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The Practice and Implications of Finding Fluid During Point-of-Care Ultrasonography
A Review

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IMPORTANCE Point-of-care ultrasonography (POCUS) is an increasingly affordable and portable technology that is an important part of 21st-century medicine. When appropriately used, POCUS has the potential to expedite diagnosis and improve procedural success and safety. POCUS is now being adopted in medical education as early as the first year of medical school. While potentially powerful and versatile, POCUS is a user-dependent technology that has not been formalized or standardized yet within internal medicine residency training programs. Physicians and residency directors are trying to determine whether to incorporate POCUS, and if so, how. In this systematic review, basic concepts and applications of POCUS are examined, as are issues surrounding training and implementation.

OBSERVATIONS A key use of POCUS is to detect fluid, and this is a cornerstone of POCUS teaching. Even in inexperienced hands, POCUS has shown to be more sensitive and specific than physical examination for conditions such as ascites, pleural effusion, and pericardial effusion. Detecting fluid requires a basic understanding of ultrasonography operation, sonographic anatomy, and probe orientation. Once fluid is localized, ultrasonographic guidance can increase success and decrease complications of common procedures such as thoracentesis or paracentesis.

CONCLUSIONS AND RELEVANCE POCUS can augment physical examination and procedural efficacy but requires appropriate education and program setup. As POCUS continues to spread, internal medicine physicians need to clarify how they intend to use this technology. Equipment is now increasingly accessible, but programs need to determine how to allocate time and resources to training, clinical use, and quality assurance. Programs that develop robust implementation processes that establish proper scope of practice and include quality assurance that use image archival and feedback can ensure POCUS will positively impact patient care across hospital systems.

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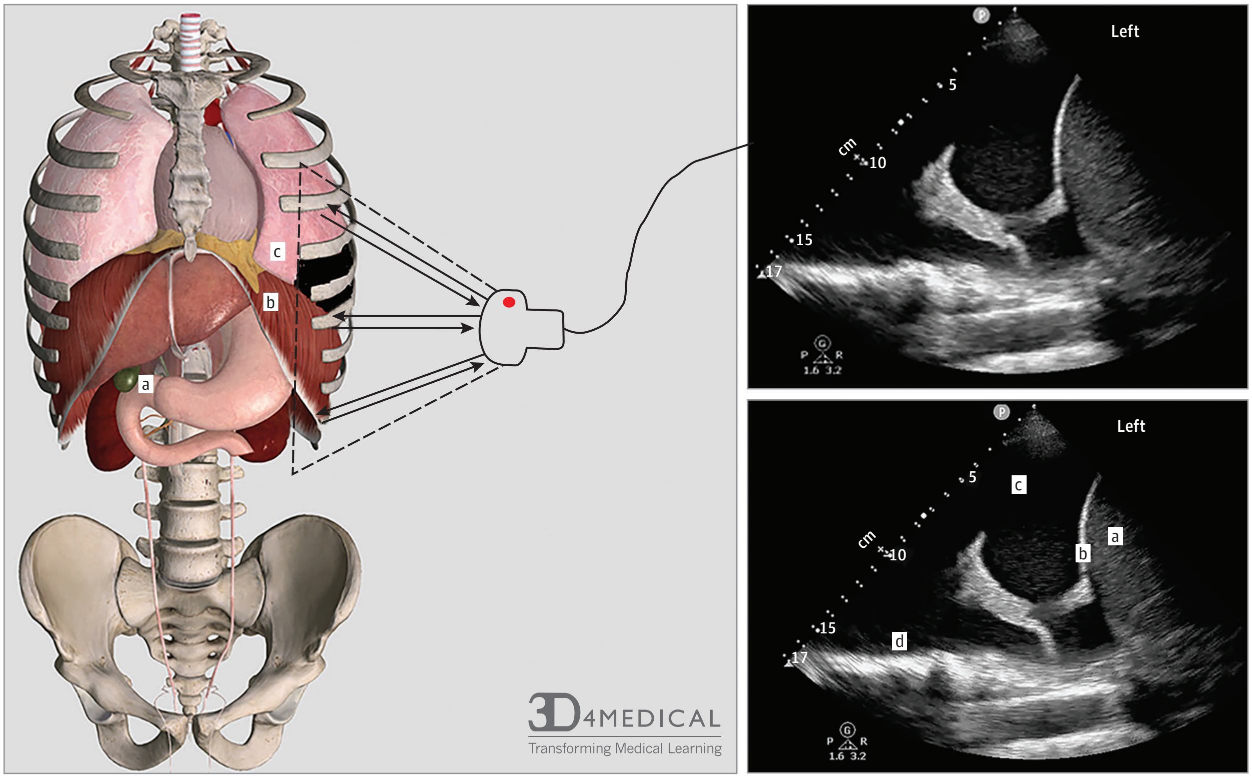
Point-of-care ultrasonography (POCUS)—ultrasonography used by a clinician at the bedside to aid in diagnosis and procedural guidance—continues to spread throughout medical specialties and medical education.[1] POCUS has been shown to decrease hospital lengths of stay, reduce health care costs,[2,3] increase procedural safety and success,[4] and improve diagnostic accuracy.[5] As the equipment becomes increasingly accessible, a basic understanding of the principles and use of this technology is an essential part of practicing and teaching 21st-century medicine.[6]

