

Use of Transoesophageal Echocardiography during the Peri-operative Period for Trauma Patients.

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Abstract

The medical facility at Camp Bastion continues to evolve as a consequence of the increased throughput of battlefield trauma patients. There is a requirement for rapid and accurate diagnosis of haemodynamic instability and continued haemodynamic monitoring throughout the peri-operative period. Transoesophageal echocardiography (TOE) has been used for this purpose in the arena of cardiac anaesthesia since the mid 1980s. It is being introduced to other peri-operative settings where severe haemodynamic instability is expected. The old proverb: 'There are none so blind as those who cannot see' (Jeremiah 5:21) is applicable to this topic, in that TOE is proven to be a rapid, portable, safe and effective tool in the assessment of the haemodynamically unstable patient. This paper explores the application of TOE for the assessment of the major causes of haemodynamic instability in the trauma population.

Introduction

British military forces are currently committed to Operation HERRICK in Afghanistan. The medical support includes a Role IIE (enhanced) medical facility at Camp Bastion, Helmand Province, Afghanistan. The facility was initially designed as a surgical resuscitation node with limitation of clinical imaging, laboratory support and holding ability. As the operational workload has increased the facility has greatly expanded, but continues to be supported by a multi-national Role III facility at Kandahar. Records show that the majority of cases present as a consequence of traumatic injuries sustained in the battlefield [1,2]. The majority of the caseload presented for orthopaedic management of traumatic injury to the limbs. There was a wide variation in the severity of injuries, with 36% presenting with an injury severity score of greater than 16 during the period April 2006 to July 2008 [2]. Battlefield injuries are incited by external forces produced by blast, deceleration and concussion, either in isolation or in combination. It is well recognised that these mechanisms can affect central structures in addition to the limbs [3-5]. Severe central vascular injury occurred in 27 UK military trauma patients during the period 2003-2007, with only 3 patients surviving [6]. This is reported as the most common unsuspected visceral injury resulting in death in civilian accident victims [7]. In consideration of the potential compound pathology of the cases and of the expansion of facilities at the Role IIE hospital, it seems reasonable to have access to accurate, rapid and portable imaging of the heart and great vessels. Transoesophageal Echocardiography (TOE) is becoming more established in the peri-operative period of civilian trauma patients [8-10]. The quality of images acquired with TOE is equivalent to that acquired by helical computed tomography

MINOR CAUSES	MAJOR CAUSES
Left ventricular systolic dysfunction	Dynamic left ventricular outflow obstruction
Right ventricular systolic dysfunction	Valvular pathology
Low systemic vascular resistance	Massive pleural effusion
Pericardial compression	Ventricular septal rupture
Hypovolaemia	Pulmonary embolus
Reduced left ventricular compliance	Traumatic myocardial contusion
Mitral regurgitation	Tension pneumothorax
Abnormal heart rhythm	

Table 1: Causes of haemodynamic disturbance that may be diagnosed by TOE.

and magnetic resonance imaging for the assessment of aortic lesions [11-14]. The only exception being that the air space of the trachea produces a blind spot in the distal ascending aorta and the proximal aortic arch. The ability of TOE to predictably provide high quality images of the heart and guide surgical intervention has been well established in cardiac surgical patients [15-20].

TOE has clear benefits over standard haemodynamic monitoring and the pulmonary artery catheter when assessing volume status and regional ventricular function [21-22]. Diagnosis of some of the less common causes of haemodynamic instability (Table 1), are difficult to diagnose without some form of imaging. In 2003 the American College of Cardiology and American Heart Association Task Force on Practice Guidelines (ACC/AHA/ASE) published that there was sufficient evidence of improved clinical outcome when TOE was utilised as a continuous haemodynamic monitor [23]. The mass of evidence supporting the utility of TOE since 1994 has led to a similar

