GUIDELINES AND STANDARDS

Recommendations for Cardiac Point-of-Care Ultrasound in Children: A Report from the American Society of Echocardiography*

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Cardiac point-of-care ultrasound has the potential to improve patient care, but its application to children requires consideration of anatomic and physiologic differences from adult populations, and corresponding technical aspects of performance. This document is the product of an American Society of Echocardiography task force composed of representatives from pediatric cardiology, pediatric critical care medicine, pediatric emergency medicine, pediatric anesthesiology, and others, assembled to provide expert guidance. This diverse group aimed to identify common considerations across disciplines to guide evolution of indications, and to identify common requirements and infrastructure necessary for optimal performance, training, and quality assurance in the practice of cardiac point-of-care ultrasound in children. The recommendations presented are intended to facilitate collaboration among subspecialties and with pediatric echocardiography laboratories by identifying key considerations regarding (1) indications, (2) imaging recommendations, (3) training and competency assessment, and (4) quality assurance.

Keywords: Point-of-care ultrasound, Pediatrics

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PURPOSE OF THIS DOCUMENT

Ultrasound is a powerful tool for evaluating cardiac structures and function. Technological advances and education have led to widespread bedside use of point-of-care ultrasound (POCUS) by practitioners from a variety of disciplines and subspecialties. One of the goals of the American Society of Echocardiography (ASE) is to provide education and guidance in cardiac imaging to practitioners across a range of diverse clinical and experiential backgrounds.

Two prior ASE task forces addressed the use of cardiac POCUS in adults, resulting in the development of educational modules (available on the ASE website[1]) and published recommendations for echocardiography laboratories participating in training.[2] These prior task forces specifically excluded children because of unique considerations within this population. First, practice patterns differ, with relatively delayed clinical use of pediatric cardiac POCUS. Cardiac

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Abbreviations

ASE = American Society of Echocardiography

CHD = Congenital heart disease

IVC = Inferior vena cava

POCUS = Point-of-care ultrasound

RV = Right ventricular

TTE = Transthoracic echocardiography

POCUS is an American College of Graduate Medical Education–required skill in adult critical care and emergency medicine training,[3,4] with established certification processes for critical care physicians and hospitalists.[5] In contrast, availability of training in pediatric noncardiology specialties is limited and not standardized, with a relative paucity of infrastructural support mechanisms in children's hospitals.[6-8] Second, training, practice recommendations, and equipment requirements for cardiac POCUS in the pediatric population must specifically address the technical differences in scanning children, such as the spatial and temporal resolution challenges of imaging hearts with a wide spectrum of imaging depths and heart rates varying with age. Third, application in children must account for relative prevalence of disease. Cardiac disease is relatively rare in children compared with adults and when present is more likely to be related to congenital heart disease (CHD), which requires a more detailed anatomic evaluation than can be addressed by cardiac POCUS. Because of these important differences, the ASE convened this task force to address specific considerations of cardiac POCUS in children.

The optimal use of any imaging modality requires an understanding of the strengths and limitations of the technique, appropriate indications, and the practitioner's expertise. Improper use can result in significant clinical consequences, including missed diagnoses (and thus missed opportunity for appropriate patient care) or inaccurate diagnoses (which may lead to additional testing and health care costs, or even direct patient harm). The goal of this document is not to restrict the use of ultrasound but to provide recommendations regarding the use of cardiac POCUS by noncardiology clinicians in the pediatric population, including consideration of which indications or settings could be adequately addressed by cardiac POCUS instead of performing transthoracic echocardiography (TTE) and situations in which TTE is clearly necessary.

Although several societies have published recommendations and indications for pediatric cardiac POCUS within their patient populations,[9,10] the ASE established this task force to leverage expertise in cardiac ultrasound from multiple disciplines (pediatric cardiology [both cardiologists and sonographers], pediatric anesthesiology, pediatric emergency medicine, and pediatric critical care) in the hope of producing a document that could be used broadly by all practitioners of pediatric cardiac POCUS. We recognize that specialties will have some variation in how pediatric cardiac POCUS is used, on the basis of clinical focus and corresponding potential unique applications, but the imaging views, equipment needs and requirements for reliable teaching, quality assurance, and documentation will be common to all groups. The goal of this document is to provide guidance regarding appropriate indications, as well as outlining the infrastructure necessary for optimal performance, training, and quality assurance in the practice of cardiac POCUS. Issues regarding billing and financial impact would require broader, multidisciplinary discussion of the relative valuation of echocardiography and cardiac POCUS within the context of Current Procedural Terminology codes, which is beyond the scope of this document.

This guideline addresses four major areas: indications, imaging recommendations, training and competency assessment, and quality assurance.

DEFINITIONS

In this document, the term *cardiac POCUS* is used to describe ultrasound image acquisition and interpretation of cardiac structures by pediatric noncardiology clinicians to evaluate size, systolic function, and/or physiology. The expectation is that cardiac POCUS involves a focused evaluation of the heart, performed at the bedside, to assist in rapid clinical decision-making and management. Cardiac POCUS does not include anatomic evaluation of CHD, which requires TTE interpreted by a pediatric cardiologist. This guideline applies only to performance of cardiac POCUS in the pediatric population (≤18 years of age). Any references to cardiac POCUS in adults is specified. This guideline would not apply to situations in which the heart is only briefly evaluated as part of a global assessment, such as focused assessment with sonography in trauma but would apply in situations where the indication or intent is specifically to evaluate ventricular systolic function or cardiac physiology. Because of the unique anatomic and physiologic needs of patients in the neonatal intensive care setting, targeted neonatal echocardiography is excluded from this document but will be addressed by a separate working group. However, the current guideline does address the use of POCUS in neonates without suspicion of CHD who present to the emergency department or other care settings.

