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Review of intraoperative TOE

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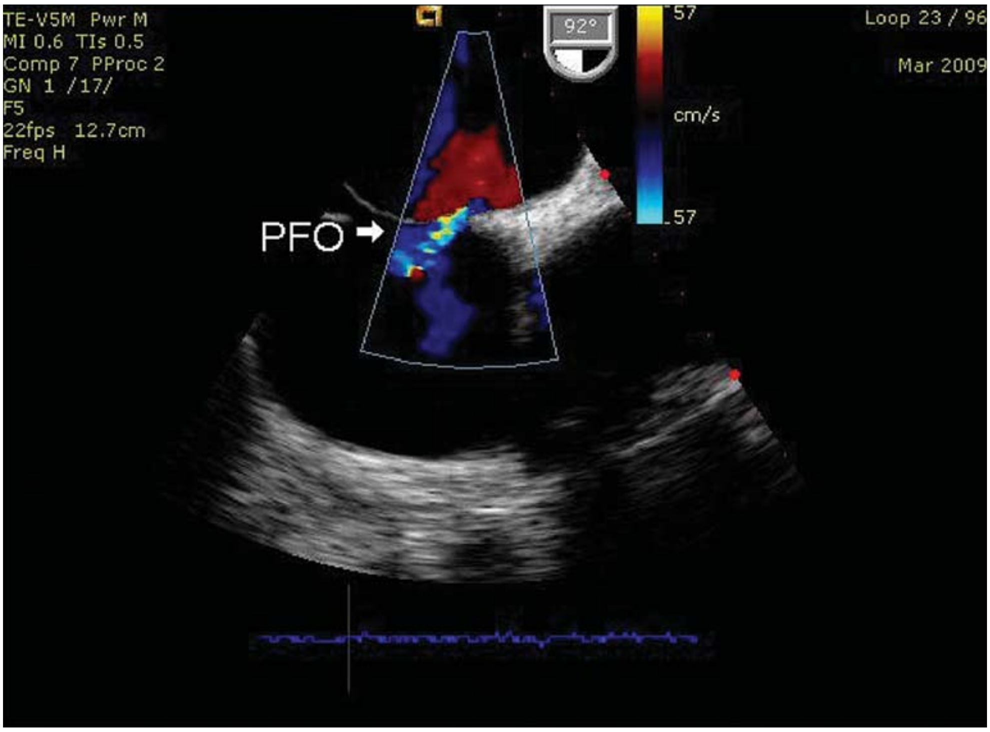


Example: Patent foramen ovale.
This patent foramen ovale was an incidental finding during coronary artery surgery. An atriotomy was performed and the defect closed.

Introduction

In 2000, Westmead Hospital Department of Anaesthesia made a survey of the use of intraoperative transoesophageal echocardiography (TOE) by cardiac surgical units throughout Australia. At that time, 80% of cardiac units were using intraoperative TOE, of which the anaesthetist was primarily responsible for the interpretation in 72%. Were we to conduct the same survey in 2009, I believe we would be hard pressed to find a unit where intraoperative TOE is not an essential component of practice for the cardiac anaesthetist.

For valvular surgery, and for valve repairs in particular, intraoperative TOE has become a standard of care. While there is still some debate about the necessity and cost benefit analysis for its use for the routine coronary artery bypass graft (CABG) patient with good left ventricular function, it is also true that with advances in interventional cardiology, these less complicated patients are likely to be undergoing stenting procedures instead of surgery.

The older, sicker, patient with multiple co-morbidities who may be undergoing combined valve coronary artery grafting surgery or re-do surgery now makes up an increasing proportion of our workload. The purpose of this review is to outline the current status and role of intraoperative TOE in the cardiac surgery unit as well as the particular challenges involved with its use in the intraoperative environment.

