Review article: Clinical impact of non-cardiologist-performed transthoracic echocardiography in emergency medicine, intensive care medicine and anaesthesia

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Abstract

There is increased realisation of the emerging role of point-of-care transthoracic echocardiography (TTE) as ‘ultrasound-assisted examination’, given the low sensitivity of clinical examination for cardiovascular pathologies and the time-critical nature of these pathologies. There is evidence that point-of-care TTE provides higher accuracy in patient assessment and management, with potential prognostic impact by assessing the severity of cardiac dysfunction and response to treatment. Point-of-care TTE is increasingly used by non-cardiologists, as a diagnostic, screening or monitoring tool. The literature shows that TTE identifies new clinical findings, and conversely can accurately rule out clinically important pathologies. Recent reports have examined more advanced ultrasound devices and patients in the critical care settings of emergency medicine, intensive care and anaesthesia. The diagnostic capability of new portable devices is improving rapidly and outdating its predecessors, thereby improving confidence in echocardiography findings.

Key words: critical illness, emergency medical services, point-of-care system, transthoracic echocardiography.

Introduction

The first echocardiography machine was developed more than 50 years ago.1 Since then ultrasound technology has seen significant development, allowing echocardiographic examination of critically ill patients at the bedside by cardiologists and non-cardiologists. The ease of performing bedside studies has been significantly facilitated by smaller portable machines with high-quality imaging. It is sometimes referred to as ‘point-of-care’ transthoracic echocardiography (TTE) examination, which is often goal-focused – with the aim of answering specific clinical questions. Conceptually though, it might be considered as ‘ultrasound-assisted examination’ and the findings can be integrated into the clinical diagnosis and interpreted within the context of...
the examined patient. This might reduce the time to adjust management when compared with conventional referral for echocardiography by a third party.

Point-of-care TTE examination is not necessarily comprehensive and might not necessarily be a substitute for a complete study conducted in the echocardiography laboratory. TTE in the echocardiography laboratory allows a more detailed assessment and uses the full range of echocardiographic modalities, whereas point-of-care TTE is often conducted in time-critical fashion. Following patient stabilisation, point-of-care TTE can lead to a referral for a comprehensive TTE in the echo laboratory. There is evidence that routine use of a point-of-care TTE study in non-acute settings, such as general medicine and outpatient cardiology, might reduce the requirement for comprehensive TTE with potential cost and time savings.\(^2,3\)

Several prospective studies in the cardiology literature demonstrated the impact of point-of-care TTE conducted by cardiac sonographers and interpreted by cardiologists on critically ill patients. The change in diagnosis reported in intensive care patients ranged from 19\% to 59\%, and changes in management ranged from 34\% to 58\%.\(^4\) Comparable therapeutic changes were seen in 51\% of patients with shock (systolic blood pressure <100 mmHg) who underwent a point-of-care TTE examination in the ICU and CCU.\(^5\) In ED patients with predominantly chest pain and shortness of breath as presenting symptoms, point-of-care TTE examination by expert echocardiographers led to a change in diagnosis in 25\% and change in management in 37\% of examined patients. When no change occurred in the diagnosis, there was an increase in physicians’ confidence in their diagnosis and planned management.\(^6\) In an earlier study on patients presenting to the ED with chest pain and non-specific electrocardiographic changes, point-of-care TTE identified new cardiac abnormalities in 16\%, resulting in changes to management in 19\% of examined patients.\(^7\) Studies in patients with suspected acute coronary syndrome, non-diagnostic electrocardiography and normal first Troponine found that point-of-care TTE during chest pain had a negative predictive value ranging from 91\% to 100\%.\(^8,9\)

Rugolotto et al.\(^10\) demonstrated, in acute cardiac settings, a change in diagnosis in 19.1\%, and in therapy in 29.6\% of examined patients with an increase in the accuracy of clinical diagnosis of cardiac pathologies. They identified unexpected major pathologies, such as severe aortic stenosis or ventricular failure. The impact was higher for patients without a prior cardiac history or hospitalisation. Other studies demonstrated that point-of-care TTE performed by cardiologists led to alteration in 23\% of diagnostic work-up and 36\% to 50\% of patient management\(^11\) and resolved clinical questions about left ventricular function, valvular abnormality and pericardial effusion in 98\% of cases.\(^12\) Point-of-care TTE helped to identify unsuspected cardiac findings\(^13-15\) and reduced the failure to detect major clinical abnormalities from 43\% to 21\%.\(^16,17\)

The use of point-of-care TTE by non-cardiologists in emergency medicine, anaesthesia and intensive care has allowed better understanding of haemodynamic state and conditions, such as sepsis and acute cor pulmonale.\(^18-22\) This review will consider the clinical impact of point-of-care TTE when performed by non-cardiologists in intensive care medicine, emergency medicine and anaesthesia. It also reviews the literature addressing the accuracy of point-of-care TTE performed by non-cardiologists and the educational literature addressing the training requirements for point-of-care TTE.

