotator cuff and deltoid muscles, which facilitate concavity compression. In the normal shoulder, anterior and posterior forces are balanced by the opposing vectors of the subscapularis and posterior rotator cuff musculature (teres minor and infraspinatus) [8]. With rotator cuff arthropathy, these force couples have been disrupted due to the presence of a massive rotator cuff tear. Neer theorized in 1983 that this disruption allowed for proximal humeral head migration and abnormal contact with the coracoacromial arch [4–9]. With additional loss of the anterosuperior rotator cuff, the individual would display pseudoparalysis of the shoulder. Subsequent cartilage degradation and glenohumeral joint fluid extravasation would potentiate the displeasing kinematics of the glenohumeral joint. Other authors have implicated calcium phosphate formation during this process as a precipitating factor with regard to the development of rotator cuff arthropathy. Crystal deposition within the glenohumeral joint initiates a robust response from macrophages, triggering a cascade of cytokine production that results in collagenase release and further cartilage degradation [10]. Though there are various theories as to how rotator cuff arthropathy develops, the end result is the same with unfavorable shoulder kinematics associated with shoulder pain and function loss.

Radiographic Findings and Seebauer Classification

As rotator cuff arthropathy represents the continuum of a disease process, so do the radiographic changes in rotator cuff arthropathy, which include varying degrees of humeral head instability, osteopenia, remodeling of the greater

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tuberosity (femoralization), and erosion of the coracoacromial arch (acetabularization). Outcomes regarding treatment of reverse shoulder arthroplasty are variable, and as such, previous attempts have been made to categorize the severity of disease for treatment purposes. Visotsky and coauthors proposed a treatment algorithm based upon radiographic findings. The Seebauer classification is based upon the degree of superior humeral migration and instability of the center of humeral head rotation (Fig. 1a–d) [11]. With types Ia and Ib, shoulder arthroplasty options involve hemiarthroplasty with or without an extended humeral head prosthesis. With a decentered humeral head in types IIa and IIb, reverse shoulder arthroplasty would be the more appropriate option. A prospective study reviewing 63 patients with cuff tear arthropathy indicated significant differences in Constant scores when hemiarthroplasty versus reverse shoulder arthroplasty (favored) was used in the type IIa scenario [12].

Indications and Contraindications for Reverse Total Shoulder Arthroplasty

The primary indications for reverse total shoulder arthroplasty include glenohumeral arthrosis associated with rotator cuff deficiency, failed unconstrained total shoulder arthroplasty, and tumor reconstruction [3, 4]. Some surgeons have advocated its use for other clinical scenarios such as massive rotator cuff tears without arthritis and proximal humerus fractures [4, 13, 14]. Annual volume regarding shoulder arthroplasty has increased dramatically with a corresponding increase in the number of reverse total shoulder arthroplasties, which has been tempered by complication rates approaching 30 % [15]. Due to continued concerns regarding implant longevity and complication rates, patient selection remains of paramount importance when performing this procedure.

Axillary nerve injury, glenoid vault deficiency precluding baseplate fixation, and infection are all absolute contraindications to reverse total shoulder arthroplasty. The patient must be aware of the increased complication rate regarding reverse shoulder arthroplasty and that historical data has indicated clinical deterioration approximately 6–8 years post implantation [16, 17].

Grammont Principles

Current reverse shoulder implant designs may be traced to Paul Grammont's original foray in 1985. The construct consisted of an all polyethylene humeral component and a 42 mm glenosphere (Fig. 2). Both components were cemented through a trans-acromial approach in seven of the eight cases performed. Three patients demonstrated 60° or less of forward elevation [18]. Dissatisfied with these results and cognizant of the historical issues related to constrained designs, Grammont realized that the semi-constrained implant would require medialization of the center of rotation. This change from a lateral to medialized position would reduce torque at the glenoid implant interface and convert shearing force vectors to compression with increasing degrees of abduction. Medialization of the center of rotation and inferior displacement of the humerus would result in deltoid recruitment and subsequent improvement in active forward flexion and abduction [19]. In 1991, Grammont subsequently revised the glenoid component to an uncemented design with a central peg and divergent screws to counteract shearing forces at the glenoid. The glenoid component was reduced to a half sphere with two sizes, 36 and 42 mm. With regard to the humeral side, a non-anatomic inclination angle of 155° was chosen to maximize motion stability while reducing component impingement [19]. The Delta III design contained five parts: the metaglene (baseplate), glenosphere, humeral cup liner, epiphyseal component, and the humeral stem. A monoblock humeral stem was made available for cement fixation purposes. The metaglene contained four peripherally divergent screws. In 1996, a Morse taper with a centrally countersunk screw was incorporated into the Delta III design to reduce the risk of glenosphere-metaglene disassociation [18, 19]. The original Grammont design has served as a foundation by which various iterations of the device have been released. Currently, most reverse shoulder arthroplasty systems demonstrate modularity for both the humeral and glenoid components allowing for appropriate soft tissue balancing and tensioning intraoperatively. A common theme among implant designs involves metaglene fixation with multidirectional locking and nonlocking screws around a central post or screw. The degree of lateral offset is dictated by specific surgical technique regarding the implant system. Humeral neck shaft inclination also varies by implant type. Most modern reverse shoulder arthroplasty systems have multiple humeral cup liner depths with metallic extensions for use during revision scenarios.

The Grammont design medializes the center of rotation, allowing for recruitment of anterior and posterior deltoid fibers (Fig. 3) [18]. With a fixed center of rotation and humeral lengthening, the individual should demonstrate improved active forward flexion and abduction. It is these same design characteristics that negatively affect external and internal rotation arcs. Decreased lateral offset, medialized center of rotation, and teres minor atrophy are all factors that affect postoperative external rotation. Gerber and coauthors have suggested combined latissimus and teres major tendon transfers to improve external rotation in the setting of reverse shoulder arthroplasty [20]. Increasing retroversion of the humeral implant may allow for improved external rotation but at the expense of internal rotation. Internal rotation may not improve with reverse shoulder arthroplasty due the altered force vectors even with an intact subscapularis.

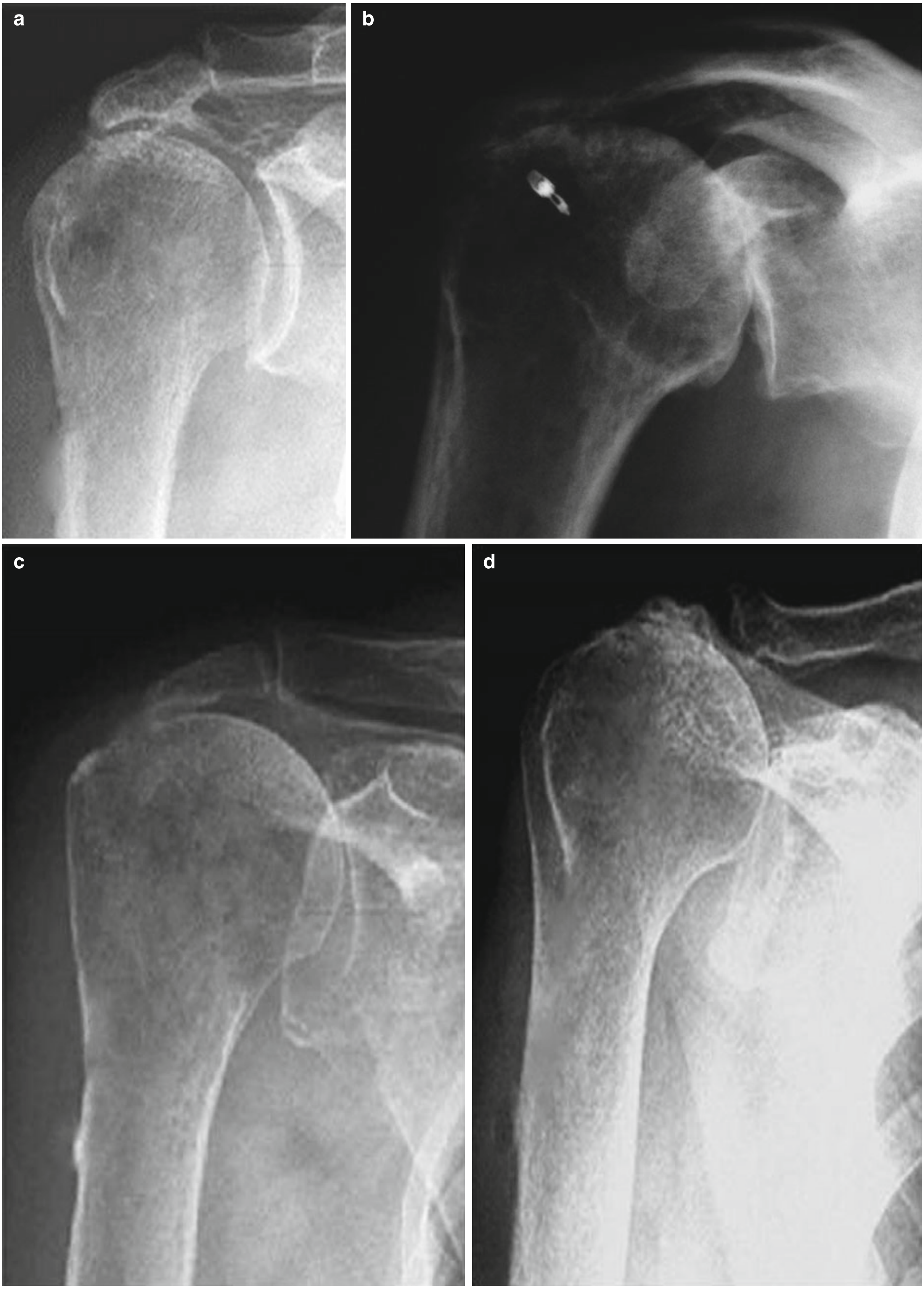

Fig. 1 Seebauer classification for rotator cuff arthropathy. (**a**) Type IA demonstrates a stable-centered humeral head with minimal superior migration, acetabularization of the acromion, and femoralization of the humeral head. (**b**) Type Ib demonstrates medial erosion of the glenoid with intact force couples. (**c**) Type IIa involves a decentered humeral head with limited stability, compromised force couples, and superior migration of the humeral head. (**d**) Type IIb demonstrates an incompetent coracoacromial arch with anterior-superior escape of the humeral head

Additionally, the anterior deltoid cannot compensate in the setting of subscapularis deficiency. To maximize internal rotation, some surgeons have advocated the subscapularis sparing superior-lateral approach [21–23].

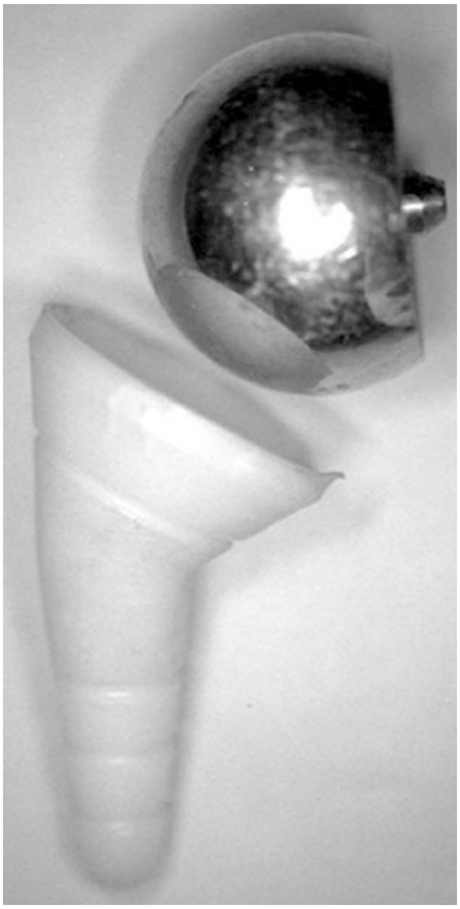

Fig. 2 Grammont's initial reverse total shoulder prosthesis (Reprinted with permission from Elsevier, from: Boileau et al. [18])

Surgical Technique: Critical Concepts and Key Steps

Even among fellowship trained shoulder surgeons, the reverse total shoulder arthroplasty procedure remains technically demanding and is associated with complication rates greater than that of unconstrained total shoulder arthroplasty [24]. Reconstructive failure secondary to instability, component dissociation, infection, or implant loosening presents a clinical scenario that may not have an appropriate solution [3]. Several key steps nonspecific to a defined implant system will be reviewed.

A majority of surgeons utilize the deltopectoral approach, though the European experience has demonstrated viability with the superior-lateral technique. Each approach has its proponents, opponents, advantages, and disadvantages. With regard to the superior-lateral approach, the subscapularis remains intact as the deltoid is split to gain access to the glenohumeral joint through a probable massive rotator cuff tear. Some reports have indicated reduced risk of anterior instability with this approach due to the intact subscapularis. Opponents cite difficulty with glenoid visualization, decreased postoperative external rotation, and an inability to address revision scenarios that require component extraction , tendon transfers, and bone grafting [15, 25]. Our preference is the deltopectoral approach, as this exposure may be extended for revision cases, allowing for improved visualization of the glenoid, and identification and safeguarding of the axillary nerve. The subscapularis is either tenotomized or "peeled" from the lesser tuberosity and later reapproximated or allowed to medialize without reattachment. Advocates of repair cite improved internal rotation and reduced incidence of anterior instability [4]. However, Mole and Favard in their multicenter study of 484 patients who had undergone reverse total shoulder arthroplasty, did not demonstrate statistically

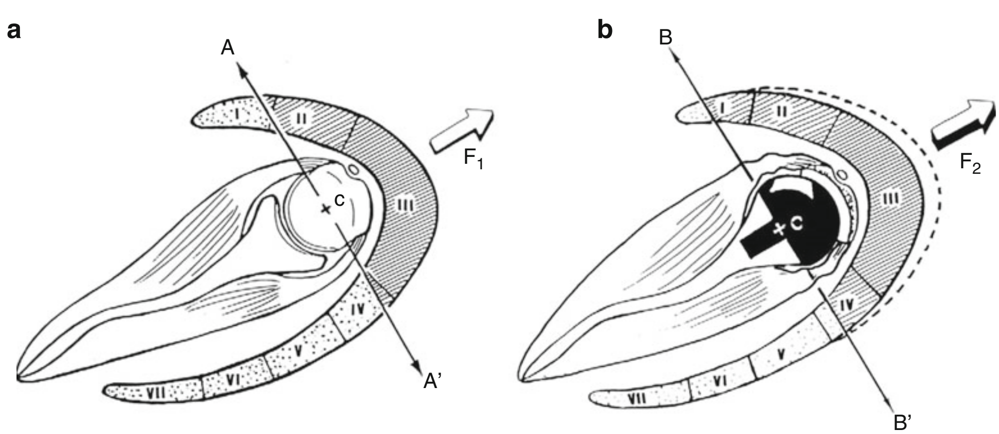

Fig. 3 (**a**) In the normal shoulder, only deltoid segments II and III assist with forward elevation. (**b**) After reverse shoulder arthroplasty, a medialized center of rotation allows for recruitment of additional deltoid regions I and IV with the potential for improved active abduction and forward flexion (Adapted, with permission from Elsevier, from: Boileau et al. [18])

different outcomes when comparing subscapularis repair versus tenotomy without repair [16]. Additionally, Clark and coauthors performed a retrospective cohort study of 120 patients, of which 55 underwent repair of the subscapularis during reverse total shoulder arthroplasty. They concluded that reattachment of the subscapularis did not have any positive effect on complication rate, dislocation rate, pain relief, and range of motion gains [26]. Despite these reports, we currently advocate primary repair of the subscapularis when technically feasible to reduce the potential risk of anterior instability and improve the potential for internal rotation.