Indications and usefulness of TOE during cardiac surgery

The American Society of Echocardiography (ASE) and Society of Cardiovascular Anesthesiologists (SCA) taskforce has published evidence-based practice guidelines[1] for perioperative TOE. Category 1 indications are those supported by the strongest evidence or expert opinion and where TOE has been shown to be useful in improving clinical outcomes. Intraoperative applications of TOE in this category include valve repairs, congenital heart surgery for most lesions requiring cardiopulmonary bypass, surgical resection in hypertrophic obstructive cardiomyopathy and intraoperative evaluation of aortic valve function in repair of type A aortic dissections. The use of TOE for coronary artery bypass graft (CABG) surgery is a Category 2 indication i.e. possibly beneficial, but appropriate clinical indications are less certain. Although there is still a lack of direct evidence of improved patient outcome from its use, there is still evidence that routine intraoperative TOE is beneficial and cost effective[2].

The particular advantages and uses of TOE for CABG surgery are summarised in following sub headings.

Assessment of ventricular function and planning for weaning from bypass – diagnosis of the cause of any difficulty in separating from bypass

Assessment of ventricular function in the pre-bypass period allows for planning the inotropic or mechanical support for weaning post-bypass. It is not uncommon to find that systolic ventricular function is markedly different from how it was assessed at the time of coronary angiography. The ventricle may have been stunned or ischaemic at this time and since improved, alternately further deterioration may have occurred as a consequence of infarction or ongoing ischaemia.

If there is any difficulty weaning from bypass, the cause, such as left ventricular global or regional dysfunction, or right ventricular dysfunction perhaps as a reaction to protamine administration, can be defined by TOE, and the success or otherwise of any interventions assessed. TOE has largely supplanted pulmonary artery catheters in this regard as TOE gives more information as to the *cause* of poor cardiac output. Pulmonary artery catheters still have a role in many units however, particularly in the postoperative unit where TOE cannot be continued and/or the expertise to interpret is not readily available.

Ischaemia monitoring

Limited ability exists to monitor cardiac ischaemia under general anaesthesia. TOE is a relatively safe and continuous monitor which gives an early indicator of ischaemia by the assessment of regional wall motion, as well as the ability to localise the region of the myocardium at risk. Once identified, steps can be taken to improve coronary perfusion and reduce myocardial oxygen consumption, or early heparinisation instituted.

New regional wall motion abnormalities (RWMA), after re-vascularisation in the immediate post bypass period may be an indication of problems with grafts. Although TOE cannot itself differentiate between a graft problem and myocardia stunning (where perfusion to the affected area of myocardium has been restored by grafting but the consequent reperfusion injury results in persisting wall dysfunction), the presence and site of the RWMA as seen with TOE will prompt re-inspection. Surgical confidence in the grafts to the affected region will determine whether re-grafting needs to be pursued.

Another important cause of a RWMA that may be diagnosed and managed with the aid of TOE is intracardiac air. Air may be introduced at the time of removal of cardioplegia or left ventricular venting cannulae and tends to result in inferior wall motion abnormality due to the anterior position of the right coronary ostia. This is dealt with by prolonging the time spent on partial bypass support while the RWMA is monitored with TOE. As improvement occurs relatively rapidly in this situation, the safe time to recommence weaning can be judged with the help of TOE monitoring.

Assessing the requirement for, contraindications to and correct placement of intraaortic balloon pump

In addition to confirming the diagnosis (i.e. poor left ventricular function or acute ischaemia) for which the intra-aortic balloon pump is necessary, TOE is useful for assessment of atheroma in the descending aorta (increased risk of emboli), excluding contraindications such as aortic regurgitation, as well as to assist and confirm correct placement in the proximal descending aorta.

Diagnosis of defects not previously recognised

A common example of a previously unrecognised defect is a patient foramen ovale (PFO). Whether it is justified, however, to extend coronary artery bypass surgery to close a PFO found incidentally is controversial[3] unless the risk of paradoxical emboli is high such as a history of paradoxical embolism. In procedures that involve atriotomy anyway, such as mitral or tricuspid valve surgery, the defect would certainly be closed.

