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Recommendations for transoesophageal echocardiography: update 2010

F.A. Flachskampf[1]*, L. Badano[2], W.G. Daniel[1], R.O. Feneck[3], K.F. Fox[4], Alan G. Fraser[5], Agnes Pasquet[6], M. Pepi[7], L. Perez de Isla[8], and J.L. Zamorano[8] for the European Association of Echocardiography; endorsed by the Echo Committee of the European Association of Cardiothoracic Anaesthesiologists

Document Reviewers: J.R.T.C. Roelandt[a] and L. Piérard[b]

[1]Med.Klinik 2, University of Erlangen, Erlangen, Germany; [2]Department of Cardiology, University of Padova, Padova, Italy; [3]Department of Anaesthesia, St Thomas' Hospital London, London, UK; [4]Imperial College, London, UK; [5]Wales Heart Research Institute, School of Medicine, Cardiff University, Cardiff, UK; [6]Cliniques Universitaires St Luc de Bruxelles, Brussels, Belgium; [7]Centro Cardiologico Monzino IRCCS Milan, Italy; [8]University Clinic San Carlos, Madrid, Spain

[a]Department of Cardiology, Thoraxcentre, Erasmus MC, Rotterdam, The Netherlands; and [b]Department of Cardiology, Université de Liège, Liège, Belgium

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Transoesophageal echocardiography (TOE) is a standard and indispensable technique in clinical practice. The present recommendations represent an update and extension of the recommendations published in 2001 by the Working Group on Echocardiography of the European Society of Cardiology. New developments covered include technical advances such as 3D transoesophageal echo as well as developing applications such as transoesophageal echo in aortic valve repair and in valvular interventions, as well as a full section on perioperative TOE.

Keywords Transoesophageal echocardiography • Interventional cardiology • 3D echocardiography

Introduction

Since its introduction in the 1980s, transoesophageal echocardiography (TOE) has become a standard and indispensable technique in clinical practice. It should be available in every echocardiographic laboratory as well as in every centre performing cardiac surgery. The present recommendations represent an update and extension of the recommendations published in 2001 by the Working Group on Echocardiography of the European Society of Cardiology,[1] the precursor of the present European Association of Echocardiography. Technology has evolved considerably, as multiplane TOE has become standard and real-time three-dimensional TOE is now increasingly used. Large clinical experience has been gathered in all typical indications, including the universal acceptance of TOE as an important intra-operative tool especially in valve repair.[2] As stated in 2001, these recommendations are not intended as a comprehensive review of the technique, which is available in many textbooks, but rather as a statement of current standards in indications, patient preparation and safety precautions, and performance of the procedure according to diagnostic requirements.

Training and competence

In order to provide patients with a clinically useful TOE, the operator must be competent in the procedure, the environment and supporting team must be appropriately equipped and trained, and a programme of quality control should be in place to ensure the validity and reproducibility of the reports issued. Individual competence requires acquisition of knowledge and practical skill during a period of supervised training. Few data exist on the amount of training required to achieve competency, but a number of organizations have specified the contents of a training programme. Evidence of competency is established through completion of a training programme, but specific accreditation in TOE is being increasingly recognized. The joint European Association of Echocardiography (EAE) and European Association of Cardiothoracic Anaesthesiologists (EACTA) accreditation requires individuals to train under a supervisor, to pass a multiple choice question exam testing theoretical knowledge and image interpretation, and to submit a log book of 125 procedures undertaken (75 if the applicant already holds transthoracic echo accreditation). The

* Corresponding author. Tel: +49 9131 853 5301, Email: frank.flachskampf@uk-erlangen.de

Table 1 Studies required to achieve competence/undertake accreditation of various organizations and their re-accreditation requirements, together with web source

Organization	Studies	Exam	Re-accreditation (studies/CME)
EAE/EACTA accreditation, www.escardio.org	125 (75 if TTE accredited)	Yes	50 studies/year and 30 h CME over 5 years
ACC/ASE guidance, http://www.asefiles.org/COCATS.pdf	125 (TOE) 150 (Intraop)	N/A	–
NBE TOE accreditation, www.echoboards.org	300	Yes	After 10 years; >50 in 2 of last 3 years; 15 h CME in last 3 years
ACTA; BSE accreditation; www.bsecho.org	125 (75 if TTE accredited)	Yes	After 5 years; 40 studies/year and 15 h CME over 5 years

ACTA, Association of Cardiothoracic Anaesthetists; ASE, American Society of Echocardiography; ACC, American College of Cardiology; BSE, British Society of Echocardiography; CME, continuing medical education; EACTA, European Society of Cardiac Anaesthesiologists; EAE, European Association of Echocardiography; N/A, not applicable; NBE, National Board of Echocardiography (USA); TTE, transthoracic echocardiography.

reports are graded by external examiners. Individual competence must be maintained by continuing practice and learning.[3] EAE/EACTA accreditation is valid for a period of 5 years and then re-accreditation requires submission of evidence of continued practice and learning on a 5-yearly basis. *Table 1* lists the requirements of different organizations for competence or accreditation together with the requirements for re-accreditation in TOE. Minimum standards for a TOE echo laboratory have been established by the EAE,[4] with recommended minimum room sizes of 20 m^2, cleaning and sterilizing equipment, suction, oxygen supply, resuscitation equipment with facilities to monitor ECG, blood pressure, saturation, and recover patients after TOE. Room size may be less relevant in theatres or in intensive care units. Quality control is an important criterion for accrediting TOE laboratories.

Indications

In general, TOE is indicated whenever the transthoracic examination is inconclusive and the potential new information is important enough to warrant the very small risk and moderate discomfort of the procedure. Typically, this involves clinical questions about cardiovascular structures that are not seen well or not seen at all from the transthoracic approach, such as the left atrial appendage, the pulmonary veins, the atrial septum, or the thoracic aorta, and also clinical questions where the best available image quality is of crucial importance, such as in infective endocarditis or the assessment of prosthetic valves.[5,6] In patients who are extremely difficult to examine transthoracically (e.g. postoperative and ventilated patients), this may include classic indications for transthoracic echocardiography, such as the evaluation of left ventricular function. The principal indications are given in *Table 2*. Furthermore, an important field for TOE is intra-operative monitoring during cardiac surgery or peri-interventional imaging, e.g. in percutaneous valve interventions or positioning of occluding devices for atrial septal defects, patent foramen ovale, ventricular septal defects and paraprosthetic leaks, or electrophysiological procedures.

Risks and precautions

Serious complications of TOE are very rare.[7,8] A recent review listed four deaths attributed to the procedure in over 40 000 TOE examinations. Major complications included laryngospasm, arrhythmias including cardiac arrest, oesophageal perforation, and haemorrhage from oesophageal tumour.[8] For comparison, a recent gastroenterological survey of over 100 000 cases of upper gastrointestinal endosonographic procedures found a mortality of 0.01% and a perforation rate of 0.03%.[9] Any true resistance to introduction of the probe, which may occur due to entrapment of the probe tip in the piriform recess, an oesophageal diverticulum, an oesophageal obstruction, e.g. a tumour, or due to hiatus hernia, should be respected and the procedure aborted. Upper endoscopy should then be performed prior to a new attempt. Note that oesophageal perforation may manifest in a delayed fashion with fever, neck pain, and subcutaneous emphysema. Death during or immediately after TOE has been reported in patients with acute aortic dissection, where the putative mechanism was retching and an attending sharp surge in blood pressure. Therefore, in the context of aortic dissection, blood pressure must be tightly controlled during the procedure by administration of sedatives and/or titration of blood pressure. Anticoagulation or thrombocytopenia entail an enhanced bleeding risk but are not absolute contraindications to TOE. Bradycardia or tachycardia may occur, especially during probe introduction. Sedation may lead to hypoxia and apnoea. If sedatives are used, after TOE patients should be allowed to recover in the recumbent position under surveillance. Duration of effect depends on sedative type and dose and for midazolam typically ranges between 20 and 80 min, although assessment of recovery should be individualized.[10,11] Rarely, methemoglobinaemia due to the topical anaesthetic agents prilocaine and benzocaine, in particular, has been observed.[12] Endocarditis prophylaxis is not recommended for TOE; however, instrument cleaning and disinfection prescriptions must be observed carefully. Electrical current leakage may occur after damage to the probe, such as from the patient's teeth; therefore, the probe has to be inspected after each use for damage. Periodic leakage current tests are also recommended by the manufacturers.

Table 2 Principal TOE indications: essential views and structures in specific clinical situations (reproduced, with permission, from Reference 1)

1) Search for a potential cardiovascular source of embolism
Left ventricular apex or aneurysm (transgastric and low-transoesophageal two-chamber views)
Aortic and mitral valve (look for vegetations, degenerative changes, or tumours, e.g. fibroelastoma)
Ascending and descending aorta, aortic arch
Left atrial appendage (including pulsed wave Doppler); note spontaneous contrast
Left atrial body including atrial septum; note spontaneous contrast
Fossa ovalis/foramen ovale/atrial septal defect/atrial septal aneurysm; contrast + Valsalva
2) Infective endocarditis
Mitral valve in multiple cross-sections
Aortic valve in long- and short-axis views; para-aortic tissue (in particular short-axis views of aortic valve and aortic root) to rule out abscess
Tricuspid valve in transgastric views, low oesophageal view, and right ventricular inflow-outflow view
Pacemaker, central intravenous lines, aortic grafts, Eustachian valve, pulmonic valve in high-basal short-axis view of the right heart (inflow–outflow view of the right ventricle)
3) Aortic dissection, aortic aneurysm
Ascending aorta in long- and short-axis views; note maximal diameter, flap, intramural haematoma, para-aortic fluid
Descending aorta in long- and short-axis views; note maximal diameter, flap, intramural haematoma, para-aortic fluid
Aortic arch; note maximal diameter, flap, intramural haematoma, para-aortic fluid
Aortic valve (regurgitation—note mechanism, annular and aortic diameters, number of cusps)
Relation of dissection membrane to coronary ostia
Pericardial effusion, pleural effusion
Entry/re-entry sites of dissection (use colour Doppler)
Spontaneous contrast or thrombus formation in false lumen (use colour Doppler to characterize flow/absence of flow in false lumen)
4) Mitral regurgitation (note systolic or mean blood pressure)
Mitral anatomy (transgastric basal short-axis view, multiple lower transoesophageal views). Emphasis on detection of mechanism and origin of regurgitation (detection and mapping of prolapse/flail to leaflets and scallops, papillary muscle and chordal integrity, vegetations, paraprosthetic leaks)
Colour Doppler mapping of regurgitant jet with emphasis on jet width and proximal convergence zone
Left upper pulmonary, and, if eccentric jet present, also right upper pulmonary venous pulsed Doppler
5) Prosthetic valve evaluation
Morphologic and/or Doppler evidence of obstruction (reduced opening/mobility of cusps/disks/leaflets and elevated velocities by CW Doppler)
Morphologic and Doppler evidence of regurgitation, with mapping of the origin of regurgitation to specific sites (transprosthetic, paraprosthetic); presence of dehiscence/rocking of prosthesis
Presence of morphologic changes in the prosthetic structure: calcification, immobilization, rupture, or perforation of bioprosthesis leaflets; absence of occluder in mechanical prostheses
Presence of additional paraprosthetic structures (vegetation/thrombus/pannus, suture material, strand, abscess, pseudoaneurysm, fistula)

Patient preparation and equipment

It is mandatory to ask every conscious patient in advance about swallowing problems and any history of oesophageal disease, such as strictures, diverticula, tumours, or recent gastro-oesophageal surgery. A discussion with the patient about the procedure, risks, and benefits, including implications of topical anaesthesia (oral intake should be avoided for ~2 h after the examination) and sedation (e.g. unfitness for driving for at least 12 h), should precede the examination. Informed consent is mandatory in conscious patients and should be documented. At least a 4 h fast (preferably 6 h, with clear liquids allowed until 2 h prior to the examination) before TOE should be observed, except in emergency situations; the possibility of diabetic gastroparesis should be kept in mind.

TOE should be performed with multiplane equipment. The ECG must be monitored throughout the procedure. An intravenous line should be in place both for sedation and in the event of complications, and a supply of oxygen as well as equipment for suction should be at hand, especially if sedation is used. Blood pressure and oxygen saturation monitoring, including baseline values prior to the examination, are desirable. Dental fixtures have to be removed, and a bite guard should be in place. Topical oropharyngeal anaesthesia with an agent such as lidocaine is usually given. Sedatives should be used sparingly, if needed, especially in frail or severely compromised patients. A typical dose in a stable patient is 2–4 mg of intravenous midazolam (0.075 mg/kg), but lower doses may be sufficient; other sedatives or analgesics such as fentanyl may be used instead. Whenever sedatives are used, availability of and experience with resuscitation equipment are mandatory. A benzodiazepine antagonist, e.g. flumazenil (0.3–0.6 mg), must be available. The instrument tip has to be unlocked regarding flexion and extension during intubation of the oesophagus. Awake patients are usually examined in the lateral decubitus position, to facilitate drainage of saliva, but introduction of the instrument is sometimes easier with the patient sitting upright. In ventilated patients, use of a laryngoscope can facilitate oesophageal intubation. After each examination, probes have to be disinfected, inspected for damage, and checked for electrical safety according to manufacturer's guidelines.

Documentation

Video recording or digital documentation of the examination is mandatory. A written report and a log of examinations, the use of echo contrast, adjunctive medication, and examiners must be kept. In the report, it is desirable (especially with computerized report generation) to specify whether certain cardiac structures have or have not been studied. It is mandatory to note all side effects and complications.

