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Point-of-Care Ultrasound

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Abstract

Purpose of the Review Point-of-care ultrasound using small ultrasound devices has expanded beyond emergency and critical care medicine to many other subspecialties. Awareness of the strengths and limitations of the technology and knowledge of the appropriate settings and common indications for point-of-care ultrasound is important.

Recent Findings Point-of-care ultrasound is widely embraced as an extension of the physical exam and is employed in acute care and medical education settings. Echocardiography laboratories involved in education must individualize training to the intended scope of practice of the user. Advances in artificial intelligence may assist in image acquisition and interpretation by novice users.

Summary Point-of-care ultrasound is widely available in a variety of clinical settings. The field has advanced substantially in the past 2 decades and will likely continue to expand with advancement in technology, reduced cost, and improved opportunities to assist new users.

Keywords POCUS · Cardiac · Ultrasound · Echocardiography · Education · Training

Introduction

From laptops to tablets to telephones, there has been increasing interest in the miniaturization of technology over the past several decades. The same can also be said of ultrasound technology. Health care providers can now perform point-of-care ultrasound, known as POCUS, at the bedside using handheld machines of varying sizes that are considerably more portable than traditional full platform systems (Fig. 1). POCUS use has been widely embraced by emergency medicine (EM) providers and has additionally permeated an array of other specialties such as critical care (CC), trauma, vascular medicine, obstetrics, and rheumatology. POCUS has made relatively low-cost technology available in resource-limited settings globally [1–4]. Most recently, POCUS has been heavily utilized during the COVID-19 pandemic [5, 6].

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Although POCUS is used to examine many organ systems, in this article we primarily review the use of POCUS for cardiac indications. We acknowledge that another moniker for cardiac POCUS is focused cardiac ultrasound (FCU) and consider both of these terms interchangeable. Throughout this piece, the focus is on utilization of small ultrasound devices at the bedside as an extension of the clinical assessment or for the purpose of rapid triage of a narrow list of indications pertinent to a particular clinical setting. In some cases, cardiovascular providers fully trained in echocardiography may also use small devices in this capacity, and conversely, non-cardiovascular providers can use full platform systems in a focused way. In both scenarios, this would be considered a cardiac POCUS examination.

Origins of POCUS and Current State of the Technology

The first prototype of a portable ultrasound unit was produced for military use in 1998 [7]. Literature reports of POCUS in clinical use started to sprout in the early 2000s. A host of names were assigned to portable ultrasounds, including SPUD (small portable ultrasound devices), HCU (hand-carried ultrasound), pocket echocardiography, and perhaps more sustained, POCUS. Early portable machines were often still not sufficiently portable to avoid using a cart to transport.