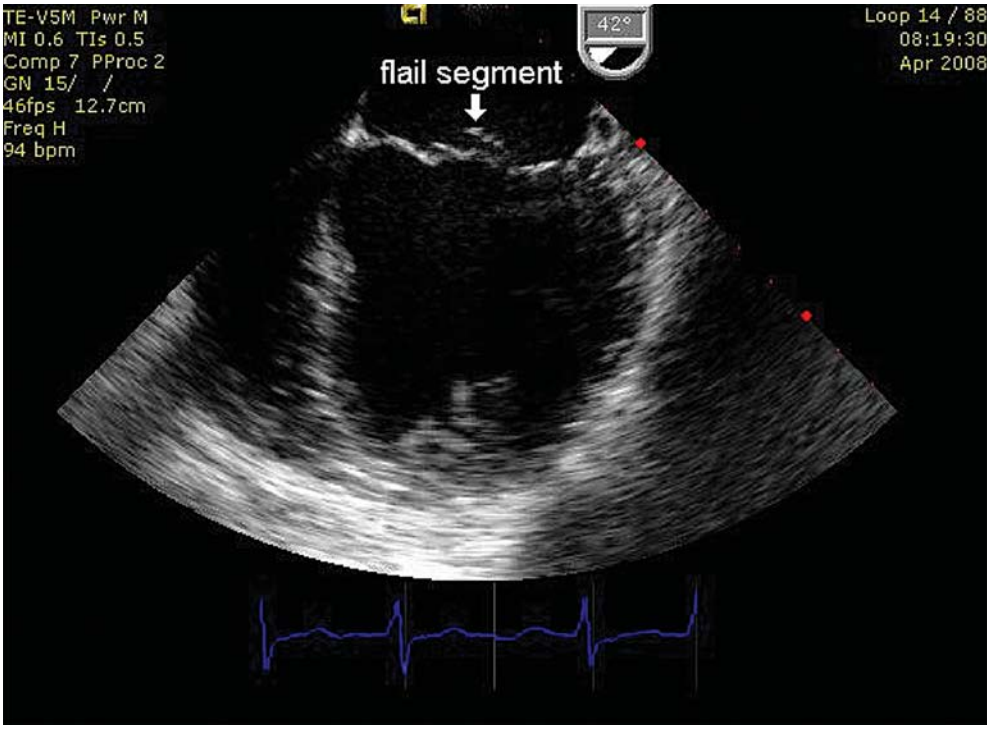
Assessment of aortic atheroma as a screening test for epiaortic scanning

Avoiding dislodgement of atheroma during surgical manipulation of the ascending aorta is a critical component of any stroke reduction strategy during cardiac surgery[4–7]. These manipulations include cannulation for bypass, aortic cross clamping, placement of cardioplegia cannula and anastomoses of the proximal ends of coronary grafts. While these manipulations occur in the blind spot for TOE (due to the interposition of the trachea and left bronchus) TOE is useful as a screening test. If there is no significant atheroma detected by TOE in the descending aorta, then moderate or severe atheroma is then highly unlikely in the ascending aorta[8]. If descending aortic atheroma is detected, then epiaortic ultrasound screening of the ascending aorta may be performed by the surgeon using a high frequency linear array transducer in a sterile sheath placed directly over the ascending aorta[9,10]. The information obtained may lead to a change in site of cannulation, cross clamp or proximal anastomoses or even avoidance of proximal anastomoses altogether. Such interventions have been shown to reduce the risk of adverse neurological events[11–13].