General course of the examination

Unlike transthoracic echocardiography, TOE is uncomfortable for the patient. Therefore, the duration of the examination must be

limited, and the procedure cannot be repeated frequently. The examiner should aim to ensure that

(1) the diagnostic goal is satisfied,
(2) the structures not well visualized by transthoracic echo are thoroughly investigated (e.g. the left atrial appendage and the aorta), and
(3) the study is complete.

Thus, depending on patient tolerance and circumstances, the examiner may restrict the examination to just one critical structure, such as scanning the left atrial appendage and left atrium to rule out thrombi before the electrical cardioversion of atrial fibrillation. On the other hand, in the sedated or anaesthetized patient, a systematic and thorough approach, satisfying all three listed goals, will ensure maximal diagnostic benefit from the procedure.

Analogous to transthoracic echocardiography, TOE views are mainly defined by internal landmarks, not by specification of probe position and plane angulation. Where degrees of viewing plane are given, 0° denotes a transverse and 90° a vertical view, with clockwise plane rotation when looking in the direction of the ultrasound beam. Plane rotation (or switching from transverse to longitudinal in biplane probes), shaft rotation, anteflexion, retroflexion, and sideward flexion of the tip, and finally probe advancement and withdrawal are the manoeuvres available to the examiner to change the view. Anteflexion flexes the tip mechanically upwards anteriorly, thereby usually improving contact with the anterior gastric or oesophageal wall, and retroflexion flexes it upwards posteriorly, thereby often deteriorating transducer contact with the gastric or oesophageal wall. Sideward (lateral) flexion (to the right or left of the transducer face) can be used instead of plane rotation to fine tune views and improve contact with oesophageal or gastric wall, but is less important with the use of multiplane transducers. Probe shaft rotation is described as clockwise or counterclockwise as seen from the examiner's viewpoint looking down the shaft of the probe.

The following description is intended to outline a complete examination. Pathological findings or special questions may necessitate a more detailed examination of particular structures, which is beyond the scope of this article.

The typical TOE examination comprises three major steps:

- the proper transoesophageal examination, which may be conceptually divided into lower oesophageal views, mainly to image the ventricles, and upper transoesophageal views, mainly to image the valves, atria, and great vessels. However, sharply defined transducer positions or windows do not exist, since they vary individually and have to be adjusted for each view. Often, upper and lower transoesophageal views can be obtained from approximately the same transducer position by flexing or extending the tip of the transducer, since the optimal oesophageal window often is small.
- the transgastric examination
- the examination of the aorta.

The sequence of these elements may be chosen individually; many operators start with transoesophageal views, followed by transgastric views, and finally visualize the descending aorta and aortic arch pulling the instrument back from the position in the gastric fundus. Although any number of additional views may be necessary to better delineate pathological findings (e.g. vegetations, thrombi, etc.), the italicized views are essential for a complete TOE examination, and colour Doppler, pulsed, and continuous wave Doppler should be used as indicated.

Lower transoesophageal views

With the imaging plane in the transverse position, immediately above the diaphragm the orifice of the inferior vena cava, the right atrium, and the tricuspid valve are visualized in a long-axis view (*Figure 1*). Adjacent to the septal tricuspid leaflet, the orifice of the coronary sinus may be seen, which courses upwards (towards the transducer). The anterior (or sometimes posterior) tricuspid leaflet is seen to the left, and the septal to the right.

Slightly further up, a (foreshortened) *transoesophageal four-chamber view* is obtained (*Figure 2*). Sometimes a low degree of rotation (10–20°) is useful to exclude the aortic valve. The probe should be straightened before withdrawal from the stomach to minimize foreshortening, as long as image quality is maintained. In the transoesophageal four-chamber view, the left ventricle is on the right side of the sector and the right ventricle on the left. The left atrium is on top, and septal and lateral walls of the left ventricle, as well as the right ventricular free wall, are seen. The anterior mitral leaflet is seen on the left and the posterior on the right side; the septal tricuspid leaflet is on the right side and the anterior tricuspid leaflet on the left side. The *transoesophageal two-chamber view* (*Figure 3*) is obtained at ~60–90°, with the convex anterior wall to the right, the straight inferior wall to the left, and the apex in the far field. The posterior mitral leaflet is on the left side and the anterior leaflet on the right side. Frequently, the left atrial appendage is seen on the right side of the base of

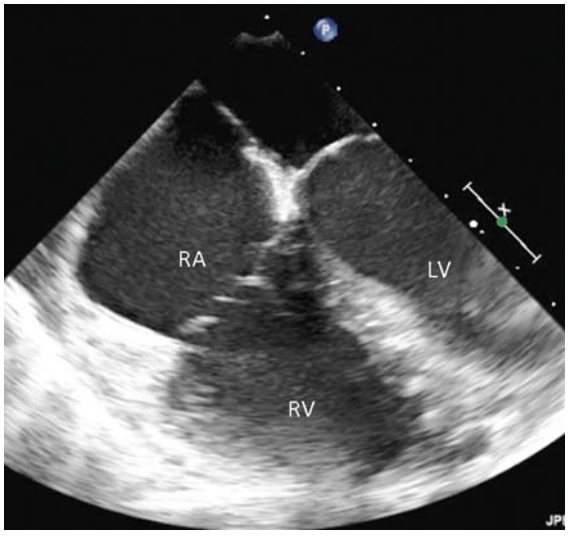

Figure 1 Low transoesophageal view of right ventricle (RV), right atrium (RA), and tricuspid valve. This is a transoesophageal four-chamber view modified by slight counterclockwise shaft rotation.

the left ventricle (in the sector image). Further plane rotation brings into view the *transoesophageal long-axis view* of the left ventricle (*Figure 4*) at ~120–150°, with the anterior mitral leaflet, the aortic valve and ascending aorta, and the anteroseptal left ventricular segments on the right side (from near to far field), and the posterior mitral leaflet and posterior left ventricular wall on the left side. These three views of the left ventricle (four-chamber, two-chamber, and long-axis) are the essential oesophageal views for evaluating the left ventricle, including segmental wall motion abnormalities. The mitral valve can be studied in detail (after appropriate depth reduction) in the same views enumerated for the left ventricle. The use of *multiple transoesophageal cross-sections* of the mitral valve, especially with a multiplane transducer, including spectral Doppler of transmitral flow and colour Doppler mapping of the left atrium, allows mapping of mitral pathology and regurgitant jet origin to leaflets and leaflet segments (scallops in the posterior mitral leaflet). This is discussed in more detail in the section on the mitral valve. Pulsed Doppler tracings of pulmonary venous flow can be recorded from both the left and the right upper pulmonary veins. Spontaneous echo contrast ('smoke') in

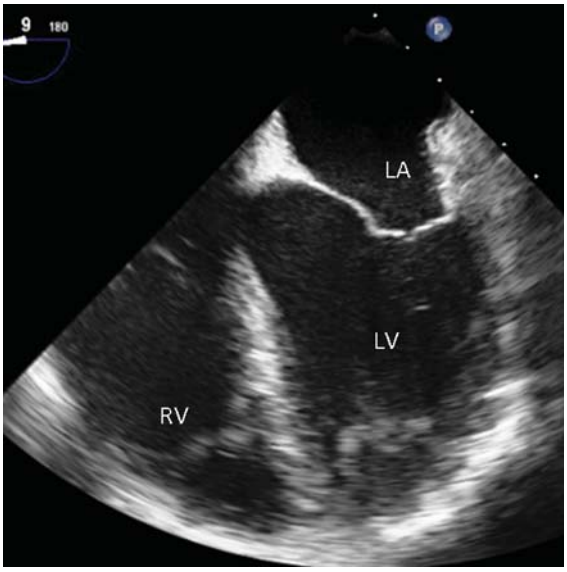

Figure 2 Transoesophageal four-chamber view. LA, left atrium.

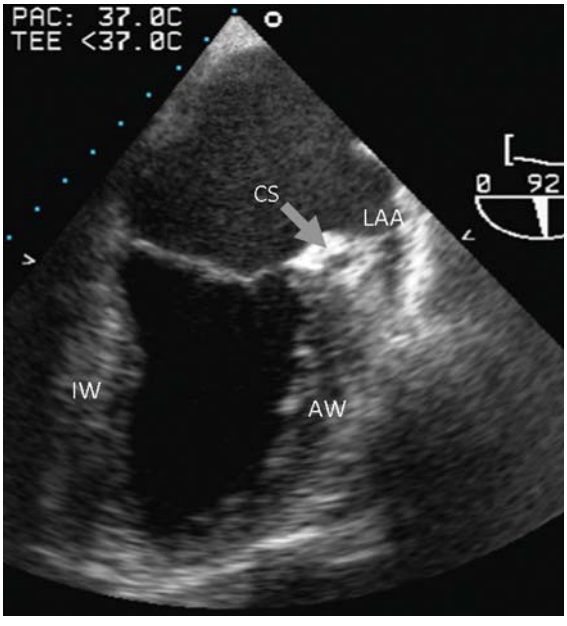

Figure 3 Transoesophageal two-chamber view. AW, anterior wall; IW, inferior wall; LAA, left atrial appendage; CS, coronary sinus.

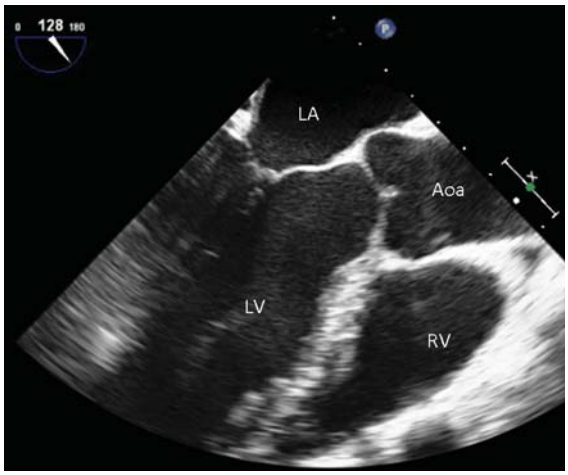

Figure 4 Transoesophageal long-axis view of the left ventricle. Aoa, ascending aorta.

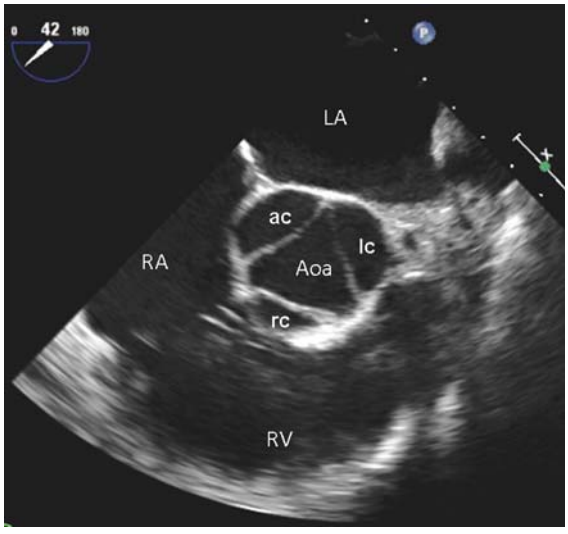

Figure 5 Aortic valve short-axis view (ac, acoronary; lc, left coronary; rc, right coronary cusp and sinus).

the left atrium and/or appendage should be noted. Since spontaneous echo contrast is gain-dependent, it should be ensured that gain levels are high enough not to miss it.

Upper transoesophageal views

Flexion of the tip or withdrawal of the probe will display the aortic valve and both atria from an upper transoesophageal position. *Short- and long-axis views of the aortic valve* (*Figures 5* and *6*) should be obtained by looking for a circular aortic root in the short-axis views (at 40–70°) and a central closure of the two visualized aortic leaflets, as well as a maximal visualized length of the ascending aorta in the long-axis view (at 130–160°). The short-axis view shows the left coronary cusp in the upper right third, the non-coronary cusp in the upper left third, and the right coronary cusp in the lower third (anteriorly), while the long-axis view has the non-coronary aortic cusp on top and the right coronary cusp at the bottom (i.e. anteriorly). If the transducer is slightly withdrawn from the aortic valve in a short-axis view, the coronary ostia can be identified by adjusting the plane individually, located at ~2 o'clock (left coronary ostium) and 6 o'clock (right coronary ostium) of the circumference of the aortic root. The right coronary ostium is frequently visualized more easily in the long-axis view of the aortic valve. Colour Doppler mapping should be performed in both aortic valve views. Spectral Doppler assessment of aortic flow velocities is better achieved in transgastric long-axis views due to more coaxial beam alignment. The maximal visualizable extent of the *ascending aorta* (*Figure 7*) should be documented, which necessitates withdrawal of the probe to display the upper part of the ascending aorta (displayed on the right sector side), with an angle between 130 and 160°, especially where the ascending aorta courses anteriorly of the right pulmonary artery. The right atrium, the tricuspid valve, inflow and outflow tract of the right ventricle, the pulmonary valve, and the main pulmonary trunk are seen in counterclockwise continuity, with the aortic valve in the centre, in the short-axis view of the aortic valve (*Figure 5*). This view (also called the *right ventricular inflow–outflow view*) resembles an upside down parasternal aortic valve short-axis view. Colour Doppler evaluation of the tricuspid and—less satisfactorily—the pulmonary valve can be performed. If visualization of the distal right ventricular outflow tract, the pulmonary valve, and the proximal main pulmonary artery are of particular interest, a plane rotation to a lower angle (100–130°) or counterclockwise shaft rotation brings these structures into view.

