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Concise Definitive Review: Focused Critical Care Echocardiography in the ICU

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Abstract

Objective—Portable ultrasound is now used routinely in many intensive care units (ICUs) for various clinical applications. Echocardiography performed by non-cardiologists, both transesophageal (TEE) and transthoracic (TTE), has evolved to broad applications in diagnosis, monitoring, and management of critically ill patients. This review provides a current update on Focused Critical Care Echocardiography (FCCE) for the management of critically ill patients.

Method—Source data were obtained from a PubMed search of the medical literature, including the PubMed “related articles” search methodology.

Summary and Conclusions—While studies demonstrating improved clinical outcomes for critically ill patients managed by FCCE are generally lacking, there is evidence to suggest that some intermediate outcomes are improved. Furthermore, non-cardiologists can learn FCCE and adequately interpret the information obtained. Non-cardiologists can also successfully incorporate FCCE into advanced cardiopulmonary life support (ACLS). Formal training and proctoring are important for safe application of FCCE in clinical practice. Further outcomes-based research is urgently needed to evaluate the efficacy of FCCE

Keywords

Echocardiography; monitoring; critical care

Echocardiography performed by non-cardiologists, both transesophageal (TEE) and transthoracic (TTE), has evolved from applications in cardiac anesthesia to broad applications in diagnosis, monitoring, and management of critically ill patients. This review

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Rationale for Critical Care Echocardiography

Physician knowledge of a critically ill patient's physiology is limited, as many relevant parameters are not apparent on physical examination.(1) Historically, pulmonary artery catheters (PACs) were used to characterize cardiovascular physiology(2) and dominated critical care (patient management guidelines) for decades. However, PACs utilization has significantly decreased amidst recognition that a) there were risks associated with their use, b) technical proficiency varied dramatically from center to center, c) the "static" parameters measured by the PAC poorly predicted fluid responsiveness,(3–6) and d) prospective studies showed no benefit from routine PAC use,(7–12) although a recent meta-analysis suggested benefit to preoperative PAC placement to improve post-operative outcomes in moderate to high-risk surgical patients.(13) The limits of traditional hemodynamic monitoring, particularly in the ICU, presented possibilities for not just a change in technology, but for a change in paradigm. The new paradigm in assessing acute cardiopulmonary physiology emphasizes the importance of integrated diagnostic information as well as insights relevant to patient-specific therapy. Echocardiography achieves these goals by enabling familiar and novel assessments of diagnosis and patient-tailored therapy, as emphasized in recent reviews of critical care echocardiography(14–17) and a *Critical Care Medicine* supplement on the topic.(18)

Comprehensive expertise in echocardiography requires substantial training to ensure quality and avoid significant risks of misinterpretation. Focused applications of echocardiography may allow for a lesser degree, albeit still formalized, of training than comprehensive echocardiography. Studies suggest that general critical care,(19–21) emergency medicine(22–24) and hospitalist(25) physicians can successfully acquire the skills necessary to perform and interpret FCCE.

FCCE is particularly useful in the diagnosis and management of circulatory and respiratory failure. Early studies suggested that FCCE commonly changed clinical management, although these studies emphasized settings where echocardiography was independently indicated (e.g., shock after cardiac surgery) and in some respects begged the question being posed.(19, 26–31) Despite a lack of gold standard evidence, there is reasonable consensus that FCCE provides diagnostic information unavailable from other modalities. A recent consensus statement confirmed that echocardiography is indicated in "hypotension or hemodynamic instability of uncertain or suspected cardiac etiology,"(32) the clinical setting in which FCCE is most commonly applied.

Focused critical care echocardiography – definition

Multiple subspecialist groups have declared interest in employing less-than-comprehensive echocardiographic exams, including neonatologists,(33) emergency physicians,(34) trauma surgeons,(35) and medical/surgical intensivists.(36) Various terms have been employed to designate such less-than-complete echocardiograms, including "focused," "limited," "point-of-care" and "targeted." In critical care settings, we advocate the term FCCE, which we

understand to incorporate both TTE and limited TEE. Implicit in these terms is the comparison to the standard, comprehensive echocardiogram performed by certified sonographers or cardiologists and interpreted by appropriately credentialed expert echocardiographers, as defined in consensus documents by academic societies.(32, 37–39) A complete echocardiogram provides all standard views from all standard windows and includes careful quantitative assessment of cardiac chambers and valves.

