Use of echocardiography and modalities of patient monitoring of trauma patients

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Purpose of review

Trauma patients require evaluation of the anatomic structure as well as the hemodynamic profile of the heart to improve effectiveness of resuscitation. They are prone to hemodynamic instability and must be monitored with various modalities to detect deterioration early. Newer, less invasive ultrasound technologies are replacing familiar 'gold standard' modalities of the past. This article reviews the indications, roles, imaging approaches, and limitations of modern echocardiography. A brief review of other ICU monitoring modalities is also presented.

Recent findings

Echocardiography has emerged as a first-line diagnostic tool for assessment of trauma patients, especially those with hemodynamic compromise. It yields crucial information about structural damage as well as the hemodynamic profile and can be performed through either the transesophageal or transthoracic route. Quick and systematic use of echocardiography for diagnosis and management of critically injured patients may lead to improved outcomes.

Summary

Echocardiography plays an important role in the trauma bay for diagnosis of thoracic injury and at the bedside in the ICU for evaluation of the hemodynamic profile.

Keywords

echocardiography, ICU monitoring, trauma

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Introduction

Trauma is a distinct critical illness with homeostatic imbalances due to external stimuli and structural damage. In trauma bays and ICUs, 'gold standard' techniques for diagnosis and monitoring are being replaced by newer, less invasive ultrasound technologies. Ultrasonography permits rapid assessment, especially when computed tomography (CT) is not available or feasible [1••]. Echocardiography is becoming a vital diagnostic component during triage and follow-up care, as it provides accurate real-time imaging of the heart [2]. This article reviews the indications, roles, imaging approaches, and limitations of modern echocardiography. A brief review of other ICU monitoring modalities is also presented.

Echocardiography

According to the most recent joint guidelines of the American College of Cardiology, American Heart Association and American Society of Echocardiography (ACC/AHA/ASE), noninvasive transthoracic echocardiography (TTE) or minimally invasive transesophageal echocardiography (TEE) with Doppler-augmented imaging is indicated in many critically injured patients when an appropriately trained and experienced sonographer and interpreter are available (Table 1). TEE may be preferable in [3,4••]

(1) hemodynamically unstable patients with suboptimal TTE images,
(2) mechanically ventilated hemodynamically unstable patients,
(3) major trauma or postoperative patients unable to be positioned for adequate TTE, and
(4) suspected aortic dissection or aortic injury.

Ultrasound competence and technique are easily learned, and training is now included in fellowship programs and postgraduate courses at critical care meetings [5,6•].

Role of echocardiography

The role of echocardiography in critically ill and injured patients is expanding. In thoracic trauma, the mechanism of injury could be blunt or direct impact, penetrating trauma, deceleration injury, upward displacement of abdominal viscera into the thorax, or atmospheric pressure

Table 1 Indications for echocardiography in trauma patients

Disorder	Indication level
Serious blunt or penetrating chest trauma	Class I
Mechanically ventilated patients with multiple trauma or chest trauma	Class I
Trauma patients with suspicion of preexisting valvular or myocardial disease	Class I
Hemodynamically unstable polytrauma patients without obvious chest injury but with a mechanism of trauma suggesting potential cardiac or aortic injury (i.e. deceleration or crush injury)	Class I
Widening mediastinum or suspicion of postinjury aortic damage	Class I
Potential catheter, guidewire, pacer electrode or pericardiocentesis needle injury with or without signs of tamponade	Class I
Evaluation of hemodynamics in multiple trauma or chest trauma patients with PAC monitoring data that are disparate from the clinical scenario	Class IIa
As a follow-up study to victims of serious blunt or penetrating injury	Class IIa
Suspected myocardial contusion in hemodynamically stable patients with a normal ECG	Class III
Critically ill hemodynamically unstable patients	Class I
Patient with suspected aortic dissection using TEE probe	Class I
Hemodynamically stable patient not expected to have cardiac disease	Class III
Re-evaluation of hemodynamically stable patients	Class III