With regard to humeral preparation, the humeral head is generally osteotomized in neutral to slight retroversion. More recent studies have suggested resecting the humeral head in native version for the patient to maximize active external rotation [27]. Neck shaft inclination varies depending upon the implant system with Grammont-based implants reliant upon the 155° angle [18]. The tendon of the long head of the biceps tendon is tenodesed adjacent to the pectoralis major tendon insertion. Glenoid labrum removal, sequential capsular releases, and partial release of the long head of the triceps tendon from the infraglenoid tubercle should allow adequate exposure for baseplate implantation. Careful attention must be paid to the native version of the glenoid and the amount of glenoid vault available for baseplate fixation. Some systems require placement of a central guidewire from which glenoid reaming is based. It is critical to avoid excessive medialization, superior tilt, and version (anterior or posterior) of the glenoid during the reaming step. Some authors have advocated inferior tilt with baseplate positioning to reduce the incidence of scapular notching, whereas others have indicated minimal benefit with this technique and similar patient outcomes with or without inferior tilt of the glenoid component [28–31]. Most surgeons agree that the baseplate must be placed as inferior as possible on the glenoid face, but not beyond the glenoid rim, to minimize notching and to allow for improved adduction of the arm. Most implant systems achieve baseplate fixation through multiple screw fixation augmented by a central post or screw placement. Superior and inferior screw lengths range from 24 to 36 mm with anterior and posterior screws approaching 18 mm. Central screw length in the DJO/Encore prosthesis is most commonly 30–40 mm (Fig. 4a, b). Locking screws are generally reserved for placement in the base of the coracoid and the lateral pillar of the scapula [32]. When technically feasible, a larger glenosphere (i.e., 42 versus 38 mm), should be utilized to impart improved stability to the construct.

Once the glenosphere has been implanted, the humeral side is reamed and broached. Modern reverse shoulder arthroplasty designs demonstrate modularity that allows for press fit reconstruction. Controversy remains regarding the amount of version necessary to maximize range of motion and functional outcome. Mole and Favard's study in 2007 recommended neutral version based upon better outcomes involving activities of daily living, strength, Constant scores, and implant failure rate [16]. More recently, Favard et al. noted diminished inferior impingement and scapular notching rates with near anatomic version of the humerus. The authors cautioned regarding the adoption of this technique as the effects on external rotation, internal rotation, and anterior-posterior impingement have not been clearly defined [27]. Humeral cup liner depths vary based upon implant systems, but most allow for multiple thicknesses, degrees of constraint, and metallic spacers for revision situations. Intraoperative reduction is generally accomplished by gentle longitudinal traction and downward push on the humerus. Stability and assessment of soft tissue tensioning remains a qualitative analysis. We will generally perform the following assessments to assure appropriate stability of the construct: the conjoint tendon should demonstrate increased but not

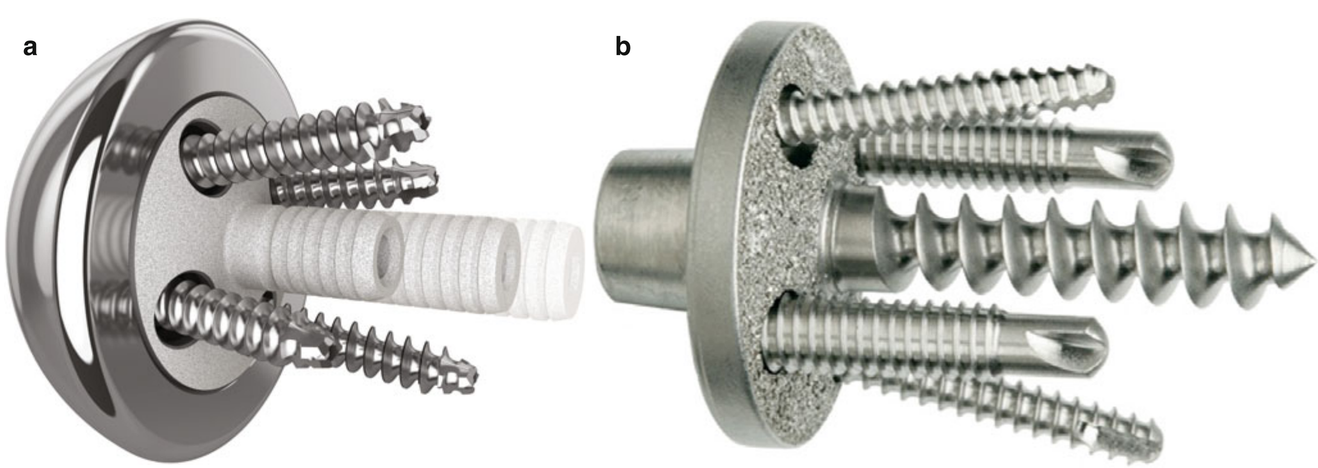

Fig. 4 (**a**) Depuy-Synthes Delta Xtend™ metaglene with post and peripheral screws with locking capability (Courtesy of Depuy-Synthes®). (**b**) Baseplate with central and peripheral screw fixation of the RSP™ (Courtesy of DJO/Encore®)

excessive tension (i.e., bowstring); dislocation with abduction and internal rotation of the arm should not occur; minimal gapping should occur with adduction of the arm; and humeral cup glenosphere dissociation should not occur with longitudinal traction of the arm. The final construct may result in lengthening of the arm with reports indicating an average of 2–3 cm [33]. We reapproximate the subscapularis to the remaining portion of the lesser tuberosity and use a closed circuit suction drain to reduce the risk of hematoma formation. Postoperatively, the patient is placed into a sling and allowed to perform active elbow, wrist, and digital exercises for the first one to two weeks. At that point, pendulum and active assisted forward flexion exercises are allowed with the use of a home pulley system. Sling use is generally discontinued at 4–6 weeks after surgery.

Authors' Preferred Surgical Technique

Prior to surgical intervention, a thorough history and physical exam should be performed. Particular attention must be paid to previous or remote history of infection, prior shoulder surgery, and medical comorbidities, which may contribute to a suboptimal outcome for the patient. The physical exam should focus on evaluation of the soft tissue envelope, integrity of the deltoid and teres minor, and co-existing cervical spine issues, which may affect the ability to achieve pain relief and improved function after reverse shoulder arthroplasty. Appropriate imaging with plain radiographs and CT scan will allow for preoperative templating (Fig. 5a, b). Unless otherwise contraindicated, all anticoagulant and antiplatelet therapy should be discontinued at least 5–7 days prior to intervention. Glycemic control should be optimized to reduce the risk of postoperative infection. Perioperative IV antibiotics such as a first generation cephalosporin or Vancomycin (for patients allergic to penicillin) are administered within an hour of intervention. In the setting of revision surgery when an infection has been confirmed or suspected, antibiotics are withheld until soft tissue samples have been obtained for frozen section and culture. Pain management is achieved through a multimodal approach involving peripheral nerve blocks (interscalene) and the use of a patient controlled intravenous analgesia device.

The patient after induction is placed in the semi-Fowler position on the operative table utilizing a commercially available beach chair positioner that permits unencumbered access to the shoulder (Fig. 6). The operative extremity is prepped and draped free for the intervention (Fig. 7). Implantation of the Depuy Delta Xtend reverse shoulder prosthesis can be achieved through a superior lateral or deltopectoral approach. We prefer the deltopectoral approach as it affords improved ability to visualize the glenoid and to address revision scenarios. The skin incision begins from the inferior border of the clavicle and transverses over the coracoid process and toward the deltoid insertion (Fig. 8). The subcutaneous tissue planes are elevated to identify the cephalic vein, which is mobilized laterally in a majority of cases. Incise the clavipectoral fascia from the coracoacromial ligament to the superior

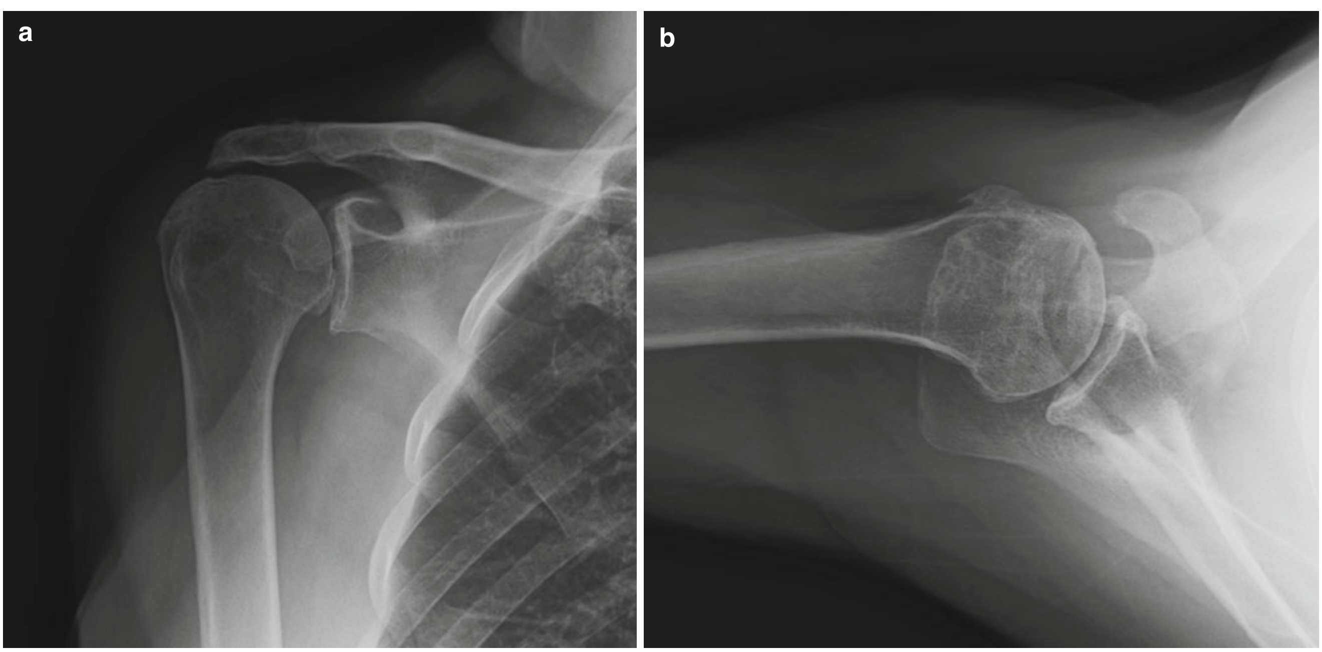

Fig. 5 (**a**, **b**) AP and axillary lateral radiographs demonstrate stereotypical changes of rotator cuff arthropathy with proximal humeral head migration, femoralization of the humeral head, acetabularization of the acromion, and minimal surgical neck osteophyte formation

Fig. 6 A commercially available beach chair positioner allows for safe positioning of the neck and head, as well as facile access to the shoulder during shoulder arthroplasty

Fig. 7 The operative shoulder is draped free for the procedure. Surgical preference dictates whether a padded Mayo stand or commercially available arm positioner is utilized during the intervention

border of the pectoralis major insertion (Fig. 9a, b). Humeroscapular interface will need to be released with careful blunt and sharp dissection. Adhesions posterior to the conjoint tendon should also be carefully released and the musculocutaneous nerve identified. Palpate the axillary nerve at the anterior-inferior border of the subscapularis. Intermittent reassessment of the nerve should be performed to confirm its integrity. The anterior humeral circumflex vessels should be ligated with electrocautery (Fig. 10). Tenodese the biceps tendon at the level of the pectoralis major insertion and transect it proximally. Perform a peel of the subscapularis off of the lesser tuberosity and tag the tendon with three to four #2 nonabsorbable sutures. A Darrach retractor is placed inferiorly at the humeral insertion of the capsule. A fishtail elevator and knife are used to release the capsule to the 6 o'clock position. The humeral head should be easily dislocated with gentle extension and adduction of the arm (Fig. 11). With the shoulder dislocated, position the starting reamer at the most superior lateral location and create a pilot hole to gain intramedullary access to the humerus (Fig. 12). All reaming steps should be performed by hand to avoid iatrogenic injury to the humerus. Ream the humeral canal until the endosteal surface provides torsional resistance (Fig. 13). Select the appropriate handle size and cutting jig and seat the two devices on top of the humeral head. An orientation pin is placed proximally to calculate the degree of retroversion. We generally place the humeral component in neutral to slight retroversion to preserve internal rotation. The cutting jig is stabilized with three pins approximately 2 mm inferior to the proximal region of the greater tuberosity. The humeral head resection is performed with a sagittal saw. A metallic cover-plate is then placed to protect the osteotomy site (Fig. 14a–d).

Fig. 8 During the deltopectoral approach, the skin incision begins from the inferior border of the clavicle and transverses over the coracoid process and toward the deltoid insertion. Revision cases may proceed through the incision from the index procedure if appropriately positioned for the surgical approach screws

Glenoid exposure is of paramount importance for proper positioning of the glenosphere. The remaining labrum and biceps tendon origin are excised sharply with a knife. A 360°

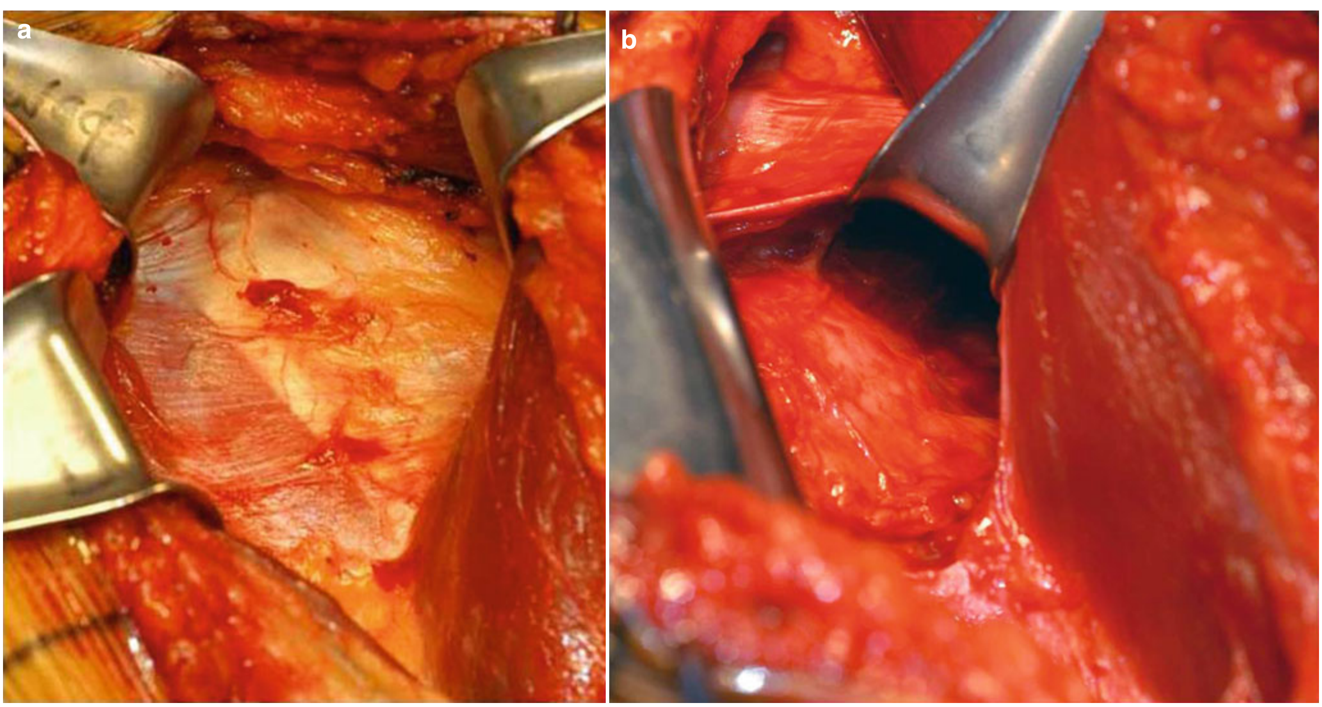

Fig. 9 (**a**) After identification of the cephalic vein, the deltoid muscle is mobilized laterally, allowing for visualization of the pectoralis major tendon insertion. At this point, the clavipectoral fascia is incised and the biceps tendon transected or tenodesed adjacent to the pectoralis major tendon insertion. (**b**) The pectoralis major insertion may require partial release for exposure purposes screws