POCUS has been compared with the stethoscope.[7,8] Just as the stethoscope improved upon existing examination techniques, POCUS used by medical students and residents with focused training has been shown to offer more diagnostic accuracy than either their own physical examinations or those of experienced clinicians.[9-11] However, POCUS requires dedicated practice to correctly obtain and interpret difficult images, often uses image archival, and can be viewed as a distinct diagnostic entity rather than solely part of the physical examination. POCUS should not be viewed as a replacement of the physical examination; rather as a tool that can augment diagnostic capabilities.

Performing high-quality POCUS requires comprehension of basic concepts in ultrasonography, knowledge of normal and pathologic anatomy, and skill in both acquiring and interpreting images. The most straightforward use of diagnostic ultrasonography is in finding fluid. Localization of fluid using ultrasonography can make procedures more safe and effective. We aim to review the principles of diagnostic and procedural ultrasonography with a focus on its utility in finding and accessing fluid in several key thoracic and abdominal areas as an adjunct to basic diagnosis and procedures. Appropriate use of POCUS requires investment in equipment, adequate

Figure 1. Evaluation of Left Pleural Effusion



A left-sided pleural effusion found using a phased array probe. The probe has been placed in coronal plane with the probe indicator (red dot) aimed toward the patient's head. Solid black arrows represent scan lines created by sound waves emitted from and returning to the probe - the piezoelectric effect. When scanning, ultrasound gel is placed on the probe to create an air-free interface between the probe and patient's skin. The ultrasound frame shows the indicator ("P") on the upper left side of the image and contains (a) spleen, (b) diaphragm, (c) anechoic space above the diaphragm indicating fluid in the pleural cavity, and (d) vertebrae of the thoracic spine seen through pleural fluid (ie, the "spine sign"). The density seen within the anechoic effusion is consolidated lung parenchyma. The image on the left was used with permission from 3D4Medical.

education and training, and understanding limitations of both the technology and the user. We will discuss aspects of education, training, competency, and reimbursement.

Basic Ultrasonography Concepts

Diagnostic ultrasonography uses sound waves in the MHz range, far above the upper end of human hearing (20 kHz). Piezoelectric crystals on the surface of ultrasound probes interface between mechanical sound waves and electrical signals, with each crystal both sending and receiving sound waves, represented graphically as "scan lines" (**Figure 1**). Hundreds of scan lines are then converted to a 2-dimensional (2-D) image or "frame" that is refreshed (typically 20 or more times per second) to create a moving image. This 2-D or "B-mode" scan forms a plane that can be directed to interrogate the body in whatever direction is desired.