Valvular surgery

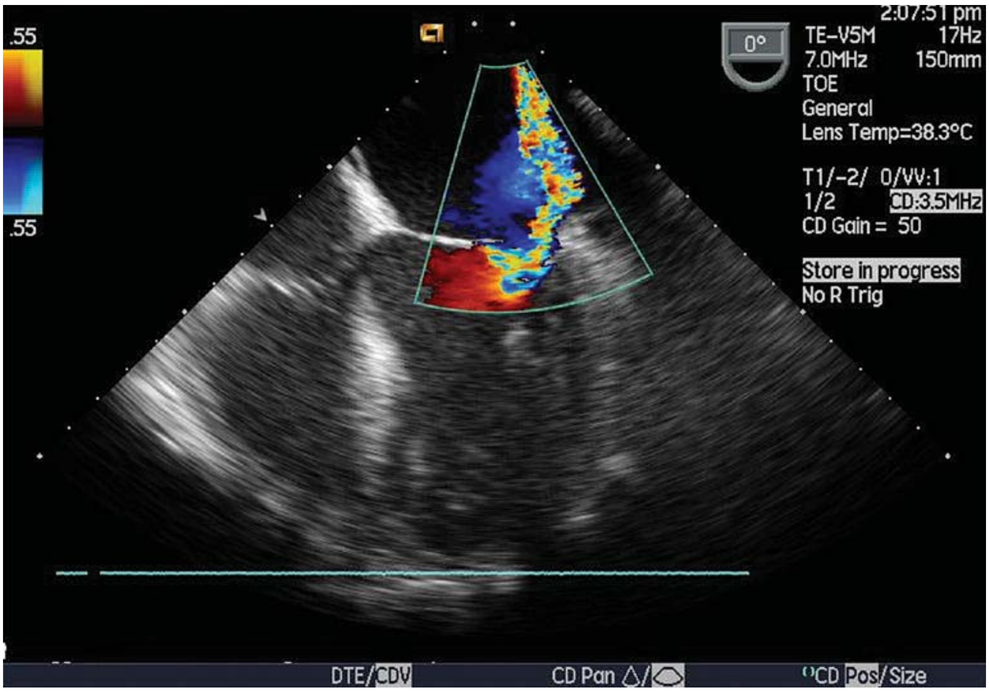
Valve repair surgery is a Class I indication for intraoperative TOE (strongest evidence, shown to be useful in improving clinical outcomes)[1]. The majority of valve repairs are of the mitral valve for regurgitation. Repair in mitral stenosis, which is invariably rheumatic in nature, is less common due to technical difficulties, a high likelihood of causing regurgitation and the inevitable progression of the disease process in the repaired valve. The repair procedure for mitral regurgitation depends entirely on the mechanism of regurgitation and here TOE plays an important role in the pre-bypass period. Immediately after separation from bypass TOE is also critical to ensure adequacy of repair, as well as evaluating other possible complications such as systolic anterior motion of the mitral valve (SAM). This safety net allows the surgeon to attempt a repair (with all its advantages of better preservation of LV function and avoidance of long term anticoagulation) even in the more technically difficult cases, safe in the knowledge that if the result is unsatisfactory, then replacement can proceed subsequently at the same operation without subjecting the patient to the risk of leaving the operating room with a suboptimal result.

In patients presenting for valve replacement surgery where the decision to replace has been made prior to surgery, intraoperative TOE is less critical but still useful. Paravalvular (or periprosthetic) regurgitation is sought on the post bypass TOE exam, and if more than trivial require consideration of return to bypass. For some particular types of valve replacement, however, TOE remains critical. An