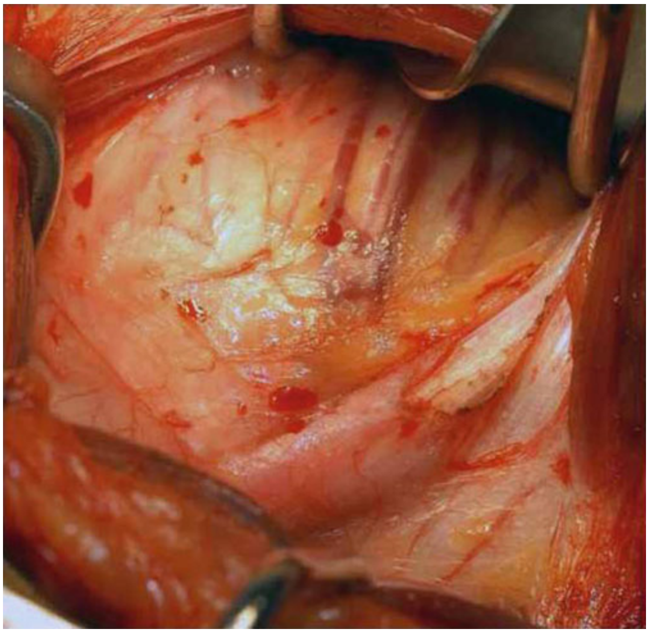

Fig. 10 Gentle digital or blunt dissection should occur posterior to the conjoint tendon taking care to identify and protect the musculocutaneous nerve. The anterior circumflex vessels are encountered and will need to be ligated or cauterized prior to release of the subscapularis. The axillary nerve should be routinely visualized and palpated prior to release of the subscapularis

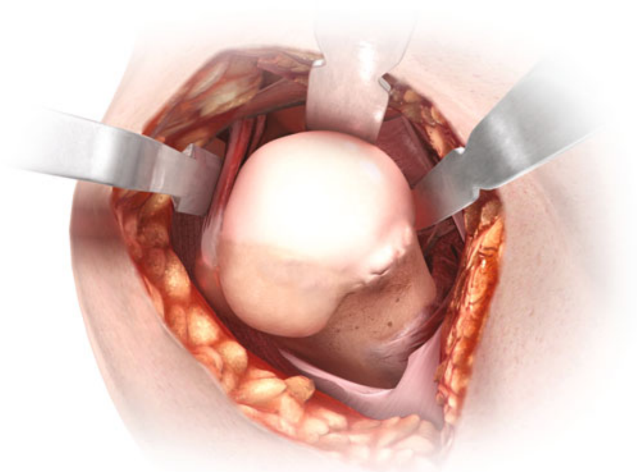

Fig. 11 Following release of the subscapularis and capsule, the humeral head should be readily dislocated with gentle extension and adduction of the arm (Courtesy of Depuy-Synthes®)

release of the subscapularis, if intact, is performed. The posterior, inferior, and superior capsules are released with careful attention paid to the location of the axillary nerve at all times. To adequately visualize the lateral pillar of the glenoid, the origin of the long head of the triceps tendon may be partially released. A forked retractor or modified Sonnabend are then utilized to displace the proximal humerus (Fig. 15).

Fig. 12 With the shoulder dislocated, position the starting reamer at the most superior-lateral location and create a pilot hole to gain intramedullary access to the humerus. Do not use power to ream the humeral canal to avoid iatrogenic injury

All osteophytes may be removed with small osteotomes or small rongeur. Metaglene position should be chosen to obtain adequate glenoid fixation while minimizing the risk of mechanical impingement. The metaglene central peg ought to be positioned posterior and inferior to the intersection of the glenoid axis. Particular attention should be pain to glenoid morphology on preoperative imaging studies, as metaglene position will need to be adjusted based upon adequacy of and screw and post fixation. The metaglene positioner is placed flush with the inferior glenoid rim and a guide pin is advanced perpendicular to the glenoid face. Avoid superior tilt of the pin placement, which may result in suboptimal positioning of the metaglene and glenosphere (Fig. 16a, b). A two-step reaming process allows for appropriate preparation of the glenoid followed by a central cannulated drill bit to prepare for the metaglene post (Fig. 17a–d). Implant the final metaglene into position using autograft to address minor deficiencies in the glenoid surface. The metaglene rotation should be positioned to allow for inferior

Fig. 13 Use graduated reamers on hand power until interference fit is felt within the diaphyseal portion of the humerus (Courtesy of Depuy-Synthes®)

screw placement within the scapular neck and superior screw placement within the coracoid base. The metaglene allows for ± 10° of angulation for the locking screws (Fig. 18). A soft tissue drill guide and 2.5 mm drill bit are both used to cannulate the glenoid for placement of the inferior screw. We recommend interval drilling and "sounding" of the pilot hole with the depth gauge to measure the appropriate length screw. If the screw is deemed to be inadequate (less than 36 mm), reposition the drill within the 20° cone. If this fails, rotate the metaglene to achieve adequate inferior and superior screw fixation. Seat the screw into position using a 1.2 mm guide pin, but do not lock the screw until all screws have been placed (Fig. 19). After seating of the peripheral screws, tighten the interior screw head with the internal rod to lock the implants. We will generally place the final glenosphere, which comes in 38- and 42 mm diameters and standard/eccentric sphericities. The 42 mm glenosphere provides improved range of motion and stability, but may not be feasible to use in patients with smaller glenoids. A 1.5 mm guide pin is placed within the central hole of the metaglene followed by engagement of the 3.5 mm hex screwdriver with the final glenosphere. Slide the glenosphere until it comes into contact with the metaglene, avoiding cross threading of the central screw and post. Rotate the glenosphere in a clockwise fashion until the scapula rotates with movement. Intermittently tap with the soft impactor and a mallet followed by clockwise tightening of the glenosphere (Fig. 20a, b). After final glenosphere implantation, the shoulder is re-dislocated for proximal humerus preparation.

The previously defined reamer size is used for the proximal reaming guide. The guide is recessed such that the "horseshoe" plate lays flush with the osteotomy site. Once this is seated, a decision must be made to proceed with cement or cementless fixation. As many patients with rotator cuff arthropathy demonstrate osteoporotic bone, previous iterations of the Delta prosthesis generally required cement fixation of a monoblock humeral stem (Fig. 21). The Delta Xtend provides improved modularity and initial "scratch fit" fixation with hydroxyapatite coating (Fig. 22). We have transitioned to use of the press fit modular humeral stem for a majority of our cases that involve reverse shoulder arthroplasty. In the event of proximal humeral bone loss (i.e., revision scenario) or poor quality bone, we will use the monoblock stem, and third-generation cement fixation technique with the use of a distal cement restrictor. Soft tissue tensioning is achieved with the use of the positioning jig during trial and final humeral stem implantation (Fig. 23). With the press fit technique, a central or eccentric adaptor is chosen for preparation of the epiphysis. A sizing disc allows for determination of epiphyseal size. Both steps should allow for maximal coverage of the osteotomy size without violating the cortical wall of the epiphysis. While leaving the appropriate adaptor in place, the size one or two reamer is used on hand power to prepare the epiphysis, making sure to seat the reamer until it makes contact with base of the adaptor (Fig. 24a–h). Distal humeral broaching is then performed with the previously established reamer diameter. The distal humeral broach contains an attached goniometer that will guide epiphyseal orientation and optimal press fit. The broach is seated into position and the angle is recorded for later reproduction on the trial humeral implant (Fig. 25). The trial humeral implant is seated and a reduction can be performed. Humeral cup liners in this system allow for high mobility, standard, and constrained articulations. Depths range from +3 to +9 mm with the ability to achieve 18 mm of humeral length with the use of a +9 mm metallic spacer.

Soft tissue tensioning and stability may be assessed by following several general guidelines during the trial reduction. The prosthetic joint should not separate in neutral position with longitudinal traction. The conjoint tendon will demonstrate increased tension with digital palpation. External rotation and adduction maneuvers should allow no

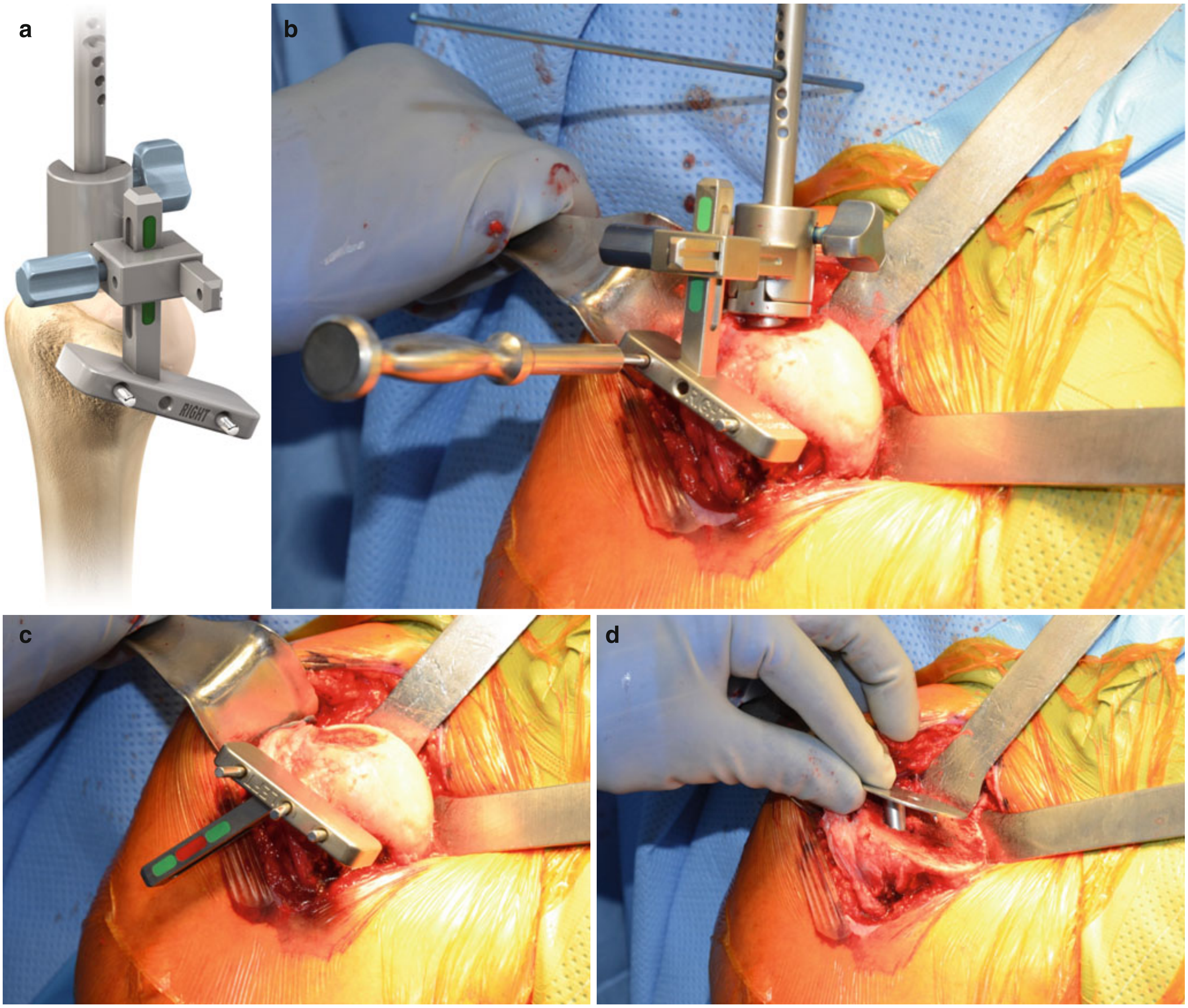

Fig. 14 (**a**, **b**) Select the appropriate handle size and cutting jig and seat the two devices on top of the humeral head. An orientation pin is placed proximally to calculate the degree of retroversion. We generally place the humeral component in neutral to slight retroversion to preserve internal rotation. (**c**) The cutting jig is stabilized with three pins approximately 2 mm inferior to the proximal region of the greater tuberosity. (**d**) The humeral head resection is performed with a sagittal saw, and a metallic coverplate is then placed to protect the osteotomy site

more than 2–3 mm of gapping between the glenosphere and the humeral cup liner. The construct should remain stable with maximum internal and external rotation. If subluxation or frank instability occurs with any of these steps, stability may be improved by increasing humeral cup liner depth, removing soft tissue or osseous structures that cause impingement, changing to a 42 mm glenosphere or use of the +9 mm humeral spacer. Once satisfied with the stability of the construct, the final humeral cup liner is inserted followed by glenohumeral reduction. In the event that the subscapularis can be repaired, we will place three to four drill holes through the proximal humerus approximately 1 cm below the osteotomy level for suture management purposes. The subscapularis is reapproximated to the remaining portion of the lesser tuberosity with the previously placed #2 nonabsorbable sutures (Fig. 26). The axillary nerve's integrity is reconfirmed. The soft tissues are closed in layers over a suction drain.

The patient's operative extremity is immobilized in a sling or similar device. Active elbow, wrist, and digital exercises are allowed postoperative day 1. Pendulum, passive forward flexion, and passive abduction exercises are permitted at 2 weeks postoperatively. Active range of motion exercises, including isometrics, is allowed at 6 weeks. The patient should be cautioned to avoid internal rotation and "push-off" activities for the first 6 weeks to reduce the risk of an instability event. The patient should additionally understand that shoulder function is highly dependent on compliance with therapy protocols and to expect incremental functional improvement for up to 1 year after surgery.

