The role of peri-operative transoesophageal echocardiography

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ABSTRACT

Cardiac surgery and anaesthesia have come a long way since the late 1970s when Transoesophageal Echocardiography (TOE) was introduced into the peri-operative arena. The development of many surgical procedures and the reduction in peri-operative morbidity and mortality can be directly related to the use of TOE. In complicated surgery it has the benefit of providing real time interrogation of cardiac structures and function that can be reliable and repeatable. As with many interventions a full understanding of the limitations, possible artefacts and operating environment is required to benefit patient care. In 1996 an American Society of Anaesthesiologists/Society of Cardiovascular Anaesthesiologists Task Force published guidelines on the indications for intra-operative TOE. These published guidelines have been updated in 2003 and have recently been reviewed once again in the USA and Europe. In this document we discuss the role of peri-operative TOE and its use and value during some Category I procedures.

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INTRODUCTION

In 1976 transoesophageal echocardiography (TOE) was introduced into clinical practice.[1] Within a decade, its use extended from cardiology departments into the cardiac surgical arena. However, at that time few probes were available for the operating theatre. Indeed in a report from the United States in 1988, only about 50 TOE probes were accessible for intra-operative use.[2] Furthermore, despite its utility for cardiac surgery, it became evident that few cardiologists were able to spend long periods in the operating theatre. Over time much enthusiasm and expertise for TOE has developed amongst cardiac anaesthesiologists, and by 2001, 94% of respondents in a survey of the Society of Cardiovascular Anaesthesiologists utilised intra-operative echocardiography in their routine practice.[3]

Over the past 30 years technology has improved tremendously and intra-operative TOE has become an established imaging modality and the gold standard intra-operative cardiac monitor and diagnostic tool in certain cardiac procedures, e.g. mitral valve repair, congenital heart surgery, etc.[4] There is evidence that intra-operative TOE provides valuable information which significantly influences clinical management and improves patient outcome. Several investigators have documented its benefits in critically ill patients and complex cardiovascular surgery.[5,6,7,8,9,10] More recent retrospective analyses of prospectively collected data suggest that around 5.6% of surgical procedures are altered on the basis of intra-operative echocardiographic findings and that there are cost-benefit savings particularly during combined valve and graft operations.[11,12,13] Recently, the roles for peri-operative echocardiography have also extended to include intensive care[14,15] and non-cardiac surgery.[16,17,18] Although it is complex to scientifically prove the benefits of a diagnostic monitor, TOE has been shown to strongly influence intra-operative anaesthetic decisions, particularly in patients with increased risk factors for haemodynamic instability or myocardial ischaemia. In a prospective observational case series of 98 patients undergoing abdominal surgery, the judgement of the anaesthetists was that TOE led to useful alterations in intra-operative care such as administration of fluids, vasoactive drugs and β blockers. In some patients, use of the pulmonary artery catheter was obviated.[19] Similarly, in another case series comprising 90 patients undergoing vascular, visceral and chest surgery, TOE directed changes in drug (47%) and fluid therapy (24%).[20]

PERFORMING AN INTRA-OPERATIVE TOE

A Task Force of the American Society of Echocardiography and Society of Cardiovascular Anaesthesiologists has developed guidelines for performing a comprehensive intra-operative multiplane TOE examination based on a series of 20 anatomical cross-sectional images.[21] These guidelines promote training in TOE, assist assessment of quality and completeness of individual studies, and facilitate comparison of studies performed at different centres. A very similar set of guidelines was recommended in 2001 by the Working Group on Echocardiography of the European Society of Cardiology.[22]

Because the oesophagus is in close relationship to the left atrium and posterior aspect of the heart, a high frequency (5 MHz) 2-dimensional (2-D) TOE transducer can provide clear images of most cardiac structures. With pulse wave (PWD) and continuous wave Doppler (CWD), blood flow velocity and direction of flow can be determined. The use of Colour-flow Doppler (CFD) adds to the ability to make a qualitative assessment of cardiac function. The multiplane facility has increased the possible 2-D views of a routine TOE examination, but still requires the examiner to mentally reconstruct a 3-dimensional (3-D) interpretation.