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revision of the 'Practice Guidelines for Peri-Operative TOE by the American Society of Anesthesiologists (ASA) and the Society of Cardiovascular Anesthesiologists' in May 2010 [24]. They recommend the use of TOE when the nature of the planned surgery or the patient's cardiovascular physiology may precipitate adverse haemodynamic, pulmonary or neurological sequelae. Furthermore, it is recommended for use when life-threatening circulatory instability persists despite corrective therapy. It has been consistently demonstrated that examination with TOE can alter the management of the patient in the critical care and post-operative setting [25-30]. As a consequence, the ASA and the Society of Cardiovascular Anesthesiologists recommends its use if the clinician expects it will be beneficial and that other modalities can not be instituted in a timely manner [24].

Equipment for Transoesophageal Echocardiography

The equipment consists of an echocardiography machine together with a TOE probe. Ultrasonic images are formed by the reflection of pulses of sound from tissues. The frequency of sound utilised in ultrasound is greater than 20 kHz, which is above the human audible frequency range (20 – 20 kHz). TOE probes are fitted with very high frequency transducers (3.5–7 MHz) to produce high resolution images. Low frequency transducers (2-4 MHz) are required in transthoracic echocardiography to penetrate through the chest wall, but the resolution is greatly attenuated.

The multiplane angle TOE probe can be moved physically as well as steered electronically ('phased array' system) from 0°-180° to optimise the image. Further optimisation is achieved by adjusting: image depth, focal zone, sector width, brightness, zoom and freeze. Two-dimensional images are supplemented with Doppler tracking of tissue motion. Colour Doppler, pulsed wave (PW) Doppler and continuous wave Doppler is applied depending on the tissue being analysed.

Echocardiographic Evaluation for Trauma

The American Society of Echocardiography (ASE) and the Society of Cardiovascular Anesthesiologists (SCA) have developed guidelines for comprehensive examination of the heart and great vessels, suggesting that between 12 and 20 standard views are required to avoid missing an unsuspected abnormality [31]. It has been demonstrated that this examination can be performed expeditiously [32, 33]. Brooks et al [34] reported a mean time of 27 minutes for complete examination in a series of patients presenting with trauma to the chest. This was in stark contrast to 76 minutes required for arch aortography. Many algorithms have been postulated for rapid, focused, goal-directed and simplified transthoracic echocardiography in trauma and critically ill patients [35-38]. In a similar manner, the order of image acquisition for TOE could be tailored to clinical suspicion.

Assessment of Hypovolaemia

Hypovolaemia is often the main contributor to haemodynamic instability in multiple trauma patients. It appears as a small, vigorously contracting left ventricle with reduction of the end diastolic area (EDA) and end systolic area (ESA). Accurate measurement of the areas can be performed using the transgastric mid short axis view. These values have been shown to correlate well with pre-load [39, 40]. M-mode imaging at the level of the papillary muscles will give the impression of obliteration of the cavity. This is termed 'kissing' of the papillary muscles. Hypovolaemia is associated with a reduction in the diastolic filling

velocity of the left ventricle (LV). This can be demonstrated by the application of PW Doppler across the mitral valve. The tendency of the superior vena cava to collapse when it is under-filled provides a useful surrogate marker for hypovolaemia. The pressure across the wall of the vessel varies throughout the respiratory cycle, which is manifest by changes in its diameter. A variation in diameter of greater than 36% is indicative of hypovolaemia [41].

Assessment of Left Ventricular Function

It is vital to differentiate between hypovolaemia and pump failure. Injury to the myocardium can occur as a direct consequence of the trauma or secondary to ischaemia. Cardiac contusion has been reported to occur in up to 70% of patients with blunt thoracic trauma [42, 43]. Changes in cardiac isoenzymes, electrocardiograph and increases in pulmonary artery wedge pressure may occur later and are insensitive [3, 44, 45].