**Methodology**

The literature search included Cochrane Library, Medline (1966–present), EMBASE (1988–present) and CINHAL (EBSCO, Google Scholar, PubMed and SCOPUS). The search terms used were echocardiography, transthoracic echocardiography in combination with the following terms: clinical competence, prospective studies, observational variation, cross-sectional studies, emergency medical services, stroke volume, critical illness, hypotension, complication, ultrasonography, ventricular dysfunction, sensitivity and specificity and point-of-care system. In addition, the bibliographies of relevant literature were searched.

One thousand, two hundred and thirty-six papers were screened. Seventy-four papers were identified as relevant and were included in this review. Only 17 papers fulfilled the inclusion criteria of being clinical randomised or prospective clinical studies, addressing the diagnostic and management impact of non-cardiologist-performed point-of-care TTE and involving ventricular, pericardial or valvular pathology.

Studies identified in this review have been classified into five major groups: (i) the impact of intensivist-performed point-of-care TTE; (ii) the impact of emergency physician-performed point-of-care TTE in the ED and prehospital settings; (iii) the impact of anaesthetist-performed point-of-care TTE; (iv) the accuracy of non-
cardiologist-performed point-of-care TTE; and (v) the training requirements for point-of-care TTE.

Impact of intensivist-performed point-of-care transthoracic echocardiography

A summary of studies where TTE was performed by intensive care physicians is shown in Table 1. In addition to its use as a monitoring tool, point-of-care TTE is used to identify the underlying causes of haemodynamic instability, respiratory distress, volume status and response to initiated therapy. The change in management resulting from TTE reported in the literature ranged from 16% to 51%.24,25,28

The diagnostic impact of point-of-care TTE is by identification of underlying valve pathologies and other cardiac pathologies, such as sepsis-related ventricular dysfunction and acute cor pulmonale. The therapeutic impact included initiation or alterations of inotrope, vasoactive agents, fluid therapy and pharmacological therapies. Point-of-care TTE facilitates optimisation of timing of surgical intervention and provides important prognostic information facilitating decision-making, such as limitation of treatment. Intensivists have also used point-of-care TTE successfully to predict cardiac related ventilator weaning failure by assessing ventricular function.29

Jensen et al.23 reported on the use of Focus Assessed Transthoracic Echo protocol (FATE) as a tool to monitor ICU patients (50% post-cardiac surgery). They performed 227 examinations; 66% of the patients were intubated and 97% had sufficient image quality. Images were 58.4% subcostal, 80% apical and 69% left parasternal views. The protocol added new information in 37.3%, helped in making a decision in 24.5% and provided supportive clinical information in 35.6% of patients.

Echocardiographic examination of the inferior vena cava (IVC) from the long axis subcostal view might point towards changes in cardiac output response to fluid therapy in the critically ill by assessing respiratory variation of the IVC diameter in intubated patients with sepsis. A 12% or greater variation between maximum and minimum diameter of IVC over a single respiratory cycle can predict an increase of cardiac output with a positive predictive value of 93% and negative predictive value of 92%.27

The role of TTE in intensive care has changed considerably over the past 20 years. Studies conducted in the 1990s on intubated patients in general intensive care settings predominantly used transoesophageal echocardiography, as TTE was considered suboptimal because of poor imaging and the lower ability of TTE to address clinical problems, such as cardiac vegetations, intra-atrial thrombi or masses, and aortic dissection. However, TTE was still accurate in detecting 100% of cases of pericardial effusion and in 77% of patients needing assessment of left ventricular systolic function.24,30 In the last 10 years the limitations in the use of TTE on intubated patients have declined with a reported failure to obtain interpretable images with TTE of only 2% to 4.5%.23,26

Impact of emergency physician-performed point-of-care transthoracic echocardiography in the ED and prehospital setting

The literature is limited in the setting of TTE performed by emergency physicians in the ED, and is summarised in Table 2. Mayron et al.36 were the first to report the impact of point-of-care two-dimensional TTE in trauma and non-traumatic unexplained hypotension in peri-arrest and arrested patients. TTE identified reversible causes of arrest in the critically ill, such as pulmonary embolism and cardiac tamponade, allowing early medical treatment and early transfer to the operating theatre for definitive surgical treatment.