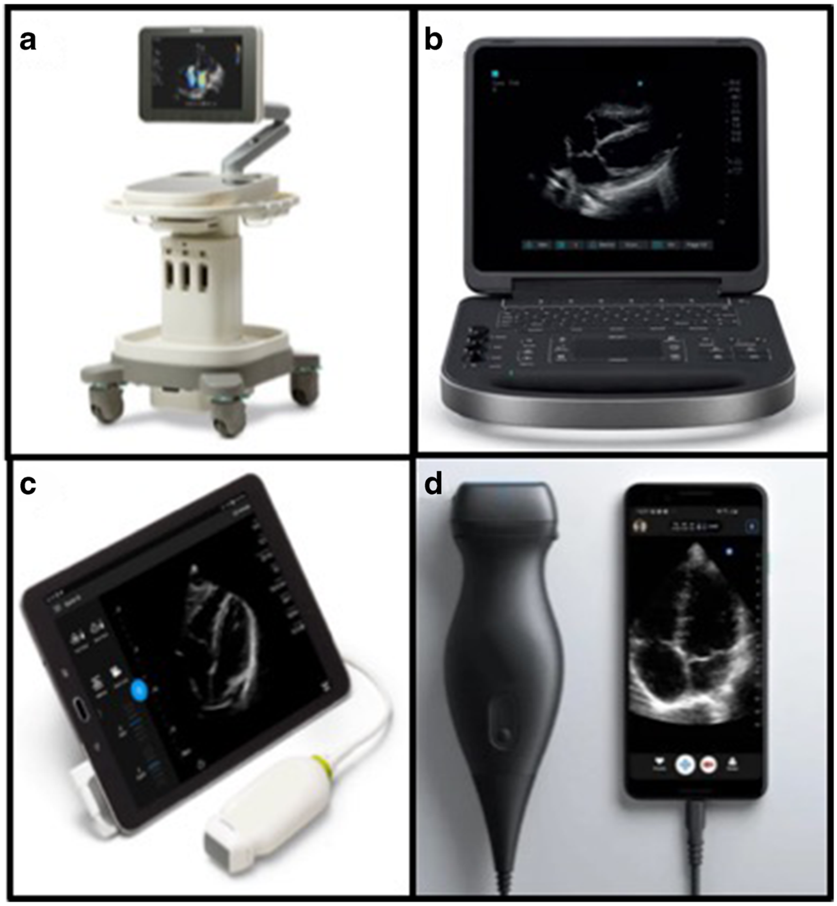

Fig. 1 Point-of-care ultrasound (POCUS) machines. Modern POCUS systems can be attached to a cart for easy of movement and portability (A), carried in laptop-sized housing (B), attached to a tablet (C), or even a cell phone (D)

Some were mounted on poles, others in large laptop formats that were transported to the bedside in wheeled carry cases. Image quality was limited. Color flow and spectral Doppler were initially unavailable. Measurement options were limited. Storage of images was either not possible or was limited to flash storage. Uploading to a picture archiving communications system (PACS) was typically not possible, thus limiting comparison to previous studies. Battery power was limited, posing challenges in resource-limited settings with unpredictable power grids. There was no standardized reporting mechanism. There was also great debate about the merits of using what were perceived to be inferior devices compared with full platform systems, including what qualifications or training was required to perform and interpret these quick bedside examinations. Thus, validation studies compare cardiac POCUS against full platform machines when used by cardiovascular specialists and by trainees ensued [8–11,12•]. Nonetheless, the advantages of POCUS with regard to portability, low cost, and availability to assist in time-dependent patient care decisions, particularly in settings where formal echocardiograms are not immediately available, were enthusiastically embraced by early adopters such as EM and CC providers, serving to motivate the industry's ongoing commitment to improve POCUS technology.

Today, POCUS devices have become far more sophisticated. Image quality is reasonably good when used by a trained provider, though may still be limited by body habitus (Fig. 2). Harmonic imaging is a feature of many systems. Color flow Doppler is widely available. Spectral Doppler is available on some systems. Other systems have implemented measurement packages and applications. Most systems now allow for storage in DICOM format to allow uploading to PACS systems. Wireless and Bluetooth technology now facilitate transducer recognition, battery charging, and image transfer. Touch screen technology is common and screen sizes have become so small that they either fit in a pocket or utilize a display application on a cell phone. Unique probe technology has become available that uses a silicon chip array instead of piezoelectric crystals, allowing images to be displayed in a variety of formats that would previously have required separate probes. Lastly, artificial intelligence has crept into the POCUS world, using technology-assisted image acquisition for less experienced users.

In sum, POCUS technology has made huge strides over the past 2 decades with enhanced practicality in clinical practice. In no way to detract from this success, it bears