PAC, pulmonary artery catheter; TEE, transesophageal echocardiography.

change, as in explosion accidents. Echocardiography aids in visualization of structural damage caused by traumatic forces that may produce cardiac contusion, concussion, muscle rupture, valvular disruption, great vessel or coronary artery injury, aortic dissection or rupture, pulmonary contusion, hemothorax, pneumothorax, or diaphragm rupture, as well as esophageal injury. Disordered physiology can affect the hemodynamic profile and may be secondary to hypotension, anemia, coronary vasoconstriction, or catecholamine storm [7•]. Echocardiography may assist in these instances with rapid diagnosis and treatment via assessment of the hemodynamic profile, evaluation of volume status, and calculation of cardiac index [8]. TTE is completely safe and can provide quick answers to unexplained hemodynamic instability. TEE, although invasive, is safe and has been used in medical, coronary care, and surgical patients to guide volume infusion and administration of vasopressors, anticoagulants, and antibiotics [9–11]. Furthermore, TEE may have better image acquisition than TTE because of its limited acoustic window. We use TTE in our initial assessment of patients in shock.

Volume status or preload can be estimated from two-dimensional echo images and/or Doppler flow assessment of left ventricular end-diastolic (LVED) area, LVED volume, left ventricular ejection time, the inferior vena cava (IVC) dispensability, and the superior vena cava (SVC) collapsibility, all of which have been used as surrogates for preload assessment. LVED area is calculated via the two-dimensional parasternal short-axis view during TTE (Fig. 1) or the transgastric short-axis view during TEE (Fig. 2). It has been shown to correlate with hypovolemia in acute blood loss. LVED area index can also help predict preload in ventilated patients with early septic shock [12–18].

Dynamic changes in left ventricular stroke area, as seen on continuous TEE-automated border detection, can

Figure 1 Parasternal short-axis view during transthoracic echocardiography

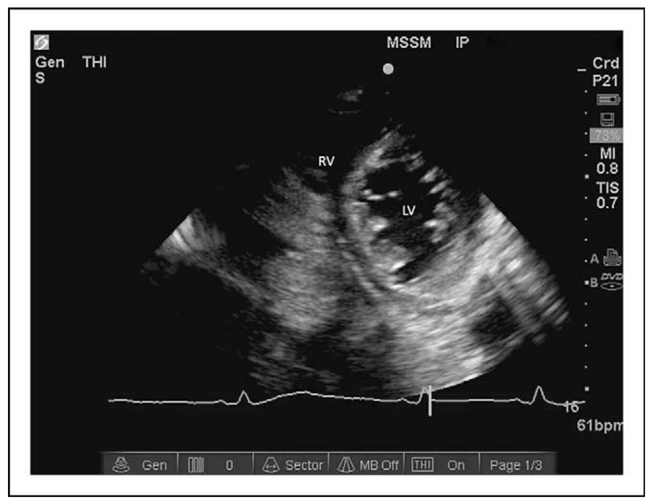

Figure 2 The transgastric short-axis view during transesophageal echocardiography

predict volume responsiveness during cardiac surgery, but this technique is difficult to apply in the ICU [19]. We use serial measurements with focused TTE examination for monitoring critically ill or injured patients in our ICU. We routinely use TTE to assess volume status, cardiac output, and ventricular function in order to manage hemodynamic instability in preference to the more invasive pulmonary artery catheter (PAC).

Vena cava measurement is a useful predictor of shock and volume responsiveness in trauma patients [13]. Shock patients, in particular, have smaller vessel diameter and increased vascular collapsibility. TEE can be used to evaluate the effect of respiratory alterations on SVC collapsibility. When the external thoracic cavity pressure is greater than SVC pressure, the SVC collapses, indicating hypovolemia; collapsibility greater than 36% indicates that a patient could be fluid responsive [14]. IVC diameter can be visualized with TTE in mechanically ventilated patients [20]. Using the subcostal long-axis view in M-mode, the diameter of the IVC is measured and maximum and minimum diameters are obtained to calculate an IVC distensibility index. A reduced IVC diameter after volume resuscitation predicts volume responsiveness in mechanically ventilated septic patients [21].