The role of ultrasound in resuscitation is recognised and the incorporation of a focused TTE into advanced life support algorithm to identify underlying reversible causes in arrest patients has been suggested.37 In cardiac arrest patients with non-shockable rhythms of pulseless electrical activity or asystole, the TTE finding of no cardiac activity was associated with universal poor outcome.35,38 In the prehospital setting, Breikreutz et al.28 prospectively evaluated the effect of a focused echocardiography evaluation in life support (FEEL). The protocol was applied after routine clinical assessment and electrocardiography on 104 patients requiring peri-resuscitation care and 100 arrested patients undergoing cardiopulmonary resuscitation. The FEEL protocol led to a change in therapy in 89% of patients in the cardiopulmonary resuscitation group and 66% of patients in the peri-resuscitation group.

Jones et al.39 demonstrated in a randomised trial that early TTE increases the likelihood of detecting the correct diagnosis of non-traumatic undifferentiated hypotension from 50% to 80%. The reported outcomes of ED prospective studies assessing the impact of physician-performed TTE are heterogeneous (Table 2). In patients with cardiomegaly, TTE identified 60% of
## Table 1. Prospective observational studies performed in the ICU

<table>
<thead>
<tr>
<th>Study</th>
<th>Device</th>
<th>Cohort</th>
<th>Objectives</th>
<th>Indications for TTE</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jensen et al.23</td>
<td>Vivid 5 and Vivid 7 G.E. Vingmed, Horten, Norway</td>
<td>Intensivists examined 210 patients in a cardiac and non-cardiac ICU</td>
<td>Assess the role of echocardiography in haemodynamic monitoring</td>
<td>Lack of expected clinical progress</td>
<td>TTE added new information in 37.3%, helped in making a decision in 24.5% and provided supportive clinical information in 35.6% of patients</td>
</tr>
<tr>
<td>Vignon et al.24</td>
<td>Hewlett-Packard Sonos 500 or a Ving Med CFM 750</td>
<td>Intensivists examined 111 patients in two tertiary referral ICUs</td>
<td>Evaluate the ability of TTE to solve clinical problems</td>
<td>Suspected LV dysfunction, pulmonary hypertension, pericardial effusion and valvular assessment</td>
<td>Modification of treatment in 16% of patients after TTE. TTE solved 100% of pericardial effusion and 77.5% of other clinical problems</td>
</tr>
<tr>
<td>Orme et al.25</td>
<td>Acuson CV70 ultrasound system (Siemens Medical Solutions, Camberley, UK)</td>
<td>Intensivists and cardiologists examined 217 patients in a general ICU</td>
<td>Identify impact and percentage of change in the management</td>
<td>Ventricular function assessment</td>
<td>51.2% change in management. TTE yielded similar therapeutic impact to TOE. High percentage of cardiac abnormalities (44%). Unsuspected cardiac findings in 9% of patients</td>
</tr>
<tr>
<td>Marcelino et al.26</td>
<td>Not specified</td>
<td>Intensivists examined 208 hypotensive patients in a general ICU</td>
<td>Exclude severe cardiac dysfunction, Evaluate other non-severe cardiac alterations, Determine cardiac index, Analyse IVC size</td>
<td>Evaluate hypotensive patients who are not responding to fluid therapy in a 30 min period</td>
<td>44% of examined patients had cardiac abnormalities</td>
</tr>
<tr>
<td>Feissel et al.27</td>
<td>Not specified</td>
<td>An experienced intensivist conducted all studies on 39 intubated septic shock patients</td>
<td>Assess IVC diameter variation with respiration and responsiveness to fluid therapy</td>
<td>Identify fluid therapy responders and optimise fluid therapy</td>
<td>A 12% change in IVC diameter allowed differentiation between responders and non-responders to fluid therapy</td>
</tr>
<tr>
<td>Vignon et al.28</td>
<td>SonoHeart Elite, SonoSite Inc., Bothel, WA, USA and Sonos 5500 Philips Medical Systems, Andover, MA, USA</td>
<td>Three intensivists with level III echocardiography training examined 55 patients</td>
<td>Evaluate HCU device and assess the impact of both devices on diagnoses and management</td>
<td>Hypotension, Respiratory distress and failure, Chest trauma, Cardiac arrest, Chest pain, Systemic embolisation, Infective endocarditis</td>
<td>49% change in management with HCU and 51% change with standard TTE, 80% diagnostic accuracy HCU in comparison with 92% in standard TTE</td>
</tr>
</tbody>
</table>