From an upper transoesophageal window, the atrial septum with the oval fossa should be visualized in at least two planes (transverse and longitudinal or sagittal view). The *transverse view of the right atrium* is usually a minor modification of the transoesophageal four-chamber view with reduced depth. It shows the left atrium on top, the atrial septum as approximately horizontal structure, and the tricuspid valve to the right. Neither caval vein is seen in this view. The *longitudinal, sagittal, or bicaval view of the right atrium* (at 90°; *Figure 8*) displays the orifices of the superior (right sector side) and inferior caval veins (left sector side) and the right atrial appendage; the tricuspid valve is not seen. This view allows in particular the evaluation of atrial septal defects of

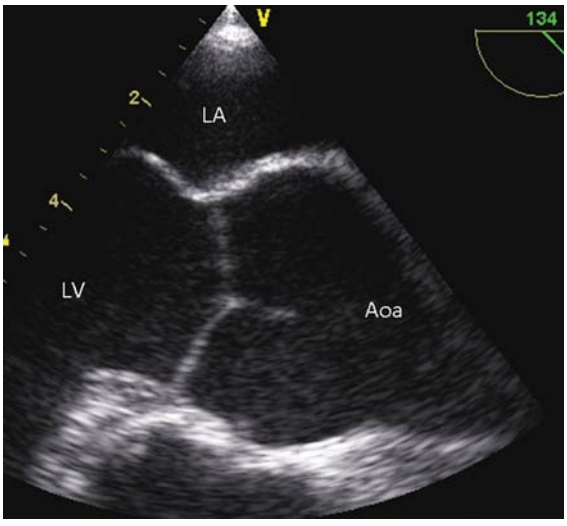

Figure 6 Aortic valve long-axis view (magnification).

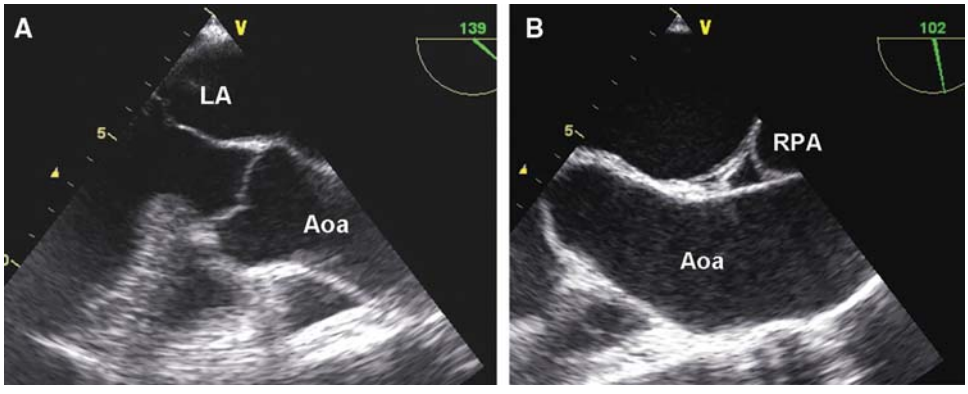

Figure 7 Long-axis view of the ascending aorta. (*A*) Proximal ascending aorta. (*B*) In the same patient, after retraction of the probe and adjustment of the plane orientation, a long portion of the dilated ascending aorta is seen. RPA, right pulmonary artery.

secundum type, the foramen ovale, pacemaker leads, and intravenous lines. If patency of the foramen ovale is to be checked, echo contrast should be applied and monitored during spontaneous breathing and, importantly, on release of a Valsalva manoeuvre.

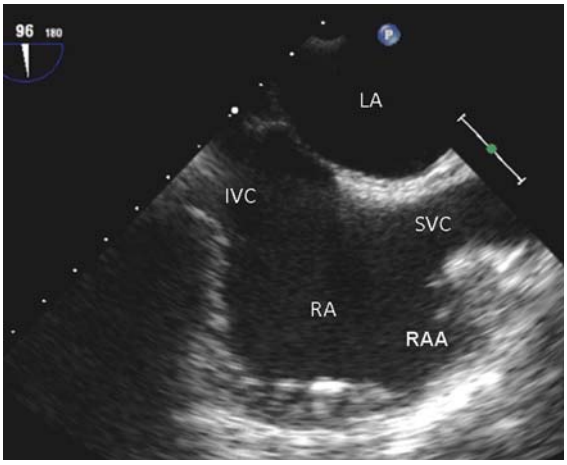

Figure 8 Left and right atrium and atrial septum in longitudinal (sagittal) view. Note orifice of superior (SVC) and inferior vena cava (IVC) and right atrial appendage (RAA).

Views of cranial structures of the heart and great vessels are obtained by withdrawing and anteflecting the probe in the transverse (0°) plane from a position showing the mitral valve in the centre of the sector. On the right side of the screen, the *left atrial appendage* is seen (*Figure 9*); careful study of this structure which varies in size, shape (e.g. presence and number of distinct lobes), and orientation often requires additional plane rotation between 0 and 90°. *Pulsed wave Doppler recording of appendage flow* is useful to assess the risk of thrombus formation. Further withdrawal and anteflexion displays the *left upper pulmonary vein* (*Figure 10*). Clockwise shaft rotation displays the *short-axis view of the ascending aorta*, accompanied on the left side by the *superior vena cava* (*Figure 11*), and on the right side by the *main pulmonary artery*. The right pulmonary artery courses to the left side of the sector posteriorly of the ascending aorta. The left pulmonary artery is poorly seen and courses to the right side of the sector.

The *orifice of the right upper pulmonary* vein is seen at the junction of right atrium and superior vena cava and posterior to the latter, both in transverse and longitudinal views (*Figure 12*). This junction is the location of the transthoracically often poorly visualized sinus venosus atrial defects. In a longitudinal (90°) view, the orifice of the right upper pulmonary vein can be located between left atrium and right pulmonary artery.

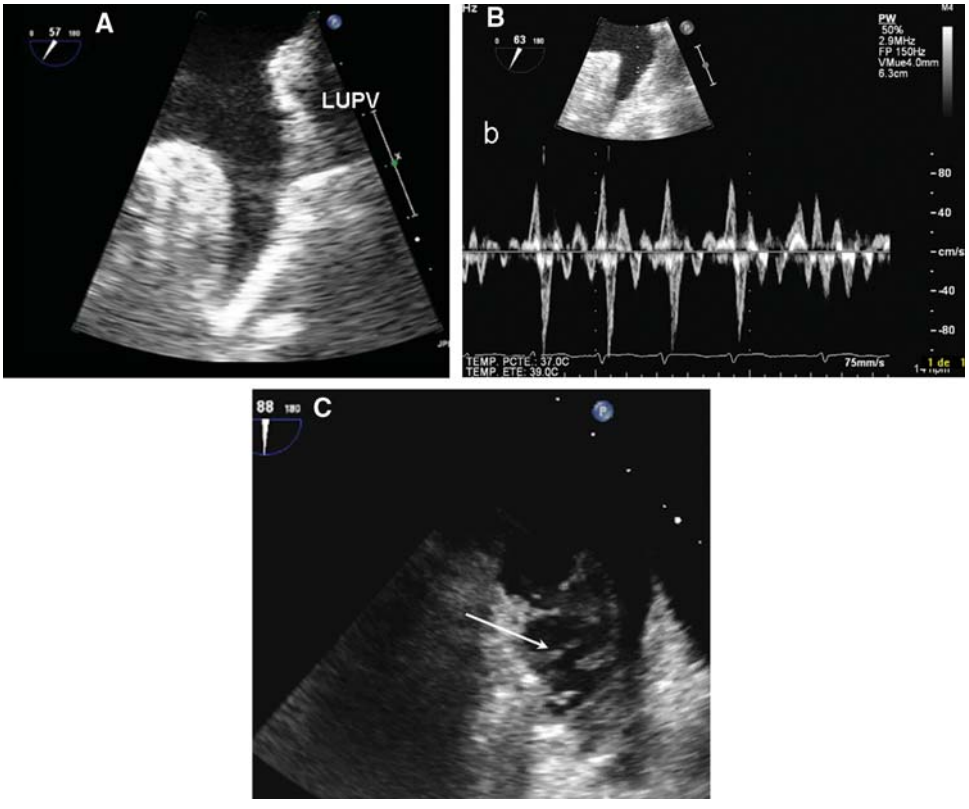

Figure 9 (*A*) Left atrial appendage. (*B*) Pulsed wave Doppler recording of emptying (upward) and filling (downward) velocities in atrial fibrillation. The velocities are quite high (>25 cm/s), indicating relatively low risk of thrombus generation. LUPV, left upper pulmonary vein. (*C*) Example of left atrial appendage with marked pectinate muscles (arrow). There is no thrombus.

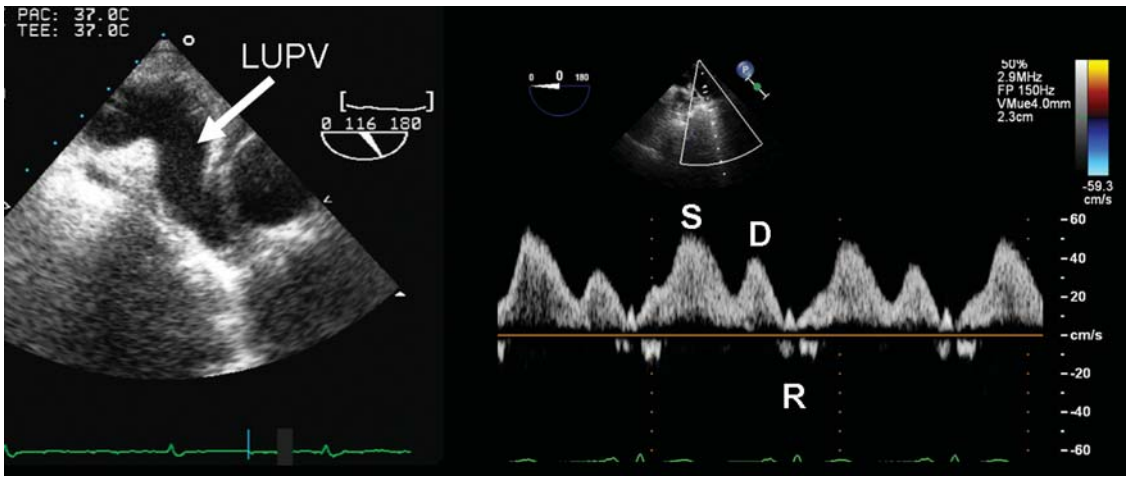

Figure 10 Left: left upper pulmonary vein (LUPV) imaged in an approximately longitudinal view. Right: pulsed Doppler recording of normal pulmonary venous inflow from the left upper pulmonary vein. Positive (upward) velocities are directed into the left atrium. S, systolic wave; D, diastolic wave; R, reverse wave.

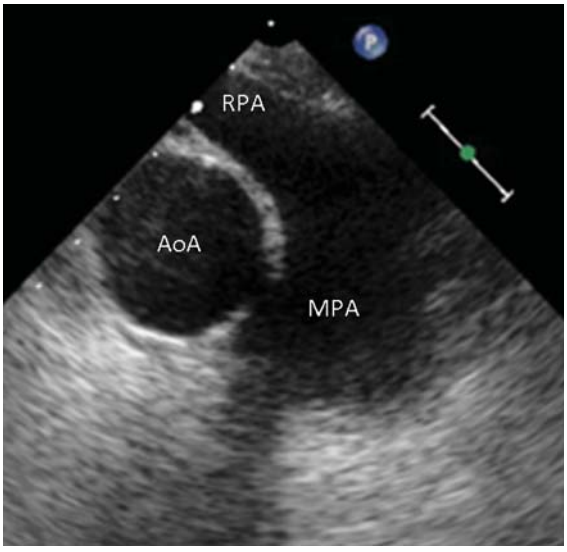

Figure 11 Short-axis view of ascending aorta and main pulmonary artery (MPA), with bifurcation and origin of right pulmonary artery (RPA), from the upper transoesophageal window.

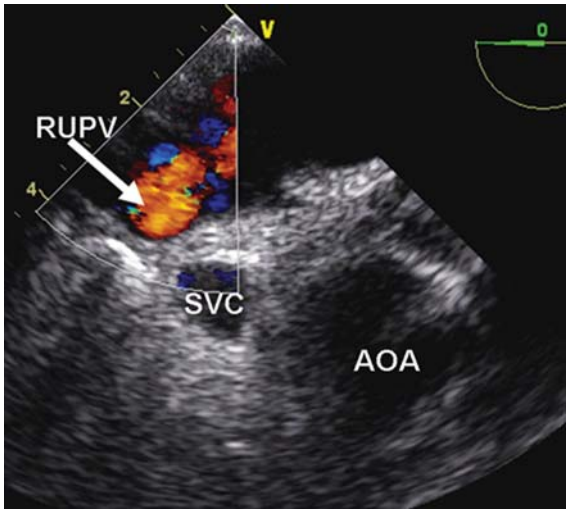

Figure 12 Transverse view of upper left atrium. Colour Doppler display of inflow from right upper pulmonary vein (RUPV, arrow). SVC, superior vena cava; AoA, ascedending aorta.

Transgastric views

The transducer is positioned in the upper stomach (gastric fundus), enabling *left ventricular short-axis and two-chamber views* (*Figures 13* and *14*). In the left ventricular short-axis view at the mid-papillary level (at 0°), the anterolateral papillary muscle is seen at ~5 o'clock and the posteromedial approximately between 11 and 2 o'clock. The free wall of the right ventricle is seen on the left sector side. Counterclockwise, the mid-segments of the septal, anteroseptal, anterior (farthest from the transducer), lateral, posterior, and inferior (closest to the transducer) left ventricular walls are seen. In the left ventricular two-chamber view (at 90°), the inferior wall is seen in the near field of the sector and the anterior wall at the bottom of the sector. The apex, which often is not well visualized, is to the left and the mitral valve to the right of the sector. Wall motion abnormalities, thrombi, and pathology of the subvalvular mitral apparatus, which is particularly well displayed in the transgastric two-chamber view, should be noted.