Indications for Concomitant Latissimus and Teres Major Tendon Transfers

Several authors have advocated latissimus and teres major tendon transfers in the setting of reverse shoulder arthroplasty for rotator cuff arthropathy associated with loss of external rotation [20, 34, 35]. The loss of external rotation may be due to structural or functional deficiency of the infraspinatus and teres minor. Simovitch and coauthors demonstrated lower Constant scores and negative external rotation arcs in patients who underwent reverse shoulder arthroplasty with preoperative evidence of teres minor fatty atrophy [23]. Boileau et al. demonstrated improved forward flexion and external rotation in a series of 17 patients through a single deltopectoral approach [35]. More recently, Gerber and others demonstrated durability of the combined transfer at a mean follow-up of 53 months in the setting of reverse shoulder arthroplasty. One of us has utilized the single deltopectoral approach as described by Boileau in patients undergoing reverse shoulder arthroplasty with a preoperative external lag sign or Hornblower's sign. The deltopectoral approach affords direct access to the combined insertion of the latissimus and teres major, once the proximal portion of the pectoralis major tendon is released. Careful dissection should allow adequate visualization and protection of the radial and axillary nerves. Subperiosteal detachment of the combined insertion is followed by gentle release of adhesions in a lateral to medial direction, not to exceed 6 cm. Boileau and coauthors have estimated 3–5 cm of tendon excursion with this technique [35]. The tendon ends are tagged with #5 nonabsorbable suture (Fig. 27a–d). The final glenosphere has already been implanted. The trial humeral stem is dislocated, and the tendons are transferred to the remaining greater tuberosity or humeral shaft through a soft tissue window posterior to the humeral diaphysis. Drill holes are placed in the humeral diaphysis at the same level of the native latissimus and teres major tendon insertions. The drill holes are directed from the bicipital groove toward the posterolateral humeral cortex. One suture limb is delivered from posterior to anterior and hand tied to the corresponding

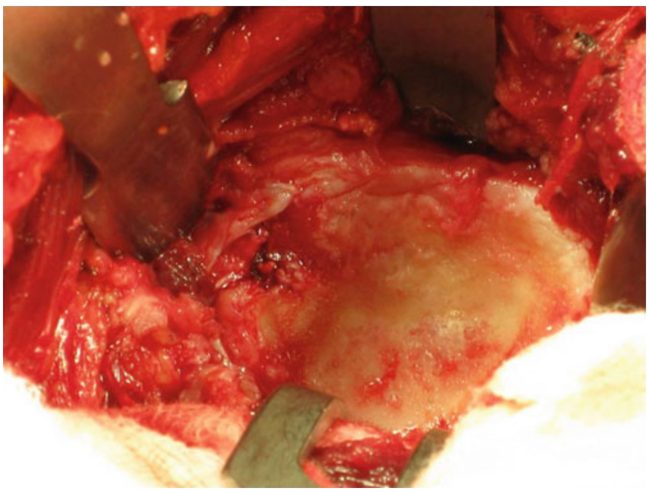

Fig. 15 Sequential capsular releases should afford an appropriate view of the glenoid face for metaglene and glenosphere placement. Common retractors include a forked retractor or modified Sonnabend, Hohmman, and anterior glenoid retractor

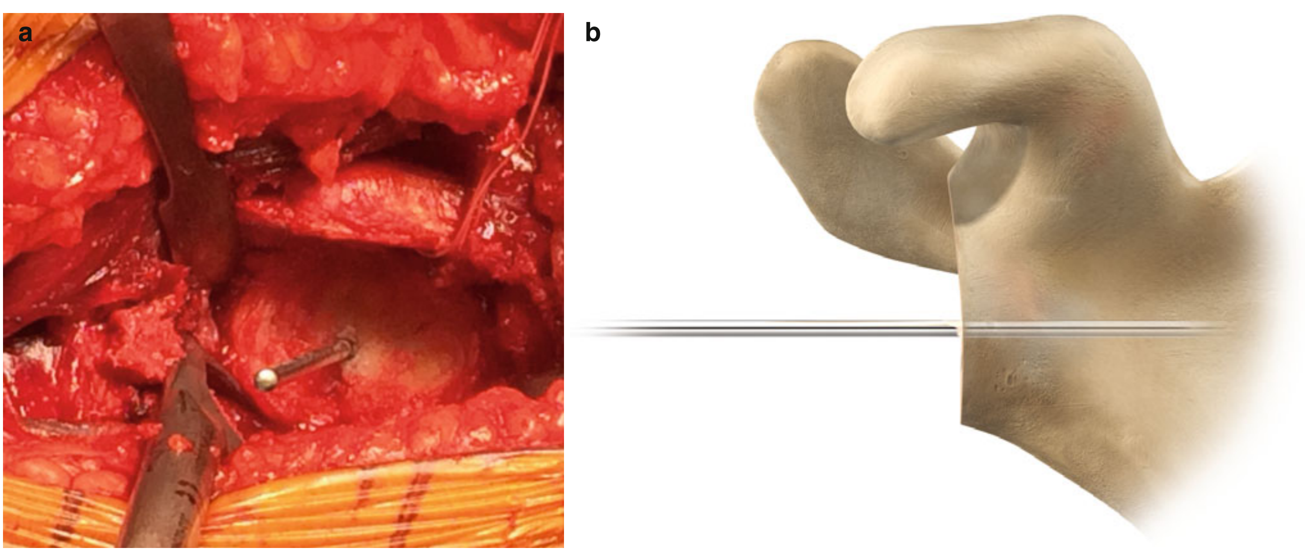

Fig. 16 (**a**) The metaglene guide pin should be placed slightly inferior and posterior to the intersection of the glenoid axes. (**b**) Avoid superior tilt to reduce the risk mechanical impingement and postoperative scapular notching (Courtesy of Depuy-Synthes®)

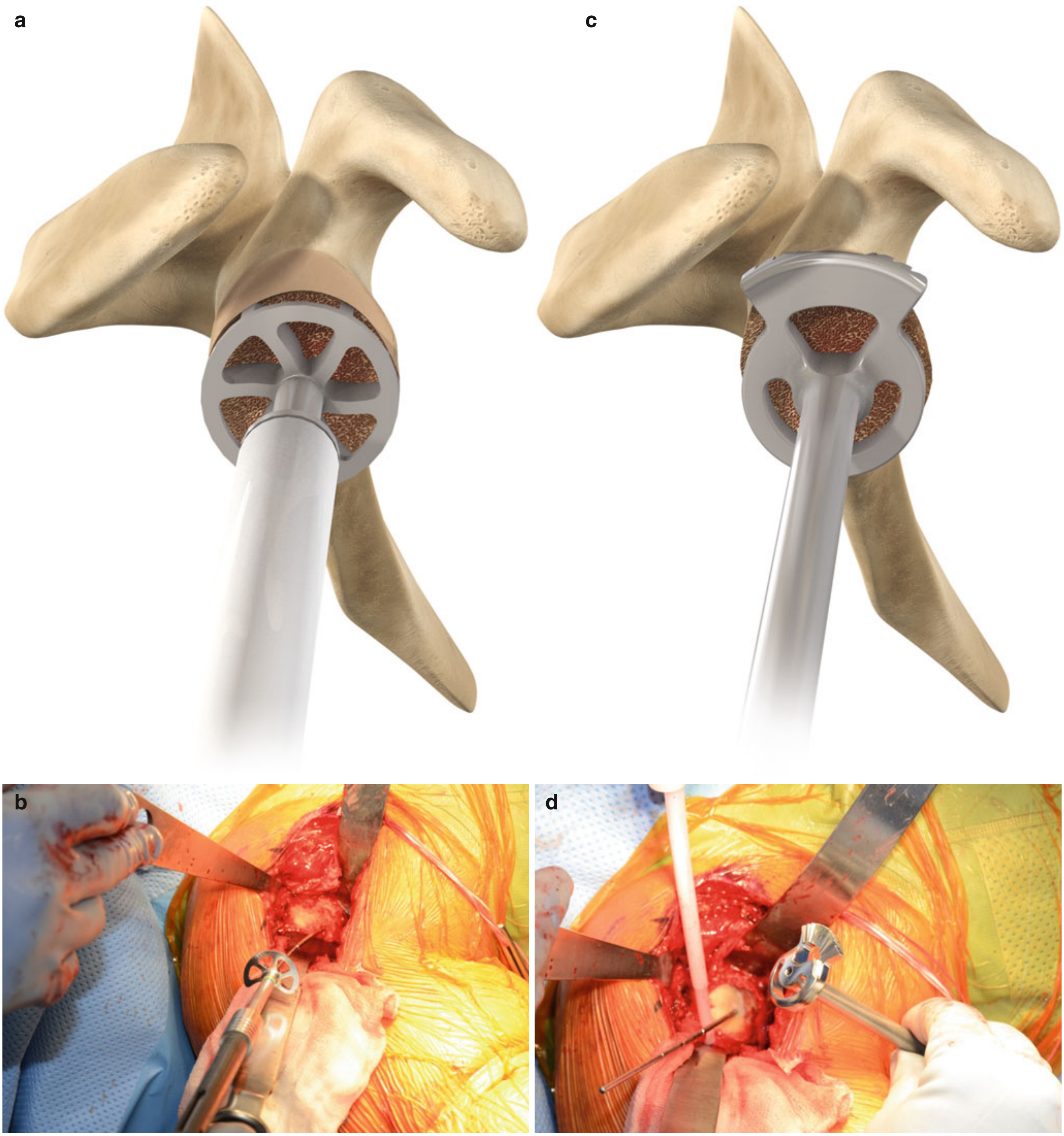

Fig. 17 (**a–d**) A two-step reaming process allows for appropriate preparation of the glenoid followed by a central cannulated drill bit to prepare for the metaglene post. Address glenoid deficiencies prior to implantation of the final baseplate

suture partner (Fig. 28a–c). As an alternative, commercially available suture anchors may be utilized rather than bone tunnels for reapproximation of the transferred tendon complex. The final humeral implant and liner are impacted into appropriate position. The pectoralis major tendon is repaired, and the subscapularis is reapproximated in a manner previously described. Layered wound closure is performed over a drain.

Postoperatively, the patient is placed into an abduction-external rotation brace. For the first six weeks, only elbow, wrist, and digital exercises are permitted. The patient then begins physician-directed therapy with a focus on passive forward flexion, abduction, and external rotation. Internal rotation is restricted to neutral rotation for 6–9 weeks and to the greater trochanter from weeks 9 to 12. At 3 months, the

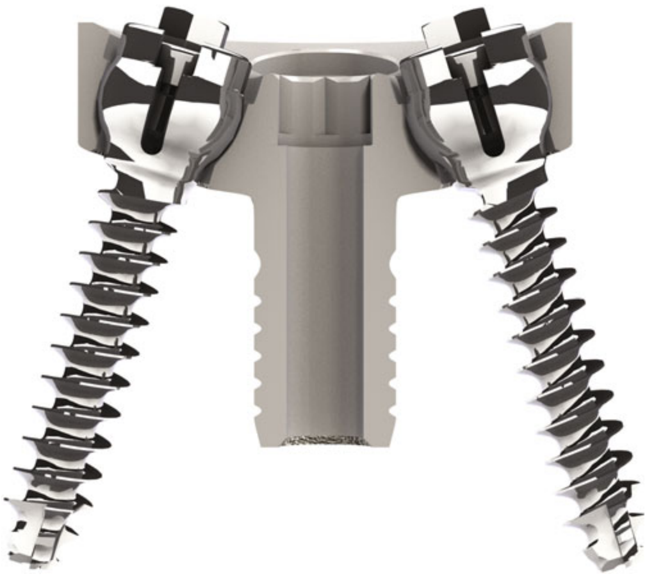

Fig. 18 The metaglene allows for ± 10° of angulation for the locking screws (Courtesy of Depuy-Synthes®)

Fig. 19 Seat the nonlocking or locking screw into position using a 1.2 mm guide pin, but do not lock the screw until all screws have been placed to adequately compress the baseplate to the glenoid surface (Courtesy of Depuy-Synthes®)

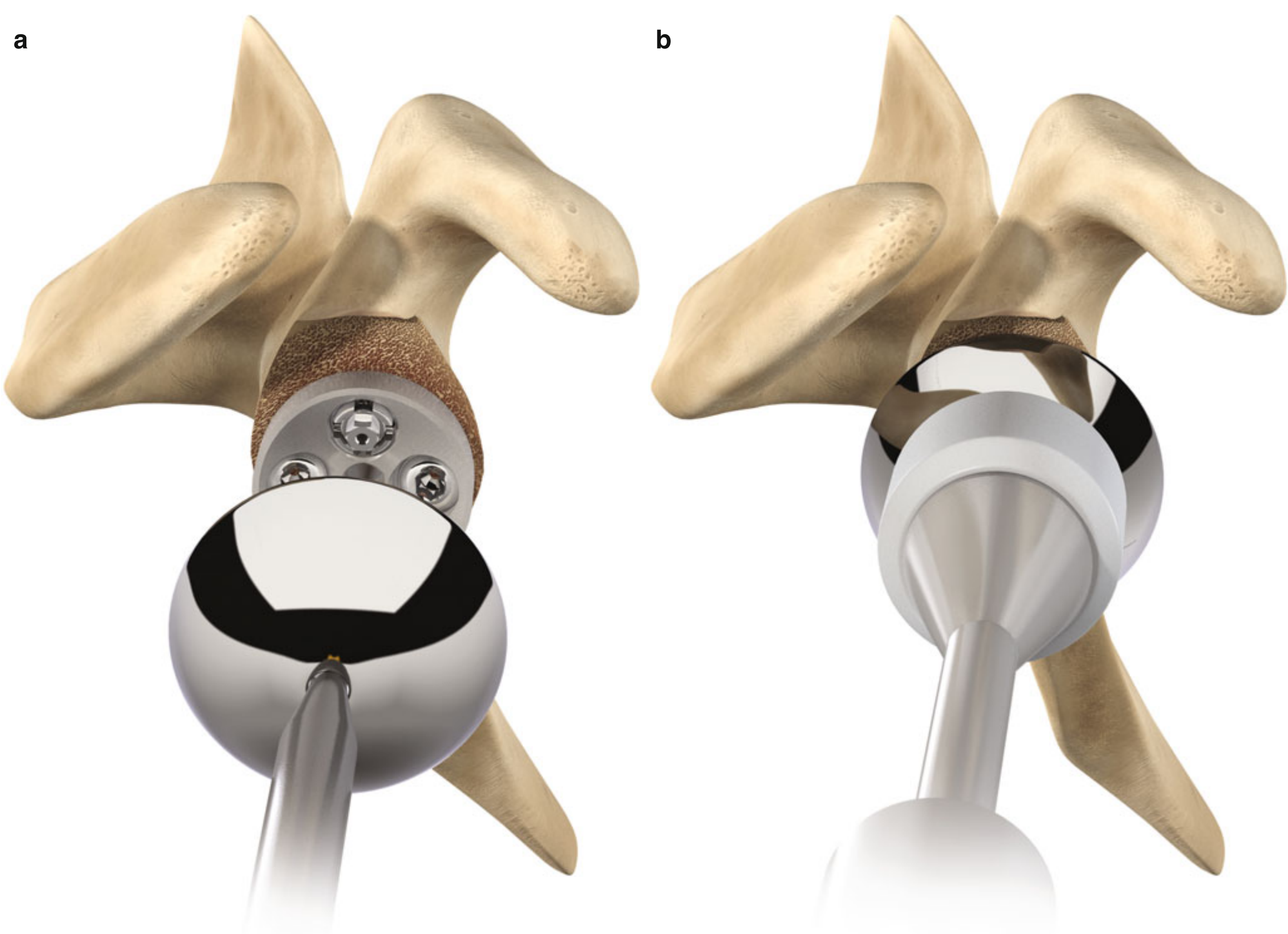

Fig. 20 (**a**, **b**) The glenosphere is initially advanced over a central guide wire. Clockwise rotation with intermittent impaction will result in locking of the Morse taper. The scapula should begin to rotate when the glenosphere has seated completely (Courtesy of Depuy-Synthes®)

Fig. 21 Patients with osteoporotic bone and/or revision cases with humeral bone loss may benefit from the use of the cemented monoblock stem (Courtesy of Depuy-Synthes®)

Fig. 22 The Delta Xtend™ provides improved modularity and initial "scratch fit" fixation with hydroxyapatite coating on the proximal portion of the humeral stem and the epiphyseal component (Courtesy of Depuy-Synthes®)

strengthening may be allowed. Maintenance exercises should be performed for 6–12 months after surgery.