In a study involving 100 consecutive patients with shock, TTE had adequate image quality in 99%, and its sensitivity and specificity for diagnosing a cardiac cause of shock were 100 and 95%, respectively [22]. Another recent paper showed that data obtained using TTE for 'bedside echocardiographic assessment in trauma' (BEAT) examination correlated well with PAC data regarding cardiac function and volume status [23•]. The BEAT examination, which also assesses cardiac index and pericardial effusion, can easily be learned and may one day serve as a screening tool to identify patients who require continuous cardiac monitoring rather than 'spot' echocardiography.

A novel approach introduced in the late 1990s is transnasal placement of a 16F TEE probe. Using topical anesthesia, light sedation, and control of heart rate, transnasal TEE probes can be placed in awake patients with cardiovascular risk factors but without major hemodynamic compromise and can provide adequate imaging of regional wall motion abnormalities as well as cardiac monitoring during induction of general anesthesia [24]. Transnasal placement does not cause oral or esophageal trauma as the probe is relatively thin. It is safe and well tolerated, even in intubated patients, reportedly remaining in place for long periods to allow serial monitoring [25]. Continuous monitoring with this probe may be problematic, however, because of translational and rotational movement [26]. The diagnostic capability of the transnasal probe equals that of transoral monoplane TEE but is inferior to conventional multiplane TEE. The probe is also suitable for the cardiac four-chamber view but it may not be satisfactory for the left ventricular short-axis view [27].

Hemodynamic determinations can be predicted by other means as well, such as by passive leg-raising maneuvers in spontaneously breathing patients, or by using respiratory variation as a surrogate of stroke volume for predicting volume responsiveness in patients who are fully adapted to mechanical ventilation and without arrhythmia [15,28].

Limitations of echocardiography

TTE is easier to conduct, but its image quality is limited by hyperinflated lungs during positive pressure ventilation, postoperative subcutaneous emphysema, surgical incisions, drains or appliances, inadequate patient positioning, and the uncooperative patient [4••]. TEE image quality is limited by the need for an experienced operator and the type of trauma, such as head, neck, or esophageal injury. Inherent risks of TEE include dental trauma, failed esophageal insertion, and possible pharyngeal perforation. Trauma patients with suspected esophageal damage should not have TEE until the esophageal and gastric lumens are clear of damage.

Bastos *et al.* [29] recommended that hemodynamically stable patients be evaluated with multidetector CT, thereby avoiding other imaging, but we feel this would limit intensivists to a single view at a given time, expose the patient to large doses of radiation, and may not offer continuous benefit for the patient. Furthermore, Meyer *et al.* [30] concluded that, in patients without hemopneumothoraces, echocardiography did not miss significant cardiac injuries.

Use of echocardiography in monitoring other thoracic structures

Although invasive aortography, helical CT, intravascular ultrasound, and MRI are useful for the diagnosis of aortic trauma, echocardiography is valuable in managing any acute decompensation in chest trauma patients [31]. Although the American Association for the Surgery of Trauma [32,33] advises that CT, when feasible, is best for diagnosis, unstable patients who cannot tolerate CT or transfer to the radiology suite could be diagnosed accurately with ultrasonography [34].

The same echocardiography probe could also be used to evaluate lung, pleural, and limited diaphragmatic injury and their role in hemodynamic compromise. Lichtenstein [35,36•] described the Bedside Lung Ultrasound in Emergency (BLUE) protocol for evaluating acute pulmonary disorder. By combining echocardiography with pulmonary, abdominal and vascular ultrasound, physicians can diagnose, treat, and monitor many conditions of critical illness.

