British Journal of Anaesthesia **97** (**1**): 77–84 (2006)
doi:10.1093/bja/ael122 Advance Access publication June 1, 2006

BJA

Transoesophageal echocardiography (TOE) in the operating room

J. D. Kneeshaw*

Department of Anaesthesia, Papworth Hospital, Cambridge CB3 8RE, UK
**E-mail: j.kneeshaw@ntlworld.com*

Perioperative transoesophageal echocardiography (TOE) was introduced from cardiology into cardiac anaesthesia in the 1980s. Initially TOE was used mainly as a monitor of left ventricular ischaemia, but now provides real-time dynamic information about the anatomy and physiology of the whole heart. TOE is of value in the management of patients undergoing procedures including cardiac valvular repair, surgery for endocarditis, surgery of the thoracic aorta, and may contribute useful information in a wide range of cardiac pathology. It is also useful in guiding therapy in haemodynamically unstable patients in the operating room and the intensive care unit. TOE is relatively cheap and non-invasive, but it should not be used as a stand alone device but as a tool which provides data in addition to the data acquired from other forms of monitoring. The use of TOE carries not only the benefits of a rapid and effective investigation, but also risks associated with the procedure itself and the burden of providing training and experience for practitioners. The establishment of TOE in perioperative cardiac anaesthetic care has resulted in a significant change in the role of the anaesthetist who, using TOE, can provide new information which may change the course and the outcome of surgical procedures.

Br J Anaesth 2006; **97**: 77–84

Keywords: monitoring, transoesophageal echocardiography; surgery, cardiovascular

Echocardiography is a non-invasive imaging modality used as a first line diagnostic tool in cardiology. Transthoracic echocardiography (TTE) is not useful in patients in the operating room, because the required transthoracic echocardiographic windows are not available and surgery makes the acquisition of useful high quality images almost impossible. Transoesophageal echocardiography (TOE, or TEE in North America) was initially used in cardiology to define lesions in patients with poor quality TTE images and where better definition of cardiac structures was required. Perioperative TOE was introduced into the arena of cardiac anaesthesia in the late 1980s in the USA where it was considered primarily a tool for monitoring the left ventricle. It is considered to be non-invasive because the addition of an intra-oesophageal device in anaesthetized and intubated patients is relatively easy requiring no additional anaesthesia or airway management. TOE rapidly gained both credence and popularity in the USA and by the mid-1990s had begun to spread to UK and European cardiothoracic centres. Since then, its use has expanded enormously and it is now recognized as an excellent perioperative diagnostic tool rather than just a monitoring device. It is of value in selected patient groups[1] and has been shown to be of benefit in cardiac surgical practice,[2] where it often provides new and important information about pathology and may guide both surgical and anaesthetic therapy. In some areas such as conservative surgical valvular repair its use is considered mandatory. TOE has also been found to be of use in some non-cardiac surgical procedures, in particular in the management of neurosurgical patients and of haemodynamically unstable patients. The role of TOE in the intensive care unit is also increasing. Specialist cardiothoracic intensive care units began to adopt TOE soon after the introduction of TOE to cardiac surgical operating rooms. In intensive care it was found to be of particular value in managing haemodynamic instability in the post-cardiopulmonary bypass period. TOE is now also being used as a rapid imaging modality in the general intensive care unit as an adjunct to other monitoring modalities to provide data in haemodynamically unstable patients. It is not surprising that a tool which can provide real time cardiac imaging relatively non-invasively is now making its debut in emergency rooms.

This expansion in TOE carries with it not only the benefits of a rapid and highly effective investigation, but also the risks associated with the procedure itself and the burden of providing adequate training and experience for its practitioners. This training requirement in order to use TOE as an effective tool has added a new dimension to training in cardiac anaesthesia.

