# Echocardiography in cardiac arrest

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**Purpose of review**

Successful resuscitation requires potentially reversible causes to be diagnosed and reversed, and many of these can readily be diagnosed using echocardiography. Although members of the resuscitation team routinely use adjuncts to their clinical examination in order to differentiate these causes, the use of echocardiography is not yet considered standard. The purpose of this review is to discuss the potential for echocardiography to aid diagnosis and treatment during resuscitation, together with some of the perceived challenges that currently limit its widespread use.

**Recent findings**

Many studies have demonstrated the value of echocardiography in the assessment of critically ill patients in the intensive care unit and emergency room settings, including more recently the use of focused echocardiography. This can be performed within the time frame allowed during the pulse check of the advanced life support (ALS) algorithm. ALS-compliant focused echocardiography can be taught to nonexpert practitioners such that high-quality cardiopulmonary resuscitation is not compromised while diagnosing/excluding some of the potential causes of cardiac arrest.

**Summary**

Persistent and worsening haemodynamic instability are regarded as clear indications for echocardiography. The focused application of this well established technique within the ALS algorithm provides the resuscitation team with a potentially powerful diagnostic tool that can be used to diagnose/exclude some of the potentially treatable causes of cardiac arrest as well as to guide therapeutic interventions. The impact of routine periresuscitation echocardiography on patient outcomes both for in-hospital and prehospital care remains an exciting avenue for future research.

**Keywords**

cardiac arrest, echocardiography, focused echo, periresuscitation, resuscitation

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## Introduction

Since its inception over 60 years ago, echocardiography has remained largely the province of the cardiologist, providing a tool to evaluate anatomical and physiological abnormalities of the heart. In recent years, the application of echocardiography has extended to the critically ill, principally to patients following cardiac surgery, but more recently to include diagnosis and monitoring in the general intensive care unit. Although persistent/developing haemodynamic instability is considered a Class I indication for echocardiography [1], current resuscitation guidelines do not recommend its routine use except in exceptional circumstances [2]. The same guidelines do, however, include the use of other basic tools for assessment (including NIBP, ECG, oxygen saturation and $ETCO_2$ monitoring) to be performed in parallel to and as an extension of clinical examination while resuscitative efforts are commenced.

Where a primary electrical cause for cardiac arrest is found, definitive treatment is generally directed towards reversing the electrical abnormality (cardioversion/defibrillation/pacing). By contrast, where a nonelectrical cause of cardiac arrest is diagnosed [pulseless electrical activity (PEA)/asystole], practitioners are urged to exclude and reverse potentially treatable causes, as otherwise the outlook is poor [3]. Of the main potentially treatable underlying causes [4], only three may be definitively diagnosed at the bedside using existing standard monitoring/investigation (hypoxia, hypothermia, and hypo/hyperkalaemia). The remainder remain dependent on subjective clinical assessment (severe hypovolaemia, tamponade, pulmonary embolism, coronary thrombosis and tension pneumothorax), radiography (tension pneumothorax) or laboratory investigation (toxin-related arrest). Although the American Heart Association (AHA) continues to recommend the use of history and clinical examination to direct the management of

PEA/asystole, these may be unreliable, resulting in inappropriate use/denial of interventions [2,5]. Appropriately applied and interpreted echocardiography can diagnose/exclude many potentially reversible causes of cardiac arrest while guiding potentially life-saving therapeutic interventions. This review will discuss the potential role of echocardiography in nontraumatic cardiac arrest and the potential implications for education, training and research in this area.

## Echocardiography in the diagnosis of cardiac arrest

Detection of cardiac output during cardiac arrest is generally performed by palpating central pulses and/or noninvasive blood pressure measurement; however, both of these methods have been shown to be inaccurate [6–9]. Indeed, up to 45% of healthcare professionals are unable to accurately assess central pulses during cardiac arrest, potentially resulting in prolonged periods with no chest compression and premature cessation of resuscitation [7,9]. Although the intensive care unit patients frequently have arterial pressures transduced and therefore these inaccuracies may be irrelevant, this is not necessarily true in other non-ICU settings. Here, focused echocardiography has been shown to identify the presence or absence of cardiac kinetic motion during resuscitation [10–15] and identify potentially shockable rhythm disturbance where the ECG is unhelpful [16].