Key Points

- In this document, cardiac POCUS is defined as the ultrasound evaluation of cardiac structures by pediatric noncardiology clinicians to assess size, systolic function, and/or physiology, in patients ≤18 years of age, most commonly with a structurally normal heart.
- This guideline applies only to the pediatric population and excludes targeted neonatal echocardiography.
- Anatomic evaluation for CHD requires comprehensive TTE and is outside the scope of cardiac POCUS.
- Application of cardiac POCUS in children requires understanding of appropriate indications and technical considerations.

I. INDICATIONS

Translating cardiac POCUS to clinical care requires integrating the needs of local patient populations, the demands of highly variable clinical practice contexts, and the clinician's skill set. Potential applications for cardiac POCUS will continue to evolve, and an exhaustive list of indications among various noncardiology specialties cannot be provided here. However, by harmonizing previously published cardiac POCUS applications across noncardiology specialties, this task force proposes a consistent framework for determining cardiac POCUS indications. In a diverse, evolving clinical landscape, local echocardiography laboratories should play essential roles in translating this broad definition of cardiac POCUS indications to the specific requirements and limitations of local practice settings.

A. Framework for Cardiac POCUS Indications

Cardiac POCUS involves the visual assessment of cardiac structures and systolic function to elucidate underlying physiology and response to therapy. Ultrasound images are incorporated with clinical signs and symptoms as well as vital sign trends and laboratory data to clarify clinical condition. Given time constraints, not all cardiac structures typically visualized by TTE are interrogated. Potential clinical impacts of structures left unseen (e.g., the aortic arch) are typically not considered in depth. Cardiac POCUS is thus best viewed as a problem-oriented, physiology-based imaging tool to complement other data elements and facilitate patient management, typically in patients with normal cardiac anatomy. Cardiac POCUS is not a comprehensive cardiac evaluation. It is often used by clinicians with different perspectives of disease manifestation and in settings in which clinical problems must be rapidly assessed or may not be addressed by standard cardiology TTE reports, such as assessing for fluid responsiveness or inotropic needs in critically ill children.[11,12] Thus, the range of applications needs to be broad enough to maximize clinical effectiveness while respecting the patient-centered approach unique to each practice setting. Three key, common elements should govern the use of cardiac POCUS in any clinical environment:

1. The assessed structure is amenable to ultrasound technology.
2. The identified physiology and subsequent management decisions are frequently encountered in the clinical care setting and/or the condition requires urgent or emergent assessment to guide potentially life-sustaining management.
3. Pediatric noncardiology clinicians can reliably assess the physiology at the bedside following dedicated education and supervised training.

The first element acknowledges limitations imposed by the interface of the technology, the clinician, and the patient during ultrasound interrogation. For example, smaller ultrasound devices used in care may have reduced image quality and diagnostic accuracy independent of operator experience.[13-15] Some lesions, such as valvular vegetations or coronary artery anomalies, may be difficult to visualize even by the most experienced echocardiographers acquiring optimal transthoracic echocardiographic images on larger ultrasound platforms[16,17] and are thus outside the scope of cardiac POCUS. Patient factors such as limited acoustic windows due to underlying clinical condition or inability to reposition potentially critically ill or intubated patients (e.g., to a left lateral decubitus position) may further limit obtainable data. In general, only limited conclusions can be rendered from limited images.

Second, cardiac POCUS applications should also target physiologies that are frequently encountered and managed and/or require urgent or emergent intervention. For example, "shock" is a diagnosis routinely evaluated by pediatric acute care clinicians. Shock is characterized by hypovolemic, cardiogenic, obstructive, and distributive etiologies, either alone or in combination. Clinical assessment alone may not determine ventricular preload or identify the cause of suboptimal therapeutic responses.[18] Correlating real-time POCUS findings and characteristic physical examination signs often leads to better understanding of the underlying pathophysiology and can guide therapies,[19,20] as now suggested by international societies and guidelines.[12,21,22] In addition, conditions that may be rare in pediatric populations, but for which rapid diagnosis may lead to lifesaving interventions, should also be considered among appropriate indications for cardiac POCUS by trained clinicians. For example, in a child presenting with tachycardia, hypotension, and enlarged cardiac silhouette on chest radiography, a large pericardial effusion identified on cardiac POCUS by an appropriately trained clinician can distinguish tamponade physiology from other causes of shock and dramatically alter management.

Third, cardiac POCUS indications should focus on applications in which clinicians can demonstrate reliable performance following training. The literature supports cardiac POCUS applications in which even novice trainees can demonstrate high levels of performance in the clinical setting following focused training.[23-26] Reliable performance is enhanced by using dichotomous or semiquantitative methods of assessment (e.g., present or absent, normal or depressed). Core competencies within cardiac POCUS applications should be defined, which will be discussed in a later section.

Key Points

- Cardiac POCUS is a problem-oriented, physiology-based imaging tool performed by noncardiology clinicians to complement other clinical data elements and enhance patient management.
- Cardiac POCUS clinical applications should be governed by three requirements: pathophysiology amenable to ultrasound interrogation, frequently encountered clinical scenario and/or requiring urgent intervention, and sufficient availability of effective training.

B. Proposed Indications for Cardiac POCUS

To date, there are four collaborative publications by cardiac POCUS subspecialty experts suggesting applications for noncardiology pediatric clinicians, including guidelines from the European Society of Paediatric and Neonatal Intensive Care, the Society of Critical Care Medicine, and two Delphi consensus statements from the P2 Network (a workgroup of pediatric emergency medicine POCUS specialists).[9,27-29] This task force evaluated recommendations from these guidelines within the context of previous statements from the ASE regarding nonpediatric cardiac POCUS.[2,30] This resulted in the following definition of current cardiac POCUS indications.

