

American Society of Regional Anesthesia and Pain Medicine expert panel recommendations on point-of-care ultrasound education and training for regional anesthesiologists and pain physicians—part I: clinical indications

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ABSTRACT

Point-of-care ultrasound (POCUS) is a critical skill for all regional anesthesiologists and pain physicians to help diagnose relevant complications related to routine practice and guide perioperative management. In an effort to inform the regional anesthesia and pain community as well as address a need for structured education and training, the American Society of Regional Anesthesia and Pain Medicine (ASRA) commissioned this narrative review to provide recommendations for POCUS. The guidelines were written by content and educational experts and approved by the Guidelines Committee and the Board of Directors of the ASRA. In part I of this two-part series, clinical indications for POCUS in the perioperative and chronic pain setting are described. The clinical review addresses airway ultrasound, lung ultrasound, gastric ultrasound, the focus assessment with sonography for trauma examination and focused cardiac ultrasound for the regional anesthesiologist and pain physician. It also provides foundational knowledge regarding ultrasound physics, discusses the impact of handheld devices and finally, offers insight into the role of POCUS in the pediatric population.

visualization of peripheral nerves for procedural purposes has a significant benefit to regional anesthesiologists and chronic pain physicians despite having separate indications in radiology.^{1–3} It is this diversity in clinical ultrasound practice among subspecialties that underlies the American Medical Association's recommendation that 'policy on ultrasound imaging...(and) criteria for granting ultrasound privileges (be) based upon background and training for the use of ultrasound technology and strongly recommends that these criteria are in accordance with recommended training and education standards developed by each physician's respective specialty'.⁴ Based on these recommendations, there exist guidelines for training, competency and credentialing in POCUS in emergency medicine⁵ and critical care medicine,^{6,7} and there is currently a work product for POCUS available through the American Society of Anesthesiologists (ASA).⁸ Despite the availability of significant resources in the form of numerous live courses⁹ and an educational review series on POCUS,^{10–15} no specific guidelines or recommendations exist on the use of POCUS for regional anesthesiologists and pain physicians. Given ASRA's early leadership in providing recommendations for procedural-based bedside ultrasound in the form of ultrasound-guided regional anesthesia and ultrasound-guided interventional pain procedures, there was a call to address the need for formal POCUS recommendations.^{2,3}

The American Society of Regional Anesthesia and Pain Medicine (ASRA) Guidelines Committee appointed a task force to develop recommendations for the clinical indications for POCUS as a foundation for education and training in POCUS. The task force aims to provide alignment between regional anesthesiologists and acute and chronic pain physicians for training recommendations in the perioperative and/or chronic pain setting. The

INTRODUCTION

Point-of-care ultrasound (POCUS) has become a powerful tool at the bedside because of the potential for improving patient management. Modern ultrasound (US) equipment provides excellent image quality, portability, simplicity and availability in various clinical settings. Although ultrasound and echocardiography have historically been within the purview of radiologists and cardiologists, the emergence of POCUS as a bedside tool to supplement the physical examination has resulted in tremendous expansion into other subspecialties. Although there is overlap, there are unique subspecialty clinical applications. For example, ultrasound



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recommendations are based on the current best evidence and will consider each clinical setting's commonalities and uniqueness.

In part I of a two-part review article series, we will discuss the clinical indications for POCUS for the regional anesthesiologist and pain physician. The skills discussed are airway ultrasound, lung ultrasound (LUS), gastric ultrasound, the focused assessment with sonography for trauma (FAST) examination and focused cardiac ultrasound (FoCUS). The authors acknowledge that musculoskeletal ultrasound and neurosonography are other emerging diagnostic skills but are outside the scope of this POCUS article.

We also provide foundational knowledge regarding ultrasound physics, the impact of handheld devices and finally, insight into the role of POCUS in the pediatric population.¹⁵ Ultimately, these task force recommendations will outline the clinical indications of POCUS and lay the foundation for defining criteria for education, training, competency and credentialing for the regional anesthesia and pain physician.

METHODS

An expert panel was assembled for this project based on the recommendations from the ASRA's Guidelines Committee and Board of Directors. This panel consists of national and international experts in POCUS. Specifically, the qualifications for panel selection involved multiple publications in POCUS, leadership through participation in and/or development of POCUS education and expertise and leadership in regional anesthesia and pain medicine to ensure all topics are accurately covered and appropriate for education and training recommendations. To define areas of competency, a systematic literature search (MEDLINE, PubMed and Ovid) was performed, looking at clinical indications and utilization of POCUS for anesthesiologists, regional anesthesiologists and pain physicians. Findings were not filtered by risk of bias or Grading of Recommendations, Assessment, Development and Evaluations (GRADE) of evidence. When appropriate, recommendations were drawn from other subspecialties such as critical care, cardiology, emergency medicine, surgery and radiology. Keywords used included: point-of-care ultrasound, ultrasound, regional anesthesiology, perioperative point-of-care ultrasound, chronic pain, acute pain, ultrasonography/standards, clinical competency/standards, ultrasound physics, curriculum, education, training, barriers to education, barriers to training, airway ultrasound, lung ultrasound, pulmonary ultrasound, focused cardiac ultrasound, gastric ultrasound, pediatric point-of-care ultrasound and handheld ultrasound. Based on these relevant clinical skills (airway ultrasound, lung ultrasound, focused cardiac ultrasound, gastric ultrasound, abdominal/pelvic ultrasound), corresponding groups were tasked with describing educational goals and requirements for competency for regional anesthesiologists and pain physicians. The writing process was then conducted in leader-facilitated groups. Contributing authors were granted access to review the document in its entirety and gave final approval to the recommendations.