Global LV function is assessed by viewing the contractility and thickening of the myocardium. Quantification of contractility is achieved by measuring the EDA and ESA in the transgastric mid short axis view (Figure 1). The fractional area change can be calculated as (EDA-ESA)/EDA x 100. Derivation of the ejection fraction, stroke volume and cardiac output from a 2D image requires the application of formulae to calculate the end diastolic volume (EDV) and end systolic volume (ESV). The biplane and single plane ellipsoid methods have been recommended by the ASE [48]. The latter method requires acquisition of the end diastolic and end systolic frames from a single mid oesophageal four chamber loop. The endocardial borders are traced and volume is calculated ($8A^2/9L$) using the assumption that the LV is ellipsoid. The volumes are applied to calculate the ejection fraction, defined as (EDV-ESV) / EDV x 100 and stroke volume, defined as EDV-ESV. Error can be incurred by foreshortening of the ventricle and by regional wall motion abnormalities (RWMA). RWMA are defined as areas of the myocardium that do not thicken during systole (Figure 2). The myocardium has been divided into 16 anatomical segments to facilitate matching of the RWMA to its concomitant blood supply [31]. Five echocardiographic views are required to visualise all of these segments.

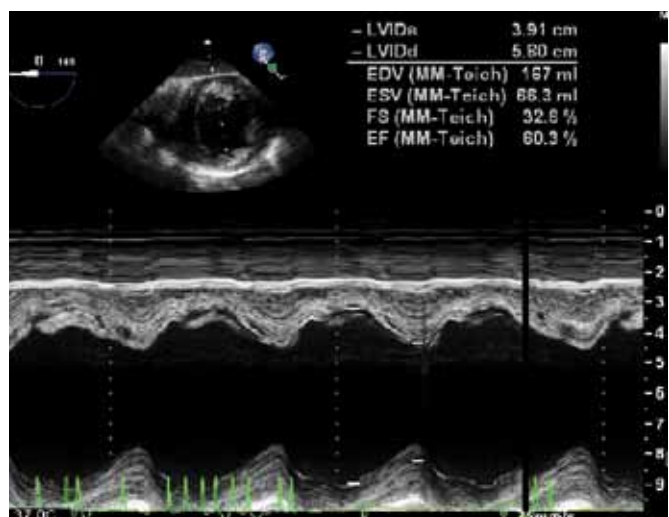


Figure 1. Assessment of left ventricular function (Transgastric mid short axis view). Doppler has been applied across the left ventricle. Movement of the inferior and anterior walls are plotted against time (M mode). EF, ejection fraction; FS, fractional shortening; LVIDs, left ventricular internal diameter in systole; LVIDd, left ventricular internal diameter in diastole.

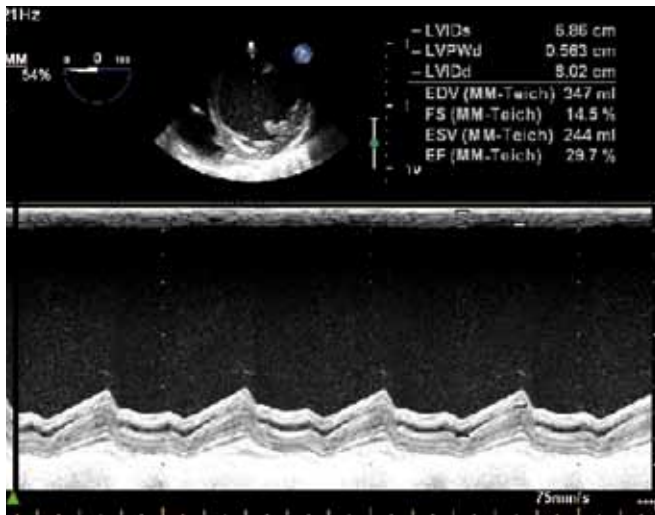


Figure 2. Inferior wall akinesia (Transgastric mid short axis view). Doppler has been applied across the left ventricle. Normal thickening and movement of the anterior wall can be seen during systole. In contrast, the inferior wall is akinetic. EF, ejection fraction; FS, fractional shortening; LVIDs, left ventricular internal diameter in systole; LVIDd, left ventricular internal diameter in diastole.

