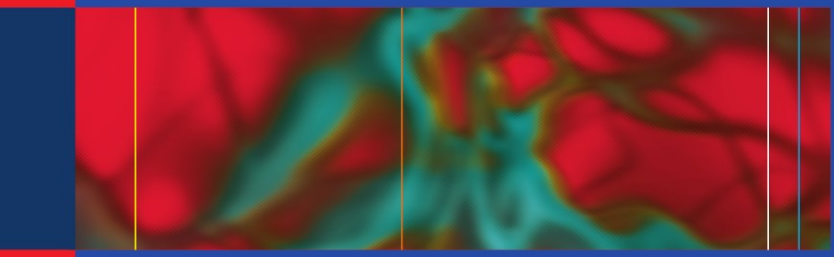
M. Belham



Transesophageal Echocardiography in Clinical Practice

Springer

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Mark Belham

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To Elizabeth, Alice, and Jessica

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Preface

The first transesophageal echocardiogram (TOE/TEE) was performed in 1976 (M-mode only) and there were some who doubted that it would find a place in mainstream cardiac imaging. Over the last 30 years the technological advances in TEE have been exponential and have been reflected by its increasing utilization. Currently, almost all echocardiography labs will undertake TEE and the vast majority of valve operations are performed with TEE guidance.

Those readers who have been exposed to TEE and other cardiac imaging modalities will know that the spatial and temporal resolution of transesophageal echocardiography is unsurpassed and that it is relatively easy to get good images with minimal training. The same readers will also be aware that, for these reasons, there are practitioners who bypass the appropriate training and use TEE as a very blunt diagnostic tool. The fact that transesophageal echocardiography can be used by such individuals is a travesty; I believe that performing a TEE study should be considered a privilege and with that privilege comes the responsibility of learning.

The purpose of this book is to give practical guidance to those undertaking training in the art of transesophageal echocardiography. It is not an exhaustive text to be used for reference, but one that should be used in conjunction with hands-on experience. If used correctly, it will help you on the road to realizing the true potential of TEE in your hands.

Thank you for taking the time to read it!

Cambridge, UK — Dr. Mark Belham

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Chapter 1
Introduction

1.1 The Role of Transesophageal Echocardiography (TEE)

When imaging a patient's heart, the number of modalities available to choose seems to be ever increasing and the clinician needs to be aware of the strengths and weaknesses of each modality in order to best answer the questions posed. If more than one modality can answer the question, then an appreciation of local expertise and patient preference is needed (although in general, echocardiography can answer the question and should be the first line investigation).

1.1.1 Guidelines for the Use of TEE

A joint working group including the American Society of Echocardiography produced guidelines for the use of TEE in 2007.[1,2] The list of indications is similar to those for transthoracic echocardiography (TTE), provided the results of the study are used to guide the management of the patient. They recommend that transesophageal echocardiography should be used as an adjunct, and subsequent to a full TTE examination, when the TEE can add information that is not obtained by TTE and that is required for clinical decision making (e.g., etiology of valvular regurgitation and suitability for surgical repair). TEE should be used as the primary imaging modality in the non-peroperative setting for patients in atrial

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flutter/fibrillation (to facilitate clinical decision making with respect to anticoagulation and/or suitability for cardioversion), for cases of suspected endocarditis (with moderate or high pre-test probability of having the disease) and for cases of suspected thoracic acute aortic syndrome.

1.1.2 Contraindications to Transesophageal Echocardiography

The risks of major complications occurring as a result of a TEE should be negligible. In one study, published by the Mayo clinic, of 3,827 TEE procedures carried out over a 3-year period, there were major complications in 0.22% of patients mainly due to laryngospasm but also 1 death and 1 case of sustained VT.[3] Others have also reported rare but serious esophageal trauma, but only in patients with undiagnosed esophageal pathology.[4] The risk profile will depend on whether the case is an emergency or elective one. In an emergency case, the risks of hemodynamic instability and arrhythmias are potentially high and a careful risk–benefit analysis is required prior to TEE. In elective cases, the major risk is related to potential trauma, but such complications are likely to happen only if a study is undertaken on a patient with significant pre-existing oropharyngeal, esophageal, or gastric pathology (e.g., varices at high risk of bleeding or obstructing/restricting tumors) or in patients who have had recent surgery. Every care should be taken to avoid complications and it would, therefore, be considered an absolute contraindication to perform a TEE in such patients. Oropharyngeal, esophageal, or gastric surgery in the distant past is a relative contraindication, and the potential risks (quantified after discussion with the relevant surgeon) need to be weighed against the potential benefits of TEE as an imaging modality. As it is possible for patients to have serious but undiagnosed pathology, our echo lab has a checklist incorporated into a specific TEE integrated care pathway document (Appendix 1); the questions are designed to identify high-risk individuals. In such high-risk individuals and in some cases of known pathology (i.e., small varices, previous recurrent epistaxis), TEE may not be absolutely contraindicated, but it would be advisable to discuss with the responsible gastroenterologist

or ENT surgeon prior to making a decision; this may include a request for imaging by that specialist. Other relative contraindications include patients on warfarin with an INR greater than four, patients with oxygen saturations <95% (despite 4 L of nasal cannulae oxygen) and those with severe latex® allergy.

1.2 Equipment and Personnel

1.2.1 Room and Equipment

TEE studies should be undertaken using a high specification machine (with dedicated software presets) and probe that are well maintained; the machine being not more than 5-years old. The room should be 20 m^2 (or larger) and well ventilated. There must be a constant and reliable oxygen supply, suction facilities, and full resuscitation equipment near by (ideally in the room).

1.2.2 Monitoring

Continual ECG recordings (usually single lead via echo machine but must be of a quality that will detect arrhythmias), continual pulse oxymeter recordings, and intermittent blood pressure recordings should be monitored.

1.2.3 Personnel

In the echo lab, I believe there should be three people – the operator, a technician, and a nurse/physician's assistant. The operator should be experienced in TEE and appropriately accredited. The technician needs to have a good knowledge of echocardiography to ensure image optimization. The nurse/physician's assistant must be experienced in airway management, suction, and the general care of the sedated patient. All personnel must be trained in basic life support and at least one member of the team must be competent at advanced life support.

1.3 Preparation of the Patient

1.3.1 Nil by Mouth

The patient should not eat or drink for a minimum of 4 and preferably 6 h before an elective TEE. For a morning list, I would normally advise nil by mouth (NBM) from midnight. For an afternoon list, patients can have a light breakfast before 8 a.m. and then NBM. Patients are advised to take their normal medication (unless stated otherwise) with a sip of water (not less than 2 h before the procedure). Special attention to diabetics undergoing elective TEE is necessary and advice to these patients' needs to be individualized (Appendix 2). For nonelective TEE studies, risks and benefits need to be weighed up in individuals who have eaten less than 4 h previously. Intravenous metoclopramide (to aid gastric emptying) may be helpful, and in exceptional situations, intubation with rapid sequence induction can be necessary.

1.3.2 Consent

Informed consent should be gained from the patient prior to the TEE examination. The patient needs to be aware of the reasons for the procedure, any alternatives, what the procedure entails, and the potential risks (including published and unit/operator specific complication rates). In our institute, the patient is given an information booklet (sent with their appointment date and logistical information if the procedure is elective) to read (Appendix 3); this is an adaptation of the advice given by the American Society of Echocardiography (www.asecho.org) that has a specific site for patient information about TEE (www.seemyheart.org/tee). Immediately prior to undergoing TEE, the patient is given a further information sheet (Appendix 4) and a procedure specific consent form (Appendix 5); the operator then explains about the procedure, answers any queries, and invites the patient to sign the consent form.

1.4 Sedation and Local Anesthesia

The majority of adult TEE studies are performed by giving the patient an oropharyngeal local anesthetic (spray or gel) and/or sedation. Occasionally (usually at patients' request), procedures are performed with neither or, at the other extreme, under general anesthesia.

1.4.1 Oropharyngeal Local Anesthetic

When using oropharyngeal local anesthetic, I use xylocaine® spray, which has the same cautions and contraindications to use as do other forms of lignocaine. Having asked the patient to say "aargh," I spray the posterior pharynx with 5 doses/sprays, and then request them to gargle the liquid for 10–15 s prior to swallowing. I then repeat the step again and finally spray the hard and soft palate with 5–10 doses (total for patient not exceeding 20 doses/sprays). If oropharyngeal local anesthetic is used, the patient must remain nil by mouth for 1 h after application; they can then take cold fluids and/or food but must not eat or drink anything hot for a total of 4 h following application.

1.4.2 Intravenous Sedation

When using sedation, I give intravenous midazolam. This has the same cautions and contraindications to use as do other benzodiazepines, but compared with diazepam (the most frequently used alternative), the recovery after use is faster and the amnesia is more profound. Once the patient is in the left lateral (recovery) position, all pre-study observations have been completed and we are ready to start the TOE 1–2 mg of midazolam is given. Occasionally a further 1–2 mg is given prior to intubation with the TOE probe if the patient is very anxious, but patient compliance is essential for a successful intubation, and so it is important not to

over sedate. Once the TEE probe is in the esophagus, further 1–2 mg aliquots of midazolam are given (up to a maximum of 10 mg in total per patient) titrating against the patients' comfort and level of consciousness. (Do not give large boluses as this can lead to excessive sedation with associated risk of sedation-related complications.) If sedation is used, the patient should be looked after by an adult for a minimum of 12 h and most institutes advise against driving, using dangerous machinery (including kettles, irons, and cookers), lighting fires, making life changing decisions, purchasing expensive goods, signing cheques for large amounts of money, or signing legal documents for 24 h.

1.4.3 What method(s) to Use?

There are arguments for and against both methods, and the decision about which method or combination of methods to use will often depend on the patients' wish. Other important influences include respiratory function, hemodynamic stability, and the likelihood that a patient will require repeat studies. Previously, I have used sedation alone but my practice has evolved, and now, in general, I give oropharyngeal local anesthetic spray as outlined above, and then, as a result, use smaller amounts of sedation. I believe that using this combination reduces recovery time and risk of respiratory/cardiovascular depression while maintaining patient comfort.

As a transesophageal echocardiographer, keep an open mind and become experienced with both methods (on their own or in combination) and then develop the methods that best suit you, your echo lab, and your patients.

1.5 Intubation

Published data and our departmental audit indicate that an experienced operator should be able to successfully intubate 99% of patients with oropharyngeal local anesthesia and/or sedation, with the other 1% requiring general anesthesia or an alternative imaging modality. Preparation and patient compliance are both essential for successful, nontraumatic intubation. The patient needs to be

as comfortable as possible. Ideally they should lie in the left lateral (recovery) position with their neck in the midline and slightly flexed. I will give the oropharyngeal local anesthetic prior to them lying down, but before giving any sedation, I talk through the process of intubation and what I expect of them. I tell them that "…the first part is the worst part…" and that they will get a gagging sensation but that once the probe is past the back of their tongue that sensation will settle down. Then the mouth guard is positioned and a small amount of sedation given. It is important to get the order right as some patients will become very sleepy and refuse to open their mouth even after 1–2 mg of midazolam leaving you to wait or requiring reversal of the sedation before you have even started! With the mouth guard in position, give a little suction to ensure minimal oral secretions prior to introducing the probe. The probe tip is flexed (60–80°) to aid intubation. (Note: The lock should be left off.) The probe is then put through the mouth guard (which is held firmly in place by the assistant as biting the probe will damage it and that can be very expensive) and advanced gently but firmly along the central line of the tongue toward the posterior wall of the oropharynx. Simultaneous with probe advancement, tell the patient that the probe is coming to the back of the tongue and ask them to swallow. Sometimes patients can deviate the probe away from the centre line with tongue movements/rumination and push the probe into the palatopharyngeal folds; in these circumstances, I use my index finger (inserted into the oral cavity outside the mouth guard) to guide the probe. Once the probe reaches the posterior oropharynx, a gag reflex will be invoked and the patient will retch, and this is the time to continue to advance the probe (with or without flexion) as the gag reflex and retching closes the epiglottis across the trachea and will allow safe intubation of the esophagus. With the probe in the esophagus, further sedation can be given and the imaging begins.

1.6 Anatomical Considerations and Terminology

To understand the views obtained during a transesophageal echocardiographic study and some of the limitations of this method of cardiac imaging, you must appreciate the relationship

of the esophagus and stomach to other thoracic structures. It is also important to know the agreed terminology for each of the basic views so that we can effectively communicate.

From the level of T1 to T4, the esophagus has lung on the left and right side, the trachea anteriorly and vertebrae posteriorly, and so no image is obtained. At the level of T4 (Fig. 1.1), the aortic arch is anterior to the esophagus and (sometimes with the left brachiocephalic vein and distal right pulmonary artery) can be visualized with appropriate probe manipulation. The superior vena cava is anterior and to the right at this level but cannot be visualized due to the interposition of the trachea. Between T4 and T8 (Fig. 1.2), the ascending aorta, superior vena cava, pulmonary trunk, and right pulmonary artery lie anterior to the esophagus and are usually the first images seen as the probe is advanced without need for further manipulation (upper esophageal window). The left pulmonary artery is also anterior to the esophagus at this level, but is obscured by the left main bronchus. From about the level of T8 to the level of T12

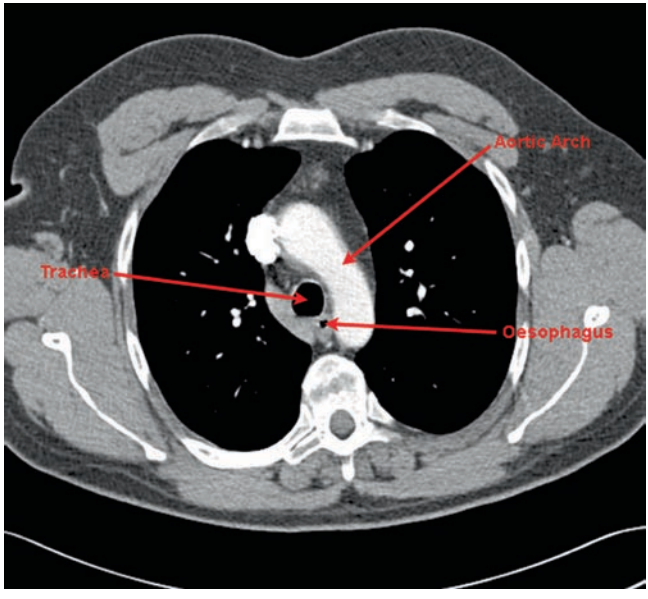

FIGURE 1.1. Thoracic CT slice taken at the level of T4 showing the relationship of the esophagus to the trachea and aortic arch.

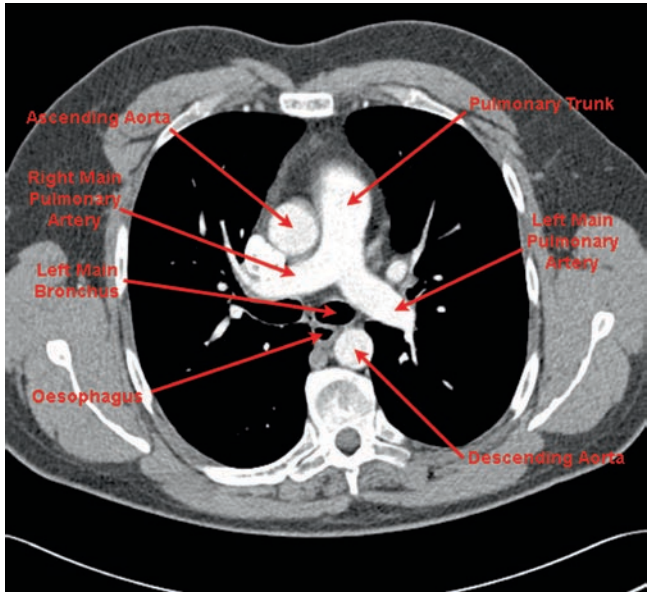

FIGURE 1.2. Thoracic CT slice taken at the level of T6 showing the relationship of the esophagus to the trachea/left main bronchus, descending aorta, ascending aorta, pulmonary trunk, and main pulmonary arteries.

(Fig. 1.3), the left atrium is immediately anterior to the esophagus, thus allowing unimpeded visualization of all the intracardiac structures (mid esophageal window). Posterior to the esophagus from T4 to T12 is the descending aorta; this is usually imaged at the end of the study by complete rotation (clockwise or anticlockwise) and subsequent slow withdrawal of the probe. Below the diaphragm the stomach is directly inferior to the ventricles and these can be visualized by flexing the probe tip to bring it into apposition with the lesser curvature of the stomach (transgastric window).

1.7 Image Acquisition and Probe Manipulation

The basic concepts and terminology of image acquisition and probe manipulation will be discussed here with specific details of what is required for certain structures being covered in later chapters.

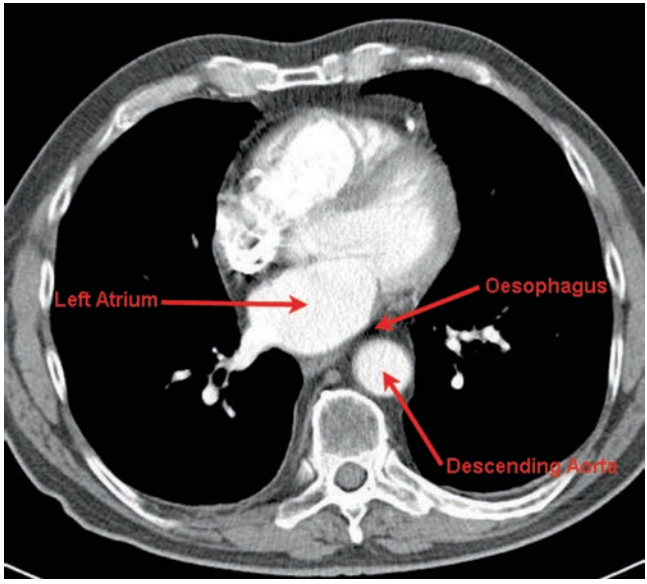

FIGURE 1.3. Thoracic CT slice taken at the level of T10 showing the relationship of the esophagus to the left atrium and descending aorta.

When considering the assessment of specific cardiac structures, it should always be remembered that there can be marked interindividual variability such that any text can only be a guide. With each study undertaken adjustments to probe depth, degree of rotation and flexion and image plane angle will be needed to optimize the image dependent on what is seen.

There are three main echocardiographic windows used during the standard TEE examination. These are the upper esophageal, mid esophageal, and transgastric and are approximately 20–30, 30–40, and 40–50 cm from the incisors respectively. Once at the appropriate level, the probe can be manipulated in order to obtain the required image. The probe can be advanced or withdrawn and can be turned to the patient's left (anticlockwise) or right (clockwise). In addition, the imaging plane can be rotated using the button on the underside of the probe handle, and the tip of the

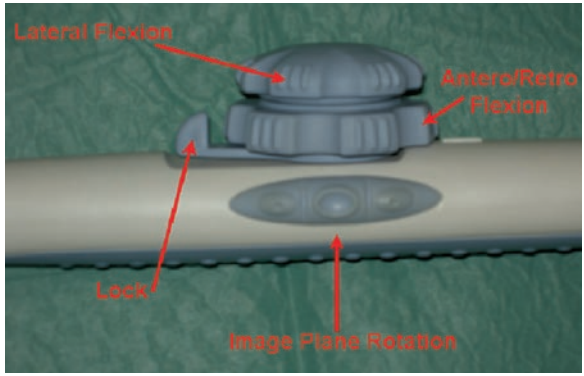

FIGURE 1.4. TOE probe handle with button for imaging plane rotation, cogs for probe tip flexion, and lock for fixing probe tip in position.

probe can be flexed using the two cogs on the side of the probe handle (Fig. 1.4). The imaging plane angle can be rotated between

> When optimizing the image, whatever you do, do it slowly; then, if the image looks worse do the opposite.

0 and 180° and in each chapter the range of angles needed for certain images has be outlined.
Flexion of the probe refines the view obtained. To anteflex the tip (Fig. 1.5), the large cog on the handle is turned anticlockwise (away from the patient), and to retroflex the tip (Fig. 1.6), it is turned clockwise (toward the patient). To lateral flex the tip (Fig. 1.7), to the right/anteriorly, the small cog on the handle is turned anticlockwise (away from patient), and to lateral flex the tip to the left/posteriorly, it is turned clockwise (toward the patient).

1.8 Physics

In addition to changing the image plane angle and manipulating the probe, the operator must have an understanding of the Physics of ultrasound in order to ensure optimal image quality. Although the

FIGURE 1.5. Anteflexed probe tip.

mere mention of "the P word" can make most TOE operators ill, some knowledge of this mystic subject is essential. This section will concentrate on the basics; it will cover those factors that are under the operator's control and I hope you will find it to be of practical value.

1.8.1 Characteristics of Ultrasound

Sound is mechanical energy that is propagated through a medium by vibration of molecules. Sound can be described in terms of propagation velocity (c), wavelength (λ), and frequency (f), where $c = f \times \lambda$. Propagation velocity is constant within a homogenous medium; it is approximately 1,540 m/s in human tissue. Therefore, with a constant velocity, the frequency and wavelength are inversely proportional.

FIGURE 1.6. Retroflexed probe tip.

1.8.2 Tissue Penetration

When ultrasound passes through a medium, the strength of the beam is progressively reduced (attenuation) due to a combination of absorption, reflection, refraction, and scattering. Attenuation is measured in decibels (dB) and is dependent on the medium through which the ultrasound travels and the frequency it is transmitted at (Table 1.1).

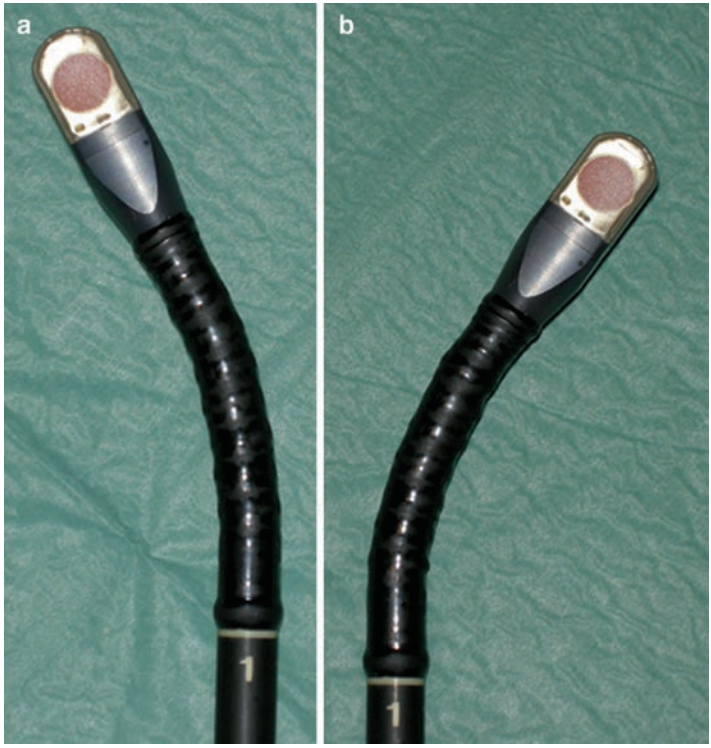

FIGURE 1.7. Laterally flexed probe tip.

Table 1.1 Approximate values for the attenuation of ultrasound in different human mediums.

Blood	0.18 dB/cm/MHz
Fat	0.63 dB/cm/MHz
Soft tissue	1 dB/cm/MHz
Myocardium	1.8 dB/cm/MHz
Skeletal muscle	1.3–3.3 dB/cm/MHz
Bone	20 dB/cm/MH
Lung	41 dB/cm/MHz

1.8.3 Spatial Resolution

This term refers to the ability to detect two points in space that are separate and display them as such; it is subdivided in two-dimensional imaging into lateral and axial. Lateral resolution (the ability to distinguish two points side by side) is dependent on beam width, which must be less than the distance between the two points in order for them to be recognized as separate. The beam width is smallest (and lateral resolution best) within the near field (Fresnel zone); the near field is longer at higher frequencies. Axial resolution (the ability to distinguish two points on the same scan line) is dependent on the wavelength; the distance between the two points needs to be greater than half a pulse length (pulse length = number of cycles × wavelength). Wavelength is smallest (and axial resolution best) at higher frequencies. Lateral resolution is always worse than axial resolution, and consequently, measurements are best taken axially rather than laterally.

1.8.4 Temporal Resolution

The ability to resolve two points in time is very important for real time two- (three-) dimensional echocardiography and is directly related to the frame rate. The frame rate is the time required to generate one frame. Each frame is made up of multiple scan lines so the major determinants of frame rate are the scan line density and the pulse repetition frequency (PRF). Frame rates increase with increasing scan line density which is achieved by reducing the sector width. Frame rates also increase at higher pulse repetition frequencies. PRF is proportional to the velocity of ultrasound in that medium (this effectively is a constant) and inversely proportional to the distance traveled by the ultrasound (dependent on sector depth and tissue penetration). The PRF can, therefore, be increased (with consequent increase in frame rate and temporal resolution) directly by decreasing the sector width or indirectly by increasing the transmission frequency (and thus decreasing the depth of penetration).

1.8.5 Image Optimization

The practical relevance of what has been described above is that by using a high-frequency transducer (standard TEE probe transmits at a frequency of 5–7.5 MHz) and placing it next to the heart with minimal soft tissue between (i.e., in the esophagus) the operator automatically achieves excellent axial, lateral, and temporal resolution with relatively small amounts of attenuation. It is, therefore, possible to get clear images of the heart with almost no effort (excepting the need to intubate the patient), and it is perhaps this near instant gratification that leads interventional cardiologists to positively push their way into the echo lab to do a TEE when it would normally take a threat of violence to get them into the echo lab to do a transthoracic echocardiogram. There are, however, cases when image quality is not immediately perfect, and for such instances, it is worth knowing how to improve the quality of your study. For those who perform transthoracic echocardiograms, you will probably be familiar with the following as the principles are exactly the same.

Frequency: High frequency transmission is good for the near field but leads to marked loss of resolution in the far field and decreases the depth of tissue penetration due to attenuation. These factors can result in suboptimal imaging of the ventricles (especially the left ventricular apex) from the mid esophageal window. The frequency can be reduced to improve imaging of the ventricles from the mid esophageal window. The frequency can be changed within the probe's frequency range directly or via "presets" depending on the machine's software and operators should be aware how to do this within their own echo labs.

Image sector depth: This should be adjusted so that the bottom of the sector is approximately 1 cm distal to the area of interest (e.g., mitral valve); this will optimize the temporal resolution.

Image sector width: This should be adjusted so that the sector is approximately 1 cm wider than the area of interest (e.g., mitral valve); this will optimize the temporal resolution.

Focus: Lateral resolution is increased by focusing the beam but this limits the near field depth and increases beam divergence distal to the focal point (with proportionally greater loss of lateral resolution in the far field). The focus point can be

manually adjusted and should be placed just distal to the point of interest.

Overall gain: It is important to have sufficient gain but remember that excessive gain will reduce lateral resolution.

Time gain compensation (TGC): The further an object from the transducer, the greater the attenuation of its reflected signal. To compensate for this variation in signal strength, the echo machine has a slide potentiometer that allows the operator to amplify more distant signals relative to near signals. As a rough guide, I start with the TGC aligned in a curve (Fig. 1.8), with further adjustments being made depending on the image obtained.

Compress: This function redistributes the entire grey scale range to those echoes that are above the compress level. Decreasing the compress level can be done manually and produces a more black and white image. Normally, I do not adjust the compress from its standard setting; the exception is that I find decreasing the compress especially helpful when looking for left atrial appendage thrombus.

FIGURE 1.8. Time Gain Compensation slide potentiometer aligned in a curve (recommended starting position).

Zoom: Write zoom (regional expansion selection) is a preprocessing function that magnifies and increases spatial and temporal resolution; this can only be done in "real time." Read zoom is a postprocessing function that magnifies without increasing resolution,; this is the mode of image manipulation used for digitally stored images. It is my normal approach to use write zoom in all TOE studies to optimize visualization of any area of interest. It should be remembered that the degree of magnification and improved resolution is inversely proportional to the size of the zoomed area.

1.9 Targeted vs. Complete TOE Studies

A transesophageal echo study should be planned; this seems an obvious statement but is all too often forgotten. Before starting, you need to know what question is to be answered and what information is already available. The TOE is almost always performed after a transthoracic echo study and this should, where possible, be reviewed by the operator prior to commencing the TOE.

The first part of the TOE study should then be targeted to specifically answer the question (e.g., etiology of mitral regurgitation). Once again it seems unnecessary to make such a statement, yet history is littered with accounts of intolerant patients removing the probe prior to completion of the study leaving a red faced operator with beautiful, but superfluous pictures and the question unanswered. To add insult to injury in such cases the aforementioned patient is often unwilling to have the TOE repeated!

Once the question posed is answered there are two main options. The first option is to conclude the study at that point; this option is favored by some and certainly increases the throughput of your TOE lab. The second option is to continue and perform a complete study; this is my preferred option providing the patient is tolerating the procedure and there is no hemodynamic instability. The reasons I perform a complete rather than targeted study are:

- The study stands alone and as such can confirm or refute previous findings.
- A complete study can be compared to previous studies and be used to monitor progression of pathology as it is often performed at a time interval after the transthoracic study.
- A complete study can identify important but coincidental pathology.
- By performing complete studies the operator is better able to understand the variations of normality and maintains manipulation skills.