The *long-axis view of the left ventricle*, with assessment of left ventricular outflow tract and aortic valve, is obtained at ~100–120° and sometimes minor clockwise shaft rotation

(*Figure 15*). The aortic valve is seen in the far field. Elevated or reversed flow velocities in the outflow tract or through the aortic valve should be documented. It is frequently difficult to achieve this view, and the ascending aorta is not seen well. Additionally, or alternatively in case of difficulty in obtaining the long-axis view of the left ventricle from the typical transgastric position, a *deep transgastric long-axis view or five-chamber view* (*Figure 16*), including the aortic valve, can be obtained by advancing the probe further into the gastric fundus and using maximal anteflexion of the probe. Note that this view will display cardiac structures roughly like a transthoracic apical four-chamber view, i.e. upside down compared with the transoesophageal four-chamber view. Rotation to 60–90° creates a modified transgastric apical long-axis view of the left ventricle. These views are particularly useful for the Doppler examination of the left ventricular outflow tract and aortic valve.

A *short-axis view of the mitral valve* (*Figure 17*) is obtained further basally from the mid-papillary muscle short-axis view by slightly withdrawing and anteflexing the instrument, and sometimes adding 10–20° of rotation. The origin of mitral regurgitation jets by colour Doppler, as well as flail or prolapsing portions, and systolic anterior motion of the leaflets, can be detected in this view. Although this view is often not easy to obtain, it is very helpful in assessing the origin of mitral regurgitant jets.

Additional views of the right heart, which are not routinely obtained, but are important whenever right heart pathology has to be evaluated, are generated by rotating the probe from the transgastric left ventricular short-axis position to the right, positioning the right ventricle in the centre of the sector, and steering the plane angulation first to ~30°, producing a short-axis view of the tricuspid valve, with the posterior leaflet to the upper left, the septal leaflet to the upper right, and the large anterior leaflet in the lower half of valve cross-section. A right ventricular inflow view can be obtained by further rotation. At ~90°, a long axis of the right ventricular inflow is seen, which is analogous to the left ventricular two-chamber view in that the apex is to the left and the right atrium to the right. Further rotation discloses the right ventricular outflow tract, with the pulmonary valve located at the bottom of the sector.

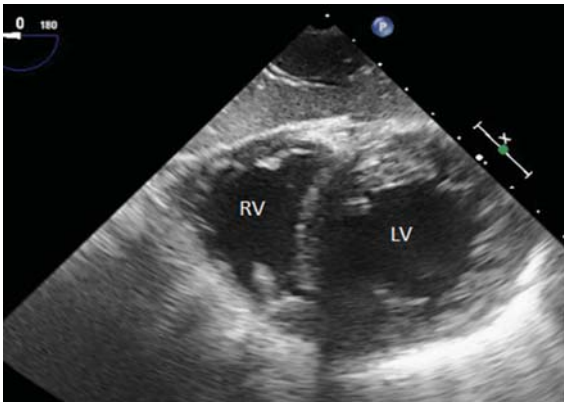

Figure 13 Transgastric short-axis view of the left (LV) and right ventricle (RV).

Aortic views

Unless aortic pathology is the primary indication for a study, the thoracic aorta is usually examined at the end of the TOE after the cardiac examination. Between the upper abdomen and the aortic arch, the oesophagus and the descending aorta change their anterior–posterior relationships (at the diaphragm the oesophagus lies anterior to the aorta; at mid-thorax it is medially located; at the aortic arch it is posterior). Therefore, the complete length of the thoracic descending aorta should be scanned in the *short-axis view* (supplemented by long-axis views) by gentle rotation of the probe to maintain correct visualization of aortic walls along the entire course of the vessel (*Figure 18*). The take-off of the left subclavian artery can usually be seen, and often part of the distal

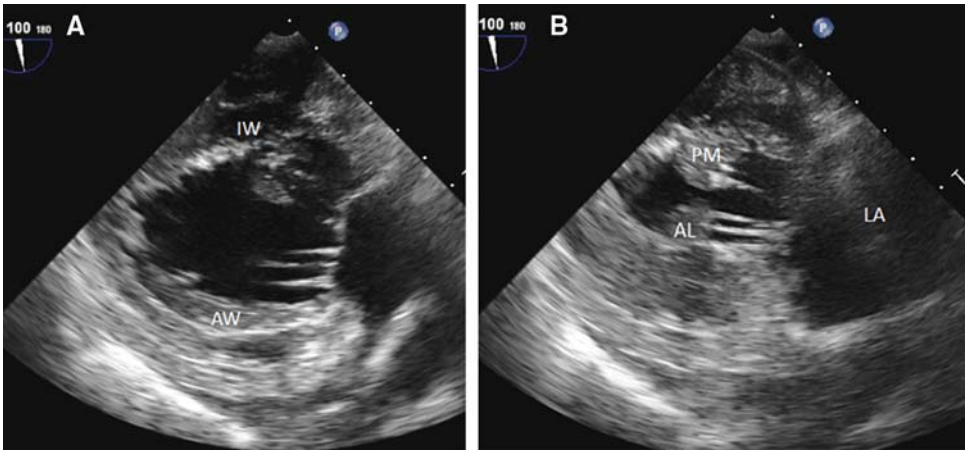

Figure 14 Transgastric two-chamber view. The apex is to the left, and the left atrium to the right in the image. (*A*) Cross-section showing the cavity of the left ventricle. (*B*) Slightly modified view intersecting both papillary muscles and chordal subvalvular apparatus. AW, anterior wall; IW, inferior wall; AL, anterolateral papillary muscle; PM, posteromedial papillary muscle.

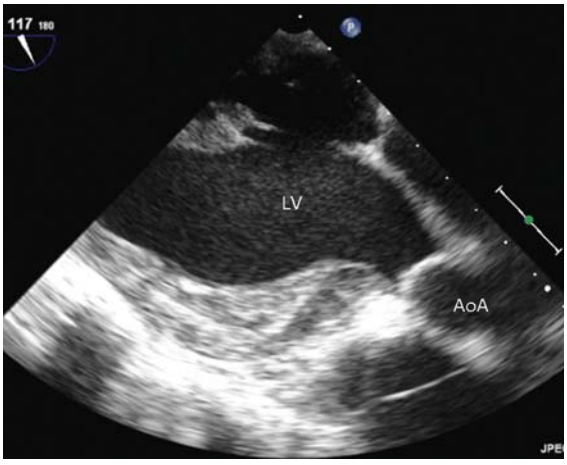

Figure 15 Transgastric long-axis view of the left ventricle (117°). AoA, ascending aorta.

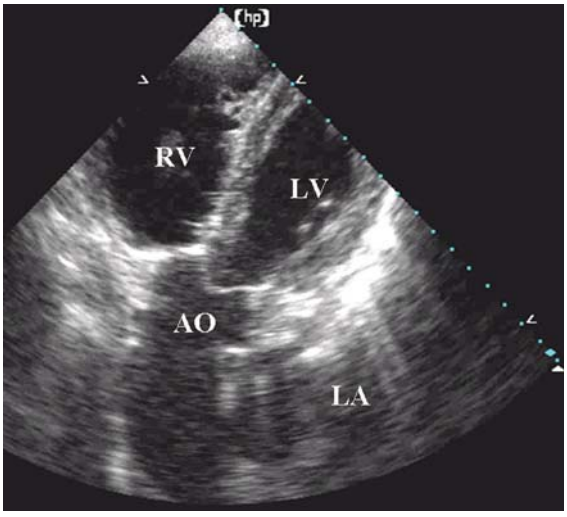

Figure 16 Deep transgastric long-axis view of the left ventricle, with maximal anteflexion. RV, right ventricle.

arch and the supra-aortic branches can be visualized; probe shaft rotation may be useful to adjust the images. Clockwise rotation and slight probe withdrawal at the junction of aortic arch and descending aorta display the long axis of the aortic arch, with the anterior aortic arch wall in the far field of the sector, and partially the superior ascending aorta. At 90°, a short axis of the aortic arch is obtained. By rotating the transducer and advancing further into the oesophagus, the distal portion of the ascending aorta may be recorded. However, due to the interposition of the trachea or left main bronchus, some portion of the arch or distal ascending aorta will usually not be visualized. The location of findings in the descending aorta can be described either by the distance of the probe tip to incisors, or by the cardiac structures at the same distance.

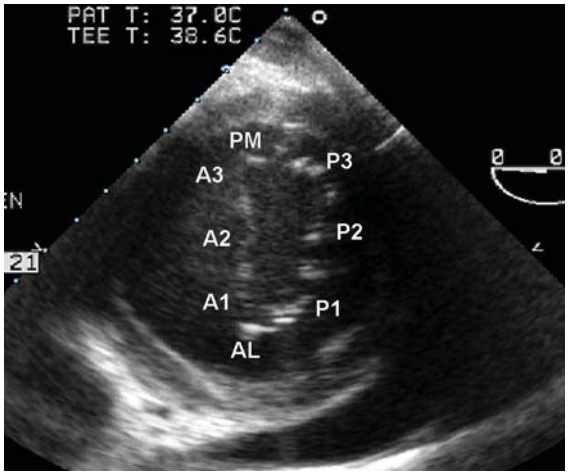

Figure 17 Short-axis view of the open mitral valve from the transgastric position. AL, anterolateral; PM, posteromedial commissure. A1–A3 and P1–P3 denominate the respective leaflet scallops.

Assessment of the mitral valve

Anatomically, it is standard practice to divide each mitral leaflet into three segments, defined by dividing the attachment of each leaflet to the atrioventricular junction (annulus) into three equal parts, and then by dropping perpendicular lines to the closure line of the valve (*Figure 19*). The body of the anterior leaflet is a single structure which is attached along approximately one-third of the circumference of the annulus, between the fibrous trigones. The 'posterior' leaflet occupies the lateral and inferior parts of the left atrioventricular junction and is attached along approximately two-thirds of the circumference of the mitral annulus. Usually, the posterior leaflet has three scallops, but their size and also the number of scallops can vary. It is difficult even with TOE to identify the clefts between the scallops precisely, and so an echocardiographic approximation of the site of disease to the lateral, middle, or medial thirds of the posterior mitral leaflet (P1, P2, and P3, respectively) may not correspond exactly either with the precise anatomy of the scallops or with the exact location of findings on surgical inspection. 3D TOE provides en face views of the mitral valve as if seen by the surgeon after left atriotomy, which are felt to be advantageous for communication with the surgeon due to their intuitive appeal; see corresponding section below.

Detailed echocardiographic assessment of the mitral valve leaflets should be performed using 2D imaging planes that show the leaflet tips in a long-axis orientation. Because TOE provides a multitude of possible cross-sections through the mitral valve, a systematic reference framework is necessary for orientation. One way to analyse the mitral anatomy is by rotating the orientation of the image through 360° (*Figure 20*). However, to show the anatomy well and completely, this requires to position the probe so that the pivot around which all the imaging planes are rotated lies at the centre of the annulus. This requirement is often difficult or impossible to fulfil with sufficient image quality. Therefore, plane

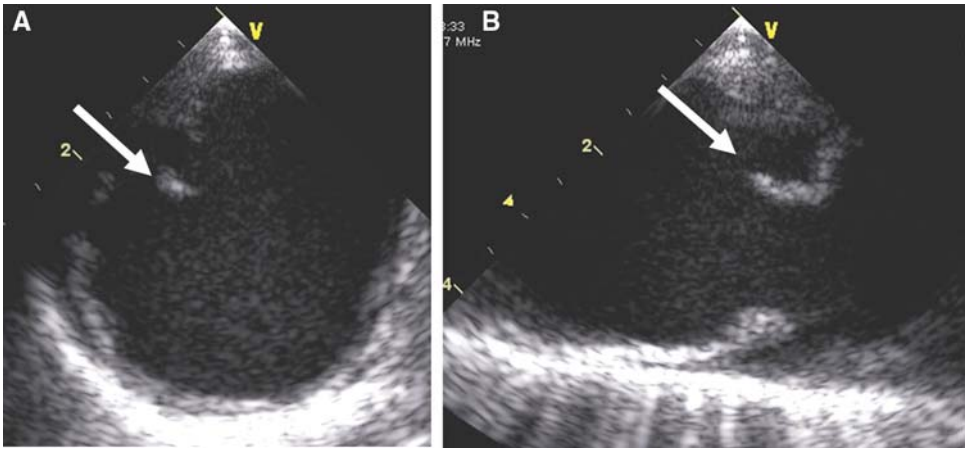

Figure 18 Descending aorta: (*A*) short-axis view; (*B*) long-axis view. The aorta shows atherosclerotic lesions, some of which (arrow) have superimposed mobile thrombus.

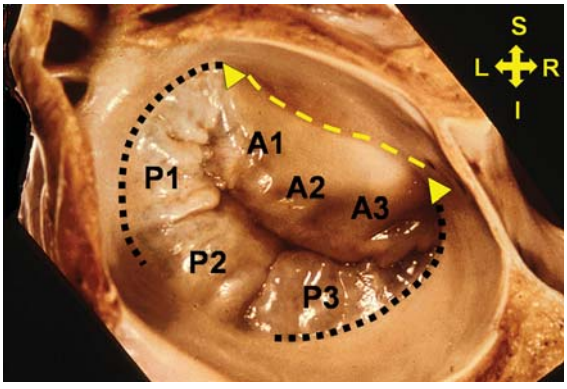

Figure 19 Pathologic specimen of the closed mitral valve, seen from the atrial side ('surgeon's view'). A1–3 and P1–3 designate the leaflet scallops. The yellow triangles indicate the site of the fibrous trigones; the dotted black lines show the most common location of the fibrous mitral annulus. Opposite P2 the mitral annulus is usually composed only of ventricular myocardium. S, superior; I, inferior; L, left; R, right. Courtesy of JRTC Roelandt, Rotterdam, The Netherlands.

rotation alone often is not sufficient and should be supplemented by systematically analysing parallel planes as depicted in *Figure 20*.