Complications Associated with Reverse Total Shoulder Arthroplasty

A previous analysis by the current authors regarding complications in reverse shoulder arthroplasty demonstrated a mean complication rate of 24.4 % with range from 6.25 to 50 % [3]. The most common complications in decreasing order of frequency were scapular notching, hematoma formation, glenoid component dissociation, glenohumeral dislocation, acromial or scapular spine fracture, infection, humeral component loosening, and nerve injury. Scapular notching is a nearly ubiquitous finding with an incidence of 50–96 % reported in the literature [7, 21, 36]. Notching is caused by direct interaction between the humeral prosthesis and the lateral pillar of the scapula. Polyethylene debris formation may initiate osteolysis and further degradation of the scapular neck. Some studies have indicated increased incidence and progression of notching with duration of implantation [37]. The clinical sequelae of notching remains a matter of debate. Some studies have not shown a negative effect on pain and Constant scores [37], whereas others have demonstrated clinical deterioration [30, 38]. Sirveaux and coauthors have developed a classification system for degree of notching that has allowed for improved communication among surgeons and radiologists when assessing constructs at risk for failure (Fig. 29) [22]. The incidence of scapular notching is dependent on several variables: degree of glenosphere offset, craniocaudal positioning of the glenosphere, duration of implantation, and proximal humeral anatomy. To reduce scapular notching , proponents of the Grammont style prosthesis have recommended placement of the baseplate such that it sits at the inferior rim of the glenoid [5, 18, 21, 28, 39, 40]. Reverse shoulder replacement systems that contain a lat-

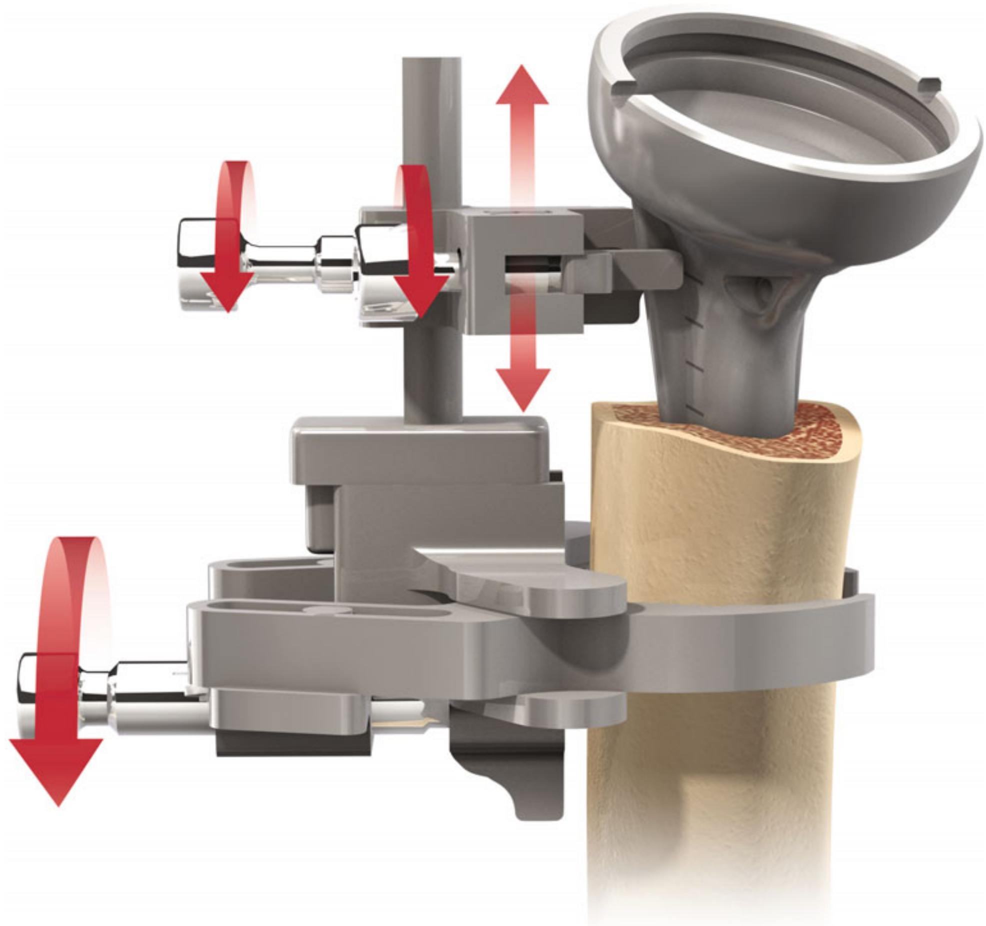

Fig. 23 In the setting of proximal humeral deficiency or poor quality bone, we will use the monoblock stem, distal cement restrictor, and third-generation cement fixation technique. Soft tissue tensioning is gauged with the use of the positioning jig during trial and final humeral stem implantation (Courtesy of Depuy-Synthes®)

eralized center of rotation have demonstrated reduced notching rates [41]. Similarly, Boileau and colleagues demonstrated decreased scapular notching rates with lateralized center of rotation with placement of bone graft medial to the metaglene. Graft union was apparent in all shoulders, and only nine of 42 patients demonstrated notching at 2-year follow-up. The authors concluded that increased offset could be achieved without metallic extension, allowing the center of rotation to remain at the metaglene-glenoid interface [42].

When excluding scapular notching and hematoma formation, the next most common complication is construct instability with rates spanning 2.4–31 % [4, 21, 38, 43, 44]. Instability generally occurs in an anterior direction and is associated with adduction, extension, and internal rotation of the shoulder (i.e., push-off from a chair). Several factors have been implicated in the development of instability such as deltoid dysfunction, glenosphere diameter, soft tissue tension, mechanical impingement, and implant malposition. Gerber and colleagues have suggested that dislocation events within the first three months of intervention may indicate an error in surgical technique [4]. In the event of a dislocation, an initial attempt at closed reduction is appropriate but may not be successful prompting an open procedure. It is advisable to have the necessary revision instrumentation and implants to adequately address this scenario. In addition to the integrity of the deltoid, specific implant parameters affect soft tissue tension and glenohumeral joint stability. In the Grammont-style prosthesis, medialization of the center of rotation, "inferiorization" of the proximal humerus, and a valgus neck osteotomy enhance compressive forces of the prosthetic joint and impart improved stability to the construct [4]. Larger glenospheres may provide improved stability and range of motion. Some systems contain humeral cup liners that have varying degrees of constraint (i.e., increased cup depth) at the expense of range of motion. Those implant systems that contain increased lateral offset may allow for improved soft tissue tensioning without inferior translation of the humerus. In the setting of proximal humerus deficiency, instability issues can be addressed with humeral allograft, use of a thicker humeral cup insert, metallic spacers or cemented humeral stem fixation.

Modifications to the baseplate design and method of fixation have resulted in a decrease of glenoid implant dissociation. Initially, failure rates ranged from approximately 12 to 40 % and were attributed to inadequate baseplate fixation and increased lateral offset [45, 46]. Specific to the DJO/

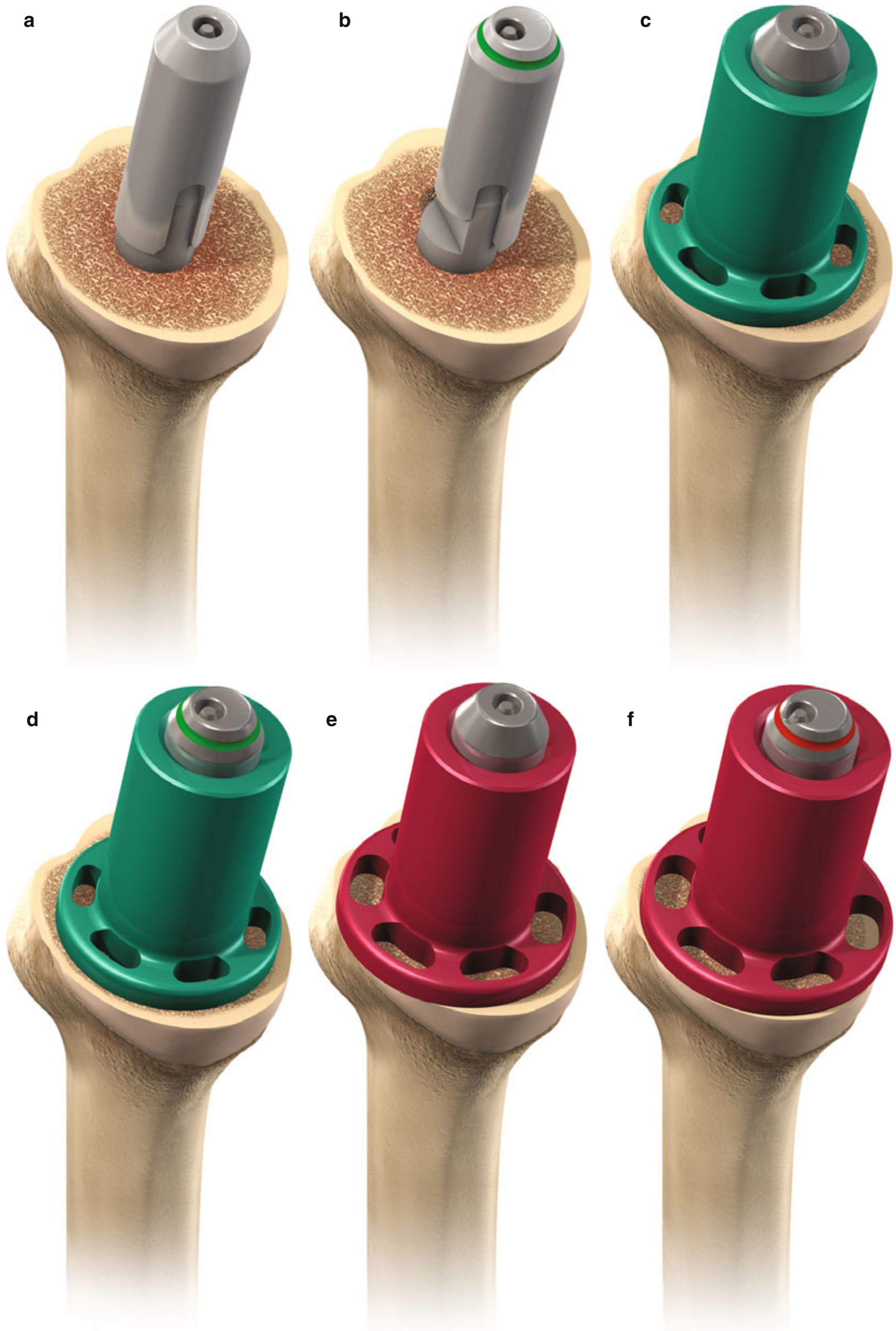

Fig. 24 When performing a press fit technique, the epiphyseal component must be appropriately sized. Central (**a**) and eccentric (**b**) adaptors allow for appropriate positioning of the proximal reamer with sizing disks ″1″ (**c**, **d**) or ″2″ (**e**, **f**), depending on the morphology and size of the epiphyseal portion of the humerus (Courtesy of Depuy-Synthes®). (**g**, **h**) The proximal portion of the humerus is then prepared with the corresponding hand held reamer

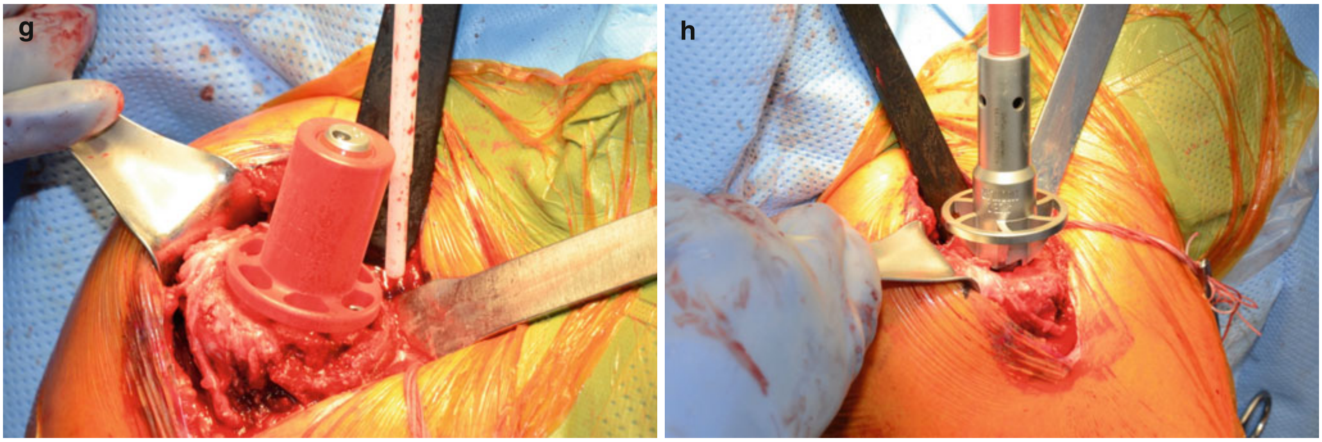

Fig. 24 (continued)

Fig. 25 The distal humeral broach utilizes a goniometer guides epiphyseal orientation and optimal press fit (Courtesy of Depuy-Synthes®)

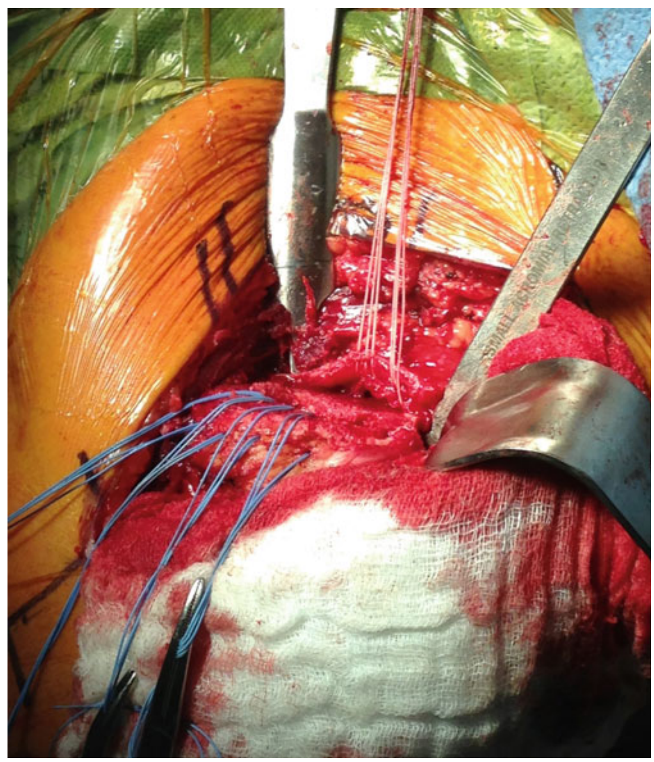

Fig. 26 The subscapularis is repaired with the use of drill holes and nonabsorbable passing sutures through the proximal humerus approximately 1 cm distal to the osteotomy site

Encore RSP design, decreased lateral offset, inferior tilt of the baseplate, and larger diameter peripheral locking screws effected a significant decrease in baseplate failure rate to less than 0.5 % [47]. The Delta III baseplate was also modified to a convex-shaped back for improved surface contact and diminished micromotion with respect to the concavity of the prepared glenoid. In the setting of aseptic glenoid component loosening, revision options include one- and two-stage reconstruction. Some authors have advocated staged intervention with autogenous bone graft and hemiarthroplasty conversion [48], whereas others have performed single-stage baseplate revision with allograft and locking screw fixation [49].

