Echocardiography in intensive care

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Since its inception in the early 1950s by Edler and Hertz, echocardiography has developed from simple amplitude (A) and brightness (B) modes, through motion (M) mode, to the present day real-time 2D and 3D imaging modalities. Its role has extended beyond cardiology into the operating theatres, as a perioperative monitor, and into the realm of critical care and emergency medicine.

**Physics of echocardiography**

Ultrasound waves are formed when a voltage is applied across a substance with piezoelectric properties. Echocardiography transducers are commonly made from lead-zirconate-titanate-5 (PZT-5). The electric impulses are delivered to the transducer in various patterns to create pulses of ultrasound. Some of this acoustic energy is reflected back to the transducer, which is received by the PZT-5 crystal and is converted back into electrical energy. This signal is then processed and displayed on a monitor.

The frequency used by the transducer affects both the resolution of the image obtained and the penetration of the ultrasound beam into the body. Transthoracic echocardiography (TTE) employs low-frequency transducers (2–4 MHz), which allows better penetration of the acoustic energy through the chest wall, but at the cost of reduced longitudinal resolution. Transoesophageal echocardiography (TOE) does not require such penetration and so uses higher frequency transducers (3.5–7 MHz) to produce better resolution imaging.

**Training and accreditation**

Echocardiography is a tool that requires skill both to perform and to interpret. In the UK, the accreditation process requires the candidate to pass a written examination and submit a logbook within a 2 yr period. The written examination is composed of theoretical multiple choice questions and a practical interpretation of echocardiographic images. The minimum number of echocardiographic examinations over a continuous 24 month period is 125 for perioperative TOE and 250 for TTE accreditation (information available at www.bsecho.org/). Accreditation or certification is not compulsory but is highly recommended by professional bodies.

More recently, a number of centres have been organizing critical care and emergency medicine echocardiography courses. These are designed to train personnel to perform abbreviated, but focused, echocardiography with the aim of a quick diagnosis in an unstable patient. Some research has shown that ‘novice’ echocardiographers can be trained to a standard for clinical use after a limited number of practice studies. However, even straightforward conditions may be misdiagnosed or misinterpreted by staff with inadequate training, leading to inappropriate management or interventions. Quality assurance may become an issue. Personnel making such diagnoses require sufficient assessment of echocardiography skills (Table 1), continuing medical education, and maintenance of competency.

**Indications for TOE and TTE**

The original guidelines for the use of perioperative TOE were published in 1996. Use in intensive care unit (ICU) for unstable patients with unexplained haemodynamic disturbances, suspected valve disease, or thromboembolic problems is a category I indication, suggesting TOE is frequently useful in improving clinical outcomes. The guidelines for the clinical application of echocardiography in the critically ill or injured patient were updated in 2003 and are listed in Table 2.

**Impact of echocardiography**

The use of echocardiography on the ICU is increasing. Using an abbreviated focus assessed protocol, TTE has been shown to contribute positively to patient care in 97% of critically ill patients. TTE has the advantage of being non-invasive, but poor picture quality can render image interpretation difficult. Positive pressure
ventilation, high levels of positive end-expiratory pressure, intrathoracic surgery, or chest trauma all present challenges to adequate image acquisition using the transthoracic approach. This means that TOE is frequently more useful in the ICU setting, and is the first line echocardiographic examination whenever a patient has an endotracheal tube in situ. Although it is classified as a semi-invasive procedure, the safety profile of TOE has been well documented, the incidence of oesophageal perforation is estimated at 1 in 5000, and mortality 1 in 10 000.

Preload assessment

One of the most commonly observed findings in the haemodynamically unstable patient is hypovolaemia. Short axis images of the left ventricle (LV) provide real-time assessment of ventricular filling, which may not be accurately reflected by the pulmonary capillary wedge pressure. Visualization of LV end-diastolic (LVED) and end-systolic (LVES) areas provide a rapid estimation of intracardiac volume status. Hypovolaemic patients usually have a hyperdynamic LV with a reduced end-diastolic volume and ‘kissing’ papillary muscles in systole, indicating an increased ejection fraction with an empty ventricle at end-systole. This can easily be displayed by utilizing M mode imaging (Fig. 1). Septic patients tend to have a reduced afterload, which is usually demonstrated by a normal LVED area, but a reduced LVES area. Patients with chronic cardiac failure have a dilated LV and may be hypovolaemic even with a higher LVED area.

Myocardial function

Global LV systolic function may be assessed by viewing the contractility and thickening of the myocardium during systole. In a normovolaemic patient, measurement of LVED and LVES areas can be used to estimate ejection fraction. The use of TOE in an ICU setting has been shown to provide better information on myocardial function than the use of pulmonary artery catheter-derived indices. Echocardiography also allows for the identification of regional wall motion abnormalities (RWMA). This is a more sensitive marker of myocardial ischaemia than ECG changes and may aid decision-making when considering insertion of an intra-aortic balloon pump, coronary angiography, or proceeding to

Table 1: Indications for performing echocardiography in the critically ill patient