To perform a complete study, it important that an operator has their own routine and checklist to ensure nothing is missed. Whatever routine is followed it should be based on the recommendations of the American Society of Echocardiography[5] and the European Society of Echocardiography.[6]

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Chapter 2
The Left Ventricle

Assessment of the left ventricle may be the primary objective in a peroperative TEE study (especially for noncardiac surgery), in ventilated patients or in patients "resistant" to ultrasound via the transthoracic approach (due to body habitus). In other studies, it is secondary, but a very important objective. Whether a primary or secondary objective, it is necessary to have a systematic approach to ensure the appropriate images are obtained.

2.1 Standard Image Planes

The standard image planes that are required to assess the left ventricle are the mid esophageal (ME) 4 chambers (4Ch; Fig. 2.1), 2 chambers (2Ch; Fig. 2.2) and long axis (LAX; Fig. 2.3) views and transgastric (TG) basal short axis (bSAX; Fig. 2.4), mid short axis (mSAX; Fig. 2.5), 2 chambers (2Ch; Fig. 2.6), and long axis (LAX; Fig. 2.7) views. For those familiar with transthoracic echocardiography (TTE), the mid esophageal views are analogous to the transthoracic apical views; the transgastric short axis and long axis views are analogous to the transthoracic parasternal short axis and long axis views. The transgastric 2 chambers view looks at the same walls as the TTE apical 2 chambers view, but is interrogating radial as opposed to longitudinal contractility. The approximate image plane angles used for each view are outlined above.

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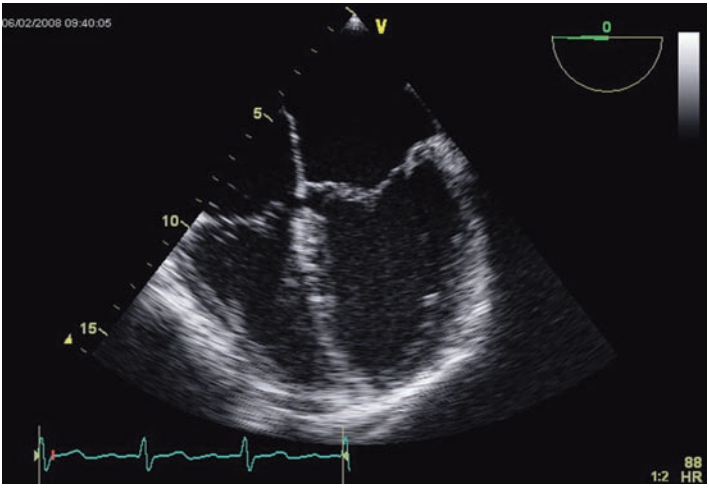

FIGURE 2.1. Mid esophageal 4 chambers (ME 4Ch) view.

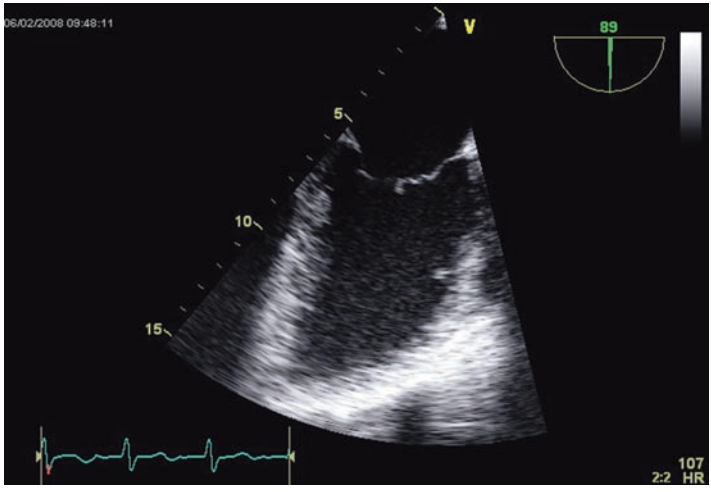

FIGURE 2.2. Mid esophageal 2 chambers (ME 2Ch) view.

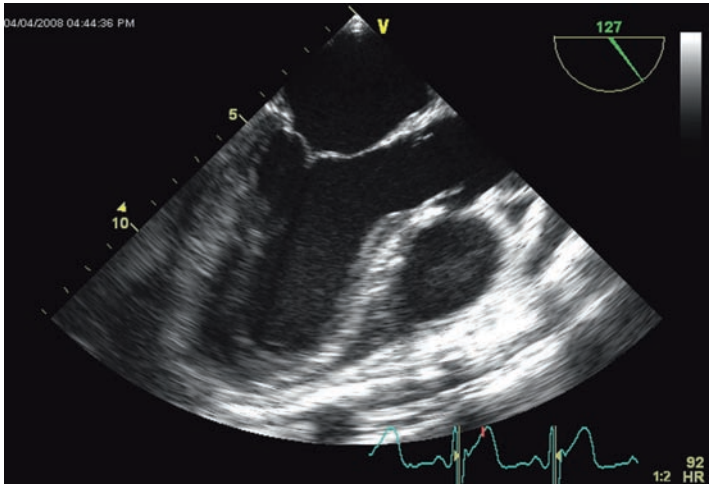

FIGURE 2.3. Mid esophageal long axis (ME LAX) view.

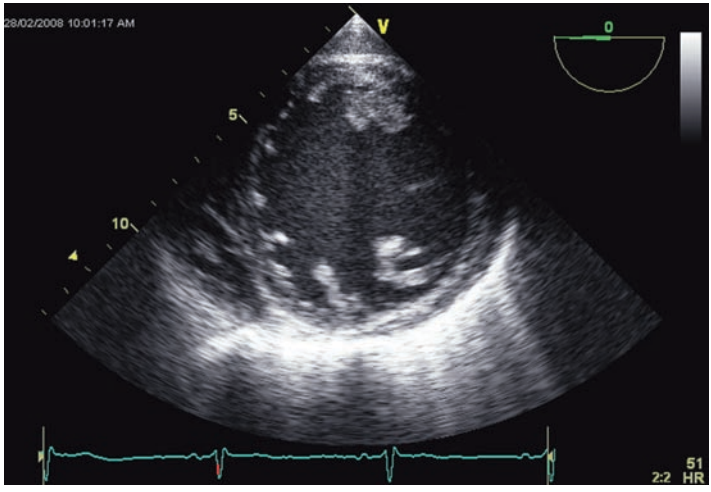

FIGURE 2.4. Transgastric basal short axis (TG bSAX) view.

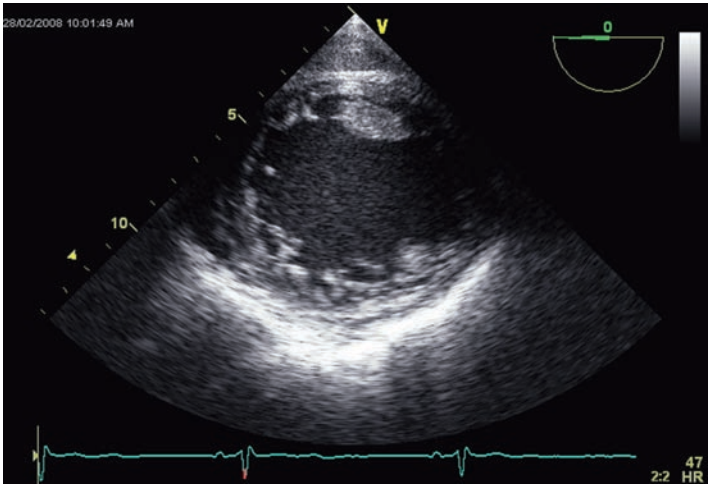

FIGURE 2.5. Transgastric mid short axis (TG mSAX) view.

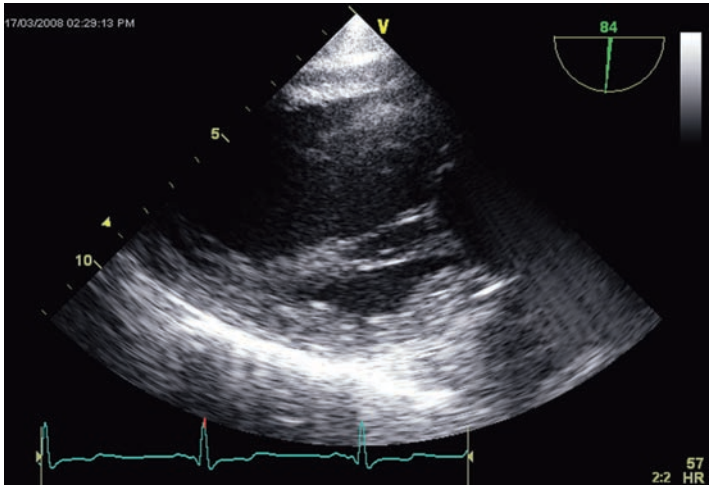

FIGURE 2.6. Transgastric 2 chambers (TG 2Ch) view.

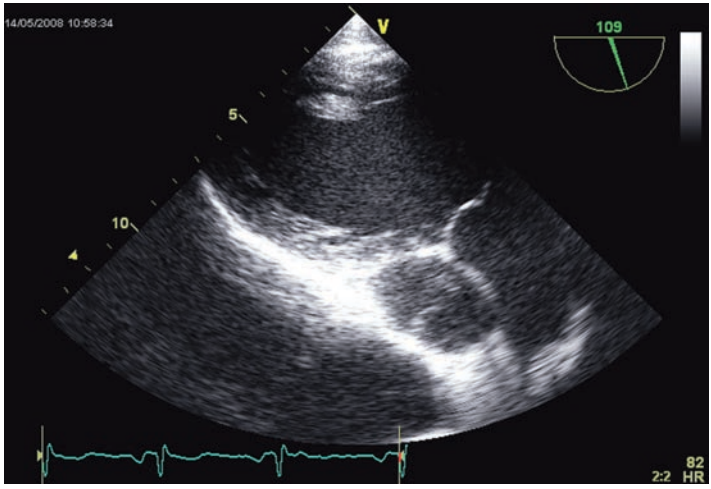

FIGURE 2.7. Transgastric long axis (TG LAX) view.

LV Image Plane Angles

ME 4Ch – 0–40°
ME 2Ch – 80–120°
ME LAX – 120–160°
TG SAX – 0–40°
TG 2Ch – 80–120°
TG LAX – 80–120°

2.2 Data Set Required

From these image planes the operator needs to assess the following as a minimum: the cavity size, the wall thickness/mass, regional wall motion, global systolic function, and global diastolic function. Reference limits for chamber size, mass, and systolic function are quoted in Table 2.1; the values are based on the ASE/EAE consensus document published in 2005.[1] All measurements

should be averaged over 3–5 consecutive beats of good quality in patients in sinus rhythm (10 beats if in atrial fibrillation [AF]). Having intubated the patient, advance the probe to the mid esophageal level to obtain the 4 chambers view; from here it is possible to get an immediate impression of the left ventricular structure and function. To adequately visualize the endocardial borders of all the segments in this, and the other mid esophageal views, it is often necessary to adjust the settings to optimize your image; the focus point should be moved toward the apex, the image sector width reduced, and on occasions, the imaging frequency reduced. After 2D imaging, spectral and tissue Doppler imaging is undertaken to evaluate left ventricular diastolic function. Having completed the ME 4 chambers view data acquisition, move around the scan plane angles at the mid esophageal level imaging the ME 2 Ch then ME LAX views for further two-dimensional and Doppler assessment of the left ventricle. When increasing the image plane angle from 0° to 160° it is usually necessary to manually rotate the probe anticlockwise (to the left) in order to maintain an appropriate cut through the left ventricle. At this point almost all the necessary data on left ventricular structure and function has been obtained, and if the study is terminated early (due to patient compliance), then at least the questions can be answered. Then continue scanning in the esophagus (looking at the right ventricle, atria, valves, etc.) before proceeding to the transgastric views; the reason for deferring this stage of the study until all the relevant esophageal imaging has been completed is that it is not well tolerated by the nonanesthetized patient and can lead to premature interruption of the study.

LV Assessment

Chamber/cavity size
Wall thickness/mass
Systolic function
Diastolic function

> The ME 4Ch view is the easiest to obtain and recognize and so can be used to orientate the operator. If you get "lost" during a study, return to this view and start again.

2.3 Chamber Size

The measurements of chamber/cavity size that should be quoted are the left ventricular internal dimension at end diastole (LVIDd), the left ventricular internal dimension at end systole (LVIDs), the LV end diastolic volume (EDV), and the LV end systolic volume (ESV). The linear dimensions are ideally measured in the transgastric 2 Ch view using two-dimensional imaging; the alternative is the ME 2 chambers view, but there is a greater potential for measurement error as accuracy in this window is dependant on lateral, as opposed to axial, resolution. When measuring the linear dimensions using two-dimensional imaging, convention states that these measurements are taken from the endocardium of the anterior wall to the endocardium of the inferior wall in a line perpendicular to the long axis of the left ventricle at the junction of the basal and mid thirds of the long axis. End diastole can be defined at the onset of the QRS, but is preferably defined as the frame in the cardiac cycle after mitral valve closure or the frame in the cardiac cycle in which the cardiac dimension is the largest (my preference). End systole is best defined as the frame preceding mitral valve opening, or the time in the cardiac cycle in which the cardiac dimension is the smallest (my preference). The LVIDd and LVIDs can also be measured using M-mode in the transgastric 2 chambers view, but care is required to ensure the cursor is perpendicular to the long axis of the ventricle. Also, if using M-mode the reference limits are different because the dimensions are bigger than those measured using 2D.

Left ventricular volumes should be estimated using the modified Simpson's rule in the ME 2 chambers view. The ME 4 chambers view should not normally be used as, in this view, the long axis of the left ventricle is often foreshortened as a result of the probe tip being anteflexed (in order to bring it into apposition with the esophageal

wall; this often being necessary to ensure adequate image quality), whereas even with the probe tip anteflexed, the mid esophageal 2 chambers view does not foreshorten the LV as it is perpendicularly orientated. From a practical point of view, the LV cavity is planimetered (i.e., you trace the endocardial border excluding the papillary muscles with the basal border being delineated by a straight line connecting the inferior and anterior mitral valve insertion points) at end diastole and end systole and the echo machine, using automated software, gives you the answer. For those wanting a more detailed description on methodology, and the theoretical advantages and disadvantages of the modified Simpson's rule, I would recommend getting a bigger book (and a life!).

2.4 Wall Thickness and Mass

The left ventricular wall thickness can be visually estimated from the mid esophageal views. If, however, an accurate measurement is required, the transgastric window (mid short axis) is recommended as the spatial resolution is improved (as detailed above), and thus the potential for measurement errors reduced. The posterior (inferolateral) and septal wall thickness at end diastole (PWTd and SWTd respectively) should be measured and reported as normal (<10 mm in females and <11 mm in males) or increased; if increased the distribution should be stated (i.e., global vs. regional). Irrespective of the wall thickness, this should not be translated into whether hypertrophy is present or absent as hypertrophy is defined according to left ventricular mass corrected for body surface area (BSA). Mass can be calculated using linear equations, or methods based on the area length formula or the truncated ellipsoid model. The linear equations are more practically applicable and have a large evidence base to support their use. If mass is calculated using a linear equation, the ASE recommend the Devereaux equation where LV mass = $0.8 \times \{1.04[(\text{LVIDd} + \text{PWTd} + \text{SWTd})^3 - (\text{LVIDd})^3]\} + 0.6$ g. This is a well-validated equation and is usually integrated into standard machine software so that when the left ventricular cavity dimensions and wall thicknesses are measured, the mass is automatically calculated; it can only be used if wall thickness is uniform through the ventricle and should not be

used in the presence of regional hypertrophy (e.g., hypertrophic cardiomyopathy) or thinning (e.g., myocardial infarction). Once the mass has been calculated, it needs to be corrected for body surface area; the BSA being derived from the patients' height and weight using either standard charts or putting them into patients details on the echo machine, and allowing it to perform the calculation (the latter method having the distinct advantages of being less time consuming and probably more accurate). When calculating the LV mass using wall thickness derived from TEE, it is to be noted that the calculated mass is 5–10 g/m^2 greater than if derived from transthoracic echocardiography.

Combining mass and relative wall thickness (RWT: [2 × PWTd]/LVIDd) permits categorization of an increased LV mass as concentric or eccentric hypertrophy and allows identification of concentric remodeling as outlined in Table 2.2.

2.5 Systolic Function

Left ventricular systolic function can be assessed in many ways, but simplistically it can be described in terms of global and regional function.

2.5.1 Ejection Fraction

The most common method of quantifying global systolic function during a TEE examination is the measurement of the ejection fraction (EF). As with TTE, the EF is calculated from the left ventricular volumes that are estimated using the modified Simpson's rule:

EF = (end diastolic volume – end systolic volume)/end diastolic volume,

$$EF = (EDV - ESV)/EDV$$

Unlike TTE, the EF is estimated solely from the 2 chambers view due to the foreshortening of the LV in the 4 chambers view (as described earlier), and therefore, is a less-accurate measure in the presence of variations of wall motion (e.g., ischemic

heart disease) when compared with the transthoracic method that averages the values calculated from the 4 and 2 chambers views.

2.5.2 *Fractional Shortening*

The fractional shortening (FS) is another well-used measure of global LV function and is calculated using the LVIDd and LVIDs as measured from the TG or ME 2 chambers views:

$$FS = (LVIDd - LVIDs)/LVIDd$$

This measures radial contractility and has many limitations, but is reproducible and well validated as a prognostic measurement when assessing the left ventricles pathophysiological response to such valve lesions as mitral regurgitation.

2.5.3 *dP/dt*

Measuring the change in left ventricular pressure with time (dP/dt) using Doppler echocardiography requires mitral regurgitation (MR) to be present. The continuous wave Doppler of the MR is then recorded at a sweep speed of at least 100 mm/s and on a scale of up to 4 m/s (Fig. 2.8). The time taken for the velocity of the MR jet to increase from 1 to 3 m/s is then measured; this is equivalent to the time taken for the left ventricular pressure to increase by 32 mm Hg (using the simplified Bernoulli equation pressure = $4v^2$; 1 m/s = 4 mm Hg and 3 m/s = 36 mm Hg therefore the difference is 32 mm Hg). Thirty two is then divided by the time (in milliseconds) and multiplied by 1,000 (to convert milliseconds to seconds) and the resultant value expressed in mm Hg/s. The dP/dt can either be measured using online software (Fig. 2.8; measurement 1 [708 mm Hg/s]), or when this is not available, manually. To calculate dP/dt manually, a caliper marker is placed on the MR tracing at 1 m/s (Fig. 2.8; measurement 2) and 3 m/s (Fig. 2.8; measurement 3) and the time between the caliper measured (Fig. 2.8; measurement 4). In this example, the time taken (when measured manually) for the velocity of the MR jet to increase from 1 to 3 m/s is 40 ms; the dP/dt

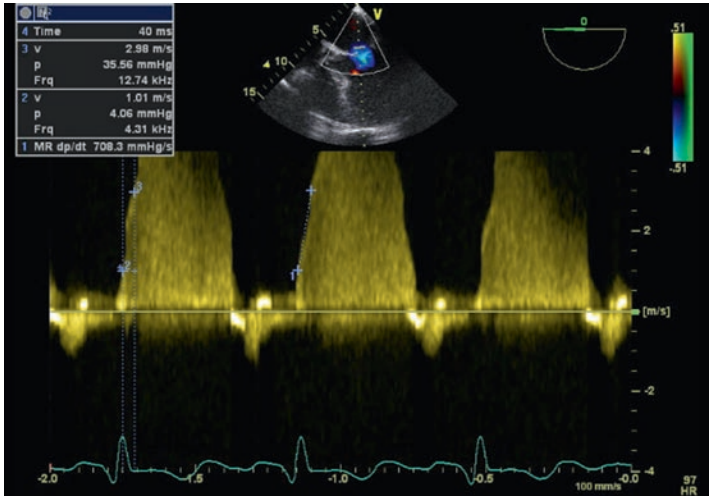

FIGURE 2.8. Continuous wave Doppler recording of a mitral regurgitant jet with the d*P*/d*t* measured using online software (measurement 1) and manually (measurements 2, 3, and 4).

is therefore calculated as (32/40) × 1,000 = 800 mm Hg/s. The normal d*P*/d*t* is greater than 1,200 mm Hg/s (equivalent to a measured time less than 27 ms) and values less than 1,000 mm Hg/s would be considered as definitively abnormal (equivalent to a measured time more than 32 ms). As a measure of global LV systolic function, I find the d*P*/d*t* is helpful especially in the ischemic population with regional wall motion variation, but the caveat to this is that small differences in time measurement cause large changes in the d*P*/d*t* (as demonstrated in Fig. 2.8 where the automated d*P*/d*t*, based on time of approximately 46 ms, was almost 100 mm Hg/s less than the manually derived value based on a time of 40 ms).

2.5.4 Stroke Distance

The left ventricular stroke distance (SD) is equivalent to the left ventricular outflow tract (LVOT) velocity time integral obtained by tracing around the pulse wave Doppler profile from the LVOT. The pulse wave Doppler profile is recorded from the transgastric LAX

(Fig. 2.9) and can be challenging to get good quality traces. This parameter has been shown in the postinfarct population to correlate with mortality; values less than 50% of age predicted lower limit of normal identifying a group with an especially poor outcome (where normal lower limit of stroke distance = 30.5 – [0.244 × age])[2]. From my point of view the applicability of the LV stroke distance as a measure of systolic function in other clinical scenarios is uncertain and coupled with the technical difficulties of obtaining good traces means that I rarely use it as a measure of LV systolic function in my TEE studies. Despite my reservations, I believe operators should be aware of it as there are times when it may be useful.

2.5.5 *Regional Segmental Assessment*

Assessment of regional systolic function should be based on the ASE and EAE recommended qualitative grading scale for wall motion.[3] Wall motion analysis should be undertaken in each of the left ventricular views according to the standard 16 segment model

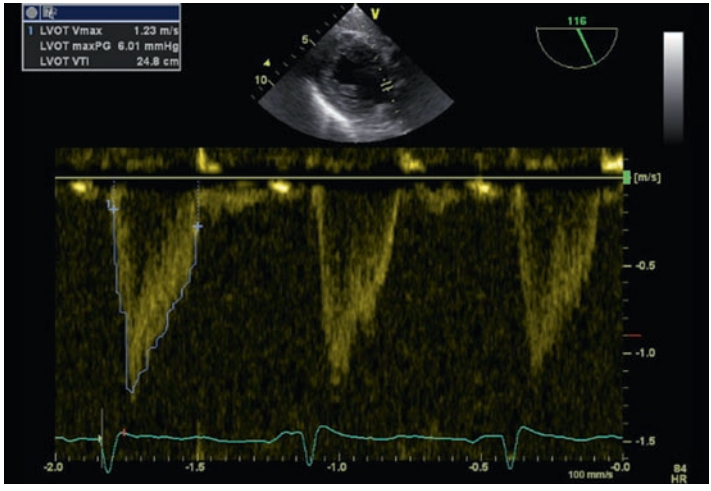

FIGURE 2.9. Left ventricular outflow tract (LVOT) pulse wave Doppler recording from the transgastric long axis view. LVOT velocity time integral obtained by tracing around the pulse wave Doppler profile (24.8 cm).

(i.e., 6 basal segments, 6 mid segments, and 4 apical segments). In the four chambers view, the anterolateral wall (to the right of the screen) and inferior septum (in the middle of the screen) are visualized; the basal, mid, and apical segment of each wall should be scored. The anterior wall (to the right of the screen) and the inferior wall (to the left of the screen) are seen in the ME 2 chamber view and the basal, mid, and apical segment of each wall should be scored. Finally, in the mid esophageal long axis view, the anterior septum (to the right of the screen) and the inferolateral wall (to the left of the screen) are evaluated. According to the convention of the 16 segment model, only the basal and mid segments of the walls in the LAX view are scored as the apical segments have already been represented in the 4 chambers view. The caveat to this is that the imaging of the septal and lateral apical segments can be better in the LAX view as opposed to the 4 chambers view and in this case the LAX view should be used to score. All the basal and mid (and occasionally the apical) segments can also be imaged in the transgastric views where radial contractility is seen. Although not essential, if the mid esophageal images are good, it is still worth scoring the segments in these views as a cross reference.

ASE Wall Motion Scoring

1 = Normal/hyperkinetic
2 = Hypokinetic
3 = Akinetic
4 = Dyskinetic
5 = Aneurysmal

2.5.6 Wall Motion Score Index

Having scored all the segments that it has been possible to adequately visualize, the wall motion score index (WMSI) can be calculated by dividing the total wall motion score by the number of segments scored. The WMSI is a guide to global left ventricular systolic function and has prognostic implications; the higher the WMSI the greater the left ventricular systolic impairment and the

worse the prognosis (although there is not a single figure that differentiates bad from good a value of greater than 1.2 is not good).

2.5.7 *Coronary Artery Distribution*

When wall motion abnormalities are present, it is important to try to correlate the myocardial segments with likely coronary artery supply as outlined in Fig. 2.10. In nonsurgical scenarios, this can be used to differentiate single from multivessel coronary artery disease. Specifically in perioperative cardiac cases, it can identify which arterial territory is hypoperfused; invaluable information especially if there is any difficulty coming off bypass. As can be seen, the transgastric mid short axis view has all coronary artery territories represented simultaneously and is, therefore, a good view for monitoring for ischemia.

2.6 Diastolic Function

No study of left ventricular function is complete until the left ventricular diastolic function has been properly evaluated. The caveats

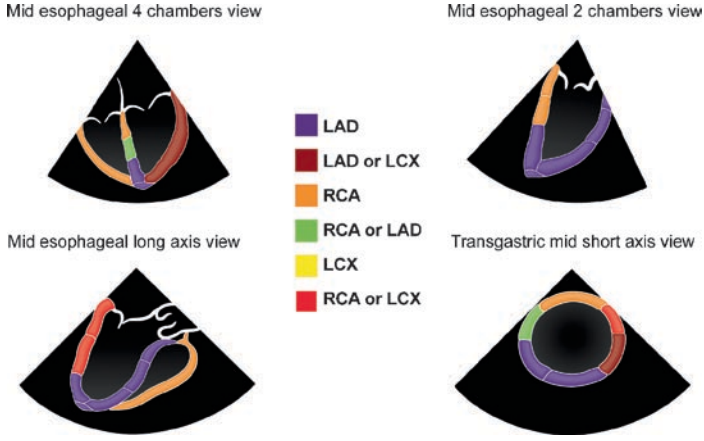

FIGURE 2.10. Correlation of the myocardial segments with likely coronary artery supply.

to this are the presence of significant mitral valve disease (stenosis or regurgitation), atrioventricular dissociation (e.g., complete heart block, VVI pacing, or ventricular tachycardia), and/or atrial flutter/fibrillation. When evaluating diastolic function, there are many parameters that can be used; no one is sufficiently robust to be used in isolation and so algorithms of combinations of parameters have been developed. There is no absolute right or wrong method of assessment and each operator needs to consider for themselves how they wish to tackle the question of diastolic function remembering that most studies on the subject have utilized transthoracic echocardiography. The following stepwise method of assessment is based on personal experience and the available literature, including European Society of Cardiology guidelines published in 2007[4] and joint European Association of Echocardiography/American Society of Echocardiography recommendations.[5] All readers are encouraged to read both of the ESC and EAE/ASE papers to aid understanding and develop their own thoughts on the subject.

When assessing diastolic function, the combination of specific measurements used are the transmitral *E*/*A* ratio, the transmitral *E* wave deceleration time, the annular *e′* and the duration of *A* wave reversed flow; the measurement of these parameters will be discussed here. Also included in the algorithm are the left ventricular mass, left atrial size, and tricuspid regurgitant jet velocity (and derived pulmonary arterial systolic pressure [PASP]); the measurement of these parameters is discussed in their relevant sections. Other indices such as the ratio of the isovolumetric relaxation time (IVRT) to the time difference between the onset of the transmitral E wave and the onset of the annular e′ ($T_{E\text{-}e'}$) and changes in *E*/*A* ratio with valsalva are not included in the algorithm but warrant consideration.

The transmitral flow is first recorded using continuous wave Doppler to ensure the maximal velocities are obtained. The actual measuring of the *E*/*A* ratio and *E* wave deceleration time (Edt) are made, by convention, from recordings using pulse wave Doppler in the ME 4 chambers or long axis view (Fig. 2.11). The color Doppler is applied to align the Doppler cursor with blood flow and then the image of the valve is zoomed (thus increasing resolution prior to sample volume positioning). A 1–3-mm sample volume is then positioned at the tips of the leaflets in their fully

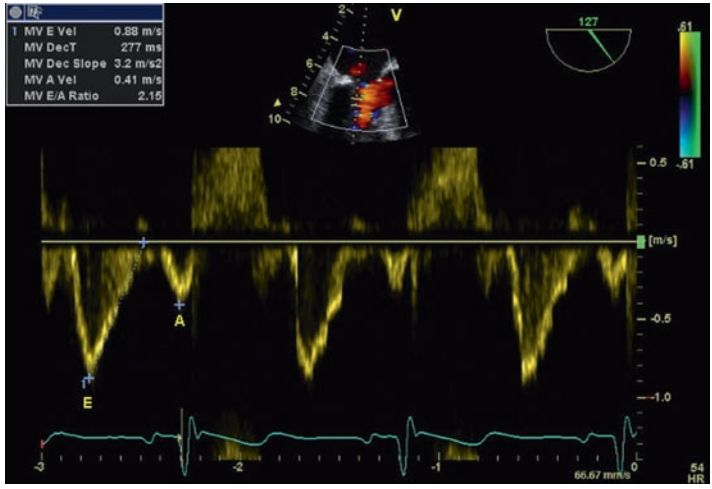

FIGURE 2.11. Pulse wave Doppler recording of the mitral inflow taken from the mid esophageal long axis view demonstrating the measurement of the peak E wave velocity, peak A wave velocity and the E wave deceleration time.

open diastolic position in order to acquire the pulse wave Doppler recording.