The classification of mechanisms of regurgitation that is most commonly used by cardiac surgeons was developed by Carpentier[13] (*Table 3*). It is based on the relative mobility of all the segments of both leaflets, compared with the mobility and position of the leaflets next to the anterolateral commissure taken as a reference point. However, this concept originally stems from surgical inspection while the patient is on cardiopulmonary bypass and when the heart is flaccid due to cardioplegia; for this reason, it is recommended that additionally the regional pattern of closure of the mitral valve leaflets is described in terms of coaptation (whether or not the leaflets touch each during systole) and apposition (whether or not the leaflets are symmetrically aligned opposite each other in systole).

In systole, the mitral annulus is not planar but saddle-shaped, with high points that are anterior and posterior and low points that are lateral and medial. Similar to transthoracic imaging, a transoesophageal four-chamber view crosses through the low points of the annulus and thus is more likely to display prolapse than are apical two-chamber or long-axis images which cross the mitral annulus at its high points. As in transthoracic imaging, mitral valve prolapse should only be diagnosed confidently when the mitral leaflets appear beyond the plane of the annulus in longitudinally orientated images, i.e. long-axis views. When mitral regurgitation is provoked by chronic dilatation of the left ventricle or during acute ischaemia, increased traction and downwards and outwards displacement of the subvalvar apparatus increase the distance between the bodies of the mitral leaflets and the plane of the annulus and reduce the overlap of the tips of the leaflets (apposition of the rough zones). This is termed secondary, functional, or ischaemic mitral regurgitation. These changes can be quantified by measuring the 'tenting' area or volume (by 2D or 3D echo, respectively), or simply by the distance between the coaptation point of the leaflets and the plane of the annulus (the tenting height[14,15]). In this type of mitral regurgitation, there are likely to be multiple regurgitant jets arising along a large portion of the closure line. If no clear regurgitant pathology is identified and if the annulus and tenting height are normal, then alternative explanations such as a perforated leaflet or a cleft should be considered.

During TOE, the severity of mitral regurgitation should be graded using the same criteria recommended for transthoracic imaging.[16,17] When performing grading of residual regurgitation compared with preoperative regurgitation in the operating room after bypass, it is important to ensure that left ventricular function and blood pressure have recovered, the Nyquist limit and gain settings for colour Doppler have been kept constant, and that frame rates for colour Doppler are maximized. In the anaesthetised patient with low blood pressure, the severity especially of functional mitral regurgitation is typically underestimated. Systolic

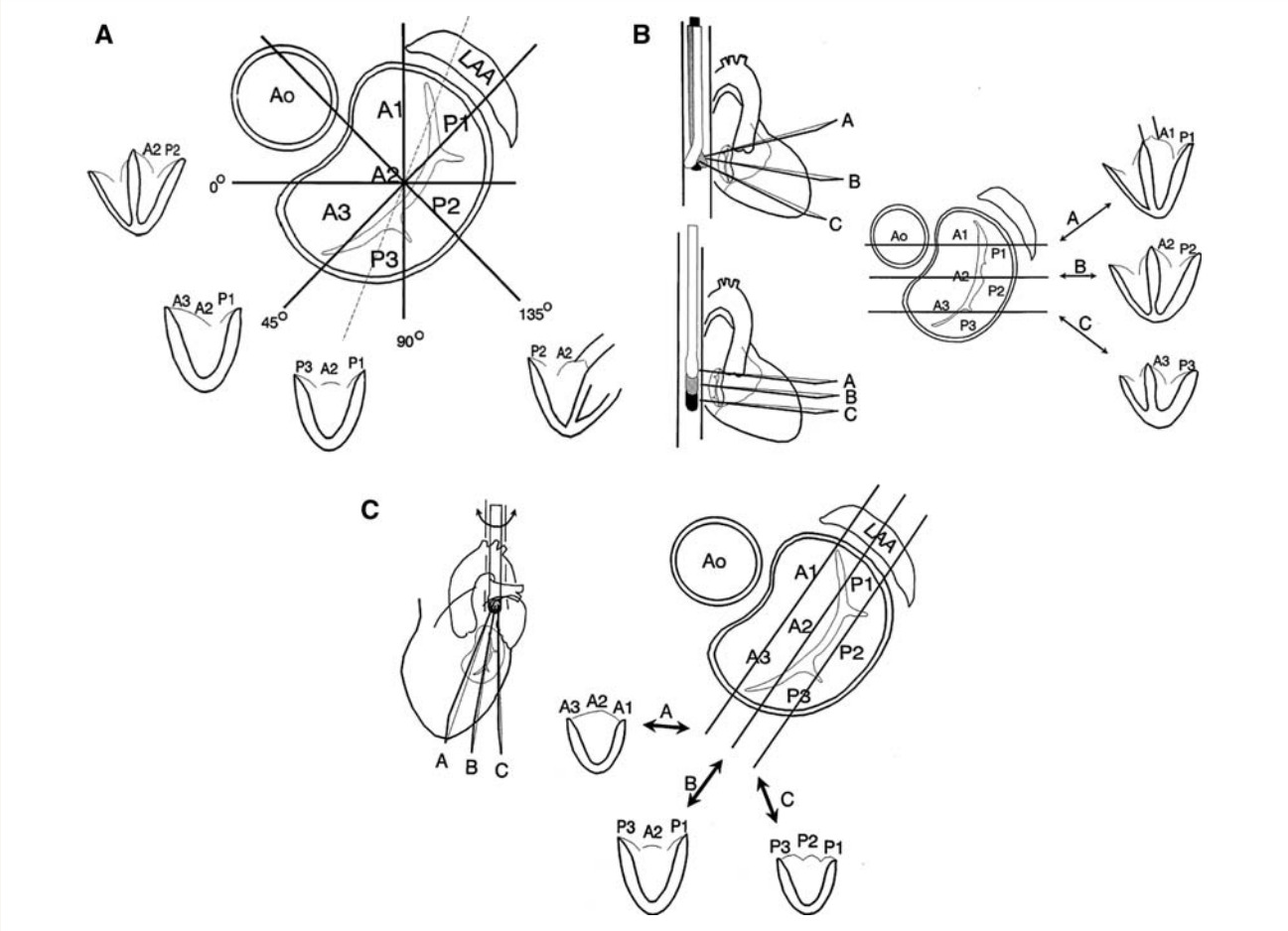

Figure 20 Examination of the mitral valve. Screen depiction of relative position of mitral leaflets and segments/scallops in typical transoesophageal cross-sections created by three different examination manoeuvres. Note that individual anatomy, especially scallop morphology, is variable, and so is the relation of image plane orientation to individual anatomy; the schematic drawings should therefore be understood as approximations. A1–A3, anterior leaflet segments; P1–P3, posterior leaflet segments; Ao, aortic valve; LAA, left atrial appendage. (*A*) Examination by rotation of imaging cross-section with fixed transducer position positioned at the level of the mitral valve centre. (*B*) Examination by flexion/withdrawal and retroflexion/advancement of the transesophageal transducer, while rotation angle is fixed in a transverse orientation (0°). (*C*) Examination by probe shaft rotation (counterclockwise from plane A to C), while rotation angle is fixed in an orientation approximating the mitral closure line (45–90°). Note that the aortic valve is not imaged in these planes. Reproduced, with permission, from Foster *et al.*[47]

blood pressure should be recorded during any echocardiographic study of the severity of mitral regurgitation, whether before or during cardiac surgery. It is not necessary to perform pre-operative TOE in all patients before mitral valve surgery; if transthoracic images are of sufficient quality for a detailed diagnosis to be made, then TOE can be postponed until the patient is anaesthetized prior to surgery.

Mitral prostheses should be assessed in a similar fashion to the native mitral valve; here, it is often easy to use mainly systematic plane rotation from a fixed viewing point in order to assess the prosthesis and its circumference. This is particularly valuable to localize and quantify the size of paraprosthetic leaks. Occluder motion is well assessed, thrombi or vegetations identified, and colour Doppler as well as continuous wave Doppler examination for regurgitation or obstruction performed. However, structures on the ventricular side of the prosthetic ring or occluder may be masked by shadowing. For 3D assessment see the corresponding section.

Percutaneous interventions in mitral regurgitation have opened a new field for TOE guidance and surveillance, which will possibly further benefit from 3D imagery. In the EVEREST I safety and feasibility trial, TOE was successfully used for this purpose as the primary imaging modality.[18]

Assessment of the aortic valve and aortic root

TOE is used for assessing the aortic valve in several frequent scenarios, including but not restricted to, endocarditis (*Figure 21*), improved characterization of stenotic or regurgitant lesions, aortic prosthetic malfunction, preparation for aortic valve surgery (especially if repair is contemplated), aortic interventions, or in the context of dissection of the ascending aorta.

The main views to assess aortic valve and root morphology, which are long- and short-axis views of these structures, have been

reviewed previously in this text. Doppler assessment by continuous or pulsed wave Doppler can only be obtained with good alignment between ultrasound beam and flow direction using a deep transgastric long-axis view (*Figure 16*). The normal aortic valve is composed of three cusps, surrounded by a dilatation of the aortic wall called the Sinus Valsalvae. Each of the cusps is named according to the coronary ostium in the corresponding sinus. Congenital abnormalities of the aortic valves include the bicuspid valve, sometimes associated with co-arctation of the aorta or with dilatation of the aortic root, and rarely the unicuspid or quadricuspid valve. Several types of bicuspid aortic valves may be distinguished according to the presence and location of the raphe.[19]

Although aortic valve replacement remains the most frequent treatment for aortic valve stenosis, repair techniques are increasingly used for the treatment of aortic regurgitation.[20] Therefore, an accurate diagnosis of the mechanism of valve dysfunction is a key point for determining the feasibility of the technique and guide the decision for repair of replacement of the aortic valve. TOE assessment of the aortic valve must always take into account the characteristics of the aortic root. The aortic valve, aortic root, and left ventricular outflow tract should be inspected in short- and long-axis views. Subvalvar (*Figure 22*) or supravalvar stenosis is visualized especially in the long-axis view. The normal aortic valve is very thin and may be difficult to image specially in diastole in long-axis view. A bicuspid or stenotic valve may display 'doming' in the long-axis view. Presence, location, and severity of calcifications on the free margins of the leaflet bodies can be evaluated best in the short-axis view. This view is also used for the measurement of aortic valve orifice area by planimetry. To allow precise measurements, the cross-sectional plane must contain the smallest orifice of the valve and thus the probe position and orientation must be adjusted to obtain the smallest valve orifice area at tips of the leaflets, which is of particular importance in the doming valve. Use of biplane or 3D TOE may help locate the right position for planimetry. A key point in considering repair of the aortic valve is the mobility of the aortic leaflets. Restricted motion due to calcification suggests valve replacement rather than repair. On the other hand, regurgitation due to excessive tissue motion, as in prolapse, is more amenable to repair. Prolapse of aortic leaflets may be defined analogously to mitral valve prolapse as diastolic displacement of an aortic leaflet (or part thereof) towards the left ventricle beyond the plane of the aortic annulus in diastole. The diagnosis is made in long-axis view but precise location requires frequently the use of short-axis view and back-and-forth rotation between these two standard views, particularly when pathology involves the 'upper' leaflet in long-axis view which may be the non-coronary or the left coronary leaflet. Several kinds of prolapse exist (*Figure 23*):

- flail leaflet, when there is no more leaflet coaptation and the leaflet is 'floating' in the outflow tract, often with a 'spoon' appearance;
- prolapse proper of a leaflet, when the leaflet body is displaced below the level of the annulus plane and thus coaptation length is severely reduced allowing regurgitation during diastole;

Table 3 Carpentier classification and mechanisms of mitral regurgitation[13]

Carpentier classification	Definition	Differential diagnosis
Type 1	Normal leaflet mobility	Annular enlargement; perforated leaflet; congenital cleft; annular calcification
Type 2	Increased mobility ('prolapse'); includes 'flail leaflet'	Elongated cords; ruptured cords; excessive leaflet tissue
Type 3	Restricted mobility; during diastole (3A); during systole (3B)	Thickened, rigid leaflets; commissural fusion; shortened or fused tendinous cords; dilated left ventricle with impaired function

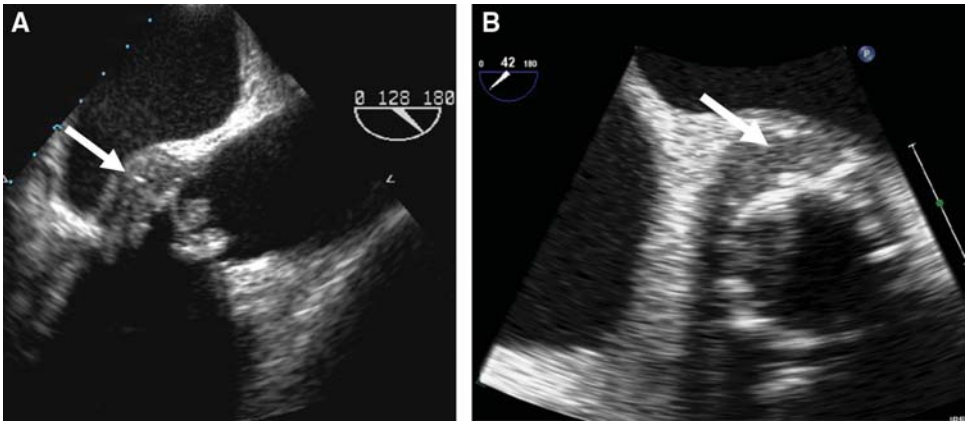

Figure 21 Infective endocarditis of bioprosthesis in aortic position, with paraprosthetic abscess characterized by aortic wall thickening with central zone of reduced reflectivity (arrows). (*A*) Long-axis view. (*B*) Short-axis view.