Recent introduction of 3-D TOE has made such reconstruction unnecessary, although the 3-D image still depends on the quality of acquired 2-D information. The spatial and temporal resolution of the new matrix array transoesophageal transducer (Philips, Andover, Massachusetts, USA) with more than 3000 piezoelectric elements, allows clear 3-D images at acceptable frame rates. A single 3-D volume acquisition over three to five cardiac cycles allows comprehensive 2-D evaluation in any plane extracted from the dataset.[23] It reduces significantly the number of steps required to complete a comprehensive examination, thus minimising examination time.[24] However, detailed quantification i.e. off line intra-operative geometric analysis using integrated 3-D mitral valve and left ventricular quantification software is slightly cumbersome.[25] Early evidence suggests that real-time 3-D TOE adds additional information to the intra-operative comprehensive examination and decision making process during cardiac surgery.[26] In addition, 3-D images facilitate communication between the echocardiographer and other members of the surgical team.[27] It is expected that a combined 2-D and 3-D TOE examination will, in the foreseeable future, become routine for intra-operative surgical guidance.[28]

Doppler tissue imaging (DTI) is a supplementary modality that measures myocardial velocities, strain and strain rates from specific myocardial segments. From these data, it is possible to obtain quantitative information on regional and global ventricular function as well as left ventricular filling pressure. There is debate on the utility of this information in the peri-operative period owing to dynamic alterations in myocardial loading conditions and difficulty with obtaining angle independent measurements.[29,30] Unless the operator understands and sticks to all the rules of Doppler, these data may be misleading and incorrect.

Recently in paediatric practice, a miniature TOE probe enabling multiplane 2-D imaging has been introduced (Philips, Andover, Massachusetts, USA). The 48-element transducer measures 8.2 x 7mm in diameter at the tip with a 5.2mm diameter shaft. This technology allows diagnostic intra-operative TOE assessment of children and neonates as small as 2-2.5kg.[31]

INDICATIONS AND PRACTICE GUIDELINES

Early experience with the use of peri-operative echocardiography was obtained from its application in cardiac anaesthetic practice; recently however, its role has extended to include non-cardiac surgery and intensive care.[18] In 1996 an American Society of Anaesthesiologists/Society of Cardiovascular Anaesthesiologists Task Force published guidelines on the indications for intra-operative TOE.[32] They divided the indications into three categories based on the strength of supporting evidence or expert opinion that this tool improves clinical outcome:

- **Category I indications** are supported by strong evidence and expert opinion that TOE is indicated, very useful and will improve patient outcome. These category I indications encompass the everyday practice of the intra-operative anaesthetist-echocardiographer and will be discussed in more detail in this review.
- **Category II indications** are supported by weaker evidence and less expert opinion that TOE will make a difference under these circumstances. Here it may be useful and make a difference to outcome.
- **Category III indications** have little scientific support or expert opinion that TOE will improve the outcome for patients with these conditions. This is often due to lack of available relevant scientific evidence.

These published guidelines have been updated in 2003[33] and has recently been reviewed once again in the USA[34] and Europe (in progress - personal communication). The most striking new change

is that the Task Force of the American Society of Anaesthesiologists and the Society of Cardiovascular Anaesthesiologists now recommends that "for adult patients without contraindications, TEE should be used in all open heart (e.g. valvular procedures) and all thoracic aortic surgical procedures, and should be considered in CABG surgeries as well". Application of this new standard is dependant on available technology, funding, as well as user knowledge and skills. Categories II and III include most peri-operative situations in the "cardiac surgical patient"; owing to their extensive list, they will not be discussed in this document.