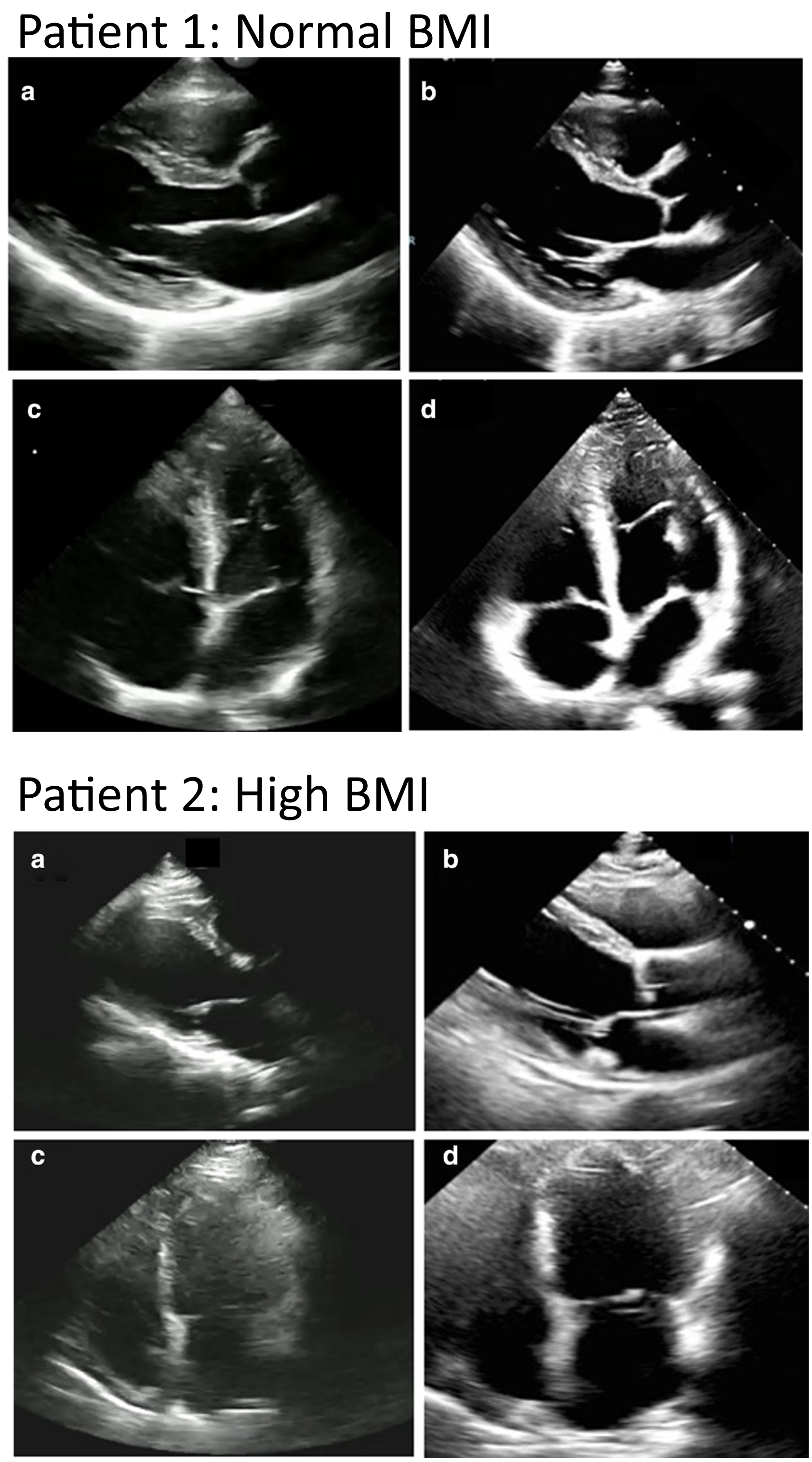

Fig. 2 Side by side parasternal and apical 4 chamber images in Patient 1 with a normal BMI (top 4 panels) compared with Patient 2 with a high BMI (bottom 4 panels) using a point-of-care ultrasound system (panels A and C) and a full platform system (panels B and D). Under conditions which typically challenge image quality even with a full platform system, a point-of-care ultrasound system may have more limitations

noting there are tradeoffs related to the image quality of these small devices and the extent of training of POCUS users (Table 1). When full platform echocardiography systems are available and used by trained and certified sonographers and physicians, they should still be considered the mainstream for high quality diagnostic imaging. Although there is offline software that can be used to do strain imaging on a single handheld device, sophisticated and automated quantitation packages as well as 3D imaging are still largely the domain of the full-featured

Table 1 Comparison of point-of-care ultrasound to standard full platform echocardiogram

Feature	POCUS	Full platform echocardiogram
Goal of exam	Quick look	Definitive
Protocol	Limited, can be part of a multi-organ exam	Complete
Scope of practice	Targeted to certain clinical questions/settings	Comprehensive
Imager	Healthcare provider	Sonographer
Interpretation	Real time, read by healthcare provider acquiring images	Some delay, read by trained echocardiographer
Training	Brief, variable	Extensive, standardized
Machine attributes:		
Size	Ultra-portable, lightweight	Large, bulky, space occupying
Expense	Relatively low, as low as US $2000	Expensive
Image quality	Adequate for many applications, can be limited in obese and vented patients	Highest resolution available in echocardiography
Color flow Doppler	Available	Standard
Spectral Doppler	Limited availability	Standard
3D Echo	Not available	Available
Complex quantitation	Not possible	Standard
Artificial Intelligence	In development	In development

POCUS point-of-care ultrasound

platforms. Importantly, the number of views and scope of image acquisition in a POCUS examination is intentionally limited. For instance, the American Institute of Ultrasound Medicine (AIUM) recommends a 5-view cardiac POCUS examination that includes the parasternal long, parasternal short, apical 4-chamber, subcostal 4-chamber view and subcostal inferior vena cava (IVC) views [13]. Moreover, by nature of its use for specific indications, not all POCUS users have a broad and deep training in image interpretation. For this reason, formal and complete examinations interpreted by echocardiographers are still warranted in many instances. That said, we will next explore the variety of settings and purposes for which cardiac POCUS has been useful and is most commonly employed.