Other ICU monitoring modalities

Monitoring of trauma patients, similar to monitoring of any critical patient, includes noninvasive standard ECG, intermittent cuff blood pressure measurement, oxygen saturation, and urine output. In trauma patients, however, traditional vital signs have failed to predict mortality or the need for life-saving interventions until after cardiovascular collapse [37]. Reduction in pulse pressure, heart rate variability, and tissue oxygenation may be more useful for prehospital trauma care during transport to the hospital.

Invasive monitoring, when indicated, includes arterial blood pressure measurement, central venous pressure, PAC measurements, gastric tonometry, mixed venous oxygen saturation, transesophageal Doppler, and arterial blood gas analysis.

Electrocardiographic monitoring

The monitoring modality closest to ideal is the reliable and reproducible ECG. The ECG can detect disturbances in cardiac rate and rhythm as well as indicate myocardial ischemia. It is integral to intensive care monitoring [26].

Pulse oximetry

Also known as the ‘fifth vital sign’, pulse oximetry measures arterial hemoglobin–oxygen saturation. Transcutaneous devices permit continuous measurement. Sensitivity is lost below 70% saturation, but numbers above 90% correlate well with p_aO_2 concentration above 60 mmHg [6•].

Arterial pressure measurement

Cannulation of radial, axillary, femoral, or brachial arteries with an indwelling catheter remains the most practical means for measuring hemodynamic parameters and can also be used for easy blood sampling, but results correlate poorly with tissue perfusion [38]. In our unit, we prefer to cannulate the axillary artery with or without ultrasound guidance. It is easy to cannulate and there is less catheter displacement with patient movement.

Pulmonary artery catheter

PACs, the ‘gold standard’ for guiding therapy since the 1970s, have fallen out of favor and in fact are actually controversial in certain settings because of their high risk-to-benefit ratio and the difficulty in proper evaluation of PAC data [39]. PACs are being replaced by newer, less invasive technologies, in part due to concern over excess mortality. The ‘PAC-Man’ study by Harvey *et al.* [40], which looked at 1041 patients in 65 ICUs in the United Kingdom, indicated no clear evidence of benefit or harm with the use of PACs in the management of critically ill patients. A post-hoc analysis of the PAC-Man study data revealed no benefit associated with PAC-directed management [41]. Other recent multicenter trials have shown that PACs are not associated with excess mortality [42••]. A recent review suggested that intensivists do not know how to use PACs effectively [43]. Vincent *et al.* [44•] urged physicians to review the basics of hemodynamic monitoring and management and suggested three key principles: correct measurement, correct data interpretation, and correct application. We believe that PACs are best used for monitoring the trend of cardiac output, mixed venous oxygen, and pulmonary artery pressures.

Pulse contour analysis measurement of cardiac output

Arterial pulse contour analysis is a promising new technology that allows cardiac output monitoring without the need for central venous cannulation [45]. Once only yielding systolic arterial pressure variations, a static quantification, arterial pulse contour analysis has evolved to yield real-time and continuous left ventricular stroke volume variation (SVV). Because it analyzes the intermittent changes produced by positive airway pressure on the preload and stroke volume, it can be used only in patients who are fully adapted to mechanical ventilation and without any arrhythmia [46]. Preload responsiveness can be determined via this modality as the computer determines SBP, pulse pressure, or SVV.

Vigileo-FloTrac is an example of a minimally invasive cardiac output monitor that utilizes continuous arterial waveform analysis without external calibration. It is not accurate enough to replace more invasive cardiac output monitoring systems [47,48]. LiDCOplus requires central venous and arterial cannulation and utilizes lithium dilution cardiac output measurements to calibrate a pulse pressure analysis algorithm, thereby providing continuous cardiac output measurement [49]. LiDCOplus derived cardiac output has shown good correlation with data obtained from the PAC thermodilution technique [50]. This technology is undergoing continuous refinement as its use is expanding [51].