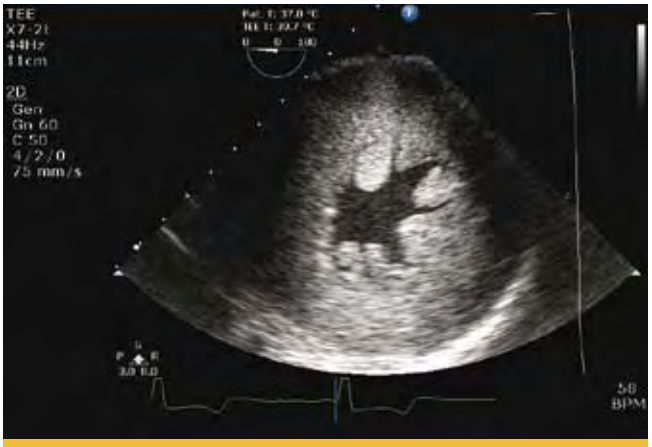

FIGURE 1a: A real-time transgastric short axis view of the left ventricle allows accurate qualitative evaluation of ventricular filling and function and is of great value in acute situations. This image demonstrates a non-compliant left ventricle with severe concentric hypertrophy and preserved systolic function. Should this patient become unstable, volume loading and a higher filling pressure will be the management of choice.

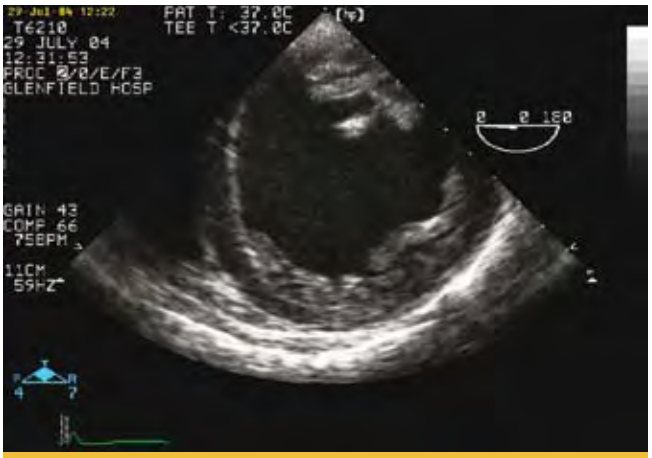

FIGURE 1b: A real-time transgastric short axis view of a failing and dilated left ventricle: Should this patient become unstable, inotropic support will be required.

Category I indications

Life-threatening, persistent haemodynamic instability in the acute setting is an important indication for TOE. The use of a pulmonary artery (PA) catheter in combination with the thermodilution technique has been common in such situations.[35] However, there is no conclusive evidence to date that using a PA catheter improves outcome in critically ill patients.[36] During haemodynamic evaluation TOE has proved reliable and comparative with the PA catheter and standard thermodilution techniques.[37] It can provide a real time and quick analysis of cardiovascular dysfunction and its use prior to other forms of invasive monitoring has been suggested.[38] A survey has shown that among anaesthesiologists with echocardiography training in the USA and Canada, TOE was preferred as monitor to the PA catheter in critically ill patients and complex cardiovascular surgery.[39] TOE examination may provide information quicker and less invasive than the PA catheter and can avoid uncertainty when the cause of instability is unclear or resistant to treatment. It will also provide more extensive real time information with regards to heart function and structure. However, when data from both a PA catheter and TOE are available, they should be viewed as complementary.[40]

Visualisation of left ventricular and right ventricular function, interpreting regional wall motion abnormalities and detection of global systolic or diastolic dysfunction can assist the trained clinician. Real-time echocardiography images of ventricular filling, ejection and cardiac structures allows accurate qualitative evaluation of cardiac output, and is of great value in acute situations (Figure 1a, Figure 1b). Intermittent quantification of cardiac output by TOE may be obtained by measuring the Doppler velocity of blood flow across a specific valve (e.g. the aortic valve). Studies show that the 95% level of agreement of measurements of cardiac output estimated by TOE and also by thermodilution is within 1 litre min^{-1}. Whilst these measurements are repeatable within observers, there may be much interobserver variability.

Ischaemic heart disease is an important cause of peri-operative morbidity and mortality. Compared with monitoring of myocardial ischaemia by ECG and S-T segment analysis, TOE enables earlier identification.[41] Early myocardial ischaemia may be detected by visualising loss of normal systolic wall thickening and inward motion, in transverse and longitudinal cross-sectional planes in the transgastric position.[42,43] Analysis of ventricular segments can elucidate the affected coronary arteries. Following diagnosis, response to therapy or intervention can be assessed in real time by TOE.