The velocity of the mitral annulus in early diastole (e') is measured from recordings made using the Doppler tissue imaging (Dti) preset with a pulsed wave sample volume placed at or within 10 mm of the annular insertion point of the mitral valve (Fig. 2.12). Image quality can be enhanced by zooming on the annulus before applying the PW Doppler, and by adjusting the sample volume size to encompass the entire annular diastolic excursion (usually 5–10 mm). Measurements of annular e' should not be taken if the angle of incidence of the sample volume and the plane of annular relaxation is greater than 20°, if there is significant annular calcification, or if there are significant regional wall motion abnormalities (if wall affected this will reduce e' and if wall not affected may cause compensatory increase in e'). Ideally, to calculate the E:e' ratio, the lateral and septal annular velocities should be measured; practically, however, the angle of incidence will often be too great to allow accurate measurement of the septal annular velocity.

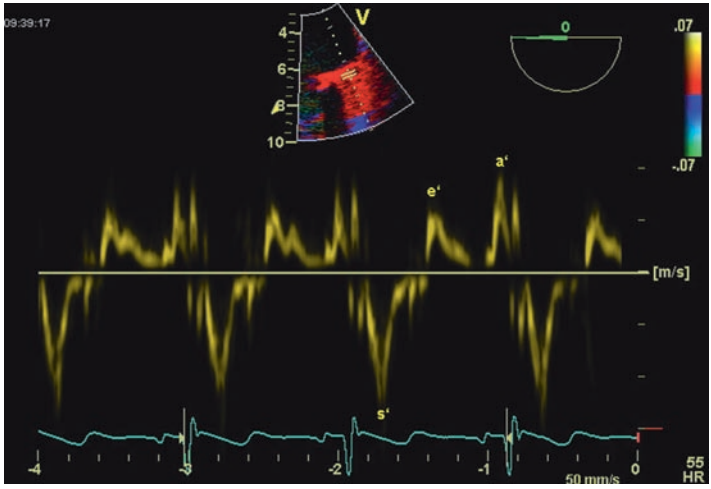

FIGURE 2.12. Pulse wave Doppler tissue imaging (Dti) recording from the lateral mitral annulus recorded from the mid esophageal 4 chambers view demonstrating early diastolic (*e´*), late diastolic (*a'*) and systolic (*s'*) velocities.

The duration of atrial systolic reversed flow into the pulmonary veins (Ar) is measured from the pulse wave Doppler recording obtained by placing the sample volume (2–3 mm) greater than 0.5 cm into either the right of left upper pulmonary veins (Fig. 2.13). The duration of transmitral atrial systolic forward flow (*A*) used in the calculation of Ar – *A* is measured from the pulse wave Doppler recording obtained by placing the sample volume at the level of the mitral valve annulus (as opposed to the leaflet tips).

All Doppler measurements should be taken from images with the gain reduced to a minimum and recorded at a sweep speed of 50–100 mm/s. All measurements should be averaged over a minimum of three beats. When comparing measurements taken from different sites (e.g., Ar – *A*) the R-R interval of each recording should be similar.

Step one in the assessment of diastolic function is the assessment of systolic function. In the presence of left ventricular systolic dysfunction (LVSD: EF <50%) there will be left ventricular diastolic dysfunction (LVDD); the question then is how severe is the

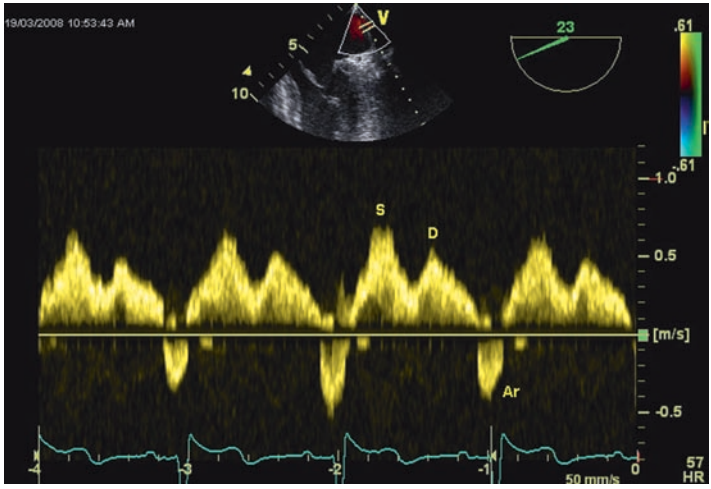

FIGURE 2.13. Pulsed wave Doppler of pulmonary vein flow demonstrating systolic (S) and early diastolic (D) forward flow followed by reversed flow during atrial systole (Ar).

dysfunction. The severity of diastolic dysfunction is correlated with the left ventricular end diastolic pressure (EDP) that, in turn, reflects the mean left atrial pressure (LAP). In the presence of systolic impairment LV EDP can be estimated by measuring the transmitral Edt. The normal LV EDP is less than or equal to 16 mm Hg and an Edt > 250 ms has been shown to correlate well with pressures below this level. An Edt <250 ms indicates elevation of the LV EDP with values less than 150 ms identifying patients with markedly elevated pressures and an overall poor prognosis. If the left ventricular systolic function is normal (LV EF >55%) or near normal (LV EF 50–55%) then proceed to step two.

EDP Estimation in LVSD

Edt <150 ms = EDP >25 mm Hg
Edt <250 ms = EDP >15 mm Hg

Step two is the measurement of the *E*/*A* ratio. An *E*/*A* ratio less than 1.0 indicates impaired relaxation and grade I diastolic dysfunction. This can then be refined into grade I (normal left atrial pressure; mild diastolic dysfunction) and grade IA (elevated left atrial pressure; mild-moderate diastolic dysfunction) based on an estimation of the LAP as outlined below. If the *E*/*A* ratio is greater than or equal to 1.0 then diastolic function may be normal or the *E*/*A* ratio may have pseudonormalized, and the diastolic function be moderately or even severely impaired; to try and differentiate between the two possibilities move onto step three.

Step three is the measuring of the annular *e′* and the calculation of the transmitral *E*: annular *e′* ratio. For the calculation of the *E*:*e′* ratio the EAE/ASE recommend using the average of the septal *e′* and lateral *e′*; if it is not technically feasible to measure both the use of either single site measurement is a valid alternative, but the cut-off values differ as described below.

- An *E*:*e′* (septal, lateral, or average *e′*) ratio ≤8 indicates normal left ventricular filling pressures and diastolic function.
- An *E*:*e′* (septal) ratio ≥15 *or* an *E*:*e′* (lateral) ratio ≥12 *or* an *E*:*e′* (average) ≥13 indicates elevation of LV filling pressures (i.e., LVEDP >16 mm Hg or mean LAP >12 mm Hg) and moderate-severe (grade II-III) diastolic dysfunction. In moderate (grade II) diastolic dysfunction the *E*/*A* ratio is 1.0–2.0 and in severe (grade III) diastolic dysfunction the *E*/*A* ratio is greater than 2. Severe diastolic dysfunction can be subdivided into reversible (IIIa) and irreversible (IIIb) with consequent implications on prognosis. True differentiation between grades IIIa and IIIb requires repeat evaluation of Doppler parameters after a period of appropriate treatment (e.g., diuretics and vasodilators) although acute alteration of the preload can imply the grade of diastolic dysfunction.
- An *E*:*e′* (septal) ratio >8 and <15 *or* an *E*:*e′* (lateral) ratio >8 and <12 *or* an *E*:*e′* (average) >8 and <13 then the interpretation is indeterminate and it is necessary to progress to step four.

Step four is the measuring of the Ar − *A* duration. In general, increases in the Ar − *A* duration reflect progressive increases in resistance to left atrial emptying (i.e., higher LVEDP), but this

assumption is not valid in the presence of sinus tachycardia or first degree AV block; in such instances atrial contraction often occurs before early diastolic mitral and pulmonary venous flow velocities have declined to zero thus increasing the width of the mitral A wave and decreasing the apparent duration of atrial systolic flow reversal in the pulmonary veins. Bearing in mind these caveats an Ar – *A* < 0 ms is normal, and such values in the presence of an *E*/*A* ratio ≥1 and an indeterminate E:e′ suggests normal diastolic function. An Ar – *A* ≥30 ms is prolonged, and predicts an elevated LVEDP. Patients with an *E*/*A* ≥ 1, an indeterminate E:e′ and an Ar – *A* ≥ 30 ms should be classified as having moderate (grade II) diastolic function. Patients with an *E*/*A* ≥ 1, an indeterminate *E*:*e′* and an Ar – *A* ≥ 0 and <30 ms remain undefined, and it is then necessary to progress to the final step.

Step five involves the measuring of left ventricular mass, left atrial size and the tricuspid regurgitant jet velocity. The tricuspid regurgitant (TR) jet velocity (and/or PASP) is only included in the absence of known pulmonary disease as it is then considered, if elevated, to reflect increased pulmonary venous pressure. Each parameter is given a point score (Table 2.3) depending on whether it is normal (0 points), mildly abnormal (1 point) or moderate-severely abnormal (2 points). In the case of the TR velocity there is a single cut off value to reflect current guidelines. A total score of 2 or more points suggests diastolic dysfunction (grade II; moderate); a score of 0 or 1 point suggests normal diastolic function.

Table 2.1. Reference limits (normal values) for left ventricular dimensions, volumes, mass, and systolic function.

	Male	Female
LVIDd (cm)	4.2–5.9	3.9–5.3
LVIDd/BSA (cm/m^2)	2.2–3.1	2.4–3.2
EDV (mL)	67–155	56–104
EDV/BSA (mL/m^2)	35–75	35–75
Mass (g)	88–224	67–162
Mass/BSA (g/m^2)	49–115	43–95
Fractional shortening (%)	25–43	27–45
Ejection fraction (%)	55–80	55–80

LVIDd left ventricular internal dimension at end diastole; *BSA* body surface area; *EDV* end diastolic volume

Table 2.2. Categorization of an increased left ventricular mass and identification of concentric remodeling based on the relative wall thickness and mass of the left ventricle.

	Increased mass	Normal mass
RWT	Concentric	Concentric
>0.42	Hypertrophy	Remodeling
RWT	Eccentric	
<0.42	Hypertrophy	Normal

RWT relative wall thickness

Table 2.3. Indices used in the assessment of diastolic function with associated scores dependant on normality or degree of abnormality.

	0	1	2
LV mass (g) ♀	<163	163–186	>186
LV mass (g) ♂	<225	225–258	>258
LV mass (g/m^2) ♀	<96	96–108	>108
LV mass (g/m^2) ♂	<116	116–131	>131
LA diameter (cm)	<4.6	4.6–4.9	>4.9
TR velocity (m/s)			>3.0
PASP (mm Hg)			>35

LV left ventricle; *LA* left atrium; *TR* tricuspid regurgitation; *PASP* pulmonary artery systolic pressure

References

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2. Metcalf MJ et al. *Lancet* 1989; i: 1371–3.
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4. Paulus WJ et al. *Eur Heart J*. 2007; 28:2539–2550.
5. Nagueh SF et al. *JASE*. 2009; 22(2):107–133.

A systematic approach to left ventricular assessment.

View	Level	Angle	Data acquired
4Ch	ME	0–40	Qualitative estimation of systolic function Regional wall motion assessment • Anterolateral wall • Inferior septum Mitral Doppler (CW and PW) Annular Doppler tissue imaging (septal and lateral) Pulmonary vein Doppler (PW in LUPV)
2Ch	ME	80–120	Volume measurements (EDV and ESV) Ejection fraction calculation Regional wall motion assessment • Anterior wall • Inferior wall
LAX	ME	120–160	Regional wall motion assessment • Inferolateral wall • Anterior septum Mitral Doppler (CW and PW)
SAX	TG	0–40	Wall thickness measurements (posterior and septal) Regional wall motion assessment • All walls
2Ch	TG	80–120	Internal dimension measurements (LVIDd and LVIDs) Fractional shortening calculation Regional wall motion assessment • Anterior wall • Inferior wall
LAX	TG	80–120	Regional wall motion assessment • Inferolateral wall • Anterior septum Aortic Doppler (CW and PW)

Chapter 3
The Left Atrium

The fully developed human left atrium (LA) consists of the true atrial septum, a superior smooth walled portion, and an inferior trabeculated portion. The smooth walled portion is larger and originates embryologically from the pulmonary veins that combine to form a common pulmonary vein before becoming integrated with the inferior portion of the left atrium. The trabeculated portion of the adult LA is confined to the appendage (LAA) and is all that remains is of the primitive left atrium.

3.1 Standard Image Planes

The postero-superior wall of the LA is adjacent to the mid esophagus, and all mid esophageal views image the left atrial cavity by default. There are therefore no specific left atrial views.

3.2 Left Atrial Size

Pathological increases in left atrial size have been shown to be associated with a poorer prognosis in various conditions with left atrial volume (indexed for body surface area) demonstrating the best correlation. Ideally, therefore, any echocardiographic assessment should include LA volume as part of the parameters measured. The two recommended methods of measuring volume are the ellipsoid and the

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modified Simpson's, but neither is possible via the transesophageal approach. The reasons for this are firstly that due to near field drop out, the posterior wall of the LA is not directly visualized, so it is not possible to accurately measure the long axis; an integral measurement in the ellipsoid model. Secondly, due to near field drop out and the narrow proximal beam width, it is not possible to encompass the whole LA; accurate planimetry of the LA is not possible, and therefore, volume can not be calculated using Simpson's rule. For the same reasons it is not possible to accurately measure the left atrial area, and therefore, the only objective measure of left atrial size that is feasible during TOE examinations is the transverse diameter.

Comparing linear dimensions measured by transthoracic and transesophageal echocardiography the best correlation has been found with the transverse diameter measured in the 4 chambers view[1] ($R = 0.91$).

The operator should therefore, try to acquire a good ME 4 chambers view with clear visualization of the left atrial septal and lateral walls, and measure the maximal systolic dimension at the mid atrial level (Fig. 3.1).

In a population study of normal subjects the mid LA dimension was 3.7 ± 0.4 cm. Values greater than 4.5 cm (mean + 2 SD) should

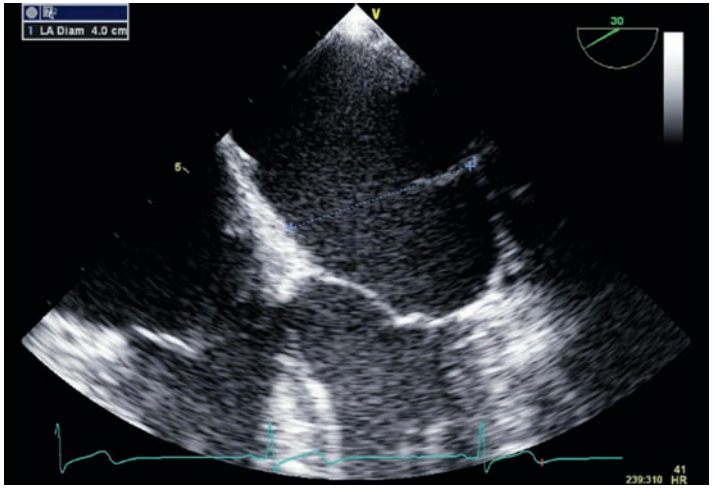

FIGURE 3.1. Measuring of the maximal systolic dimension of the left atrium from the mid esophageal 4 chambers view.

be considered abnormal and values greater than 5.3 cm (i.e., greater than the mean + 4 SD) should be considered severely abnormal.

3.3 Left Atrial Appendage

The purpose of the left atrial appendage (LAA) is not fully understood. One hypothesis is that the LAA acts as a capacitance chamber allowing sudden changes in LA volume to be accommodated without marked increases in left atrial pressure (LAP). From a practical perspective, however, the LAA acts as a cul-de-sac with a high incidence of thrombus especially in the presence of atrial fibrillation (AF). It is shaped like an old fashioned money purse with a thin neck and somewhat bulbous body. The orifice of the neck of the appendage curves around the lateral aspect of the LA between the left upper pulmonary vein (LUPV) (posteriorly) and the junction of the LA and pulmonary trunk (anteriorly). Both its shape and position relative to the esophagus demonstrate marked inter-individual variability, and so a complete assessment of the LAA is one of the more challenging tasks in a TEE study. For LAA imaging, I usually start at the mid esophageal 4 chambers view and then withdraw the probe slightly (not quite as far as the upper esophageal window). The probe is then maximally ante-flexed and the image plane angle rotated until the appendage is seen. The LAA should be interrogated in at least 3 planes with the first 2D image usually acquired at somewhere between 0° and 60° (Fig. 3.2), the second between 60° and 120°, and the final image acquired between 120° and 180° (Fig. 3.3). In order to obtain the clearest image (and properly assess one of the most topographically complex cardiac structures) in each plane it is often necessary to adjust the probe depth and manually rotate the probe (clockwise or anti-clockwise). Further 2D image optimization is achieved by reducing the image sector depth and width (or zoom function used) to improve spatial and temporal resolution. Assessment of the LAA in each view should first be done without lateral flexion then repeated with the use of right (±left) lateral flexion. After 2D evaluation blood flow within the LAA should be assessed (especially when there are multiple trabeculations or if diverticulae/out pouching are present) using color Doppler with a low aliasing velocity (20–25 cm/s) to ensure that there is

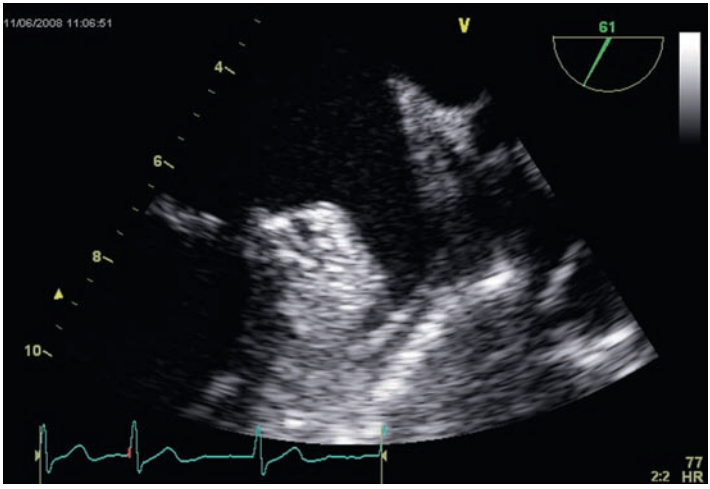

FIGURE 3.2. Left atrial appendage imaged in 2D at 61°.

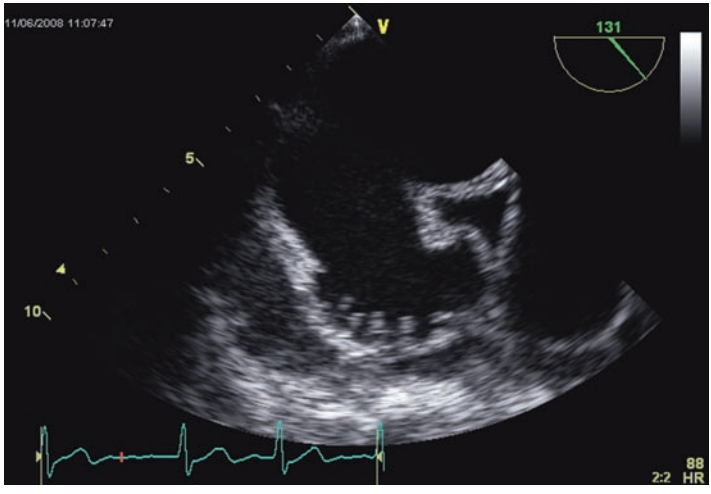

FIGURE 3.3. Left atrial appendage imaged in 2D at 131°.

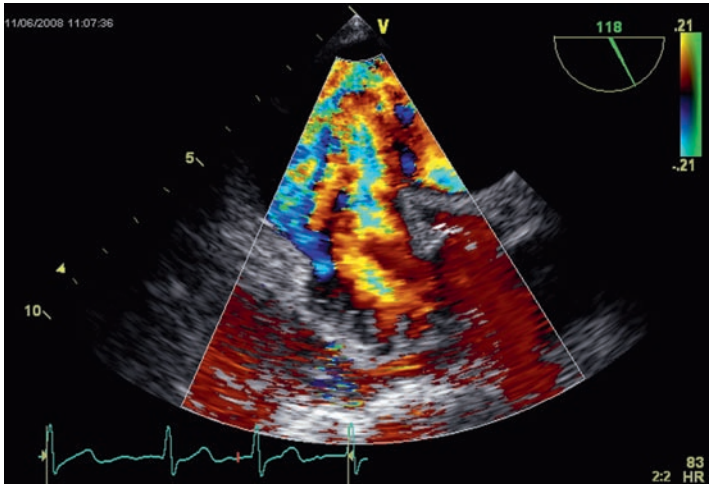

FIGURE 3.4. Left atrial appendage imaged in 2D with additional color Doppler at a low aliasing velocity (21 cm/s) demonstrating good flow in all areas.

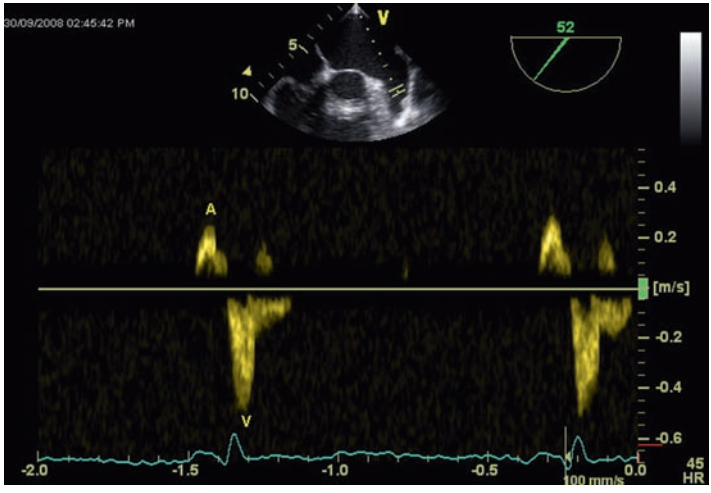

FIGURE 3.5. Pulse wave Doppler of left atrial appendage blood flow demonstrating emptying (A) and filling (V) velocities.

reasonable flow in all areas (Fig. 3.4). Finally the global contractile function of the LAA is evaluated using pulse wave Doppler, and by measuring the peak emptying velocity (Fig. 3.5).

Normal peak LAA emptying velocity is >25 cm/s

Because of the challenges of good appendage interrogation, I believe it is important that the operators take some time to visualize normal appendages so that they understand the variations of normality that exist, and are thus able to accurately risk stratify in pre-cardioversion and stroke cases.

3.4 Pulmonary Veins

Normally there are four pulmonary veins (PV) that drain into the left atrium; right upper (RU), right lower (RL), left upper (LU) and left lower (LL).

3.4.1 Right

Evaluation of the right sided veins is usually straight forward. From the mid esophageal 4 chambers view the probe is rotated to the right (with the image sector angle at 0–30° and depth at about 10 cm) such that the inter-atrial septum is horizontal and in the centre of the screen (Fig. 3.6). Color Doppler is added to the left side of the screen and the probe is advanced slowly until 2 distinct pulmonary inflows are seen (Fig. 3.7); the more horizontal flow is from the RLPV and the more vertical flow is from the RUPV. The RUPV can also be seen by maintaining the probe depth, rotating the image sector plane to the bicaval view at 80–120° (Fig. 3.8), and then manually rotating the probe clockwise/to the right (Fig. 3.9). This latter view of the RUPV is especially useful in patients' with atrial septal defects (ASD) when excluding anomalous pulmonary venous drainage (most commonly the RUPV) and when assessing the distance between

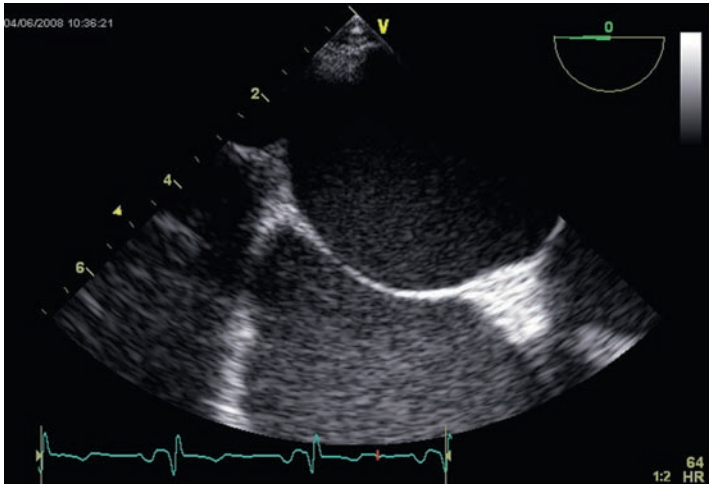

FIGURE 3.6. Mid esophageal 4 chambers view with the probe rotated so that the inter-atrial septum is horizontal and in the centre of the screen.

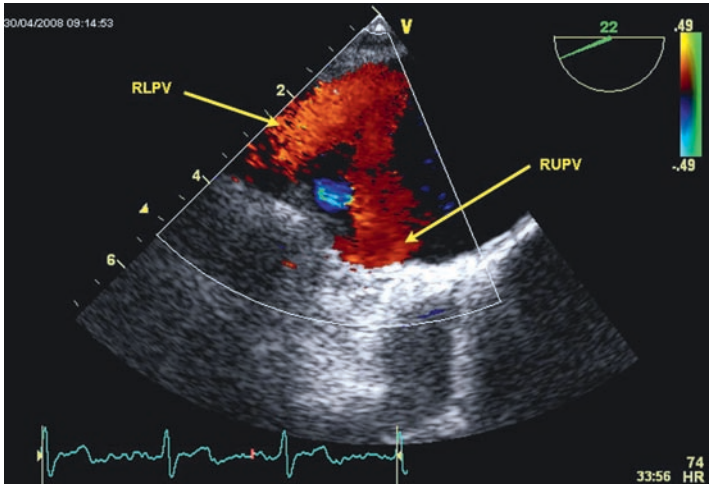

FIGURE 3.7. Color Doppler demonstrating two distinct right pulmonary vein inflows (red). The more horizontal flow is from the lower (RLPV) and the more vertical flow is from the upper (RUPV) pulmonary vein.

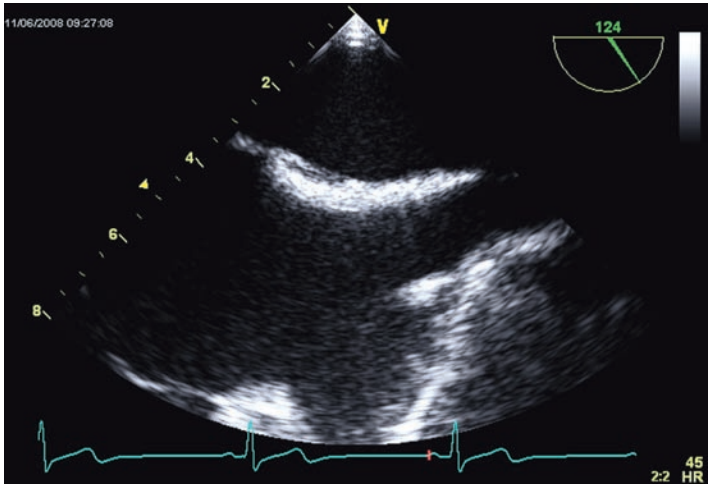

FIGURE 3.8. The bicaval view at 124°.

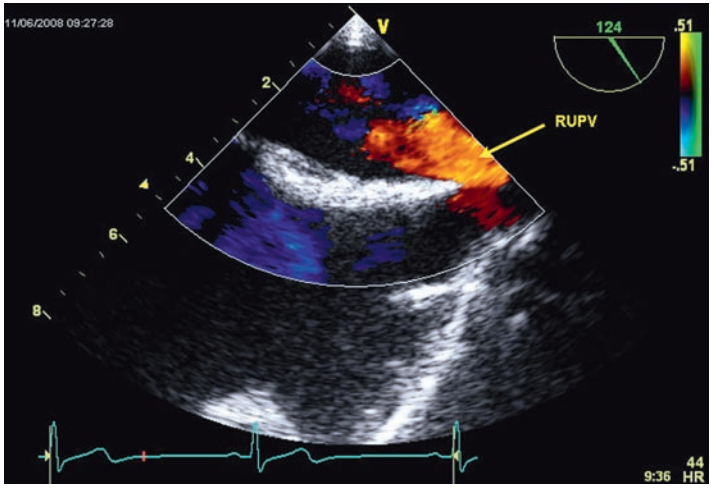

FIGURE 3.9. The bicaval view with superadded manual rotation of the probe clockwise/to the right. Color Doppler demonstrating right upper pulmonary vein (RUPV) inflow (red).

the rim of the ASD and the RUPV prior to considering percutaneous closure.