> Cardiac POCUS can be used to evaluate physiologic causes and subsequent effects of hypotension, shock, and circulatory arrest, including preload and volume responsiveness, qualitative left ventricular (LV) systolic function, presence of pericardial effusion, and qualitative assessment of right ventricular (RV) size and systolic pressure.

This definition does not specify methods of assessment; this task force recognizes a need for noncardiology disciplines to better define practice parameters for specialty-specific cardiac POCUS applications, objectives, and methods of measurement as well as to continue to develop literature supportive of educational translation to optimized care. For example, in determining fluid responsiveness, a clinician may incorporate assessments of inferior vena cava (IVC) morphology, respiratory variability, and size relative to the aorta,[11,31] or by measuring LV outflow tract velocity variation,[32] all of which have supportive data and limitations. Given the relevance of fluid balance in the practice of acute care clinicians[33-35] (and a concurrent lack of clinical gold standards), this task force aims to avoid being prescriptive regarding applications in noncardiology disciplines, but rather to remain collaborative in optimizing evaluative platforms. Echocardiography laboratories can play an important collaborative role in guiding and supporting safe and effective implementation of cardiac POCUS within the context of the local practice setting. Specifying indications, establishing clinical stepwise algorithms, and standardizing feasible protocols will be key strategies to help translate the use of POCUS into bedside care successfully. Multicenter prospective studies are needed to validate the specific roles of POCUS in improving pediatric patients' outcomes.

It is widely agreed that cardiac POCUS is not suitable to diagnose CHD.[9,36,37] Although cardiac POCUS assessment may incidentally identify clinical features consistent with CHD, it is insufficient to critically evaluate CHD, which should remain firmly in the domain of pediatric cardiology expertise. Cardiac POCUS is problem oriented, and clinical questions are answered using discrete outcome measures, such as volume responsiveness or ventricular systolic function. Assessment of signs or symptoms for which CHD should be in the differential (e.g., cyanosis, heart murmurs, blood pressure discrepancies) requires anatomic considerations well beyond the scope of cardiac POCUS and should be referred for pediatric cardiology consultation and evaluation. Incidental suspicion of CHD or anatomic or functional abnormalities on any cardiac POCUS evaluation also requires pediatric cardiology evaluation.

In patients with known CHD, strong caution is warranted regarding cardiac POCUS use by noncardiology clinicians. Anatomic considerations may invalidate typical diagnostic targets (such as evaluation of tamponade physiology with a functional single ventricle, or evaluation of systolic function of a systemic right ventricle). Therefore, such evaluations should be limited in nature and be supported by pediatric cardiology consultation after initial stabilization and evaluation.

Multiple studies have demonstrated that trained, noncardiologist pediatric subspecialists can evaluate LV systolic function via cardiac POCUS with reasonable accuracy.[24,25,38-41] However, borderline systolic dysfunction was among the missed diagnoses in a large series.[41] Even with standard echocardiography, qualitative estimation alone can have wide limits of agreement with potential for clinically significant differences,[42] and qualitative evaluation of the right ventricle is particularly difficult.[43] Mild systolic dysfunction and regional wall motion abnormalities, particularly in a previously healthy child, are important findings and may be seen in children with acute inflammatory cardiac conditions, such as myocarditis or multisystem inflammatory syndrome in children (Videos 1 and 2 available at www.onlinejase.com), and some forms of CHD, such as coronary artery anomalies. These findings may thus require a full echocardiogram for anatomic and/or quantitative function assessment.[44-46] Initially subtle cardiac dysfunction can also rapidly progress and lead to patient deterioration.[45,47,48] Pediatric cardiac POCUS users should be aware of this limitation and consider early referral for standard echocardiography if evaluation of systolic function is equivocal or other clinical signs suggest risk for myocardial dysfunction, inflammation, or injury, to avoid missing subclinical dysfunction.

The use of pediatric cardiac POCUS outside of emergency or critical care scenarios has yet to be defined. Appropriate use criteria exist for echocardiography in pediatric outpatient, adult outpatient, and adult emergency settings,[49-52] but analogous criteria do not exist for cardiac POCUS. Specifically, the utility of cardiac POCUS is unknown in nonemergent pediatric scenarios like isolated chest pain, syncope, or murmur, particularly given the low prevalence and vastly different spectrum of cardiac disease in children compared with adults presenting with these scenarios.[53-57] The lack of anatomic evaluation for CHD, including congenital coronary artery or aortic arch anomalies, in cardiac POCUS raises concern for the risk for missed diagnoses and false reassurances for clinicians and families. Further research is needed to measure the impact of cardiac POCUS in these nonemergent scenarios, including diagnostic yield, downstream testing, patient satisfaction,[35] and adherence to follow-up cardiology evaluation. In the absence of data, restraint is recommended in the use or interpretation of positive or negative cardiac POCUS findings in this context.

Echocardiography laboratories should also recognize that the spectrum of POCUS practice in the clinical setting extends beyond cardiac POCUS and that other ultrasound images with clinical relevance may accompany cardiovascular assessments. For example, lung ultrasound to evaluate for pneumothorax may be an important component of assessing a child presenting with hypoxia and hypotension. Acknowledging limitations within specialty-specific care is important for all clinicians.