Assessment of Right Ventricular Function

The right ventricular (RV) wall is most vulnerable to cardiac contusion by virtue of its proximity to the sternum. A multi-centre trial demonstrated that 32% of 117 patients presenting with blunt chest trauma suffered damage to the right ventricle [3]. The RV is best evaluated in the mid oesophageal four-chamber (Figure 3) and transgastric mid short axis views. Global function is assessed in a similar way to that discussed for the LV.

Pulmonary embolism should always be considered in the context of cardiorespiratory deterioration in the trauma population. A large and sudden increase in RV afterload is manifest as: dilatation and hypokinesia of the RV, diastolic septal flattening, functional tricuspid regurgitation and pulmonary hypertension. In severe cases the thrombus can be visualised in the proximal pulmonary arteries or right heart chambers. Small emboli may not produce any echocardiographic abnormalities.

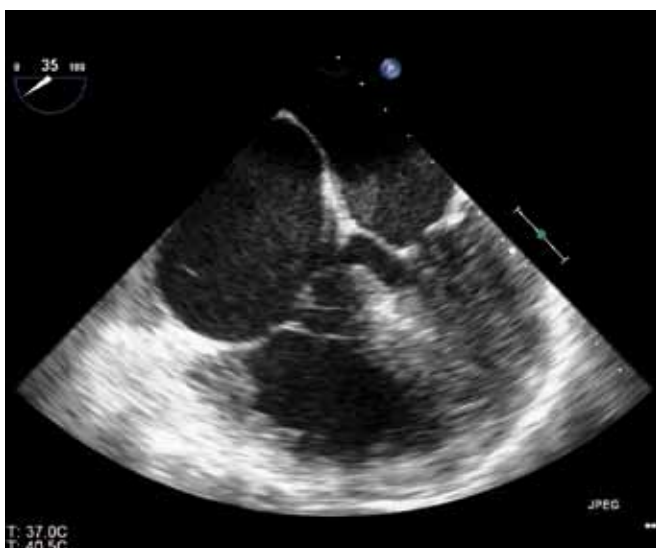


Figure 3. Assessment of right ventricular function (Mid oesophageal four chamber view). The right sided heart structures are on the left

and the atria are at the apex of the view. This view shows failure of the right ventricle with concurrent dilatation of the right atrium.

Assessment of Cardiac Tamponade

Haemopericardium or pericardial effusion can present with or without frank tamponade. The classical clinical signs of tamponade may not be present in the mechanically ventilated patient. Further diagnostic difficulty may arise because the collection of blood can clot and become loculated in a specific area. Unclothed blood appears as an echolucent space encompassing under-filled or collapsed cardiac chambers. It is best evaluated in the four-chamber and transgastric mid short axis views (Figure 4). It is graded as small (<0.5cm), moderate (0.5-2cm) or large (>2cm). As little as 1cm has been shown to cause tamponade [46].



Figure 4. Pericardial effusion and tamponade of the heart (Transgastric mid short axis view)

Assessment of Valvular Function

The mitral valve (MV) and aortic valve (AV) are at a greater risk of traumatic injury than right-sided valves because of the higher pressures in the left side of the heart [42]. The aortic valve is the most vulnerable to trauma, with laceration or detachment of the cusps from the aortic annulus occurring [43]. The four standard views for systematic examination of the AV are: mid-oesophageal AV short axis and long axis views; deep transgastric long axis view; and transgastric long axis view. The most common traumatic injury to the mitral valve is rupture of the chordae tendinae and papillary muscles [47]. Examination of the MV and its apparatus requires four standard mid oesophageal views and two transgastric views. Each valve should be assessed using 2D imaging, colour flow Doppler and spectral Doppler. The normal area of the AV is 2.5 cm² and that of the MV is 4-6 cm² with pressure gradients across them being <12mmHg and <6 mmHg, respectively.