HCU, hand-carried ultrasound; ICU, intensive care unit; IVC, inferior vena cava; LV, left ventricle; TOE, transoesophageal echocardiography; TTE, transthoracic echocardiography.
Table 2. Prospective observational studies performed in the ED

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>Jones et al.22</td>
<td>Shimadzu SDU-400 ultrasound system</td>
<td>Emergency physician and emergency medicine trainees examined 184 patients</td>
<td>Undifferentiated symptomatic and non-traumatic hypotension in ED patient</td>
<td>Determine the specificity of hyperdynamic LV for septic shock</td>
<td>Hyperdynamic LV has 94% specificity for septic shock</td>
</tr>
<tr>
<td>Blaivas 31</td>
<td>Not specified</td>
<td>Emergency physician conducted TTE on 103 patients</td>
<td>Patients with dyspnoea after appropriate clinical work-up</td>
<td>To evaluate the frequency of pericardial effusion in patient presenting with dyspnoea and no other explanation for shortness of breath</td>
<td>Accurately identified size of pericardial effusion and determined patient disposition</td>
</tr>
<tr>
<td>Liu et al.32</td>
<td>Optig™ (Agilent Technologies, Andover, MA, USA)</td>
<td>Emergency physicians with full cardiology training examined 100 patients</td>
<td>Patients presenting to the ED and found to have cardiomegaly after clinical and radiological evaluation</td>
<td>Evaluation of the effect of point-of-care TTE effect on diagnosis and management</td>
<td>60% reduction of missed cardiovascular abnormality after clinical examination</td>
</tr>
<tr>
<td>Tayal and Kline33</td>
<td>Shimadzu SDU-400</td>
<td>Emergency physicians examined 20 patients</td>
<td>PEA and near PEA cardiac arrest and blood pressure below 90 mmHg or patients with no palpable blood pressure but with palpable pulse</td>
<td>Assess the ability of emergency point-of-care TTE to assist with decision-making in patients with PEA and near PEA</td>
<td>Patients with no cardiac kinetic activity on echo did not respond to ACLS measures. 12 patients with kinetic cardiac motion, including seven with pericardial effusion, survived hospital discharge</td>
</tr>
<tr>
<td>Blaivas and Fox34</td>
<td>Aloka 2000. Aloka Inc., Tokyo, Japan</td>
<td>Emergency medicine physicians and trainees conducted echocardiography on 168 patients</td>
<td>Cardiac arrest patients arriving to the ED with ongoing CPR</td>
<td>To examine the role of point-of-care TTE in patients receiving CPR</td>
<td>Patients with no cardiac activity on TTE did not survive to leave the ED regardless of duration of down time</td>
</tr>
<tr>
<td>Salen et al.35</td>
<td>Not specified</td>
<td>Emergency physicians examined 70 patients</td>
<td>Cardiac arrest patients in non-shockable rhythms (PEA and asystole)</td>
<td>Identify the ability of point-of-care TTE to predict outcome</td>
<td>Patients with asystole on ECG lacked sonographic evidence of cardiac activity, whereas 36% of subject with PEA showed cardiac activity on echo</td>
</tr>
</tbody>
</table>

ACLS, advanced cardiac life support; CPR, cardiopulmonary resuscitation; ECG, electrocardiography; LV, left ventricle; PEA, pulseless electrical activity; TTE, transthoracic echocardiography.
missed findings after clinical evaluation. Portable device missed only 5% of major findings. 

Impact of anaesthetist-performed point-of-care transthoracic echocardiography

The use of point-of-care TTE by anaesthetists is an emerging change in clinical practice, where transoesophageal echocardiography has been the predominant modality used. Four studies have addressed the impact of anaesthetist-performed TTE in the perioperative settings of non-cardiac surgery. The reported change in management ranges from 43% to 82%. Common indications for TTE included assessment of clinically undifferentiated murmur, haemodynamic instability, ventricular function or exertional dyspnoea. Anaesthetist-performed point-of-care TTE led to new diagnoses predominantly for significant valvular pathology, ventricular dysfunction and other conditions, such as regional wall motion abnormality and significant pulmonary hypertension. The main impact was in the form of changes in anaesthetic technique, including cancellation of surgery, change in fluid and inotropic therapy and preoperative cardiology referral. Canty et al. reported 54% change in management in patients after a focused TTE in the preoperative clinic. In a recent study on patients scheduled for emergency non-cardiac surgery, new cardiac findings were identified in 67% of patients, leading to 44% change in management.