3.4.2 Left

The left upper pulmonary vein drains into the atrium close to the appendage. Starting from the ME 4 chambers view the probe is withdrawn slightly, and the color Doppler is added on the right side of the screen. The image plane angle is then rotated until the LAA is seen (between 0° and 60°). The LUPV will come into view to the right of the LAA and is identified by its red coded blood flow (Fig. 3.10). It is sometimes possible to visualize the left lower pulmonary vein (LLPV) by merely advancing the probe at 0–60° (Fig. 3.11), and in this view the more vertical flow comes from the upper pulmonary vein. It is, however, more consistently feasible to image the LLPV by maintaining the 2D sector settings and color Doppler as for the LUPV then rotating the image sector plan to 80–120° (with or without additionally rotating the probe

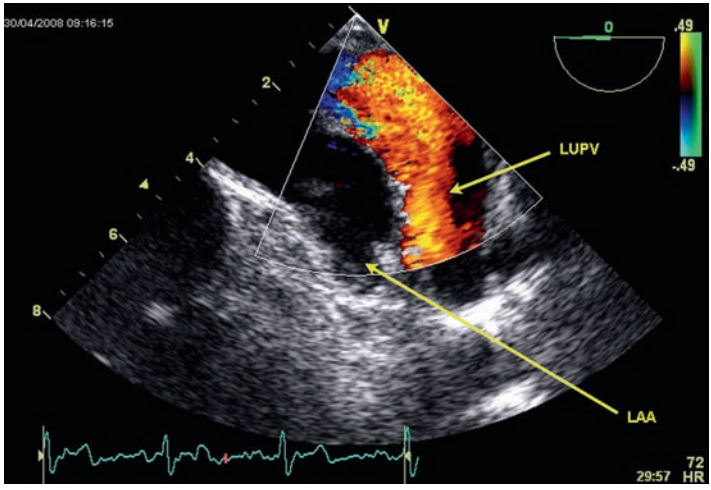

FIGURE 3.10. Left upper pulmonary vein inflow (LUPV) seen in this view to the right of/lateral to the left atrial appendage (LAA).

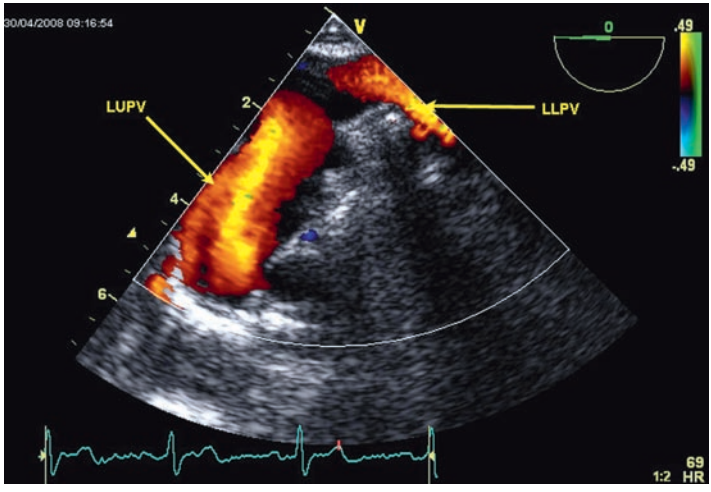

FIGURE 3.11. Left upper and lower pulmonary vein inflow (red coded blood flow). The more vertical flow comes from the upper (LUPV) and the more horizontal flow is from the lower (LLPV) pulmonary vein.

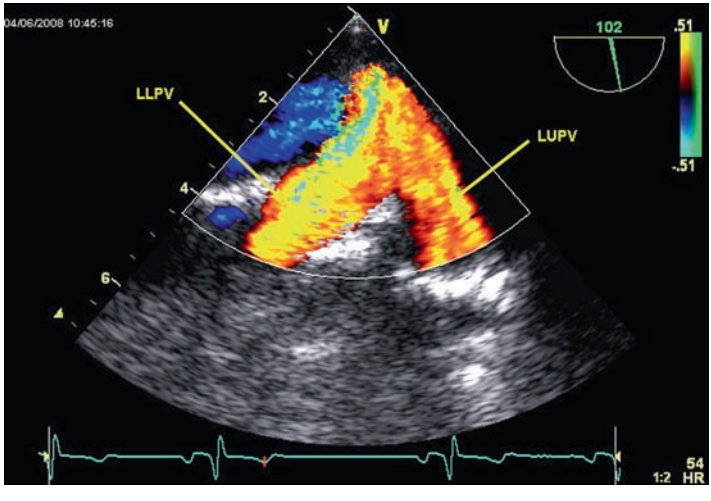

FIGURE 3.12. Left upper (LUPV) and lower (LLPV) pulmonary vein inflow (red coded blood flow). In this view the flow to the right of the screen is from the upper and the flow to the left of the screen is from the lower pulmonary vein.

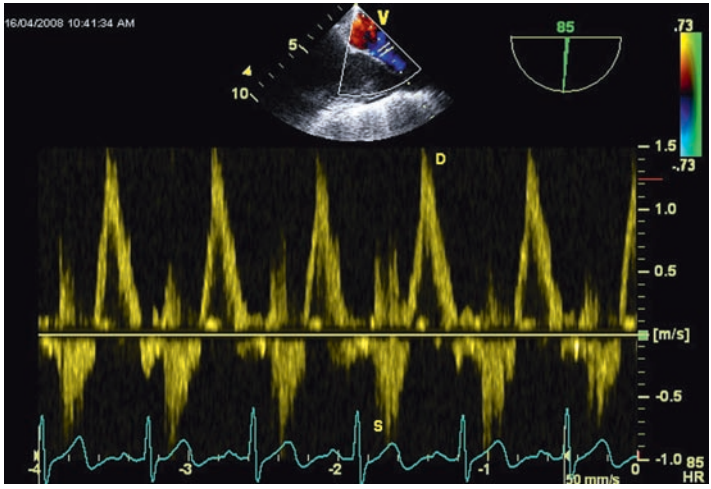

FIGURE 3.13. Pulsed wave Doppler of pulmonary vein flow demonstrating systolic flow reversal (S) followed by very dominant early diastolic forward flow (D). This suggests severe mitral regurgitation.

anti-clockwise) until 2 separate inflows are seen converging vertically (Fig. 3.12); in this view the flow to the right of the screen is the LUPV, and the flow to the left of the screen is the LLPV.

Having undertaken 2D/color Doppler assessment of the pulmonary veins it is standard practice to interrogate flow with pulsed wave Doppler (Fig. 2.13). Normal flow consists of forward systolic (S) and early diastolic (D) flow followed by reversed flow during atrial systole (Ar). When describing pulmonary vein flow patterns it should be documented whether systolic forward flow is dominant or recessive when compared to diastolic forward flow or if it is reversed (Fig. 3.13: suggesting severe mitral regurgitation). The duration of A wave reversal can also be measured as part of a diastolic function assessment as detailed in Chap. 2.

References

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Chapter 4
The Mitral Valve

The mitral valve is so named due to its appearance that resembles a bishops' miter. Transesophageal echocardiography and the mitral valve (that sits only 5–10 cm from the transducer with nothing but blood between them) were made for each other with the spatial and temporal resolution of the technique allowing the valve with its complex structure and motion to be perfectly described. Assessment of the mitral valve (MV) is, therefore, one of the commonest indications for TEE and should be undertaken in all patients being evaluated for (preoperatively) or undergoing (perioperatively) MV surgery.

4.1 Valve Structure

The MV is one of the atrio-ventricular valves (the tricuspid valve being the other one) and has an anterior and a posterior leaflet. The posterior leaflet has clefts that divide it into 3 scallops (P1, P2, and P3); the anterior leaflet has no such scallops, but is described as having three regions that reflect those of the posterior leaflet (A1, A2, and A3 respectively). In addition to the points of apposition along the leaflets, there are anterior (adjacent to A1/P1) and posterior (adjacent to A3/P3) commissures. The nonleaflet apparatus consists of the saddle-shaped mitral annulus, the chordae tendinae (primary chordae attached to the free edges of the leaflets, secondary and tertiary chordae attached to body of leaflets), and papillary

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muscles (anterior: chordae attached to lateral aspects of leaflets; posterior: chordae attached to medial aspects of leaflets).

The function of the valve is complex and is dependent on each component as well as the left ventricle (especially the basal segments) and left atrium. A complete assessment of the valve should, therefore, include an interrogation of these chambers.

4.2 Standard Image Planes

There are seven standard views that operators are recommended to use when assessing the mitral valve. Evaluation usually starts with the mid esophageal views and concludes with the transgastric views. Start by obtaining the mid esophageal (ME) 4 chambers (4Ch) view with the image sector width and depth adjusted in order to include both ventricles (including the cardiac apex) and both AV valves; use 2D then add color Doppler to the valves. This allows a quick overview of atrial size, ventricular size and function as well as an initial impression of the valvular structure and function. The image sector depth is then decreased to a level that just allows inclusion of the mitral leaflets and the chordae, and further optimization of the image may be gained by using the zoom mode. The valve should be imaged at 0–20° then 20–40° as this will transect different scallops. Once interrogation of the valve in the 4CV is complete, the image sector depth is increased back to its previous level (to include the LV apex), and the imaging plane angle is rotated between 40° and 80° to the commissural (CM) view where upon the depth is again decreased (±zoom added). The same depth adjustments are made sequentially as the imaging plane angle is rotated to acquire the mid esophageal 2 chambers (2Ch; 80–120°) view and finally the ME long axis (LAX; 120–160°) view. With all imaging plane rotations described, it is necessary to simultaneously manually rotate the probe [gently] anticlockwise to maintain the appropriate cut through the left ventricle and mitral valve. The depth does not need to be adjusted as described, but I prefer to do this as orientation is easier and it allows concurrent assessment of left ventricular regional and global systolic function (avoiding repetition). In each view, the valve should be kept central while the probe depth is changed and flexion (anterior, posterior, and lateral) is applied in order to fully evaluate each leaflet and the commissures completely (2D alone then with

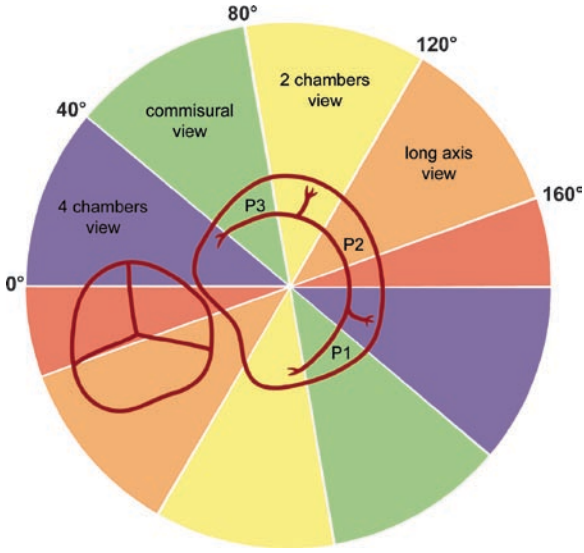

FIGURE 4.1. Diagrammatic representation of the relationship between each mid esophageal view and the parts of the mitral valve leaflets seen.

additional color Doppler). The relationship between each mid esophageal view and the parts of the leaflets seen is diagrammatically represented in Fig. 4.1, but it should be remembered that variations in the orientation of the leaflets between individuals means that nothing is absolute and the scallops seen in each image plane may vary in different patients. When describing which scallops are seen in each view, the list starts with scallop furthest to the right of the screen. To remember which leaflet is which an aide memoir is that the anterior leaflet is always next to the aortic valve.

MV Imaging Planes

ME 4Ch – 0–40°

ME CM – 40–80°

ME 2Ch – 80–120°

ME LAX–-120–160°

TG SAX – 0–40°
TG 2Ch – 80–120°
TG LAX – 80–120°

4.2.1 *Four Chambers View*

In the mid esophageal 4 chambers view at zero degrees, P2 and A2 (±A3) are seen (Fig. 4.2). By rotating between 20° and 40°, while maintaining a 4Ch view, P1 is then visualized (as opposed to P2) with A2 ± A3 (Fig. 4.3; considering the hinge points to demarcate one scallop from the next) as opposed to just (Fig. 4.3)). Having evaluated the leaflet motion, function, and chordal integrity with 2D echocardiography, color Doppler is added to identify any regurgitation; this is done in this view and in each subsequent view.

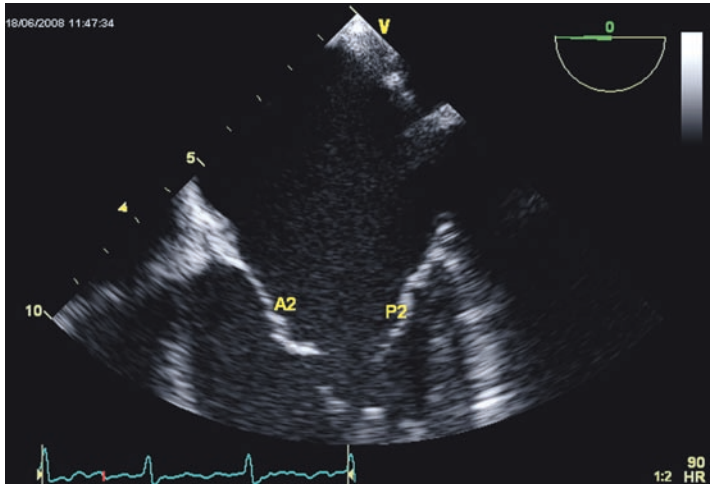

FIGURE 4.2. Mid esophageal 4 chambers view at zero degrees with P2 and A2 visualized.

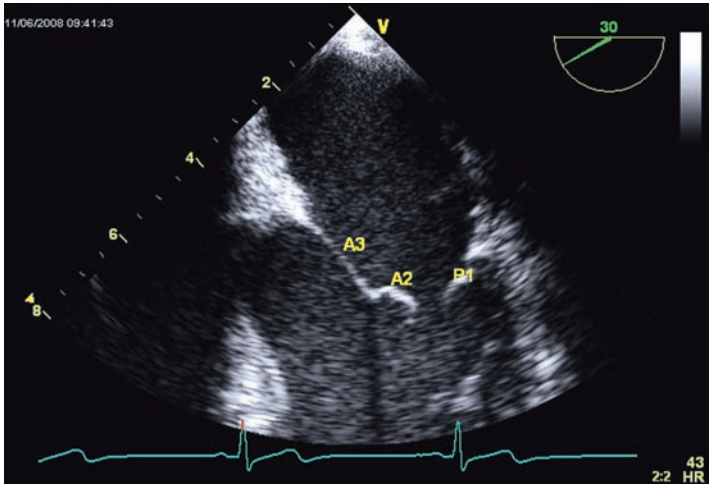

FIGURE 4.3. Mid esophageal 4 chambers view at 30° with P1, A2, and A3 visualized.

4.2.2 *Commissural View*

The CM view allows the operator to directly visualize P1, A2, P3, and both commissures (Fig. 4.4); behind each of these scallops lies its opposite (i.e., A1, P2, and A3), and the inability to visualize these scallops infers normal (mirrored) motion and function. This view usually allows excellent imaging of the chordae and the papillary muscles and helps in the understanding of what attaches to where.

4.2.3 *Two Chambers and the Long Axis Views*

The 2 chambers and the long axis views usually intersect A1, A2, and P3 (Fig. 4.5) and A2 and P2 (Fig. 4.6) respectively; as with the ME 4Ch view the points of intersect are not always the same in every patient and depending on cardiac orientation as well as probe manipulation P2 can be seen in the 2Ch view, and, less commonly, A1 and P3 can be visualized in the long axis view.

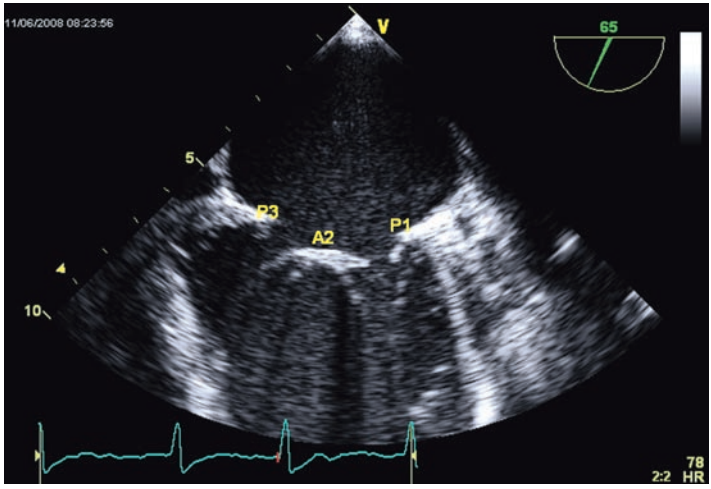

FIGURE 4.4. Mid esophageal commissural view with P1, A2, P3, and both commissures visualized.

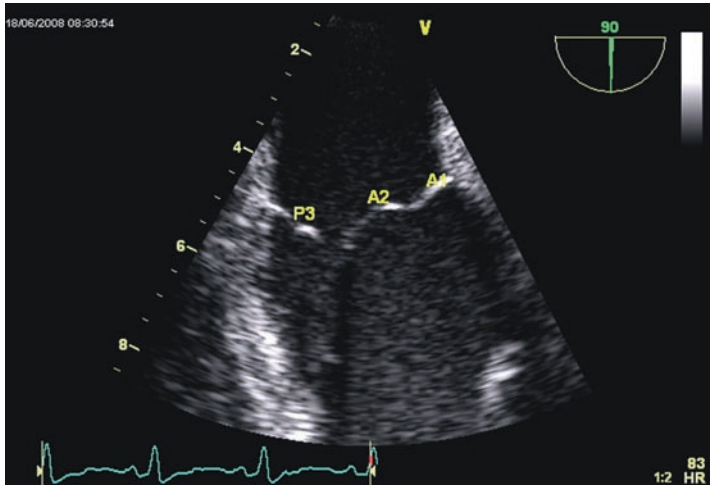

FIGURE 4.5. Mid esophageal 2 chambers view with A1, A2, and P3 visualized.

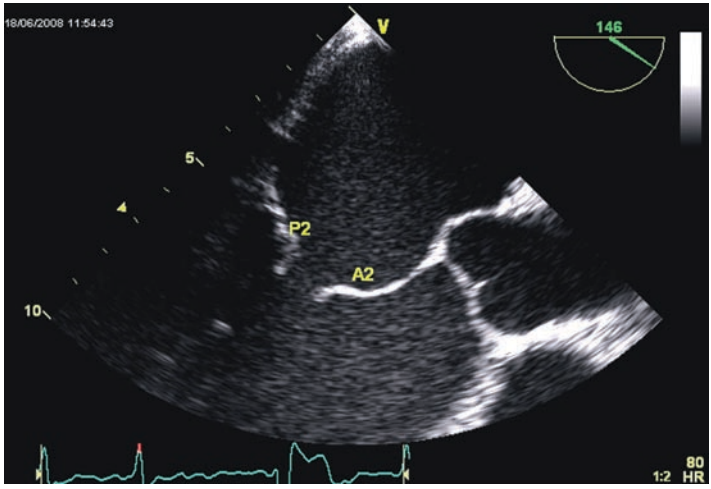

FIGURE 4.6. Mid esophageal long axis view with A2 and P2 visualized.

4.2.4 Mitral Annulus

Before concluding the evaluation of the MV at the mid esophageal level the mitral annulus should be assessed in the mid esophageal views to exclude dilatation. By convention it is measured at end systole (the beat just prior to MV opening) in the 4 and 2 chambers views (from the insertion point of the posterior leaflet to the insertion point of the anterior leaflet). The upper limit of normal for the annular diameter is 3.1 cm in the 4 chambers views and 2.8 cm in the 2 chambers views.

Having completed the mid esophageal views, the study of the MV is concluded with the transgastric views.

4.2.5 Transgastric Views

Once all the mid esophageal views are completed, proceed to the transgastric window first obtaining the basal short axis (SAX) view from where it is possible to see all 6 scallops and both commissures (Figs. 4.7 and 4.8). This view is useful because of the completeness of leaflet visualization it offers, but unfortunately, image

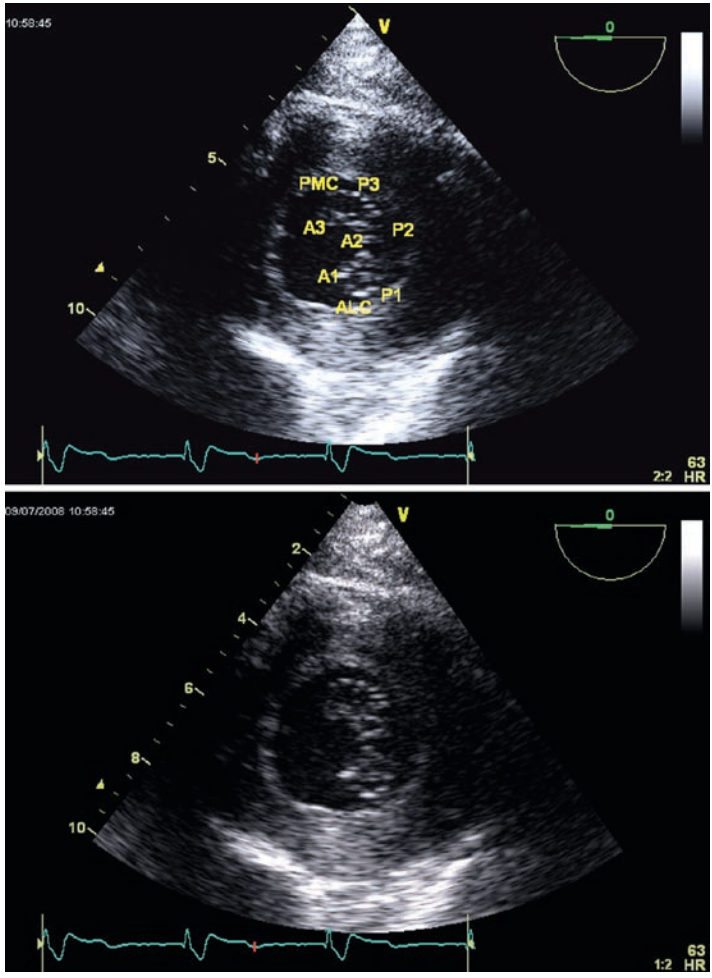

FIGURE 4.7. Transgastric the basal short axis view (valve closed) with all 6 scallops and both commissures (anterolateral [ALC] and posteromedial [PMC]) visualized.

quality can be hampered by valve orientation and relatively poor resolution such that it is often no better than that obtained from the transthoracic parasternal short axis. Although it is often a struggle to

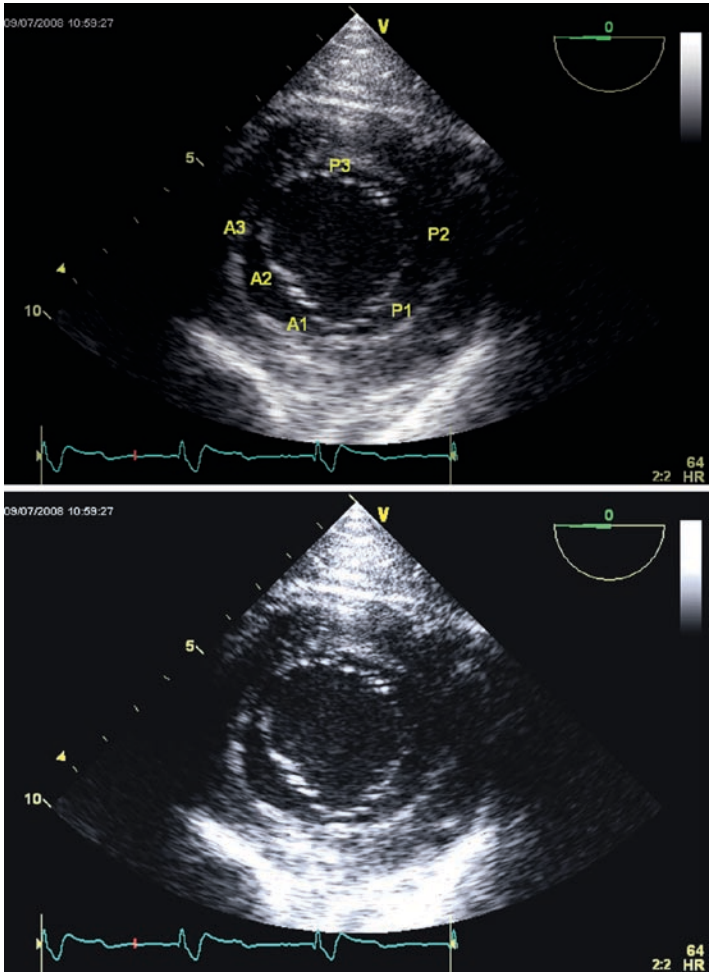

FIGURE 4.8. Transgastric the basal short axis view (valve open) with all 6 scallops visualized.

get a good MV SAX view, the transgastric 2 chambers and long axis views (the last two standard views for assessing the MV) are usually pretty straightforward to obtain and are excellent for looking at the papillary muscles (PM) and chordae; the leaflets can be seen, but

they lie on the periphery of the image with consequent reductions in resolution. To get the optimal views of the papillary muscles and chordae, start at the basal TG SAX view and advance the probe and/or reduce the anterior flexion in order to achieve a mid SAX view of the left ventricle that cuts through the papillary muscles (see Fig. 2.5); try and get a cut through both although this is frequently not possible, and so you may have to undertake sequential imaging of each PM. Having obtained a good SAX view, rotate the image plane angle first to the 2 chambers then the long axis views; additionally, gentle, anticlockwise rotation may be needed to maintain the papillary muscles in the middle of the image plane. This concludes the basic imaging of the mitral valve.

A systematic approach to the assessment of the normal mitral valve.

View	Level	Angle (degrees)	Data acquired
4Ch	ME	0–20	P2 and A2 (±A3) [P2 furthest to the right of the screen] Annulus measurement Qualitative estimation of biventricular systolic function Left atrial diameter measurement Tricuspid valve regurgitant jet velocity
4Ch	ME	20–40	P1 and A2 (±A3) [P1 furthest to the right of the screen] Qualitative estimation of biventricular systolic function Tricuspid valve regurgitant jet velocity
CM	ME	40–80	P1, A2, and P3 [P1 furthest to the right of the screen] Anterolateral commissure [to the right of the screen] Posteromedial commissure [to the left of the screen] Chordae tendinae and papillary muscles
2Ch	ME	80–120	A1, A2, and P3 [A1 furthest to the right of the screen] Annulus measurement LV volume measurements (EDV and ESV) LV ejection fraction calculation
LAX	ME	120–160	A2 and P2 [A2 furthest to the right of the screen] Qualitative estimation of left ventricular systolic function
SAX	TG	0–40	All 6 scallops and both commissures Qualitative estimation of left ventricular systolic function
2Ch	TG	80–120	Chordae tendinae and papillary muscles Internal dimension measurements (LVIDd and LVIDs) Fractional shortening calculation
LAX	TG	80–120	Chordae tendinae and papillary muscles Qualitative estimation of left ventricular systolic function

Chapter 5
The Aortic Valve and Aorta

5.1 Aortic Valve

The aortic valve (AV) is a semi lunar valve and, like the mitral valve, lies close to the esophagus allowing excellent visualization with TEE.

5.1.1 Valve Structure

The valve itself consists of 3 cusps (right, left, and noncoronary) attached to a fibrous annulus, and unlike the atrio-ventricular valves, it does not have any anchoring supports (e.g., chordae tendinae) to maintain the integrity. The integrity is dependant mainly on the annulus geometry and the ratio of annulus: cusp area. The annulus geometry is affected by the inter-ventricular septum and proximal aortic root, and pathologies of either can alter the annular shape and cause incompetence of the valve. There is about 30% overlap of each cusp with its neighbor, and the total cusp area must exceed the cross sectional area of the annulus in order to maintain competency with a normal ratio being greater than 1.6:1; any pathology that decreases cusp area or increases annular area will therefore lead to incompetence and regurgitation through the valve.

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DOI 10.1007/978-1-84882-621-2_5,

5.1.2 Standard Image Planes

There are five standard views that operators are recommended to use when assessing the AV. As with all valvular assessments the operator should assess first with 2D then with color, pulsed wave, and continuous wave Doppler.

5.1.3 Five Chambers View

Starting in the mid esophagus (ME) and having briefly imaged the 4 chambers (4Ch) view the probe is withdrawn slightly to obtain the 5 chambers (5Ch) view; the image sector depth is then reduced in order to visualize the valve close up in 2D (Fig. 5.1), and with color Doppler. In this view the noncoronary cusp (NCC) or left coronary cusp (LCC) is seen superiorly with the right coronary cusp (RCC) seen inferiorly.

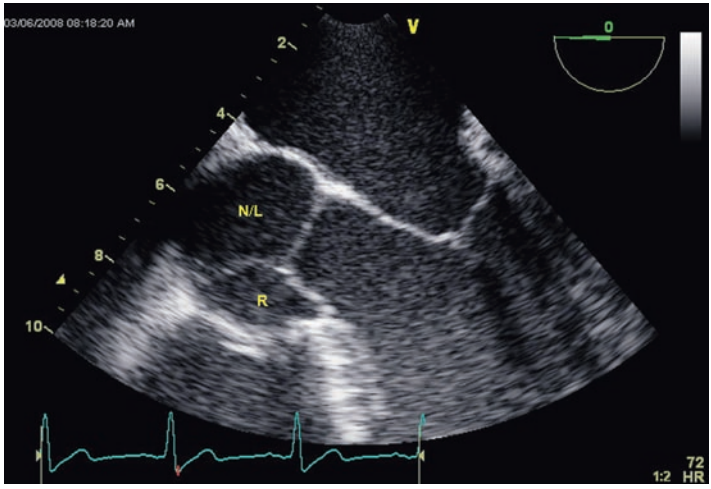

FIGURE 5.1. Mid esophageal 5 chambers view with the noncoronary (N) cusp or left (L) coronary cusp at the *top* and the right (R) coronary cusp at the *bottom*.

5.1.4 Short Axis View

Maintaining this esophageal level the image plane angle is slowly rotated between 40° and 80°, whilst gently manually rotating the probe clockwise (to the right) to obtain the AV short axis (SAX) view. In order to remain spatially orientated it is best to undertake these manipulations at a greater image sector depth so as to have more landmarks to guide you. Once the AV SAX view is obtained (Fig. 5.2) the image sector depth can be reduced once more for closer evaluation of the valve. The probe depth may need to be adjusted and some degree of lateral flexion applied in order to get a perfect "en face" view of the valve, and once achieved, it will allow an exquisite view of all 3 cusps (Fig. 5.3).