## Echocardiography and the underlying cause of cardiac arrest

The potential causes of cardiac arrest that can be diagnosed using echocardiography include tamponade, coronary artery disease, pulmonary embolism and hypovolaemia. Extension of the use of ultrasound beyond the heart to exclude pneumothorax and the cause of hypovolaemia is recommended by some, but is beyond the scope of this article [17,18].

## Hypovolaemia

Echocardiography is used routinely to assess left and right ventricular filling pressures, which when interpreted in conjunction with other physiological parameters of cardiac function can be used to determine the optimal filling status for the patient. Left ventricular end-diastolic volume has been shown to correlate well with blood loss in both animal and human studies and can reportedly detect small changes in intravascular volume [19]. In the critically ill, a number of parameters have been found to indicate severe hypovolaemia. These include the presence of a small, hyperkinetic left ventricle (in the presence of a normal right ventricle) with end-systolic cavity obliteration, a left ventricular end-diastolic area of less than 5.5 $cm^2/m^2$ body surface area and/or a small inferior vena cava (IVC) with inspiratory collapse, in spontaneously breathing patients, or small IVC at end expiration with variable respiratory change, in mechanically ventilated patients [20–25]. Hypovolaemia leading to cardiac arrest is likely to be severe and although there is debate in the literature regarding the sensitivity and specificity of echocardiographic features of hypovolaemia in the arrested state, the finding of a small, under filled left ventricle, with collapsed caval veins suggests the need for aggressive volume resuscitation and a search for the cause of hypovolaemia.

## Tamponade and pericardiocentesis

The physiological features of tamponade result from an increase in intrapericardial pressure causing an adverse effect on cardiac function due to impaired chamber filling. Development of tamponade relates, therefore, to intrapericardial pressure rather than volume, and thus the rate of accumulation. The traditional clinical features of Beck's triad (elevated jugular venous pressure, muffled heart sounds and hypotension) are often absent or difficult to diagnose in the periresuscitation state. Echocardiographic features routinely sought in order to determine the haemodynamic significance of a collection include the presence of a swinging heart, right ventricular diastolic collapse, right atrial diastolic collapse, pseudo-systolic anterior motion, an enlarged nonpulsatile vena cava (all parts of the respiratory cycle) and reciprocal changes in the size of cardiac chambers and transvalvular flows (vary with respiration) [26]. Demonstration of these echocardiographic features of tamponade has become (possibly erroneously) synonymous with the diagnosis of tamponade, which is a clinical diagnosis. In cardiac arrest, demonstration of a pericardial collection should lead to consideration for immediate drainage, as echocardiographic features of tamponade may not be present in certain circumstances (particularly following cardiac surgery).

The AHA and American Society of Echocardiography (ASE) taskforce recommend pericardiocentesis be performed under echocardiographic guidance (Class I), with success rates of greater than 90%, depending on the volume and location of the collection and operator experience. Major complications include cardiac perforation, pneumothorax, coronary perforation, trauma to abdominal organs and death [27,28]. The risk of complications falls significantly with echocardiography-guided pericardiocentesis (major 1.2%, minor 3.5%) [29–31]. In addition to guiding the optimal approach to drainage, introduction of a small amount of agitated saline can confirm placement of the needle in the pericardial space or misplacement in a cardiac chamber [32]. Indeed, echocardiography has been used routinely in some centres for over 30 years to guide pericardiocentesis with a view to reducing complications [27].