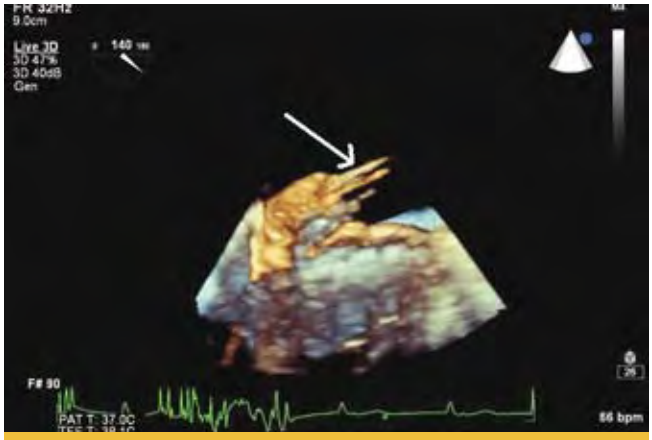

FIGURE 2a: This live 3-D image demonstrates several flail P2 chordae causing severe prolapse of the middle scallop of the posterior mitral valve leaflet.

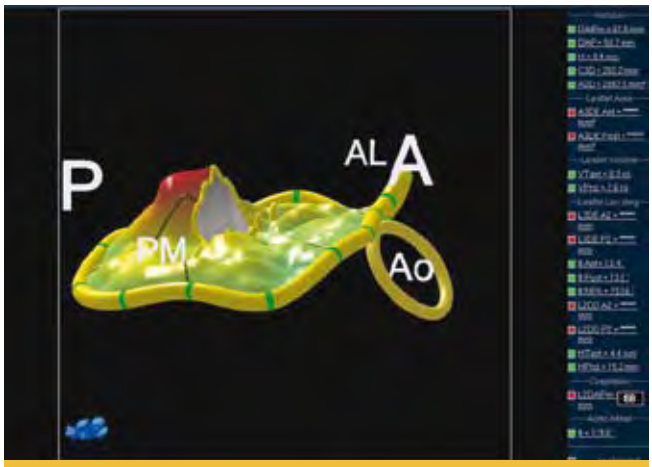

FIGURE 2b: This reconstruction of the same mitral valve provides a graphic image which may assist to quantify the pathology.

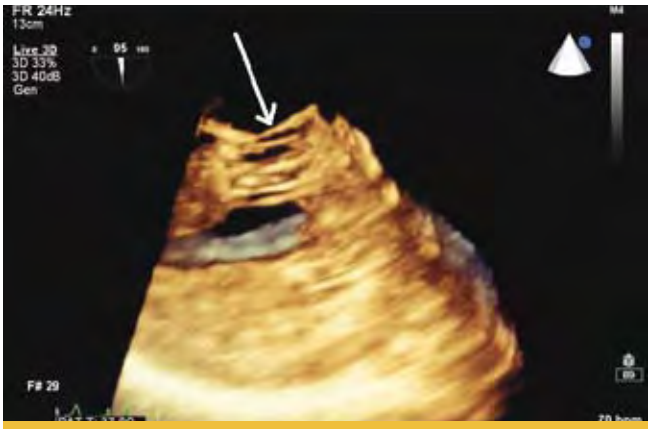

FIGURE 2c: After repair of the same mitral valve with several artificial chordae to the posterior leaflet, either 2-D or 3-D echo can confirm competence in the operating theatre. The artificial chordae are clearly visible on this live 3-D image.