AV Imaging Planes

ME 5Ch – 0–40°
ME AV SAX – 40–80°
ME AV LAX – 120–160
Deep TG LAX – 0–40
TG LAX – 0–40°

5.1.5 Long Axis View

The third mid esophageal view recommended for AV assessment is the (AV) long axis (LAX) view; this is similar to the left ventricular LAX view but may require further manipulation to ensure the appropriate cut through the valve and proximal aortic root (i.e., with the root being imaged in as close to horizontal projection as possible). Starting from the SAX view the image sector depth is again increased to assist orientation. The image plane angle is then rotated between 120° and 160° (although image may be acquired at angles 100–120°) with or without some manual anticlockwise rotation being applied. Then the sector depth is reduced to give a close up of the valve and proximal root (Fig. 5.4). The RCC is the inferior cusp, and depending on the orientation of the valve/

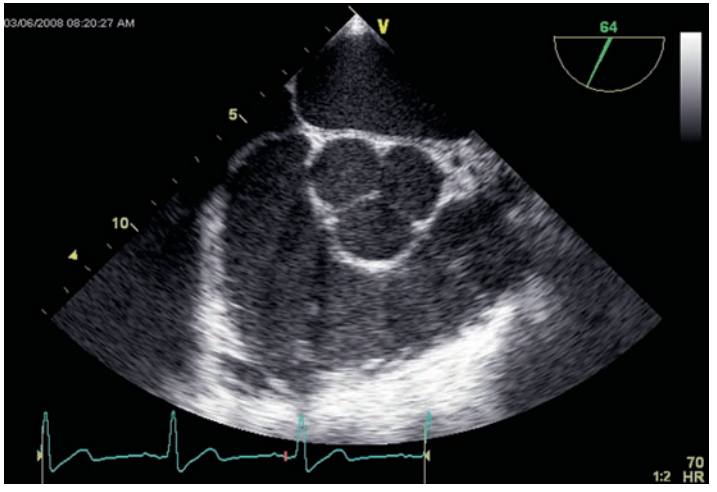

FIGURE 5.2. Mid esophageal aortic valve short axis view with an image sector depth of 14 cm allowing operator orientation while localizing the aortic valve.

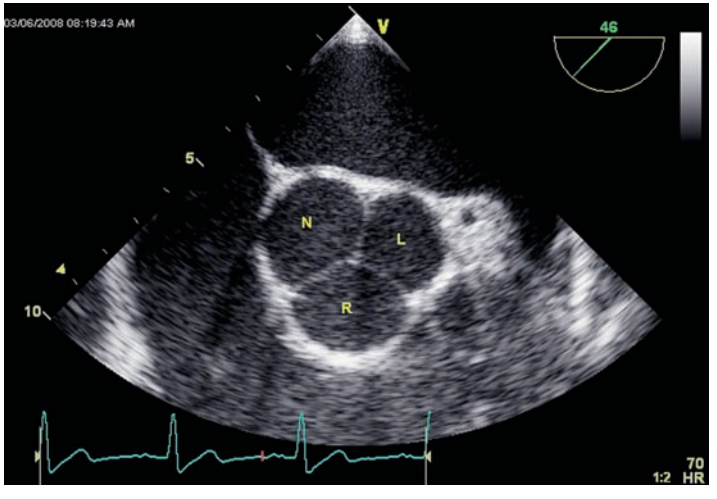

FIGURE 5.3. Mid esophageal aortic valve short axis view with reduced image sector depth allowing a close up "en face" view of the aortic valve. All 3 cusps are seen; noncoronary (N) *top left*, left coronary (L) *top right*, and right (R) coronary at the *bottom*.

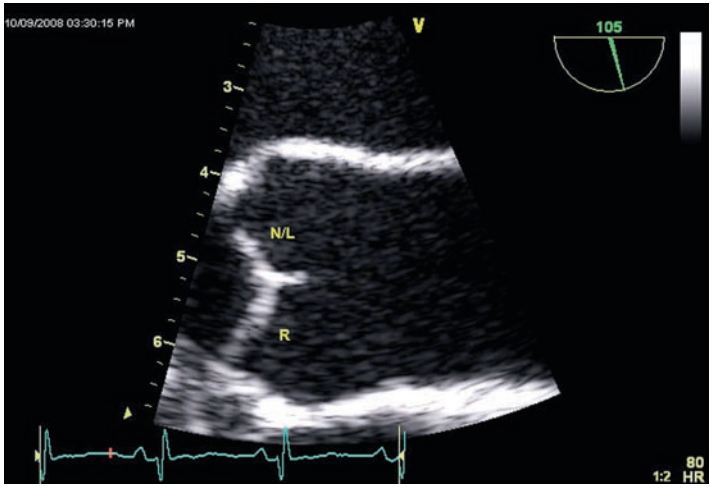

FIGURE 5.4. Mid esophageal aortic valve long axis view with zoomed image of the aortic valve and proximal aorta. In this view, the right (R) coronary cusp is at the *bottom* and, depending on the orientation of the valve/aorta relative to the probe, the noncoronary (N) or the left (L) coronary cusp is at the *top*.

aorta relative to the probe, the NCC or the LCC is the superior cusp seen. Depending on the orientation of the valve and proximal aorta relative to the esophagus, a gentle rotation of the probe manually in a clockwise or anticlockwise fashion may be required to optimize the image. This completes the esophageal views, and up to this point only a qualitative assessment has been made (2D and color Doppler) as the orientation of the valve relative to the probe does not allow for meaningful quantitative Doppler to be undertaken.

5.1.6 Transgastric Views

The last two views are transgastric and allow co-axial alignment of the ultrasound beam, meaning they can be used for spectral Doppler interrogation (pulsed and continuous wave). The distance

of the valve from the probe however, reduces the 2D resolution considerably. The most consistently attainable view is the TG LAX as described in Chap. 2 (Fig. 2.7); in order to optimize visualization of the valve rotating the probe to the right can be helpful. The second transgastric view is the deep transgastric view found at 0–40° by first obtaining the TG SAX view of the LV and then advancing the probe. It should be noted that it is not always possible to get the deep TG view and patients' tend to find it quite uncomfortable so I frequently omit it from my routine studies.

5.2 Aorta

5.2.1 Root

The aortic root extends from the fibrous annulus that supports the AV to the portion of the proximal ascending aorta that lies just distal to the sino-tubular junction, and can be seen in the same views as those used to visualize the AV (although slight manipulations are often required to optimize the imaging of one area at the expense of the other). When describing the root the dimensions of the annulus, sinus of Valsalva and the sino-tubular junction should be quoted (Fig. 5.5). The sinus of Valsalva measurement should be given as an absolute value and also as corrected for body surface area (BSA); the value corrected for BSA should be compared to published normograms[1] in order to ascertain if there is any dilatation. Measurements should be taken in the plane perpendicular to the long axis of that portion of the aorta. There is some lack of consensus as to whether the 2D measurements should be taken from "leading edge to leading edge" or from "inner edge to inner edge"; a lot of operators undertake the later method, but it should be remembered that the normograms that are used to define normal and abnormal were derived from transthoracic data using the "leading edge" technique.

In addition to the quantitative assessment of the root a qualitative assessment of the shape of the sino-tubular junction should be made and any effacement highlighted.

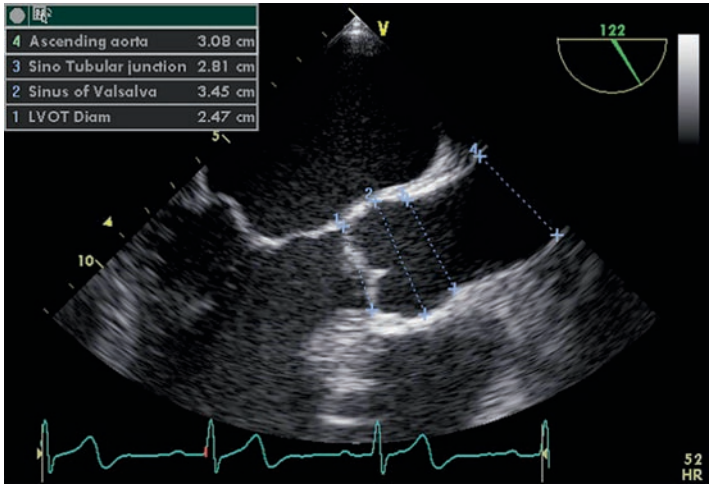

FIGURE 5.5. Mid esophageal aortic valve long axis view demonstrating the measurement of the dimensions of the aortic valve annulus (LVOT Diam), sinus of Valsalva, sino-tubular junction, and proximal ascending aorta.

5.2.2 Coronary Ostia

The coronary ostia are well seen in the mid esophageal AV short (left [LCA] and right [RCA]) and AV long (RCA) axis views. In the SAX view the left main stem (LMS) and proximal portion of the anterior descending (LAD) and circumflex (LCx) branches can be seen (Fig. 5.6). The RCA is seen in the SAX view although it is usually better seen in the LAX view (Fig. 5.7). Assessment of the ostia and proximal arteries consists of identifying the sinus of Valsalva they originate from (i.e., ensure no anomalous origins), and a qualitative assessment of flow using color Doppler (Fig. 5.8); the latter allowing identification of high velocity turbulent flow that may suggest a proximal coronary artery stenosis. It is possible to quantitatively assess proximal coronary artery flow using pulse wave Doppler, but great expertise is required in analyzing the results, and the methods are beyond the scope of this text.

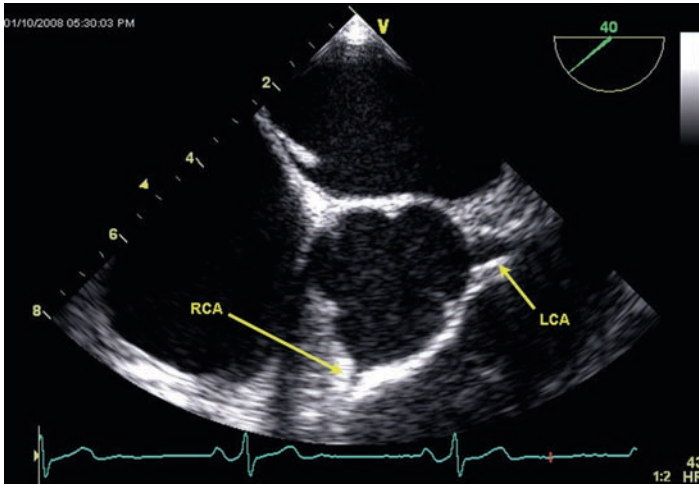

FIGURE 5.6. Mid esophageal aortic valve short axis view with the left coronary ostium (LCA) and right coronary ostium (RCA) visualized.

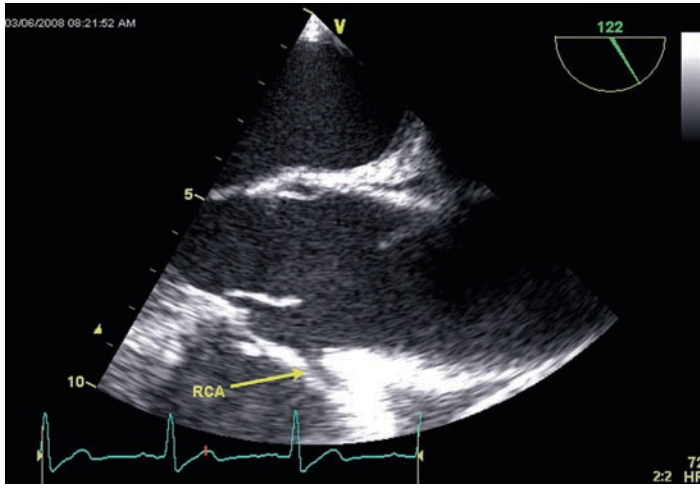

FIGURE 5.7. Mid esophageal aortic valve long axis view with the right coronary artery (RCA) visualized.

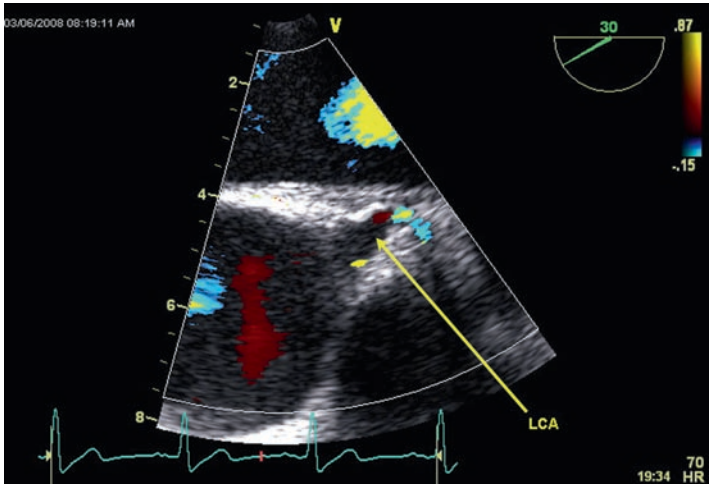

FIGURE 5.8. Mid esophageal aortic valve short axis view with color Doppler demonstrating flow in the left coronary artery (LCA).

5.2.3 Ascending, Arch, and Descending

To visualize the rest of the aorta there are six additional views recommended. Having assessed the aortic root in the mid esophageal AV LAX view the probe is withdrawn slightly, and the image plane angle decreased to between 80° and 120° to look at the ascending aorta in long axis (Fig. 5.9); in this view the diameter of the ascending aorta is measured. Maintaining the probe depth the image plane angle is rotated between 0° and 40° to produce the ascending aorta SAX view (Fig. 5.10).

The other four views are the short and long axis views of the descending aorta and aortic arch and this part of aortic imaging is often deferred until the end of the study. Having completed all other aspects of the TEE study the image plane angle is set to zero and the probe is manually rotated through 180° to face posteriorly in the ME. The descending aorta is thus imaged in SAX (Fig. 5.11). Maintain the probe position and rotating the image plane angle to 80–120° the descending aorta is seen in long axis (Fig. 5.12). The image plane is then returned to zero degrees and the probe is gradually withdrawn in order to assess the proximal

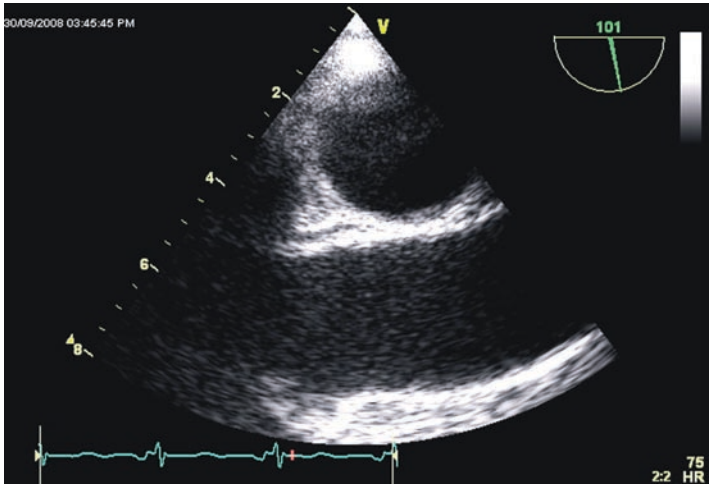

FIGURE 5.9. Mid esophageal ascending aortic long axis view.

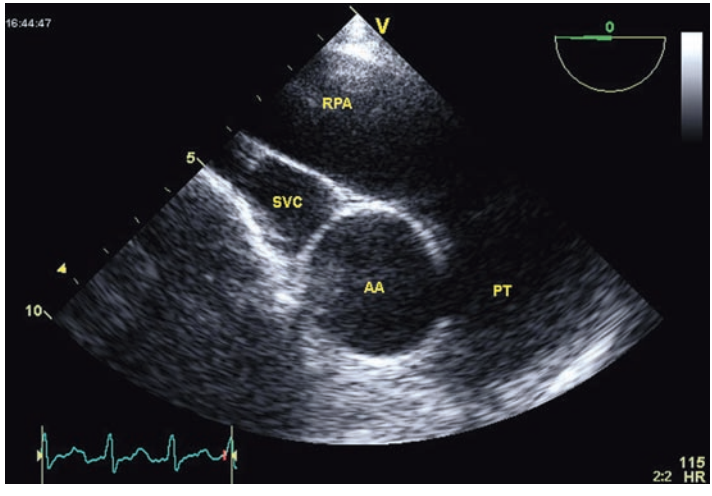

FIGURE 5.10. Mid esophageal ascending aortic short axis view with ascending aorta (AA), superior vena cava (SVC), pulmonary trunk (PT), and right pulmonary artery (RPA) visualized.

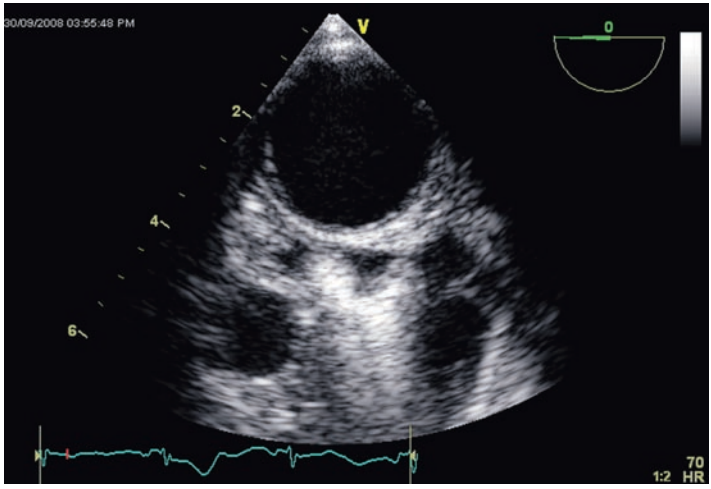

FIGURE 5.11. Descending aortic short axis view.

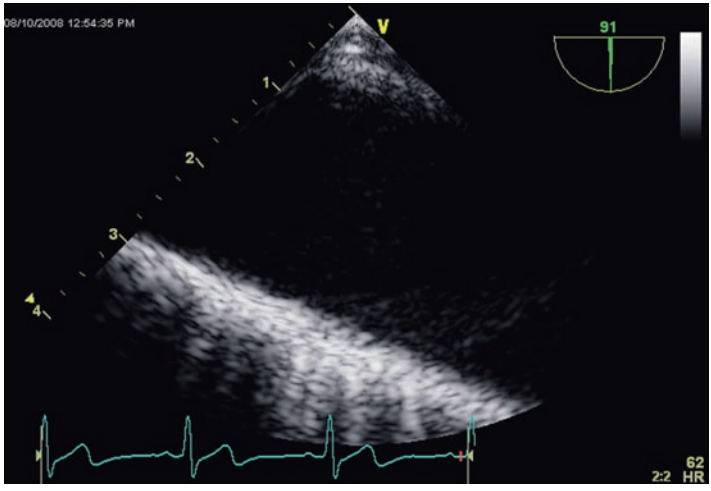

FIGURE 5.12. Descending aortic long axis view.

part of the thoracic descending aorta and the aortic arch. In order to maintain the aorta in the centre of the image sector, it is necessary to rotate the probe to the right (anteriorly) as the probe is

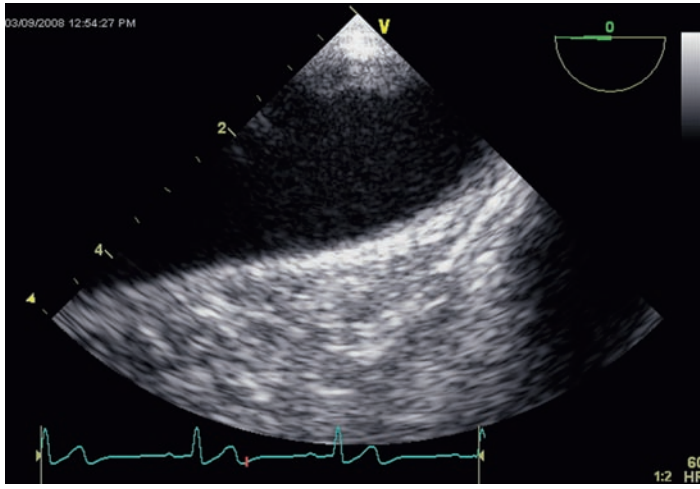

FIGURE 5.13. Upper esophageal aortic arch long axis view.

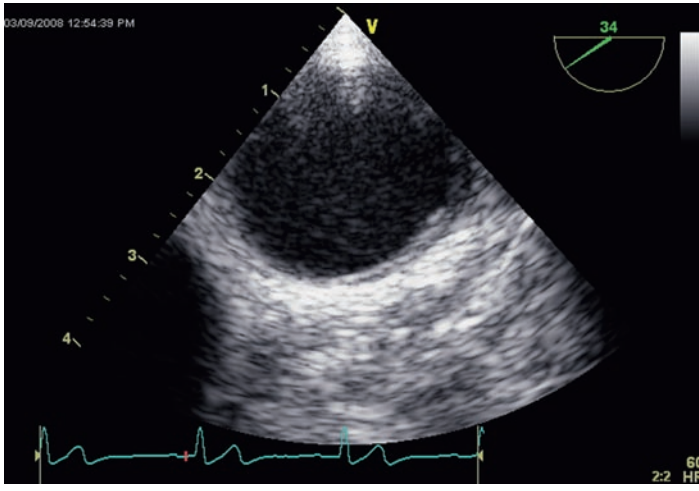

FIGURE 5.14. Upper esophageal aortic arch short axis view.

withdrawn (the aorta and esophagus twisting around each other within the thoracic cavity; the ascending aorta/aortic arch lying anterior to the esophagus and the descending aorta lying posterior to it).

The arch is first seen in a long axis projection (Fig. 5.13), and then by rotating to 80–120° (although sometimes at lesser angles), in the SAX projection (Fig. 5.14). These arch views are very useful especially in assessing stroke patients (looking for arch atheroma), but are often not well tolerated as the probe at this depth within the esophagus tends to induce a significant gag reflex in the majority of patients.

References

1. Roman MJ et al. *Am J Cardiol.* 1989;64:507–512.

Chapter 6
The Right Heart

6.1 Right Ventricle

The right ventricle (RV) comprises a main pumping chamber and an infundibulum. The infundibulum (or right ventricular outflow tract [RVOT]) acts as a conduit between the main chamber of the RV and the pulmonary valve (PV).

The shape of the main chamber is somewhere between triangular and crescenteric with anterior and inferior (diaphragmatic) free walls and the interventricular septum. By convention the labeling of the septal segments of the RV follow those of the left ventricle. The anterior and inferior walls are, however, divided into basal and apical segments only.

6.1.1 Data Set Required

As with the left ventricle the assessment of the RV should include chamber size, wall thickness and ventricular function, but because of its' geometric complexity, this is more of a qualitative than completely quantitative exercise when using transesophageal two dimensional imaging.

Chamber size is important because dilatation is the end point of almost all pathologies that affect the RV whether the process involves volume overload, pressure overload or a primary myopathic process.

M. Belham, *Transesophageal Echocardiography in Clinical Practice*, 81
DOI 10.1007/978-1-84882-621-2_6,

Function is also important but less easy to quantify. When describing RV function during a TEE study the assessment is confined to systolic function. Usually this is a qualitative (visual) assessment of regional contractility and overall systolic function. There are semiquantitative methods of assessing right ventricular systolic function and these will be described. There are no routinely used or well-validated methods of assessing right ventricular diastolic function.

6.1.2 Four Chambers View

Beginning the assessment of the RV at the mid esophageal level the first standard view is the 4 chambers view (4CV) that is analogous to the transthoracic 4 chambers view with the anterior free wall and septum being visualized. The image plane should be adjusted to maximize the tricuspid annulus diameter (usually between 0° and 20°) with care taken not to foreshorten the apex. In this view the basal and mid end diastolic diameters, the base to apex end diastolic length, and the diastolic area of the RV can be measured (Figs. 6.1 and 6.2).

Normal RV Dimensions (4CV)
Basal RV diameter < 2.8 cm
Mid RV diameter < 3.3 cm
Base-apex length < 7.9 cm

6.1.3 Right Ventricular Systolic Function

A semiquantitative assessment of right ventricular systolic function can be made in the 4CV using three different methods. The first method is the measurement of RV fractional area change (FAC) calculated as:

$$\text{RV FAC} = (\text{RV diastolic area} - \text{RV systolic area})/\text{RV diastolic}$$

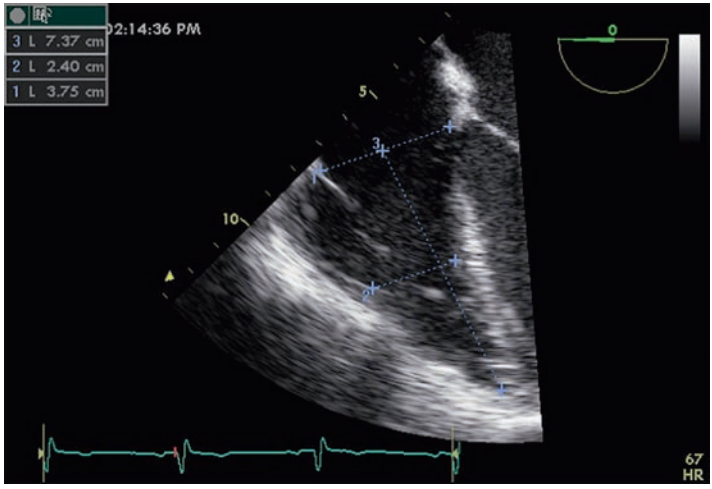

FIGURE 6.1. Mid esophageal 4 chambers view demonstrating the measuring of the right ventricular basal and mid end diastolic diameters (measurements 1 and 2 respectively) and the base to apex end diastolic length (measurement 3).

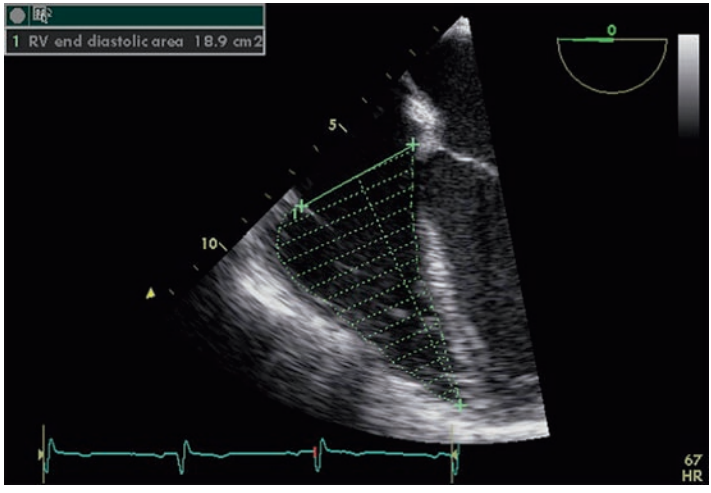

FIGURE 6.2. Mid esophageal 4 chambers view demonstrating the measuring of the end diastolic area of the right ventricle.

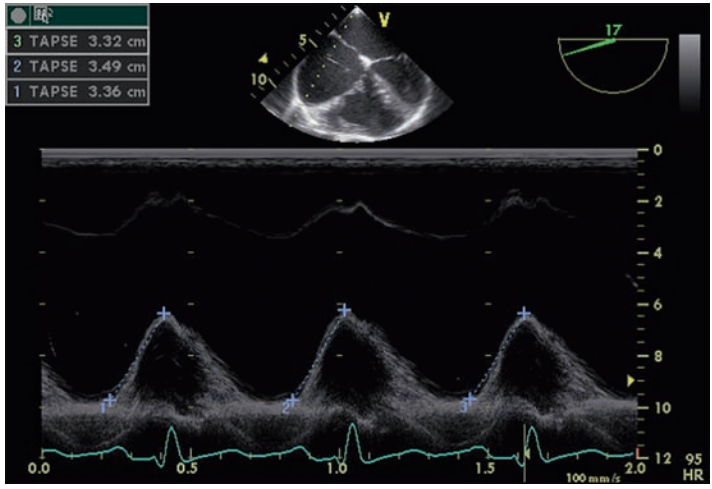

FIGURE 6.3. M-mode recording of tricuspid annular motion from the mid esophageal 4 chambers view with measurement of the tricuspid annulus peak systolic excursion (TAPSE).

Values for echocardiographically obtained RV fractional area change have been shown to correlate well with MRI derived RV ejection fraction and are normally in the range of 32–60%.

The second method looks at the tricuspid annulus peak systolic excursion (TAPSE), and is measured using M-mode (Fig. 6.3) with the cursor aligned as closely as possible to the plane of systolic motion. The normal TAPSE is greater than 2.0 cm; values less than 1.5 cm identifying populations with poorer prognosis.

The third method uses Doppler tissue imaging to measure the tricuspid annulus peak systolic velocity (Fig. 6.4: S′), which is mathematically the first derivative of the TAPSE. Lower values have prognostic implications with values <10 cm/s conferring a poorer outlook.

Although there is evidence to support the use of all three of these methods the latter two have the disadvantage of being angle dependent (and alignment can be very challenging using transesophageal echocardiography), and because they reflect longitudinal function, they are less sensitive than methods that assess global right ventricular function (unlike the left ventricle measures of longitudinal function of the RV decline after measures of radial function).

