Chapter 13
Focused Cardiac Ultrasound in the CT ICU: Helpful or Just Another Toy?

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Introduction

Cardiac imaging in the CTICU (cardiothoracic intensive care unit) is an essential tool in the pre- and postoperative management of patients. The critical nature and complex instrumentation of these patients makes the ability to perform cardiac imaging at the bedside paramount. While plain radiography is commonly used to assess endotracheal tube and line position as well as the lung fields, it is of little help in assessing cardiovascular structure and hemodynamics. Echocardiography is the mainstay for cardiac imaging in the CTICU as the equipment is readily brought to the bedside and results are available in real time with no need for advanced image processing or image display on a dedicated workstation.

While echocardiography is an indispensible tool in the evaluation of critically ill CTICU patients, comprehensive examinations performed by a sonographer and interpreted by a cardiologist are not typically available 24/7. In addition, at times patients may need urgent or frequent serial evaluation, which are difficult for echocardiography labs to address quickly and/or frequently enough. Miniaturized ultrasound platforms, which are easier to operate and substantially smaller in size and lower in cost, have become available in the last decade. This has lead to the concept of focused cardiac ultrasound (FCU) examination. **FCU is an examination of the cardiovascular system using ultrasound by a non-cardiologist to identify a defined list of diagnoses in specific clinical settings.** These FCU findings when used in conjunction with other bedside measures, such as physical exam and

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monitoring devices, allow formulation of a diagnostic impression and guide appropriate triage and management. This chapter will address the use of FCU in critically ill patients, with a focus on the CTICU where data is available.

Search Strategy

A literature search of English language publications in Medline from 2007 to 2017 was used to identify published data on FCU use in the ICU/CTICU setting (Table 13.1). A 10-year span was selected (rather than longer) because this technology has been rapidly evolving. Terms used for FCU were: "ultraportable echocardiography", "focused cardiovascular ultrasound", "focused transthoracic echocardiography", "focused echocardiography", "focused cardiac ultrasound", "point of care transthoracic echocardiography", "point of care echocardiography", "point of care cardiac ultrasound", "hand-held echocardiography", "hand-held cardiac ultrasound", "hand-held ultrasound", "pocket echocardiography", "pocket-sized transthoracic echocardiography", "pocket-sized echocardiography", "pocket-size echocardiography", "pocket-size cardiac ultrasound", "pocket ultrasound", "hand-carried echocardiography", "hand-carried cardiac ultrasound", "hand-carried ultrasound", "hand-carried ultrasonography", "point of care ultrasound", "cardiovascular limited ultrasound examination", "bedside ultrasonography", "bedside ultrasound", "bedside echocardiography", "goal-directed transthoracic echocardiography", "bedside cardiac ultrasound". FCU search terms were combined with terms for CTICU: "cardiac surgery", "thoracic surgery", "cardiothoracic surgery", "critical care", "critically ill patients", "surgical icu", "surgical intensive care", "intensive care unit", "intensivist".

Papers that focused primarily on the following topics were excluded for further review in this chapter: pre-operative assessment (n = 3), trauma (n = 1), pediatric critical care (n = 5), case reports (n = 2), or imaging by medical students or nurses (n = 5). Several papers were not pertinent including non-cardiac applications (n = 6), non-ICU setting (n = 2) or multi-organ point of care ultrasound in which the cardiac results are not reported separately (n = 4). Of the remaining 69, a remarkable number were review articles or opinion/editorials (n = 30), which unfortunately speaks to the plethora of opinion on this topic rather than critical evaluation. This chapter is not intended to review the use of bedside ultrasound in non-cardiac thoracic applications (lung) or ultrasound procedural guidance.