Recommendations

- Cardiac POCUS can be used to evaluate physiologic causes and effects of hypotension, shock, and circulatory arrest, including preload and volume responsiveness, qualitative LV systolic function, presence of pericardial effusion, and qualitative assessment of RV size and systolic pressure.
- Cardiac POCUS is not appropriate to evaluate signs or symptoms that suggest CHD (e.g., cyanosis, heart murmurs) and should not be used to rule in or rule out CHD. Clinical suspicion of CHD should be referred for pediatric cardiology consultation and is beyond the scope of cardiac POCUS.
- Strong caution is recommended when using cardiac POCUS in patients with known CHD. Cardiac POCUS may have a role in immediate stabilization of such patients but should be followed by support and evaluation by pediatric cardiologists.
- Mild systolic dysfunction in children can be an important clinical finding but is difficult to exclude by cardiac POCUS; standard echocardiography is recommended if there is uncertainty by cardiac POCUS or if there are clinical concerns for cardiac dysfunction or injury.
- Local echocardiography laboratories should have an opportunity to be involved in the adoption and implementation of cardiac POCUS indications appropriate for their local institutions.
- Cardiac POCUS is appropriate in pediatric patients presenting with hemodynamic instability or acute respiratory distress when CHD is not suspected. Its role in nonemergent situations remains to be defined.

II. IMAGING RECOMMENDATIONS

A. Equipment and Technical Considerations

Cardiac POCUS is not defined by the type of machine used but is most often performed with ultrasound devices with fewer image optimization tools and, important to pediatrics, fewer transducer options compared with standard echocardiography machines.[58,59] Ultrasound machines designated for cardiac POCUS in children should ideally have both low-frequency (~2-2.5 MHz) and higher frequency (≥~7.5 MHz) sector probes available, because of the wide range of imaging depths encountered in the pediatric population.[59] Default commercially available packages typically contain single, low-frequency sector probes designed for use in larger patients or adults. Most ultrasound companies have released pediatric, higher frequency sector probes compatible with POCUS machines, but these may be an additional cost during technology procurement.

If higher frequency probes are unavailable, caution is warranted using lower frequency sector probes in smaller patients, particularly infants. The footprint of these larger sector probes can prevent scanning between small rib spaces. Additionally, near-field imaging can be obliterated with use of lower frequency, increasing the risk for missing pathology in anterior structures of smaller patients, particularly in the right ventricle or apical portions of the heart. If only a lower frequency transducer is available during a pediatric emergency, subcostal views can be helpful to evaluate the heart. Using the liver as an acoustic window places the heart in the far field and enhances image quality.[60,61]

Additional caution is warranted during cardiac imaging with some of the more recent multifaceted handheld devices or probes, with or without piezoelectric crystals, which rely on probe mimicry technology and do not use more traditional sector probes.

Recently, deep learning algorithms have been used to provide real-time prescriptive guidance (turn-by-turn instructions) to help even novice operators obtain cardiac imaging planes.[62] However, even if available, algorithms trained from adult echocardiogram data sets should not be used in children without validation and research.

Recommendations

- Ultrasound equipment for cardiac POCUS in pediatrics should be selected with a range of frequencies for the range of depths in this population.
- An ultrasound probe for a given pediatric patient should be chosen with consideration of frequency and footprint size.

B. Imaging Overview

Cardiac POCUS should consist of B-mode (two-dimensional black and white) imaging with limited use of color Doppler imaging. Cardiac POCUS examinations should be brief and focused on crucial aspects of the clinical scenario, to avoid delay in medical management. Recommended scan time is no more than 5 to 7 min, with the study typically consisting of no more than 10 stored images. The targeted nature of cardiac POCUS does not allow a comprehensive evaluation of the heart. Limited cooperation in children and technical limitations when imaging cardiac structures at higher heart rates also limit the sensitivity of pediatric cardiac POCUS. Thus, a "rule-in" mentality should be used during bedside evaluation, to identify specific findings if positive. Although some specific questions can be ruled out, such as a large pericardial effusion or severe ventricular systolic dysfunction, a more global "rule-out" approach is discouraged; what may appear to be borderline depressed systolic function or localized pericardial effusion can still lead to significant clinical impact or be harbingers of impending hemodynamic compromise. A cardiac POCUS study with no identified abnormalities should not be equated with a structurally and functionally normal heart.

Recommendation

- Cardiac POCUS assessment should be focused on the clinical scenario, to act upon abnormal findings identified. However, a normal cardiac POCUS study is not sufficient to rule out significant cardiac disease.

C. Recommended Imaging Views

There are predominantly five imaging views used for cardiac POCUS interrogation (transducer position, image orientation, and imaging goals are presented in Table 1):

- subcostal (also known as subxiphoid) long-axis (or four-chamber) view,
- subcostal IVC view,
- parasternal long-axis view,
- parasternal short-axis view, and
- apical four-chamber view.

The task force recommends probe indicator position (and thus image orientation) consistent with traditional cardiac ultrasound imaging, with the transducer indicator pointing to the patient's left except for the parasternal long-axis view. We recognize that some established POCUS protocols instruct indicator position during cardiac imaging to be consistent with body ultrasound (i.e., indicator to the right) to facilitate coordination with total body imaging (e.g., focused assessment with sonography in trauma examination). Regardless of indicator position, the displayed and recorded cardiac image orientation should reflect patient anatomic cardiac position as found in traditional cardiac imaging, with leftward cardiac structures displayed on the right side of the screen. One potential strategy is to use left-right image inversion, which is usually available on device image controls.

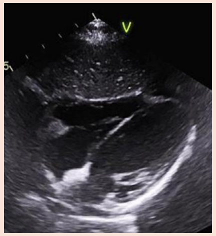
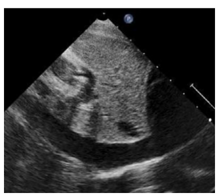
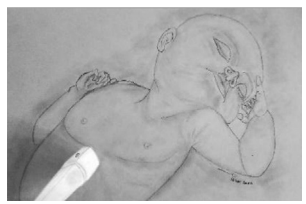
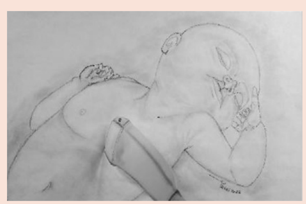
"Apex-up" imaging is most frequently used for cardiac POCUS apical and subcostal views. "Apex-down" imaging is well established in pediatric and congenital echocardiography to assist in imaging complex atrioventricular connections and orientations seen in CHD. Although apex-down imaging could facilitate collaboration with pediatric cardiology, it is not used in any other applications of POCUS imaging, and cardiac POCUS is predominantly intended to assess patients with normal cardiac anatomy. Thus, either orientation (apex up or apex down) may be used, according to training and local practice.