- partial leaflet prolapse, when only part of a leaflet is prolapsing; frequently the leaflet is divided in two parts by a fibrous band, and only the free margin portion prolapses.

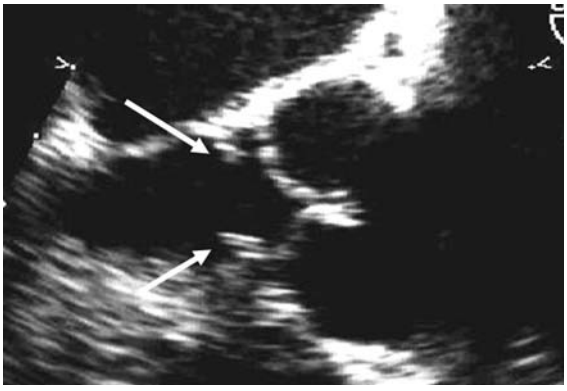

Figure 22 Subvalvular aortic stenosis due a subaortic membrane. Long-axis view.

Colour Doppler localizes the origin and course of aortic regurgitant jets, e.g. a central jet due to central loss of coaptation, or a commissural or eccentric jet due asymmetric leaflet restriction or a leaflet prolapse. In the presence of a prolapse, colour Doppler flow exhibits eccentric aortic regurgitation away from the prolapsing leaflet, which may help identify the location of the prolapse (*Figure 23*). Diastolic coaptation of the valve is well seen in the short-axis view. Loss of central coaptation is associated with aortic insufficiency and usually the consequence of aortic root dilatation.

The aortic root, best assessed in long-axis views, is the proximal part of the ascending aorta comprising the sinus of Valsalva located above the valve and the sinotubular junction, which is the narrowed portion just above the sinus of Valsalva making the junction with the tubular part of the root (ascending aorta). Dilatation of the aortic root frequently causes aortic regurgitation and is a risk factor for aortic dissection. Several long-axis view diameter measurements are helpful in characterizing the aortic root and ascending aorta (*Figures 24* and *25*). Dilatation of the aortic root can be located at the level of the sinus of Valsalva, the sinotubular junction or the tubular portion of the ascending aorta; precise location is important to guide the surgeon for the repair

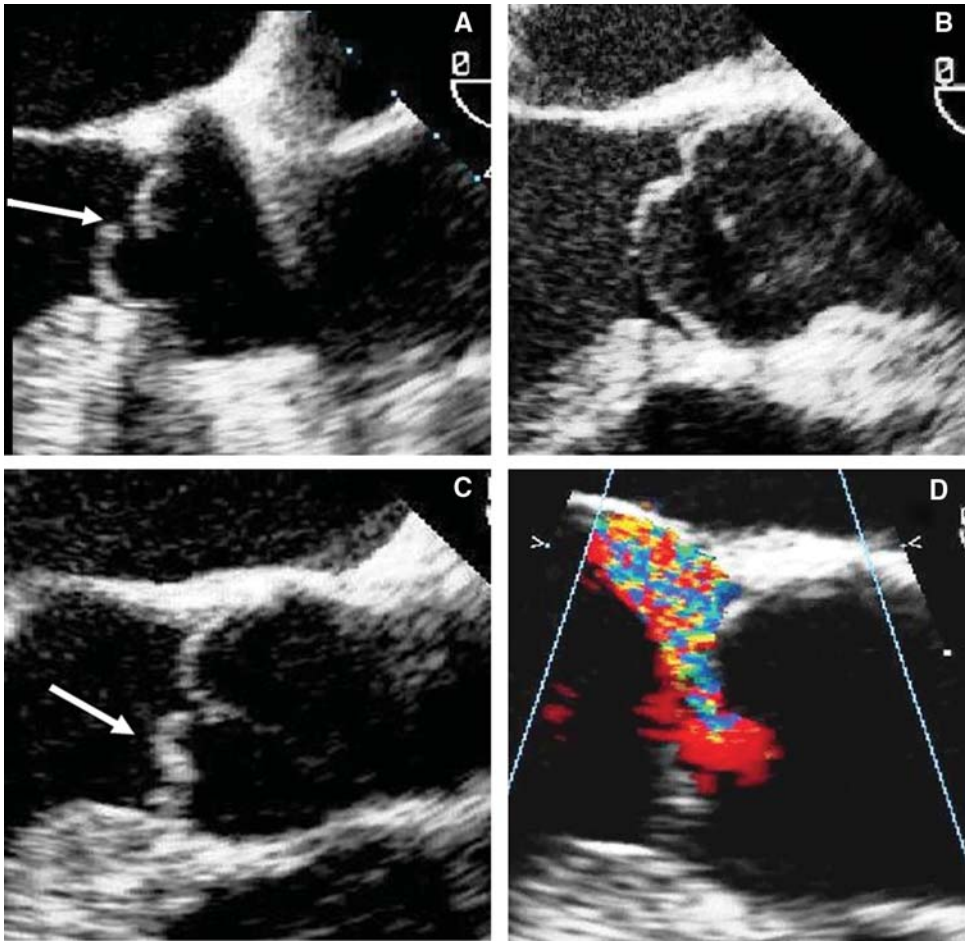

Figure 23 Prolapse and flail of the aortic valve; long-axis views. (*A*) Flail leaflet. (*B*) Whole cusp prolapse. (*C*) Partial cusp prolapse, fibrous band highlighted by arrow. (*D*) Colour Doppler corresponding to case C, showing eccentric regurgitant jet.

procedure. Dilatation of the aortic root is sometimes associated with bicuspid aortic valve and Marfan's disease, but most frequently related to age or hypertension. Reference dimensions of the aortic root have been published.[21]

Aortic dissection can induce aortic regurgitation by several mechanisms:[22] dilatation of the ascending aorta, rupture of the attachment of a cusp, or prolapse of the dissection flap through the aortic valve. Correct identification of the mechanism by TOE may prevent unnecessary aortic valve replacement.

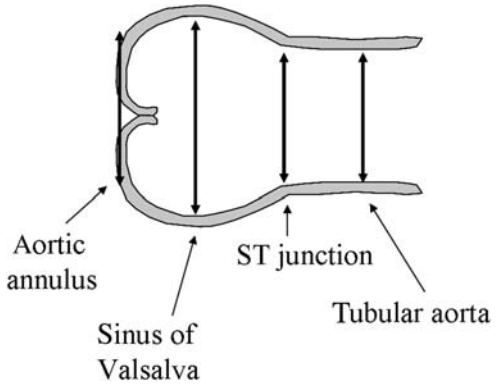

Figure 24 Typical measurements of the aortic root apparatus. ST, sinotubular.

Aortic valve prostheses are assessed in the same views as native aortic valves, and multiple views are necessary to minimize the impact of acoustic shadowing. In mechanical valves, obstruction may occur by thrombosis or pannus (fibroconnective tissue). Restricted occluder motion may lead to both obstruction and regurgitation. However, it is not always possible to detect and quantify restricted occluder motion in aortic prostheses by TOE.[23] Degenerated bioprostheses may develop stenosis by thickened and immobilized leaflets. While TOE provides good assessment of leaflet morphology and mobility, gradients are often better obtained transthoracically. By TOE, they can best be recorded in a transgastric long-axis view or in a deep transgastric five-chamber or long-axis view. Regurgitation in the presence of an aortic prosthesis can be transprosthetic, paraprosthetic, or both. Short-axis views at the level of the sewing ring allow best to differentiate transprosthetic and paraprosthetic leakage. If a paraprosthetic leak is large (dehiscence), it may compromise the stability of the sewing ring, leading to rocking of the whole prosthesis. For details of functional evaluation of prosthetic valves see reference 6.

Prosthetic infective endocarditis is characterized by vegetations which in mechanical prostheses are usually attached to the prosthetic ring, while in bioprostheses they may also arise from the leaflets. An echo free space or localized aortic wall thickening next to

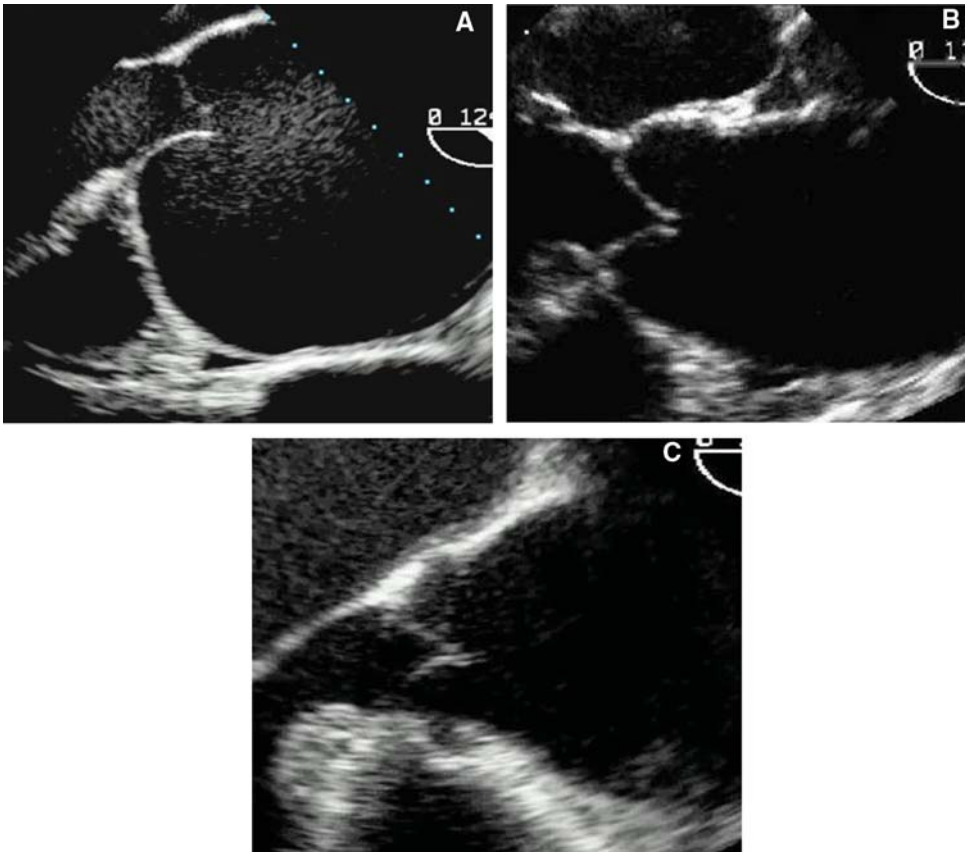

Figure 25 (*A*) Dilatation of the sinus of Valsalva. (*B*) Effacement of sinotubular junction. (*C*) Dilatation of the ascending aorta.

the prosthetic sewing ring is highly suspicious of an abscess (*Figure 21*), typically in the region of the non-coronary sinus of Valsalva.

An emerging application of TOE relates to interventional or transcatheter (transapical or transfemoral) aortic valve replacement.[24,25] Before intervention, the aortic annulus diameter is of critical importance for selection of prosthetic size. Implantation can be TOE-guided, although deployment of the prosthesis in most laboratories relies more heavily on fluoroscopy. Immediately after deployment, TOE is essential to evaluate aortic regurgitation, which if severe and paraprosthetic may prompt re-insufflation of the deployment balloon in the prosthesis in order to improve apposition of the prosthetic ring to the aortic wall.

Three-dimensional (3D) TOE

The recent advent of 3D imaging has considerably enhanced TOE by providing relatively high image quality and several unique views, and by its capability to show intuitively understandable 3D images to physicians not specialized in imaging. The one already commercially available 3D TOE probe besides 3D imaging provides the same modalities as a standard transoesophageal transducer (2D imaging and all Doppler modalities). 3D imaging can be performed in several modes:

- Real-time, simultaneous biplane imaging ('X-plane'), typically orthogonal, but plane orientations can be changed; includes colour Doppler.
- Real-time ('live') 3D, where a real-time 3D data set is obtained and displayed. The sector angle is lower than that of the typical 2D sector and depends on the desired scan line density.
- A zoom modality for real-time 3D.
- A modality encompassing the classic full sector width ('full volume'), but necessitating previous acquisition of several heart cycles and therefore not fully 'live'; this option can also be used with colour Doppler.