<table>
<thead>
<tr>
<th>Category</th>
<th>Conditions for which there is evidence and/or general agreement that a given procedure is useful and effective</th>
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</thead>
<tbody>
<tr>
<td>I</td>
<td>The haemodynamically unstable patient</td>
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<tr>
<td></td>
<td>Suspected aortic dissection</td>
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<tr>
<td></td>
<td>Serious blunt or penetrating chest trauma (suspected pericardial effusion or tamponade)</td>
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<tr>
<td></td>
<td>Mechanically ventilated multiple-trauma or chest trauma patient</td>
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<tr>
<td></td>
<td>Suspected pre-existing valvular or myocardial disease in the trauma patient</td>
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<td></td>
<td>Widening of the mediastinum, suspected aortic injury</td>
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<tr>
<td></td>
<td>Potential catheter, guidewire, pacemaker electrode or pericardiocentesis needle injury with or without signs of tamponade</td>
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<table>
<thead>
<tr>
<th>Category</th>
<th>Conditions for which there is conflicting evidence or divergence of opinion, but the weight of evidence/opinion is in favour of usefulness</th>
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<tbody>
<tr>
<td>IIa</td>
<td>Evaluation of haemodynamics in multiple-trauma or chest trauma patients with pulmonary artery catheter monitoring and data disparate with clinical situation</td>
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<tr>
<td></td>
<td>Follow-up study on victims of serious trauma</td>
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<thead>
<tr>
<th>Category</th>
<th>Conditions for which there is evidence and/or general agreement that the procedure is not useful and in some cases may be harmful</th>
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<tr>
<td>III</td>
<td>The haemodynamically stable patient not expected to have cardiac disease</td>
</tr>
<tr>
<td></td>
<td>Re-evaluation follow-up studies on haemodynamically stable patients</td>
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<tr>
<td></td>
<td>Suspected myocardial contusion in the haemodynamically stable patient with a normal ECG who has no abnormal physical findings</td>
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revascularization. The assessment of LV diastolic dysfunction is complex and beyond the scope of this article. Evaluation of the right ventricle (RV) is also essential, as tricuspid regurgitation, RV overload (greatly increased size), limited tricuspid descent, and poor RV wall contraction may indicate right-sided heart failure. RV dilatation is often associated with LV underfilling and poor cardiac output.

Cardiac tamponade
Frank cardiac tamponade is a clinical diagnosis and prompt return to theatre and pericardial evacuation should not be delayed by investigations. However, echocardiography may aid in the diagnosis in combination with clinical signs where the picture is less clear.9 The classical picture shows compressed cardiac chambers surrounded by a pericardial fluid collection (Fig. 2), typically with RV diastolic collapse. However, this is not often seen, more frequently, a pericardial collection will be demonstrated, and the amount of blood estimated by measuring the diameter of the collection. A diameter of >1 cm is often said to be significant, but this may not accurately reflect pressure within the pericardial compartment, which is more important clinically.

Thromboembolic disease
Pulmonary angiography remains the gold standard for diagnosis of pulmonary embolism (PE). Other available imaging modalities include ventilation–perfusion scanning, spiral computed tomography (CT), and magnetic resonance imaging (MRI) angiography. Although echocardiography has a low sensitivity for the detection of PE, it may be useful in the unstable patient, unfit for transfer to a radiological environment. Very occasionally, a thrombus may be visualized in the right atrium, traversing through the RV or in the proximal pulmonary arteries. However, 80% of patients with shock and PE will have signs of RV strain,9 such as dilatation and dysfunction. Visualization of thrombus within the left atrial appendage may elucidate the source of systemic emboli and may precipitate patient anticoagulation.

Valvular disease
The use of TOE in cardiac surgery for assessment of cardiac valve function is well established. In the unstable postoperative cardiac patient, TOE allows evaluation of a valve repair or assessment of a valve replacement for malfunction or paravalvular leak. TTE can detect vegetations but the superior resolution of TOE makes it better suited for this in patients with suspected endocarditis. Vegetations typically lie on the atrial side of mitral and tricuspid valves, and on the ventricular side of aortic (Fig. 3) and pulmonary valves.

Left ventricular outflow obstruction
Systolic anterior motion (SAM) of the mitral valve usually occurs when there is a combination of hypovolaemia, LV hypertrophy with increased myocardial contractility, and vasodilatation. In this setting, the increase in velocity of blood flow through the LV outflow tract (LVOT), coupled with a shortened systolic time, draws the anterior mitral valve leaflet into the LVOT. This dynamic obstruction can result in cardiovascular collapse and prompt diagnosis with echocardiography is essential to implement the correct management. Treatment includes i.v. fluids, vasopressors, and β-blockade.

Aortic dissection
With the advent of modern scanners, CT with contrast has become the gold standard for diagnosing acute aortic dissection; however, the role of TOE is expanding. TOE is able to rapidly assess complications such as aortic valve incompetence, pericardial collection, and coronary artery involvement represented by RWMAs. In
some centres, it is now routine for patients with suspected acute aortic dissection to be transferred directly to the operating theatre, where TOE is performed as the initial investigation of choice.

Trauma

Thoracic injuries account for almost one quarter of deaths due to trauma. A rapid, focused assessment with echocardiography can detect pericardial collection, myocardial contusion, mediastinal haematomas, aortic intramural haematomas, aortic dissection or transection, and pleural collections (Fig. 4).

Other pathologies

Interatrial septal defects, including patent foramen ovale, interventricular septal defects, pleural effusions, mobile atheroma in the aorta, and occasionally hepatic pathology may all be detected using echocardiography.

References

2. Lemola K, Yamada E, Jagasia D, Kerber RE. A hand-carried personal ultrasound device for rapid evaluation of left ventricular function: use after limited echo training. Echocardiography 2003; 20: 309

Please see multiple choice questions 5–8