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RECOMMENDATIONS

Recommendations for transoesophageal echocardiography: EACVI update 2014

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With this document, we update the recommendations for transoesophageal echocardiography (TOE) of the European Association of Cardiovascular Imaging. The document focusses on the areas of interventional TOE, in particular transcatheter aortic, mitral, and left atrial appendage interventions, as well as on the role of TOE in infective endocarditis, adult congenital heart disease, and aortic disease.

Keywords transoesophageal echocardiography • 3D echo • interventional echocardiography

Introduction

This update of the recommendations for transoesophageal echocardiography (TOE) of the European Association of Cardiovascular Imaging (EACVI) relates to the former European Association of Echocardiography documents published in 2001 and 2010.[1,2] Detailed guidance concerning indications, instruments, performance, and precautions can be found there, as well as in similar publications.[3] This new document is intended to provide some additional, updated recommendations particularly in some fields under rapid evolution, in particular the use of TOE in the context of catheter-based interventions, thus not replacing but amending the 2010 document.[4] For these interventions TOE data are crucial both in informing management decisions by the interdisciplinary Heart Team as well as during or after the procedure. While no fundamental changes in TOE hardware have occurred since the publication of the previous documents, the use of 3D-capable transducers has expanded and software related to 3D data sets continues to evolve, allowing more complex processing, e.g. measurements of linear dimensions or curved areas of valvular structures or linking TOE data sets with simultaneous fluoroscopic images.

In the USA, in 2007 and 2011 appropriate use criteria documents for echo, including TOE, have been formulated by the pertinent societies.[5,6] These documents are created by a 'process [which] combines evidence-based medicine and practice experience by engaging a technical panel in a modified Delphi exercise'.[5] As such, they constitute expert opinions on good practice which are primarily related to and geared towards the US-American healthcare system, which clearly differs in many important ways from other scenarios. Nevertheless, the compilation, evolution, and critical discussion of such criteria can inform non-US-American users of TOE. For example, reviewing their TOE databases in the light of appropriateness criteria Bhatia *et al.*[7] found that the most frequent TOE indication ranked as 'inappropriate' or overuse was search for endocarditis in patients with low pre-test likelihood (e.g. transient fever, known alternative source of infection, or negative blood cultures/atypical pathogen for endocarditis). On the other hand, it has been pointed out[6] that appropriateness criteria are rarely applied to procedures *not* performed, thus identifying overuse rather than underuse—certainly as important a concern as overuse, given current constraints in health care in large parts of Europe and elsewhere.

Imaging before and during transcatheter aortic valve implantation/replacement

Pre-operative TOE

Assessment of aortic valve anatomy and severity of aortic valve stenosis, together with aortic valve annulus sizing, are crucial in the

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pre-procedural evaluation of candidates for transcatheter aortic valve implantation (TAVI). Aortic valve anatomy and morphology should be assessed in detail: bicuspid aortic valve is generally considered a relative contraindication to TAVI; extensive or asymmetric calcification, especially of the commissures and of the edge of the leaflets may result in unfavourable deployment of the valve and complications like paraprosthetic regurgitation and coronary occlusion. Two-dimensional TOE is the method of choice in evaluating asymmetry of cusps and bicuspid valve, extent and location of calcification, and aortic area. Accurate measurement of aortic annulus is crucial for TAVI feasibility and selection of prosthetic size.[8–11] 2D transthoracic echo and TOE are the most frequently used methods to measure the aortic annulus. However, in patients referred for TAVI, measurements of the aortic annulus using transthoracic echo, TOE, and cardiac computed tomography (CT) are close but not identical, and the method used has important clinical implications on the choice of prosthetic valve size. An annulus diameter by TOE is obtained in the aortic long-axis at the mid-oesophagus level with ∼120° rotation. The ascending aorta should be seen in the long axis, avoiding tangential cuts. In this view the left or the non-coronary cusp is seen posteriorly and the right cusp is seen anteriorly. This view is also commonly used to decide on the 'landing zone' during TAVI. The annular dimension most commonly used in decision-making for TAVI bisects the annulus at its maximum diameter during early systole, from the hinge point of the right coronary cusp to the commissure between left and non-coronary cusp (*Figure 1A* and *B*). However, the aortic annulus may not be circular in all patients, and a long-axis view may not provide a representative diameter of the area where the percutaneous valve is intended to be implanted. Therefore, the use of 3D TOE may provide a more accurate assessment of the aortic valve annular size with better correlation with CT measurements.[12,13] This is achieved by visualizing a short-axis view of the aortic annulus, defined as a virtual ring formed by joining the basal attachments of the aortic leaflets (*Figure 2*). In this short-axis view, the maximum diameter, the minimum diameter, and the area of aortic annulus are measured in systole. Several studies demonstrated that aortic annulus measurements by TOE showed a slight underestimation in comparison with CT (more pronounced with 2D TOE than with 3D TOE). To date, most of the series have provided good results by using 2D echo for aortic annulus sizing; however, CT or 3D TOE-guided prosthesis sizing leads to implantation of larger prostheses than if guided by 2D TOE or 2D transthoracic echo, reinforcing the importance of a 3D assessment of the annulus.[14] Moreover, the distance from the left main coronary ostium to the aortic annulus pre-operatively and to the aortic prosthesis post-operatively can be assessed by 3D TOE.[15]

TOE for guidance of the procedure

Several steps of the procedure may be guided by TOE: the aortic valve crossing, balloon dilatation, and positioning and deployment of the prosthesis (*Figure 3*). However, the need for patient sedation in order to tolerate the TOE probe has led to most institutions performing this procedure under fluoroscopy only. Nevertheless, TOE can help to monitor catheter and prosthesis positioning as well as evaluate results and complications. Immediately after valve deployment, prosthetic valve stent position, shape, leaflet motion, and aortic regurgitation should be rapidly assessed with TOE. Differences in monitoring and imaging the procedure are due to main characteristics of the two types of prostheses most commonly implanted: the shorter, balloon-expanded Edwards Sapien prosthesis (Edwards Life Science), which is anchored at the annulus and extends to a level below the sino-tubular junction, and the longer self-expandable Core Valve (Medtronic), which extends from the annulus into the proximal ascending aorta. The optimal positioning of the Edwards Sapien prosthesis is with the ventricular side of the prosthesis positioned 2–4 mm below the annulus in the left ventricular outflow tract (without interfering with the mitral leaflets). For the CoreValve, the ventricular edge of the prosthesis should be placed 5–10 mm below the aortic annular plane. It is important to confirm that all the prosthetic cusps are moving well, that the valve stent has assumed a circular configuration (using 2D or 3D views), and that there is no significant transprosthetic or paraprosthetic regurgitation. Some (generally mild) regurgitation through the prosthesis is common while the delivery

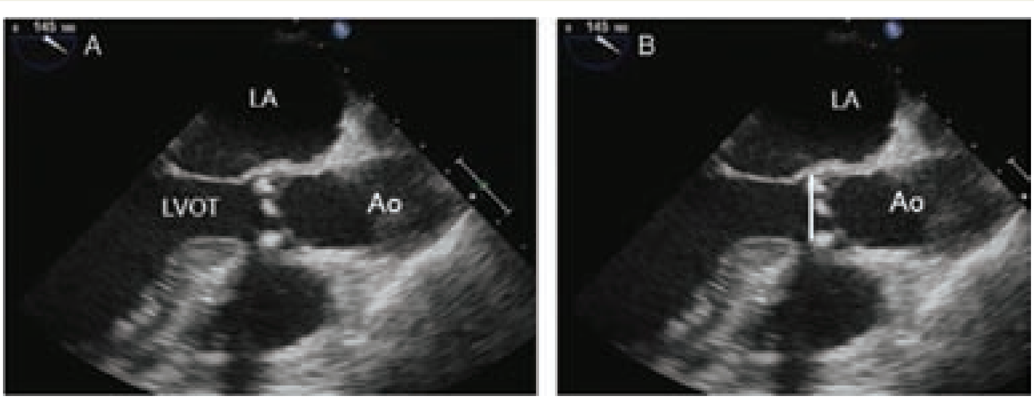

Figure 1 (*A*) Long-axis TOE view showing the left ventricular outflow tract (LVOT), aortic root (Ao), and left atrium (LA). (*B*) Same view as (A), showing the measurement of the annulus: from the hinge point of the right coronary cusp to the left-non-coronary commissure.