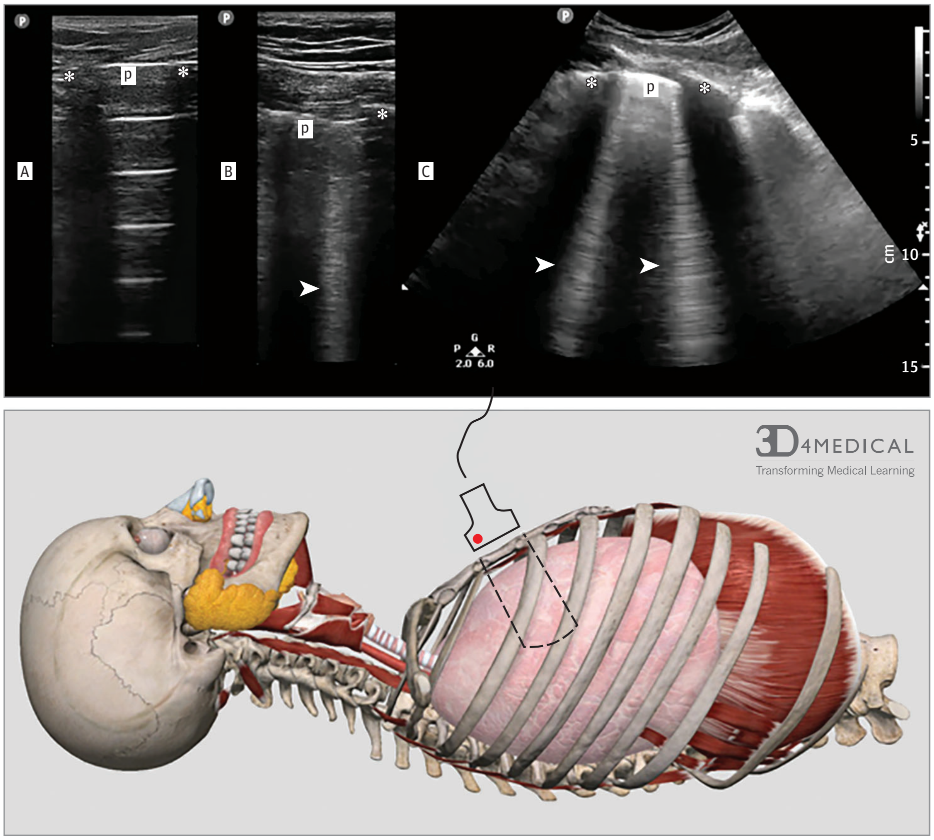
This versatility requires the operator to have a thorough understanding of probe orientation relative to anatomic planes and to the screen display. Each probe has an "indicator" that corresponds to a side of the screen. By convention in radiology imaging and most POCUS, the indicator corresponds to the left side of the screen as it is viewed by the operator. Of note, cardiology has adopted an opposite convention that can cause confusion when integrated cardiac and abdominal examinations are performed.[12]

Probe selection is determined based on the size and shape of the probe face ("footprint") as well as frequency, with higher frequency ultrasound providing better resolution but poorer penetration. There are many types of probes, but basic types used in POCUS include phased array (cardiac), linear (vascular), and curvilinear (abdominal) transducers. A phased array probe uses a lower frequency range (1-5 MHz) and directs an electronically steered beam that originates from a single point to generate images, allowing interrogation between ribs specifically for performing cardiac evaluations. A linear probe is typically high frequency (approximately 5-12 MHz and higher) and can be used to visualize superficial structures such as skin, soft tissue, and vessels. A curvilinear probe also uses lower frequency (approximately 1-6 MHz) and is typically used for abdominal and pelvic scanning which require deeper penetration.