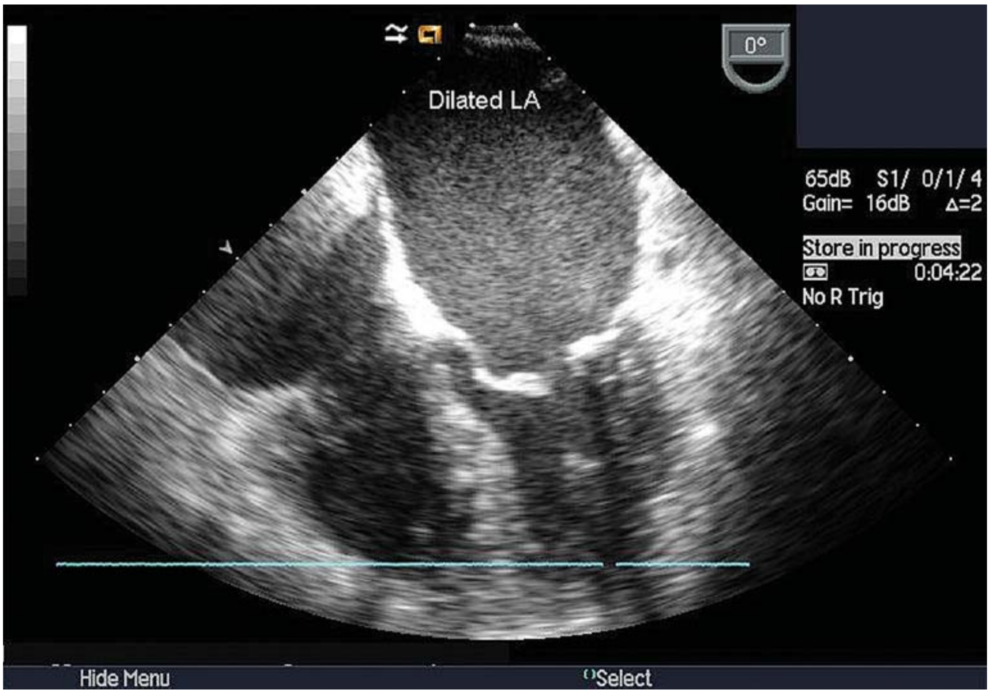
Valvular surgery example 1: Flail mitral valve posterior leaflet.

Valve example 1: This was a case of a flail segment of the posterior mitral valve leaflet causing severe mitral regurgitation. This is a common operation as the middle scallop (so called "P2") of the posterior leaflet is the least well supported by annular fibrous tissue. Fortunately the shorter broader posterior leaflet is very amenable to repair by resection of affected portion, plication of the annulus and placement of an annuloplasty for annular reinforcement and prevention of later dilatation. The flail posterior leaflet is seen in the first (pre-bypass) clip, colour Doppler would show an eccentric severe jet of MR characteristically directed away from the posterior leaflet. The post-bypass clip shows the echogenic annuloplasty ring and a markedly reduced annular area with no significant mitral regurgitation now seen.



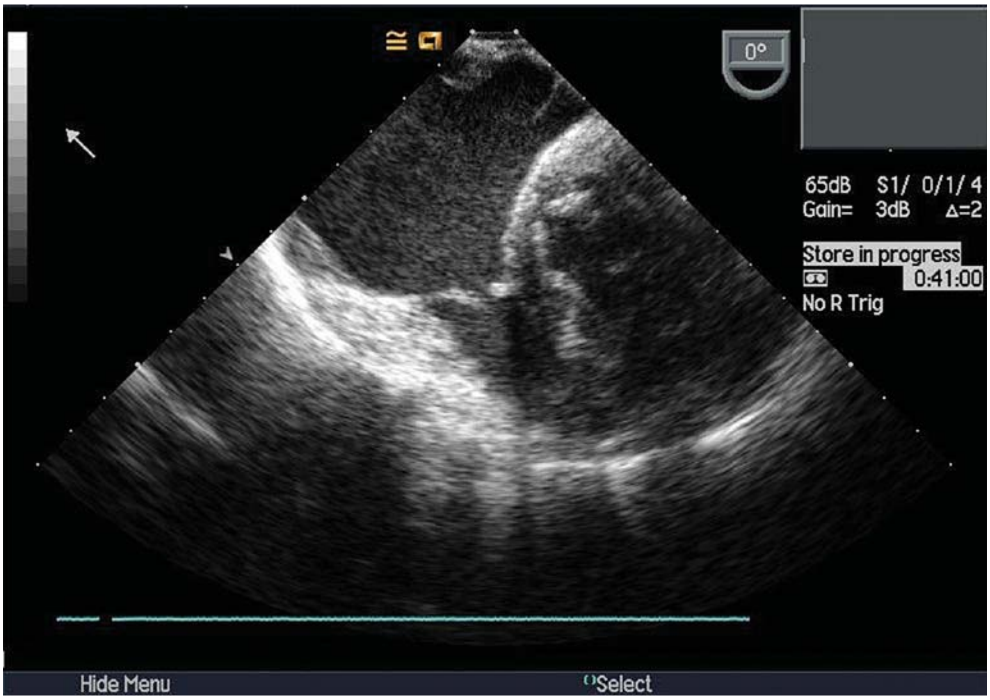
Valvular surgery example 2: Flail anterior leaflet of mitral valve.