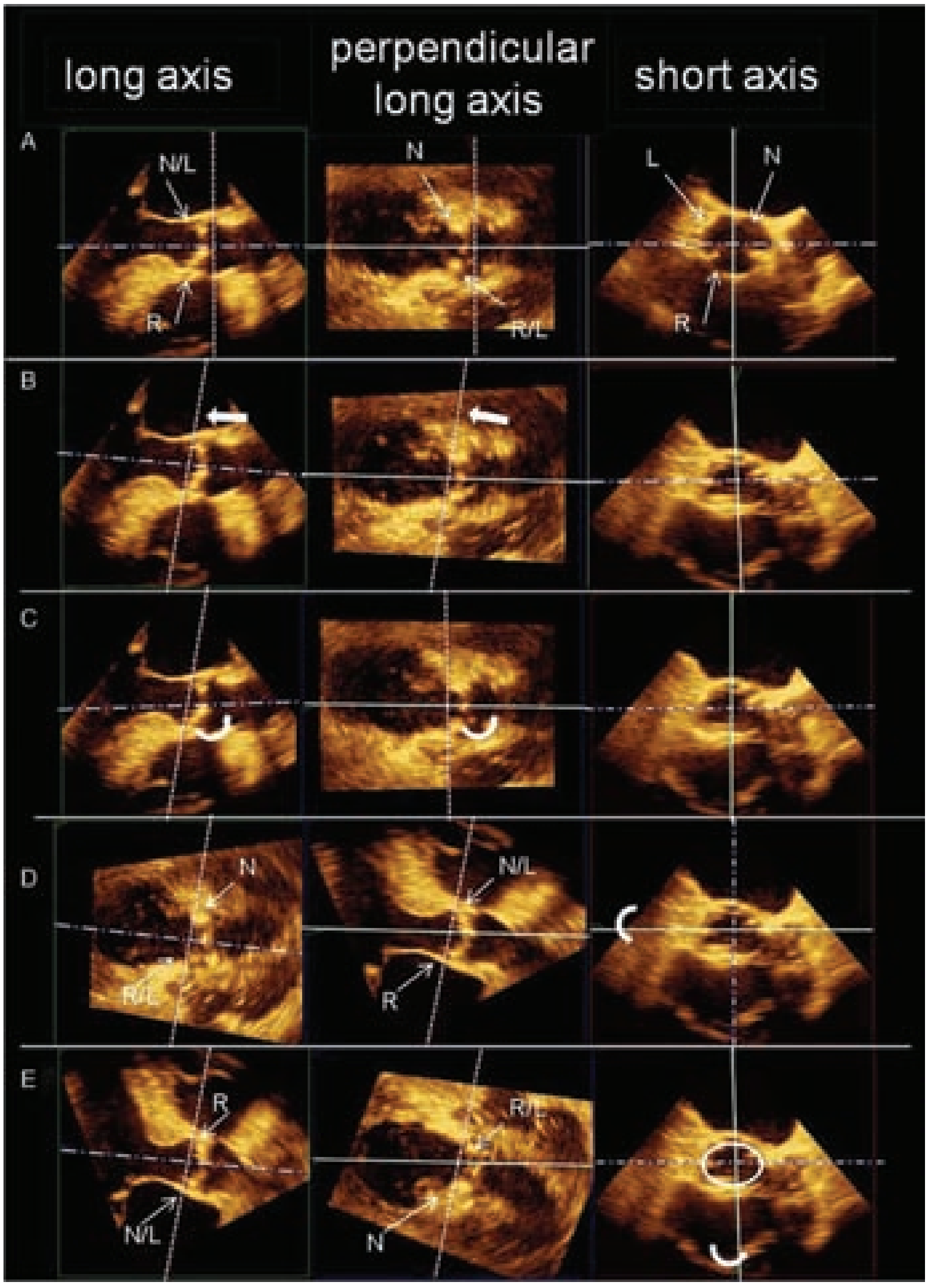

Figure 2 Stepwise approach to measuring the aortic annulus area from transoesophageal 3D echocardiographic data. In the composite figure, the 'classic' long-axis view (LAX) of the aortic valve and ascending aorta, as typically acquired around 120°, is to the left, the perpendicular long-axis (LAX) view of the aortic valve and ascending aorta in the middle (this plane is not part of the 2D examination), and the short-axis view (SAX), as typically acquired around 30°, is displayed to the right. This SAX view, however, is oriented as if looking from the left ventricular outflow tract and thus a mirror image of the typical 2D TOE SAX view. N, R, and L denote the three cusps, with N/L or R/L where the cusp identity may vary individually. Row (*A*): initial orientation of the three planes, which are perpendicular to each other and all centred on the centre of the aortic valve. Row (*B*): adjustment of the SAX such that the line controlling the SAX view is aligned (arrows) to the lowermost cusp attachments ('nadirs') visible in the two LAX views. The SAX should now be roughly in the correct position, containing the three nadirs of the cusp attachments. Row (*C*): to check the correct position of the SAX, the classic and the perpendicular LAX views are rotated around their central common axis (curved arrow) in order to fine-tune the SAX view position making sure that the lowermost attachment point ('nadir') of each cusp has been identified in the left and middle planes and incorporated into the SAX view. Row (*D*): after a rotation by 90°, the classic LAX becomes the perpendicular LAX and vice versa. Row (*E*): further rotation of the LAX views generates views that are rotated around the long axis by 180° from their position in C and 90° from their position in D. During the rotation from C to D and from D to E the lowermost point of attachment (nadir) of each cusp is checked and the SAX corrected accordingly. In the right picture, the contour of the aortic annulus is inscribed as an idealized ellipse to clarify that the annulus is non-circular.