Table 13.1 PICO table of focused cardiac ultrasound in the ICU setting

Patients	Intervention	Comparator	Outcomes
Patients being treated in an ICU setting	Focused cardiac ultrasound	Usual care and/or comprehensive echocardiography	Diagnostic accuracy Management change Patient outcome

Results

Confounding Factors in the Literature: Setting/Personnel/Equipment

Only two studies have specifically studied use of FCU in the CTICU setting and in neither of these was the imaging done by a cardiovascular surgeon or resident [1, 2]. The remainder of the papers reviewed were performed in a variety of ICU settings (surgical, medical, and unspecified ICU). It is important to restrict this review to studies where FCU was performed in the ICU setting, as ICU patients are the most difficult patients to image. They frequently are ventilated, have bandages restricting access to the chest wall and are difficult to position in an optimal left lateral decubitus position. Providers with limited experience in cardiac ultrasound will have the most difficultly obtaining useable images in these patients. Accuracy and feasibility where FCU is performed on non-ICU inpatients, outpatients or in the emergency room setting simple don't apply to the ICU.

Assessing the cardiac status at the bedside of critically ill patients after hours or after a change in clinical status is certainly a common scenario for physicians who practice in an ICU setting. While one could argue that cardiac surgical trainees would pickup FCU rapidly given their familiarity with echocardiography and cardiovascular anatomy/pathology, there is simply no significant literature to demonstrate proven clinical value of this strategy. The majority of FCU ICU use published involves imaging by an intensivist, emergency medicine physician or anesthesiologist. A critical look at the value of FCU in the ICU requires understanding the training level of the physician performing and interpreting the images. The results from studies in which the images are acquired or interpreted by providers who have completed level II training in echocardiography or a yearlong ultrasound fellowship simply can't be applied to physicians who have received FCU training. For this reason several studies that were identified in the original search were omitted from further discussion [1–9]. The concept behind FCU is getting trainees or practicing physicians enough training to become proficient in a limited number of high yield cardiac ultrasound views that require limited training and can be performed quickly (Table 13.2).

The final confounder when looking at the FCU CTICU use literature is the equipment used. Ultrasound platforms for cardiac imaging can be broadly characterized into four groups: (1) full functionality platforms, (2) small ultrasound platforms, (3) hand-carried platforms, (4) pocket devices. The size, expense, functionality and

Table 13.2 Key features of an FCU examination in the CTICU

Performed at point of care/bedside
Adjunct (not replacement) to physical examination
Problem/symptom directed
Simplified, targeted imaging protocol
Real time interpretation of imaging
Qualitative over quantitative interpretation
Actionable results for clinical decision making

image quality of these instruments vary substantially. FCU users typically prefer smaller devices, as their portability and ease of use make them well suited for the ICU environment. The larger devices can be used, but increase expense and add functionalities that a provider who had limited FCU training can't take advantage of or may attempt to use without the appropriate training risking erroneous assessments. Unfortunately there is no standardization of terminology in the field. A study that advocates the value of "bedside ultrasound in the ICU" could have been performed by a level II trained echocardiographer on a full platform device or by an FCU user with 6 hours of training on a pocket sized platform. While both have valid data, their applicability is markedly different.

Protocols

For cardiac imaging in the CTICU, a limited number of views requires less training to master and should be adequate to assess the typical focused questions that arise [10, 11]. Because some views may be limited in a specific patient due to surgical wounds and bandages, familiarity with the subcostal, parasternal and apical windows is reasonable. Providers should not perform any view without being competent in acquisition and interpretation of that view. The parasternal short and long axis views are easier to master than apical or subcostal views [12–14]. Parasternal landmarks are more reliable, and these views consistently provide more interpretable images than apical views. [14, 15] Importantly in the ICU, parasternal views and subcostal views are less dependent on patient positioning and can be performed in a supine, ventilated patient.

FCU Diagnosis

There are a multitude of cardiac diagnoses that can be made using cardiac ultrasound in hands of providers without formal echocardiographic or dedicated ultrasound fellowship training. The FCU user in the CTICU should seek to become proficient in identifying abnormalities that: (1) Are pertinent to their scope of practice in the CTICU. (2) Are within their image acquisition and image interpretation expertise. (3) Have high value when used in combination with other bedside data to direct patient management. (4) Can be acquired quickly at the bedside. (5) Can be obtained in critically ill, supine, ventilated, bandaged and instrumented patients. (6) Have evidence-based data supporting accurate diagnosis by physicians with limited training in cardiac ultrasound.