## Coronary artery thrombosis

Coronary artery disease is the major cause of cardiac arrest in the western world, either as a result of acute arrhythmia, severe ventricular dysfunction or a complication arising from prior myocardial infarction (MI). Echocardiography is used routinely in the diagnosis of MI/ischaemia, the evaluation of its complications, monitoring of therapeutic interventions and risk stratification. In cardiac arrest where there is ongoing cardiac activity, echocardiography may reveal regional wall motion abnormalities (RWMAs) related either to previous MI or new ischaemia [26]. Although RWMAs are not 100% sensitive or specific for coronary artery disease, in the context of cardiac arrest, these findings may alter both the cardiovascular support and therapeutic interventions undertaken (e.g. avoidance of drugs that increase myocardial oxygen demand, insertion of an intra-aortic balloon pump and rapid/immediate revascularization). Free wall rupture is documented in 0.8–6.2% of patients after MI [33] and frequently results in sudden death due to tamponade. Where the presentation is subacute, early diagnosis using echocardiography may be life saving [1]. Other complications of coronary artery disease (ventricular septal defect, mitral regurgitation, intracardiac thrombus, right ventricular infarction) resulting in cardiogenic shock are readily detectable using echocardiography, and where suspected, urgent echocardiography is indicated [1,34••].

## Pulmonary embolism

Pulmonary embolism resulting in cardiac arrest is likely to be massive, resulting from occlusion of more than two-thirds of the pulmonary vascular bed (Table 1). Echocardiography is recommended in current guidelines for investigation of suspected pulmonary embolism only in a patient too unstable to transfer for computerized tomography (CT) scanning [35•], the extreme of which is during cardiac arrest. Transthoracic echocardiography (TTE) findings of right ventricular dilatation in the absence of significant left-sided valve or ventricular disease or known pulmonary disease indicate a high probability of pulmonary embolism, with the diagnosis confirmed by the demonstration of thrombus in the right heart and/or pulmonary arteries [26,35•].

The sensitivity and specificity of transoesophageal echocardiography (TEE) in diagnosis of pulmonary embolism remains debated. In some studies, the presence of right ventricular hypokinesis identifies patients with at least 30% nonperfused lung who may benefit from thrombolysis, others have not found correlation between the extent of the perfusion abnormality and the degree of right ventricular dilatation/dysfunction; however, the degree of right ventricular dysfunction on TTE does correlate with mortality [1,26,35•,36–38].

## Echocardiography in the postcardiac arrest setting

Echocardiography is routinely used in the critical care environment in order to diagnose underlying cardiac pathology and monitor the effects (beneficial or otherwise) of therapeutic interventions. In the postcardiac arrest setting, echocardiography may be used to determine the optimal volaemic status, identify further complications related to the initial cause of cardiac arrest (e.g. recurrent/ongoing ischaemia) and monitor cardiac output. In addition, echocardiography can be used to guide the clinician in maximizing the cardiac output while minimizing any increase in myocardial oxygen demand – by optimizing filling status, heart rate and atrioventricular delay [26].

## Performance of advanced life support-conformed periresuscitation echocardiography

In the periarrest setting, a fully comprehensive TTE study is neither necessary nor relevant and excessive periods of time spent scanning and distraction of the team from performance of high-quality CPR is detrimental. Thus, rapid, accurate advanced life support (ALS)-compliant focused echocardiography as an extension to the clinical examination, with a view to rule in/rule out the potential causes of cardiac arrest, needs to be performed. Indeed, current ASE guidelines recommend that limited, focused TEE should be performed in case of intra-operative cardiac arrest [39]. The 10-s pulse check provides an opportunity where TTE may be performed by an experienced echocardiographer conversant with ALS guidelines.

