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# Ultrasound and the Pregnant Patient

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**Abstract** Ultrasound is widely used in all medical specialties. There are multiple reasons for the increased use of ultrasound including its ease of use, point-of-care determination, and rapid confirmation of clinical diagnoses. Ultrasound is a valuable tool that can assist in the diagnosis and treatment of obstetric patients for both obstetric and non-obstetric conditions. In this review, we will describe the common applications for point-of-care ultrasound in the perioperative period including intravenous placement and guidance for vascular access, head and neck evaluation (airway exam, difficult airway), lung and chest evaluation (pleural effusions, pneumonia), echocardiography (transthoracic echocardiography and transesophageal echocardiography), evaluation of gastric contents, postoperative pain management (transversus abdominis plane block) and regional anesthesia, neuraxial (spinal and epidural conduction), bladder volume estimation, and trauma evaluation (focused assessment with sonography in trauma) exam for detection of intraperitoneal fluid and hemorrhage.

**Keywords** Ultrasound · Obstetric anesthesia · Point-of-care ultrasound (POCUS) · Echocardiography · FAST exam · ROSE exam · Lung ultrasound · Ultrasound-guided nerve block · Ultrasound-guided transversus abdominis plane (TAP) block · Focused assessment with sonography for obstetrics (FASO) · 3-D ultrasound

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## Introduction

The use of ultrasound is growing considerably and becoming more widespread in all medical specialties. There are multiple reasons for the increased use of ultrasound including its ease of use, point-of-care determination, and rapid confirmation of clinical diagnoses [1••]. Ultrasound is a valuable tool that can assist in the diagnosis and treatment of obstetric patients for both obstetric and non-obstetric conditions. Our aim is to discuss the multitude of different uses for ultrasound guidance (USG) in both diagnosis and intervention during pregnancy.

Point-of-care ultrasound (POCUS) is the use of ultrasound imaging to assist patient management at the bedside (i.e., at the point of care). In the perioperative period, POCUS should be performed by appropriately trained anesthesiologists. It has been demonstrated that POCUS may improve patient safety in the perioperative period [2]. With the development of the Perioperative Surgical Home model and the increasing utilization of Enhanced Recovery after Surgery (ERAS) programs, the need for anesthesiologists with training in POCUS is likely to substantially increase in the future [1••]. POCUS is useful not only as a diagnostic tool but also for procedural guidance.

In this review, we will describe the common applications for POCUS in the perioperative period including intravenous (IV) placement and guidance for other vascular access, head and neck evaluation (airway exam, difficult airway), lung and chest evaluation (pleural effusions, pneumonia), echocardiography (transthoracic echocardiography [TTE] and transesophageal echocardiography [TEE]), evaluation of gastric contents, postoperative pain management (transversus abdominis plane (TAP) block) and regional anesthesia, neuraxial (spinal and epidural conduction), bladder volume estimation, and trauma evaluation (focused assessment with sonography in trauma (FAST)) exam for detection of intraperitoneal fluid and hemorrhage.

## Extremities—Intravenous Placement

Comorbidities such as preeclampsia, obesity, diabetes, renal insufficiency, and sickle cell disease may contribute to challenging IV catheter placement in the obstetric population. Parturients who present for vaginal labor and delivery or cesarean delivery should have at least one large bore peripheral intravenous catheter, commonly defined as 18 gauge or larger. These IVs are typically placed by nursing staff at most facilities with anesthesia providers as backup. A high-frequency linear probe similar to what is typically used for central line placement can be utilized for difficult peripheral IV catheter placement patients in both the out-of-plane and in-plane approach. Multiple recent studies have shown that USG increases the success rate of IV placement in patients who were identified as difficult for peripheral venous access [3–5].

Probe selection: high-frequency 13–6-MHz linear array transducer.