Origins of echocardiography

Medical ultrasonography began in Lund, Sweden, in 1953 when Inge Edler and Carl Hertz, a cardiologist and a postgraduate physics student respectively, using equipment borrowed from the maritime world produced the first recording of cardiac activity. Their findings were published in 1954.[3] These simple recordings of the movement of the walls of cardiac chambers and cardiac valves (Fig. 1) later became known as M (Motion) mode recordings and are still used today to accurately describe the motion of structures such as the aortic valve. By combining the M mode scans of an array of ultrasonic transducers into a fan shaped sector the two-dimensional moving image was created (Fig. 2). TOE probes can be described simply as the attachment of a miniature, high frequency, phased array ultrasound transducer to the distal end of a gastroscope mechanism. The transducer may then be flexed forwards, backwards and laterally within the confines of the oesophagus and proximal stomach to allow the imaging plane to sweep through different areas of the heart. When the probe is placed in the oesophagus it is only 60–90 mm away from the mitral and aortic valves. At this proximity low power, very high frequency ultrasound, which consequently has very short wavelengths, will produce images of extremely high spatial resolution. Early TOE probes produced one plane of imaging which was in the transverse plane and at right angles to the orientation of the probe. Subsequent development in probe technology allowed a second vertical image plane at right angles to the first. Current probes are referred to as multiplane and can electronically produce an image plane which can be rotated a full 180° (Fig. 3). The addition of spectral Doppler display of blood velocities and then later colour flow Doppler (CFD) display of blood velocity have enabled further analysis of cardiac physiology. This analysis encompasses reasonably accurate calculation of trans-valvular pressure gradients, regurgitant valvular orifice areas, shunt fractions and even cardiac output. Three-dimensional transoesophageal imaging is expected to be available within the next year.

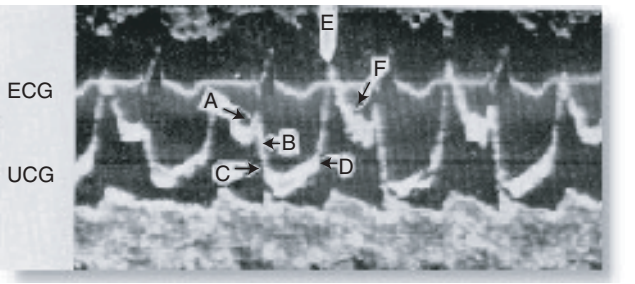

Fig 1 An M mode trace of movement of the anterior mitral valve leaflet (UCG) by Edler and Hertz.[3]

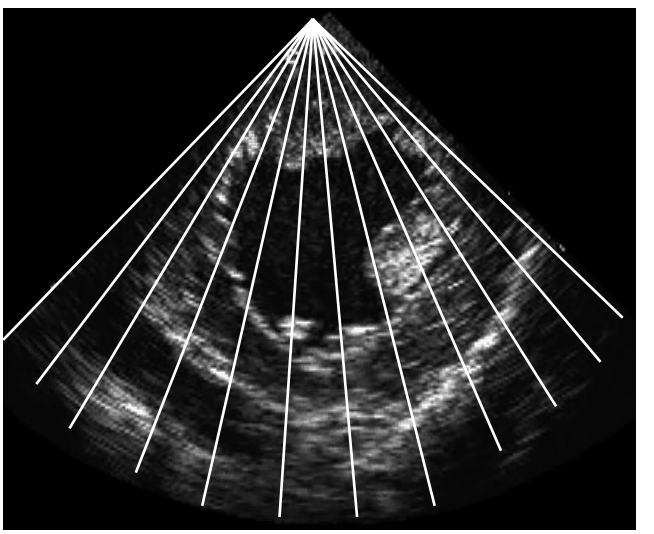

Fig 2 Schematic diagram demonstrating the combination of multiple linear scan lines to form a two-dimensional image. In this case a short axis TOE view of the left ventricle. (Only a few of the several hundred lines are represented.)