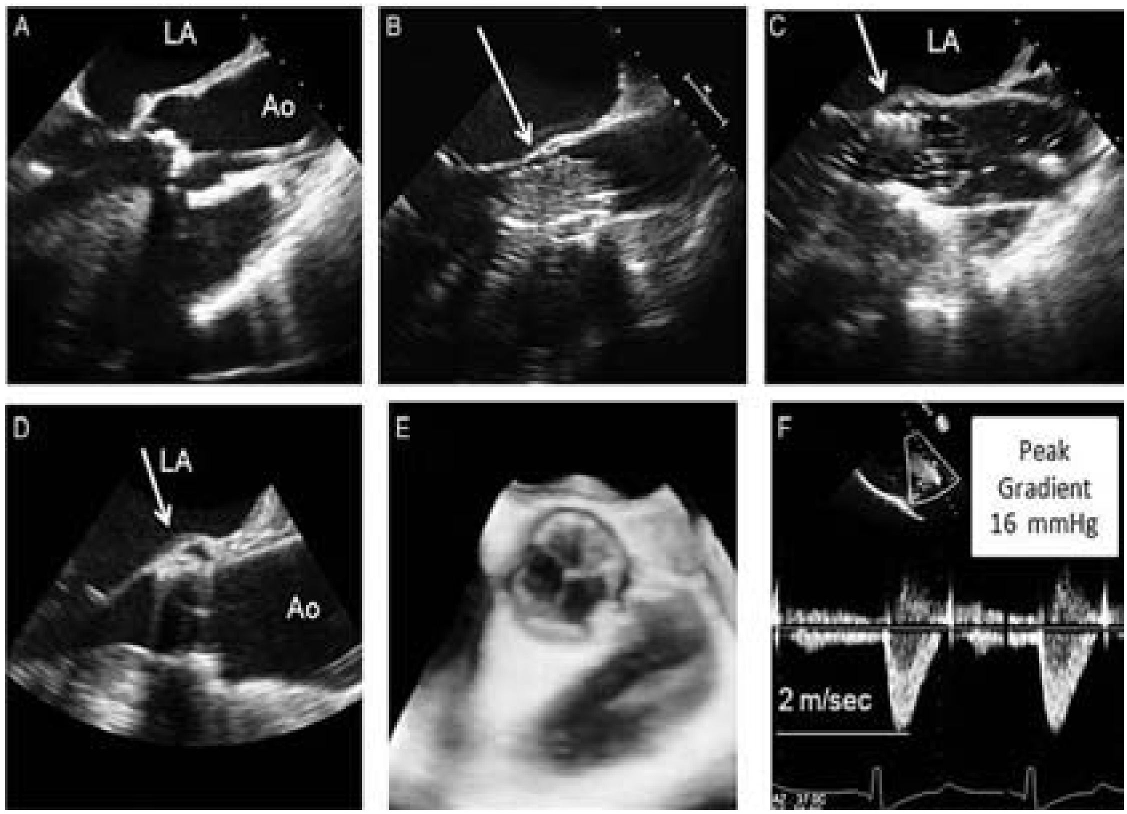

Figure 3 Monitoring TAVI. (*A*) Passage of the catheter across the aortic valve; (*B*) ballooning of the valve (arrow); see also Supplementary data online, SupplVideoValvuloplasty. (*C*) Deployment of the prosthesis (arrow); see also Supplementary data online, SupplVideoTAVIdeployment. (*D*) A long-axis view of the implanted valve (arrow); (*E*) A 3D short-axis view of the implanted valve; (*F*) a deep transgastric view showing the Doppler gradient of the implanted prosthesis. LA, left atrium; Ao, proximal aorta.

apparatus and/or guidewire remains across the valve and may persist, to a lesser degree, after their removal. Besides the visualization of all anatomic and functional details in the mid-oesophagus long- and short-axis views, a transgastric TOE examination including continuous-wave, pulsed-wave, and colour Doppler should be used to confirm satisfactory prosthetic functioning before the probe is finally removed. This window is essential to ensure that all regurgitant jets are detected and allow measurements of peak and mean prosthetic gradients.

Incomplete expansion or incorrect positioning of the device, or inappropriate prosthetic size may cause significant paraprosthetic regurgitation (*Figure 4*). Assessment of severity of paraprosthetic and transprosthetic aortic regurgitation follows the approach for native valves, but distinguishing moderate and severe regurgitation is often difficult. A rough rule for paraprosthetic regurgitation is that a regurgitation orifice comprising >20% of the circumference (>72°) in a short-axis view most likely represents severe regurgitation.[16] 3D TOE is an additional tool to define the severity and precise location of paraprosthetic and/or central regurgitation. Significant regurgitation may be an indication for repeat balloon inflation to attempt a maximal expansion of the valve (or in the case of failure to implant a second device).

TOE in evaluating procedural complications

Severe hypotension, cardiac arrhythmias, and acute ECG changes may occur during all phases of the procedure and TOE can immediately identify potential complications. Indeed, cardiac tamponade secondary to wire perforation of the left or right ventricle, left ventricular dysfunction, severe aortic regurgitation, or new or increased mitral regurgitation can be immediately diagnosed by TOE. Occlusion of the coronary ostia may occur by fragment embolization or by an obstructive portion of the valve frame, sealing cuff, or native cusp. This life-threatening complication may be promptly diagnosed with TOE which shows the disappearance of diastolic left main coronary artery flow and new left ventricular dysfunction. 3D TOE may also directly visualize the distance of the left main coronary ostium to the implanted valve showing whether the prosthesis reaches or overlaps the coronary ostium (15; *Figure 5*). Rarely, a tear or rupture of the aortic root may be observed during the procedure after balloon valvuloplasty or prosthesis deployment, especially in the presence of extensive annular calcification or prosthesis oversizing. Possible sources of peri-interventional ischaemic stroke detectable by TOE are aortic cusp fragment embolization, atheroembolism, thrombo-

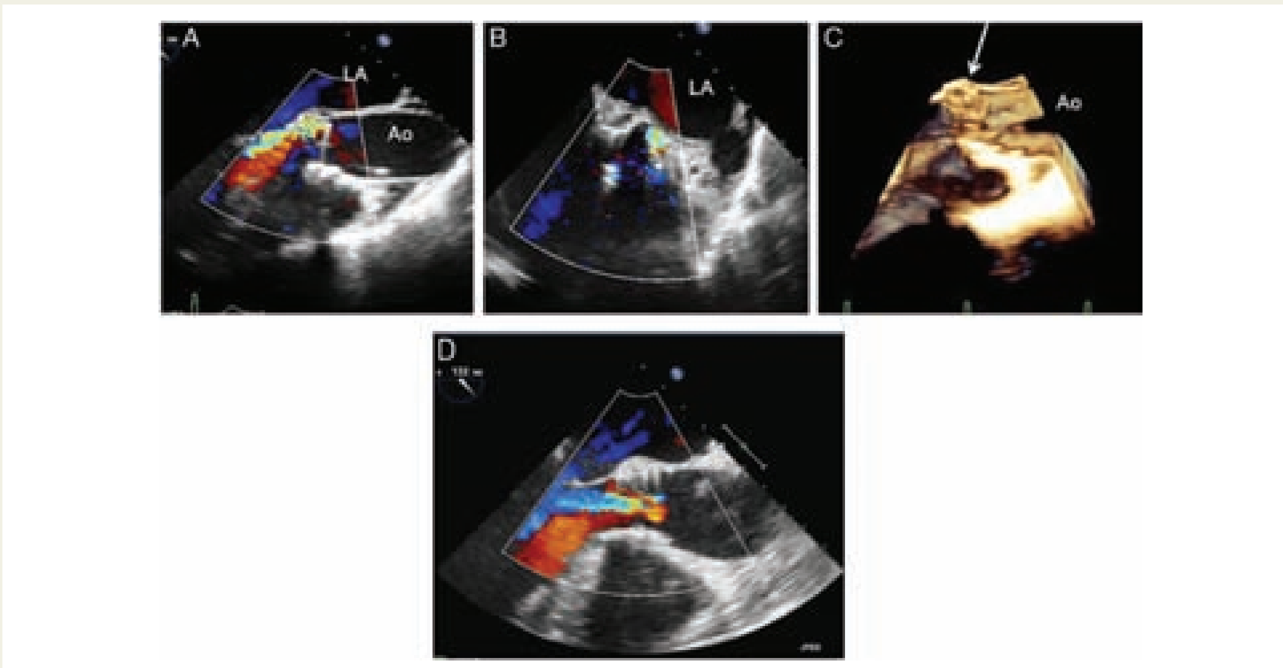

Figure 4 Paraprosthetic regurgitation. (*A*) Regurgitant jet due to a paraprosthetic leak detected in the long-axis view; see also Supplementary data online, SupplVideoParaprosthReg. (*B*) Corresponding short-axis view. (*C*) 3D clearly defines the morphology and dimension of the leak (arrow). (*D*) Moderate-to-severe transprosthetic regurgitation; note proximal convergence zone indicating central origin of jet. See also Supplementary data online, SupplVideoTransprosthReg. LA, left atrium; Ao, proximal aorta.

embolism from catheters, air embolism, or aortic arch dissection extending into the supra-aortic vessels.