## Head and Neck (Airway)

Pregnancy poses a unique situation for airway management. There is significantly more difficulty in visualizing the airway and related structures due to multiple factors, most importantly, airway edema and mucosal swelling. The parturient is also at increased risk for hypoxemia and apnea secondary to an increased minute ventilation (MV) and decreased functional residual capacity (FRC) compared to the non-pregnant adult [6, 7]. These increased risks can be further exacerbated by IV fluid administration, oxytocin infusion, and Valsalva maneuvers during the second stage of delivery [8, 9].

Difficult airway assessment and intervention can be done using POCUS at the bedside. Airway structures that are not easily identified by palpation can be visualized by USG. Ezri et al. [10] found on ultrasound guided evaluation that the distance from the skin to the anterior aspect of trachea at the level of the vocal cord was significantly greater in patients with difficult laryngoscopy. The hyomental distance ratio (defined as this distance measured with the head in the neutral position to the head hyperextended) ultrasonographically measured can be used to distinguish patients with easy versus difficult laryngoscopy [11]. In the situation of "cannot ventilate and cannot intubate," ultrasound can help to identify the cricothyroid membrane to facilitate emergent cricothyroidotomy (Fig. 1) [12].

Tracheal ultrasound (also known as the tracheal rapid ultrasound exam (TRUE)) can be used to confirm correct tracheal tube placement and can be applied to "real time" or directly after tracheal tube placement, so that placement can be evaluated rapidly within seconds (Video-1) [13]. In the future, a safer rapid sequence induction (RSI) and intubation procedure may involve use of a TRUE-like confirmation as an important addition to the standard methods of confirmation including bilateral breath sounds, presence of end tidal $CO_2$, and chest rise during positive pressure ventilation, especially with the high incidence of a difficult airway in pregnancy [14].

Probe selection: Linear medium- to high-frequency (5–14 MHz) transducer for superficial airway structures (0–5 cm beneath the skin surface). The curved low-frequency transducer (~4.0 MHz) for obtaining sagittal and parasagittal views of the tongue and structures in the submandibular and supraglottic regions, mainly for its wider field of view.

## Chest—Acute Lung-Related Pathology

Two ultrasound protocols are available for the rapid real time diagnosis of lung pathology. The bedside lung ultrasound in emergency (BLUE) protocol for the immediate diagnosis of acute respiratory failure and the fluid administration limited by lung sonography (FALLS) protocol for the management of acute circulatory failure have been described. In the BLUE protocol, profiles have been designed for pneumonia, congestive heart failure, COPD, asthma, pulmonary embolism, and pneumothorax with diagnostic accuracies over 90% [15]. In the utilization of *M* mode echocardiography, disappearance of pleural sliding and the "beach" sign is a cardinal sign of pneumothorax (Fig. 2).

The BLUE protocol is often utilized when the physician is unable to clinically determine the cause of acute respiratory failure. Ultrasound (US)-derived data is incorporated into one