Increased tension within the deltoid origin can result in fatigue fractures of the acromion and scapular spine. The reported prevalence of acromial fractures after reverse total shoulder arthroplasty is 1–7 % [50]. Walch and coauthors in their study reported a nearly 4 % incidence of these injuries

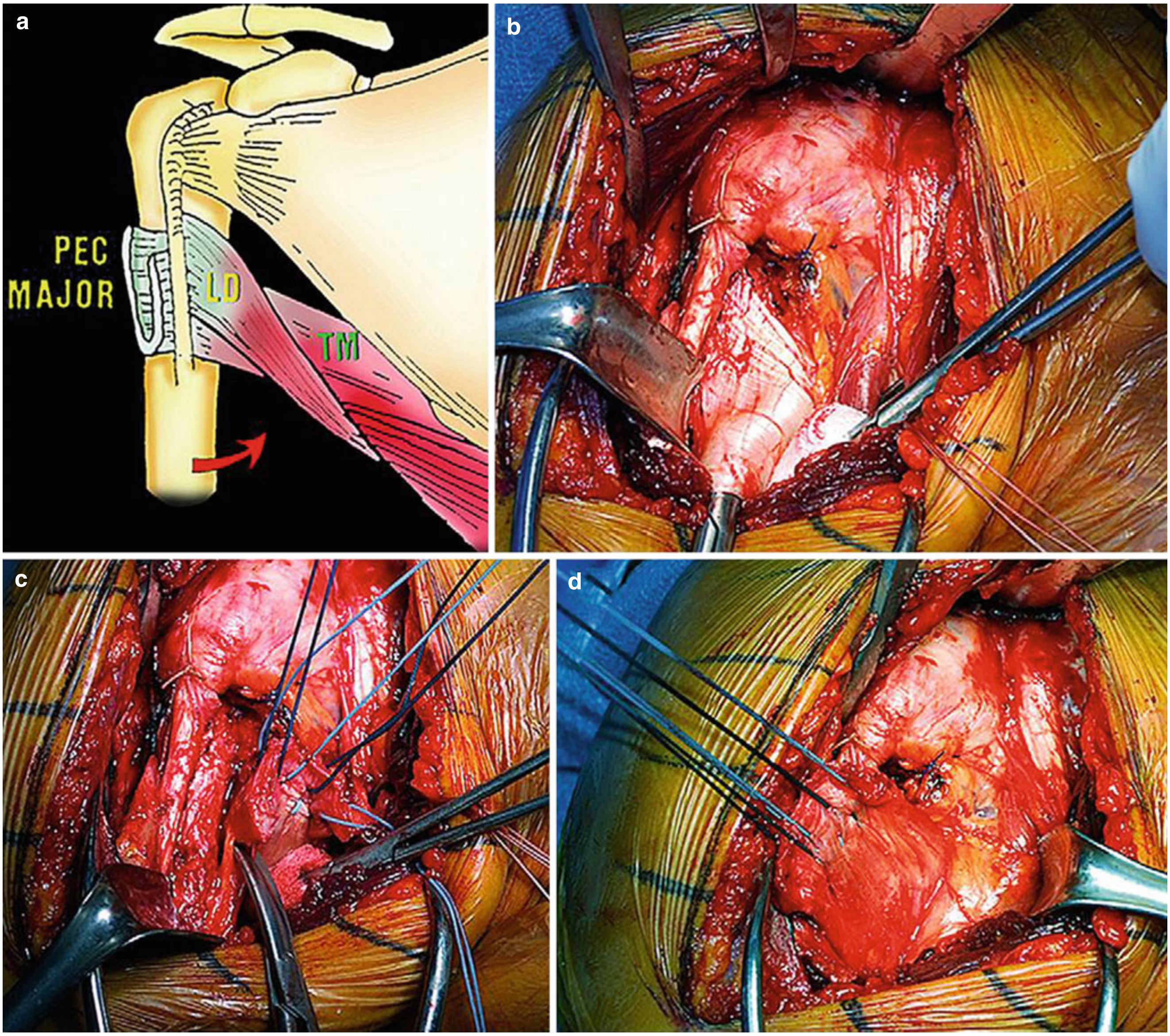

Fig. 27 (**a**) A portion of the pectoralis major insertion must be released to visualize the latissimus dorsi and teres major tendons. (**b**) Identification of the axillary and radial nerves is required prior to release of the latissimus and teres major tendon complex. (**c**) Adhesions are released bluntly under direct vision to gain excursion of the released tendons. (**d**) The tendon complex is then captured with a modified Mason-Allen or equivalent suture configuration using large caliber nonabsorbable suture (Reproduced, with permission from Elsevier, from: Boileau et al. [35])

after surgical intervention. Active forward elevation, patient satisfaction, and Constant scores were listed as poor in this study after development of these fractures [15]. Plain radiographs may not delineate the fracture, so a high index of suspicion is necessary when patients present with pain and sudden deterioration of active shoulder motion. Levy and colleagues proposed a classification scheme founded on CT scan evaluation and indicated that fractures at the base of the acromion (type III) demonstrated inferior clinical results and outcome scores when compared to other types. Of equal importance, the authors concluded that nonoperative management of these injuries resulted in minimal improvement from preoperative level of function [50]. Displaced acromial or scapular spine fractures may require open reduction with internal fixation to restore deltoid tension and stability to the reverse shoulder construct.

Infection after shoulder arthroplasty remains a devastating complication with functional, psychological, and fiscal implications. Our previous analysis indicated an overall prevalence of 0.7 % [3]. Mole and Favard reported an infection rate five times that of our analysis in those patients undergoing reverse total shoulder arthroplasty [16]. Some have attributed this increase to hematoma formation and volumetric dead space associated with an absent rotator cuff

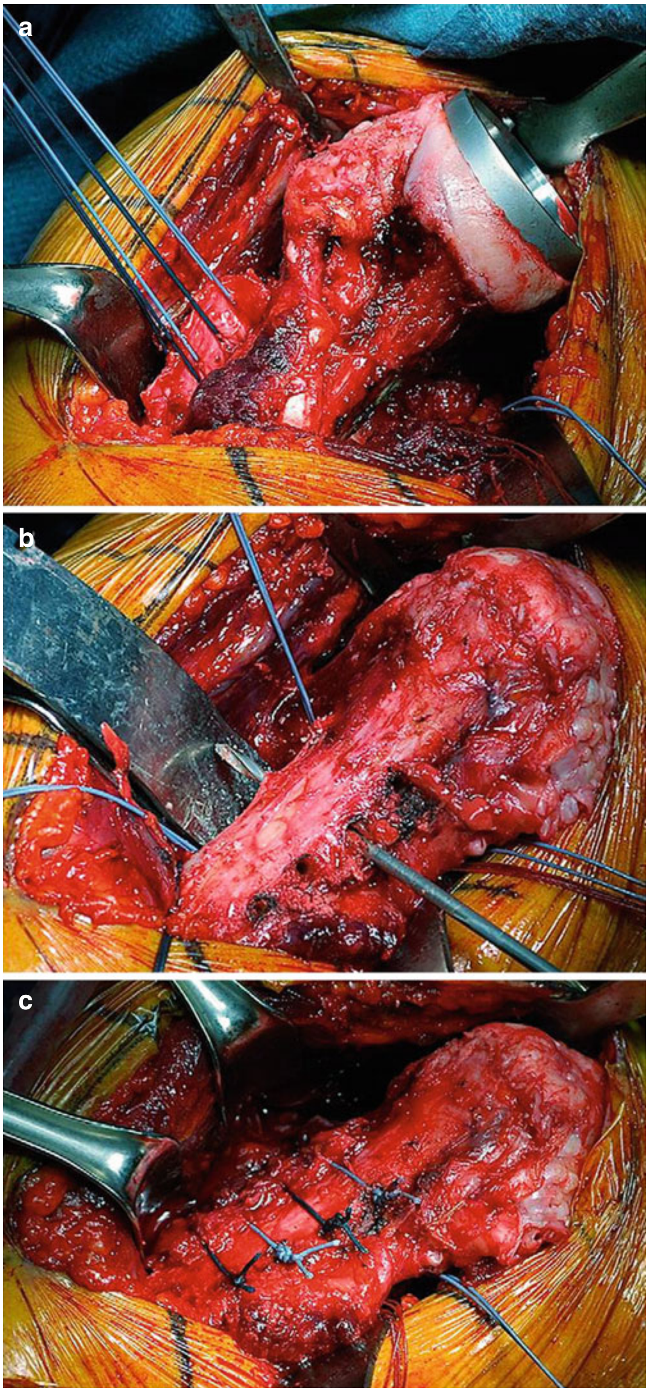

Fig. 28 (**a**) The tendon complex is passed posterior to the dislocated proximal humerus at the meta-diaphyseal region. (**b**) Drill holes are placed just lateral to the bicipital groove with the arm internally rotated to allow for exit at the desired location for the tendon transfer. (**c**) One suture limb from each pair is brought through the drill hole, whereas the corresponding limb travels posterior to the proximal humerus. Sutures are tied with the arm in slight internal rotation (Reproduced, with permission from Elsevier, from: Boileau et al. [34])

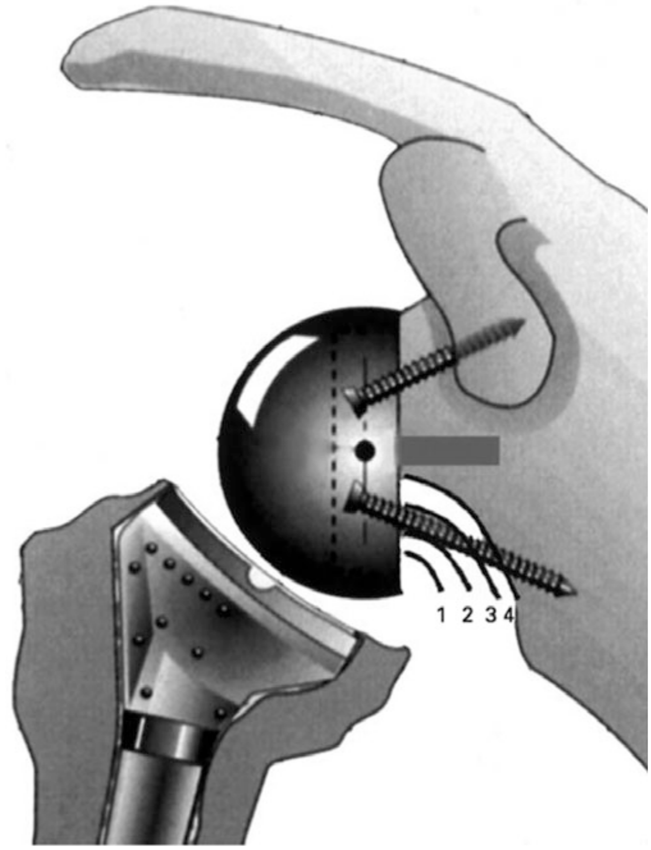

Fig. 29 Scapular notching classification as defined by Sirveaux and et al. [22]. Grade 1 defects are within the inferior scapular pillar. Grade 2 defects extend to the inferior screw. Grade 3 involves the entire inferior screw. Grade 4 defects involve the baseplate, which increased the probability of baseplate loosening and failure (Adapted, with permission, from: Sirveaux et al. [22])

[4]. Infection rates are even higher in revision situations [21, 51]. In the setting of a painful and stiff reverse total shoulder, the surgeon should have a heightened awareness of infection, even if inflammatory markers such as C-reactive protein, erythrocyte sedimentation rate, and complete blood count are normal. Radiographs may not show evidence of loosening, as some of these cases present within 3 months of implantation. Prosthetic joint aspiration also may not reveal a causative organism. Sperling and coauthors in their series demonstrated that the most common organisms associated with shoulder arthroplasty in order of frequency were *Staphylococcus aureus*, coagulase-negative *Staphylococcus*, and *Propionibacterium acnes* [3]. A more recent review by Matsen and colleagues underscored the importance of *P. acnes*, as nearly 51 % of all reported acute and chronic infections after shoulder arthroplasty were caused by this organism. Their investigation concluded that male gender, humeral stem osteolysis, biofilm formation, and cloudy fluid at time of revision surgery were all independent prognostic factors regarding cultures positive for *P. acnes* [52]. Due to the slow doubling rate of *P. acnes*, we recommend that a minimum of three to four tissue samples be obtained during revision surgery for frozen section analysis and that cultures should be

monitored for a minimum of 10–14 days [53]. The treatment algorithm for periprosthetic infections of the shoulder mirrors that of previously established protocols for hip and knee arthroplasties. If the intraoperative assessment during revision surgery raises the likelihood of infection, we recommend implant removal and antibiotic cement spacer placement for its bactericidal activity and maintenance of the soft tissue envelope. Consultation should be obtained with an Infectious Disease specialist for tailoring of antibiotic therapy. If delayed exchange is being considered, the preoperative work-up should include screening labs (complete blood count with differential, erythrocyte sedimentation rate, and C-reactive protein) and shoulder joint aspiration after cessation of antibiotic treatment. Additional tissue samples should be obtained at the time of revision surgery. If frozen section analysis does not indicate acute inflammation, then definitive revision arthroplasty may be performed. It is important to counsel the patient prior to revision surgery that the treatment plan may include removal of retained implants with antibiotic cement spacer placement. Patients should also be aware that significant glenoid and humeral bone deficiencies may preclude re-implantation with a reverse shoulder prosthesis with the options of hemiarthroplasty and resection arthroplasty remaining.

Neurologic Injury

Our previous review indicated a prevalence of nearly 1 % regarding neural injuries sustained during total shoulder arthroplasty [3]. More recently, Ladermann et al. demonstrated a nearly tenfold increased risk of peripheral nerve injury when comparing reverse total shoulder arthroplasty to unconstrained shoulder arthroplasty. Electromyographic analysis revealed subclinical injury to the plexus or axillary nerve in 9 of 19 shoulders in the reverse arthroplasty group, eight of which resolved at 6 months postoperatively. The authors hypothesized that humeral lengthening may have contributed to these injuries. The threshold for humeral lengthening to avoid neurologic injury could not be determined as the study was underpowered secondary to sample size. They concluded that injuries to the axillary nerve and plexus are common but transient with reverse shoulder arthroplasty [33].