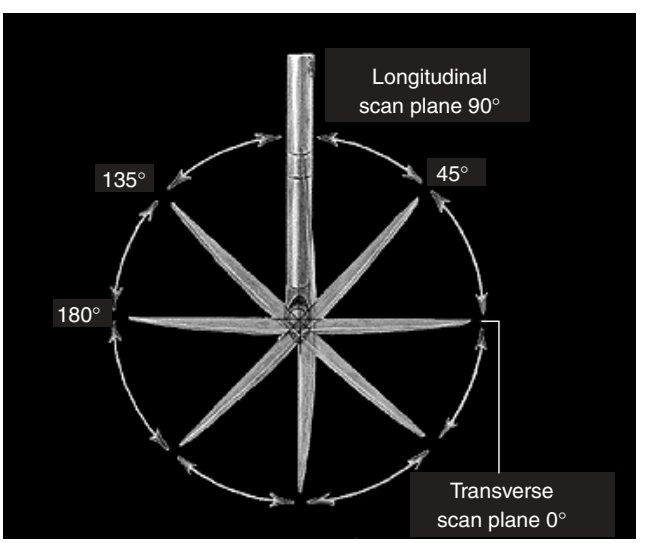

Fig 3 Rotation (180°) of the scan plane by a multiplane transducer.

Normal comprehensive TOE examination

In diagnostic cardiology, TOE is usually only undertaken after a comprehensive TTE examination, and therefore tends to focus on the object or objects of interest. In perioperative practice this is not the case, and most practitioners feel that unless urgency precludes, all patients studied with TOE should have a full and comprehensive examination of the heart and as much of the great vessels as can be seen. This should include the descending thoracic aorta and if possible the vena cava and hepatic veins. This systematic approach makes it less likely that unsuspected abnormalities will be missed. Several sets of guidelines for a comprehensive examination have been published, and these suggest between 12 and 20 standard views.[4] It is essential that

data from TOE investigations in the operating room are fully documented to allow comparison with past and future findings.[5] At least this should take the form of a written proforma report and at best digital images and video loops should also be retained and archived.

Why did TOE come into the operating room and what can it do?

Very soon after cardiologists embraced TOE, cardiac anaesthetists saw an opening for a development in their practice. In the early 1980s TOE was very new technology. It was portable, and in the context of cardiac surgery it was relatively non-invasive. TOE is compatible with intraoperative use because, unlike TTE, it does not require a hand held transducer on the chest wall and it does not compete with any space needed by the surgeon. Placement of the probe in the mid-oesophagus is easy for the anaesthetist, and because all the views of the heart are obtained with the device behind the heart, it can provide images even when the chest is open. In some ways it could be argued that its introduction into the operating room was somewhat speculative, because there was at that time no evidence for any benefit to patient care.

In the late 1980s and the early 1990s there was some doubt being cast on the usefulness of some other forms of monitoring. There was also at the same time a perceived need for a form of monitoring which was capable of the early detection of myocardial ischaemia, particularly in patients undergoing surgical myocardial revascularization. Very soon after TOE appeared as an ischaemia monitor it became clear that there was much more information to be gleaned than just the state of the left ventricle. A skilled operator could, within 10 min or so, make an anatomical and functional assessment of the whole heart. In some patients this detected pathology which had not been described previously and led to changes in surgical and anaesthetic management of these patients.

It was fortuitous that at about the same time that anaesthetists began to bring TOE into the operating room, cardiac surgeons began to realize that it was possible to carry out more conservative cardiac surgery and to repair rather than resect and replace some cardiac valves. This process started in 1983, when Alain Carpentier in France published his first work on mitral valve repair.[6] Valvular repair surgery requires a dynamic assessment not just of the severity of valvular dysfunction, but a very precise description of the location and mechanism of regurgitant valves. TOE, with a high definition probe placed a few centimetres from the mitral valve gave surgeons the information they needed to create repair strategies for such valves. TOE is also a very useful diagnostic modality in other valvular conditions. It has also had a significant effect in acute diseases of the aorta such as acute dissection, where the ability to accurately determine if the ascending aorta is involved makes the difference between surgical or non-surgical treatment of the patient.

TOE was originally the preserve of non-invasive cardiologists and a few radiologists so why are anaesthetists, and in particular cardiac anaesthetists, doing it?