Mitral valve repair and replacement are now performed earlier in disease staging than before.[44] The role of intra-operative TOE for these conditions is well established,[33,45] and has significant impact upon post-operative outcome.[46,47]

Owing to the close relationship of the mitral valve to the oesophagus, clear images can be obtained. By using different views and scanning modalities including 3-D TOE, specific leaflet morphology can be identified and pathology quantified[48] (Figure 2a, Figure 2b, Figure 2c). Ventricular dysfunction that has prognostic value may be confirmed by TOE. At the end of surgery, TOE is used to provide quality assurance by checking for residual mitral regurgitation and paraprosthetic leak.[49] (Figure 3a, Figure 3b) In addition to having detailed anatomical knowledge of the mitral valve, echocardiographers have to appreciate that under general anaesthesia there are functional alterations compared with the pre-operative state, e.g. the severity of mitral regurgitation may be underestimated in the operating theatre because of a reduction in preload.[50,51,52]

Aortic valve repair procedures are usually complex and require the echocardiographer to have a good understanding of different mechanisms of pathology and possible surgical procedures.[53,54] The vast majority of aortic valves suitable for repair are functionally regurgitant (AR) rather than stenotic. Although the severity of AR is certainly a consideration, identifying its mechanism by TOE may help the surgeon to distinguish those valves suitable for repair from chronic fixed abnormalities requiring aortic valve replacement (Figure 4). A functional classification of mechanisms of aortic regurgitation pathology has been described to assist during AV repair procedures.[55] A valve sparing procedure involving resuspension of the cusps is often performed in patients with aortic dissection without additional leaflet pathology. Understanding the different mechanisms of AR in a patient with acute type A aortic dissection is essential to guarantee successful surgical outcome[56] (Figure 5a, Figure 5b).

The quality of an aortic valve repair procedure can be assessed early, during cardiopulmonary bypass soon after the aortic cross clamp has been removed. If the repair is unsuccessful, the high aortic pressure due to non-pulsatile bypass flow will cause aortic valve regurgitation, which can be demonstrated by TOE. Residual aortic regurgitation is a poor prognostic indicator of long term outcome and in such cases a second bypass run and replacement of the valve is indicated.

FIGURE 3a: This 3-D zoom image demonstrates prolapse of the middle scallop (P2) of the posterior mitral valve leaflet. Severe calcification of the posterior annulus is also visible clearly.

FIGURE 3b: During repair the surgeon commented on the extreme calcification of the annulus. After repair with complete ring prosthesis a high velocity paraprosthesis regurgitant jet was observed. The arrow points at a residual cleft between P1 and P2 on the anterolateral side outside the annuloplasty ring.

Although routine valve replacement is considered a category II indication, TOE provides information that can guide modifications of anaesthetic and surgical care which lead to improved outcome.[57] Use of TOE during more complex valve replacement like stentless aortic valve or homograft is invaluable and classed as category I.[33] These prostheses require surgical experience and accurate intra-operative TOE analysis such as precise diameter measurements of the aortic root and ascending aorta as well as the origin of the coronary ostia.[58,59] Discrepancy between measurements due to dilatation of the ascending aorta may lead to tethering and splaying of the stentless prosthetic leaflets after implantation, which may result in AR. Considering these variations in pathology, the surgeon will then have to replace or remodel the sinotubular junction and or part of the ascending aorta. After AV replacement with a homograft or stentless valve immediate post-bypass TOE is used to evaluate leaflet mobility and coaptation. The prosthesis inside the native root will have the appearance of a "tube within a tube", often with a potential space where the different layers of sinus of Valsalva wall and prosthesis overlap. Any turbulent flow pattern on colour Doppler may indicate valve malposition due to imprecise sizing and implantation.

The Ross procedure involves the replacement of a diseased aortic valve, usually in the younger age group, with the patient's own pulmonary autograft.[60] The pulmonary valve is then replaced with a cryopreserved homograft. Accurate pre- and post-surgical assessment of the aortic and pulmonary anatomy is essential for these procedures. Left ventricular contractility and regional wall function should be carefully evaluated for any sign of ischaemia, because the first septal perforator of the left anterior descending coronary artery can be damaged during harvesting of the pulmonary valve.