Role of POCUS in Various Settings

POCUS as An Extension of the Physical Examination Cardiac POCUS has been increasingly adopted by a wide variety of users as an extension of the physical exam and clinical assessment. This means that anywhere in which an examination takes place, cardiac POCUS might also take place. This can occur once during an outpatient encounter or serially during an inpatient admission.

POCUS has been shown to aid medical students, internal medicine (IM) residents, and cardiologists in diagnoses that are often inadequately assessed on physical examination. For instance, chamber size such as ventricular hypertrophy and atrial enlargement have been easily identified by POCUS users after brief training [10, 14]. Left ventricular dysfunction can also be identified even with limited training [15]. In the hands of IM residents who had brief training, a POCUS exam using a pocket-sized machine in patients admitted with acute decompensated heart failure best predicted a left ventricular ejection fraction < 40%, even after considering the physical exam, EKG, chest radiography, and brain natriuretic peptide levels. Moreover, the diagnosis by POCUS was made on average 22 h prior to standard echocardiography [16].

Volume assessment at the bedside is often hampered by inexperience with neck vein assessment or limited by obesity. Determination of volume status through evaluation of IVC size and collapsibility using POCUS may be imperfect. However, for IM residents it proved superior to physical examination at estimating right atrial pressure by jugular venous pressure, with a nearly 70% improvement in sensitivity [17]. In the advanced heart failure (HF) clinic, rotating resident physicians were reliably able to acquire quality images of the IVC and accurately assess a patient's volume status [18]. In this study, nearly a quarter of patients initially thought to be euvolemic by physical exam were in fact found to be hypervolemic upon POCUS visualization of the IVC. Moreover, IVC plethora assessed at the bedside once admitted with HF failure can be a useful predictor of both 90-day mortality and HF readmission [19, 20].

In the outpatient primary care setting where the symptoms of clinically important cardiac pathology may first be discovered, POCUS examination can provide a quick, qualitative initial screen for suspected etiologies and identify findings that are unsuspected yet of prognostic importance. Recently, POCUS-assessed left atrial size in the outpatient setting was shown to be associated with significant 5.5-year mortality (odds ratio 2.4 after adjusting for age), while the absence of this sign in patients under the age of 65 and without diabetes was associated with a 1.2% mortality rate at 5.5 years. Using this information prospectively would be expected to reduce the cost associated with echocardiography referral by 33% [21]. This study highlights not only the value of POCUS to detect important findings likely to be missed on exam but also the attractiveness of POCUS as a low-cost way to refine referral for more expensive high-end echocardiograms. Indeed, POCUS may be the only option in underserved settings where a high-end machine may be cost-prohibitive and where POCUS availability may help reduce resulting health care disparities [22].

POCUS in Acute Care Settings With the need for urgent triage and evaluation, POCUS has become embedded in EM practices. In a recently published update, the American College of Emergency Physicians identify 5 main areas of POCUS scope of practice in the emergency department (ED) setting. These include both cardiac and non-cardiac POCUS applications. The five areas include resuscitation, diagnosis, procedural guidance, signs/symptom evaluation, and therapeutic or monitoring indications [23••]. Cardiac applications exemplified within this scope of practice include the use of POCUS to detect the presence of cardiac activity during cardiac arrest, delineate the pathway for a patient presenting with HF (preserved vs reduced LVEF), evaluate the cause of nonspecific dyspnea, aid in the diagnosis and management of cardiac tamponade, and evaluate central venous volume. [24–28]. Cardiac POCUS has also been incorporated into the American Trauma Life Support algorithm via the Focused Assessment with Sonography in Trauma (FAST) protocol [29–32]. In a study of patients with penetrating trauma, POCUS was shown to reduce time to surgical management by just under 30 min compared with a non-POCUS group and was associated with a survival difference of 43% in those who had a POCUS examination compared with those who did not [31].