Anatomic structures demonstrate varying degrees of echogenicity, or brightness, when visualized with ultrasonography. Fluid is anechoic and appears black. Solid organs such as the heart, liver, and spleen appear as varying shades of gray. Hyperechoic structures appear very white and include tendons, diaphragm, pericardium, air, and bone. Air and bone are impediments to ultrasound and will cause artifacts such as scatter (air) or shadowing (bone).

Ultrasonography can also incorporate techniques such as Doppler, speckle tracking, contrast enhancement, oscillation, and

Figure 2. Interrogating the Pleural Line



The probe has been placed in a sagittal orientation at the midclavicular line, with the probe indicator (red dot) aimed toward the patient's head. An asterisk indicates bony rib cortex with subsequent bone shadow. The "p" indicates the pleural line. The solid white arrowheads indicate "B lines." A, A linear probe showing normal sonographic lung appearance with horizontal artifacts equidistant from the pleural line, called "A lines." B, A linear probe demonstrating abnormal B lines indicative of alveolar interstitial syndrome. C, A curvilinear probe revealing abnormal B lines across several intercostal spaces, indicating interstitial fluid. The image on the bottom was used with permission from 3D4Medical.

3-dimensional (3-D) visualization; however, the majority of POCUS is performed using basic 2-D ultrasonography.

Pleural Effusion

In 1976, ultrasound was shown to be able to detect as little as 3 to 5 mL of fluid and has been used as the gold standard in evaluating other radiographic techniques.[13,14] A detailed physical examination can approach the accuracy of chest radiography for pleural effusion but only with larger amounts of fluid (more than 200 cc).[15] Ultrasonography is more accurate than either physical examination or chest radiography for smaller effusions.[15-17] POCUS for pleural effusion has demonstrated high accuracy across practice environments and can greatly improve workflow expediency, time to definitive treatment, and decreased hospital lengths of stay over consultant-performed imaging.[18,19]

Pleural effusion is best detected by placing a curvilinear or phased array probe in the midaxillary line with the indicator directed toward the patient's head, yielding an image in the coronal plane (Figure 1). The liver or spleen, kidney, and diaphragm should be identified. In a normal lung, neither lung parenchyma nor thoracic spine can be visualized owing to scattering of sound waves by air. A "mirror image" artifact, in which the area above the diaphragm appears to look like liver or spleen tissue, is normal and indicates absence of pleural effusion. When present, fluid will be seen as an anechoic (black) triangular area superior to the diaphragm. Presence of fluid allows visualization of the vertebral bodies or proximal ribs to continue into the thorax, creating the "spine sign." With larger amounts of fluid, consolidated (or atelectatic) lung tissue may be seen moving within the anechoic fluid. Ultrasonography can be used to quantify the amount of fluid, and the presence of septations or echogenic material within the fluid may predict exudative effusions.[20,21]

Pulmonary Edema

Historically, ultrasonography of the lung had been thought impossible due to interference from air. However, ultrasound can visualize the pleural line where the interface between parietal and visceral pleura creates a sliding appearance of lung pleura against the chest wall (**Video**, 1).[22] French intensivist Daniel Lichtenstein described the use of a reverberation artifact at the pleural line known as a "B-line." This was an alphabetically chosen nomenclature and is not to be confused with Kerley B lines that appear on chest radiography. Ultrasonography B-lines occur owing to fluid-air interfaces within the interstitial spaces that cause sound beams to bounce back and forth, creating hyperechoic reverberation artifacts that extend from the pleural line to the bottom of the screen (**Figure 2**). Presence of abnormal interstitial fluid gave rise to the term alveolar interstitial syndrome, which comprises a constellation of pathologies that cause pulmonary edema or fibrosis (**Video**, 2) and is identified by detection of B-lines.[23]