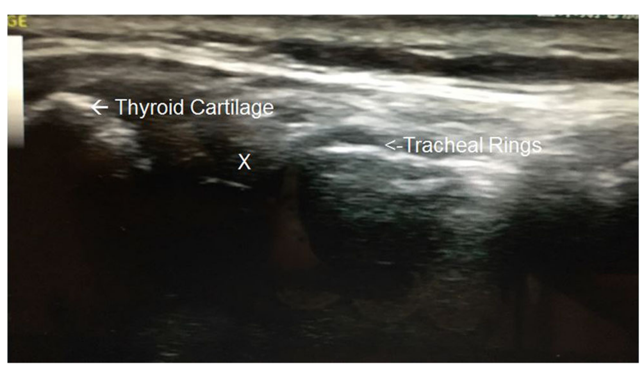


**Fig. 1** Cricothyroid membrane view. *legend* In this image, the cricothyroid membrane is labeled as an "*X*"

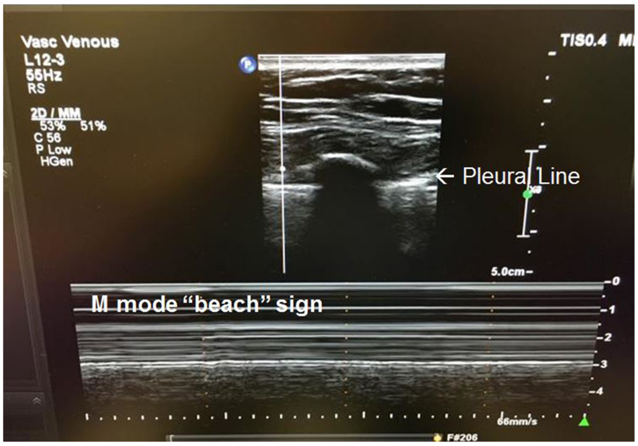


**Fig. 2** Pneumothorax view. *legend* Disappearance of pleural line sliding and the appearance of the "beach" sign in *M* mode is a sign of pneumothorax

of the established profiles in order to arrive at a clinical diagnosis. These profiles were established based on the examination of 300 adult patients admitted to the intensive care unit in acute respiratory failure [15]. Another protocol entitled FALLS specifically highlights interlobular septal thickening as a marker for pulmonary edema, which can help guide fluid resuscitation and avoid volume overload. These two protocols are relatively easy to use, requiring only a convex ultrasound probe and simple training [15].

Most pulmonary guidelines do not currently mention or support the use of lung ultrasound (LUS) for the diagnosis of pneumonia. A recently conducted meta-analysis by Chavez et al. [16] found that LUS has a high sensitivity (>90%) and specificity (>95%) for the diagnosis of adult pneumonia. There are some distinct advantages of LUS over chest X-ray, including avoidance of radiation especially in the pregnant patient. LUS can be done at the bedside, is quick to perform, and is not dependent on resource limited mobile X-ray machines that require an additional operator. It does, however, require some additional training on the part of the practitioner [16].

Probe selection: high-frequency 13–6-MHz linear array transducer.

## Chest—Pleural Effusions

POCUS for the evaluation and diagnosis of pleural disease provides several advantages over radiologic imaging including avoidance of radiation, superior portability, and the ability to image live in real time. Ultrasound has clearly shown an advantage over the traditional bedside physical exam for the identification of pleural fluid as well as discerning the difference between fluid and consolidation. It may also provide a safety advantage during thoracentesis, leading to less complications including pneumothorax, while simultaneously increasing the probability of a successful procedure [17, 18]. Standard grayscale ultrasound imaging may not be able to discriminate between small pleural effusions and pleural thickening. The addition of color Doppler imaging, available on many standard ultrasound platforms, may be able to detect the movement of the pleural fluid, providing a definitive diagnosis [15]

Probe selection: high-frequency 13–6-MHz linear array transducer.

## Chest—Echocardiography

TTE is widely utilized throughout medicine for clinical, diagnosis, and research. The use of TTE, rather than TEE, by non-cardiac anesthesiologists, is also increasing with particular emphasis on the use of TTE for perioperative management [19•]. Currently, intensive care physicians, trauma physicians, cardiologists, and anesthesiologists are using TTE to provide hemodynamic assessments in patients with life-threatening illnesses such as sepsis, respiratory failure, congestive heart failure (CHF), shock, and traumatic injuries, as well as patients with significant respiratory and cardiac diseases undergoing non-cardiac surgery and high-risk non-cardiac procedures. As an emerging technology, TTE not only provides volumetric and flow data but also has the ability to show the functioning heart with advanced two- and three-dimensional graphical images (Fig. 3 and Video-2) [19•]. Of particular benefit in the management of parturients with compromised cardiac conditions is the use of standardized repeatable TTE examinations throughout pregnancy [19•].