Assessment of Left Ventricular Outflow Tract

Obstruction to the outflow tract is best assessed in the mid oesophageal AV long axis view. The obstruction can be fixed or dynamic. Fixed obstruction is often secondary to subaortic narrowing, bicuspid AV or aortic coarctation. Dynamic obstruction is the main pathology in the trauma population, where the distance between the anterior mitral leaflet and the interventricular septum is reduced during systole. This is

attributed to the combination of hypovolaemia, increased LV contractility and reduced afterload. Clinically, it can result in collapse of the patient and requires urgent management with intravenous fluids, vasopressors and beta blockade. The latter treatment is quite distinct from routine management of haemodynamic instability.

Assessment of the Aorta

TOE is becoming the tool of choice for the diagnosis of aortic dissection and the evaluation of its complications due to its high sensitivity and specificity [11-14]. Dissection involving the proximal aorta is best assessed in the mid oesophageal AV long axis view. An intimal flap may be seen to moving freely within the proximal aorta and can prolapse through the AV into the outflow tract. Entry and exit points may be identified using colour flow Doppler. The diagnosis is complicated when the false lumen contains haematoma, with the only echocardiographic finding being thickening of the wall of the aorta. Various imaging artifacts can resemble dissection of the aorta, including the presence of the innominate vein in the upper oesophageal aortic arch view.

Rupture of the aorta is associated with deceleration injury. The common site of injury is the isthmus, where the aorta is tethered by the ligamentum arteriosum just distal to the origin of the subclavian artery. However, the site of rupture can vary and it is recommended that the whole of the aorta from the arch to the diaphragm is examined. The aorta is imaged in the short and long axis views, starting in the upper oesophagus and its course followed distally. The screen depth should be reduced to 6cm. The echocardiographic image of rupture is typically an intimal flap with a characteristic free edge (Figure 5). The aorta is usually surrounded with haematoma and a false aneurysm may be seen. The diameter of the aorta should decrease from the arch to the proximal descending aorta, with even a small increase raising suspicion of rupture.

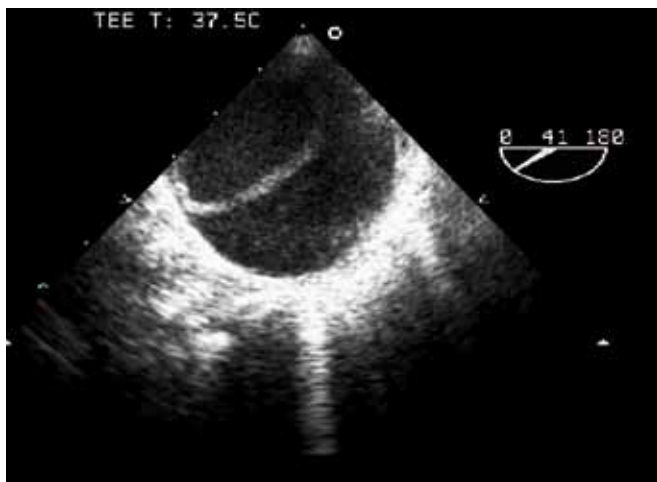


Figure 5. Dissection of the descending thoracic aorta with intimal flap (Descending thoracic aorta short axis view)

Assessment of Pleural Cavities

Aerated lung tissue is poorly visualised with echocardiography, but pleural spaces and pleural fluid can be seen. The left pleural space is in the far field beyond the descending thoracic aorta in the long and short axis views of the descending aorta. In the short axis view a pleural effusion is seen as an echo-free space in the shape of a tiger's claw (Figure 6). The right pleural space is in the right field

beyond the mid-oesophageal four chamber view. Pleural effusions can cause compression of the heart and haemodynamic instability if larger than 1.5 litres.