Valve example 2: In this case it was a portion of the anterior leaflet of the mitral valve which was flail. A severe, eccentric jet of mitral regurgitation can be seen which is characteristically directed away from the affected leaflet. The longer anterior leaflet is more difficult to repair and has a higher failure rate subsequently. This valve was replaced.



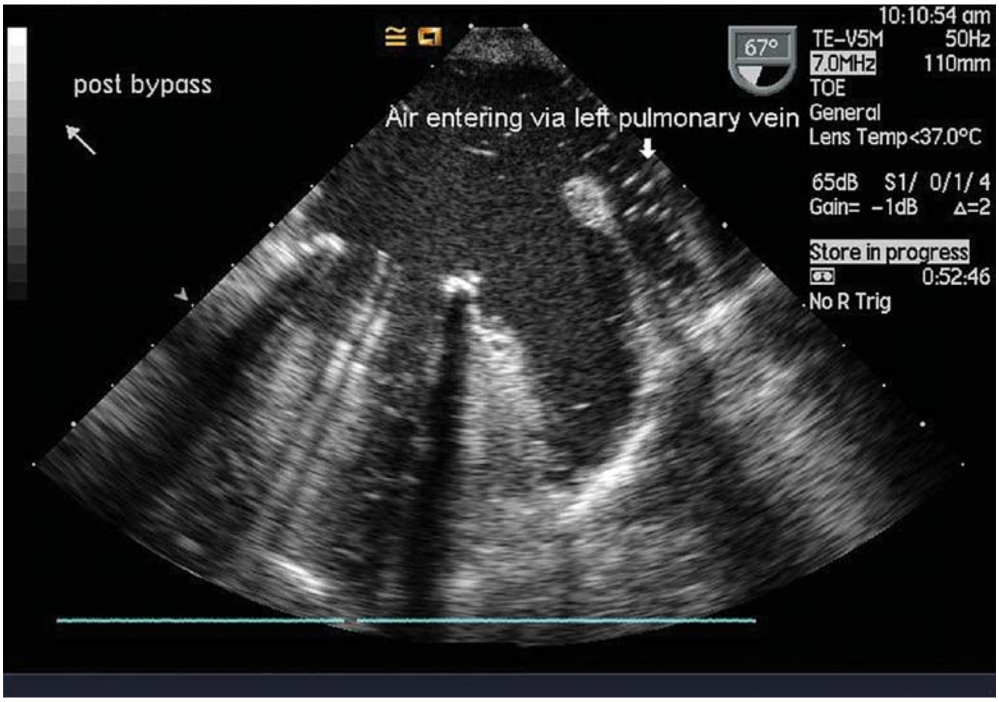
Valvular surgery example 3: Rheumatic mitral valve.

Valve example 3: This regurgitant and stenotic mitral valve had a rheumatic aetiology. Such valves are not amenable to repair and this valve was replaced. Diastolic bowing of the anterior leaflet that is characteristic of rheumatic disease can be seen. The posterior leaflet is also thickened and abnormal, note also the dilated left atrium with spontaneous echo contrast.



Valvular surgery example 4: Rheumatic tricuspid valve.

Valve example 4: This patient had severe mitral and tricuspid regurgitation and was intended for mitral replacement and tricuspid repair. The tricuspid valve is rarely replaced as the transvalvular gradient associated with a prosthetic valve inevitably leads to some degree of stenosis when placed in the tricuspid position. A less than perfect repair with an annuloplasty ring and some residual regurgitation is generally preferred to tricuspid stenosis. In this case however the pre-bypass TOE showed thickened abnormal tricuspid leaflets with impaired diastolic excursion. This evidence of rheumatic involvement of the tricuspid valve leads to the valve being replaced rather than repaired.