Future Considerations

Kim and colleagues in 2011 calculated an estimate of the annual volume of shoulder arthroplasties in the United States from 2000 to 2008 using the Nationwide Sample Database, an inpatient survey sponsored by the federal Agency for Healthcare Research and Quality [54]. The data demonstrated a dramatic increase in the number of total shoulder arthroplasties per year beginning in 2004, which coincidentally represented the year the reverse shoulder prosthesis was approved for use by the U.S. Food and Drug Administration. By 2008, the study estimated that approximately 50,000 shoulder arthroplasties were performed annually. The authors recommended further refinement of the indications for reverse shoulder arthroplasty and shoulder arthroplasty in general, as well as long-term studies to assess implant survivorship and relevant outcome measures [54]. Enthusiasm for the reverse shoulder prosthesis has not diminished despite the increased incidence of complications when compared to unconstrained total shoulder arthroplasty [51]. Indications for its use have actually expanded to include primary treatment of three- and four-part proximal humerus fractures in the elderly, revision scenarios secondary to failed total shoulder arthroplasty or fracture fixation of the proximal humerus, and revision of failed reverse shoulder arthroplasty [4, 13, 14]. Long-term data regarding these aforementioned clinical scenarios is lacking. Cognizant of these issues, surgeons in collaboration with industry have more recently focused on platform systems. Some of these commercially available systems allow for staged conversion in patients who have undergone a hemiarthroplasty for fracture or other degenerative conditions to a reverse prosthesis with stem retention. Data regarding these implant systems is limited to abstract reports and short follow-up [55, 56].

The reverse shoulder prosthesis has demonstrated favorable short- to mid-term results in patients with rotator cuff arthropathy and as a salvage procedure for failed unconstrained total shoulder arthroplasty. Due to the elevated complication rate with reverse shoulder arthroplasty, we continue to recommend its use for elderly (older than 65), low-demand patients with pseudoparalysis, arthropathy of the shoulder, and adequate glenoid bone stock. Longer follow-up will provide helpful data regarding the appropriateness of this procedure for the additional indications of proximal humerus fractures and massive irreparable rotator cuff tears without arthropathy.

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New Concepts on the Glenoid Fixation in Reverse Shoulder Prosthesis

Stefano Gumina and Vittorio Candela

Posterior Glenoid Bone Loss

Rotator cuff tears can alter glenohumeral mechanics and predispose the glenoid to abnormal wear patterns [1]. The technical aspect of joint replacement increases in complexity with increasing bone loss and posterior glenohumeral subluxation [2–4], especially in cases of type B glenoid morphology according to Walch's classification (Fig. 1) [5].

Assessing the preoperative glenoid morphology and correcting it are fundamental for the surgical procedure since posterior glenoid erosion is not only a risk factor for glenoid loosening but also it results in worse function outcomes and pain [6–8]. In this situation, the theoretical goal of shoulder surgeons performing an arthroplasty is to restore native joint biomechanics by improving glenoid version and maintaining or restoring the glenohumeral joint line.

Biomechanics of Glenoid Retroversion and Posterior Bone Loss

Shoulder biomechanics is inevitably altered by glenoid bone loss, resulting in humeral head displacement and eccentric stresses placed on the glenoid component leading to polyethylene wear, component loosening, or instability. Posterior glenoid bone loss results in altered net humeral joint reaction forces which pass outside the effective glenoid arc, creating joint instability (Fig. 2). Bryce et al. [9] studying the relationship between glenoid wear and humeral head subluxation in their cadaveric biomechanical model demonstrated that subluxation is steadily present already with 2.5° of glenoid retroversion. The degree of bone loss and glenoid retroversion directly influence both glenohumeral forces and humeral head displacement; every 4° increase in retroversion resulted in a 2° shift of joint reactive forces away from the glenoid midline [8]. This condition causes approximately 0.5 mm of posterior humeral head displacement for every corresponding degree of glenoid retroversion. Altered joint forces cause humeral head subluxation which can lead to eccentric loading of the glenoid component, a mechanism described as "rocking-horse," and associated to high tensile forces across the glenoid component-bone interface [9, 10].

Farron et al. [11] using three-dimensional finite element analysis stated that retroversion of 20° created a posterior contact point on the glenoid, increasing stresses within the cement mantle and glenoid bone by 326 % and 162 %, respectively. Retroversion of just 10° resulted in an increase in micromotion at the bone-cement interface by >700 %, and they concluded that retroversion beyond this point should be corrected. Placing the glenoid implant in 15° of retroversion (in cadaveric shoulders), Shapiro et al. [12] evaluated the effects of a glenoid component version on joint biomechanics. This procedure significantly decreased the glenohumeral contact area, increased contact pressures, and decreased inferior and posterior glenohumeral forces.

Treatment Options

Eccentric Reaming

Eccentric reaming is a common procedure performed prior to component insertion with the aim to improve excessive

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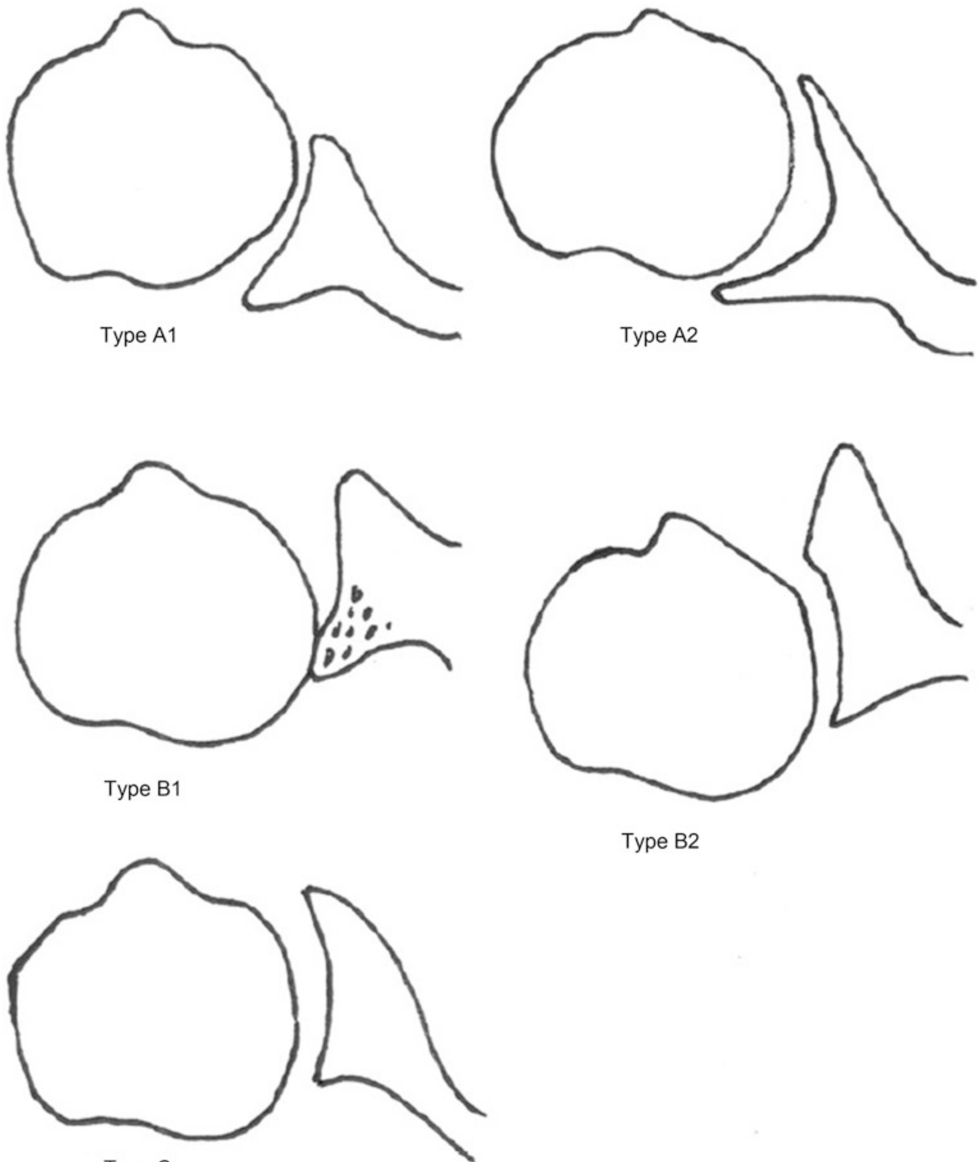

Fig. 1 Glenoid morphology according to Walch's classification [5]

glenoid retroversion. An excessive reaming can reduce the subchondral bone available for implant support, medialize the joint line, and allow cortical perforation of the polyethylene implant.

Walch et al. [13] found that motorized reaming was significantly associated with glenoid loosening for both subsidence and posterior tilt and so suggested that subchondral bone be preserved to provide sufficient osseous support to withstand the stresses experienced by the glenoid implant.

Many studies have been performed with the aim to define the limits of eccentric reaming in order to minimize the removal of subchondral bone while maximizing version correction. Attempting to correct 15° of retroversion, Gillespie et al. [14] found implant peg penetration or inadequate bone support in four of eight cadaveric specimens studied. Correcting even 10° of version, a significant decrease in anteroposterior glenoid diameter was found. Clavert et al. [15] reamed to neutral version five cadaveric scapulae in which they have previously created posterior

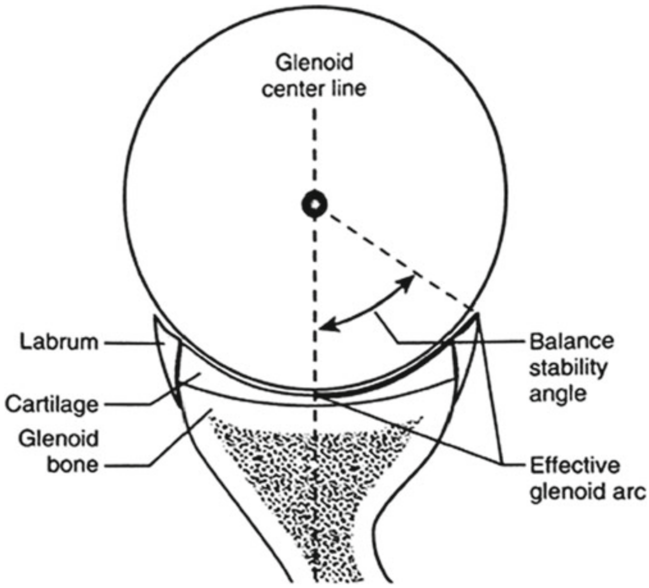

Fig. 2 Principles of biomechanic of the shoulder with no glenoid defects

glenoid defects and placed a pegged glenoid component. The result was one peg perforation in all five specimens and one fracture of the anterior glenoid rim leading the authors to conclude that if version exceeds 15°, the surgeon should consider alternatives to reaming the anterior aspect of the glenoid, such as posterior deficiency bone grafting.

Computer software has allowed investigators to simulate the effect that reaming has on glenoid component implantation.

Iannotti et al. [16], using a three-dimensional surgical simulator, compared ideal versus actual retroversion correction and came to the conclusion that retroversion of >19° would have been associated to peg perforation if ideal component placement had been performed.

Nowak et al. [17] considered a version <12° as optimal to implant a standard glenoid component, while version of >18° resulted in peg penetration. However, it is important to note that glenoid perforation after a short-term follow-up period is not correlated to adverse clinical effects or radiographic findings, lacking the literature of long-term follow-up studies.

In summary, an eccentric reaming is restricted by the available bone stock and should be limited to mild defects with no more than 10–15° of glenoid retroversion; an excessive reaming should be avoided to reduce the risk of loss of subchondral bone support, cortical perforation, and consequent implant loosening.

Glenoid Bone Grafts

When posterior glenoid bone loss is too excessive, bone grafting is a valid method to improve version, re-establish the joint line, and restore glenoid bone deficiency with the potential for biologic incorporation.

Bone grafting is a valid method when there is insufficient bone stock for component fixation or an inability to correct component position with glenoid reaming as it would result in an incorrect glenoid implant in cases of retroversion >15° [18–20]. The aim of bone grafting is that of improving version, re-establishing the joint line, and restoring glenoid bone deficiency with the potential for biologic incorporation. Problems connected to this procedure are nonunion, resorption, or subsidence, in addition to the technical demand of graft placement and fixation [19, 21–27].

Few studies evaluated the clinical and radiological outcomes of reverse shoulder arthroplasty using bone grafting for excessive glenoid retroversion.

Mizuno et al. [28] studied 27 reverse shoulder replacements performed for the treatment of primary glenohumeral osteoarthritis with a biconcave glenoid; retroversion (mean: 32°) and humeral head subluxation (mean: 87 %) were not such as to be corrected by asymmetric reaming. Ten patients required a bone graft if version could not be corrected to within 10° of neutral or when the baseplate surface contact was <80 %. Constant score increased from 31 to 76 points ($p < 0.0001$). In four (15 %) of 27 patients, a complication occurred, with three patients having neurologic issues and one patient having early glenoid loosening. At the latest follow-up evaluation (mean FU: 44 months), 25 patients (93 %) were either very satisfied or satisfied with their results. No radiolucent lines were observed around the central peg or screws; no recurrence of posterior instability was found. The authors concluded that reverse shoulder arthroplasty offers a viable solution for the treatment of severe static posterior glenohumeral instability and severe glenoid erosion. Wall et al. reviewed the results of reverse total shoulder arthroplasty in 240 patients (mean age: 72 years) according to different surgical indications [29]. Of those patients, 33 underwent reverse total shoulder arthroplasty because of severe posterior glenoid bone loss and posterior humeral head subluxation. The mean Constant score after a mean FU of 38 months passed from 24.7 to 65.1 points and mean shoulder flexion from 77° to 115°. A rapid loosening of both the graft and implant was found, and this patient needed surgery for conversion to a cuff tear arthroplasty.

Our Experience

In our practice, each patient submitted to reverse shoulder prosthesis undergoes preoperative evaluation with standard Rx examination (true AP and axillary view) and CT scan (with 3D reconstructions) in order to obtain a detailed surgical planning. In case of glenoid retroversion <15°, we perform an eccentric reaming in order to restore a correct joint congruity and the right glenoid version. If retroversion is >15°, we utilize a bone grafting using the humeral head bone (Fig. 3a).

Augmented Glenoid Components

In alternative to eccentric reaming and bone grafting, augmented glenoid components were designed.

Clinical and radiological outcomes regarding this technique are controversial. Rice et al. [30] reviewing 14 shoulders treated with an asymmetric wedge-shaped posteriorly augmented glenoid component (mean FU: 60 months) found only two clinical unsatisfactory results. However, more than half of the glenoid components demonstrated radiolucent lines, and one-third demonstrated moderate or severe posterior glenohumeral subluxation, although no revision surgery was performed.

Rice et al. concluded that the contribution of the modified glenoid component to overall correction of glenoid bone wear and humeral subluxation seemed marginal, and use of this implant was discontinued.

In the last years, we have seen the development of a stepped, posteriorly augmented glenoid design that places the component perpendicular to the vector of joint forces and allows for improved biomechanical properties [31–33].