Early intraoperative echocardiography was speculative and involved anaesthetists borrowing equipment and learning from cardiology colleagues. As the practice expanded it became clear that very few cardiologists were able to spend long periods in the operating room and cardiology has in the last 20 yr become a much more invasive specialty. Fewer cardiologists have interests in non-invasive imaging rather than in the invasive branches of the specialty. Also the cardiovascular physiology of anaesthetized, supine patients in the operating room is very different to the physiology of awake patients in an echo laboratory, and the anaesthetist's knowledge and understanding of this modified physiology allows them to better interpret the information coming from the echo machine. In current practice in the UK, TOE is said to account for around 10% of all echocardiograms performed, but of these TOEs, 90% are performed not by cardiologists but, by cardiac anaesthetists. Indeed all registrars aspiring to a consultant post in UK cardiac anaesthesia will expect to be able to perform a basic TOE study. This has naturally led to the establishment of training and accreditation in echocardiography for anaesthetists and for others with an interest in perioperative echocardiography.

TOE as a monitor of ischaemia

The standard views in most systematic TOE examinations include at least four views of the left ventricle (Fig. 4). About 16 or 17 anatomical myocardial segments have been named in standard TOE views. These are nearly consistent with the segments' names used in other cardiac imaging modalities [magnetic resonance imaging (MRI), PET, etc.]. The nomenclature of the segments has been confusing but rationalization into a standard system for all imaging systems has been published and will eventually be adopted.[7] In the late 1980s and early 1990s the emphasis was primarily to see the left ventricle in four standard views and to assess ventricular wall motion in as many segments as possible. This allowed assessment and quantification of global left ventricular function. Individual myocardial segments are observed for systolic thickening and for endomyocardial movement. Areas which do not thicken in systole or which do not move towards the centre of the ventricle in systole are described as regional wall motion abnormalities (RWMA). The application of anatomical knowledge of the usual blood supply of the myocardium from the three principle coronary arteries allows the attribution of any RWMAs to the circulation of one of the three coronary arteries (Fig. 5). TOE was found to be good at detecting new left ventricular RWMAs, associated with ischaemia. In particular the transgastric short axis mid view of the left ventricle demonstrates areas of myocardium subtended by each of the three coronary arteries. It is therefore the most

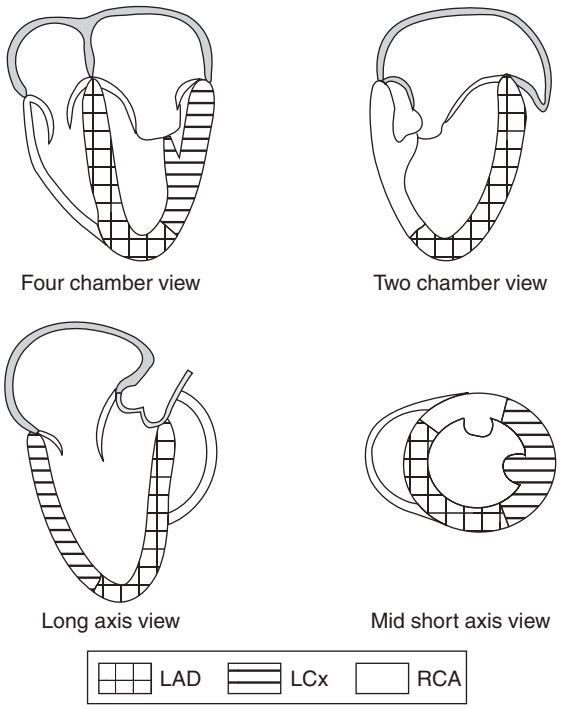

Fig 4 Four standard views of the left ventricle demonstrating the areas of myocardium supplied by each of the coronary arteries. LAD, left anterior descending; Cx, circumflex; RCA, right coronary artery.