Transoesophageal imaging in percutaneous mitral valve edge-to-edge repair

Percutaneous mitral valve repair has evolved into a therapeutic option for high surgical risk or inoperable patients with severe mitral regurgitation.[17,18] Both functional regurgitation and valvular insufficiency due to prolapse and flail leaflet are amenable to interventional treatment. Two strategies have been developed for the interventional therapy of mitral regurgitation:

(i) The edge-to-edge adherence of anterior and posterior mitral leaflet tips using a clip at the site of the regurgitation (preferentially segments A2/P2), which is similar to the surgical technique described by Alfieri. The clip anchors the prolapsed leaflet or flail in the case of degenerative mitral regurgitation, while it improves coaptation of the tethered leaflets in the case of functional regurgitation. In addition, the tissue bridge created by the clip may reduce annular dilatation.

(ii) Direct and indirect mitral annuloplasty, with indirect annuloplasty using a device implanted into the coronary sinus. This technique, however, has not found wide acceptance in clinical practice due to the limited effectiveness, and echocardiographic guidance will therefore not be discussed.

In mitral edge-to-edge repair, which has been performed until 2013 in 9000 patients, TOE has critical importance in three areas:

Pre-interventional evaluation

The indication to perform the edge-to-edge procedure has to consider patient symptoms, valvular morphology and mechanism of regurgitation, severity of mitral regurgitation, and other cardiac pathology. Mitral clipping can be used for functional mitral regurgitation as well as prolapse and flail leaflet. After confirming the presence of moderate-to-severe or severe mitral regurgitation according to current guidelines,[19] it is critical to assess the mitral valve morphology by several parameters in order to assess the likelihood of procedural success. These parameters (*Table 1*, *Figure 6*) are mostly derived from the clinical trials such as the Everest II study.[18] In functional regurgitation, coaptation length and depth have to be defined from a four-chamber view. The coaptation length has to be $\geq$2 mm and a coaptation depth of $<$11 mm. In flail mitral valves, the flail gap, which is the distance separating the flail segment from its opposing normally coapting leaflet, should be $<$10 mm to facilitate leaflet grasping. In addition, the flail/prolapse width should be $<$15 mm. Characteristics such as significant calcification of a leaflet at the site of grasping, short ($<$8 mm length) and very restrictive posterior leaflets, and mitral valve opening area $<$4 cm^2 or mean pressure gradient at rest $>$4 mmHg should result in exclusion of the patient. It is optimal to have the pathology in segments A2/P2, while pathology in segments 1 and 3 is less optimal for treatment.

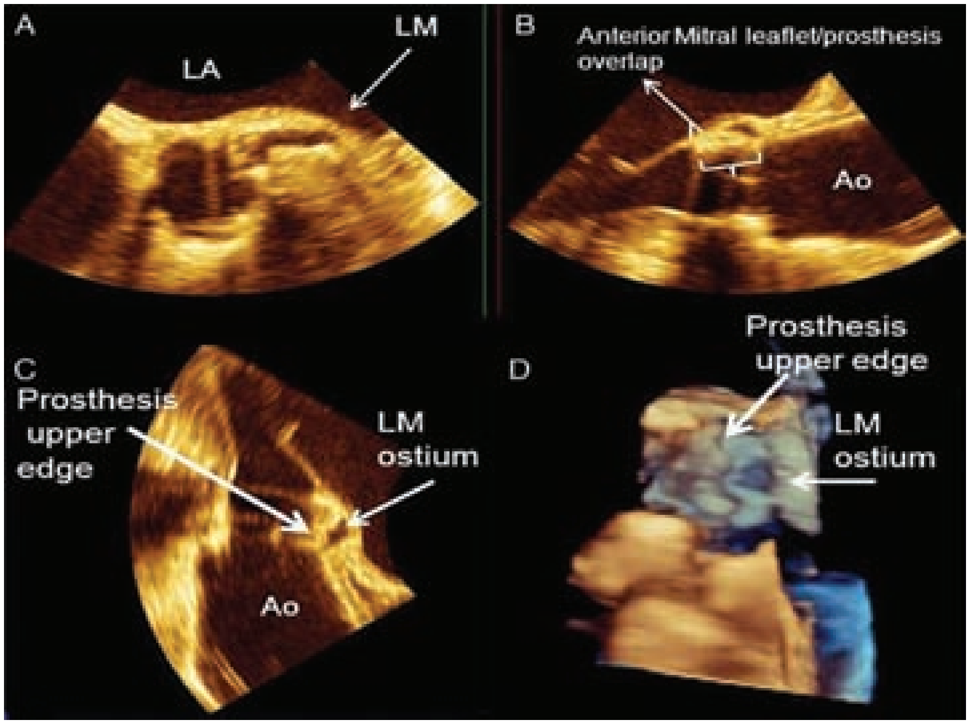

Figure 5 Example of a 3D TOE post-interventional evaluation of the aortic root and prosthesis in orthogonal views. (*A*) A short-axis view of aortic root at the level of the aortic prosthesis and the left main coronary; (*B*) a longitudinal view of the ascending aorta showing the aortic prosthesis length and the overlap of the prosthesis with the anterior mitral valve leaflet; (*C*) a longitudinal view of the ascending aorta with the take-off of the left main; this view allows the measurement of the distance between the upper edge of the prosthesis and the left main. (*D*) An en-face 3D view of the left main ostium and prosthesis upper edge. LA, left atrium; Ao, proximal aorta; LM, left main coronary ostium.

Echocardiographic guidance of the interventional procedure

Echocardiography has superior importance compared with fluoroscopy in the guidance of the mitral clipping procedure as well as the assessment of the procedural result, and should therefore be part of every such procedure.[20] Essential steps of the procedure which are guided by TOE are the transseptal puncture, the advancement of the dilator through the interatrial septum, the navigation of the clip-delivery-system in the left atrium towards the mitral valve, the positioning of the clip above the regurgitant area of the mitral valve, the adjustment of perpendicularity of the clip to the mitral valve intercommissural line, the advancement of the clip into the left ventricle, the grasping of anterior and posterior leaflet by the clip while pulling the clip back from the left ventricle towards the left atrium, and finally the closure of the clip. The transseptal puncture should be at a superior–posterior position 3.5–4 cm above the leaflets to facilitate positioning of the clip. This is controlled by a bicaval view (115–130°) and a short-axis view (30–60°). Subsequent positioning of the clip-delivery system above the mitral valve is controlled by an intercommissural view (55–75°) to adjust the medial–lateral alignment and a left ventricular outflow tract view (120–150°) to adjust the posterior–anterior alignment. 3D TOE allows for improved spatial orientation compared with 2D TOE in particular in this step as well as the subsequent alignment of the opened clip perpendicular to the coaptation line[21,22], (*Figure 7*; see also Supplementary data online, videos). If 3D TOE is not available, a transgastric short-axis view should be used to confirm the perpendicularity of the opened clip above the mitral valve as well as to reconfirm it after entrance into the left ventricle. Simultaneous grasping of the anterior and posterior leaflet must be confirmed in the left ventricular outflow tract view. A long loop should be stored to allow reviewing of this critical step and potential correction to avoid later detachment of one leaflet from the clip. Before the clip is released, good grasping of the anterior and posterior leaflet has to be assured; zoom images are helpful in this regard. Intercommissural views will allow additional analysis whether the leaflets take course into the closed clip. 3D TOE may also be used to demonstrate the resultant tissue bridge.