Acute dissection of the ascending aorta needs emergency surgical intervention. TOE can provide real time evaluation of aortic pathology in the operating theatre, which may be advantageous over the transportation of an unstable patient to potentially remote environments such as CT or MRI suites. Acute dissection with aortic valve involvement therefore falls in the category I group of indi-

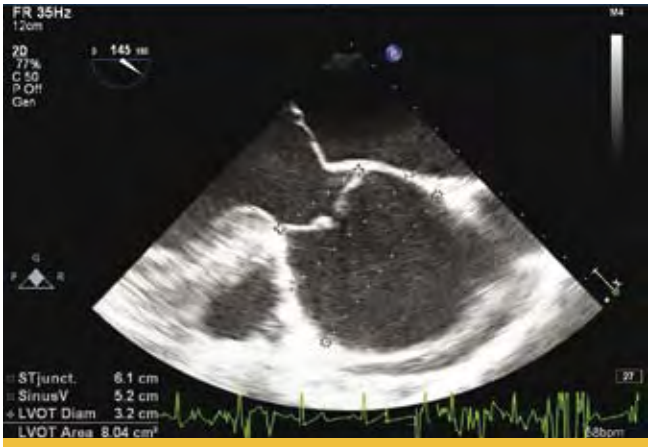

FIGURE 4: Accurate measurements of the aortic root are necessary to guide surgical repair of the aortic valve. In this patient the left ventricular outflow tract diameter measures large at 3.2cm, while the sinotubular junction is dilated at 6.1cm diameter. This means that the surgeon needs to address both the ascending aorta and annulus.

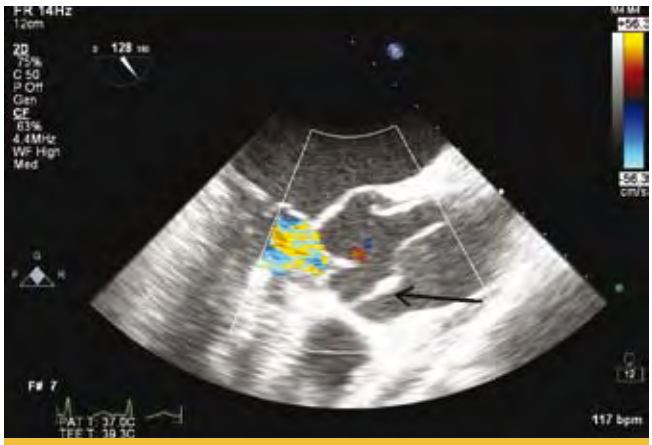

FIGURE 5a: In this patient with a dissection of the ascending aorta, the intimal flap dissects down towards the aortic root involving the ostium of the right coronary artery. The aortic valve is incompetent as demonstrated with colour flow Doppler.

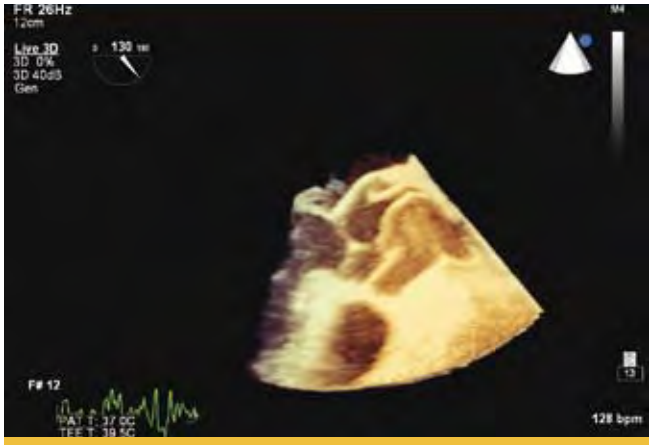

FIGURE 5b: The same dissection demonstrated in 3-D. The 3-dimensional extent of the intimal flap can be appreciated.

cations. TOE is more sensitive than trans-thoracic echo (TTE) for detection of thoracic aortic dissection and has similar sensitivity and specificity to CT and MRI imaging.[61]