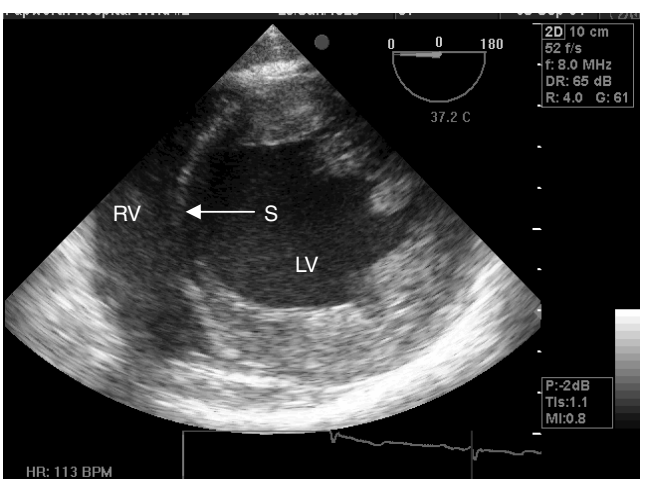

Fig 5 Transgastric short axis view of the left ventricle showing a non-thickening septum (S). LV, left ventricle; RV, right ventricle.

frequently used view for intraoperative monitoring of left ventricular ischaemia. Data were produced demonstrating that TOE could detect left ventricular wall motion abnormalities before other modalities such as the ECG could demonstrate evidence of ischaemia. In the arena of surgical revascularization it was possible to detect RWMAs which might be associated with suboptimal coronary artery revascularization[8 9] and there was then the potential to resolve such problems before the patient left the operating room. It was, however, difficult to demonstrate that this led to any benefit in outcome.

Table 1 Sensitivity and specificity of diagnostic modalities in acute Type A aortic dissection (data from Erbel and colleagues[10] and Nienaber and colleagues[11])

	Sensitivity (%)	Specificity (%)
CT	98	96
MRI	100	100
TOE	99	98

TOE in aortic disease

The accurate diagnosis of acute aortic dissection has always been important in cardiac surgery. Patients with dissections involving the ascending aorta (Stanford Type A) have a very high mortality if treated without urgent surgery and patients with acute dissection not involving the ascending aorta (Stanford Type B) in general do better without surgery. Rapid and accurate diagnosis of the condition is therefore critical. Computerized tomography (CT), MRI and TOE are all comparable in their ability to detect Type A dissection and all produce very low false negative reporting rates[10 11] (Table 1). This is true despite the blind spot of TOE in the distal ascending aorta and the proximal aortic arch produced by the air space of the trachea. MRI is the most reliable technique but, patients with acute aortic dissection are often haemodynamically unstable and have a very high mortality in the hours immediately after presentation. For this reason MRI is almost always contraindicated in such patients because of their unstable clinical condition and the frequent remoteness of MRI facilities from operating rooms. Even the fastest spiral CT, although acquiring images very quickly, requires the transfer of the patient away from the relative safety of intensive care or the operating room.

TOE, in skilled hands, has become the imaging modality of choice for such patients in many institutions because it can be performed in an anaesthetic room with the patient already prepared for surgery. TOE examination in these cases focuses on the proximal ascending aorta, looking for the dissection flap and the site of an intimal tear. TOE can also detect evidence of disruption of the aortic valve witnessed by aortic regurgitation and it can also detect fluid (blood) in the pericardial space (Fig. 6). The aortic arch and descending aorta can also be seen to assess the extent of the dissection.

TOE and conservative surgery—mitral valve repair

Until the mid-1980s, patients with clinically significant valvular disease needing surgery were treated by excision of the native valve and implantation of a prosthetic device. Although these devices are very successful, a mechanical valve requires the patient to take continuous anticoagulation therapy and biological valves, whilst avoiding warfarin type drugs, only last for 10–15 yr before a second operation is required. For these reasons surgeons began to seek valve sparing solutions for some patients. The era of modern valve