After the clip has seized the anterior and posterior leaflet, one lateral and one medial (septal) opening are created, replacing the larger native mitral valve opening. Adequate reduction of the mitral regurgitation has to be confirmed by colour Doppler, and a relevant mitral stenosis needs to be excluded. To evaluate the severity of the remaining mitral regurgitation in the complex double-orifice situation, 2D as well as 3D colour Doppler techniques should be applied.[23] In case sufficient reduction of the regurgitation severity cannot be achieved using one clip only in spite of repeated grasping for optimization, further clips may be used to achieve greater reduction of the regurgitation. Due to the multiple complex interventional steps requiring

Table 1 Recommended criteria for echocardiographic analysis of the mitral valve prior to percutaneous edge-to-edge repair

Criteria	Assessment
Mitral leaflet coaptation length	≥2 mm length recommended
Mitral leaflet coaptation depth	<11 mm depth recommended
Gap between leaflet in case of flail leaflet	<10 mm gap recommended
Width of flail leaflet area	<15 mm width recommended
Mitral valve opening area	>4 cm^2 area recommended
Leaflet thickness	≤5 mm thickness recommended
Considerable calcification of the mitral annulus	Should not be present
Marked valvular cleft or leaflet perforation	Should not be present
Marked restriction of posterior leaflet	Should not be present
Lack of primary or secondary chordae support	Should not be present
Calcification of the leaflets in the grasping area	Should not be present
Several significant regurgitant jets	Should not be present

different guiding views, the procedure requires optimal coordination between expert echocardiographers and interventionalists.

While the interventional edge-to-edge repair is a relatively safe procedure, pericardial effusion due to perforation of the atrial wall, detachment of the clip from the mitral valve after initial seating, as well as destruction of the mitral leaflets due to multiple grasping procedures or chordal rupture are potential complications. All of these complications can be easily detected by TOE.

Post-interventional evaluation

Echocardiographic follow-up studies should be performed to determine mitral regurgitation severity as well as left ventricular function. A follow-up TOE allows improved understanding of the morphological causes of recurrent significant mitral regurgitation.

TOE in left atrial appendage device closure

TOE is used for pre-procedural evaluation of the left atrial appendage, for guidance of the procedure and for follow-up studies.

- Pre-procedural evaluation. To define the presence of clots within the left atrial appendage, determine the size of its orifice, the size of the landing zone, the depth of the left atrial appendage, and the number of lobes. Sizing is done in multiple views allowing short- and long-axes analysis, and 3D TOE may be advantageous.
- Guidance of the procedure. TOE is integral part of the procedure for the following steps: transseptal puncture, analysis of multiple

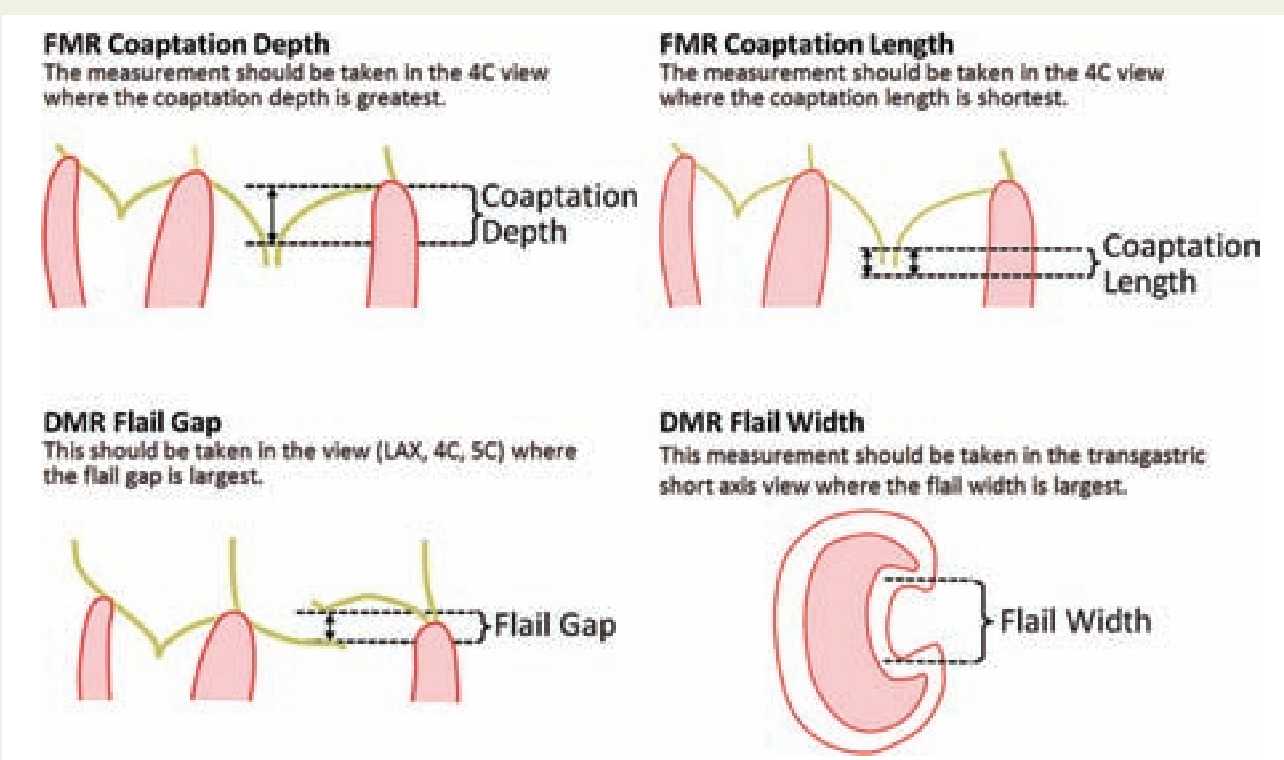

Figure 6 Parameters to describe mitral valve morphology in functional (FMR) and degenerative (DMR) mitral regurgitation.

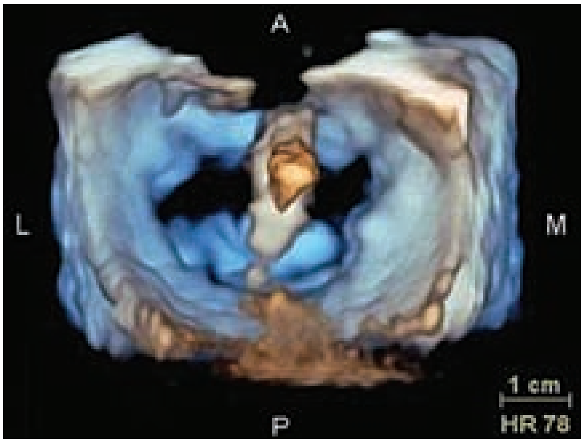

Figure 7 A 3D TOE image acquired in the zoom mode from the left atrium showing the open clip in central position above the mitral valve and perpendicular to the intercommissural line. A, anterior; L, lateral; M, medial; P, posterior (inferolateral). See also Supplementary data online, SupplVideo2DTOEbeforeclipping: 2D TOE showing both arms of the opened clip just above the mitral valve. Supplementary data online, SupplVideo3DTOEbeforeclipping: 3D TOE showing the open clip just above the mitral valve. The clip direction is perpendicular to the closure line of the mitral leaflets. See Supplementary data online, SupplVideo3DTOEafterclipping. This shows the clip-delivery system in the left atrium as well as the anterior and posterior mitral leaflet with a tissue bridge due to the closed clip. There is an opening medial and lateral to the tissue bridge.

signs of adequate device position before device release, detection of complications such as pericardial effusion, mitral valve impingement, or obstruction of the left upper pulmonary vein.

- Follow-up studies. Confirmation of adequate device position, of complete occlusion of the left atrial appendage orifice without flow inside the appendage, and exclusion of thrombus adherent to the device (see *Figure 8* and Supplementary data online, clip).