FCCE emphasizes diagnosis, evaluation and management of emergent problems as well as guidance of therapeutic interventions. One consensus document described “targeted” echocardiograms as “functional studies” used as “adjunct[s] in the clinical assessment of the hemodynamic status” of patients.(33) Another consensus document suggested that FCCE should be used to identify and treat pericardial tamponade, assess global ventricular systolic function, assess marked right ventricular impairment, volume responsiveness and confirm pacer wire placement.(34)

Protocols for FCCE (Table 1), generally emphasize the following core concepts(21, 40, 41):

The exam is performed by non-cardiologists to evaluate circulatory or respiratory failure.

The exam is time-sensitive and may be performed serially.

The exam investigates a limited number of possible diagnoses, e.g., tamponade, hypovolemic shock, severe ventricular dysfunction.

The exam may encompass multiple anatomic areas, including the abdomen, thorax and central veins

The exam does not replace a comprehensive echocardiographic exam

Technique

Sufficient evidence has accumulated to demonstrate that non-cardiologists can perform and interpret focused echocardiograms. Medical students can learn to use hand-held echocardiography devices reasonably quickly and improve their bedside diagnostic skills.(42) With minimal training, non-cardiologists can make estimates of left ventricular ejection fraction that correlate well with the gold standard.(43) They can also outperform, with echocardiography, the physical examination (for assessment of valvular dysfunction) of attending cardiologists.(44) Similar findings have been demonstrated for medical residents(45–47) and non-cardiologist medical attending physicians,(29, 48) though some concerns about accuracy remain.(49, 50)

Both TTE and TEE can be used by non-cardiologists caring for the critically ill patient. TEE provides superior image quality and the probe can be left in the esophagus during periods of dynamic resuscitation. However, widespread use of TEE is limited by the need for additional training, expense and logistics. In addition, TEE is more invasive than TTE and is, rarely, associated with complications, some of which may be significant.(27, 51, 52) TTE on the other hand, is non-invasive and, other than misdiagnosis, is practically risk-free. With modern equipment, TTE provides excellent image quality in 80–90% of critically ill

patients,(16, 30, 53–55) even with hand-held portable systems(45, 56–58) and is logistically simpler than TEE. Although some intensivists employ both modalities, most favor TTE in the evaluation of hemodynamic instability. The advent of portable, high quality and relatively low-cost TTE systems now makes it possible to use FCCE in most hospital or pre-hospital settings.

FCCE in Cardiopulmonary Resuscitation

The rationale for integration of FCCE in resuscitation is that non-arrhythmic cardiac arrest is generally fatal but may be treatable, particularly when due to tamponade, hypovolemic shock or pulmonary embolism. FCCE offers the opportunity to expedite the diagnosis and treatment of these etiologies or at least rapidly narrow the differential diagnosis. The integration of FCCE into acute cardiac life support (ACLS) has been supported by the development of the Focused Echocardiography in Emergency Life support (FEEL) protocol. (59, 60) Recognizing that FCCE in cardiopulmonary resuscitation has not yet been clearly demonstrated to improve outcome, FCCE must be performed in a way that does not cause interruptions in chest compressions, as such interruptions would likely have a deleterious effect on patient outcome. To prevent interruption in chest compressions, FEEL explicitly restricts echocardiographic exams to the pulse checks used in ACLS. In our experience subcostal or modified apical windows often allow imaging even during active chest compressions. The basic skills required for FEEL may be obtained with one day of formal training(59) and may also be applicable in pre-hospital settings.(61) However, more than one day of training is needed to master the skills of FEEL and related FCCE applications. Maintaining these skills require ongoing practice and training. Additionally, whether FCCE during cardiopulmonary resuscitation provides useful prognostic information is not certain, (62) although a large prospective study (REASON1) to address this question is ongoing.(63)

Despite the lack of rigorous outcome data, the 2010 European resuscitation guidelines recommend, “When available for use by trained clinicians, ultrasound may be of use in assisting with diagnosis and treatment of potentially reversible causes of cardiac arrest.”(64) The United Kingdom Resuscitation Council has recently responded to this recommendation by implementing a standardized training program in ACLS-compliant echo (FEEL-UK) [Dr. Susanna Price, personal communication]. Whether these changes will translate to improved outcome for patients experiencing cardiac arrest is not certain.