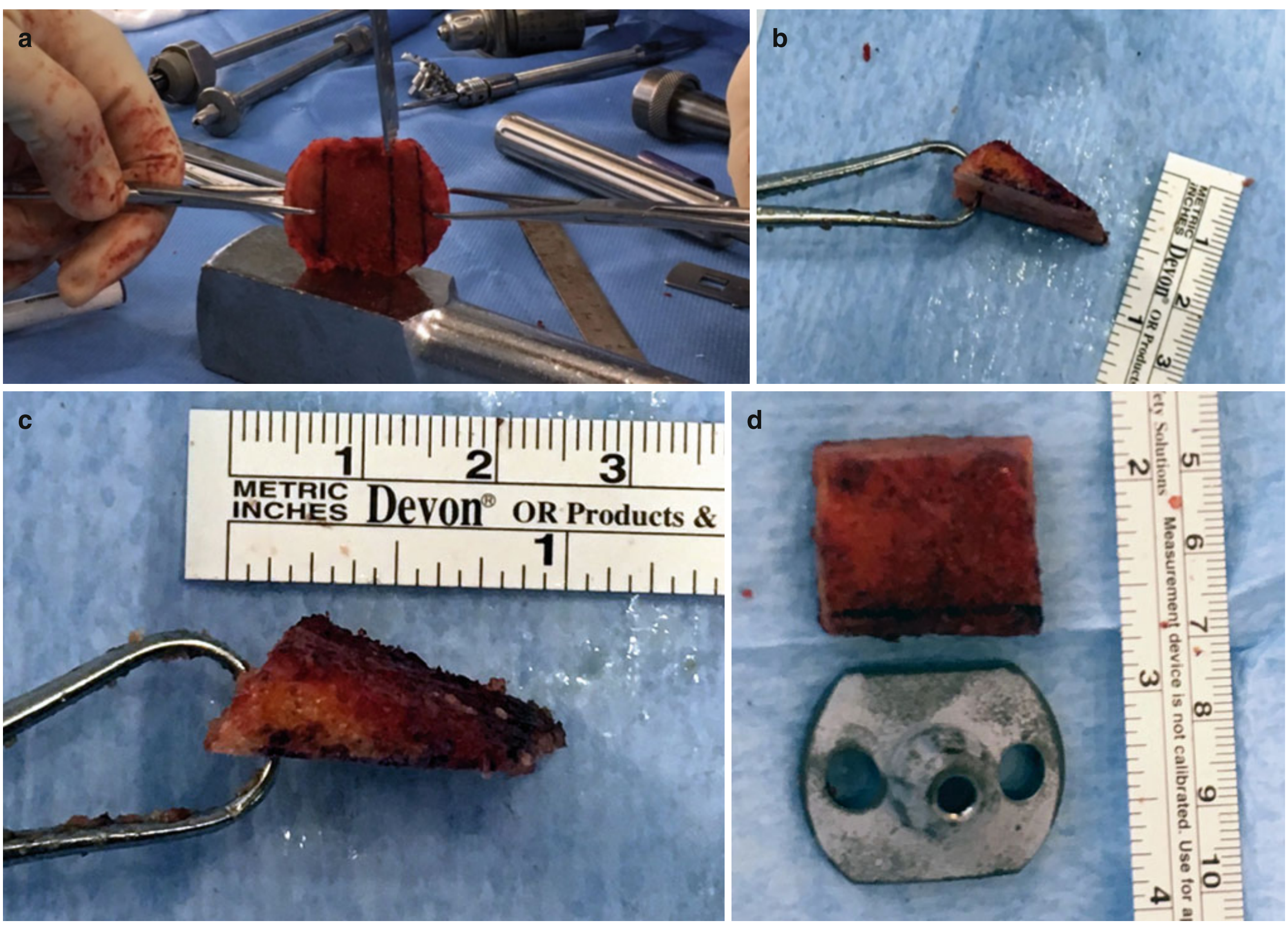

Fig. 3 Bone grafting using the humeral head bone. Intraoperative phases (**a–d**)

Iannotti et al. [33] compared the resistance to anterior glenoid lift off of four different all-polyethylene augmentation designs, under both compressive and eccentric loads. The stepped glenoid resulted to have lower initial and final lift off values compared with the augmentation designs, although not all reached significance.

Glenoid implant augmentation can improve glenoid version while preventing implant perforation, joint line medialization, and subchondral bone loss. However, more clinical studies are needed. Furthermore, augmented glenoid implantation is technically demanding procedure; a precise creation of a glenoid bone bed to seat the augmented component is essential. High rate of micromotion and the risk of loosening are reported [34].

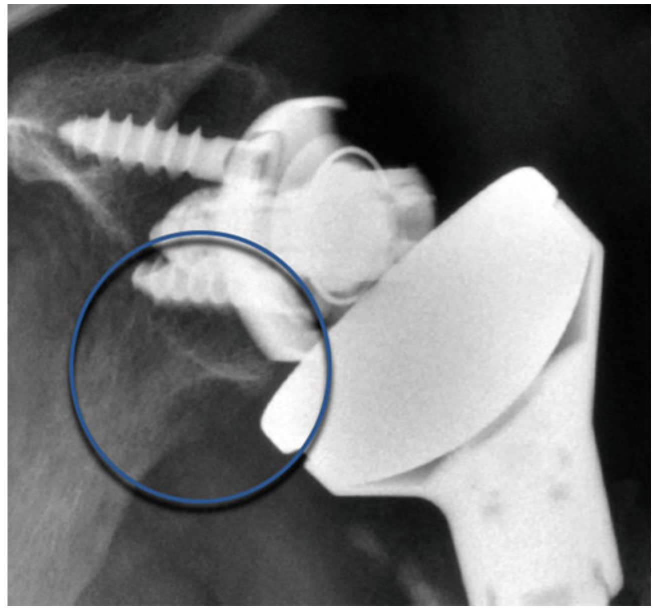

Fig. 4 Reverse shoulder arthroplasty: scapular notching

Lateralization of the Center of Rotation in Reverse Shoulder Prosthesis

The Grammont-style reverse shoulder prosthesis had two biomechanical principles: medialization of the glenohumeral center of rotation together with the lowering of the humerus [35]. These principles reduce torque on the glenoid component and increase the deltoid lever arm, overcoming the weakness or the absence of rotator cuff tendons [36, 37].

Many studies reported problems and complications attributed to this design [38–43]. The scapular notching is the most frequent, ranging from 50 to 96 % in postoperative radiograms [44–47] (Fig. 4). It consists of the inferomedial impingement of the humeral component against the scapular neck during arm adduction and rotation responsible for bone erosion and polyethylene wear. Prosthetic instability is a further complication consequent to humeral medialization because of glenohumeral impingement and the poor soft tissue tension; it has been observed in 3–6 % of cases [36, 38, 48]. Finally, patients submitted to reverse shoulder prosthesis complain of cosmetic concerns related to the loss of their normal shoulder contour [35, 36] (Fig. 5).

Fig. 5 Loss of the normal shoulder contour in a male patient submitted to a left reverse shoulder arthroplasty

With the attempt to overcome these problems, many authors have proposed different surgical techniques to obtain an increased-offset RSA. Metallic lateralization, increasing the offset of the glenosphere and/or baseplate, is an option. Historically, experience with lateralized offset prostheses led to unsatisfactory outcomes, because of high rate of glenoid loosening and screw breakage due to the increasing torque or shear force applied to the glenoid component [49, 50]. More recently, Frankle et al. [51] have demonstrated the beneficial results of metallic lateralization in reducing the scapular notching. However, in their study they reported 12 % rate of glenoid loosening after a mean follow-up of 21 months, all requiring revision. Biomechanical studies demonstrated the greater risk of baseplate-related complications after increased-offset reversed prostheses [52]. Harman et al. [52] observed that, during eccentric loading, the motion of a +7-mm increased-offset baseplate was four times greater than that observed with the Grammont medialized prosthesis. The results of both clinical and biomechanical studies led Frankle et al. to modify their initial lateral offset design, using 5-mm locking screws to increase baseplate stability and enhance glenoid component fixation [52]. Cuff et al. [53] reported encouraging early clinical results using such a design.

Boileau et al. obtained the lateralization using bony increased-offset reverse shoulder arthroplasty (BIO-RSA) [54]. According to this technique, the lateralization is obtained by placing an autogenous bone graft harvested from the humeral head on a specifically designed baseplate with a long central peg.

Once the bone graft has healed to the native scapula, the articular center of rotation is maintained at the bone-prosthesis interface. In 2011, Boileau et al. [54] published the clinical and radiological outcomes of a series of 42 patients submitted to BIO-RSA. Outcomes were equivalent to or even better than those reported with the standard medialized Grammont RSA for cuff tear arthropathy (Fig. 6) [29, 38, 44, 55].

The effect of lateralization on shoulder motion is still a motive for discussion. In their biomechanical study, Costantini et al. [56] stated that lateralization of the center of rotation leads to an increase in the overall joint contact forces across the glenosphere. Most of this increased loading occurred through compression, although increases in anterior/posterior and superior/inferior shear were also observed. Moment arms of the deltoid consistently decreased and bending moments at the implant interface increased with lateralization. Progressive lateralization resulted in improved stability. Greiner et al. [57] stated that in patients with lateralized RSA, the subscapularis and teres minor maintained their length and rotational moment arms; their flexion forces were increased and abduction capability decreased explaining why in their series they found improved rotation in lateralized RSA compared with standard implant.

Scapular notching remains the most frequent complication associated to RSA. For this reason, 19% rate of Bouleau's series [54] is not entirely satisfactory. Recently, De Wilde et al. [58] have evaluated which is the optimal way to overcome the scapular notching during an RSA implantation choosing among six different solutions (change of the angle of humeral neck shaft inclination; change in the depth of the polyethylene cup; lateralization of the center of rotation; downward glenoid inclination; increase in glenosphere radius; creation of an inferior prosthetic overhang to the glenoid bone). The authors concluded that a prosthetic overhang of about 2.5 mm created the biggest gain in notch angle.

In our surgical practice, the optimal configuration to reduce the rate of scapular notching and to produce favorable compressive forces on the glenoid bone graft is the lateralization of the implant (Fig. 7a–h) together with the positioning of the glenosphere flush to the inferior glenoid margin associated to an inferior tilt, sometimes through the help of an asymmetrical reaming and/or the use of asymmetrical bone graft.

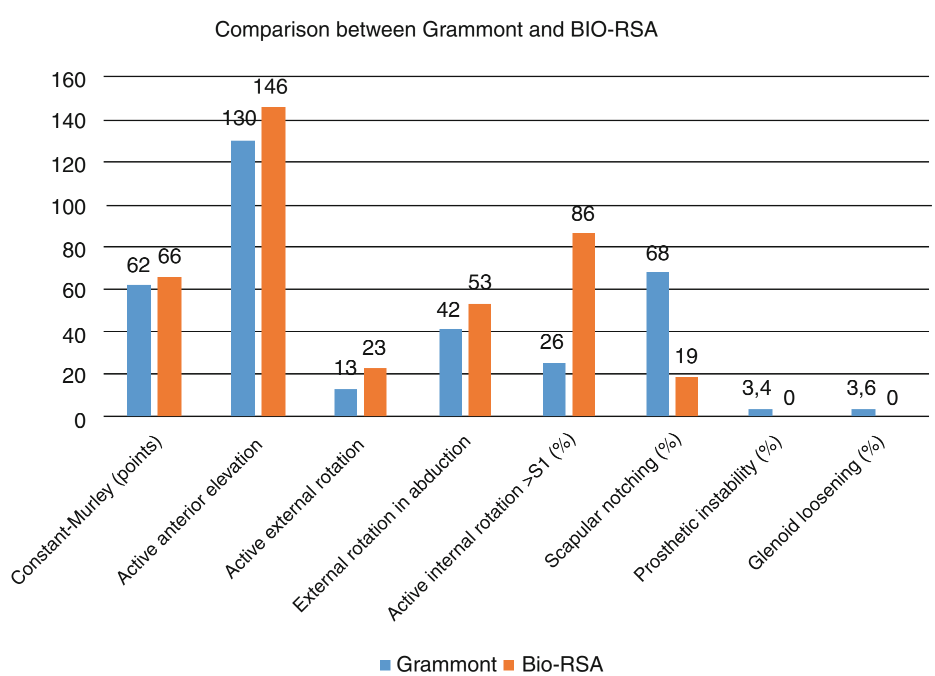

Fig. 6 Outcomes comparison between Grammont and BIO-RSA according to Boileau et al. [54]

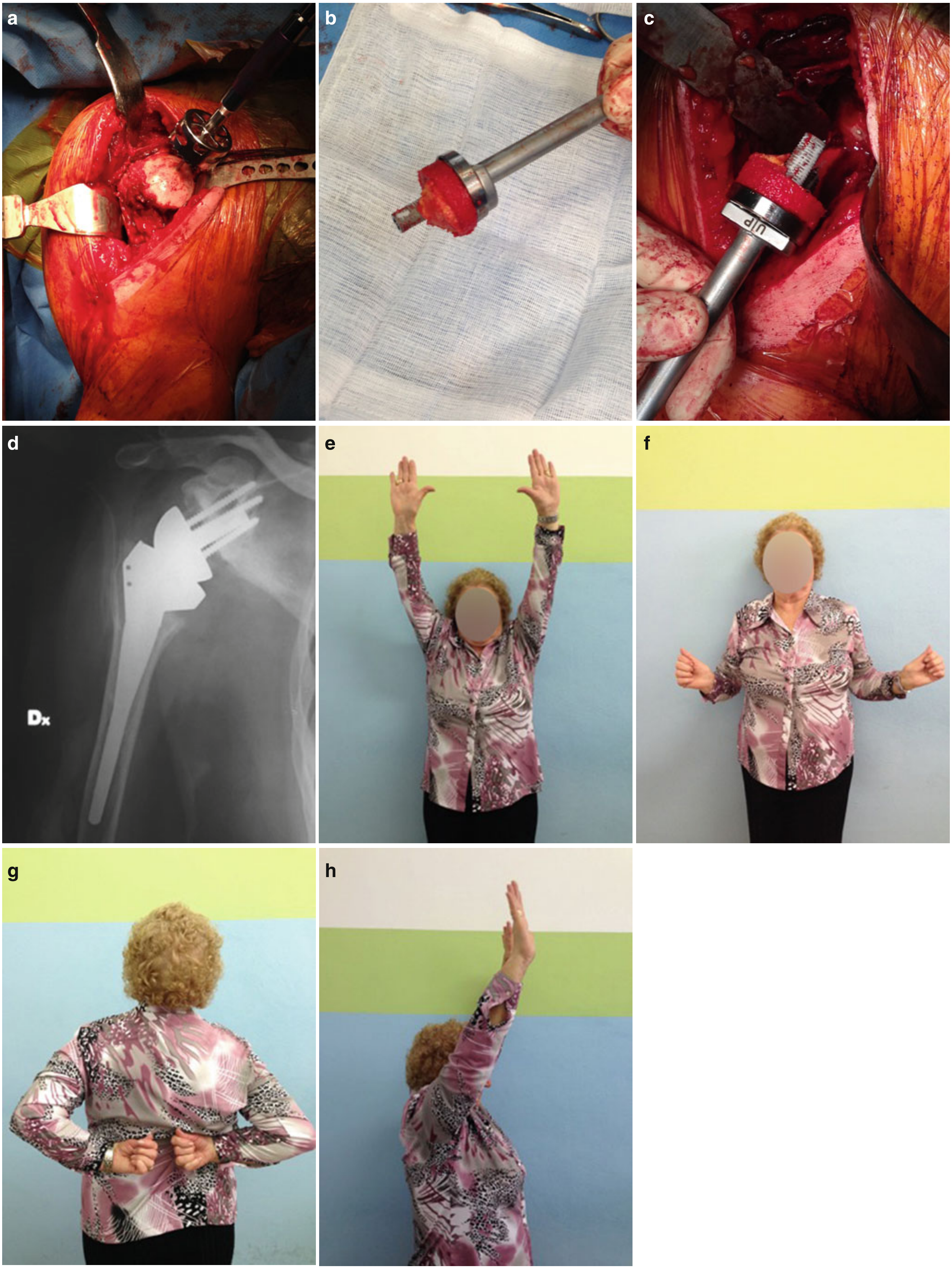

Fig. 7 Right BIO-RSA in a 71-year-old female. Intraoperative phases (**a**–**c**); radiological (**d**); and clinical (**e**–**h**) outcomes

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