TOE in infective endocarditis

TOE gives useful information concerning the diagnosis of infective endocarditis, the assessment of the severity of the disease, the prediction of short-term and long-term prognosis, and the follow-up of patients under specific antibiotic therapy. Transthoracic echo must be performed first in all cases, because it is a non-invasive technique giving useful information both for the diagnosis and the assessment of severity of infective endocarditis. TOE needs to be performed in the majority of patients with suspected infective endocarditis, because of its better image quality and better sensitivity, except in the case of good quality negative transthoracic echocardiography associated with a low level of clinical suspicion.[24]

Anatomically, infective endocarditis is characterized by a combination of vegetations and destructive lesions:[25]

(i) A vegetation presents as an oscillating mass attached to a valvular structure, with a motion independent of that of the valve, but may also present as non-oscillating mass with atypical

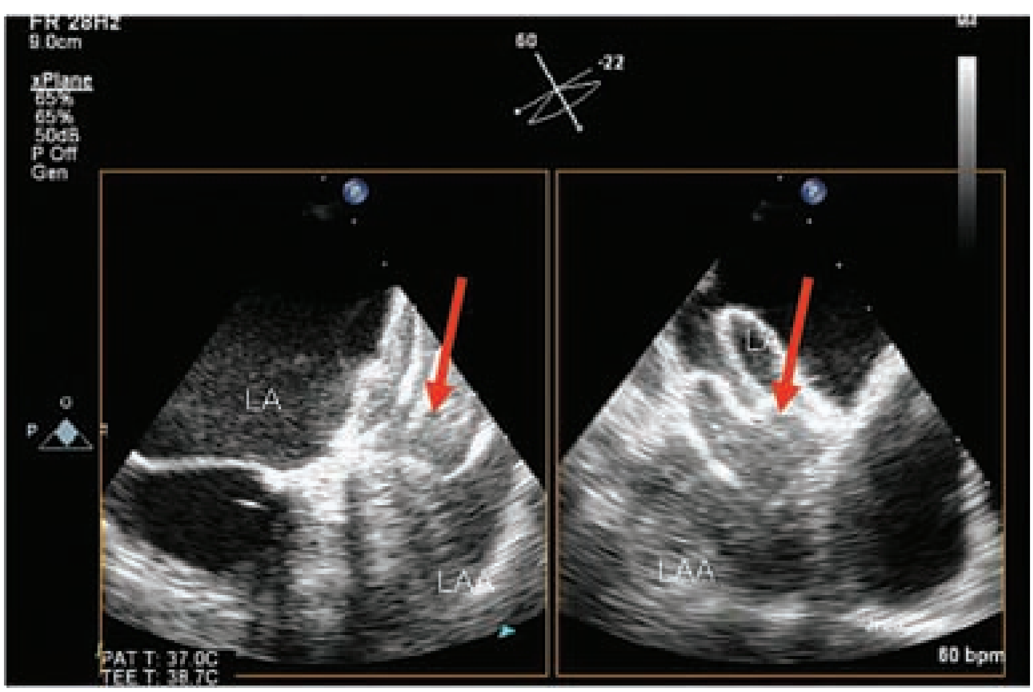

Figure 8 Simultaneous biplane view of short- and long axis of the left atrial appendage showing the occluder in place (arrow). The device consists of a body placed within the appendage and a cap at the orifice of the appendage. LA, left atrium, LAA, left atrial appendage. See also Supplementary data online, SupplVideoLAAoccluder. See legend for Figure 8.

location. Transthoracic echo has a sensitivity of ∼75% for the diagnosis of vegetations, which may be increased to 85–90% by performing TOE. However, the sensitivity of TOE is reduced in prosthetic valves and in infective endocarditis affecting intracardiac devices.

(ii) An abscess typically presents as a perivalvular zone of reduced echo density, without colour flow detected inside, and may be complicated by pseudoaneurysm and fistula (*Figure 9*). The sensitivity of TOE for the diagnosis of abscess is ∼90% with high additional value when compared with transthoracic echo.

(iii) Other destructive lesions may include valve aneurysm, perforation, or prolapse, and chordal or less frequently papillary muscle rupture. The main consequences of these lesions are severe valve regurgitation and heart failure. TOE is of major value for their assessment.

In addition, both transthoracic echo and TOE are useful for the assessment of the underlying valve disease and for the assessment of consequences of infective endocarditis, including left ventricular size and function, quantification of valve regurgitation/obstruction, assessment of right ventricular function, and of pulmonary pressures. Other important points to keep in mind regarding the role of TOE in infective endocarditis are the following:

(i) the diagnosis of infective endocarditis remains difficult in some situations (pacemaker, prosthetic valves); a negative TOE never completely rules out infective endocarditis;
(ii) TOE must be repeated in the case of persistent clinical suspicion of infective endocarditis[26]
(iii) 3D echocardiography is useful for correct description of the lesions, particularly in cases of valve perforation and abscess (*Figure 10* and Supplementary data online, clip)
(iv) transthoracic echo and TOE are complementary and both must be performed in the majority of patients.

Adult congenital heart disease

Currently, TOE is less frequently utilized to evaluate adults with congenital heart disease (CHD) due to an increasing role of CT and cardiovascular magnetic resonance in demonstrating both cardiac and vascular congenital anomalies. Diagnostic advantages of the two modalities over echocardiography in this area are specified in the corresponding guidelines.[27] Since inadequate or equivocal transthoracic echo is the main indication for selecting TOE, cardiovascular magnetic resonance, or CT, one has to realize relative merits and limitations of these three imaging techniques while planning an optimal non-invasive diagnostic algorithm for an individual patient in a given clinical scenario. The advantages of TOE involve high spatial and temporal resolution enabling excellent evaluation of thin and mobile structures, no radiation, no need for ionic contrast injection, repeatability and portability. Extensive experience in echocardiography in evaluating adult CHD, transoesophageal probe introduction and manipulation, and acquisition of relevant images are prerequisites of a complete diagnostic TOE study.

Prior to every examination one should be fully aware of:

(i) Clinical indications for the study (questions to be answered to offer a best therapeutic option).
(ii) Conclusions and uncertainties still existing after a complete transthoracic echocardiography.
(iii) Course of the disease, current clinical data, in particular the presence of arrhythmia and degree of desaturation in cyanotic patients.

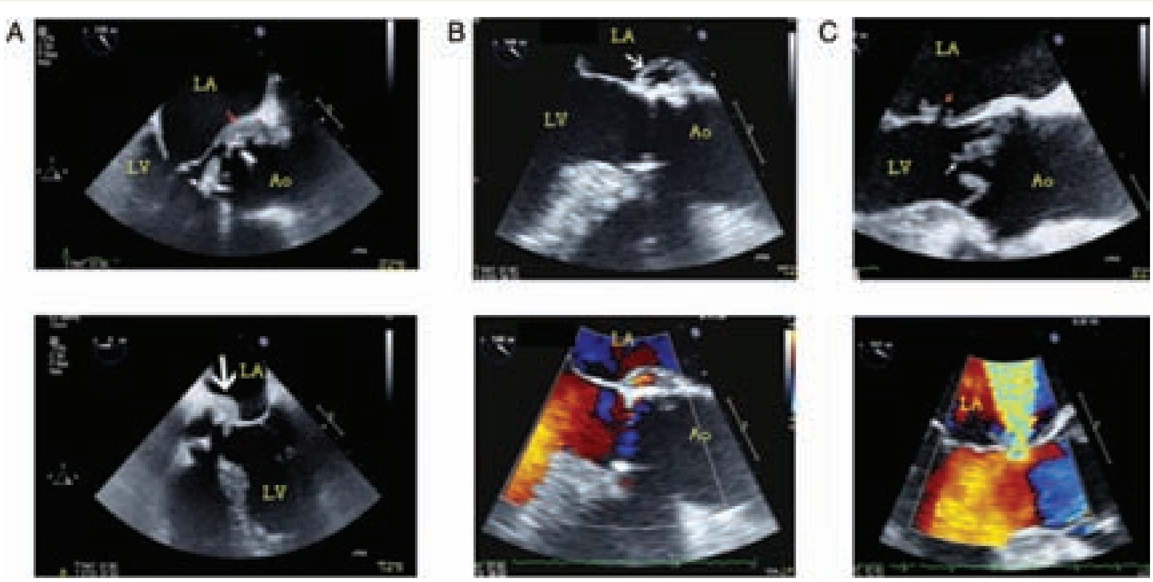

Figure 9 Perivalvular lesions in infective endocarditis: role of TOE: (*A*) abscess: thickened non-homogeneous perivalvular area with echodense or echolucent aspect. (*B*) Pseudo-aneurysm: pulsatile perivalvular echo-free space with flow detected on colour Doppler. (*C*) Mitral aneurysm with anterior mitral valve perforation into the left atrium. LA, left atrium; LV, left ventricle; Ao, aorta.