Clinically, bilateral B-lines are present with both cardiogenic and noncardiogenic pulmonary edema, diffuse interstitial pneumonia or pneumonitis, acute respiratory distress syndrome, and diffuse parenchymal fibrosis. Localized or unilateral B-lines may be seen with focal pneumonias, neoplasms, or pulmonary contusions.[24-26] Most often in the acute medical setting, assessment for B-lines is performed when there is concern for fluid overload states or decompensated heart failure. A systematic review of 7 studies[27] performed in emergency departments, intensive care units, and the prehospital arena showed a 94.1% sensitivity and 92.4% specificity when using B-lines to diagnose acute cardiogenic pulmonary edema. B-line evaluation improved accuracy for diagnosis of pulmonary edema over other available bedside tools, suggesting expedited diagnosis in cases of undifferentiated dyspnea. Another investigation[28] found that residual B-lines indicating pulmonary congestion at the time of hospital discharge was an independent predictor of short-term mortality and rehospitalization in patients with heart failure, with significant improvement in prediction over other clinical measures such as New York Heart Association class combined with brain natriuretic peptide or inferior vena cava diameter.[28]

Often, a curvilinear or phased array probe will be used when assessing for alveolar interstitial syndrome. A linear probe is best for visualizing the pleural line, but may overemphasize artifacts by not evaluating a full depth of field. While multiple areas can be interrogated, the most accessible and high-yield ultrasonography window is in the superior anterior mid-clavicular line at the second or third rib interspace. The probe should be placed in sagittal orientation with the indicator toward the patient's head, allowing ribs to be used as landmarks for the pleural line (Figure 2).[29]

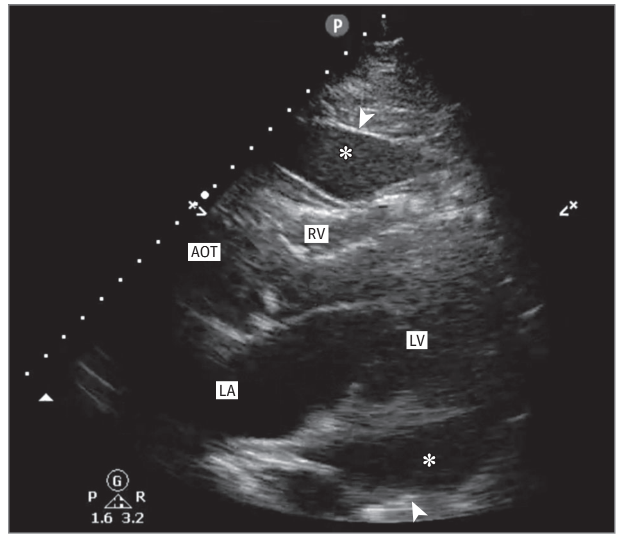
Pericardial Effusion

Pericardial effusion is a common and potentially lethal diagnosis with nonspecific symptoms.[30,31] POCUS detection of pericardial effusion was the first goal of focused cardiac ultrasonography and has been incorporated into multiple ultrasonography protocols,[32] such as the Focused Assessment with Sonography and Trauma (FAST) and the Rapid Ultrasound in Shock and Hypotension (RUSH) examinations, as well as integrated examinations for undifferentiated dyspnea.[33-35] Presence of any degree of pericardial effusion is an independent predictor of mortality,[36] and up to one-third of large effusions will progress to tamponade.[30,37]

The accuracy of the history and physical examination to detect pericardial effusion is limited. The Beck classic triad of jugular venous distension, hypotension, and muffled heart sounds is a late finding and is neither sensitive nor specific for tamponade.[33,38,39] POCUS is highly accurate for detecting pericardial effusions of any size and can suggest tamponade physiology prior to vital sign changes or physical examination findings.[39,40]