By nature of the ED setting, one of the most critical uses of cardiac POCUS is for cardiac arrest. A recent meta-analysis of 15 studies investigating the association between cardiac motion and outcomes in adult cardiac arrest found an odds ratio of 12.4 for return of spontaneous circulation when cardiac motion was present. Conversely, 94% of patients who had no cardiac motion on POCUS did not survive to admission [33]. In a multicenter, prospective observational study, cardiac POCUS was used in advanced cardiac life support (ACLS) for out-of-hospital cardiac arrest patients presenting to the ED with PEA arrest or asystole, and cardiac activity detected on POCUS was most associated with survival [34]. Importantly, cardiac POCUS identified a subset of patients who arrested due to massive pulmonary embolism (PE) or cardiac tamponade, and this group had significantly higher rates of survival to hospital discharge than all other cardiac arrest patients (15.4% vs 1.3% respectively). However, it is important not to delay resuscitation efforts when acquiring and interpreting images. Instead, the POCUS user should acquire image(s) quickly and defer interpretation until compressions have resumed [35, 36].

POCUS can also be useful in detecting right ventricular (RV) dilatation and dysfunction in patients with dyspnea and suspected or confirmed PE, a frequent issue that arises in the ED. In a study of bedside cardiac ultrasound in patients presenting to the ED with moderate to high pretest probability of PE, identification of RV dilation had 50% sensitivity, 98% specificity, positive predictive value of 88%, and negative predictive value of 88% for acute PE [37]. In a separate study, a combined strategy of a POCUS examination with venous ultrasound had a sensitivity of 87% and specificity of 69% for the diagnosis of PE. Among patients with dyspnea, the sensitivity rose to 94%. In patients with high probability of PE, the sensitivity rose to 100% [38]. For patients in whom the diagnosis of acute high-risk PE is suspected but definitive computed tomography (CT) pulmonary angiography cannot be performed, cardiac POCUS may justify emergent treatment for PE if no other cause of RV dysfunction is identified [39]. Caution should be exercised when interpreting RV size however, as proper apical views can be challenging to obtain, especially by novice users. Additionally, RV enlargement and dysfunction can be a result of a chronic condition.

Cardiac POCUS applications in the ED setting overlap with some of the common indications in CC medicine such as undifferentiated shock. Perera et al. describe use of cardiac POCUS in a more expanded RUSH (Rapid Ultrasound in Shock) protocol that includes assessment of the “pump” (LV function), the “tank” (IVC assessment of fluid status), and the “pipes” (assessment for aneurysm, dissection or DVT) [40]. Adding lung ultrasound to this protocol (known as extended FAST or EFAST) allows additional evaluation for hemothorax or tension pneumothorax. POCUS for these latter diagnoses performed favorably, and in some cases, better than chest radiography [41–43]. Once shock has been classified, change in IVC size can be used to track fluid responsiveness [44, 45]. This is particularly important in septic patients who require high-volume resuscitation initially but who subsequently develop myocardial depression.

Cardiac POCUS in Medical Education Over the past decade, there has been great interest in integrating ultrasound education to augment training in medical schools and residency programs across the USA. In the undergraduate medical education setting, ultrasound education can be favorably incorporated into the traditional preclinical curriculum to consolidate learning of anatomy, physiology, pathophysiology, and physical examination [46–48]. In fact, first-year medical students who used handheld ultrasound as part of their curriculum reported greater spatial understanding of anatomy and perceived ultrasound to be a valuable tool to use in their future careers [47]. POCUS can also be employed to improve diagnostic skills for upper-level medical students during their clinical rotations. In one study, fourth-year medical students, who spent 1 month on an echocardiography rotation learning to use hand-held cardiac ultrasound, not only developed proficiency in acquisition and interpretation of limited echocardiographic images but also demonstrated improved accuracy in diagnosing cardiac conditions compared with physical exam alone [49].

Some medical schools have moved toward even greater depth of POCUS integration into the core curriculum. Hoppmann et al. reported their institutional implementation of an innovative, longitudinal ultrasound curriculum spanning all 4 years of medical school, laying the groundwork in the first 2 years through ultrasound-enhanced anatomy and pathophysiology courses, applying ultrasound in the third-year core clinical clerkships to diagnose “bread-and-butter” disease, and finally culminating in the fourth year with a capstone course designed to prepare students for internship [50]. Considering available evidence and expert opinion, Johri et al. provide a general model for how to incorporate POCUS into each year of medical school training [51••]. In the first year, cardiac physiology and anatomy may be taught by first introducing basic cardiac POCUS windows. In the second and third years, students may begin to recognize basic cardiac pathology by acquiring images in real patients encountered during clinical clerkships. Lastly, for senior medical students, more sophisticated concepts that require higher level clinical reasoning, such as IVC assessment for fluid responsiveness, may be taught at the bedside with POCUS.