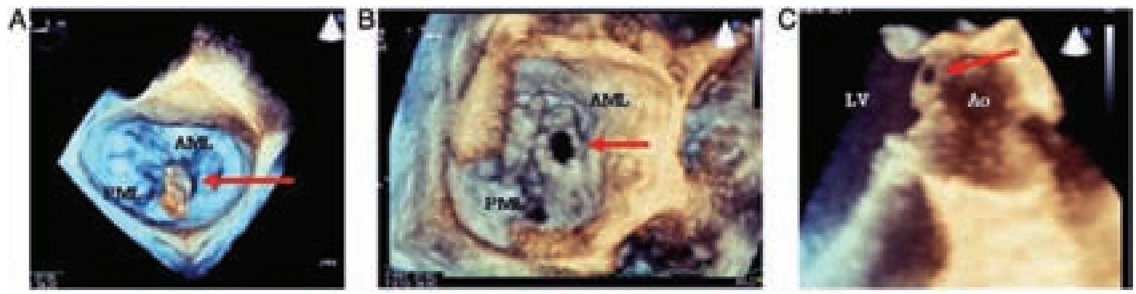

Figure 10 3D TOE in infective endocarditis: (*A*) Large mitral vegetation (arrow): 3D TOE atrial view. See also Supplementary data online, SupplVideoIEmitralvegetation. (*B*) Anterior mitral valve perforation (arrow) 3D TOE atrial view. See also Supplementary data online, SupplVideoIE-PerforationAML. (*C*) Perforation of the non-coronary aortic leaflet: 3D TOE. See also Supplementary data online, SupplVideoIEPerforationaortic-cusp. LV, left ventricle; Ao, aorta; AML, anterior mitral leaflet; PML, posterior mitral leaflet.

(iv) In patients after either surgical or percutaneous intervention: clinical diagnosis prior to the intervention, nature of the intervention/operation, cardiac morphology and function prior to and after the intervention, complications during and after a procedure, and follow-up.

TOE can be hampered or entirely precluded by several factors. Congenital or acquired oesophageal and/or bronchial disease, oropharyngeal pathology, and cervical injuries or anomalies leading to restricted neck mobility may interfere with probe introduction and tip manipulation. Therefore, a history of former oesophageal intubations should be obtained. In cyanotic patients, non-invasive monitoring of saturation (pulse oximetry) is advised. Particular care should be exercised in patients with severe pulmonary hypertension, in whom saturation should be monitored and blood pressure spikes during the examination should be avoided.

The extent of required TOE imaging depends on the clinical indication (*Table 2*). If a study is not primarily focused on a well-defined problem, such as the evaluation of atrial septal defect morphology or valvular function, TOE should provide complete information concerning cardiac anatomy based on a segmental approach similarly to transthoracic echo (*Table 3*). Studying adult CHD requires the use of all standard imaging planes and Doppler interrogations. Particular utility of transgastric planes in these patients should be emphasized, especially to estimate pressure gradients across both outflow tracts or left ventricular cardiac output by Doppler.[28,29] Although all TOE planes can be relatively easily obtained in patients with normal position of the heart within the chest (levocardia), this may be challenging in the case of mesocardia or dextrocardia. In the latter two, obtaining diagnostic images is usually difficult, requires non-standard planes adjusted to a given patient, and may be less rewarding or, in the case of dextrocardia, even not possible.

The most common indication for TOE in CHD is to evaluate an interatrial communication. In this case, the aim is to define atrial septal defect type (secundum, primum, superior/inferior vena cava, sinus coronarius), presence, and characteristics of patent foramen ovale and to establish shunt direction. The description of secundum atrial septal defect or patent foramen ovale should include the suitability for percutaneous closure. This includes the largest defect diameter, extent of tissue rims enabling successful device deployment, possible other defects missed during transthoracic echo, tissue strands crossing the defect precluding device placement, extensive Eustachian valve and Chiari network, as well as concomitant pulmonary venous anomalies. The rim characterization is of paramount importance. Rim segments may be named after the respective adjacent structures (superior vena cava, aorta, coronary sinus, inferior vena cava) or specified as a superior, anterosuperior, anteroinferior, inferior, and posterior (inferolateral). A rim width <5 mm (except at the aortic side of the defect) is generally regarded to preclude device closure. 3D TOE offers improved spatial orientation and substantial information gain with respect to the evaluation of various forms of interatrial septal pathologies,[30,31] especially by offering en-face views of the septum and the defect. The presence of a shunt is proved by colour Doppler and/or contrast injection. Sinus venosus atrial septal defects of both superior and inferior vena cava types are rare forms of the defects, which are demonstrated by TOE with great accuracy. In these pathologies, TOE also allows to demonstrate partial abnormal drainage of right upper/lower pulmonary vein into the superior/inferior caval vein, respectively, invariably coexisting with these septal defects. Primum atrial septal defect (partial atrio-ventricular septal defect) does usually

Table 2 **Indications for TOE in patients with CHD (modified after ref. 41)**

1. Diagnostic indications
(a) Non-diagnostic transthoracic echocardiography in suspected CHD
(b) Evaluation of intracardiac or extracardiac baffles following the Fontan, Senning or Mustard procedure
(c) Other general indications, not characteristic only of CHD (infective endocarditis, prosthetic valve function, prior cardioversion, etc.)
2. Perioperative indications
3. TOE-guided interventions (e.g. atrial septal defect closure)

Table 3 Segmental evaluation of heart anatomy and function in congenital heart disease

Anatomical segment/connection	Example of pathology
Atrial morphology and arrangement	Situs inversus
	Left/right atrial isomerism
	Juxtaposition of atrial appendages
	Cor triatriatum
Pulmonary or systemic venous connection	Complete/partial abnormal pulmonary venous connection, persistent left superior caval vein with or without absent right superior caval vein, pulmonary or systemic vein stenosis
Interatrial septum	Atrial septal defect
	Patent foramen ovale
	Aneurysm
	Pouch
Atrio-ventricular connection and relation	Atrio-ventricular discordance (ventricular inversion)
	Double inlet
	Criss-cross heart
	Supero-inferior ventricles
Atrio-ventricular valves	Cleft
	Double orifice
	Additional valve tissue
	Parachute mitral valve
	Hypoplasia
	Dysplasia
	Stenosis
	Atresia
	Straddling
	Overriding
	Ebstein anomaly
Interventricular septum	Ventricular septal defect
Ventricular outflow tract	Left—tunnel, discrete subvalvular obstruction
	Right—double-chambered right ventricle
Ventriculo-arterial connection	Transposition
	Double outlet
	Common arterial trunk
Great arteries	Valvular pathology
	Supravalvular obstruction
	Patent arterial duct
	Aortopulmonary window
	Major aortopulmonary collateral arteries (MAPCAS)
Coronary arteries	Abnormal origin, fistulas

not require TOE unless coexisting atrio-ventricular valve pathology needs complete evaluation of morphology and function prior to and after the repair. In some of these patients, a double-orifice left atrio-ventricular valve can be demonstrated. Occasionally, there may be a double-orifice right atrio-ventricular valve.[28] Another common indication concerns the evaluation of the left ventricular outflow tract in order to demonstrate the exact morphology (e.g. a membrane) and degree of the obstruction.[29] Occasionally, 3D TOE may offer a better insight into the anatomy of such obstruction.[32]

TOE in aortic diseases

The role of TOE in aortic diseases has changed in recent years. Although TOE is one of the techniques of choice for diagnosing thoracic of aortic diseases, transthoracic echo combined with CT is more often the primary strategy in the emergency setting and follow-up of aortic diseases. However, TOE does play a crucial role in the pre-operative, intra-operative, and post-operative control of surgically treated aortic diseases.