Example 5: De-airing.
This modified mid-oesophageal view shows the left atrial appendage and left pulmonary vein. In this case, after a mitral valve replacement (mechanical valve with "reverberation" artefact can be seen at the left of picture) air could still be seen in the left heart and appeared to be continuing to enter via the left pulmonary vein even after standard de-airing procedures. The first avi clip refers to this situation. Weaning from bypass was delayed while a Valsalva manoeuvre was performed. The second clip is during or immediately subsequent to this manoeuvre and a large amount of air, which had been sitting in the pulmonary veins, can be seen to enter the left heart where it could then be more easily removed. Weaning from bypass was only commenced once these bubbles had cleared so minimising the risk of air emboli to the cerebral circulation.

example is the stentless heterograft in the aortic valve position, which is more technically difficult to site but has advantages in the small patient as the absence of rigid sewing rings and struts allows a greater available area for flow and lower transvalvular gradients. TOE is necessary to define any abnormalities of the aortic root pre-bypass, which will need to be addressed at the time of surgery, as well as to confirm adequate function of the new valve.

Assessment of de-airing procedures

In open heart procedures such as valve surgery, air can be retained within the left heart potentially resulting in air emboli and considerable morbidity. TOE is routinely used to assess the adequacy of standard de-airing procedures. In affected patients weaning from bypass may be delayed while further de-airing manoeuvres (e.g. needle aspiration of ventricular apex, manual manipulation of left atrial appendage, Valsalva manoeuvre to push any air sitting in the pulmonary veins back to the heart where it can be more easily removed) may be undertaken, depending on what is seen on TOE to be the main source or reservoir of retained air.

Some other cardiac surgical procedures where TOE is used intraoperatively are listed below. A detailed discussion of each is beyond the scope of this article but many good references are available[14–17].

- Surgery for hypertrophic cardiomyopathy (HCM): The extent and location of septal thickening can be assessed by TOE and help guide surgical resection while post bypass the adequacy of the resection is assessed. This may allow a relatively conservative initial myomectomy, which may be followed by further excision during the same procedure if necessary so minimising the risk of ventricular septal defect complicating the procedure.
- Minimally invasive cardiac procedures where TOE is required for the accurate positioning of cannulae.
- Ventricular assist devices (VAD): TOE confirms correct placement of cannulae, excludes contraindications such as PFO, aortic regurgitation and intracardiac thrombi and can assess causes of poor LVAD performance such as hypovolaemia or obstruction to inflow or outflow cannula.
- Congenital heart disease: A category 1 indication for TOE for most lesions requiring cardiopulmonary bypass[1].
- Diagnosis of aortic dissection (Type A) and assessment of possible complications such as aortic regurgitation and tamponade.
- Selected pacemaker procedures: TOE is often used for monitoring during removal of pacemaker wires as early warning of ventricular perforation is given by the accumulation of pericardial fluid. During insertion of bi-ventricular pacemakers it can be of use to give guidance as the surgeon attempts to insert the left ventricular wire via the coronary sinus.

The particular challenges and limitations of TOE in the operating room environment

Some of the limitations of TOE in the operating room are explored in the following.

The dual role of anaesthetist and echocardiographer

So, how in practice does the anaesthetist act in this dual capacity? Does it in fact mean doing neither job well? We do not believe so but it does take practice and we have learned a few lessons along the way. Wherever possible we try to have dual staffing but this cannot always be guaranteed. When working alone, patient care and provision of anaesthesia must always take precedence, and the examination is done when circumstances allow. The sequence is generally as follows: lines and monitoring are placed, anaesthesia is induced, the TOE probe is inserted under direct vision at the time of intubation of the trachea. Once the haemodynamics are stable after induction and vasoactive and other infusions are attached and running, it is then usually possible to direct attention to the TOE exam. This may be started and sometimes achieved during urinary catheterisation and draping. Attention primarily to the anaesthesia is required during commencement of surgery, however, a period of relative stability during harvesting of grafts will generally allow further opportunity to complete the examination. The set-up and ergonomics need close attention. We have the patient monitoring and the echo screen in the same line of sight so that both can be seen at a glance without the need to turn around. Our anaesthesia monitoring is slaved to a wall monitor in order to achieve this ability to monitor the patient's status and the echo exam at the same time.