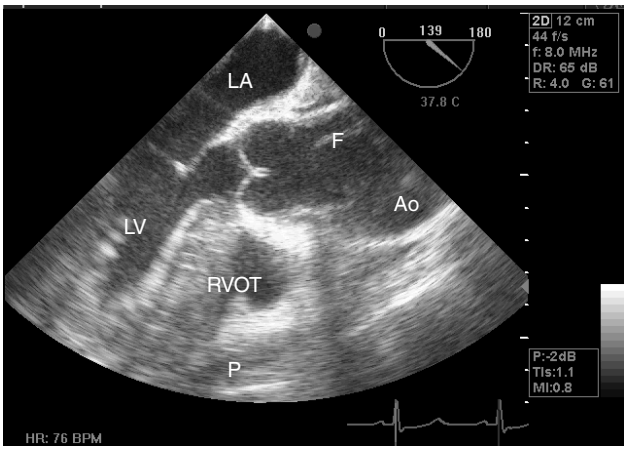

Fig 6 TOE long axis view of Type A aortic dissection demonstrating the dissection flap (F) in the proximal ascending aorta, dilatation of the aorta and free pericardial fluid (P). LA, left atrium; LV, left ventricle; Ao, ascending aorta; RVOT, right ventricular outflow tract.

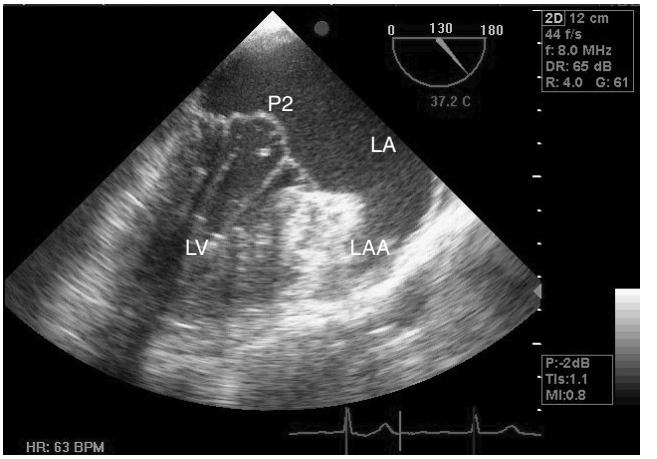

Fig 7 Pre repair TOE view of a patient with myxomatous disease of the mitral valve showing prolapse of the central scallop of the posterior leaflet (P2). LAA, left atrial appendage.

repair began in 1983 with Carpentier's first paper on the subject.[6] Over the last 20 yr the number of valve sparing procedures has increased year on year.[12] Mitral valve repair surgery in particular has received much attention. In order to repair a regurgitant mitral valve the surgeon needs to understand the precise mechanism of dysfunction in each individual patient. This assessment needs to be done dynamically with the heart beating and the ventricle maintaining a full cardiac output at a normal blood pressure. It is not adequate just to examine the valve after the patient is on cardiopulmonary bypass with the heart arrested and the left atrium open. TOE is the ideal tool to present real time images of the valve. The addition of CFD and other techniques to two-dimensional images allow the determination of which leaflet of the valve is abnormal, and, if the posterior leaflet is involved, which of its three scallops (anterolateral, middle or posteromedial) are abnormal and how they contribute to the regurgitation. With this information (Fig. 7) the surgeon can plan the operative procedure before the heart is stopped. Once the repair has been completed and the patient separated from bypass, the adequacy of the repair can be assessed by TOE before the chest is closed. If necessary, remedial work can be undertaken to the valve without recourse to a second operation. This type of echocardiography requires a considerable degree of expertise and experience because the anaesthetist is providing information which guides the surgeon and is directly contributing to, and may well change the course of the operation. TOE is becoming a care standard in mitral valve repair surgery and many surgeons will not attempt this sort of procedure without intraoperative TOE assessment of the valve and the repair.[13]

TOE in the haemodynamically unstable patient

Real time cardiac imaging is often useful in the management of haemodynamically unstable patients in the operating room and in the intensive care unit. It is very likely that this may very soon be extended to the management of patients in the emergency room. There are often circumstances when managing the hypotensive patient where even with the help of invasive monitoring it is difficult to distinguish the hypotensive patient from one with primary pump failure. Often quite simple TOE views will be able to clearly distinguish the two (Fig. 8).