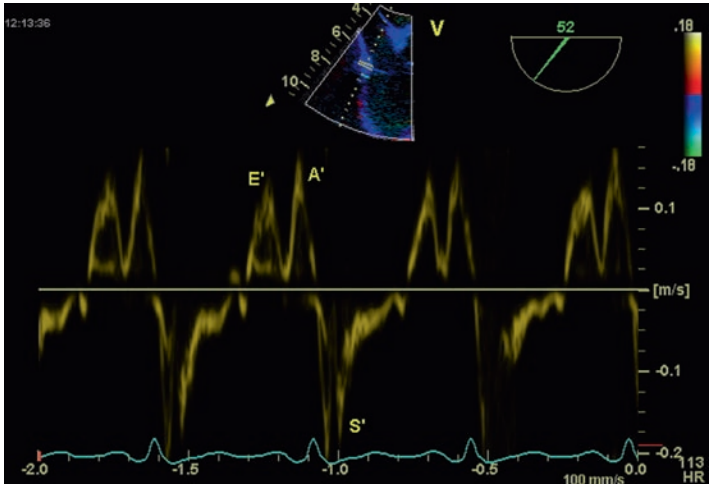

FIGURE 6.4. Doppler tissue imaging of the tricuspid annulus from the mid esophageal 4 chambers view. Early (E') and late (A') diastolic velocities and systolic (S') velocity labeled.

6.1.4 Right Ventricular Inflow–Outflow View

The right ventricular inflow-outflow view (RVI-OV) is the second recommended view; this is obtained by rotating the image plane angle between 40° and 80°, while manually rotating the probe clockwise to the right (Fig. 6.5). In this view the RVOT diameter is measured at the subpulmonary level (Fig. 6.6 measurement 1) and at the PV annulus (Fig. 6.6 measurement 2). In addition to measuring these dimensions, the radial contractility of the RVOT (to the right of the image) and inferior (diaphragmatic) wall at a basal level can also be assessed in this view.

Normal RV Dimensions (RVI-OV)
RVOT diameter (sub P) < 2.9 cm
RVOT diameter (P ann) < 2.3 cm

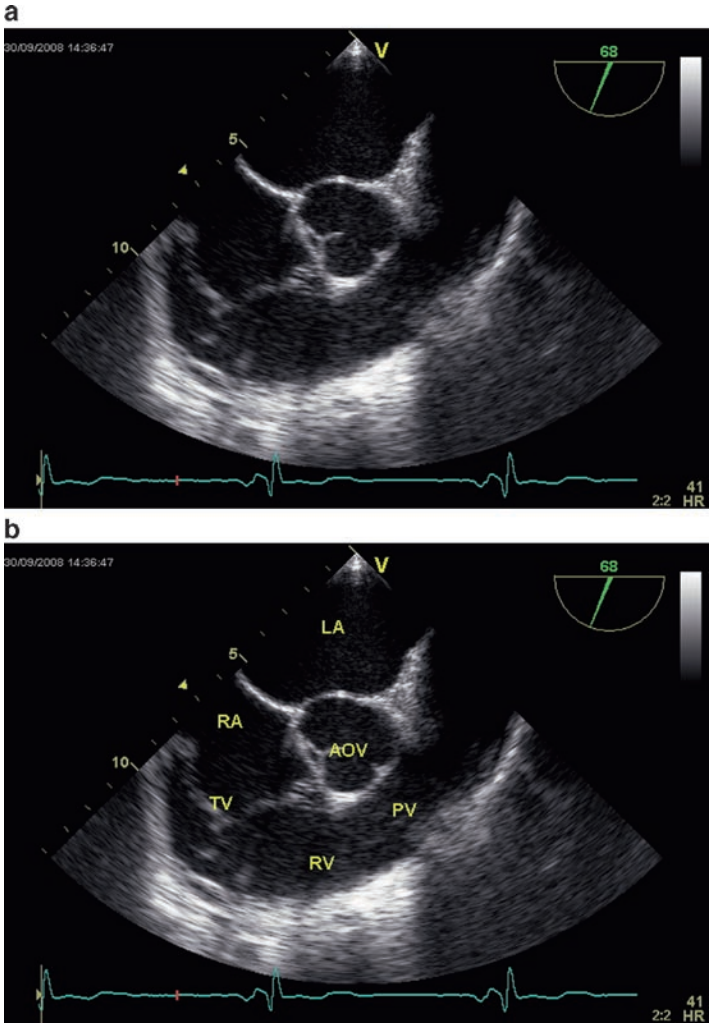

FIGURE 6.5. Mid esophageal right ventricular inflow-outflow view demonstrating the relationship between the left atrium (LA), right atrium (RA), right ventricle (RV), tricuspid valve (TV), pulmonary valve (PV) and aortic valve (AOV).

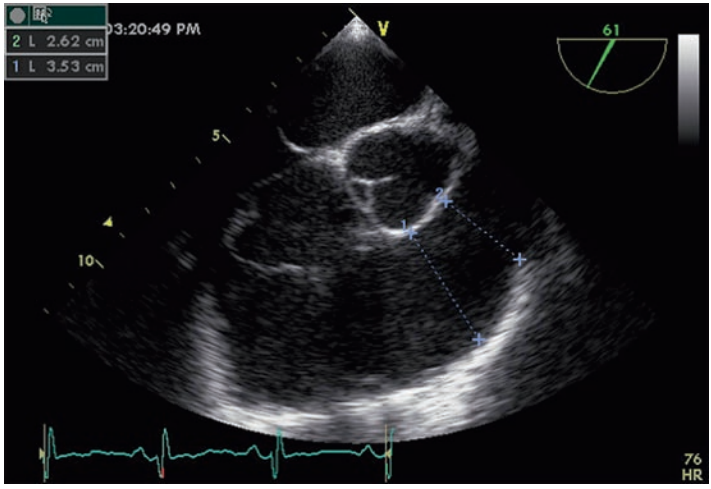

FIGURE 6.6. Mid esophageal right ventricular inflow–outflow view demonstrating the measuring of the right ventricular outflow tract diameter at the subpulmonary level (measurement 1) and at the pulmonary valve annulus (measurement 2).

6.1.5 Right Ventricular 2 Chambers View

To further assess the right ventricular function, gradually rotate the image plane angle between 80° and 120° (while manually rotating the probe to the right, and when necessary, utilizing some lateral flexion to optimize the image), thus visualizing the anterior (right of image) and inferior (left of image) free wall contractility respectively (Fig. 6.7).

6.1.6 Transgastric Views

Having completed the imaging of the RV at the mid esophageal level progress to the transgastric (TG) views. To obtain clear images, it is often necessary to advance the probe deeper and apply greater anterior flexion than is required to image the left ventricle (not quite deep TG but nearly). The two standard views are the TG short axis view at 0 to 40° (Fig. 6.8) and the TG RV

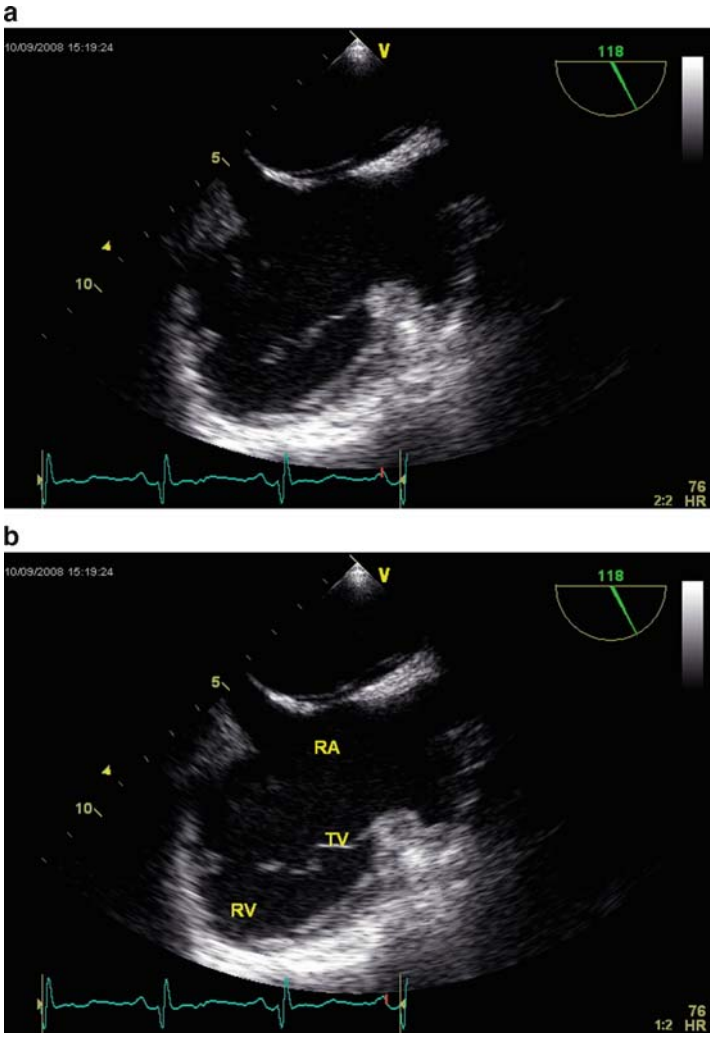

FIGURE 6.7. Mid esophageal right ventricular 2 chambers view visualizing the right atrium (RA), right ventricle (RV), and tricuspid valve (TV).

inflow view at 80–120° (Fig. 6.9), that allow further assessment of the base of the RV and its inferior/anterior walls respectively. The free wall thickness can be measured in either of these views with a value greater than 5 mm indicating right ventricular hypertrophy

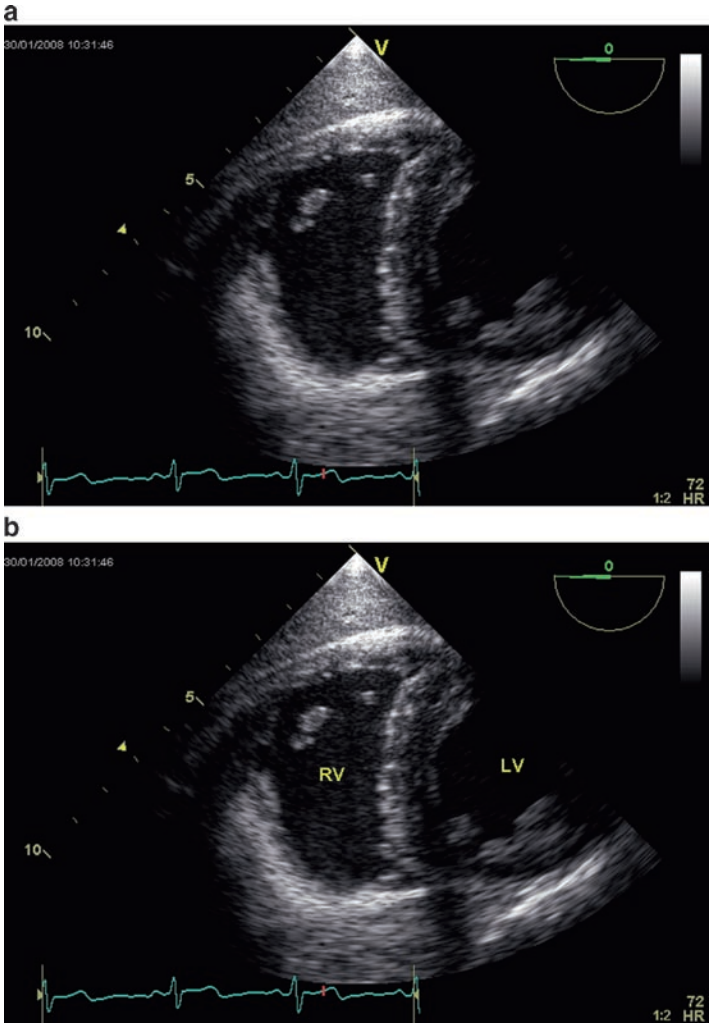

FIGURE 6.8. Transgastric right ventricular short axis view.

(RVH). The inflow view is also especially good for looking at the RV apex and imaging pacing leads. In between the two standard views it is possible to attain an inflow-outflow view (Fig. 6.10), and other nonstandard views that allow a complete visualization of all areas of the RV. To maintain orientation, it is sometimes

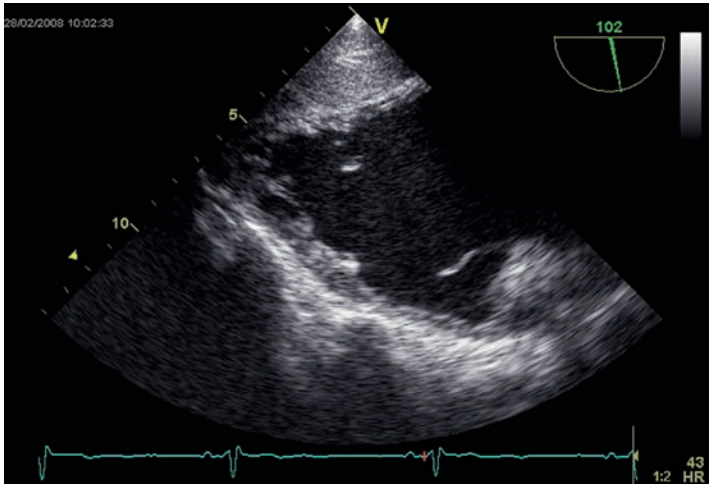

FIGURE 6.9. Transgastric right ventricular inflow view.

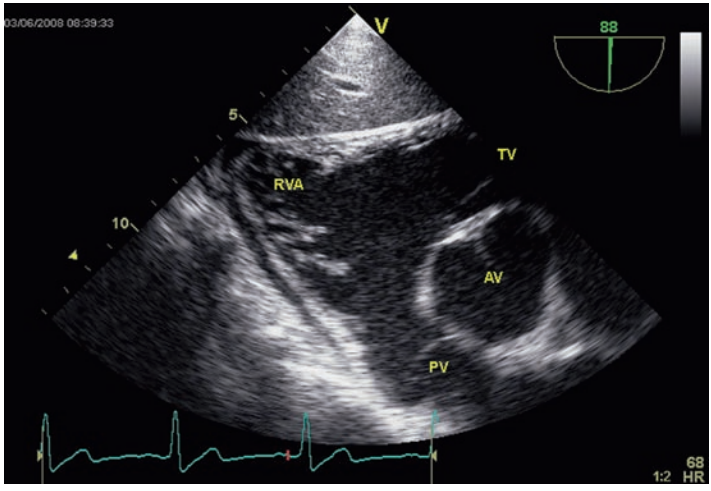

FIGURE 6.10. Transgastric right ventricular inflow–outflow view visualizing the right ventricular apex (RVA), tricuspid valve (TV), pulmonary valve (PV), and aortic valve (AV).

necessary to return to the TG SAX to ensure one is imaging the RV and not the LV; this is especially important in patients with congenital heart disease.

RV free wall thickness < 5 mm

6.2 Right Atrium and Interatrial Septum

6.2.1 Right Atrium

The right atrium (RA) is rarely the focus of a TEE study, but it should be imaged even if only fleetingly. The standard views are the mid esophageal 4 chambers and bicaval views. The RA is imaged by default in the 4CV, but the bicaval view (Fig. 6.11) is specific, and is obtained by rotating the image plane angle between 80° and 120°, while manually rotating the probe to the right (clockwise). These views allow one to ascertain the morphological correctness of the atrium (based on the shell-shaped appendage), identify the presence of a Eustachian valve (seen at the junction of the RA and inferior vena cava (IVC)) or Chiari network (a membranous structure seen within the RA itself), and ensure that the inferior and superior vena cavae are draining appropriately. In addition to these standard views, the RA can also be imaged at the gastro-esophageal junction (Fig. 6.12) as the probe is passed into the stomach; this allows visualization of the coronary sinus (CS) as it enters the RA (at the most inferior and posterior extent of the interatrial septum (IAS) adjacent to the septal leaflet of the tricuspid valve (TV)), and the mouth of the IVC. In this last view, the presence of a Eustachian valve can be confirmed and occasionally a Thebesian valve can be seen (at the mouth of the CS).

6.2.2 Interatrial Septum

The IAS consists of a relatively thick limbus surrounding a thinner central fossa ovalis. Imaging of the IAS can be included

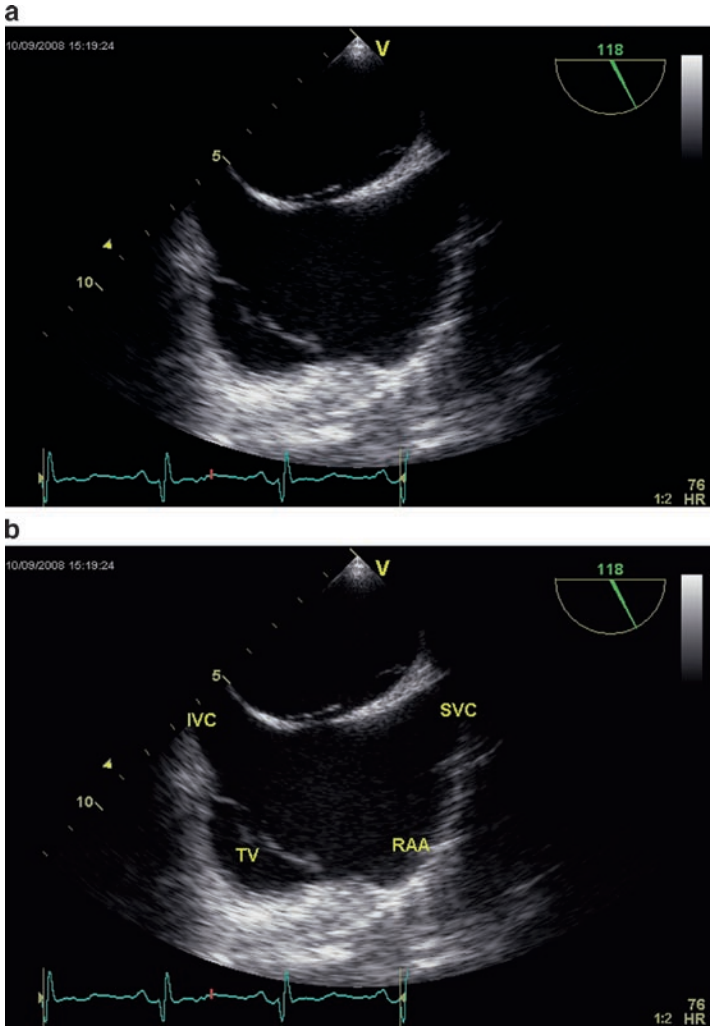

FIGURE 6.11. Mid esophageal bicaval view visualizing the inferior vena cava (IVC), superior vena cava (SVC), right atrial appendage (RAA), and tricuspid valve (TV).

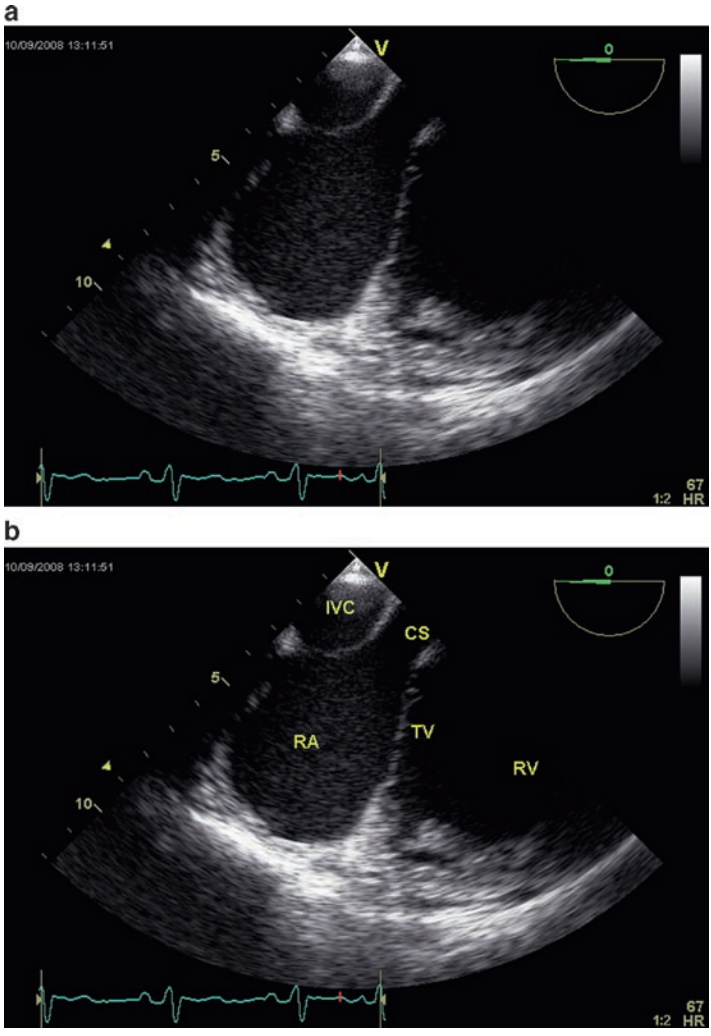

FIGURE 6.12. Right atrial view from gastro-esophageal junction allowing visualization of right ventricle (RV), tricuspid valve (TV), and the inferior vena cava (IVC), and coronary sinus (CS) as they enter the right atrium (RA).

in the overall assessment of the right or left atrium, but as the views required are generally the same views as those utilized for imaging the RA, it is included in this chapter. In a routine study the integrity of the Foramen Ovale (i.e., visually patent or not) and the overall mobility of the septum are all that are described. If significantly mobile, the peak displacement should be measured to define whether an aneurysm is present (displacement of 10 mm or more) or not. Obviously if there is a pre-study suspicion or an incidental intra-study finding of an atrial septal defect (ASD) then a more in depth interrogation of the septum is required.

6.3 Tricuspid Valve

The TV has three asymmetric leaflets; anterior, inferior (posterior), and septal. They vary between triangular and semicircular in shape. The anterior leaflet is the largest and the septal leaflet is the smallest. The septal insertion of the valve defines the right-sided atrio-ventricular valve and differentiates it from the left-sided mitral valve. The annulus of the TV is oval and is more apical than that of the mitral valve (maximal distance of 10 mm; greater than 10 mm apical displacement of the tricuspid annular plane from the mitral annular plane indicates Ebstein's anomaly). The normal valve area is slightly larger than that of the mitral valve (6–7 cm^2 compared with 4–6 cm^2). The subvalvular apparatus consists of chordae tendinae and papillary muscles similar to the mitral valve although the papillary muscles are usually indistinct and integrated with the trabeculations of the right ventricular apex.

6.3.1 Standard Views

The TV can be imaged from the mid esophageal and the TG windows. Because of the variability of leaflet size, shape, and orientation, it is not possible to be didactic about which leaflet is seen in which view, and so the labeling that follows should be considered a guide.

6.3.2 Mid Esophageal Views

The first view is the mid esophageal 4 chambers view (between 0° and 40°); it is necessary to adjust the image plane angle, manually rotate, and laterally flex to open up the annulus and valve as much as possible. Having obtained the best image at a standard depth setting, zoom on the valve to assess structure and motion of the leaflets (anterior [to left of screen] and septal [to right of screen]) in 2D (Fig. 6.13) before adding color Doppler. With retro flexion of the probe, it is sometimes possible to see the inferior leaflet instead of the anterior leaflet to the left of the image. In the nonretroflexed 4 chambers view the annular diameter can be measured (normally less than 2.8 cm) as can the apical displacement from the mitral annulus if there is significant regurgitation through the valve and concern about the possibility of Ebstein's anomaly.

The next view is the RV inflow-outflow view between 40° and 80°, which usually requires only minor adjustment with manual rotation (to the right) and lateral flexion in order to optimize the view of the valve. Again the valve is best visualized using zoom; generally the inferior leaflet is seen to the left and the anterior or septal leaflet (50:50 in the general population) to the right of the image although, on occasions, all three leaflets are seen (Fig. 6.14).

The final ME view is an adaptation of the right atrial bicaval view. The image plane is rotated between 80° and 120° and the probe manually rotated to the right (clockwise) as previously described; the probe depth and lateral flexion are then adjusted in order to visualize the valve (Fig. 6.15) that is not seen in the standard bicaval view. In this view the anterior (to the right) and inferior (to the left of the screen) leaflets are seen and should be looked at in 2D and with color Doppler.

6.3.3 Estimating Pulmonary Artery Pressure

The right atrial to RV pressure difference (RA–RV ΔP) can be estimated from the velocity of the tricuspid regurgitation obtained with continuous wave (CW) Doppler (Fig. 6.16) using the short modified Bernoulli equation ($\Delta P = 4v^2$ where ΔP is the difference in systolic pressure of the RV and RA and v is the peak velocity of the tricuspid

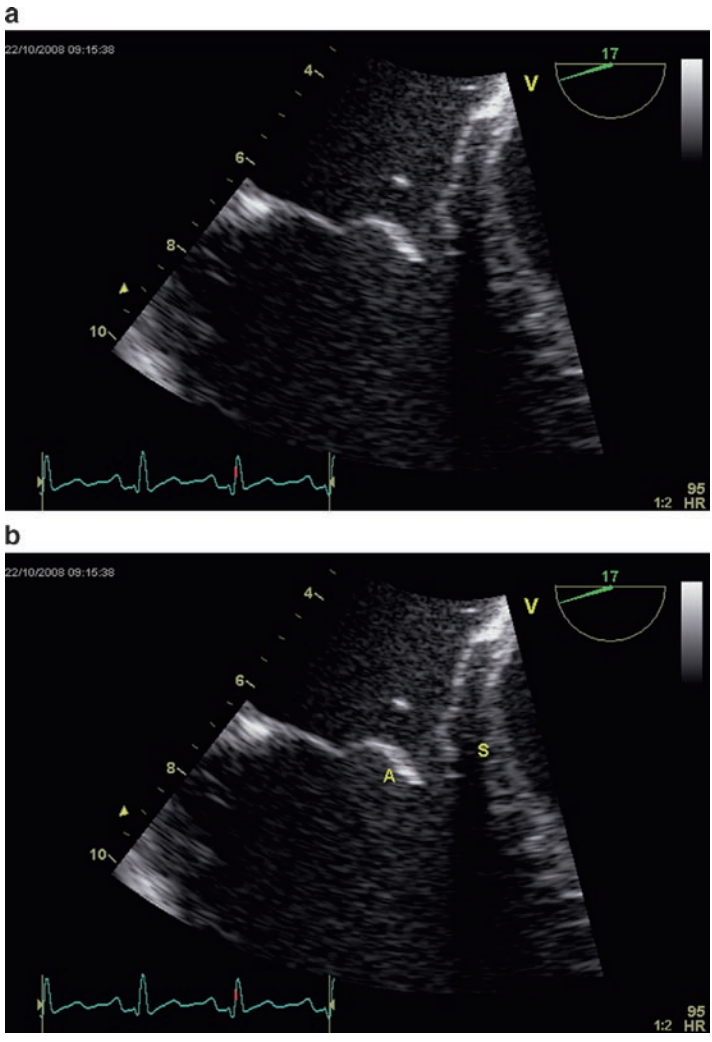

FIGURE 6.13. Zoomed image of the tricuspid valve in the mid esophageal 4 chambers view visualizing the anterior (to left of screen [A]) and septal (to right of screen [S]) leaflets.

regurgitant jet). As with all Doppler derived velocities it is important to align the cursor with the direction of the flow that is being measured because the greater the angle of incidence (θ) the lower

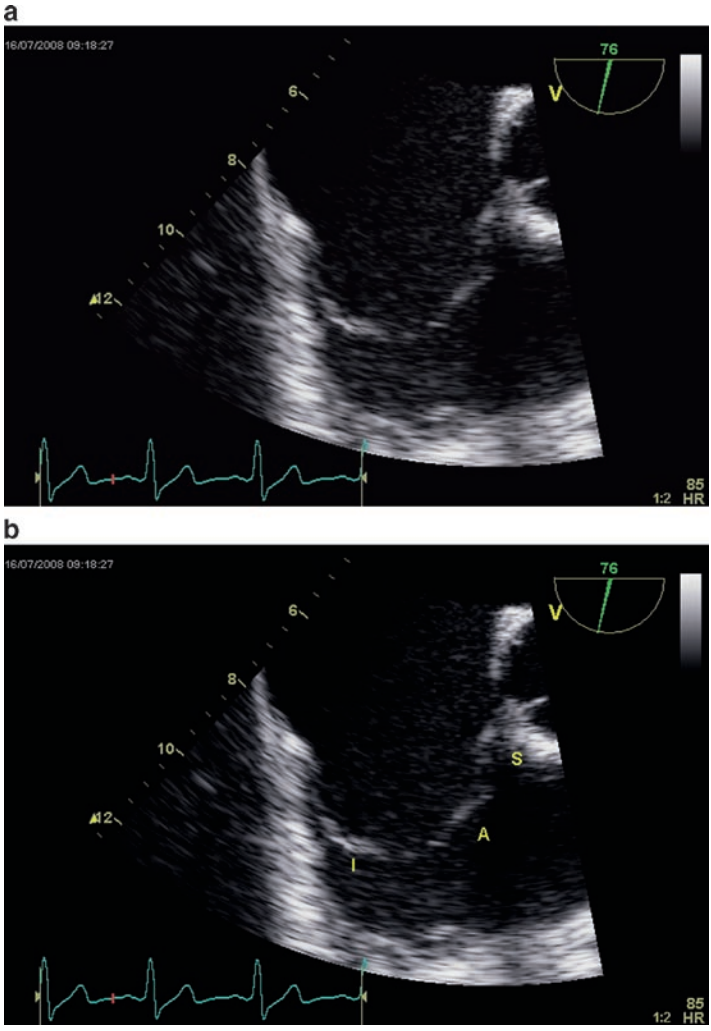

FIGURE 6.14. Zoomed mid esophageal right ventricular inflow–outflow view with visualization of all three tricuspid valve leaflets (*I* inferior, *A* anterior, and *S* septal).

the measured velocity (measured velocity = true velocity × cos θ; cos 0° = 1 and cos 90° = 0) with angles of incident >20° introducing significant errors (cos 20° = 0.94 and cos 30° = 0.87).