The American Society of Echocardiography (ASE) has released several consensus statements or guidelines to standardize a basic perioperative TTE exam and the indications for its use as a quantitative monitoring tool. TTE has the ability to non-invasively evaluate and track both right ventricular (RV)

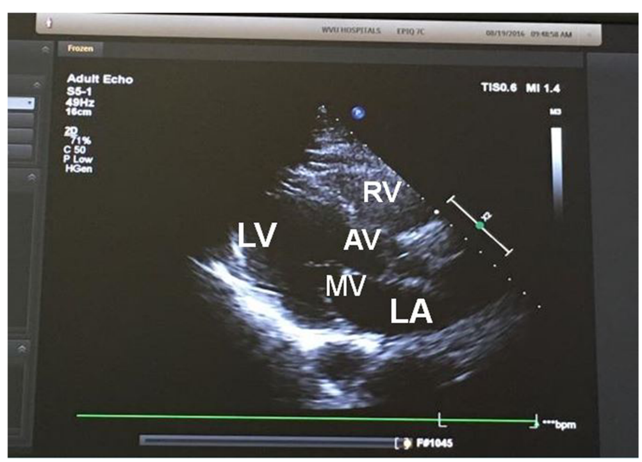


**Fig. 3** Parasternal long-axis TTE view. *legend* This view can evaluate biventricular contractility and valvular morphology. *RV* right ventricle, *AV* aortic valve, *MV* mitral valve, *LA* left atrial, *LV* left ventricle

and left ventricular (LV) hemodynamic status. In critically ill patients, TEE is now being used to monitor hemodynamics and direct intraoperative therapy.

Probe selection: 5–1-MHz phased array probe with maximum depth of 32 cm.

## Abdomen—Gastric Content Estimation

Gastric motility is thought to be significantly impaired during term pregnancy, especially in labor. Gastric content assessment can be determined ultrasonographically by measuring the cross-sectional area of the antrum (Fig. 4) [20–22]. Using US, it has been shown that gastric emptying is preserved in parturients not in labor, normal gastric emptying occurs in women who have reached term pregnancy, and gastric motility is preserved in parturients with labor epidural analgesia [21–23]. Even in obesity, Wong et al. [21] found that gastric emptying in obese term pregnant volunteers did not appear to differ after the ingestion of 50 mL compared with that after 300 mL water based on USG evaluation of gastric contents. However, opioid administration is known to slow gastric emptying [21, 22]. Due to the increased risk with aspiration, apnea, and a difficult airway in pregnancy, it is beneficial to assess gastric contents prior to cesarean section, especially when NPO status is unclear and the parturient has associated comorbidities [21, 22]. It has been demonstrated that US assessment of gastric volume by anesthesiologists is accurate and highly reproducible and that measurement of the antral cross-sectional area is easy to learn requiring approximately 30 examinations to ensure competence [24, 25].

Probe selection: 5–2-MHz curvilinear probe with scan depth 30 cm.

## Abdomen—TAP Block

TAP blocks have been proven to decrease opioid usage after cesarean section [26]. Although opioids have long been established as part of a successful multimodal pain regimen, they are associated with dose-dependent side effects and minimizing their use is advantageous, especially in this population. Although successful TAP blocks were first performed utilizing a landmark-based technique, complications such as liver injury and intraperitoneal injection have been reported [27]. The ultrasound variant of this block offers the advantages of direct needle visualization allowing confirmation of the proper spread of local anesthetic in the neurovascular plane between the internal oblique and the transversus abdominis muscle (Video-3) [26, 28••]. This can lead to a more efficacious and safer block [26, 28••].