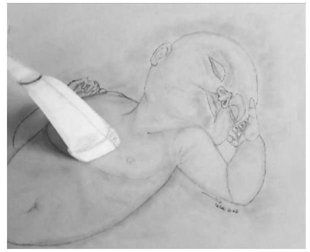
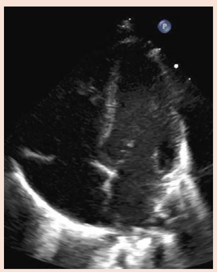
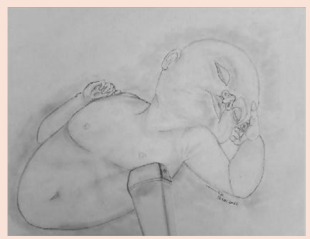
Local agreement in image display should allow the most consistent orientation of cardiac imaging across pediatric subspecialties (and adult subspecialties practicing within pediatrics). Consistent orientation of cardiac structures in displayed and stored images across subspecialties within an institution should facilitate clinical collaboration and assist in the development and maintenance of multidisciplinary quality assurance efforts.

The subcostal long-axis view allows imaging of the atria, ventricles, and pericardial space. Imaging should include a long sweep from posterior to anterior to assess the pericardial space (Figure 1, Video 3 available at www.onlinejase.com). The pleural spaces can also be evaluated with increased sector width and depth, by sweeping through the pleural spaces.

The subcostal IVC view allows estimation of volume responsiveness (Figure 2). However, many factors can influence interpretation of the IVC.[63] In children in particular, the IVC can be manually compressed by excessive pressure of the probe on the abdominal wall,

Table 1 Imaging views for cardiac POCUS

View	Transducer position	Image orientation	Potential goals
Subcostal long axis 	 Subxiphoid, indicator at 3 o'clock (toward left flank)	Centered over crux of the heart, with apex of the heart toward the right side of the screen	• Assess for pericardial effusion • Overall assessment of biventricular systolic function • Assess for pleural effusion (with increased sector width and depth)
Subcostal IVC 	 Subxiphoid, indicator at 12 o'clock (toward the head)	Centered over the intrahepatic IVC entering the right atrium (displayed on the right side of the screen)	• Qualitative assessment of IVC size (measured just below the diaphragm) and hydration status
Parasternal long axis 	 To the left of the sternum, indicator at 10 to 11 o'clock (toward the right shoulder), with patient in left lateral decubitus position if possible	Centered over the mitral valve, with LV apex on the left side of the screen	• Assessment of LV size and systolic function • Limited assessment of RV size and systolic function • Presence of pericardial effusion, differentiate pericardial vs pleural effusion • Allows color Doppler assessment of mitral or aortic regurgitation

Parasternal short-axis 	 To the left of the sternum, indicator at 1 to 2 o'clock (toward the left shoulder), with patient in left lateral decubitus position if possible	Centered over the LV papillary muscles, including the right ventricle anteriorly	• Assessment of LV size and systolic function • Assessment of RV size and systolic function • Assessment of interventricular septal configuration • Presence of pericardial effusion; presence of RV collapse
Apical four chamber 	 At the point of maximal impulse, indicator at 3 o'clock (toward the left axilla), with patient in left lateral decubitus position is possible	Centered over the cardiac apex, with the left heart displayed on the right side of the screen; all four chambers of the heart and both atrioventricular valves should be visualized	• Assessment of LV size and systolic function • Assessment of RV size and systolic function • Assessment for gross left and/or right atrial dilation • Presence of pericardial effusion; presence of RV/right atrial collapse • Allows color Doppler assessment of mitral and tricuspid regurgitation

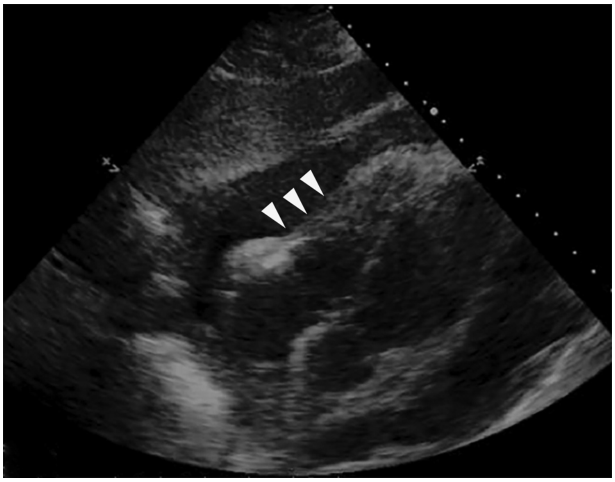


Figure 1 Subcostal long-axis view demonstrating a large, circumferential pericardial effusion in a child with acute myeloid leukemia with recurrent fevers and hypotension. Note the indentation of the RV free wall *(arrowheads)*, which is suggestive of tamponade physiology.

patients may not be developmentally mature enough to comply with a "sniff test," and IVC size varies with growth and must be interpreted in the context of body surface area.[64,65] Although IVC diameter and collapsibility index can be measured just below the diaphragm,[66] utility in children has not been demonstrated, and estimates of volume status solely by assessing the IVC should thus be interpreted with caution in this population.