While ultrasound education was first embraced by EM, increasingly, IM and family practice residency programs across the nation have shown interest and have moved toward incorporating structured longitudinal curricula to enrich the training experience [52–55]. The general consensus among IM program directors across the country is that a core POCUS curriculum for IM residents should cover basic cardiopulmonary and abdominal examinations in addition to POCUS-guided procedures and central venous line placement [56]. Additionally, use of ultrasound to improve safety of invasive bedside procedures is well supported by evidence [57–59]. Structured training requires adequate supervision by POCUS-trained faculty and can be accomplished with a mix of dedicated monthly lectures, weekly to monthly 1-h bedside POCUS rounds and regularly scheduled assessments of competency [53]. It bears mention that residents who develop proficiency must continue to regularly practice POCUS in order to reinforce and retain their skills long term. Even in as little as 1 year without dedicated use, operators lost their ability to scan and interpret images correctly [60].

Training Programs Offered by Accredited Echocardiography Laboratories

Although training can be acquired through residency programs or practice-based pathways, pathways to competency are often guided by an accredited echocardiography laboratory. The American Society of Echocardiography (ASE) recently released recommendations to guide accredited echocardiography laboratories in developing cardiac POCUS training programs for non-cardiologists [61••]. Trainees may come from diverse academic disciplines and practice settings (such as hospital medicine, EM, general IM or CC) and may also differ in their level of training (medical student, resident, or attending physician), and consequently, prior knowledge of ultrasound. Thus, it is crucial for echocardiography staff to assess an individual’s unique needs beforehand and establish clear-cut objectives to deliver an effective POCUS curriculum. In general, the curriculum should integrate cardiac anatomy and cardiac pathophysiology within the trainee’s scope of practice through in-person teaching and online didactics, direct hands-on experience with scanning and supervised image interpretation. The ASE statement recommends grouping trainees into the following 4 experience level categories: (1) trainees with no previous experience, (2) trainees with non-systematic informal training, (3) trainees with limited formal training, or (4) trainees with previous formal training (i.e., as part of a CC medicine or EM fellowship). With such a diverse group of potential learners, an optimal training program must maintain the flexibility to tailor goals and objectives, rather than applying a blanket “one size fits all” teaching model. For example, a novice learner with no prior ultrasound training may benefit most from a beginner-level curriculum that introduces basic concepts and general applications of cardiac ultrasound, goes over limited cardiac POCUS views, and emphasizes direct observation and repetitive, hands-on practice with scanning. However, operators who already possess a degree of proficiency with the fundamentals of POCUS and experience in image acquisition from prior training may find it more useful to hone their interpretative skills, delving into more advanced and nuanced interpretation under the supervision of a skilled cardiologist.

Similarly, the intended use of POCUS has some impact on the composition and expectations of the training program. For example, a tailored didactic curriculum as well as training program of at least 2 weeks and a portfolio of 30 proctored cardiac POCUS scans might be appropriate for those seeking to use POCUS as an extension of the physical exam. On the other hand, a similar curriculum with more than 100 weeks of training and a cardiac POCUS portfolio of 30–50 proctored scans with image review in comparison to a standard complete echocardiogram may be more pertinent for users of cardiac POCUS for quick bedside diagnosis, decision-making and triage. For more intensive training of POCUS in the context of CC use, the process of training and certification is more intensive.

Common to all training scenarios, curriculum should delineate the appropriate use of POCUS and help trainees to recognize device limitations. Additionally, careful attention to common errors of exclusion and omission as well as interpretation errors is imperative. Finally, the incorporation of the findings into the clinical context of the patient at hand is important. POCUS users must understand when to order a comprehensive echocardiogram to either further investigate the POCUS findings or for a more thorough examination when the index of suspicion for cardiac pathology remains high despite an unrevealing POCUS exam.