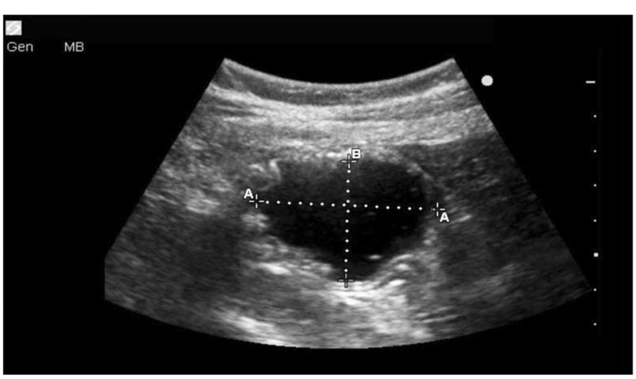


**Fig. 4** Gastric ultrasound view. *legend* Measurement of cross-sectional area to assess gastric antral contents

In a systemic review of 11 studies on the TAP block for analgesia after cesarean delivery, Fusco et al. [28••] determined that US-guided TAP block alone does not improve postoperative analgesia in comparison with intrathecal opioid but at the expense of an increased incidence of opioid-related side effects. Fusco also concluded that further studies are needed to investigate the optimum US-guided TAP block approach for analgesia following cesarean section, as well as to examine continuous catheter techniques for TAP block, in order to evaluate the efficacy of this technique in postsurgical chronic pain [28••].

Probe selection: 13–6-MHz linear array probe with depth 6 cm.

## Neuraxial—Epidural and Spinal Anesthesia/Analgesia

In pregnancy, the interspinal ligament develops laxity due to hormonal changes and can cause false loss of resistance. Additionally, the depth of the epidural space increases with weight gain during pregnancy. Preprocedural POCUS can facilitate successful epidural catheter and spinal placement by providing important anatomical information including the depth of the epidural space, the identity of a given intervertebral level, and the location of the midline and interspinous/interlaminar spaces (Video-4) [29•, 30, 31, 32].

Ansari et al. [33] determined that when performed by experienced anesthetists in both ultrasound and landmark techniques, the use of ultrasound does not appear to increase the success rate of spinal anesthesia, or reduce the procedure time, or number of attempts in obstetric patients with easily palpable spines. However, two studies by Vallejo et al. [29•] and Grau et al. [34] have demonstrated that ultrasound-guided epidural not only increases success rate for trainees but also improves their learning curve. Contrary to Ansari et al. [33], Perlas et al. [35] performed a systemic review and meta-analysis and determined that ultrasound-assisted lumbar neuraxial ultrasound for spinal and epidural anesthesia provides accurate measurement of the depth of the epidural and intrathecal space, improves efficacy of neuraxial anesthesia, increases accuracy of identification of lumbar interspaces and location of the midline, and can improve neuraxial anesthesia safety. Perlas concluded that there is significant evidence supporting the role of neuraxial ultrasound in improving the precision and efficacy of neuraxial anesthetic techniques [35].

POCUS may improve the efficacy and safety of spinal and epidural space location/selection in difficult cases [29•, 31, 32]. Chin et al. [36] examined the effect of using ultrasound to guide spinal anesthesia in obese orthopedic patients with poorly palpable spinous processes, and moderate to severe lumbar scoliosis or previous lumbar spine surgery, and showed that successful dural puncture was achieved after the first needle insertion in 65% of cases in the ultrasound group compared to just 32% in the landmark group.

Probe selection: 8–3-MHz array scan depth 15 cm.

## Ultrasound Assessment of Bladder Volume

Ultrasound can be used to evaluate and quantitate urinary retention in the perioperative and postpartum periods. Real-time ultrasound assessment of total bladder volumes in laboring women can prevent unnecessary catheterization and conversely, avoid failure to catheterize when indicated, thereby reducing the complications associated with catheterization and bladder over-distension [37]. Yip et al. [38] determined that US assessment of the postvoid residual bladder volume (PVRBV) in the postpartum period is accurate, and it can be used as a guide to determine whether transurethral catheterization is necessary.

Probe selection: 5–2-MHz scan depth 30 cm.