The parasternal long-axis and short-axis views allow evaluation of ventricular size and systolic function (Videos 4 and 5 available at www.onlinejase.com). The parasternal short-axis view may be used for rough estimation of RV pressure relative to the left ventricle by assessing the interventricular septal position (Figure 3, Video 6 available at www.onlinejase.com). However, if there is a low parasternal window (parasternal long-axis images show the apex near the transducer), the septum may appear flat because of the imaging plane despite normal RV pressure. Furthermore, the more horizontal orientation of the heart in the chest in infants may lead to a spurious appearance of septal flattening.[67] Differentiation of systolic (RV pressure overload) versus diastolic (RV volume overload) septal flattening may be difficult, particularly in the absence of an electrocardiographic tracing. Any flattening of the interventricular septum should prompt TTE for further evaluation.

The apical four-chamber view allows rapid evaluation of ventricular size and systolic function. Additionally, if the probe is directed anteriorly, the five-chamber view is obtained as the aortic valve comes into view.

Recommendations

- To facilitate multidisciplinary collaboration, cardiac POCUS should have consistent orientation of cardiac structures in displayed and stored images across subspecialties within an institution.
- POCUS images should be obtained and stored with leftward cardiac structures on the right side of the screen, except for the parasternal long-axis view.
- For apical and subcostal long-axis images, either apex-up or apex-down orientation may be used, according to training and local practice.

D. Storage and Reporting

Image storage and archiving of all cardiac POCUS examinations is considered best practice.[68] Although some institutions do not require documentation or storage of images if performed solely for the purpose of education,[69] this task force recommends recording and electronic storage of all cardiac POCUS studies as the practice standard. Shared, cloud-based, or institutional picture archiving and communication system image storage with linkage to the electronic medical record is ideal to facilitate sharing of images, comparison with prior cardiac imaging, and quality improvement and assurance practices. Ultrasound devices for cardiac POCUS application should have wireless capability for image transfer, either through the device itself or via the user's smart phone or tablet. Storage of images on the machine alone is not adequate, as space is limited, and the decreased availability of images interferes with expert consultation and longitudinal assessments of response to clinical care.

As cardiac POCUS often occurs in emergent or critical clinical scenarios, image storage may at times be limited or not clinically feasible. However, storage of at least limited images that exhibit pertinent findings contributing to medical decision-making should be the

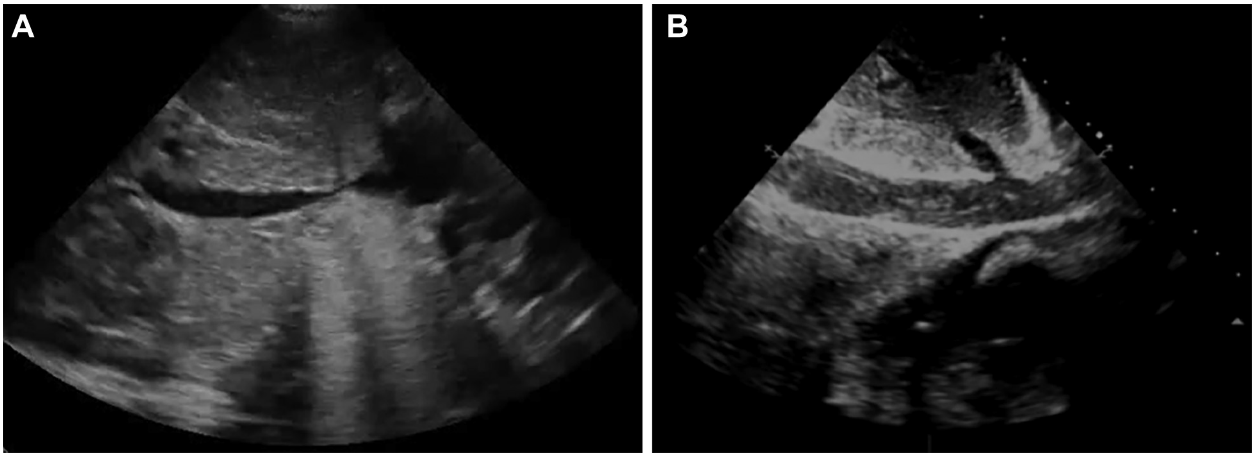


Figure 2 Subcostal IVC view. **(A)** Near complete IVC collapse in a child with hypovolemic shock, who proved to be fluid responsive. **(B)** IVC dilatation with spontaneous cavitation, suggesting a low-flow state, in a child with severe RV dysfunction after repair of gastric perforation.

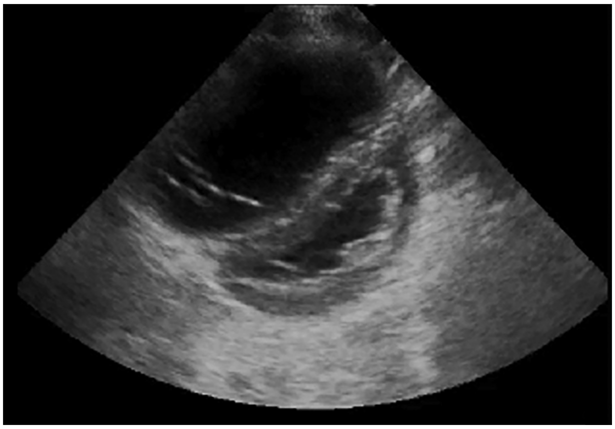


Figure 3 Parasternal short-axis view demonstrating RV dilatation with bowing of the septum into the left ventricle, indicating pulmonary hypertension in this child with shock and pertussis.

goal. Storage of clips rather than still frames provides the most useful information.