Figure 6. Left pleural effusion (Descending thoracic aorta short axis view)

Ventricular Septal Rupture

Rupture of the ventricular septum can be a direct consequence of the trauma or a late complication of infarction of the myocardium. The defect is best identified with the application of colour flow Doppler across the septum. A turbulent jet on the RV side of the septum or a region of flow acceleration on the LV side is diagnostic. Associated findings may include: biventricular dysfunction; tricuspid regurgitation; and pulmonary hypertension. It should be remembered that a defect in the apex may be missed if the view of the ventricle is foreshortened.

Safety of Transoesophageal Echocardiography

This is an invasive form of imaging, but complications are infrequent provided the contra-indications are respected and care is exercised during manipulation of the probe. In three large surveys the incidence of complications associated with the procedure ranged from 0% to 0.5%, with only one death being reported. [20, 49, 50] This rate has been consistently quoted and is comparable to the complication rate of 0.08% to 0.13% associated with upper gastrointestinal tract endoscopy [51-53]. The most frequently reported symptom is odynophagia (Table 2). Haemorrhage and oesophageal perforation occur infrequently and are more likely to occur in patients with pre-existing upper gastrointestinal pathology. As a consequence, insertion of the probe is avoided in patients with proven or suspected upper gastrointestinal pathology. The management of patients presenting with mild dysphagia in the absence of proven pathology is controversial. However, there is evidence that these patients tolerate the procedure; under the proviso insertion of the probe is performed cautiously and terminated if resistance is met [54]. Failure to insert or advance the probe has been reported to occur in 0.7% of sedated adult patients [49] and in 0.8% of anaesthetised patients [50]. This is associated with an increase in the incidence of injury to the

COMPLICATION	INCIDENCE (%)
Odynophagia	0.1
Swallowing abnormality	0.01
Oesophageal abrasions	0.06
No associated pathology	0.03
Upper gastrointestinal haemorrhage	0.03
Oesophageal perforation	0.01
Dental injury	0.03
Endotracheal tube malposition	0.03

Table 2. Complications associated with TOE [50].

oropharynx and odynophagia [55]. It is widely accepted that the procedure should be abandoned rather than risk injury to the patient.

It has been suggested that prolonged contact of the probe with the oesophageal mucosa can result in pressure necrosis. It is further proposed that thermal injury from vibration of the piezoelectric crystals may be deleterious [55, 56]. Although these hypotheses have not been supported in animal studies [56], it may occur in patients suffering from circulatory compromise [57].

Misinterpretation of the echocardiography data is an obvious risk, which is why the Association of Cardiothoracic Anaesthetists (ACTA) and the British Society of Echocardiography (BSE) have established a rigorous program for accreditation in echocardiography.

Accreditation in Transoesophageal Echocardiography

The Association of Cardiothoracic Anaesthetists (ACTA) and the British Society of Echocardiography (BSE) have jointly developed a process for training and accreditation in TOE in the UK [58]. It is not a compulsory or regulatory certificate of competence. The model is similar to that produced by the BSE for accreditation in transthoracic echocardiography and is designed to include all specialities that utilise TOE. The accreditation process consists of the compilation of a logbook and a written examination [59]. A logbook of 125 TOE studies should be collected and reported on over a period of 24 months. Ten of these cases, with full reports, should be retained electronically. A supervisor is appointed by the BSE to oversee the compilation of the logbook and to certify the clinical practice of the candidate. The written examination consists of 125 single best answer questions covering the range of the syllabus. The BSE states that the attainment of accreditation is a minimum standard and candidates will be expected to begin a process of continuing medical education towards re-accreditation. The re-accreditation process will include evidence of continuing clinical activity, distance learning and attendance at courses and conferences.

Conclusion

TOE equipment is evolving. Currently emphasis is being placed on the development of real time 3-dimensional imaging and miniaturisation of the probe. It is envisaged that this will improve portability and simplify the process for acquisition and interpretation of the images. The increasing availability of TOE equipment in the civilian sector combined with a structured training process means that it may become a routine tool in the peri-operative management of unstable trauma patients.

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