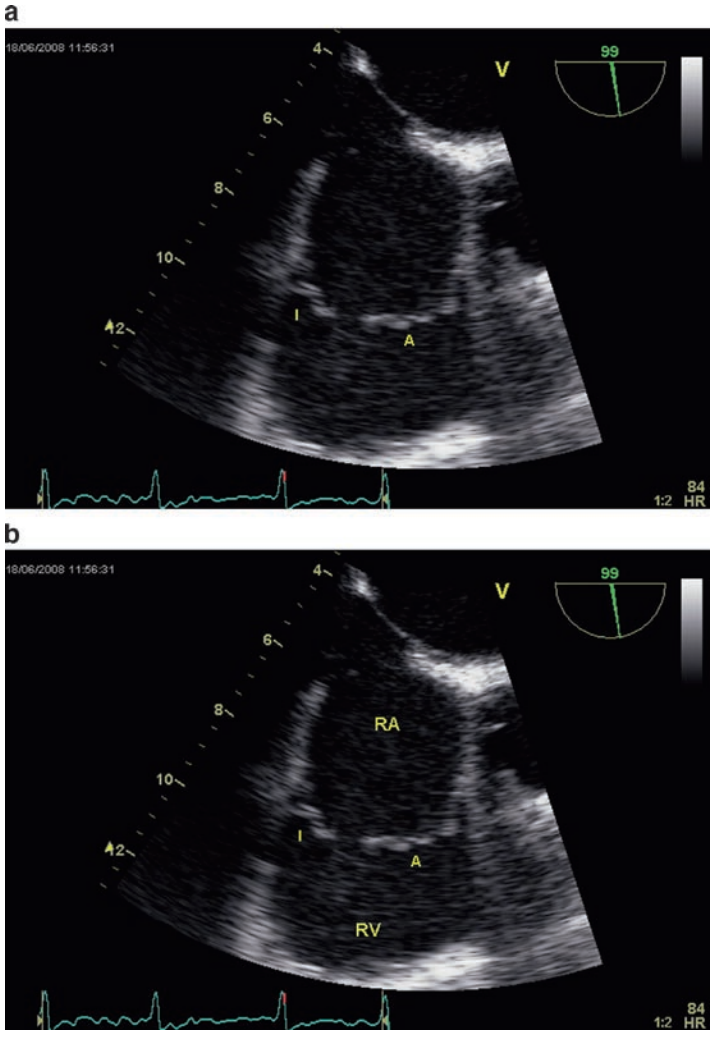

FIGURE 6.15. Adapted right atrial bicaval view visualizing the right atrium (RA), the right ventricle (RV), and the anterior (A) and inferior (I) tricuspid valve leaflets.

Using TEE the angle of incidence is usually best using the modified bicaval view, but measurements should be taken in multiple views and the largest velocity used to calculate ΔP.

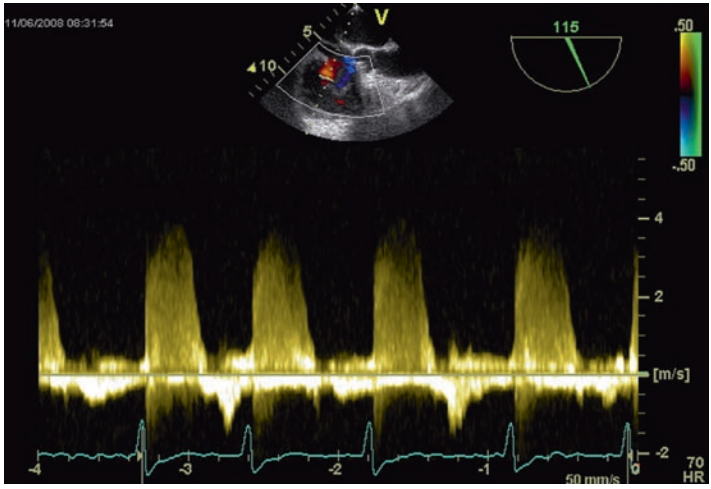

FIGURE 6.16. Continuous wave Doppler recording of a tricuspid regurgitant jet that could be used to estimate the right atrial to right ventricle pressure difference.

The pulmonary artery pressure (PAP) can then be calculated by adding the right atrial pressure to the RA–RV ΔP where right atrial pressure is either directly measured (e.g., in a patient on an intensive care ward with a central venous catheter in situ) or clinically estimated (e.g., using the jugular venous pressure). When the RA pressure cannot be directly measured nor clinically estimated some would recommend simply adding 10 mm Hg to the RA–RV ΔP in order to calculate the PAP.

6.3.4 Transgastric Views

The two standard views are based on the TG short axis view and the TG RV inflow view. From the TG SAX the probe is advanced slightly and rotated to the right. The image plane angle is then rotated until the TV is seen "en face" (between 0° and 40°). This is the only view that consistently allows visualization and accurate labeling of all three leaflets (Fig. 6.17). Maintaining the probe depth the image plane angle is then advanced between 80° and 120° to

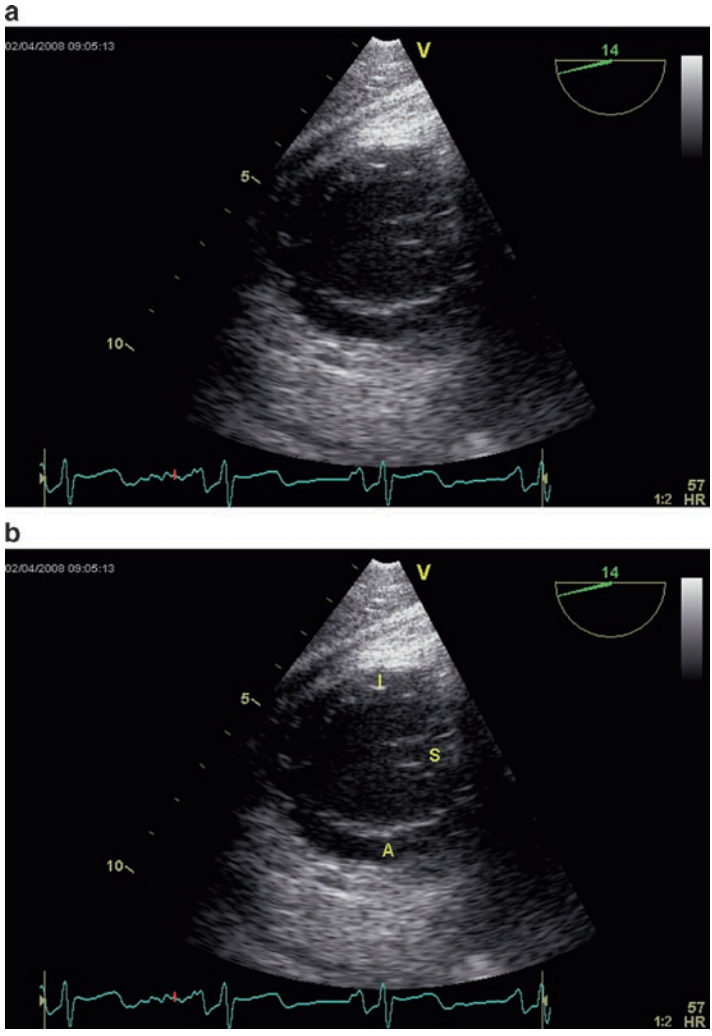

FIGURE 6.17. Transgastric right ventricular short axis view showing all three tricuspid valve leaflets (*I* inferior, *A* anterior, and *S* septal).

produce a view similar to the TG RV inflow view, but using further manual rotation to optimize the imaging of the valve rather than the ventricle. In this view the anterior (bottom most) and inferior (top most) leaflets (Fig. 6.18) and occasionally all 3 leaflets (Fig. 6.19)

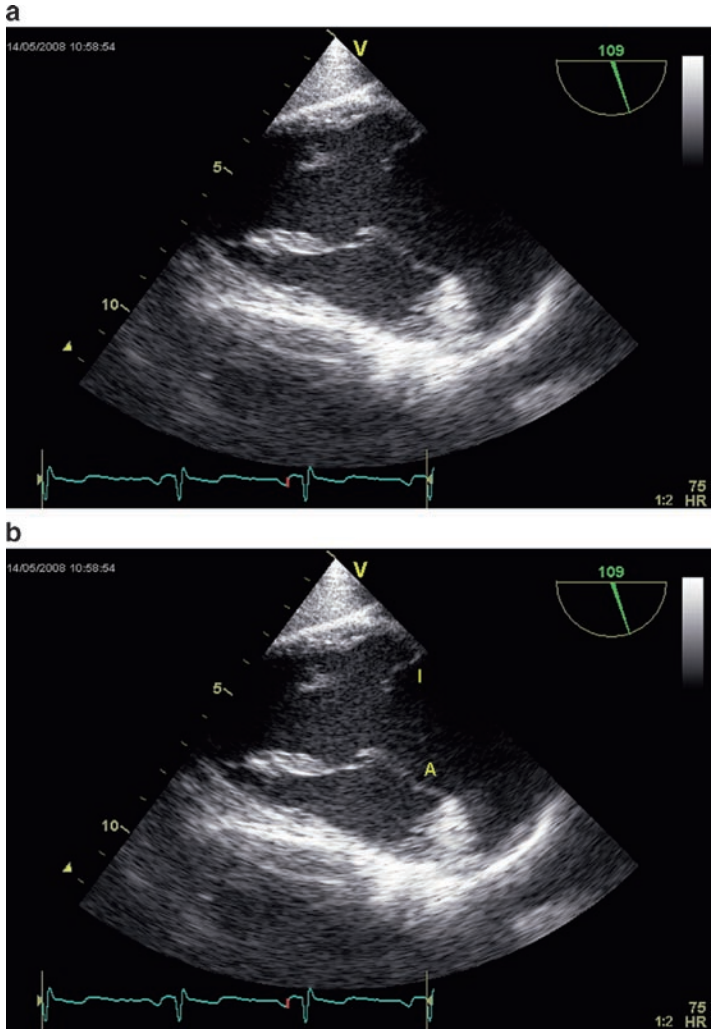

FIGURE 6.18. Adapted transgastric right ventricular inflow view allowing visualization of the anterior ([A] bottom most) and inferior ([I] top most) tricuspid valve leaflets.

are seen. Using 2 dimensional and color Doppler imaging these TG views further assess leaflet structure, integrity, and motion ensuring accurate localization of any abnormalities of the valve.

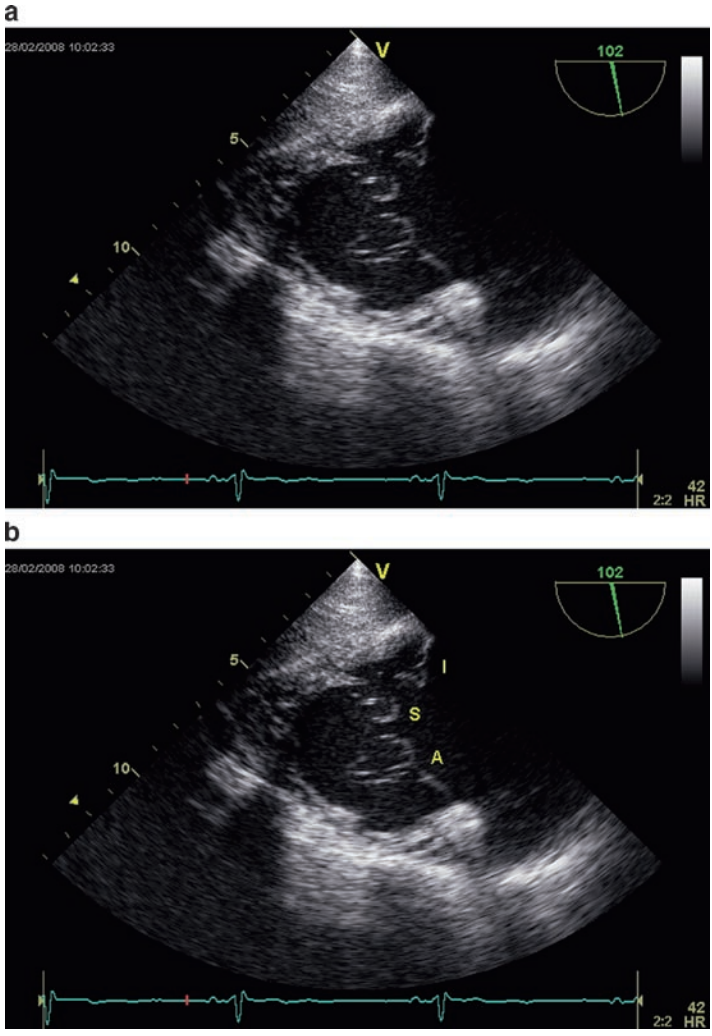

FIGURE 6.19. Adapted transgastric right ventricular inflow view allowing visualization of all three tricuspid valve leaflets (*I* inferior, *A* anterior, and *S* septal).

6.4 Pulmonary Valve

The pulmonary valve (PV) is the right-sided semilunar valve and has one posterior (left) and two anterior (anterior and right) cusps. The cusp nomenclature for both the pulmonary and aortic valves is assigned according to their position in the fetus before the heart rotates to the left; while this does not tend to affect the understanding of aortic valve cusp nomenclature, it can cause confusion when identifying which PV cusp is which.

The PV is the most anteriorly situated of the valves and thus the least well imaged using transesophageal echocardiography. The assessment of the valve is, therefore, usually limited to leaflet thickness and mobility in 2D followed by a search for regurgitation using color Doppler.

6.4.1 Mid Esophageal View

The one view in which the pulmonary valve can be consistently visualized in is the RV inflow-outflow view. Having obtained this view, zoom on the valve and then adjust the image plane angle (usually needs increasing by 10–20° from the standard RVI-O view) and utilize the lateral flexion (usually needs some right lateral flexion, but significant interindividual variability exists) in order to get the best image of the valve (Fig. 6.20). In this view the anterior and posterior cusps are visualized.

6.4.2 Other Views

The pulmonary valve can also, sometimes, be seen in the TG RV inflow-outflow view (Fig. 6.21) and the aortic arch view (Fig. 6.22). If attainable, this latter view allows reasonable beam alignment for undertakingpulsedorCWDopplerassessmentofthevalve.6.4 PulmonaryValve

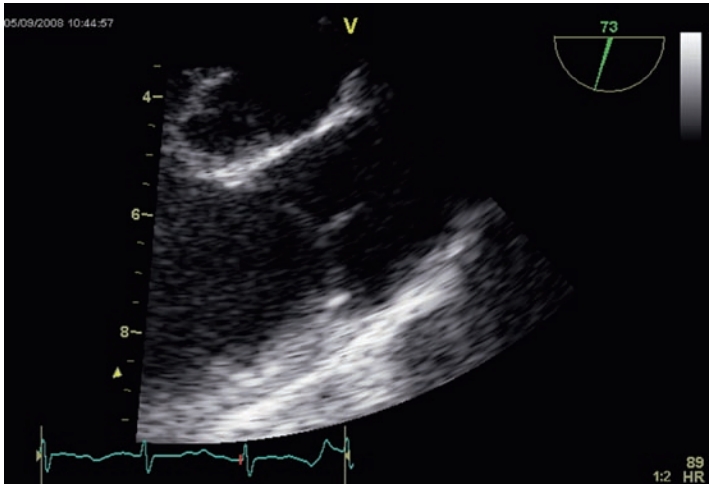

FIGURE 6.20. Adapted mid esophageal right ventricular inflow–outflow view with zoom function allowing visualization of the pulmonary valve close up.

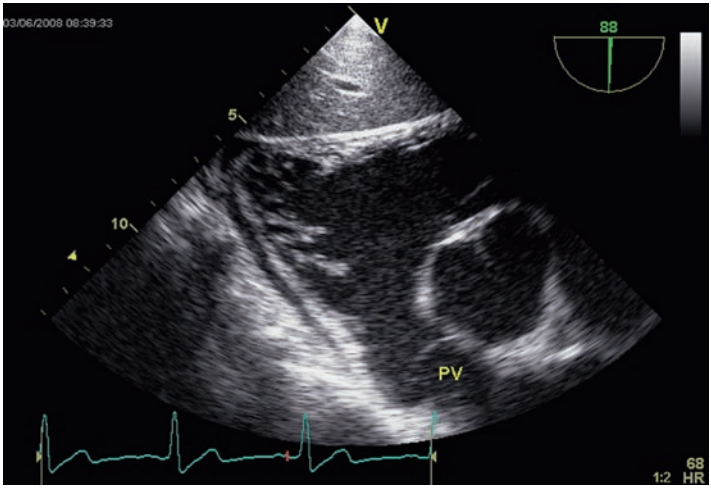

FIGURE 6.21. Transgastric right ventricular inflow–outflow view allowing visualization of the pulmonary valve (PV).

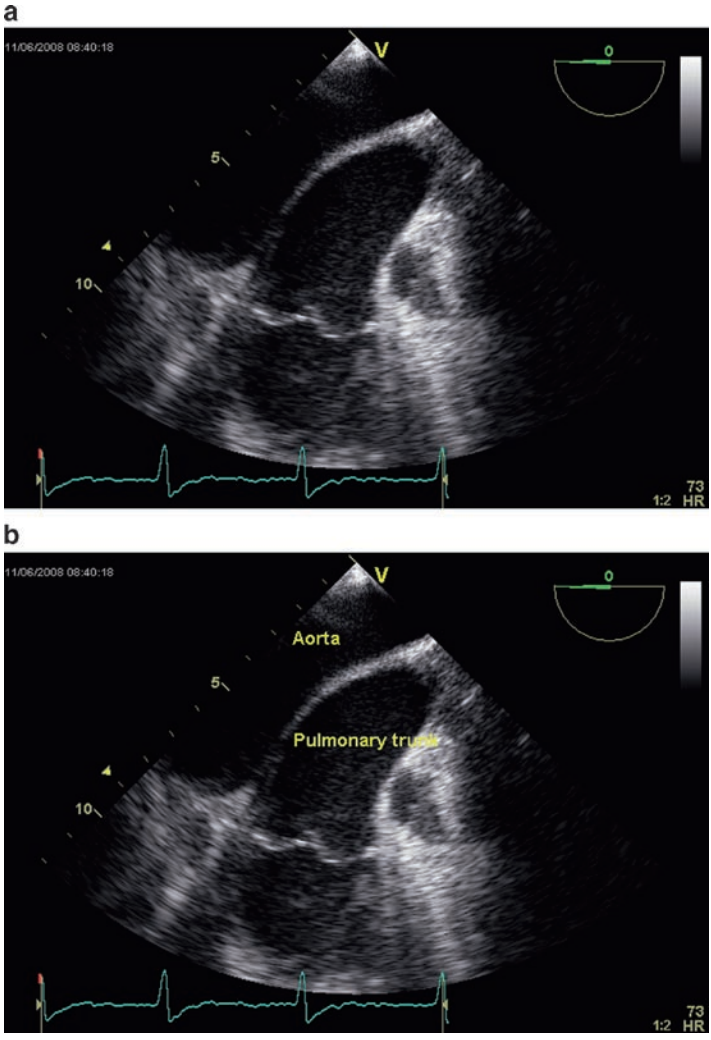

FIGURE 6.22. Adapted upper esophageal aortic arch long axis view allowing visualization of the aorta, pulmonary trunk and pulmonary valve.

Chapter 7
Artificial Valves

Although not strictly "normal," most operators will undertake studies on patients with left-sided artificial valves, and some knowledge of how to image these is necessary.

7.1 General

Prior to undertaking the TEE, it is important to read the surgical notes (if available) to elucidate the position, type, and size of the valve replacement. Also note whether additional procedures have been performed e.g., aortic root replacement (Fig. 7.1).

7.1.1 Types of Artificial Valves

Biological valves can be an autograft (i.e., as in the Ross procedure when the patients' own pulmonary valve is placed in the aortic position with a prosthetic valve being implanted in the pulmonary valve position), an allograft (i.e., from another human being [cadaveric], and also known as homograft) or a xenograft (i.e., from an animal; usually an explanted porcine valve [stented or unstented], or a valve constructed from bovine pericardium [stented]). *Mechanical* valves are mostly bileaflet (e.g., St. Jude), or tilting disc (e.g., Medtronic-Hall) types. Historically, there was another variety known as "ball and cage" (e.g., Starr-Edwards), but

M. Belham, *Transesophageal Echocardiography in Clinical Practice*, 107
DOI 10.1007/978-1-84882-621-2_7,

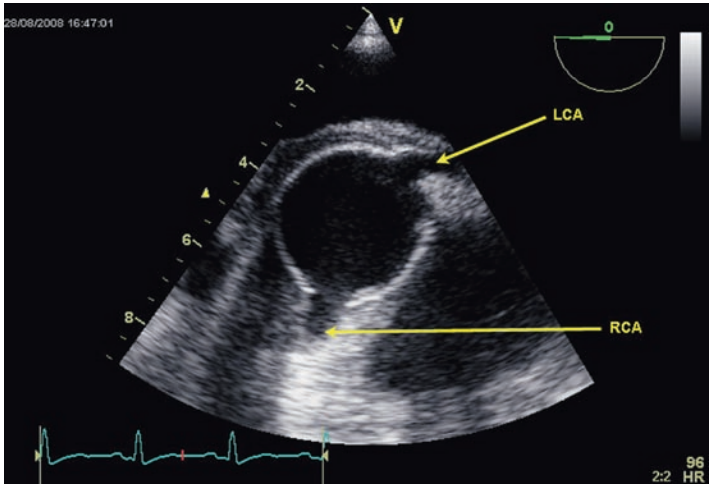

FIGURE 7.1. Aortic root replacement imaged from the mid esophageal aortic/aortic valve short axis view at the level of the left (LCA) and right (RCA) coronary ostia.

they were associated with a high complication rate, and so are no longer implanted. However, occasionally, one still comes across such valves.

7.1.2 Image Planes

The image planes used for assessing valve replacements are generally the same as for evaluating native valves in the same position with minor adjustments being required due to iatrogenic anatomical distortion. From these planes, the valve stability, leaflet motion, forward flow, and regurgitation should be evaluated.

7.1.3 Prosthesis Stability

Two dimensional imaging is used to assess prosthesis stability. As a rule, there should not be any visible mobility of the prosthesis although occasionally, there can be minor rocking of mitral valve replacements if they have been sewn onto remnants of the PMVL

(in order to maintain papillary muscle function). If excess mobility is present, it may be the result of dehiscence.

7.1.4 Leaflet Motion

Biological valves are always trileaflet (irrespective of position implanted), and the motion of the leaflets should resemble that of a native aortic valve. This can be appreciated in all standard views in stentless valve prosthesis, but often requires an "en face" view (Fig. 7.2) to be seen in stented prosthesis due to acoustic shadowing artefact that occurs in other views (Fig. 7.3).

The discs of a normally functioning mechanical prosthesis should open to 80–90° from the closure plane. Usually this is not directly appreciated by TEE as no image plane cuts through the valve replacements at an appropriate angle. Instead the discs tend to be seen end on, and the degree of opening is inferred by the loss of acoustic shadowing artefact (Fig. 7.4a, b).

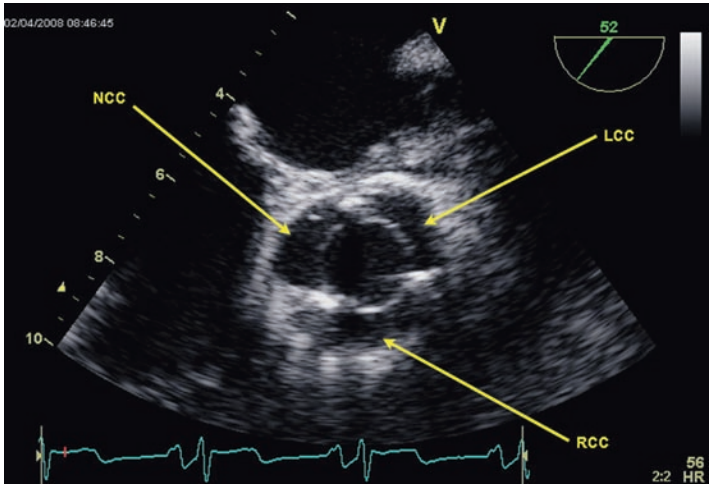

FIGURE 7.2. Stented biological prosthetic valve seen "en face" from the mid esophageal aortic valve short axis view visualizing the left (LCC), right (RCC), and non (NCC) coronary cusps.

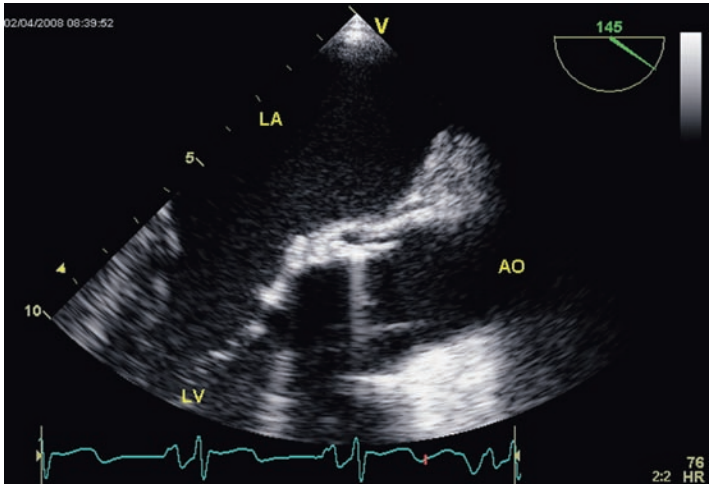

FIGURE 7.3. Stented biological prosthetic valve seen from the mid esophageal aortic valve long axis view with acoustic shadowing artefact. Left atrium (LA), left ventricle (LV), and aorta (AO) visualized.

7.1.5 Leaflet Thickness

This is only relevant for biological valves. In such valves the leaflets should be as thin and mobile as those of a native semilunar valve. As a valve degenerates, the leaflets get thicker (with or without associated calcification), and if they measure more than 3 mm, this suggests severe degeneration and primary failure of the valve.

7.1.6 Forward Flow

Forward flow is evaluated with spectral Doppler (pulsed and continuous wave) in the same way as one would assess a stenotic lesion of a native valve in the same position. Derived parameters can then be compared with normal values for that valve type and size, but bear in mind that normally functioning valves can have higher than normal Doppler-derived parameters (i.e., normal for that individual), and overall trends are more important than one-off measurements. Biological valves have a single orifice, but mechanical prostheses

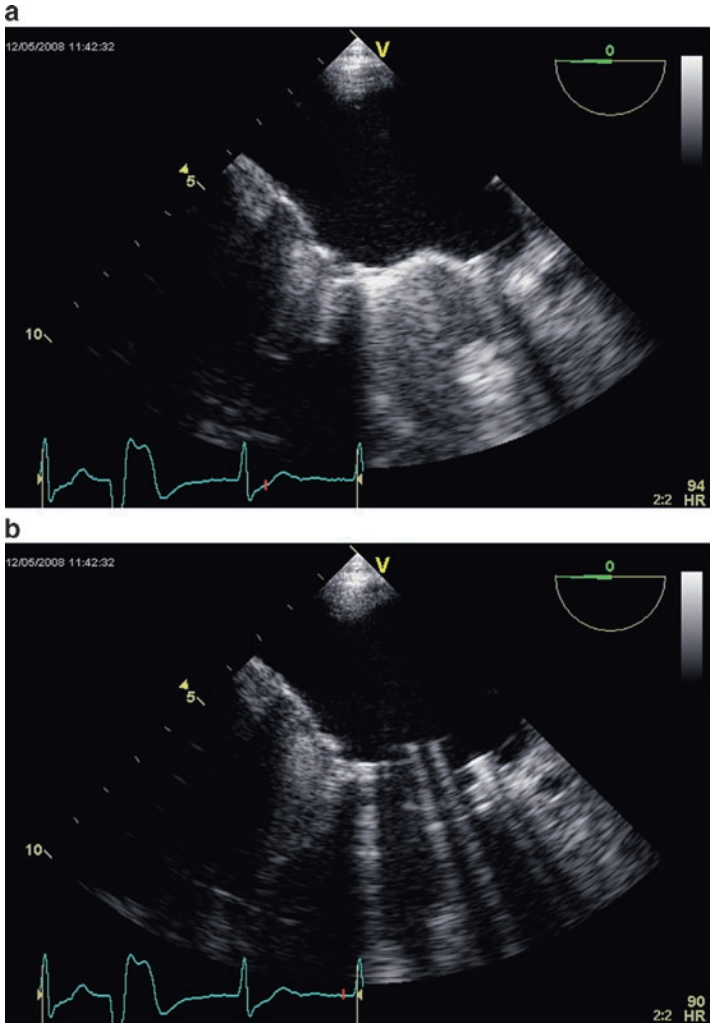

FIGURE 7.4. **(a)** Bileaflet mechanical mitral valve replacement with both discs closed as seen from the mid esophageal 4 chambers view. **(b)** Bileaflet mechanical mitral valve replacement with both discs open as seen from the mid esophageal 4 chambers view; the degree of opening inferred by the loss of acoustic shadowing artefact.