## The FAST Exam

In obstetric anesthesia and the management of obstetric complications, TTE has the ability to reshape our understanding of the cardiovascular system and management strategies. The use of TTE rather than TEE by non-cardiac anesthesiologists is rapidly increasing, with a specific focus on intraoperative management [19•]. Obstetric applications of TTE include examination of patients who have developed unexplained hypotension or dyspnea, resuscitation during severe hemorrhage, preeclampsia, use as a diagnostic tool when peripartum cardiomyopathy or pulmonary embolus is suspected, or during pulseless electrical activity (PEA) arrest.

In addition, the TTE probe can be used in this setting to evaluate fetal heart rate [19•]. Ultrasound is essential for distinguishing normal intrauterine pregnancy from threatened or spontaneous abortion, ectopic pregnancy, and other complications that may occur in patient with a positive pregnancy test [39].

Probe selection: 5–1-MHz phased array probe with scan depth or 35 cm.

## Trauma and Hemorrhage

The focused assessment with sonography for obstetrics (FASO) technique is a modification of the FAST exam and can be used to assess peripartum hemorrhage. The focused echo exam can be utilized to confirm cardiac arrest as well as to determine the effectiveness of chest compressions during cardiopulmonary resuscitation; to determine the return of spontaneous circulation (also known as ROSC); and to diagnosis myocardial insufficiency, hypovolemia, pulmonary embolus, aortic aneurysm/dissection, and pericardial effusion/tamponade [40••]. TTE can be an excellent tool in the rapid assessment of hypovolemia (Fig. 5).

Another US examination, the rapid obstetric screening exam (ROSE), has been used in patients who develop postpartum hypotension to diagnose and determine the patient's response to fluid and vasopressor therapy [19•]. In addition to volume status, one can monitor the heart's contractility as well as aid in the diagnosis of an air, blood, or amniotic fluid embolism. The six main tenants of the ROSE exam, according to Dennis [19•], are (1) the exam must be acceptable and applicable, (2) bedside test performed at the left-hand side of the woman, (3) comfortable and concise exam (obtain parasternal and apical views), (4) diagnosis and response to therapy (i.e., contractility and volume status), (5) embolism (air, blood, amniotic fluid)—right heart function and relative size, and (6) fetal heart rate assessment. These abbreviated techniques can be taught to and performed by clinicians and paramedical staff. It must be emphasized that these examinations do not replace the formal quantitative TEE exam, which could be performed later in a more controlled setting [19•].

While it appears that there are many competing protocols, what unifies these protocols is an emphasis on many of the same ultrasound examination components [41] (Table 1).


**Fig. 5** Subcostal long-axis TTE view. *legend* This view can be used to determine IVC diameter and respiratory variation in the evaluation of volume status

**Table 1** Components of proficiency in point-of-care ultrasound

| Cognitive knowledge | Workflow understanding | Manual dexterity |
|---|---|---|
| Basic physics and principles of image formation<br>Image acquisition and optimization<br>Knowledge of indications, contraindications, complications, and limitations for each specific application of POCUS | Evaluates the acuity of the situation<br>Selects appropriate transducer based on the indication<br>Patient, operator, and equipment positioning<br>Operates equipment adequately (turning on the machine, adding patient demographic data, storage, and retrieval of images, etc.)<br>Maintains situational awareness<br>Communicates findings of focused examination with surgical team and describes them in a report | Psychomotor skills necessary to conduct specific diagnostic ultrasound examination (e.g., esophageal intubation for TEE, probe manipulation)<br>Psychomotor skills necessary to manipulate probe and needle during ultrasound-guided procedures |

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*POCUS* point-of-care ultrasound, *TEE* transesophageal echocardiography

Although most facilities have US, a specific low-frequency (1–5 MHz) phased array probe is required to image deeper structures such as the heart. Several common TTE views include the parasternal long and short axis, the apical four and five chambers, and the subxiphoid. Because of the normal cardiac functional changes occurring during pregnancy and the growing gravid uterus, subcostal views may be difficult to obtain and the interpretation of small changes in structure and function must be made carefully [19•].