Mixed venous sampling

This blood value requires central venous cannulation and measures the oxygen saturation in the blood at a given location along the intravascular circuit. Oxygen delivery

Table 2 Simplistic comparison: neurocritical care 'vital signs of the brain' and hemodynamic vital signs

Hemodynamic vital signs	Vital signs of the brain	Normal value
Continuous ECG	Continuous EEG	–
Invasive blood pressure monitoring	ICP and CPP monitoring	ICP <20 mmHg; CPP ≥ 60 mmHg
Pulse oximetry	Jugular venous bulb saturation	50–75%
Blood gas analysis	Cerebral parenchymal tissue monitoring (measures tissue partial pressures of O_2 and CO_2)	O_2: 20 mmHg in white matter, 35–40 mmHg in gray matter; CO_2: 43–50 mmHg
Blood chemistry	Cerebral microdialysis	Measures glucose, lactate, pyruvate, lactate/pyruvate ratio, glutamate, glycerol

EEG, electroencephalogram; ICP, intracranial pressure; CPP, cerebral perfusion pressure; O_2, oxygen; CO_2, carbon dioxide.

or consumption derangement will yield saturations that are not physiologic. This value can guide the intensivist in optimizing cardiac contractility and output by using volume, blood products, or inotropic support as needed.

Esophageal Doppler

Cardiac output can also be calculated with a Doppler probe introduced orally or nasally into the lower esophagus, where it measures blood velocity in the descending thoracic aorta at the level of the right and left ventricular outflow tract. Left ventricular ejection time or flow time is measured and corrected for heart rate and provides an index of preload. Corrected flow time has been shown to correlate with fluid responsiveness in neurosurgical patients [12]. Chytra *et al.* [52] studied 162 patients with multiple trauma and showed that optimization of intravascular volume via esophageal Doppler guidance led to decreased blood lactate levels, lower incidence of infectious complications, and reduced ICU and hospital stays. Mortality, however, remained the same.

Supra-sternal Doppler can be used to measure blood velocity in the ascending aorta and is a noninvasive alternative to the esophageal Doppler technique. This approach is feasible and accurate in trauma and nontrauma patients admitted to the surgical intensive care service and in heart failure patients, but it did not correlate well with PAC measurements in children with congenital heart disease [53–55]. Wide usage of Doppler echocardiography is limited as it is technically demanding, time-consuming, and requires a skilled operator.

Neurocritical care monitoring

Patients with neurologic insults may benefit from transfer to a hospital with specialized neurocritical care. Neurocritical care has graduated from standard ICU monitoring protocols plus neurologic checks, as was the norm before the 1980s, to a sophisticated specialty that 'monitors the vitals of the brain' with modalities such as continuous electroencephalogram (EEG), bispectral index, jugular venous bulb saturation, intracranial pressure (ICP) and cerebral perfusion pressure (CPP) monitoring, cerebral microdialysis, and cerebral oxygen saturation monitoring [56,57••] (Table 2).

Of the invasive and noninvasive methods for monitoring ICP and the derived CPP, the 'gold standard' is ventriculostomy with an external pressure transducer. Other types of ICP microtransducers include those placed in the subdural, epidural, or intraparenchymal space. Transcranial Doppler can be used as a noninvasive surrogate for evaluating ICP. Limitations of invasive methods include increased risk of infection with increasing duration of the monitoring period and malposition of the transducer [57••].

Conclusion

Echocardiography is easy to learn and perform, rapid and accurate, and has a well defined role in thoracic trauma. It can be used to evaluate structural damage and hemodynamic parameters. It can be done via the transesophageal or transthoracic route. Each route has its own utility and limitation and should be utilized as appropriate. Echocardiography can be life saving. It can provide useful information regarding preload and volume responsiveness and can help optimize patient care. We believe that every intensivist should be able to perform focused echocardiography.

Noninvasive and invasive monitoring modalities are constantly evolving. Intensivists should be familiar with the parameters of each type to effectively manage disordered physiology. Intensivists must also familiarize themselves with the multimodality monitoring techniques of neurocritical care if they are to be closely involved in caring for patients with neurological trauma.

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Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 000–000).

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