A phased array probe is used in the evaluation of pericardial effusions; a curvilinear probe can also be used in the subxiphoid view. The pericardium appears as a hyperechoic layer surrounding the heart, and an effusion will appear as an anechoic or hypoechoic space between the visceral and parietal layers. While large effusions are often straightforward to diagnose, it is important to be aware of the normal appearance of pericardial fatty tissue to avoid overcalling an effusion (**Video**, 3), particularly when there is only a hypoechoic area in the anterior portion of a parasternal cardiac view. Effusions generally collect posteriorly and inferiorly in a supine patient and will be seen in the far field of a parasternal view or the near field of a subxiphoid view (**Video**, 4). Pleural effusions may also be seen adjacent to the heart but will not interpose themselves between the heart and the descending aorta (**Video**, 5). Basic echocardiographic features suggestive of tamponade include a pericardial effusion with systolic collapse of the right atrium, diastolic collapse of the right ventricle (**Figure 3**) (**Video**, 6 and 7), and distension of the inferior vena cava (the sonographic equivalent of jugular venous distension).[33]

Figure 3. Parasternal Long Axis View of a Pericardial Effusion Causing Tamponade



The right ventricular free wall is compressed during diastole. An asterisk indicates anechoic pericardial fluid. Arrowheads point to the hyperechoic pericardium. AOT indicates aortic outflow tract; LA, left atrium; LV, left ventricle; RV, right ventricle.

Peritoneal Fluid

Ultrasonography is considered the gold standard for diagnosing ascites and can identify as little as 100 mL of fluid, while physical examination is estimated to be only 45% to 84% sensitive and 59% to 90% specific, with overall accuracy under 60%.[41,42] The physical examination may be particularly limited when the volume of ascites is small or the patient is obese.[43] As early as 1987, a handheld ultrasound unit was noted to outperform experienced clinicians in the accurate identification of ascites.[44]

The curvilinear probe should be used to assess for intraperitoneal fluid, but a phased array probe may also suffice. Typically, the examination begins with the probe placed in the right flank at the mid-axillary line using a coronal orientation. The diaphragm, liver tip, and hepatorenal interface should be seen. Fluid usually appears as an anechoic stripe located in the recess between the liver and the kidney, known as the Morison pouch (**Video**, 8). It may also appear subdiaphragmatically, around the tip of the liver, or adjacent to the inferior pole of the kidney. Left upper quadrant positioning is similar, and the important areas to capture for fluid detection are the diaphragm, spleen tip, splenorenal recess, and the inferior left kidney (**Video**, 9). Pelvic views offer imaging of the most dependent areas of fluid collection and may be the region of first fluid localization. Fluid generally falls posteroinferiorly or lateral to the bladder (**Video**, 10).[45]

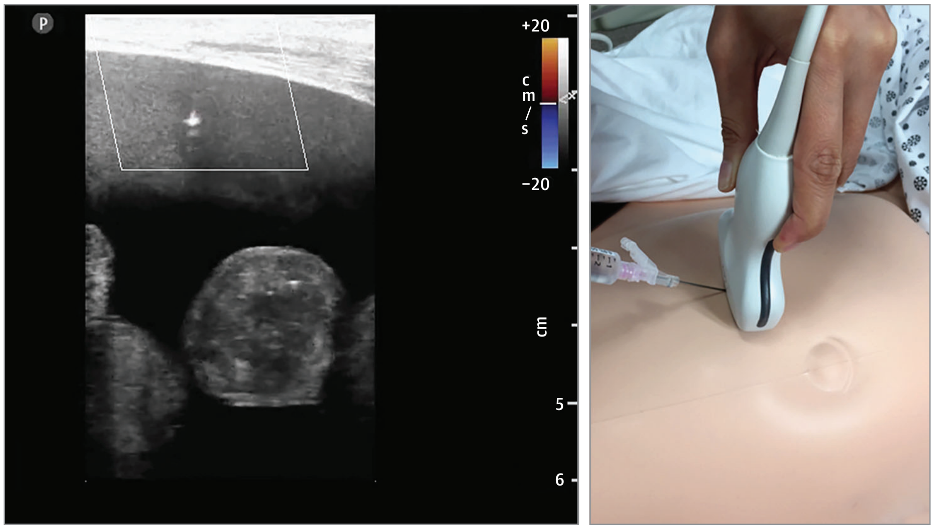
Ultrasonography-Guided Fluid Removal (Paracentesis and Thoracentesis)