Unfortunately, experienced echocardiographers are not a standard part of the cardiac arrest team and are unlikely to

**Table 1 Clinical features of pulmonary embolism**

| | Class I | Class II (moderate) | Class III (massive) | Class IV (fulminant) |
|---|---|---|---|---|
| Clinical | Dyspnoea chest pain | Tachypnoea tachycardia | Cyanosis syncope | PEA |
| Arterial BP | Normal | Normal | Low | Undetectable |
| mPAP (mmHg) | Normal | Normal | 25–30 | ±30 |
| $p_aO_2$ (mmHg) | Normal | >80 | <70 | <60 |
| %PA obstructed | <25 | 25–50 | >50 | <66 |

BP, blood pressure; mPAP, mean pulmonary artery pressure; PA, pulmonary artery; PEA, pulseless electrical activity.

become so. The question then arises as to whether it is possible to train members of the arrest team in focused echocardiography. Evidence has been accumulating in the literature over the last 10 years regarding the performance of focused echocardiography by nonexpert echo practitioners in the context of significant haemodynamic instability and cardiac arrest [40–42]. Indeed, focused ultrasound is now considered a routine part of ATLS in unstable or hypotensive patients after trauma, and in some centres, in the intensive care setting, novice echocardiographers perform and interpret studies on the critically ill as part of their routine care [17,43]. Novice practitioners have been shown to be able to be trained to perform and interpret focused studies, with an excellent correlation with studies performed by experienced practitioners and with no interruption of the resuscitation process [44,45]. Additional studies have been shown to reduce the number of potential differential diagnoses and the diagnostic accuracy of emergency room physicians in their initial assessment of patients with undifferentiated hypotension [46]. More recently, a number of ultrasound-based protocols have been devised in order to address the performance of focused ultrasound and echocardiography in the cardiac arrest/periarrest setting. Thus, there is evidence that a focused, time-limited study is adequate and that noncardiologists/nonexperts can be successfully trained to perform such studies [17,18,43,47•]. However, although studies exist that suggest focused echo can be performed in an ALS-compliant manner and that clinicians can potentially predict the outcome based on the echocardiographic findings [12,48,49], none have yet shown that the use of focused echocardiography improves outcome *per se*.

## Conclusion

Although the use of appropriately applied focused echocardiography in the periresuscitation setting is likely to improve patient care, it also provides many challenges, in particular relating to successful implementation, research and education.

### Research

The use of periresuscitation echocardiography provides huge potential for research into safety, utility and cost-effectiveness, as well as the optimal management of the cardiac arrest patient. To date, the ECG has been regarded as the gold standard in diagnosis of asystole or ventricular fibrillation; however, echocardiography may prove to be more accurate [16]. The diagnosis of electromechanical dissociation is no longer used in ALS algorithms, but echocardiography is able to demonstrate its existence, as opposed to simply profound hypotension with an impalpable pulse. The outcomes of these patient groups are different, and it may be that their management can be more tailored based on the echocardiographic findings. For example, the finding of coordinated cardiac activity confers a better outcome and should potentially be regarded as an indication to continue resuscitation efforts. Further, given the inaccuracy of palpation of the peripheral pulse, more graded use of inotropic agents may be required than are currently used where coordinated cardiac activity is detected. Finally, the routine use of echocardiography as a coordinated part of the ALS algorithm should be investigated, in both in-hospital and out-of-hospital arrests and with both physician and non-physician operators, perhaps using telemetry of images for expert review to determine whether it improves outcome. Introduction of lightweight, handheld echo machines provides important opportunities to extend research beyond the hospital setting: in assessing the prevalence of important echocardiographic findings in the critically ill patient some distance from hospital and in evaluating the role of interventions that could correct these before the patient reaches hospital (or trigger transfer direct to a specialist centre).

### Education and training

Periresuscitation echocardiography provides the only real-time bedside diagnostic tool that can diagnose some of the potentially reversible causes of cardiac arrest and can be regarded as analogous to pulse oximetry or ECG monitoring. Although the performance of periresuscitation echocardiography has been accepted by some bodies [50], internationally the method of training and number of scans required to demonstrate competency have not yet been agreed on [51••,52–54]. It is likely, however, that with progressive miniaturization of devices, improvement in image quality and the increased use of ultrasound as an extension to clinical examination in undergraduate medicine, echocardiography will become a standard part of our evaluation of the periarrest patient.

## References and recommended reading

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• of special interest
•• of outstanding interest
Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 278).


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