Clinical outcomes

Rigorous studies demonstrating improved outcomes for critically ill patients managed by FCCE are lacking. This, however, does not mean that there is no evidence to support clinical application of FCCE. In addition, the benefits of FCCE should be evaluated and interpreted in several complementary domains.

First, randomization may be unethical in settings where the benefits of FCCE are apparent without randomized study. Such situations include hemodynamic instability after cardiothoracic surgery (in which the risk of mediastinal/pericardial hematoma is high) or sudden hypotension in the coronary ICU (where mechanical complications(65–68) and cardiogenic shock(69, 70) are relatively common).

Conversely, there are situations in which randomization is clearly ethical. As part of an explicit protocol to manage circulatory or respiratory failure, FCCE has potential for benefit. Currently, the model for such care – “Early Goal-Directed Therapy” for severe sepsis and septic shock(71) – relies on measurements of central venous pressure (CVP) and caval oxygen saturation (ScvO₂). FCCE has considerable promise in such applications,(36, 54, 72–74) but given the current lack of high-quality evidence, we recommend that it be subjected to rigorous randomized, controlled trials. Early data from intraoperative and peri-operative settings suggest improved outcome with echo-guided hemodynamic management (including esophageal Doppler probes) in routine cardiac(75, 76) or major non-cardiac(77–81) surgery. These findings suggest that there may be similar benefit in FCCE-based management of conditions such as septic shock or ARDS complicated by shock.(82) These applications require additional randomized study in general ICU populations.

Third, while protocols to guide use of volume expansion, vasopressors and inotropes in patients with hypoperfusion are prime candidates for the integration of FCCE, outcome studies to support such practice are lacking. Although some evidence supports the use of FCCE in predicting response to volume expansion,(83–85) more research is needed in this field, especially with regard to spontaneously breathing patients; management algorithms to determine whether FCCE-guided hemodynamic management improves clinical outcomes need to be investigated in prospective, randomized, controlled trials. The same is true of protocols utilizing echocardiography to titrate positive pressure ventilation (e.g., by monitoring for worsening right ventricular failure)(86–90) or to guide diuresis in patients with respiratory failure, or after successful resuscitation of septic shock. Early data suggest a possible role for FCCE during spontaneous breathing trials and liberation from mechanical ventilation.(91, 92)

Fourth, it is not yet clear what role FCCE should play in the management of pulmonary embolism (PE). Patients with echocardiographic signs of right heart failure in acute PE have higher mortality and morbidity,(93) but there are not yet data demonstrating that FCCE improves outcome in PE,(94) nor is there persuasive evidence that FCCE adds prognostic information in normotensive patients.(95) Recent practice guidelines recommend that TTE is not indicated in the evaluation of suspected PE in order to establish diagnosis.(32) However, chest computed tomography might be relatively contraindicated or infeasible in certain critically ill patients (e.g. acute renal failure and/or shock). In these circumstances, FCCE may help by ruling out other causes of shock. Right heart strain and/or dilation may suggest but do not definitively rule in PE as the cause of shock. In spite of this reality, the European Society of Cardiology has suggested that echocardiography could be used to justify thrombolytics in patients presenting with shock and a high probability of PE when it is impossible to obtain definitive radiographic evidence of PE.(96) This strategy has been observed clinically,(97, 98) despite lack of evidence to support such practice with TTE. TEE, however, can diagnose large, central PEs with rare false positive results in experienced hands. The sensitivity with TEE in some series is, however, only 50%–80%.(99–101) In the absence of direct visualization of proximal PE, we do not generally recommend thrombolysis on the basis of TTE alone.(102, 103) If a decision is made to proceed on the basis of TTE findings alone, formal consultation with a highly experienced echocardiographer is recommended. Withholding thrombolytic therapy in a hypotensive

patient with known PE but no echocardiographic evidence of right heart failure seems reasonable but is not yet supported by evidence.