Although the diagnosis of amniotic fluid embolism (AFE) is clinical and often one of exclusion, TTE may help confirm right ventricular failure commonly seen with these types of embolic events as well as to determine therapy [42]. Echocardiography will commonly reveal severe pulmonary hypertension, a severely dilated hypokinetic right ventricle (acute cor pulmonale) with deviation of the interventricular septum into the left ventricle and an empty left ventricle. After the initial phase of right ventricular failure, left ventricular failure is typically the primary issue. Rarely, an embolus or transient myocardial thrombi may be seen. Additionally, echocardiography may also be helpful in guiding fluid and vasopressor administration in the acute treatment of pulmonary embolism [43].

Probe selection: 5–1-MHz phased scan depth 35 cm.

## Three-Dimensional Ultrasound

The three-dimensional (3-D) ultrasound techniques and rendering modes are now being used and applied to the study of fetal brain, face, and cardiac anatomy [44]. In addition, 3-D ultrasound has improved calculations of the volume of fetal organs and limbs and estimations of fetal birth weight. Furthermore, angiographic patterns of fetal organs and the placenta have been assessed using 3-D power Doppler ultrasound quantification [44].

## Ultrasound Limitations

Proficiency in perioperative POCUS is becoming essential for the practice of clinical anesthesiology and is critical because application of this technology without adequate training and practical experience has the potential to cause patient harm [19•] (Table 2). Additionally, "point-of-care" USG has a steep learning curve. Some issues remain unclear despite the increasing use of POCUS in our specialty. First, it is unknown if all perioperative POCUS modalities promote or result in increased patient safety. Second, when POCUS is used as a non-invasive diagnostic modality, it can lead to inadequate interpretation of

**Table 2** Basic ultrasound competencies

| | |
|---|---|
| 1 | Knowledge of equipment and probe selection |
| 2 | Positioning of self, patient, and equipment |
| 3 | Appropriate use of gel and probe contact |
| 4 | Protect probe from contamination |
| 5 | Orientation of probe with screen image |
| 6 | Probe handling and movement |
| 7 | Identification of target |
| 8 | Image optimization using gain, depth, and focus knobs |
| 9 | Use of different modes, e.g., *M* mode and Doppler |
| 10 | Differentiate long axis from short axis |
| 11 | Demonstrate the ability to store images |
| 12 | Clean the equipment to minimize infection spread and damage |

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findings and incorrect diagnoses. The evaluation of POCUS-related adverse events can be challenging, as it may not directly lead to complications. Third, the adoption of this technology by anesthesiology and other medical specialties has occurred before guidelines for appropriate use, training, and certification could be implemented. Fourth, some physicians have an inaccurate perception that as POCUS is a focused diagnostic modality, a thorough knowledge base and demonstration of proficiency are not essential before its use [1••].

Demonstration of proficiency in POCUS is not currently incorporated as an independent milestone in anesthesiology training by the Accreditation Council for Graduate Medical Education (ACGME). Most anesthesiology curricula in the USA do not currently emphasize ultrasound training except in the case of TEE and regional anesthesia and is currently subspecialty specific [1••]. However, some elements of POCUS are part of existing milestones (i.e., technical skills, pain management, and regional anesthesia) [1••]. For regional anesthesia and acute pain medicine fellowships, the American Society of Regional Anesthesia offers an Ultrasound Guided Regional Anesthesia Education and Clinical Portfolio [1••].

## Conclusion

POCUS is becoming increasingly popular in the diagnosis and rapid evaluation of multiple medical conditions and will become a mainstay in the evaluation and treatment of the pregnant patient. Adequate clinical training and experience in POCUS is essential as improper interpretation of findings can lead to an incorrect diagnosis ultimately affecting maternal safety and outcome.

**Compliance with Ethical Standards**

**Conflict of Interest** Matthew Ellison, Pavithra Ranganathan, Hong Wang, and Manuel C. Vallejo declare that they have no conflict of interest.

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

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- • Of importance
- •• Of major importance

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