The post-bypass study tends to be even more challenging as diagnostic and monitoring information from the TOE exam immediately after weaning from bypass may be required simultaneously with changing patient haemodynamics. TOE is used to guide the weaning process by assessment of ventricular filling while ventricular systolic function assessment guides the appropriateness and level of inotropic support. Attention is first given to answering the questions that may affect or stop weaning from bypass. This may be the adequacy of a valve repair, excluding paravalvular leaks after valve replacement, or new regional wall motion abnormalities after CABG. Once any such "show stoppers" have been excluded then priority is generally given to anaesthesia and the infusion of drugs, fluids and medications required in the immediate post bypass period. The full study is done as circumstances allow and often, necessarily, in an interrupted fashion.

Haemodynamic effects of surgery and anaesthesia affecting the TOE exam

Cardiac depression and vasodilatation are an inevitable consequence of anaesthesia and this can affect the severity of lesions such as central mitral regurgitation. A proper assessment can only proceed with the haemodynamics as close as possible to the awake state. This may require vasopressors or inotropes to raise mean arterial pressure.

Doppler, and spectral Doppler in particular, pose particular challenges in the post bypass period. Acute anaemia is an inevitable consequence of the haemodilution of bypass. In these circumstances the modified Bernoulli equation (pressure gradient = $4V^2$ where V is velocity as measured by spectral Doppler) may not apply, as one of the assumptions made is of an average value for mass density of blood. In severe anaemia the sudden change in blood viscosity alters the relationship between the measured velocity and calculated pressure gradient such that pressure gradient may be overestimated. Compounding this error is that cardiopulmonary bypass may induce a systemic inflammatory response and vasodilatation inducing a relatively hyperdynamic state. This will further exacerbate the tendency to overestimate pressure gradients at this time. For these reasons we place greater emphasis on the 2D appearance of valves repaired or replaced than the gradient estimated from Doppler, particularly for mitral or tricuspid valves where normal flow velocities are low and consequently the error in the calculated gradient is relatively greater.

Training and accreditation issues

The Australian and New Zealand College of Anaesthetists has published recommendations for training and practice of diagnostic perioperative TOE in adults[18]. This document, which has been influenced by work of the American Society of Echocardiography and Society of Cardiovascular Anesthesiologists amongst others[19,20], outlines recommendations for training, such as the supervision and numbers of studies required for competency. Supervisors of trainees require more formal documentation of competency which may include completion of the Postgraduate Diploma in Perioperative and Critical Care Echocardiography (entirely distance education) from the University of Melbourne, or having passed the Perioperative Transoesophageal Echocardiography Examination (PTEeXAM) administered by the National Board of Echocardiography in the USA[21]. We are fortunate at our institution to have a 12-month training program for a fifth year anaesthesia trainee in cardiac anaesthesia, echocardiography and TOE which involves time in echo lab under the tutelage of our cardiology colleagues, in addition to time in cardiac theatres[22]. Training requirements as recommended by ANZCA are fulfilled in this year even without the simultaneous undertaking of the Melbourne University Diploma which is also encouraged.

Conclusions and future directions

Real time 3D echocardiography is now a reality. Early studies would suggest additional benefits above 2D echo particularly with regards to mitral valve surgery and congenital heart disease[23] but its role remains to be defined. What is beyond dispute is that many recent advances in cardiac surgery could not have taken place without the benefit of intraoperative TOE and it is now an integral part of cardiac anaesthesia practice. While we have yet to show improved survival in the CABG patient with intraoperative TOE, its usefulness has seen it become almost routine. Other surgical operations such as valve repair could not be performed at all without the information TOE provides.

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