Other uses of TOE

TOE is helpful in a wide range of other conditions including aortic valve disease, assessment of prosthetic valves, the diagnosis and operative management of endocarditis, pericardial disease particularly effusion and tamponade, and the diagnosis of intracardiac and myocardial masses. TOE is used in non-cardiac surgical anaesthesia, in particular in neuroanaesthesia to detect air emboli, and a wide variety of other major surgical areas where haemodynamic instability may occur. There is as yet no evidence supporting this practice. However, it does seem likely that in haemodynamically compromised patients TOE may help. One difficulty in non-cardiac surgical anaesthesia may be that of training in TOE of general anaesthetists and of skill retention and practice once training has been obtained.

Which patients should get TOE?

Practice guidelines on the application of TOE have been produced both in the USA and in Europe[14 15] and in general these have divided patients up into three categories.

Category 1: TOE is useful in improving the outcome.
Category 2: TOE might be useful.
Category 3: TOE is infrequently useful.

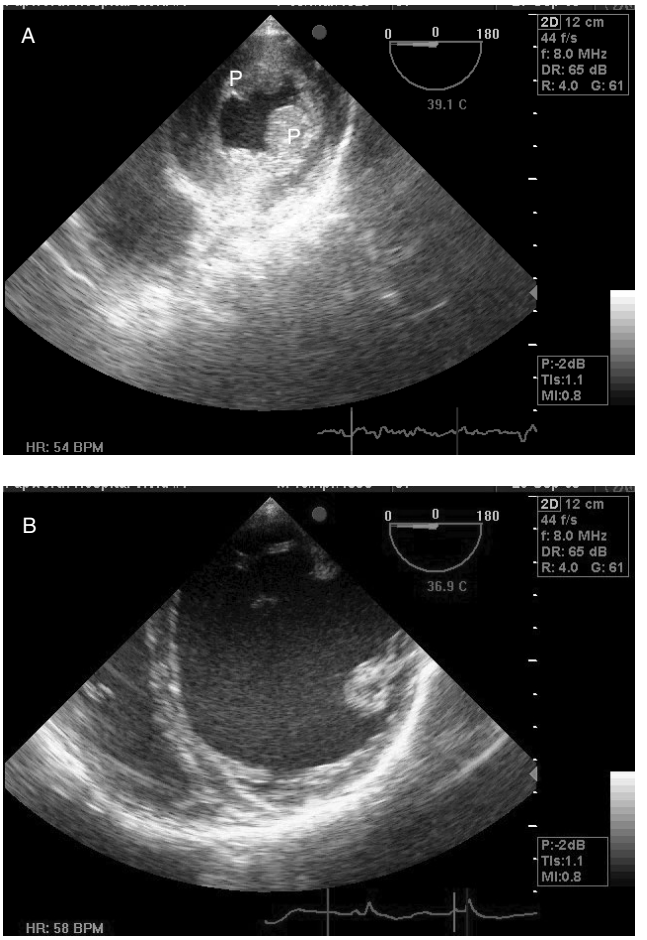

Fig 8 Causes of hypotension. (A) demonstrates a small under-filled left ventricle in which the papillary muscles are almost touching (P). (B) shows a dilated ventricle in a patient with left ventricular failure. Both scans were made with a total scan depth of 12 cm.

Category 1 indications include patients who are persistently haemodynamically unstable and not responding to treatment, patients with valve disease or hypertrophic obstructive cardiomyopathy, congenital heart disease requiring bypass, endocarditis surgery, pericardial window surgery and aortic dissection surgery. In these patients there is evidence that perioperative TOE actually does change the course of surgery and it is effective in improving outcomes.

Does TOE affect the management of cardiac surgical patients?