Rapid intra-operative assessment of the aorta is necessary to successfully guide the surgeon. The ascending and descending aorta should be visualised to demonstrate the true lumen, false lumen, intimal flap and entry site. TOE can image the ascending aorta but is limited due to the anatomical location of the trachea and left main stem bronchus, which lies between the oesophagus and aortic arch. As only 80% of the ascending aorta may be clearly visualised, it is often difficult to examine the proximal arch[62] and epi-aortic scanning may be indicated.[63]

In addition to diagnosing the extent of dissection, TOE is valuable to assess other complications. Involvement of the aortic valve and presence of a pleural or pericardial effusion with a possible tamponade has important prognostic implications (Figure 5a, Figure 5b). Impaired ventricular function and wall motion abnormalities can be evaluated and haemodynamic performance optimised in the unstable patient. Dissection extending into the coronary arteries can be diagnosed with reasonable accuracy because TOE visualises approximately 70-88% of the left, and 25-50% of the right coronary artery ostia.[64] TOE is also helpful in the operating theatre during cannulation for cardiopulmonary bypass in patients with acute Type A dissection. For example, when the transapical approach is used, real time imaging assists in guiding the cannula across the left ventricular outflow tract and aortic valve, and ensures correct positioning into the true lumen.[65]

Intra-operative TOE is essential for congenital heart surgery i.e. a category I indication.[33, 66, 67,68] Prior to surgery TOE may display clearer images than those of transthoracic echocardiography in patients with pulmonary disease or chest deformities. Cardiac structural abnormalities can be demonstrated and functional haemodynamic limitations can be measured.[69] Whether it is an anaesthetist or cardiologist, it is important that the physician performing intra-operative paediatric TOE examinations is experienced and has a proper understanding of congenital cardiac pathology and the intra-operative conditions.[70]

A complete sequential segmental TOE analysis is recommended, similar to the full pre-operative transthoracic assessment in any patient with congenital heart disease.[71] Moreover, in patients with intra- or extracardiac shunt it may be useful to calculate shunt ratio between the pulmonary and systemic circulations.[72] After cardiopulmonary bypass, TOE has been shown to provide initial quality assurance of the surgery.[73] Recently, there have been advances in 3-D TOE for adolescents,[74] as well as multiplane technology which can now be applied in children as small as 2kg.[31] A realistic problem with TOE in small children is possible probe compression of the airway and big vessels, leading to desaturation[75] and haemodynamic compromise.[76]

Hypertrophic cardiomyopathy (HCM) can be diagnosed with TOE and also falls in the category I of indications.[77] Abnormal motion of the anterior leaflet of the mitral valve onto a hypertrophic interventricular septum during late systole leads to a high pressure gradient across the left ventricular outflow tract as well as dynamic

mitral regurgitation.[78] If the patient undergoes surgical myomectomy, intra-operative TOE provides information on specific location for myomectomy as well as post-surgical integrity of the interventricular septum, mitral valve function, and patency of the left ventricular outflow tract.

TOE is an essential tool during surgical intervention for endocarditis.[33] It reveals pathology such as vegetations, abscesses and degree of extension to perivalvular tissue. Although more invasive than transthoracic echocardiography, TOE provides better views and has a higher sensitivity for detecting paravalvular abscesses, and vegetations (87-100%) on native and prosthetic valves.[79]

Although the diagnosis of pericardial effusions and use of TOE during pericardial surgery falls in category 2, the task force has classed it as category 1 in patients with posterior or loculated effusions, when TOE is used to evaluate the adequacy of a pericardial window procedure.[32,33] In spite of limited scientific evidence, it is expert opinion that TOE is beneficial during these procedures if it helps to avoid serious haemodynamic complications.[80]

Placement of intracardiac devices and monitoring of their position during port-access and other cardiac surgical interventions are also category 1 indications. For example, due to complex interaction of RV and LV function, and importance of correct positioning of LV assist device cannulae, it has been demonstrated that TOE guidance improves cardiac performance during placement of mechanical support devices.[81]

Category II and III indications

It is interesting that according to the 2003 ACC/AHA/ASE guidelines, the only category III indication for peri-operative echocardiography is surgical repair of uncomplicated secundum atrial septal defect.[33] Under category II falls the rest of the cardiac conditions, procedures and interventions when the patient may be at risk of ischaemia or haemodynamic instability. The feeling among most anaesthetic echocardiographers is that many Categories II and III indications may well be upgraded to Category I in future when more relevant scientific evidence becomes available.[34] Absence of evidence is not necessarily evidence of absence.