All cardiac POCUS examinations should have an associated report that can be shared in the patient's medical record, ideally written by the performing care provider to document basis of clinical decision-making. Standards for cardiac POCUS reporting have previously been described.[30,68] POCUS evaluation of cardiac targets is rapid and qualitative or semiquantitative (e.g., normal vs abnormal vs unknown). In general, the "eyeball" method for qualitative description of ventricular size and systolic function is used. As discussed above, subtle abnormalities such as mild dysfunction are difficult to exclude, and caution is recommended in attempting to grade degree of dysfunction more finely. Quantification of ventricular size or systolic function during cardiac POCUS is unlikely to be helpful and may lead to dissemination of false or erroneous information, particularly in the context of rapid image acquisition and/or suboptimal imaging conditions.

Recommendations

- Images from cardiac POCUS studies should be stored and linked to the patient medical record whenever clinically feasible.
- POCUS findings should be reported in the medical record and described qualitatively or semiquantitatively.

III. TRAINING AND COMPETENCY ASSESSMENT

Multiple pathways currently exist for training and certification in adult cardiac POCUS. A prior ASE guideline discussed the role of echocardiography laboratories in adult cardiac POCUS training.[2] Similar approaches and considerations apply in the pediatric population, with the addition of local decisions on scope of practice and criteria for referral to cardiology, as noted above. Training in adult cardiac POCUS may be helpful, but not sufficient for practice in pediatrics, given differences in technical performance aspects as well as an understanding of the potential for CHD causing or contributing to a given presentation. Ideally, training should involve a collaboration between cardiac POCUS-trained faculty members and pediatric cardiologists, to reflect local practice. Depending on local resources, this may require collaboration with other departments or divisions (radiology, intensive care, emergency medicine, pediatric emergency medicine, neonatal intensive care, anesthesiology), and may even extend beyond the local center.

Given the diversity of potential cardiac POCUS users, different baseline abilities of learners will influence which methods of training are best suited to achieve competency. Therefore, it is important to provide multiple methods for learners. These may include, but are not limited to, didactic lecture (live or recorded), image banks, image interpretation (live or standardized cases or with training software), instructor-guided scanning, independent scanning, simulated scenarios, objective structured clinical examination, and ongoing training.

A. Defining Cardiac POCUS Competency

Regardless of the pathway for training, the objective should be competency and skill mastery, rather than completion of a program or performance of a certain number of studies.[70,71] Defining competency and mastery enables learners to have a clear idea of training goals (including when they may practice without supervision), permits identification of practitioners able to teach and supervise others, assists in transition of practitioners to use cardiac POCUS in new environments (where expectations for competency should be the same even if applications differ), and assures patients that all testing is being done by well-trained or supervised practitioners. The concept of entrustable professional activities, as recommended by the American Association of Medical Colleges, requires that clinicians perform services for which they have demonstrated competency.[72] Learners should not independently perform cardiac POCUS, which may alter clinical decision-making, without appropriately competent supervision present or immediately available via remote access. Reliance on an independent certification or completion of a predetermined number of scans is insufficient to ensure competency, particularly with the diversity of patient sizes and physiologies in the pediatric age range.

Just as indications for cardiac POCUS may not be the same for the emergency department, operating room, and intensive care units, there is also unlikely to be a definition of competency for cardiac POCUS that fits all environments. Each specialty will likely need to determine their own definitions of competency (and thus may require specialized training to practice in that context), but these definitions will share many of the same basic skills. Because of that, paradigms for testing and quality assurance may be similar, and strategies for evaluating competency that are developed in one environment will likely be adaptable for other settings.

Despite specialty-specific variations in definitions of competency, the core competencies for independent practice of pediatric cardiac POCUS should include the following:

1. proficiency in technical skill;
2. proficiency in interpretive skill;
3. demonstration of a core fund of knowledge about normal cardiac anatomy, the physiology being evaluated, and differences in children versus adults;
4. demonstration of an understanding of ultrasound equipment and how to choose the correct equipment for the question to be answered;
5. demonstration of an understanding of the risks, benefits, and limitations of cardiac POCUS in various scenarios; and
6. proficiency in the situational application of cardiac POCUS and an ability to integrate imaging data and clinical data in real time.

Once identified, specialty-specific competencies should be published; a competency checklist would allow standardization of training and assessment. To be generalizable, the definition of cardiac POCUS competency will need to include some recommendation for

Table 2 Strategies for competency assessment

	Advantages	Disadvantages	Comments
Practice logs	Can assess volume and diversity of experience	Assesses exposure required to become competent, but not competency itself	Volume of studies is necessary but not sufficiency for competency
Objective structured clinical examinations	Allows direct observation of clinical skill and situational awareness	May not mimic the real world (e.g., variation in patient size and movement)	May use simulators, which can offer an idealized experience best for early learners
Written examinations	Easily standardized and objective	Can assess knowledge but not performance skills	Best for assessing fund of knowledge (e.g., cardiovascular physiology, ultrasound equipment, indications and limitations of cardiac POCUS)
Computerized image libraries	Can assess interpretive skills, as learners interpret curated, archived studies	Does not assess image acquisition	Cases must reflect the breadth and depth of sizes and physiologies in the pediatric population, not just adult-based libraries

a threshold level of performance in each core competency as well as a recommendation for what constitutes a level of mastery that enables one to supervise and teach others. For example, guidelines have been published for cardiac POCUS in the adult intensive care unit[4,73] and in neonatology,[37] detailing competencies along with medical and physiologic questions that can be addressed.