3D frame rates are relatively low (25–28 per s in 'full volume', higher for data sets recorded with a narrower sector angle). To obtain good quality, images should first be optimized in 2D mode, with special emphasis on gain (too much gain will loose the 3D feel and too little gain will result in 'holes') and compression (2D compression not too low, then adjust 3D compression if necessary). For 3D zoom, after 2D optimization the 3D 'zoom box' should be adjusted to include the structure of interest in the smallest volume possible in order to have a frame rate as high as possible. For 3D 'full volume', after 2D optimization, it is recommended to switch to 'live 3D' mode to adjust 3D gain, volume size, and frame rate, followed by the full-volume 3D volume acquisition in a short breath hold. Similarly, for 3D colour Doppler imaging, colour Doppler gain, scale and wall filter should first be optimized in 2D and live 3D before final 3D acquisition. The most frequent indications for 3D TOE are

- mitral valve disease,[26–29] especially mitral regurgitation secondary to mitral valve prolapse (*Figures 26* and *27*). The main advantage of 3D TOE is the accurate identification of location and extension of valve pathology (e.g. flail leaflet portions), particularly in en face views ('surgeon's view') with a viewpoint in the left atrium looking towards the left ventricular apex.
- Aortic valve disease.[28] The best 2D view for launching the 3D acquisition is a long-axis view. The 'zoom box' should include the whole aortic valve, but should not include much of the ascending aorta. 3D TOE helps to planimeter the valvular orifice area in aortic stenosis and the regurgitant orifice area in aortic regurgitation.
- Prosthetic valves (*Figure 28*). One of its main advantages is the determination of location and extension of paraprosthetic leaks.[28]
- Congenital heart disease.[30] To obtain atrial septal images of the atrial septum, bicaval or the best 2D cross-section showing the defect should be used; the 3D acquisition should include the whole atrial septum. Left and right upper pulmonary veins are well visualized using the 3D zoom.
- Guidance of percutaneous interventional procedures,[26,27] especially closure of paraprosthetic leaks and atrial septal defects, and interventional valvular procedures.

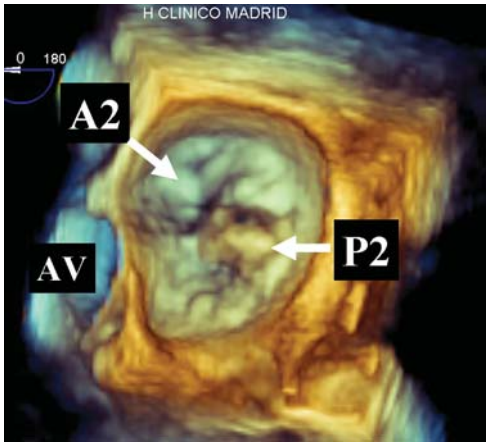

Figure 26 3D transoesophageal en face view of the mitral valve with a P2 prolapse, seen from a left atrial viewpoint (3D zoom). A2, anterior leaflet opposite to P2; AV, aortic valve region.

Perioperative TOE

Perioperative TOE was introduced into clinical practice in the early 1980s. The first reports were concerned with the assessment of left ventricular function and the detection of intra-operative air embolus.[31–34] Since that time, there has been an exponential growth in the use of TOE in surgical patients. The result is the current situation where TOE skills are widespread among cardiac anaesthesiologists, and are developing among those anaesthesiologists and others involved in major surgery, particularly neurosurgery, liver transplantation, vascular surgery, trauma surgery, and in critical care. A growing body of articles and several guidelines, most recently the Practice Guidelines for Perioperative Transoesophageal Echocardiography update[35] reflect the broad use of perioperative TOE by anaesthesiologists.

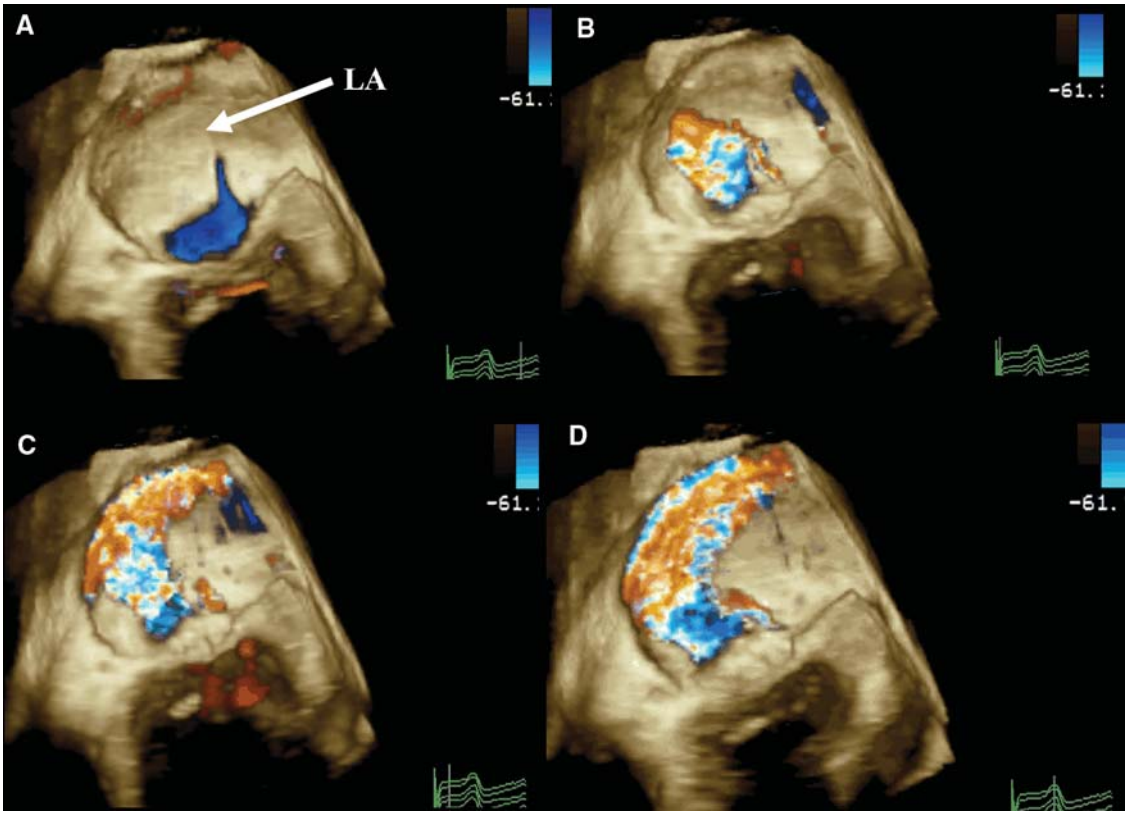

Figure 27 3D transoesophageal view of the jet of severe mitral regurgitation due to posterior mitral prolapse, seen from a left atrial perspective ('full volume', colour Doppler mode); LA, left atrium. (*A*) Diastolic frame, with open mitral valve. Note laminar blue inflow into the left ventricle across the valve. (*B*) Early systolic frame with incipient formation of turbulent jet in the left atrium. (*C*) Mid-systolic frame. The eccentric jet follows the concavity of the atrial wall. (*D*) Late systole: maximal size of colour Doppler representation of regurgitant jet.

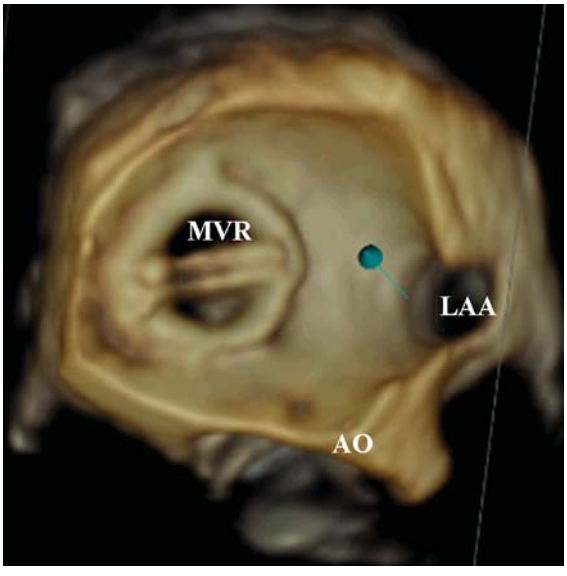

Figure 28 3D transoesophageal view of bileaflet mitral prosthesis from the atrium; the discs are in the open position. LAA, left atrial appendage; AO, location of ascending aorta.

In every surgical setting, the role of TOE is to confirm or further define the preoperative diagnosis, exclude any new deterioration or unsuspected pathology, facilitate the intra-operative management of the patient, including where necessary to aid in surgical planning, and to evaluate the results of surgery and provide information for the postoperative care of the patient.

Cardiac surgery

Cardiac surgery represents the largest clinical arena for perioperative TOE. Evidence for the indications for TOE has evolved over time. The lack of randomized controlled trials and meta-analyses has necessarily led to a cautious approach, most evident in the recommendations of the 2003 ACC/AHA guidelines.[36] These stated a Class I recommendation for TOE in a range of cardiac surgical conditions including valve repair and complex valve replacement, most congenital heart surgery, complex endocarditis, complex pericardial drainage, aortic dissection, and intracardiac device placement. They also recommended TOE as a Class I indication for the evaluation of acute, persistent, and life-threatening haemodynamic disturbances in the perioperative setting. However, a number of other cardiac surgical procedures were identified as Class II indications, including surgical procedures in patients at increased risk of myocardial ischaemia, myocardial infarction, or haemodynamic

disturbances. Arguably, this risk could be said to be relevant to all adult cardiac surgery patients, particularly in contemporary surgical practice where both the age and clinical state of patients undergoing cardiac surgery represents a greater risk than in earlier years. In the light of this changing clinical environment, the continuing publication of evidence outlining the value of intra-operative TOE for adult cardiac surgery, and the conclusion of the most recent guidelines,[35] we concur that TOE is reasonable for use in all adult patients who are undergoing either cardiac surgery or thoracic aortic surgical procedures under general anaesthesia. Recent clinical developments have included the increased use of catheter-based intracardiac procedures. Whereas septal defect closure using occluder devices is already well established, transcatheter valve procedures, particularly aortic valve replacement and mitral valve repair are novel procedures being undertaken with increasing frequency. Many centres perform these procedures with TOE monitoring, but the exact place for these procedures is still unclear.

Non-cardiac surgery

Although TOE was first utilized in non-cardiac surgery in 1983 for the detection of air embolism in neurosurgical patients, since then cardiac surgery has been the dominant clinical area of use. However, non-cardiac surgery has been increasingly identified as a potentially valuable indication for TOE. In neurosurgery, TOE may be recommended for the detection of venous air embolism.[33,37] In liver transplantation, TOE may be recommended for monitoring cardiac performance, and evaluating cardiac chamber volume and or compression.[38,39] In vascular surgery, the co-existence of coronary artery disease and high cardiovascular risk suggests that TOE may be recommended for monitoring and evaluating left ventricular function as well.[40] Numerous studies and prior guidelines have established that TOE may be valuable in patients who have unexplained severe hypotension that is unresponsive to standard treatment. Provided the expertise is available, we recommend that TOE should be used in non-cardiac surgery patients in this setting. These recommendations should also apply to major vascular trauma.[41,42] The recent guidelines of the European Society of Cardiology for perioperative cardiac management recommend TOE as a diagnostic and monitoring tool in patients with unexplained haemodynamic deterioration or signs of myocardial ischaemia during or after non-cardiac surgery.[43] A number of studies have evaluated and supported the use of TOE in orthopaedic surgery (e.g. to detect fat embolism[44,45]). Furthermore, many orthopaedic patients are frail and elderly and likely to have significant cardiovascular risk. Although TOE may be recommended in any patient with significant cardiac disease both for reasons of diagnosis and to monitor the effects of therapy, we do not feel that the use of TOE should be recommended routinely for patients undergoing orthopaedic procedures.

Critical care

The patient recovering from major surgery may experience problems in the postoperative period. These may be ongoing from the intra-operative period, or new complications. TOE may be valuable in identifying or excluding a cardiovascular cause, including valve lesions, endocarditis, and other consequences of sepsis, myocardial pump dysfunction, hypovolaemia, cardiac tamponade, aortic dissection, and intracardiac masses. Critical care patients do not suffer from the same restrictions concerning contamination of the operative field that are relevant to patients in the operating room, and therefore transthoracic imaging is a realistic alternative. Nonetheless, TOE should be performed in this setting if clinically relevant information is not obtainable by transthoracic echocardiography.

Provided that there is appropriate technology available, and that those charged with undertaking TOE have the knowledge and skills appropriate to the task, it is therefore recommended that:

- *TOE should be used* in adult patients undergoing cardiac surgery or surgery to the thoracic aorta under general anaesthesia, in particular, in valvular repair procedures.
- *TOE may be used* in patients undergoing specific types of major surgery where its value has been repeatedly documented. These include neurosurgery at risk from venous thromboembolism, liver transplantation, lung transplantation, and major vascular surgery, including vascular trauma.
- *TOE may be used* in patients undergoing major non-cardiac surgery in whom severe or life-threatening haemodynamic disturbance is either present or threatened.
- *TOE may be used* in major non-cardiac surgery in patients who are at a high cardiac risk, including severe cardiac valve disease, severe coronary heart disease, or heart failure.
- *TOE may be used* in the critical care patient in whom severe or life-threatening haemodynamic disturbance is present and unresponsive to treatment, or in patients in whom new or ongoing cardiac disease is suspected and who are not adequately assessed by transthoracic imaging or other diagnostic tests.

Importantly, major complications of TOE, including oesophageal trauma, although rare, are more common among anaesthetised patients than in those undergoing the procedure under conscious sedation.[46]

Conclusion

TOE, a minimal-risk, semi-invasive imaging procedure is nowadays an indispensable part of routine echocardiography. It provides unique and well-documented diagnostic advantages in certain clinical scenarios where the image quality of transthoracic echocardiography is impaired (e.g. the ventilated patient or the patient in the operating room), and routinely for a number of specific cardiovascular structures and clinical questions (e.g. valvular prosthetic heart disease, the presence of thrombi in the left atrial appendage, and diseases of the thoracic aorta).