Accuracy of non-cardiologist-performed transthoracic echocardiography

The additional step of conducting point-of-care TTE after cardiovascular physical examination allows improvement in diagnostic accuracy even when the clinical examination was performed by cardiologists. Non-cardiologists have demonstrated high accuracy in the assessment of left ventricular function and presence of pericardial effusion in both adult and paediatric critical care patients using TTE, with high agreement (68% to 96%) when compared with expert cardiologists. Emergency physicians made the diagnosis of pericardial effusion in a timely fashion with a sensitivity of 96%, specificity of 98% and accuracy of 97.5%. Accuracy might be influenced by the quality of the equipment, condition investigated, patient habitus and operator experience. The accuracy of portable and hand-held devices has been evaluated in multiple settings and patient cohorts. Kobal et al. demonstrated the significant additional information and added value obtained from point-of-care echocardiography. The accuracy of the portable device depends on the processing power and echocardiographic modalities available. The lack of colour flow Doppler and spectral Doppler modalities in machines used in earlier studies meant that important clinical findings could be missed. Liu et al. compared portable echocardiography with no spectral Doppler modality to standard devices in 100 ED patients. Both types of devices were used by trained emergency physicians. The use of portable devices increased the diagnostic accuracy from 62% to 83%, but missed six pulmonary hypertension, three moderate mitral regurgitation and three left ventricular dysfunction cases.

Intensivists also compared hand-held devices with standard echocardiographic machines. In patients with respiratory failure, shock, chest trauma, suspected endocarditis and potential cardiac donors in a general intensive care, Vignon et al. found that hand-held devices were comparable with standard echocardiography devices for two-dimensional modality-dependent diagnoses, such as left ventricular systolic function, but missed diagnoses dependent on optimal colour Doppler and spectral Doppler features, such as elevated left ventricular pressure, valvular lesions and pulmonary hypertension. Similar findings were seen in surgical intensive care settings with very good agreements when left ventricular ejection fraction was examined. However, only a moderate interobserver agreement was seen for left ventricle filling assessment because of the subjective element in the evaluation of filling status.

The literature must be interpreted in relation to equipment development. Portable machines have seen dramatic improvements in processing power, transducer design, colour flow and spectral Doppler modalities and image quality, such that the difference in the present time between portable machines and cart-based machines is much less than in previous generations of ultrasound equipment. More recent studies found good agreement and comparable diagnostic accuracy between portable machines and cart-based machines in both the intensive care and echocardiography laboratory settings. Pocket-sized machines in expert hands, despite the lack of spectral Doppler modality, are highly reliable and valuable screening tools for structural heart disease and abdominal aortic aneurysms.
Training in point-of-care transthoracic echocardiography

Guidelines for basic and advanced training in critical care echocardiography and ultrasonography have been published. Similarly, basic and advanced competency criteria in critical care echocardiography and ultrasonography have been outlined. Several prospective observational education studies have attempted to identify training requirements for limited TTE but have adopted variable educational paradigms. Some studies were conducted on healthy volunteers, whereas other studies examined patients in the outpatient setting, ED or ICUs.

In studies that limited education to two-dimensional modality, TTE hands-on training ranged from 1 to 10 h, with the theory component ranging from 1 to 5 h. Studies that incorporated two-dimensional and colour flow had a relatively longer hands-on component of 20 h. In some programmes, training was spread over 1 to 3 weeks.

Investigators used different end-points but generally assessed the degree of agreement between expert echocardiographers and trainees after completing the training. Image acquisition was achieved in up to 94% of patients, and accuracy in interpretation of cardiac pathologies ranged from 82% to 93%. Common findings included good agreement between expert echocardiographers and trainees in the assessment of ventricular function, pericardial effusion and valve abnormalities. Imaging quality obtained by the trainees was poorer but improved with time and number of assessments. Trainees also became faster over time and 20 to 30 studies are required to achieve adequate quality in image acquisition. Common errors by trainees were a tendency to 'overcall' and to overestimate the severity of echocardiography abnormality, leading to a lower positive predictive value.

Conclusion

Advances in ultrasound technology, lower costs of machines and increasing evidence of the role point-of-care TTE have led to increasing use of TTE to complement clinical examination. In the studies reported, accuracy of interpretation of TTE is high and the impact on diagnosis and clinical decision-making is considerable. However, there are few studies examining patient outcome.

Although investigators in emergency medicine were among the first to report the role of point-of-care TTE in the critically ill, there are several questions that have remained unanswered in the field of non-cardiologist-performed point-of-care TTE. Future challenges include training the majority of critical care specialists to at least a basic level of proficiency and make point-of-care TTE part of daily clinical practice. Further research requires larger numbers of competent clinicians in critical care echocardiography and ultrasonography.

Competing interests

None declared.

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