B. Competency Assessment

Once cardiac POCUS competency has been defined, assessing it is complicated. The literature contains a wide variety of suggestions, but with no gold standard for competency testing and a paucity of evidence-based research. This reality is likely because the "outcome" is difficult to measure in an objective way, and different competencies may require different paradigms for assessment. For example, fund of knowledge may be assessed with one-on-one mentoring or written examinations, but situational application may be best assessed with a combination of simulation and direct observation of actual patient care. A final consideration is that the definition of competency requires defining a safe, minimal rate of accuracy. This rate may vary depending on the consequence of an inaccurate diagnosis. For example, an error in the assessment of volume status would carry different implications than an error in the assessment of a large pericardial effusion.

Potential strategies to assess cardiac POCUS competency are shown in Table 2. Different strategies may be more suited for assessing different core competencies. Developing validated testing methods for competencies should be a key focus, as learners will achieve the competencies at different rates, and therefore universally applied predetermined numbers of studies performed/interpreted should be avoided as a benchmark for competency.

Support for initial and ongoing training requires infrastructure and institutional support. At a minimum, there should be an identified cardiac POCUS lead within local practice areas (department or division level) with dedicated time for education and quality assurance. Collaboration of educational efforts across practice areas can allow sharing of resources and cross-training, as well as fostering multidisciplinary clinical and quality assurance POCUS projects. An image archiving system integrated with the electronic medical record system is essential for learning purposes and quality assurance, in addition to communication with other services and medical-legal concerns, as noted in previous sections.

Recommendations on credentialling are beyond the scope of this document, as standards do not exist and will likely vary by institution and even by department or division, to identify practitioners competent to practice independently. However, local experts (e.g., pediatric cardiology, emergency medicine, neonatology, critical care, anesthesiology) should be involved in such decisions.

Key Points

- Definitions of competency in pediatric cardiac POCUS are necessary for appropriate training and criteria for independent performance and supervising and teaching others. These definitions may vary among disciplines but will likely have many shared components.
- Regardless of specialty, core competencies for pediatric cardiac POCUS should include technical skill, interpretive skill, situational awareness, a core fund of knowledge with respect to physiology being evaluated (and differences between children and adults), ultrasound equipment, and the risks, benefits, and limitations of cardiac POCUS.
- There are no gold standards for competency assessment. Competency evaluation should use a combination of different methodologies for evaluating proficiency and mastery.

Recommendations

- Pediatric cardiac POCUS training should focus on assessment of competencies rather than completion of a course or number of studies.
- Competencies should be defined by subspeciality to reflect specific applications.
- Training in pediatric cardiac POCUS requires pediatric-specific training to address variation in patient size, scanning techniques, and potential physiologies.
- Learners should not perform cardiac POCUS in children without competent oversight by an experienced supervisor who is either physically present or able to review the images remotely at the time of the study.
- Infrastructure for ongoing training should include an identified cardiac POCUS lead and an image archiving system to facilitate education and ongoing quality assurance.

IV. QUALITY ASSURANCE

For all diagnostic tools in the medical setting, there must be a built-in process for continued evaluation of examination quality in addition to infrastructure that allows the examination of the root cause of errors, the promotion of ongoing quality improvement, and the integration of new technology and evolving applications. As noted above, this includes a robust imaging archive system. In addition, the program should have well-delineated plans for review of archived studies, which involves at least some, if not all, of the following:

1. Regular conferences involving review of challenging cases, diverse pathophysiologic processes, cases leading to changes in clinical practice, and any discrepancies from subsequent diagnostic imaging.
2. Regular review of at least some of the archived studies performed by trainees and corresponding reports, with direct feedback to the trainee regarding areas of mastery and goals for improvement.
3. Educational programming that allows all individuals in the program to understand any updates to goals and expectations for performing cardiac POCUS. In addition, regular ongoing education can be used to expose the staff to new skills, procedures, and equipment.
4. A plan for nonjudgmental and anonymous reporting of concerns by other health care workers with respect to a practitioner's ability to provide cardiac POCUS to the agreed-upon standard of care.

When available, quality assurance efforts should take advantage of opportunities to compare cardiac POCUS interpretation with the interpretation of an echocardiogram performed on the same patient and within a meaningful time frame. In addition, local pediatric cardiologists are an invaluable resource for ongoing quality assurance, and should be engaged in regular efforts such as identification of discordant findings on an echocardiogram, clinical integration, and for further training.

Recommendation

- Cardiac POCUS programs must include a plan for ongoing quality assurance. This should include regular review of archived cases as well as thoughtful evaluation of instructive cases in a manner that allows continuing education and improvement in performance. This will be particularly important as both the technology and the indications for cardiac POCUS continue to evolve.

CONCLUSION

Cardiac POCUS is a rapidly growing imaging modality with current and evolving applications in the pediatric population. Specific indications, training pathways, and competencies need to be defined by individual subspecialties and cannot be globally prescribed by any one society or organization. However, certain common principles are shared regardless of area or field of clinical practice. Evolving indications are limited by the equipment and focused nature of this modality, and thus cardiac POCUS is inadequate to evaluate CHD or subtle findings (such as coronary anomalies or endocarditis). Negative findings should thus be interpreted with caution. A standardized approach to image orientation, storage, and reporting can facilitate communication and collaboration. Training pathways must consider technical aspects of scanning a wide range of patient sizes and heart rates, as well as pediatric-specific anatomy and physiology, and should focus on competency rather than number of studies. Standardized processes of image storage and review are necessary for ongoing quality assurance. Implementation of pediatric cardiac POCUS thus requires the allocation of institutional resources (financial as well as faculty time) to meet these requirements. Most important, collaboration across subspecialties and with local experts, including pediatric echocardiography laboratories, will be essential to optimize patient care delivery, use expertise and shared resources, and create the optimal environment to guide the ongoing evolution of this important modality.

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SUPPLEMENTARY DATA

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