Ultrasonographic guidance helps avoid solid organ or vascular injury and increases success of procedures by identifying the largest

Figure 4. Ultrasonography-Guided Paracentesis

A Color flow Doppler

B Clinical photograph



A, Color flow Doppler has been applied to linear probe imaging during paracentesis to evaluate for inferior epigastric artery location. The absence of color indicates that there are no vessels in the region of needle entry. B, The needle tip is seen as a hyperechoic circle anteriorly within the box, typical of the out-of-plane approach to performing paracentesis. Loops of bowel are seen posteriorly. The gray appearance of the abdominal fluid is due to malignant hemorrhagic ascites. The adjacent image shows an out-of-plane approach, where needle insertion is perpendicular to the orientation of the probe.

areas of fluid closest to the skin surface. Ultrasonography also anticipates unsuccessful attempts due to complicated loculated effusions, septations, or paucity of fluid.[5,46,47]

All 3 probes may be used in procedure performance; the curvilinear and phased array may provide better overall delineation of fluid, while the linear probe provides more superficial detail. There are 2 approaches to ultrasonographic guidance: static and dynamic. With static guidance, ultrasonography is used to find the safest and largest area of fluid, then the overlying skin is marked. The proceduralist uses that mark as the needle entry site without any further use of ultrasonography. Under dynamic performance, the operator watches needle entry using either an in-plane approach parallel with the direction of the probe, or an out-of-plane approach with needle insertion perpendicular to probe direction.[47,48]

Paracentesis (**Figure 4**) is a common procedure and is recommended in all patients presenting with new-onset ascites. However, it may be complicated by infection, visceral injury, hypotension, and bleeding.[49,50] POCUS has been shown to enhance the success of paracentesis in a prospective randomized trial[5] compared with traditional landmark technique. A retrospective study of nearly 70 000 patients who received paracenteses showed lower rates of bleeding, decreased hospital length of stay, and cost savings when ultrasonographic guidance was used.[2]

Ultrasonography-guided thoracentesis reduces morbidity associated with procedural complications, chiefly, pneumothorax.[48,51] Visualizing real-time lung movement within a respiratory cycle decreases visceral injury and increases success of drainage even after previously failed attempts.[52] Societal guidelines now recognize and include ultrasonography as an integral part of thoracentesis performance.[53,54] Use of ultrasonography vs a blind technique has demonstrated both cost savings and reduced hospital length of stay.[2]

If physicians are comfortable performing procedures such as thoracentesis and paracentesis blind (ie, without the help of devices), then adding ultrasonography is often straightforward. Simulation training using ultrasound phantoms may be particularly relevant to developing clinical success.[55] Educational efforts to define competencies needed for ultrasonography-guided procedures have been suggested to aid in design of effective training programs.[56]

Training and Education

POCUS is a user-dependent technology in 2 aspects: image acquisition and image interpretation. While factors such as machine performance and patient body habitus influence the quality of an ultrasound image, the ability to acquire an optimal image is highly dependent on operator skill. Furthermore, ultrasound image interpretation requires a thorough knowledge of anatomy, physiology, and pathology as related to the patient's clinical context. Appropriate use of POCUS requires adequate training and assessment of competency to potentially improve efficiency without sacrificing patient safety.[56] It is also important to define the scope of use of POCUS, which may include factors such as the clinical scenario, resource availability, time sensitivity of the condition, and user experience and competency.