An international, multispecialty group developed a consensus document for appropriate specific diagnostic targets for an FCU examination (Table 13.3) [11]. These included: LV dimensions and systolic function, RV size and systolic function, volume status, pericardial effusion/basic signs of tamponade and gross valvular abnormalities. The use of Doppler techniques in FCU, was not felt to be in scope by

Table 13.3 Evidence-based targets for an FCU examination

Target	Assessment	Level of evidence
LV systolic function	Normal/reduced/severely reduced	++++
LV size	Normal/enlarged	++
LVH	Normal/mild/marked	++
RV size	Normal/enlarged	+++
LA size	Normal/enlarged	++
Pericardial effusion	Absent/present/large	++++
IVC size/collapse	Small/collapsible Large/non collapsible	+++
Gross structural valve abnormalities	Abnormal	++
Large intracardiac masses	Abnormal	++
Aortic dissection	Not appropriate for users with FCU experience	
Vegetation		
Wall motion		
Intracardiac thrombus		
Congenital heart disease		

this consensus panel [11]. Although the ability to detect abnormalities at the bedside with FCU is lower than a comprehensive echocardiogram, FCU allows detection of cardiac pathology more accurately than traditional bedside physical examination assessment [16]. This is particularly true in the typical CTICU patient who is ventilated, immobile and instrumented in whom cardiac physical examination is often very limited.

Clinical Use

FCU is not just to detect disease, but should impact clinical decision-making. However, most studies have focused on evaluating FCU accuracy to detect specific abnormalities and have not addressed the added clinical value of FCU. There are limited data on the use of FCU in the ICU to affect medical decision-making, and even fewer studies addressing FCU use on patient outcome. Unfortunately, some of the studies used to justify the value of FCU in critically ill patients have not simulated real-life FCU use as the images were acquired or interpreted by providers with at least level II echocardiographic training [3, 5] or evaluated the value of comprehensive echocardiography in the ICU [17–20].

Manasia and colleagues did test the value of FCU guided management in the SICU in a 2005 paper [21]. They showed that intensivists with limited ultrasound training (10 h total didactic and hands-on) who performed a goal-directed ultrasound examination provided new information and changed management in over one-third patients and useful information (without immediate management change) in nearly one-half of patients. Killu reported on their experience with a point of care ultrasound program in three surgical ICU fellows whose training included 30 h of didactic and 25–50 examinations in several areas of diagnostic focus including lung and pleura, abdominal, procedural guidance and FCU/hemodynamics. The authors reported new diagnoses were frequently made (65%) as were changes in patient management (37%), although the contribution from FCU is not individually delineated [22].

In the absence of more studies addressing impact on patient care, the diagnostic ability of FCU in the ICU can be reviewed (Table 13.4). Providers without ultra-

Table 13.4 Useof FCU in the ICU for diagnosis and patient management

Author	Setting	Patients	Ultrasound targets	Comparison	Results	Quality evidence
Carr (2007) [29]	SICU	70	LVF/LVS IVC	Expert clinical	65–75% Concordance in assessment of hypovolemia	Low
Vignon (2007) [23]	MICU	61	LVF/LVE RVE/PE	TTE	Good agreement (kappa) LVF 0.76; LVE 0.66; RVE 0.71; PE 0.68	Low
Gunst (2008) [26]	SICU	22	LVF/LVE RVF/RVE PE/IVC	PA Catheter	“Significant correlation” with CI and CVP	Low
Mark (2009) [28]	SICU	80	Visual LVF	TTE	Mean bias −3.4 for LV EF	Low
Melamed (2009) [27]	MICU	44	LVF	TTE	82% correct classification	Low
Stawicki (2009) [35]	SICU	124	IVC	RAP	Correlation with invasive pressure at high and low RAP	Low
Vignon (2011) [30]	MICU/ SICU	201	LVF; LVE; RVE; PE; IVC;	TTE	Agreement (kappa) for LVF (0.84); LVE (0.90); RVE (0.76); IVC (0.79)	Moderate
Prekker (2013) [36]	MICU	65	IVC	Predict RAP >10	85% sensitivity	Low
Hulett (2014) [24]	MICU	*	LVF; RVF; PE; IVC	Assessment tool	Knowledge 58–86%; Acquisition skill 0–79%	Moderate
See (2014) [25]	MICU	343	LVF; LVE; RVE; PE; IVC;	Expert review FCU images	Progressive improvement from 10–20 to 30–>30 scans for LVF; RVF; PE; IVC	Moderate
Townsend (2016) [13]	SICU	390	LVF/RVE; PE; IVC	Expert review of FCU images	85% competency; LVF; RVE; IVC	Moderate