The effect of TOE on cardiac surgical practice has been described in several papers.[15 17] One group showed that in a group of 309 patients who underwent intraoperative TOE cardiac surgical patient management was changed in 81 (26%) patients.[18] In 6% of the patients the changes were in inotrope use and fluid management. However, in 62 (20%) of patients the TOE resulted in a change in the procedure carried out; 16 had an additional valve procedure performed and 18 had a valve procedure avoided. The magnitude of these figures may reflect the quality and quantity of preoperative echocardiography in institutions where interventional cardiology dominates over diagnostic cardiology.

Risks of TOE

The procedural risk of TOE is low and the most serious complications are often associated with pre-existing oesophageal pathology. In a retrospective report of 7200 cardiac surgical patients there was no mortality and a morbidity of 0.2%.[19] Cases of oesophageal perforation have been reported,[20] but oesophageal trauma in the absence of previous symptoms is rare. The overall risk of serious complications appears to be lower than the risk of upper gastrointestinal (GI) endoscopy. The following is a summary of significant complications that have been reported in perioperative TOE.

Dental injury
Vocal cord damage
Thermal injury
GI tract bleeding
Oesophageal perforation
Arrhythmia

Training and accreditation in TOE

Although TOE has been in use in the operating room for more than 20 yr it is still regarded by some as new technology. In the early years, practitioners throughout the world were mainly self-taught. In many places anaesthetists used their cardiology colleagues to help them learn the new skill. By the mid-1990s there was such rapid growth in the use of TOE that it became clear that there was a requirement for a more structured approach to training and also some means of quality assuring the output from echocardiography. TOE is not an essential subject in general anaesthetic training, but it is now essential to training in cardiac anaesthesia. A great deal of effort has been expended in establishing what level of training and experience is appropriate for intraoperative echo, and in deciding how this can be tested to ensure that decisions based on TOE findings are reliable and safe.

The approach in North America was that the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists jointly produced training guidelines for doctors using perioperative TOE.[21] These training guidelines recognized two levels of training, basic and advanced. Basic training took place as part of normal cardiac anaesthetic training and advanced training was conducted in a period of dedicated TOE training attached to a specialist service. In 1998, the first formal examination in perioperative TOE was held in the USA. This led to the establishment

of the National Boards of Echocardiography to administer the process. In the UK and Europe there was a similar joint process between Anaesthesia and Cardiology. In the mid-1990s the Association of Cardiothoracic Anaesthetists (ACTA) promoted training in TOE by supporting the establishment of hands on courses at several UK hospitals. In 2001, ACTA and the British Society of Echocardiography (BSE) jointly established a group to oversee TOE training and accreditation in the UK. The emphasis of this system is on a period of education and practice overseen by an experienced supervisor. Accreditation is granted following an examination and the presentation of a log book of echo reports. The model adopted closely follows that set up by the BSE in its accreditation in TTE. The same process is followed by cardiologists and anaesthetists, and is also open to non-physician echocardiographers. The process is not limited to perioperative practice only. In 2004, a pan European accreditation was established by the European Association of Cardiothoracic Anaesthetists and the European Association of Echocardiography (EAE). The requirements for this accreditation are almost identical to the UK system. Details of these accreditation processes are available on the internet.[22–24]

Less obvious effects

Some observers might suggest that the rapid proliferation of TOE was driven more by available technology than by clinical need, but the presentation to the anaesthetist and surgeon of real time dynamic cardiac imaging in the operating room immediately put TOE ahead of many other monitoring modalities. It should never be as the sole device for the acquisition of data but as an extra tool to build a more comprehensive understanding of the patient's cardiovascular physiology. TOE has moved from the arena of mainstream diagnostic cardiology to advanced monitoring for anaesthetists and now to perioperative diagnosis and surgical guidance. This has resulted in a significant change in the role and status of the anaesthetist. In addition to our traditional responsibilities, we are now also able to provide vital clinical information for the conduct of surgery. We can provide data which will dictate the course of the procedure and together with the surgeon we can assess the effectiveness of some surgical interventions. Many cardiac surgeons and anaesthetists are now reluctant to undertake certain procedures without TOE to guide decision-making in the operating room.

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