As of 2014, 48 of 173 US medical schools (28%) reported having a formal curriculum for ultrasonography in medical education.[57] Similarly, in 2013 only about one-fourth of entering residents reported exposure to bedside ultrasonography, with fewer than half using it in a simulated setting.[58] While opportunities for POCUS training during medical school are expanding, training opportunities during internal medicine residency and for general internists remain limited.[6] A 2012 survey of internal medicine program directors[59] revealed that only one-fourth of responding programs had ultrasonography training for their house staff, but an additional 25% planned on establishing curricula. While intensivist and pulmonologist groups have started to define proficiency standards through the American College of Chest Physicians and milestones for critical care fellowship curricula, no standards for general internal medicine POCUS training currently exist.[60,61] Cost, unavailability of equipment, faculty inexperience, and inadequate time to obtain training have been cited as reasons internal medicine has been a slow adopter of POCUS.[62]

A process for handling incidental findings discovered through POCUS should be instituted. Established programs have created verbal or written scripts which advise follow up imaging arranged through either outpatient means or obtained while the patient is in the hospital. A retrospective study of 200 Emergency Department patients identified 51 patients with incidental findings on abdominal FAST scanning which were performed for both trauma and nontraumatic reasons. Thirty-five patients received additional imaging while in the department with a majority of incidental findings confirmed on subsequent imaging. POCUS results of incidental findings were reported to the primary care doctors of patients who did not receive additional imaging. However, this study did not include information on the severity or consequence of incidental findings, and there is a paucity of literature regarding this issue.[63]

Ideally, POCUS would be incorporated longitudinally into residency training and overseen by experienced faculty, although this may take time to develop. Learning ultrasonography requires didactic and hands-on instruction combined with proctored clinical use.[6] Intensive continuing medical education courses offer an introduction to use of ultrasonography; however, there is less knowledge decay when these courses are implemented longitudinally and incorporated clinically such as in "ultrasonography rounds."[64,65] In addition to nationally available POCUS courses, in-house faculty development opportunities are being created that increase faculty confidence in both ultrasonography performance and image interpretation.[62] POCUS fellowships, which have emerged primarily from emergency medicine programs, are starting to accept internal medicine graduates. With residents in internal medicine looking for programs offering POCUS training, internal medicine residency programs that offer POCUS experience may become more competitive.

POCUS Billing, Credentialing, and Clinical Integration

POCUS is expanding during a time of uncertainty about clinician payments and value-based compensation. Radiologists are most familiar with billing for imaging studies and the associated requirements: maintaining an image archival system, developing expertise in billing compliance, and building medicolegal protections. Fee-for-service billing for POCUS is similar to billing for any other ultrasound study, which involves both a technical fee (for equipment and infrastructure) and a professional fee (for interpretation).[66] While billing can be an important source of revenue to sustain the capital, labor and ongoing maintenance of such a program, it is important that user competence, scope of use, and quality assurance mechanisms be established prior to engaging in billing.

In a hospital setting, privileging is often required to perform POCUS. Working within an institution to develop guidelines for use of POCUS can ensure that expectations are appropriately set for all clinicians.[67] A successful POCUS program must have a rigorous quality assurance component including archival of images and interpretations, confirmation that all privileged personnel are adequately trained, and assurance that studies are followed up for clinical or alternative imaging correlation.

Private and public payers have routinely emphasized value over volume, even before passage of the Patient Protection and Affordable Care Act. With the passage of the Medicare Access and CHIP Reauthorization Act in 2015, there is an increasing incentive to develop programs that reduce total costs of care, while maintaining or improving quality and outcomes. POCUS, when established and performed properly, represents a meaningful step in this direction. Its capital costs are relatively low and imaging is immediately available in the patient's room rather than relying on transport of either the patient or large equipment. Therefore, patient workflow can be improved with faster diagnosis, management, and general care delivery.

Conclusions

The concept of finding fluid using POCUS can be used as a building block for learning image acquisition techniques and developing interpretation accuracy. The spectrum of fluid detection spans a continuum from minor to emergent, and its appearance can be subtle. The implications of this apply to care in a wide range of settings, from family practice to hospitalist and subspecialty environments, and in critical care or emergency department arenas. Additionally, POCUS can improve the safety and success of accessing fluid-filled spaces through procedural guidance, and societal guidelines increasingly recognize ultrasonographic guidance as standard of care. Learning and using POCUS effectively requires time, equipment and interdisciplinary collaboration, but this investment can provide immense benefits.

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