Aortic dissection

TOE has been considered a first-line imaging modality in the diagnosis of aortic dissection, mainly in patients with haemodynamic compromise.[33,34] However, TOE is limited in visualizing the distal part of the ascending aorta and abdominal aorta and tends to be observer- and experience dependent. When the diagnosis of type A dissection is clearly established by CT or transthoracic echocardiography, confirmatory TOE does not seem justified.[33] TOE is better than non-gated CT for location of the entry tear,[35] identification of aortic regurgitation mechanisms, and assessment of false lumen flow.[33] Recent reports have highlighted the diagnostic benefit of echo contrast to TOE.[36,37] This may be helpful to

(i) clarify artefacts by intraluminal reverberations,
(ii) detect entry tears not identified without contrast by showing early arrival of contrast into the false lumen (Figure 11, see also Supplementary data online, clip),
(iii) identify retrograde or antegrade flow in the false lumen
(iv) distinguish the true and false lumen in cases where systolic expansion of the true lumen is not clear cut.

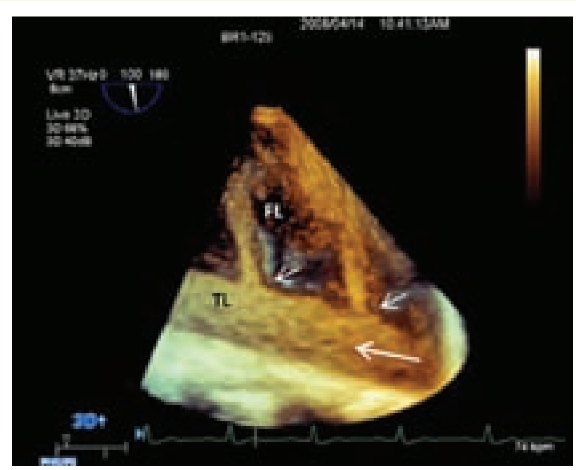

Figure 11 Type B dissection. Contrast-enhanced TOE of the descending aorta in Type B aortic dissection. Antegrade contrast flow is observed in true lumen (large arrow). Absence of significant flow in the false lumen. Small arrows show contrast-enhanced flow from the true lumen to the false lumen through secondary tears. See also Supplementary data online, SupplVideoAodescContrast.

Ideally, TOE should be performed immediately before surgery or endovascular treatment, in the operating theatre and under general anaesthesia. Particular strengths of TOE are assessment of coronary ostial involvement in Type A dissection, assessment of cannulae position, perfusion of different segments and compartments of the aorta (e.g. whether the true lumen is being perfused), and severity of residual aortic regurgitation, as well as detection of complications, such as pseudoaneurysm formation, most of which are secondary to a leak from coronary artery reimplantation to the graft tube, or communication of the distal part of the tube to the false lumen. Similarly, intra-operative TOE is highly useful during endovascular treatment in complicated descending aorta dissections. It permits correct guidewire entrance by identifying the true lumen in aortic dissections, provides additional information helpful to guide correct stent-graft positioning, and identifies suboptimal results and the presence of leaks and/or small re-entry tears, with much higher sensitivity than angiography.

Antegrade or retrograde false lumen flow, false lumen thrombosis, and the presence of communications have prognostic implications and are easily detected by TOE. In patients with residual patent false lumen in the descending aorta, the presence of a large proximal entry tear (>10 mm) defined by TOE has a high risk of mortality and indicates the need for surgical or endovascular treatment during the follow-up (see also Supplementary data online, clip SupplVideoIntimaltea, showing a 3D en face view of the intimal tear in aortic dissection; 35).

Aortic aneurysm

Intra-operative TOE should be used routinely in thoracic aortic surgery. Ascending aorta dimensions, aortic regurgitation severity, and its mechanisms enable pre-operative selection of the best surgical strategy and preparation of an adequately sized graft tube, repair, or replacement of the aortic valve, and shorten surgical ischaemia time.[38,39] Further, TOE provides highly accurate information on the functional anatomy of aortic regurgitation which is strongly and independently predictive of valve repairability and post-operative outcome.[40]

Supplementary data

Supplementary data are available at *European Heart Journal – Cardiovascular Imaging* online.

Conflicts of interest: none declared.

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IMAGE FOCUS

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Symptomatic charcoal heart

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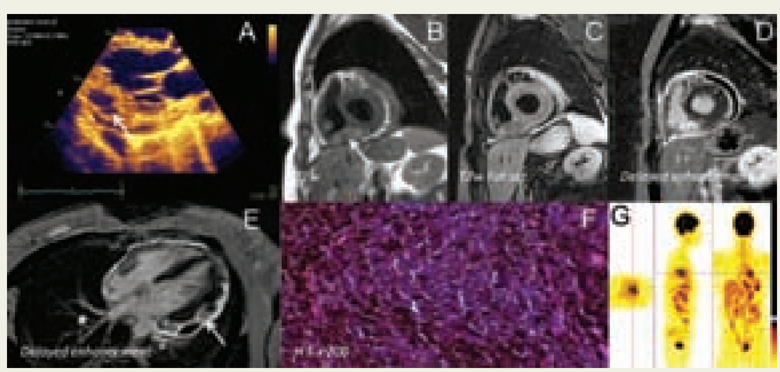

A 47-year-old woman with a past history of left choroidal malignant melanoma submitted to eye enucleation 13 years before presented to the emergency department because of pleuritic chest pain, shortness of breath, and tiredness.

Transthoracic echocardiography revealed pericardial thickening and multiple confluent hypoechoic nodular images, extending into the adjacent myocardium (*Panel A*, arrow, Supplementary data online, Clip S1). For tissue characterization, a cardiac magnetic resonance was performed, confirming diffuse pericardial thickening and multiple myocardial masses with heterogeneous behaviour and hyperintense sign in T_1- and T_2-weighted sequences, respectively, positive for perfusion and with areas of delayed enhancement along the masses and within the whole pericardium (*Panels B–E*, Supplementary data online, Clip S2–S5). These findings were compatible with the myopericardium malignant tumour involvement. A fluoro-D-glucose positron emission tomography scan excluded extracardiac tumour extension/focuses (*Panel G*). Conventional histology (*Panel F*, haematoxylin/eosin) and immunohistochemistry, positive for neural crest derived markers HMB-45 and S-100-protein, confirmed malignant melanoma metastasis on cardiac needle biopsy. The patient was put on dacarbazine chemotherapy with symptomatic relieve at a 6-month follow-up period.

Advanced metastatic malignant melanoma has a very high propensity for heart metastization, being noted in a significant number of patients at autopsy. Nevertheless, exclusive and symptomatic cardiac extension with main pericardial affection-related complains is rare, namely for primary eye tumours.

Supplementary data are available at *European Heart Journal – Cardiovascular Imaging* online.