Responsible Use: Ongoing Competency Assessment and Quality Assurance

As a responsible user of POCUS, one must ensure adequate training and ongoing competency. While POCUS residency training guidelines in many medical disciplines have led to increased utilization of POCUS, the framework for ongoing competency and quality assurance is less well established. As many hospitals are consolidated into large health systems, the challenge of competency and quality assurance oversight across many sites is amplified. One large hospital system's approach to credentialing EM physicians across an 11-hospital system was to automatically credential any EM physician with POCUS training embedded in their residency or who had undergone practice-based training prior to employment [62]. For those remaining, a 2-tiered competency based on free coursework offered internally along with practice-based training was offered. To achieve programmatic success, an infrastructure for standardization of ultrasound machine type, orders sets, and documentation and remote QA was set in place. Even with that supportive structure in place, only about half of the physicians who enrolled in the coursework completed the practice-based training to attain basic competency and only half of those sought additional training directed toward achieving intermediate competency skill set, which included cardiac POCUS. Yet, the number of POCUS studies performed continued to rise. This study highlights both the potential opportunity as well as difficulties in practice-based training and ongoing quality assurance in the clinical setting.

For specialists newer to POCUS such as those in hospital medicine, training programs and paths to competency may be even less well established which, given the availability of handheld echocardiography machines on clinical units, presents a potential safety issue. For instance, one survey of hospitalists at a single center demonstrated that 16% of providers were using POCUS but only a fraction felt confident in their skill set (both acquisition and interpretation). A large proportion of users had a knowledge deficit regarding accepted uses for POCUS and 21% were using POCUS for uses that are generally not recommended for POCUS examinations such as evaluation of aortic valve disease [63]. Some hospital medicine programs have established a multidisciplinary infrastructure to standardize credentialing and ongoing quality assurance. Disappointingly, in one study the POCUS median assessment score after a 3-day training course was 90%, yet the score dropped to 65% prior to a 1-day refresher course. Of note, the decline was substantially lower in users who created a POCUS portfolio suggesting that this, or alternatively, ongoing scanning is an important component to retention of POCUS skills and must be supported by the institution or health system [64, 65].

Future Directions

The essential skills that are required to be a proficient and competent POCUS user include an understanding of the indications and limitations of POCUS, image acquisition, image interpretation, and integration of the information gleaned into a given patient's clinical circumstance. Course work can address the indications and limitations, while clinical judgment and experience help to cultivate the integration component of proficiency. However, advancement in image acquisition and interpretation are areas in which artificial intelligence can be potentially helpful, particularly in specialties where POCUS training has not been part of residency training. Software to assist image acquisition has already been developed and is currently FDA-approved to be marketed. Additionally, there are preliminary reports of successful integration of GPS with POCUS systems to guide a novice imager to acquire a satisfactory echocardiographic exam.

On the other side of the equation is the inexperienced interpreter. One solution to overcome this deficit would be employment of point-of-care telemedicine. Telemedicine has been successfully used in a variety of settings for many types of ultrasound images, including cardiac [66]. However, such a system requires consistent telecommunication. To overcome this and offer interpretation assistance at the point of care, early investigations involving several convolutional neural networks (CNN) have shown promise. Contrary to what has been found in other studies using artificial intelligence for non-ultrasound images, the simpler rather than more complex CNNs may be more apt to perform well on the greyscale grainy images characteristic of ultrasound [67]. One commercially available product is harnessing POCUS images on a cloud-based storage system to facilitate deep learning that hopefully will eventually be employed to aid the inexperienced user. This type of artificial intelligence may be particularly relevant in resource-limited settings where telemedicine options may not be readily available or affordable. While POCUS presently remains in the hands of health care providers, with development of artificial intelligence in conjunction with low cost devices, the future may be one where POCUS devices become the latest in-demand electronics for personal use and tele-health visits might one day include self-acquired images transferred to the provider.

Conclusions

Cardiac POCUS has advanced substantially over the past 2 decades, aided both by improvement in small ultrasound device technology and also integration into residency training. Its use has expanded beyond the emergency and CC realms to the internal and family medicine arenas. Although criteria for competency and accreditation for this subspecialty of ultrasound are not standardized across all subspecialties, the training one obtains for a given specialty must be augmented by continuous quality assurance to ensure responsible use. Artificial intelligence will likely play a role in the future of POCUS to improved quality in image acquisition and interpretation.

Compliance with Ethical Standards

Conflict of Interest Drs. Jeanne M. DeCara and Linda Lee declare they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with animal subjects performed by any of the authors. All reported studies with human subjects performed by the authors have been previously published and complied with all applicable ethical standards and have been IRB approved.

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