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References

1. Flachskampf FA, Decoodt P, Fraser AG, Daniel WG, Roelandt JRTC, for the Subgroup on Transesophageal Echocardiography, Valvular Heart Disease, on behalf of the Working Group on Echocardiography of the European Society of Cardiology. Recommendations for performing transesophageal echocardiography. *Eur J Echocardiogr* 2001;**2**:8–21.
2. Shanewise JS, Cheung AT, Aronson S, Stewart WJ, Weiss RL, Mark JB *et al.* ASE/SCA guidelines for performing a comprehensive intraoperative multiplane transoesophageal echocardiography examination: recommendations of the American

Society of Echocardiography Council for Intraoperative Echocardiography and the Society of Cardiovascular Anesthesiologists Task Force for Certification in Perioperative Transoesophageal Echocardiography. *J Am Soc Echocardiogr* 1999;**12**:884–900.
3. Popescu BA, Andrade MJ, Badano LP, Fox KF, Flachskampf FA, Lancellotti P *et al.* European Association of Echocardiography recommendations for training, competence, and quality improvement in echocardiography. *Eur J Echocardiogr* 2009;**10**:893–905.
4. Nihoyannopoulos P, Fox K, Fraser A, Pinto F, on behalf of the Laboratory. Accreditation Committee of the EAE laboratory standards and accreditation. *Eur J Echocardiogr* 2007;**8**:79–87.
5. Habib G, Badano L, Tribouilloy C, Vilacosta I, Zamorano JL, Galderisi M *et al.*, European Association of Echocardiography. Recommendations for the practice of echocardiography in infective endocarditis. *Eur J Echocardiogr* 2010;**11**:202–19.
6. Zoghbi WA, Chambers JB, Dumesnil JG, Foster E, Gottdiener JS, Grayburn PA *et al.*, American Society of Echocardiography's Guidelines, Standards Committee, Task Force on Prosthetic Valves, American College of Cardiology Cardiovascular Imaging Committee, Cardiac Imaging Committee of the American Heart Association, European Association of Echocardiography, European Society of Cardiology, Japanese Society of Echocardiography, Canadian Society of Echocardiography, American College of Cardiology Foundation, American Heart Association, European Association of Echocardiography, European Society of Cardiology, Japanese Society of Echocardiography, Canadian Society of Echocardiography. Recommendations for evaluation of prosthetic valves with echocardiography and doppler ultrasound: a report from the American Society of Echocardiography's Guidelines and Standards Committee and the Task Force on Prosthetic Valves, developed in conjunction with the American College of Cardiology Cardiovascular Imaging Committee, Cardiac Imaging Committee of the American Heart Association, the European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography and the Canadian Society of Echocardiography, endorsed by the American College of Cardiology Foundation, American Heart Association, European Association of Echocardiography, a registered branch of the European Society of Cardiology, the Japanese Society of Echocardiography, and Canadian Society of Echocardiography. *J Am Soc Echocardiogr* 2009;**22**:975–1014.
7. Daniel WG, Mügge A. Transesophageal echocardiography. *N Engl J Med* 1995;**332**:1268–79.
8. Côté G, Denault A. Transoesophageal echocardiography-related complications. *Can J Anaesth* 2008;**55**:622–47.
9. Jenssen C, Faiss S, Nürnberg D. Complications of endoscopic ultrasound and endoscopic ultrasound-guided interventions—results of a survey among German centers. *Z Gastroenterol* 2008;**46**:1177–84.
10. Cohen LB, Delegge MH, Aisenberg J, Brill JV, Inadomi JM, Kochman ML *et al.*, AGA Institute. AGA Institute review of endoscopic sedation. *Gastroenterology* 2007;**133**:675–701.
11. McQuaid KR, Laine L. A systematic review and meta-analysis of randomized, controlled trials of moderate sedation for routine endoscopic procedures. *Gastrointest Endosc* 2008;**67**:910–23.
12. Novaro GM, Aronow HD, Militello MA, Garcia MJ, Sabik EM. Benzocaine induced methemoglobinemia: experience from a high-volume transoesophageal echocardiography laboratory. *J Am Soc Echocardiogr* 2003;**16**:170–5.
13. Carpentier A. Cardiac valve surgery—the 'French correction'. *J Thorac Cardiovasc Surg* 1983;**86**:323–37.
14. Yiu SF, Enriquez-Sarano M, Tribouilloy C, Seward JB, Tajik AJ. Determinants of the degree of functional mitral regurgitation in patients with systolic left ventricular dysfunction: a quantitative clinical study. *Circulation* 2000;**102**:1400–6.
15. Sonne C, Sugeng L, Watanabe N, Weinert L, Saito K, Tsukiji M *et al.* Age and body surface area dependency of mitral valve and papillary apparatus parameters: assessment by real-time three-dimensional echocardiography. *Eur J Echocardiogr* 2009;**10**:287–94.
16. Zoghbi WA, Enriquez-Sarano M, Foster E, Grayburn PA, Kraft CD, Levine RA *et al.* American Society of Echocardiography: recommendations for evaluation of the severity of native valvular regurgitation with two-dimensional and Doppler echocardiography: A report from the American Society of Echocardiography's Nomenclature and Standards Committee and The Task Force on Valvular Regurgitation, developed in conjunction with the American College of Cardiology Echocardiography Committee, The Cardiac Imaging Committee, Council on Clinical Cardiology, The American Heart Association, and the European Society of Cardiology Working Group on Echocardiography. *Eur J Echocardiogr* 2003;**4**:237–61.
17. Lancellotti P, Moura L, Pierard LA, Agricola E, Popescu B, Tribouilloy C *et al.*, on behalf of the European Association of Echocardiography. Recommendations for the assessment of valvular regurgitation. Part 2: mitral and tricuspid regurgitation. *Eur J Echocardiogr* 2010;**11**:307–32.
18. Silvestry FE, Rodriguez LL, Herrmann HC, Rohatgi S, Weiss SJ, Stewart WJ *et al.* Echocardiographic guidance and assessment of percutaneous repair for mitral regurgitation with the Evalve MitraClip: lessons learned from EVEREST I. *J Am Soc Echocardiogr* 2007;**20**:1131–40.
19. Sievers H, Schmidtke C. A classification system for the bicuspid aortic valve from 304 surgical specimens. *J Thorac Cardiovasc Surg* 2007;**133**:1226–33.
20. de Waroux JB, Pouleur AC, Goffinet C, Vancraeynest D, Van Dyck M, Robert A *et al.* Functional anatomy of aortic regurgitation: accuracy, prediction of surgical repairability, and outcome implications of transoesophageal echocardiography. *Circulation* 2007;**116**:I264–9.
21. Erbel R, Alfonso F, Boileau C, Dirsch O, Eber B, Haverich A *et al.* Diagnosis and management of aortic dissection. Recommendations of the Task Force on Aortic Dissection, European Society of Cardiology. *Eur Heart J* 2001;**22**:1642–81.
22. Movsovitz HD, Levine RA, Hilgenberg AD. Transesophageal echocardiographic description of the mechanisms of aortic regurgitation in acute type A aortic dissection: implications for aortic valve repair. *J Am Coll Cardiol* 2000;**36**:884–90.
23. Montorsi P, De Bernardi F, Muratori M, Cavoretto D, Pepi M. Role of cinefluoroscopy, transthoracic, and transesophageal echocardiography in patients with suspected prosthetic heart valve thrombosis. *Am J Cardiol* 2000;**85**:58–64.
24. Moss R, Ivens E, Pasupati S, Humphries K, Thompson CR, Munt B *et al.* Role of echocardiography in percutaneous aortic valve implantation. *J Am Coll Cardiol Imaging* 2008;**1**:15–24.
25. Chin D. Echocardiography for transcatheter aortic valve implantation. *Eur J Echocardiogr* 2009;**10**:i21–9.
26. Pepi M, Tamborini G, Maltagliati A, Galli CA, Sisillo E, Salvi L *et al.* Head-to-head comparison of two- and three-dimensional transthoracic and transoesophageal echocardiography in the localization of mitral valve prolapse. *J Am Coll Cardiol* 2006;**48**:2524–30.
27. García-Orta R, Moreno E, Vidal M, Ruiz-López F, Oyonarte JM, Lara J *et al.* Three-dimensional versus two-dimensional transoesophageal echocardiography in mitral valve repair. *J Am Soc Echocardiogr* 2007;**20**:4–12.
28. Sugeng L, Shernan SK, Weinert L, Shook D, Raman J, Jeevanandam V *et al.* Real-time three-dimensional transoesophageal echocardiography in valve disease: comparison with surgical findings and evaluation of prosthetic valves. *J Am Soc Echocardiogr* 2008;**21**:1347–54.
29. Salcedo EE, Quaife RA, Seres T, Carroll JD. A framework for systematic characterization of the mitral valve by real-time three-dimensional transesophageal echocardiography. *J Am Soc Echocardiogr* 2009;**22**:1087–99.
30. Miller AP, Nanda NC, Aaluri S, Mukhtar O, Nekkanti R, Thimmarayappa MV *et al.* Three-dimensional transoesophageal echocardiographic demonstration of anatomical defects in AV septal defect patients presenting for reoperation. *Echocardiography* 2003;**20**:105–9.
31. Matsumoto M, Oka Y, Strom J, Frishman W, Kadish A, Becker RM *et al.* Application of transoesophageal echocardiography to continuous intraoperative monitoring of left ventricular performance. *Am J Cardiol* 1980;**46**:95–105.
32. Furuya H, Suzuki T, Okumura F, Kishi Y, Uefuji T. Detection of air embolism by transoesophageal echocardiography. *Anesthesiology* 1983;**58**:124–9.
33. Cucchiara RF, Nugent M, Seward JB, Messick JM. Air embolism in upright neurosurgical patients: detection and localization by two-dimensional transoesophageal echocardiography. *Anesthesiology* 1984;**60**:353–5.
34. Roizen MF, Beaupre PN, Alpert RA, Kremer P, Cahalan MK, Shiller N *et al.* Monitoring with two-dimensional transoesophageal echocardiography. Comparison of myocardial function in patients undergoing supraceliac, suprarenal-infraceliac, or infrarenal aortic occlusion. *J Vasc Surg* 1984;**1**:300–5.
35. Practice guidelines for perioperative transoesophageal echocardiography: An updated report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. *Anesthesiology* 2010;112. (Epub ahead of print).
36. Cheitlin MD, Armstrong WF, Aurigemma GP, Beller GA, Bierman FZ, Davis JL *et al.* ACC/AHA/ASE 2003 Guideline Update for the Clinical Application of Echocardiography: summary article. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/ASE Committee to Update the 1997 Guidelines for the Clinical Application of Echocardiography). *Circulation* 2003;**108**:1146–62.
37. Fathi AR, Eshtehardi P, Meier B. Patent foramen ovale and neurosurgery in sitting position: a systematic review. *Br J Anaesth* 2009;**102**:588–96.
38. Wax DB, Torres A, Scher C, Leibowitz AB. Transoesophageal echocardiography utilization in high-volume liver transplantation centers in the United States. *J Cardiothorac Vasc Anesth* 2008;**22**:811–3.
39. Eimer MJ, Wright JM, Wang EC, Kulik L, Blei A, Flamm S *et al.* Frequency and significance of acute heart failure following liver transplantation. *Am J Cardiol* 2008;**101**:242–4.
40. Mahmood F, Christie A, Matyal R. Transoesophageal echocardiography and noncardiac surgery. *Semin Cardiothorac Vasc Anesth* 2008;**12**:265–89.
41. Pepi M, Campodonico J, Galli C, Tamborini G, Barbier P, Doria E *et al.* Rapid diagnosis and management of thoracic aortic dissection and intramural haematoma: a

prospective study of advantages of multiplane vs. biplane transoesophageal echocardiography. *Eur J Echocardiogr* 2000;**1**:72–9.
42. Smith MD, Cassidy JM, Souther S, Morris EJ, Sapin PM, Johnson SB *et al.* Transesophageal echocardiography in the diagnosis of traumatic rupture of the aorta. *N Engl J Med* 1995;**332**:356–62.
43. Poldermans D, Bax JJ, Boersma E, De Hert S, Eeckhout E, Fowkes G *et al.*, Task Force for Preoperative Cardiac Risk Assessment, Perioperative Cardiac Management in Non-cardiac Surgery, European Society of Cardiology, European Society of Anaesthesiology. Guidelines for pre-operative cardiac risk assessment and perioperative cardiac management in non-cardiac surgery: the Task Force for Preoperative Cardiac Risk Assessment and Perioperative Cardiac Management in Non-cardiac Surgery of the European Society of Cardiology (ESC) and endorsed by the European Society of Anaesthesiology (ESA). *Eur Heart J* 2009;**30**:2769–812.
44. Kato N, Nakanishi K, Yoshino S, Ogawa R. Abnormal echogenic findings detected by transoesophageal echocardiography and cardiorespiratory impairment during total knee arthroplasty with tourniquet. *Anesthesiology* 2002;**97**:1123–8.
45. Koessler MJ, Fabiani R, Hamer H, Pitto RP. The clinical relevance of embolic events detected by transoesophageal echocardiography during cemented total hip arthroplasty: a randomized clinical trial. *Anesth Analg* 2001;**92**:49–55.
46. Feneck RO. Safety and complications of transoesophageal echocardiography. In: Feneck RO, Kneeshaw J, Ranucci M (eds), *Core Topics in Transoesophageal Echocardiography*. Cambridge University Press; 2009.
47. Foster GP, Isselbacher EM, Rose GA, Torchiana DF, Akins CW, Picard MH. Accurate localization of mitral regurgitant defects using multiplane transesophageal echocardiography. *Ann Thorac Surg* 1998;**65**:1025–31.