Fifth, FCCE may also be important in the management of traumatically injured patients. There is evidence for the utility of FCCE in this setting, and thus FCCE has been incorporated into the Focused Assessment with Sonography for Trauma (FAST) examination.(104) One study noted that FCCE in penetrating truncal trauma resulted in 11% of patients rapidly diagnosed with and treated for hemopericardium. This study had a false positive operation rate of 2.7% and had no proper control group.(105) One small, non-randomized comparison with historical controls suggested improved outcome for patients with penetrating cardiac injuries after the introduction of FCCE.(106) The potential for misdiagnosis is important, however: epicardial fat pads can easily be mistaken for pericardial effusions in trauma patients. In one study, the overall sensitivity was 73% and specificity was 44%.(107) In one study of penetrating truncal trauma in the ED, FCCE had a high (66%) false positive rate,(108) while another study of blunt and penetrating truncal trauma showed that ED physicians matched cardiologist over-reads 100% of the time in 137 patients (9 with pericardial effusions) but did not report clinical outcomes such as false-positive operation rate.(109) A large literature on applications of the FAST exam exists; in most of that literature it is difficult to separate FCCE from abdominal and pleural ultrasound in terms of clinical accuracy and utility.(110)

Sixth, FCCE may be useful for expedited diagnosis in hemodynamically unstable patients. A study of non-traumatized emergency department patients with shock of uncertain etiology compared treatment with immediate FCCE on presentation with a control group in which FCCE was performed after 15 minutes. The pre-specified intermediate outcome was positive — FCCE improved early diagnostic accuracy from 50% (delayed imaging) to 80% (immediate imaging).(111) The majority of patients had sepsis or dehydration, so the primary utility of early FCCE in this study may have been the exclusion of diagnoses like pericardial tamponade or severe ventricular systolic dysfunction. Given data supporting the initial diagnostic utility of FCCE, we recommend early FCCE in patients with circulatory and/or respiratory failure, especially in severe cases where FCCE has a high pre-test probability of providing relevant information.

Two caveats relevant to research validation should be emphasized. The first is that ultrasound is dependent on operator skill, so familiarity is required before FCCE can be subjected to credible study. Centers with adequate experience may thereby feel that they lack equipoise or control groups in their center may be “contaminated” (the control group is treated more like the intervention group than is intended). Second, many early studies of echocardiography in the ICU employed comprehensive echocardiography exams rather than FCCE. Whether such results can be generalized to FCCE is not certain. Adequate training and external certification of practitioners who perform FCCE are required to minimize risks to patients and increase the probability that findings from randomized studies can be generalized to other clinical environments. Experienced centers will need to acknowledge when clinical equipoise still exists in the broader critical care community, even when they feel that they lack equipoise in their own center, to allow rigorous randomized trials of FCCE.

Logistical Considerations

Beyond the clinical utility of FCCE, practitioners interested in applying FCCE clinically must confront certain logistical considerations.

Equipment

While equipment has improved in quality, the current array of options may initially be overwhelming. We recommend local trials of various machines and vendors before final selection and emphasize the importance of secure storage and/or tracking, as these devices are expensive, highly mobile and vulnerable to theft.

Image archiving

For clinical, billing, teaching and medico-legal reasons, FCCEs should be permanently recorded. Intensivists must make explicit plans for image archiving, whether within the main echocardiography laboratory, the hospital's general radiology system or a local storage system. Local policies should be followed regarding the integration of images and written reports into the medical record.

Training and education

While human cognitive biases make it easy for practitioners to feel that "seeing is believing" or they are "extending the physical examination" with ultrasound, we emphasize the real risks of patient harm from misdiagnosis and misinterpretation of ultrasound images. Formal training and mentored/proctored review of images is mandatory with FCCE. Despite logistical barriers,(112) possible curricula are under development(113, 114) and guidelines for training and competency have been published.(115–117) Training should be combined with actual experience performing proctored FCCE examinations. Based on experience from cardiology and cardiac anesthesiology, at least 50 supervised studies are required before one can function independently, even for straightforward cases.(114, 118, 119)

Certification and Accreditation

European bodies are moving toward establishing a certification process for FCCE. Development of a similar process in the USA is **urgently** needed. Accreditation and privileging are managed at the hospital level and are also in evolution. Given the complexity of FCCE, as national certification becomes available such certification should form the basis for hospital-based credentialing in FCCE.