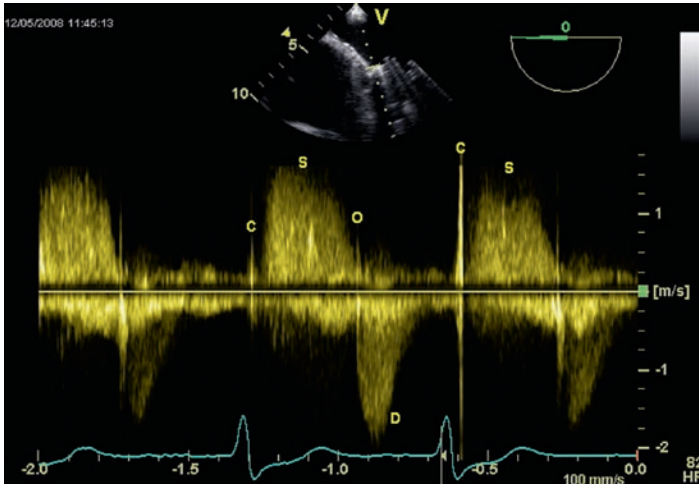

FIGURE 7.5. Continuous wave Doppler trace of a mechanical mitral valve replacement recorded from the mid esophageal 4 chambers view demonstrating high intensity opening (O) and closing (C) artefacts. The patient was in atrial fibrillation; there is normal (diastolic) forward flow (D) and an abnormal (systolic) reverse flow (S) due to a paravalvular leak.

(excepting ball and cage) have multiple orifices with a tilting disc having two (one small and one large) and a bileaflet having three (two large and a smaller central slit); this needs to be borne in mind as the Doppler-derived measurements can vary depending on the sample volume/cursor positioning. In addition to the spectral Doppler trace, the opening and closing artefacts of mechanical valves should be assessed (Fig. 7.5) as they can give early indications of malfunction (e.g., intermittent absence of flow between the opening and closing artefacts, or double opening/closing artefacts [in bileaflet valves when the opening or closing of one leaflet is inhibited by pannus/thrombus]).

7.1.7 Regurgitation

Regurgitation is identified mainly using color Doppler, and can be trans- or paravalvular. Mild transvalvular regurgitation is normal

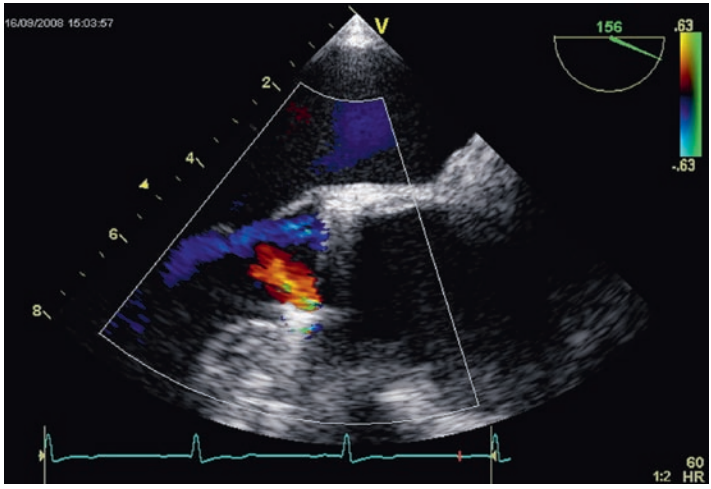

FIGURE 7.6. Mechanical aortic valve replacement seen from the mid esophageal aortic valve long axis view with two convergent (normal) transvalvular washing jets of regurgitation.

in biological valves, but any greater degree of regurgitation suggests degradation of the prosthetic material and primary valve failure. With mechanical valves, transvalvular regurgitation (Fig. 7.6) is not only normal, but essential in order to decrease the risk of thrombus formation. Ball and cage valves have a short phase of regurgitation that only lasts until the ball occludes the valve orifice, but the other valve types are designed to have continuous flow throughout the cardiac cycle such that the regurgitation lasts throughout systole (mitral position) or diastole (aortic position). Tilting disc valve replacements tend to have a large central jet, whereas bileaflet valve replacements have two large hinge jets (and up to ten other smaller jets).

Paravalvular regurgitation (regurgitation originating from outside the sewing ring) on the other hand is never normal (Fig. 7.7). When detected it is described in percentage of sewing ring affected with values over a 1/3 (33%) being considered severe.

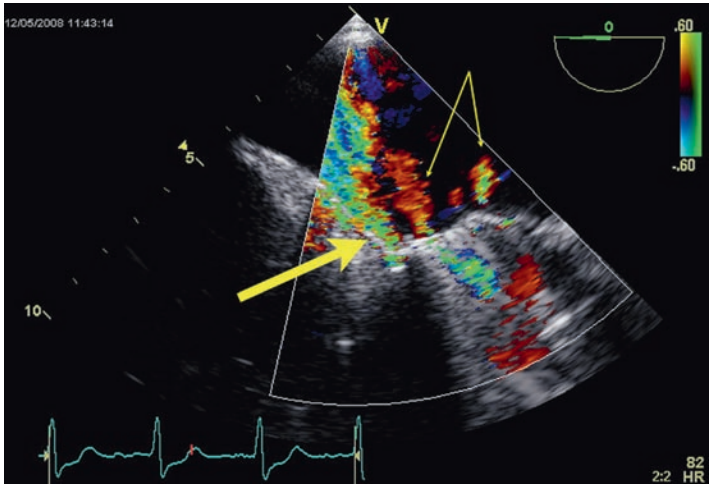

FIGURE 7.7. Bileaflet mechanical mitral valve replacement seen from the mid esophageal 4 chambers view with two small transvalvular (normal) washing jets of regurgitation (thin arrows) and a single large paravalvular (abnormal) jet of regurgitation (*thick arrow*).

7.2 Mitral Valve Replacements

The Doppler-derived parameters that should be reported when evaluating a mitral valve replacement are the peak E wave velocity, the mean transvalvular gradient, and the pressure half time.

All measurements are calculated from continuous wave Doppler recordings usually taken in the mid esophageal 4 chambers view. Pulse wave Doppler is not recommended as the peak velocity may be missed, and often exceeds the Nyquist limit. All values should be compared with normal ranges.

Peak E wave velocity is measured by placing the caliper at the maximal point of the E wave. The measurement should be undertaken with the gain reduced to a minimum.

Mean gradient is derived (by built in software) from the mitral velocity-time integral that is measured when the operator traces around the mitral Doppler recording.

Pressure half time is the time taken for the pressure to fall by a half. As the Doppler recording is effectively a graph of velocity

(*y* axis) against time (*x* axis), and as pressure is proportionate to velocity^2, this equates to the time taken for the velocity to fall to 0.7 of the peak velocity ($0.7^2 = 0.49$ or 1/2 of the peak pressure). The operator places a caliper at peak velocity and a second at 0.7 × peak velocity and then measures the time between the two points. An alternative to this manual method is to use the inbuilt measurement package that allows the operator to place a caliper at the peak velocity, and the echo machine will then produce a straight line that the operator approximates to the spectral trace and the machine will derive a pressure half time (PHT). This latter method is quicker, but is only valid if the pressure decay is linear; it should not be used if the decay is curvilinear (which is often the case).

7.3 Aortic Valve Replacements

The Doppler-derived parameters that should be reported when evaluating an aortic valve replacement are the peak transvalvular velocity, the mean transvalvular gradient, the effective orifice area (EOA), and the dimensionless index (DI).

The measurements are calculated from pulsed and continuous wave spectral Doppler recordings. The left ventricular outflow tract (LVOT) Doppler is gained by placing the pulse wave sample volume within the LVOT from one of the transgastric views. The cursor is aligned with flow and then the sample volume positioned such that it records the velocities immediately proximal to the valve replacement. The aortic (or aortic valve [AV]) Doppler is recorded using continuous wave Doppler from the same view as the LVOT Doppler.

Peak transvalvular velocity is measured by placing the caliper at the maximal point of the aortic signal recorded using continuous wave Doppler. The measurement should be undertaken with the gain reduced to a minimum.

Mean gradient is derived (by built in software) from the aortic velocity-time integral that is measured when the operator traces around the aortic continuous wave Doppler recording.

Effective orifice area is calculated using the continuity equation. The continuity equation is a differential equation, which in fluid dynamics becomes a mathematical statement that, in a steady

state, the rate at which mass enters a system is equal to the rate at which mass leaves the system (i.e., mass is preserved). In echocardiographic terms, the very long and complex equation has become simplified and expressed:

$$\text{LVOT.vti} \times \text{LVOT.csa} = \text{AV.vti} \times \text{AV.csa}$$

that becomes:

$$(\text{LVOT.vti} \times \text{LVOT.csa})/\text{AV.vti} = \text{AV.eoa},$$

where csa is cross-sectional area that in the case of the aortic valve is the same as the effective orifice area (eoa). The LVOT.csa is calculated using the formula for the area of a circle (i.e., csa = πr^2 [where r is half the diameter of the LVOT measured at the level of the hinge points of the valve replacement leaflets/discs in mid systole imaged from the ME AV LAX view]).

The calculated EOA is very important in helping to differentiate increased peak velocities, and mean gradients arising from high stroke volumes (i.e., normal) from those resulting from patient-prosthesis mismatch (small valves implanted into a large patient causing iatrogenic stenosis), and pathological valve failure (primary failure of a bio prosthetic valve or pannus/thrombus formation on a mechanical valve).

	Peak velocity/ mean gradient	Leaflet thickness/ mobility	EOA
Normal	Normal/increased	Normal	Normal
Patient-prosthesis mismatch	Normal/increased	Normal	Decreased
Pathological valve failure	Normal/increased	Increased thickness[a], reduced mobility	Decreased

[a] Increased thickness only relates to biological valves

With respect to classifying the severity of patient-prosthesis, mismatch the diagnostic values relate to the EOA indexed for body surface area (EOAi) with an EOAi < 0.85 indicating definitive

patient-prosthesis mismatch, and a value <0.65 signifying severe patient-prosthesis mismatch. As for pathological valve failure there are no absolute figures to indicate severity with clinical decisions being made on a case by case basis, and often reflecting trends in Doppler measurements as well as patients' symptoms.

Dimensionless index (DI) is a simple ratio of LVOT and AV velocity–time integrals where:

$$\text{DI} = \text{LVOT.vti}/\text{AV.vti}.$$

It obviates the need for LVOT diameter measurement with its inherent inaccuracies (that are squared when the cross-sectional area is calculated), while maintaining the important comparison between stroke volume and transvalvular flow/gradient. The cut off values for normal and abnormal are not as well defined as for the EOA or EOAi, but values greater than 0.5 are probably normal. Values less than 0.25 should be considered as being definitively abnormal. More importantly, the DI and EOA should be concordant and if there is a significant disparity it is essential that the measurements and calculations are looked carefully (usually the discordance relates to errors in measuring the LVOT diameter).

Appendices
Appendix 1: TEE integrated care pathway

Trans oesophageal echocardiogram
Day case admission pathway

Patient label	
Consultant/ Specialist	

Next of kin	
relationship	
address	
Tel no.	
GP	

I have decided to keep my valuable possessions with me on the ward. I understand that in making this decision the trust is absolved from any liability due to loss or theft

SIGNATURE.....

Date admitted		**time**		**Admitting nurse**	

Drug history	**Reason for TOE**
	Current symptoms
	Significant recent deterioration YES NO
BLOOD RESULTS **Date** **Time**	If yes report to operator
Report any abnormal results to SHO	**Past medical history**
FBC **Hb**	
WCC	
Plate	
INR	
OBS	
pulse	
Sats on air	**ALLERGIES**
Blood pressure	

Previous sedation	YES		NO	CANNULA	SITE	SIZE
Comments:						

TOE pre procedure checklist

Previous T.O.E or endoscopy	YES	NO
Previous sedation	YES	NO
Were there any problems. **If yes report problems to operator**	YES	NO
Has patient been starved for 6 hours **If no report to operator**	YES	NO
Any known problems with Nose	YES	NO
Mouth	YES	NO
Throat	YES	NO
Gullet	YES	NO
Stomach	YES	NO
Previous surgery to nose, mouth, gullet or stomach?	YES	NO

If yes to any of the above report to operator

Any recurrent vomiting	YES	NO
Any haematemesis	YES	NO
Difficulty breathing through nose	YES	NO
Unable to swallow food normally	YES	NO

If yes report to operator

Has patient had pre consent information sheet	YES	NO
Has consent been obtained	YES	NO
Have dentures been removed	YES	NO

ANY OTHER COMMENTS:

Pre procedure SAO2 | **Pulse** | **Blood pressure**

Ensure operator is aware of any abnormal results

Sedation ____ **mg of Midazolam given.** **Signed……**

Print Name……

(if outside of normal range 0 – 10 mg complete variance entry)

Throat spray used **YES** **NO**

If yes patient nil by mouth until ____

If any immediate complications please comment below

Procedure result

Post procedure

Post procedure SAO2 | **pulse** | **blood pressure**

Observations				
Time of first BP				
2nd BP 30 mins after above				
3rd BP 1 hour after above				
4th BP 1 hour after above				

oxygen administered at 4 litres **YES** **NO**

if no complete variance sheet

observations must be adjusted as patients condition dictates. Use separate observation chart if varies from above and complete variance sheet

VARIANCE SHEET

DISCHARGE PLANNING

Please record patient satisfaction with procedure

0 1 2 3 4 5 6

very unsatisfied very satisfied

Patient comments

Prior to discharge

Has patient been seen by operator yes no

Is someone available to stay with patient overnight yes no

Does patient have transport yes no **who?** _____ **when** _____

Have patients medications been returned to them yes no

Has patient been given their TTO yes no

Has cannula been removed yes no

Date _____ **time of discharge** _____ **nurse initials** _____

ALL ANSWERS MUST BE YES TO ALLOW DISCHARGE

If unable to discharge please write reasons below

Appendix 2: Guidance for diabetic patients undergoing TEE

Addenbrooke's NHS Trust

GUIDELINES FOR PATIENTS WITH INSULIN TREATED DIABETES PRIOR TO TRANSOESOPHAGEAL ECHOCARDIOGRAM

- You will require an early morning appointment

If you have 4 or 5 injections of insulin a day (i.e. 3 doses of quick acting with 1 or 2 doses of long acting):

Evening before procedure
- Take ½ of your normal bedtime insulin (this includes *Lontus*)

Morning of procedure
- No insulin (or breakfast) before the procedure
- Take 2/3 of your normal morning dose after procedure with breakfast. This includes long acting insulin if you take it in the mornings
- Take normal doses after this.

If you have 3 injections of insulin a day, or 4 and are free-mixing, or 1 injection with tablets:

As your regime is likely to be complex, please contact the diabetic specialist nurses for advice
Telephone 01223 245151 bleep 152-078

If you have 2 injections of insulin a day:

Evening before procedure
- Take your normal dose of *humulin 1*, *insulatard*, *mixtard*, *novamix* 30, *humalog mix 25, & humalog mix 50* insulins
- Do not take *ultratard* or *monotard* insulins

Day of procedure

- No insulin (or breakfast) before the procedure
- Take 2/3 of your normal morning dose after the procedure with breakfast
- Take your normal evening dose

If you require any further advice on managing your diabetes during this preparation, please contact the diabetes specialist nurse on 01223 245151 bleep 152 078

GUIDELINES FOR PATIENTS WITH TABLET TREATED DIABETES PRIOR TO TRANSOESOPHAGEAL ECHOCARDIOGRAM

- You will require an early morning appointment

Evening before procedure

- Omit tablets

Day of procedure

- No tablets or breakfast before the procedure. Bring both with you, and have your normal dose after the procedure

GUIDELINES FOR PATIENTS WITH DIET TREATED DIABETES PRIOR TO TRANSOESOPHAGEAL ECHOCARDIOGRAM

- No special precautions necessary

IMPORTANT INSTRUCTIONS FOR ALL PATIENTS WITH DIABETES

- Test your blood sugar before leaving home. If it is low, suck a glucose sweet and bring some with you for the journey in case you feel your sugar level dropping again.

Appendix 3: Patient information booklet
Transoesophageal Echocardiogram

This leaflet is for patients who are having an ultrasound scan of the heart from the oesophagus (the gullet), known as transoesophageal echocardiogram (TOE). It explains what it is for, what it involves and any possible risks.

What is a transoesophageal echocardiogram?

An echocardiogram is a scan of the heart using ultrasound (sound waves, not x-rays). It produces moving pictures of the heart as it is beating and shows the blood flowing through the heart valves. Clearer and more accurate pictures can be obtained from the oesophagus, as it lies immediately behind the heart and there is no interference from the ribs or lungs.

Why do I need it?

Pictures of your beating heart are produced on a screen monitor, so the doctor can tell whether or not your heart muscle is contracting properly and that your heart valves are working normally. Other heart problems may also be identified.

Are there any alternatives?

This type of echocardiogram is usually requested to investigate valve problems, look for holes in the heart or to see if there are any blood clots, tumours or infections inside the heart; it is the best way to diagnose these. Alternatives are sometimes a CT scan or MRI scan, although neither provide images as good as the echocardiogram.

What will happen if I don't have it?

Your doctor may be unable to diagnose and treat the cause of your symptoms.

How do I prepare for it?

- It is important that you do not eat or drink anything for at least 4 hours before the scan.
- Continue to take your normal medications (including Warfarin), unless told otherwise by your doctor. Take them with a sip of water (at least 2 hours before your procedure).
- If you are diabetic you will require additional instructions; these will be given in writing when you receive your appointment.
- Please arrange for a responsible adult to accompany you to your examination as you may need to be taken home after having a sedative.

On the day of your examination

A doctor will usually do your scan. Before your scan you will be asked various questions by a nurse or doctor and you will be asked to sign a consent form to confirm that you understand the procedure and agree to go ahead with it. Please ask any questions you want.

Please tell the nurse or doctor if you have:

- Had surgery to *and/or* if you have any known problems with your nose, throat or neck.
- Difficulty breathing through your nose.
- Had surgery to *and/or* if you have any known problems with your mouth, gullet or stomach.
- Difficulty in swallowing *and/or* if you have ever vomited up blood.

If so, it may be necessary to examine your throat and oesophagus (gullet) more closely to check that there is no obstruction or bleeding problem.

Please also tell the nurse or doctor if you have:

- An allergy to latex® (rubber) and/or lignocaine/xylocaine (local anaesthetic).
- Any food allergies (particularly an allergy to eggs).
- Any reason to believe that you are pregnant.

What does it involve?

1. The scan will take place in a private room.
2. You will be given a hospital gown to wear and then asked to lie on a bed (on your left hand side).
3. You will need to remove any dentures or glasses.
4. Your throat may be sprayed with an anaesthetic spray to numb it. You may be given a sedative (through a needle in your arm called a venflon/cannula) to help you relax.
5. We will monitor your oxygen levels with a clip lightly attached to a finger or your ear. We will give you extra oxygen through your nose.
6. A plastic bite guard will protect your front teeth and the probe. The doctor will ask you to swallow the ultrasound probe.
7. Once the probe is in place, pictures are taken of your heart. You can breathe through your nose or mouth (preferably through your nose as this helps with image quality).

How long does it take?

The examination takes about 10 to 30 minutes.

Will I have any pain or discomfort?

Swallowing the ultrasound probe is rather unpleasant, but should not be painful. Once the probe is in place it is only slightly uncomfortable.

Additional procedures

Occasionally a contrast study may be needed during your examination, using a liquid (contrast) to outline certain areas of your heart. This involves having a small injection into a vein in your arm (through the venflon/cannula). There are different types of contrast; they are harmless but some should not be used if you have certain allergies (particularly an allergy to eggs) so if you have any food allergies tell the doctor who is performing the TOE.

What happens afterwards?

After returning to the ward we advise patients to stay at least until they have had something to eat and drink and feel steady on their feet. The doctor will usually explain the results of the TOE to you; this will probably be done after he has completed all the patients on the list (i.e. at the end of the morning or afternoon) and we encourage patients to wait until they have seen the doctor. The results of your examination will be sent to the doctor who requested it.

If you had a sedative injection

You will need to stay in hospital for at least 2-3 hours to recover. You must arrange for a responsible adult to accompany you home and stay with you overnight (minimum 12 hours) as the sedative may affect your balance, memory and ability to perform certain tasks. Most specifically you must not swim, drive, operate machinery (including equipment such as the cooker, iron or kettle), return to work, drink alcohol or sign any legally binding documents for the next 24 hours.

If you had the throat spray

Don't have anything to eat or drink for one hour and nothing hot for 4 hours until the spray to numb your throat has worn off.

Are there any risks?

This is a very safe examination. Complications are rare, but may include or trauma to your gullet or stomach, leading to trauma or bleeding, which may require an operation (less than 1 in 1000). Dislodgement or damage to your teeth/crowns/dental bridgework can also occur but again is a rare complication.

If you have certain types of contrast study, there is a very small risk of an allergic reaction to the contrast.

For some patients the risks may be higher; please speak to your specialist doctor before your examination if you have any worries.

Any further questions?

If you need any more information or have any queries, please contact the Department of Echocardiography at Addenbrooke's Hospital via the switchboard on 01223 245151 or contact your Cardiologist (heart specialist) through their secretary.

Further support and information are available from the:

British Heart Foundation
08450 70 80 70
www.bhf.org.uk

British Cardiac Society
020 7383 3887
www.bcs.com

Appendix 4: TEE pre-consent information sheet

Toe Pre-Consent Information Sheet

Please read this information sheet carefully and ask questions before you decide whether or not to consent to the procedure.

Remember that you can withdraw your consent at any time even after signing a consent form.

Intended Benefits

- By taking pictures from the gullet it is possible to visualise your heart more clearly than other techniques.
- The results of this test will help your specialist to decide on the best treatment for you.

Potential Complications

- It is likely you will have a sore throat after the procedure. You may also have some minor bleeding in your mouth.
- More serious complications are rare but include:
- Dislodgement/damage to your teeth (1 in 500).
- Trauma to your gullet or stomach leading to damage/haemorrhage (bleeding) which requires an operation (less than 1 in 1000).

(Figures in brackets indicate the approximate risk of suffering that complication. For example 1 in 500 means that for every 500 operations/procedures performed 1 person will suffer from that complication).

Appendix 5: TEE specific consent form

Addenbrooke's NHS Trust

For staff use only:

Patient Details:
Surname:
First names:
Date of birth:
Hospital no:
Male/Female:
(Use hospital identification label)

Department of Cardiology

Patient agreement to investigation or treatment

Name of procedure: Transoesophageal echocardiogram

This information is for patients having an ultrasound (scan) of the heart from the oesophagus (the gullet), known as a transoesophageal echocardiogram.

Like other types of echocardiogram (eg ones taken from the front of the ribcage), it produces moving pictures of the heart as it is beating. It also shows the blood flowing through the heart valves. Using this type of scan, clearer and more accurate pictures can be obtained than by other routes. This is because the oesophagus lies immediately behind the heart and there is, therefore, no interference from the ribs or lungs. In this information we outline what the procedure involves and any significant risks with it.

Please bring this form with you to hospital.

You will be asked to read this form carefully and you and your doctor (or other appropriate health professional) will sign it to document your consent.

For staff use:

Does the patient have any special requirements? (eg interpreter or other communication method)

.....

.....

.....

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Transoesophageal echocardiogram

Before treatment

- It is important that you do not eat or drink anything for at least four hours before the test. You should continue to take your normal medications during this period (including warfarin) unless instructed to do otherwise by the doctor. Please take any medications with just a sip of water.
- You can discuss any concerns about the operation with the staff present.
- You will be given a sedative to make the procedure more comfortable; please arrange for a responsible adult to accompany you to and from the examination to help you home safely.
- Please make sure that you tell the doctor if you have
  - Had previous surgery to the throat or neck;
  - Difficulty in swallowing dry foods such as toast;
  - Ever coughed up a large amount of blood.

  This is because it might be necessary to examine your throat and oesophagus more closely than usual to check that there is no obstruction that might cause problems during the procedure.

During treatment

- The echocardiogram procedure itself takes about 10 minutes. A doctor will usually do the scan, and this will take place in a 'private' room.
- Before the procedure, you will be given a hospital gown and asked to lie on the bed.
- A plastic bite guard protects your front teeth. If you have dentures, you will need to remove them.
- Your throat will be sprayed with an anaesthetic spray to numb it.
- Your oxygen levels will be monitored with an oxygen probe, which is lightly attached to your finger. You might also be given extra oxygen via your nose, if necessary.
- The doctor will ask you to swallow the ultrasound probe. This is not very pleasant, but should not be painful. To make this more comfortable we advise most people to accept a sedative injection, which relaxes you and can make it easier.
- The sedation is usually injected through a small needle or tube in the veins of your hand or arm. People who have this conscious sedation are much more relaxed but are still awake. They also have little or no memory of the event. However, the sedation itself can leave you feeling a little sick and usually drowsy for a few hours afterwards.
- Once the echocardiogram probe is in place, it is only slightly uncomfortable. At this stage images (pictures) can be taken of your heart in action.
- During this time, you can breathe normally through your nose or mouth.
- The pictures of the beating heart are produced on a monitor screen, so the doctor can tell in more detail whether or not the heart muscle is contracting properly and the heart valves are working normally; other heart problems can often be identified.

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- Occasionally a 'contrast study' is needed during the procedure. In this modified scan, contrast liquid is used to outline particular areas of the heart. If this is required, you will have an additional small injection into a vein in your arm. The contrast is harmless except with certain allergies (particularly an allergy to eggs).

After treatment

If you had a sedative injection
You will need to stay in hospital for one to two hours to recover. Then you must arrange for a responsible adult to accompany you home. You must not drive, operate machinery (including the cooker or kettle) for the rest of the day.
If you did not have a sedative injection
You can get dressed again and go home when you are feeling ready. You should not have anything to eat or drink for 30 minutes and nothing hot for 90 minutes, ie until the anaesthetic spray used to numb your throat has worn off.

The results of your examination will be sent to the doctor who requested it who will contact you.

Serious or frequently occurring risks

- This is a very safe test with few frequent and no serious risks.
- There is very small risk of damage to the oesophagus, which might be more likely if you have had a previous history of injury or disease.
- If you have a contrast transoesophageal echocardiogram, there is a risk of slight bruising around the site of the injection (in your arm); there is also a very small risk of an allergic reaction to the contrast fluid itself. If you have a reaction we can give you medication and support to help.
- For some patients, the risks may be higher than usual. Please speak to your doctor before your operation if you have any worries.

For staff use only:
Surname:
First names:
Date of birth:
Hospital no:
Male/Female:
(Use hospital identification label)

Patient agreement to investigation or treatment

Name of proposed procedure or course of treatment
(include brief explanation if medical term not clear)

Transoesophageal echocardiogram

Statement of health professional

(To be filled in by a health professional with an **appropriate knowledge of the proposed procedure**, as specified in the Hospital's consent policy)

I have discussed the procedure with the patient and explained the following

- How it will be performed for them.
- The intended benefits of the procedure.
- Serious or frequently occurring risks and what can be done to reduce, detect and treat them.
- Any extra procedures that might become necessary during the procedure

❑ Blood transfusion

❑ Other procedure (please specify)

.....

I have also discussed what the procedure is likely to involve, the benefits and risks of any available alternative treatments (including no treatment) and any particular concerns of this patient.

This procedure will involve: ❑ Local anaesthesia ❑ Sedation

Health professional's signature..... Date: .....

Name (PRINT): ..... Job title:.....

❑ I have offered the patient information about the procedure but s/he has refused information.

Statement of the interpreter (if appropriate)

I have interpreted the information to the best of my ability, and in a way in which I believe the patient and/or the person signing on their behalf can understand:

Interpreter's signature..... Date: .....

Name (PRINT): ..... Contact details: .....

Statement of patient

For the patient: If your treatment has been planned in advance, you should already have your own copy of this consent form, which describes the benefits and risks of the procedure. If not, you will be offered a copy now. Do ask if you have any further questions. The staff at Addenbrooke's are here to help you. **You have the right to change your mind at any time before the procedure is undertaken, including after you have signed this form.**

Training doctors and other health professionals is essential to the continuation of the Health Service and improving the quality of care. Your treatment may provide an important opportunity for such training, where necessary under the careful supervision of a senior doctor. You may, however, decline to be involved in the formal training of medical and other students without this adversely affecting your care and treatment.

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Please tick boxes to indicate you have understood and agree to the statements below.

- ❑ **I agree** to the procedure (or course of treatment) described on this form.
- ❑ **I agree** to the use of photography for the purpose of diagnosis and treatment.
- ❑ **I agree** to photographs being used for teaching in medical schools.
- ❑ **I understand** that you cannot give me a guarantee that a particular person will perform the procedure. The person will, however, have appropriate experience.
- ❑ **I understand** that any tissue removed as part of the procedure or treatment may be used for diagnosis, stored or disposed of as appropriate and in a manner regulated by appropriate, ethical, legal and professional standards.
- ❑ ***I agree** that tissue removed and the results of diagnostic tests, may be used for teaching, audit and research that could benefit other patients (including genetic research and research by commercial companies). *Delete as appropriate.
- ❑ **I understand** that any procedure in addition to those described on this form will only be carried out if it is necessary to save my life or to prevent serious harm to my health.
- ❑ **I have been told** about additional procedures that might become necessary during my treatment.
- ❑ I have listed below any procedures that **I do not wish, without further discussion, to be carried out**.

.....

.....

Patient's own signature : ..... Date: .....

Name (PRINT): .....

If the patient is unable to sign but has indicated his/her consent, a witness should sign below.

Witness's own signature : ..... Date: .....

Name (PRINT): .....

Confirmation of consent by health professional : (If patient has signed in advance please sign in confirmation that he/she wishes to proceed).

On behalf of the team treating the patient, I have confirmed with the patient that s/he has no further questions and wishes the procedure to go ahead.

Health professional's signature: ..... Date:.....

Name (PRINT): ..... Job title .....

Important notes: (tick if applicable)

- ❑ The patient has withdrawn consent (ask patient to sign/date here) .....
- ❑ See also advance directive/living will (eg Jehova's Witness form)
- ❑ The patient has been given a copy of this signed form (the top copy is in the patient's records)

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