Abbreviations: SICU Surgical intensive care unit, *MICU* medical intensive care unit, *LVF* left ventricular function, *LVE* left ventricular enlargement, *RVF* right ventricular function, *RVE* RV enlargement, *IVC* inferior vena cava, *PE* pericardial effusion sound experience can learn to identify the presence or absence of **pericardial effusion** in ICU patients after brief training [7, 23–25]. As pericardial effusion is one of the simpler pathologies to detect, diagnostic accuracy has even been shown with pocket-sized devices in the ICU [7]. FCU has been shown to improve bedside assessment of LV systolic function [7, 13, 23–30]. Physicians who have had proctored hands-on FCU training can readily distinguish CHF patients with normal versus reduced LV systolic function [31, 32]. It is clear that FCU is superior to physical examination, ECG, chest radiograph, and blood chemistries for detection of **LV systolic dysfunction** in patients with ADHF [31]. FCU may also be used to identify findings suggestive of **pulmonary embolism** (right ventricular enlargement) in ICU patients [13, 23–25, 30].

Identification of **volume depletion** in a hypotensive patient or **volume excess** in a dyspneic patient can facilitate diagnosis and treatment. For patients in the CTICU, the JVP is difficult to assess as patients are supine and often have neck instrumentation. In non-ICU patients, FCU assessment of the inferior vena cava (IVC) is both more feasible and accurate than physical exam to detect elevated central venous pressure [33]. ICU FCU of the IVC correlates with central venous pressure and can assist in management [4, 13, 24, 25, 29, 30, 34–36]. However there are many confounding issues in CTICU patients that lower the value of ultrasound appraisal of the IVC as a measure of volume status including mechanical ventilation, significant tricuspid regurgitation and right heart failure [2].

Training

Several studies have demonstrated acceptable accuracy of FCU in the MICU and SICU setting [13, 23–25, 27–30, 35–38]. However, few of these studies have used surgical providers performing FCU [13, 21, 22, 34]. Training protocols differ with respect to ultrasound device, hours of didactic, duration of training, imaging protocol, number of proctored studies, use of simulation and clinical setting (Table 13.5). A structured training program is the best approach to equip providers with the necessary knowledge and technical skills to perform FCU [39, 40].

Although there is general agreement that proficiency in FCU be determined by competency-based assessment before it is used by a clinician for clinical decision-making, no validated tools exist to determine competency in FCU [11]. There is general agreement that a number of supervised and unsupervised studies be logged before a competency assessment is performed [11, 39, 40]. Focused cardiac ultrasound training should include three core components: didactic education, hands-on imaging practice, and image interpretation/review experience [39, 40]. Simulation and imaging normal subjects can be used to teach basics [13, 37, 41, 42]. However, bedside imaging in the ICU is invaluable experience and acquisition skill seems to increase with number of supervised studies performed [25, 40, 43]. Review of additional cases and images are essential because the variety of pathology experienced during hands-on training does not demonstrate all pathologies and normal variants seen in clinical practice.