Quality Assurance

As with formal echocardiography, acquisition and interpretation of FCCE are clinical skills that require continuing education, oversight and quality assurance. All groups employing FCCE should have formal methods for review of echocardiograms performed and for quality assurance of image acquisition and interpretation. Monthly conferences may be an efficient way to incorporate quality assurance, combining didactic lectures and case review. More frequent consultations among experienced readers may also be of benefit.

Summary

Critical care is entering an important phase in identifying and managing cardiorespiratory pathophysiology through the use of bedside ultrasound **by clinicians**. As bedside ultrasound modalities, particularly FCCE, become more available, it will be important to perform rigorous studies of clinical outcomes. Careful training, certification, and quality assurance are mandatory to avoid complications from FCCE, which generally relate to misdiagnosis rather than procedural complications per se. Careful attention to detail and rigor will be important to make the transition to applied critical care ultrasound as safe as possible for patients.

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Table 1

Proposed Focused Critical Care Echocardiography protocols

CCE protocol	FATE(20)	BLEEP(38)	FEEL (59)	BEAT(33)
Clinical Setting	General Critical Care	Emergency Department	Cardiac Arrest	Trauma
Windows/views				
Subcostal long axis view	X	X	X	X
Parasternal short and long axis views	X	X		X
Apical 4- & 5-chamber views	X		X	X
Assessments				
Volume status by mitral inflow				X
Volume status by IVC diameter & collapsibility		X		X
Pericardial effusion	X		X	X
LV function	X	X	X	X
RV function/dilation	X		X	X
Lung ultrasound	X			

CCE: Critical Care Echocardiography; FATE: Focused Assessment with Transthoracic Echocardiography; BLEEP: Bedside Limited Echocardiography by Emergency Physicians; BEAT: Bedside Echocardiographic Assessment in Trauma/Critical Care; FEEL, Focused Echocardiographic Examination in Life Support (also known as FEER: Focused Echocardiographic Examination in Resuscitation); IVC: inferior vena cava; LV: left ventricle; EF: ejection fraction; SV: stroke volume; RV: right ventricle.

Table 2

Comparison between Transesophageal (TEE) and Transthoracic (TTE) echocardiography.

	TEE	TTE
Image quality	Best	Variable. Generally lower than TEE.
Use in chest trauma	Best	Difficult. Subcostal view may be only available window.
Use in cardiac arrest	Limited due to accessibility on floors and pre-hospital settings.	Highly relevant. Image quality varies. Chest compressions must not be interrupted.
Accessibility	Generally restricted to perioperative period and selected ICUs/EDs.	Can be used practically everywhere.
Cost	Expensive. Requires significant maintenance.	Lower purchasing cost. Minimal maintenance.
Logistics	Requires comprehensive disinfection process, which adds to cost and complexity of utilization.	Does not require comprehensive disinfection process. Rapid turnover between patients.
Safety	Moderately invasive procedure. Associated (rarely) with minor and major complications.	No significant direct procedural risks.
Serial examination	Continuous imaging and hemodynamic monitoring once TEE probe is placed.	Intermittent, depending on image quality.

Table 3

Various critical conditions and their associated ultrasound findings

Condition	Echocardiographic findings
Severe hypovolemia/hypovolemic shock	Small left ventricular end-diastolic and end-systolic area Small, collapsible IVC LV cavity obliteration (“kissing” papillary muscles)
Tamponade	Pericardial effusion AND Chamber collapse RA/LA collapse in systole RV/LV collapse in diastole OR Variability in mitral (>25%) or tricuspid (>40%) inflow velocities
Pulmonary embolism	Direct signs: Clot in transit Clot in main pulmonary artery (seen primarily on TEE) Indirect signs: Dilated right ventricle Impaired RV free wall function, with or without intact apical function Systolic septal flattening (“D shape” sign)
Cardiogenic shock	Left ventricular failure: Global: Severely diminished contraction of all left ventricular walls Focal: hypokinesis (decreased contraction) or akinesis (no contraction) of certain LV segments Right ventricular failure: Decreased RV contraction in longitudinal aspect; decreased movement of tricuspid valve toward apex