Complications and contra-indications

Complication rates and mortality associated with the use of TOE are extremely low. Data for complications attributable to TOE are derived from cardiac anaesthetic practice. In a case series of 4 784 patients, six complications were detected, giving an incidence of 0.13%.[82] This rate is similar to that of another case series examining 7200 patients where TOE-associated morbidity and mortality was 0.2% and 0% respectively.[83] Typical injuries include a sore throat, dental injury, upper gastrointestinal haemorrhage and oesophageal perforation. Equipment familiarity and an experienced anaesthetic team avoid perhaps one of the most important potential complications - the anaesthetist's attention being distracted from patient care. The benefits of peri-operative echocardiography should therefore be weighed against the risks that it poses.[84]

There are few absolute contra-indications. Recent oesophageal surgery, oesophageal strictures, diverticulae and tumours will be contra-indications. However, TOE may be used for patients with oral, oesophageal or gastric disease, if the expected benefit outweighs the potential risk, and provided appropriate precautions are taken (e.g. smallest possible probe).[34] Anti-coagulation with warfarin or heparin within the therapeutic range can only be considered a very relative contra-indication.

TRAINING AND QUALITY ASSURANCE

A substantial level of training is required to obtain maximum benefit from TOE as a high quality peri-operative monitor and diagnostic tool. The development of training and certification in echocardiography has been a long and intensive process in Europe and the USA. Excellent comprehensive TOE courses have been developed,[85] and working groups on TOE have published extensive practice and training guidelines on both sides of the Atlantic and in Japan.[86, 87] The American Society of Cardiothoracic Anaesthesiologists (SCA) developed the first formal examination in peri-operative TOE in 1998.[88] The SCA and American Society of Echocardiography (ASE) then combined forces to establish the National Board of Echocardiography, which had the responsibility to further administer examinations and develop a certification process in clinical echocardiography.[89]

Europe has followed a similar route with the Association of Cardiothoracic Anaesthetists of Great Britain and Ireland (ACTA) joining forces with the British Society of Echocardiography (BSE) to establish an accreditation process in TOE with its first examination held in the UK in 2003.[90] Since then the European Association of Cardiothoracic Anaesthesiologists (EACTA) and the European Association of Echocardiography (EAE) produced its own Euro-

pean TOE examination and accreditation process in 2005. In 2004, the Japanese Society of Cardiovascular Anaesthesiologists launched its first TOE competency examination. The purpose of these accreditation processes is to enable recognition of special competence in peri-operative echocardiography against an objective standard. All accreditation processes consist of two parts. With the practical part the candidate must demonstrate adequate training and competency through a supervised residency program or logbook. The theoretical part requires the successful completion of a multiple choice and image clip examination.

In the case of anaesthetists, traditional TOE training is performed in the operating room during a cardiac surgical procedure with its time constraints and limitations e.g. electrocautery interference. Recently a commercial TOE simulator has been developed (Heartworks) which allows the examination of a mannequin with a realistic "digital" TOE probe.[91] This simulator greatly simplifies teaching of probe manipulations and image acquisition of normal anatomy, and has enormous potential for training. Continuous improvement of quality of peri-operative echocardiography should be pursued not only by individual practitioners, but also by echocardiography departments.[92,93]

CONCLUSION

Cardiac surgery and anaesthesia have come a long way since the late 1970s when TOE was introduced into the peri-operative arena. The development of many cardiac surgical procedures and the reduction in peri-operative morbidity and mortality can be directly related to the use of TOE.[94]

Furthermore, as our expectations for improved peri-operative outcomes continue to rise, we envisage that we will, in future, see an increase in the application of TOE for major non-cardiac surgery as well as for intensive care. With improvements in training, software, miniaturisation of technology and availability of affordable basic echocardiographic equipment, it is likely that this aspiration will be fulfilled.

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