Table 13.5 Training protocols for ICU FCU

	Specialty	Hours didactic	Proctored imaging	Studies required	Simulation	Views
Carr [29]	CC/ER	3	Y	25	N	SC; PLAX; PSAX; AP4C
Vignon [23]	CC	3	Y	5 h	N	PLAX; PSAX; SC; AP4C
Gunst [26]	CC/ Surgery	"2-day course"	*	*	N	PLAX; PSAX; SC; AP4C
Mark [28]	ER/CC	3	Y	25	N	SC; PLAX; PSAX; AP4C
Melamed [27]	CC	2	Y	4 h	N	PLAX; PSAX; SC; AP4C
Stawicki [35]	ER/CC	3	Y	25	N	IVC
Vignon [30]	CC	6	Y	6 h	N	PLAX; PSAX; SC; AP4C
Prekker [36]	CC/ER	2	Y	5	N	SC
Beraud [37]	CC	8	Y	25 ± 7	Y	PLAX; PSAX; SC; AP4C
Hulett [24]	CC	2	Y	2 h	N	PLAX; PSAX; SC; AP4C
See [25]	CC	10 (self-directed)	Y	5 (proctored); 40 total median;	N	PLAX; PSAX; SC; AP4C
Townsend [13]	Surgery	3	N	20	Y	SC; PLAX; PSAX; AP4C

Abbreviations: CC critical care, *ER* emergency medicine, *PLAX* parasternal long-axis, *PSAX* parasternal short-axis, *AP4C* apical four-chamber, *IVC* inferior vena cava

A systematic review of critical care ultrasound training studies concluded that initial focus should be on a basic qualitative approach for the assessment of global function and assessment of IVC collapsibility. The mode of education seemed most efficient when a hybrid method was used incorporating both web-based and didactic learning sessions and learning on both simulated and real patients was suggested with a minimum of 30 independent studies [40].

Recommendations Based on Data

The value of comprehensive echocardiography or cardiac ultrasound performed by providers with level II echocardiographic training or completion of an ultrasound fellowship is clear, but not pertinent to a CTICU provider who has completed only FCU training. Providers with limited training in cardiac ultrasound can reliable identify several cardiac abnormalities in ICU patients including LV systolic dysfunction, pericardial fluid, RV enlargement and IVC size and collapsibility using FCU, although published experience specifically in the CTICU is severely limited. While the ability to recognize a narrow list of cardiac diagnoses with FCU is established, there is very limited data demonstrating how FCU users can alter patient diagnosis and management plan in the CTICU. Training of CTICU providers should be formalized and include didactic, hands-on imaging and case review. Limiting the protocols to specific views both reduces the duration of training and shortens the duration of the bedside FCU examination. The highest yield views appear to be the parasternal long and short-axis views and the subcostal window. These are the views most reliably performed by novice examiners. There is good evidence that adequate clinical accuracy can be achieved with supervised imaging of 25–40 examinations.

Recommendation Summary

- Providers with limited training in cardiac ultrasound can reliable identify several cardiac abnormalities in ICU patients including LV systolic dysfunction, pericardial fluid, RV enlargement and IVC size and collapsibility using FCU (quality of evidence low, strength of recommendation weak).
- Training of CTICU providers should be formalized and include didactic, hands-on imaging and case review (quality of evidence moderate, strength of recommendation strong).

Personal Recommendations

FCU is a valuable tool at the bedside for the evaluation of patients on the intensive care unit. The key issues for successful implementation from my experience training hundreds or residents/students are:

– Formalized training needs to include didactic, but this can be performed independently.
– Formalized training needs to include proctored imaging. Performing only independent studies, while valuable to build volume is not sufficient. The value of having an experienced imager provide "tips" cannot be underestimated.
– Training that involves only simulation or performing studies on normal volunteers at a course are not adequate. While useful to learn basic views and techniques, these do not prepare providers to image in the ICU.
– Training must include case reviews. Proctored and independent imaging may not provide the breadth of clinical diagnoses the provider should be able to recognize. These can be tailored to specific subspecialties.

- Providers must stick to their skill set and scope of practice. Making diagnoses that are subtle or require more experience than the provider has can lead to clinical errors.
- Significant abnormalities should have formal echocardiographic studies ordered.
- FCU images used for clinical decision-making (rather than training only) should be stored and available for clinical review and quality assurance.

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