Ultrasound physics and equipment requirements for POCUS

Ultrasound imaging is a user-dependent tool that requires knowledge of the fundamental principles of ultrasound and the technical skills for acquisition, optimization and accurate interpretation of images.¹⁶ Most regional anesthesiologists and pain physicians are familiar with linear and curvilinear transducers for ultrasound-guided procedures and the general principles of ultrasound image generation, common artifacts and the

Table 1 Knowledge of ultrasound physics and equipment²¹

Ultrasound physics	Artifacts	Equipment	Instrument functions
Amplitude	Axial	Piezoelectric transducers	Gain
Wavelength	Shadowing		Time gain compensation
Frequency	Comet tail	Linear array	Preset
Intensity	Enhancement	2.5–12 MHz	Depth
Absorption	Reverberation	Convex array	Focus
Impedance	Mirroring	3.5–6.5 MHz	Brightness mode
Attenuation	Lateral	Phased array	Motion mode
Reflection	Side lobes	2–7.5 MHz	Color Doppler
Refraction	Refraction	Vector array (linear and phased)	Power Doppler
Scattering	Equipment		Pulse wave Doppler
Harmonics	Range ambiguity	1.25–4.5 MHz	Spectral Doppler
Axial resolution	Aliasing	Capacitive transducers	Harmonics
Lateral resolution	Ghosting	CMUT	Saving images
		CPUT	Clip function

CMUT, capacitive micromachined ultrasound transducer; CPUT, capacitive piezoelectric ultrasound transducers.

sonoanatomy of neurovascular structures. To perform an organ-based ultrasound, such as echocardiography, clinicians will need to familiarize themselves with lower frequency transducers, such as the phased array, as well as the wide dynamic range capacitive micromachined ultrasound transducers (CMUTs). The artifacts associated with phased array processing, such as ghosting, and Doppler measurements, such as aliasing, are unique and require advanced understanding.^{17 18}

Medical ultrasound is mechanical energy in the form of high frequency (>20 kHz) sound waves emitted from a piezoelectric transducer or a CMUT. The majority of the waves pass through tissue with different densities and resistance to sound (acoustic impedance), and a small fraction is reflected toward the transducer. Returned ultrasound signals alter the shape of the piezoelectric crystals or flexible plates of the CMUT, creating an electrical current proportional to the signal's strength, which is then processed to form a two-dimensional image.¹⁹ Concepts such as reflection, refraction, scattering and attenuation play an essential role in ultrasound image interpretation; however, given the scope of this article, we suggest learners reference other fundamentals of ultrasound text to explore these topics further.

Ultrasound artifacts play an important role in POCUS imaging and interpretation. With POCUS, navigating through acoustic barriers such as aerated lungs and the bony framework of the chest wall results in artifacts that can either contribute to misdiagnosis or be used as diagnostic aids.²⁰ For example, A-lines and B-lines, discussed in detail in the LUS section, can be used to guide management in focused LUS. See table 1 for a list of common ultrasound artifacts.

For POCUS, transducer selection ensures optimal axial and lateral resolution. High-frequency linear (HFL) transducers provide a rectangular image; however, due to increased attenuation, imaging depth is limited. Therefore, HFL probes are ideal for superficial structures such as the pleura and the airway. Convex (curvilinear) sequential array transducers are arranged in a curved fashion producing a fan-shaped image. Convex transducers have a lower frequency and thereby provide improved image resolution of deeper structures (penetration), a wider image in the far field and are best for imaging intra-peritoneal and retroperitoneal organs. For intrathoracic structures such as the heart and large vessels, low-frequency phased array transducers with a small footprint that use electronic field steering to image beyond acoustic barriers, such as ribs, produce

a cone-shaped image of the heart. When comparing capacitive transducers (CMUT) to traditional piezoelectric transducers, the CMUT transducer's advantages are a larger bandwidth and lower production cost.²¹ CMUT arrays can be manufactured with different operating frequencies and geometries from a single silicon wafer, allowing full-body imaging with a single transducer.²² The disadvantage is that CMUT technology is relatively new compared with piezoelectric transducers; therefore, the imaging quality and applications do not match traditional transducers.

CLINICAL INDICATIONS AND EVIDENCE FOR POCUS

We will focus on the clinical indications and evidence for airway ultrasound, LUS, gastric ultrasound, the FAST examination and FoCUS for the regional anesthesiologist and pain physician.

Although the clinical benefits of POCUS have been widely advocated by many medical specialties,^{6 23–27} the apparent positive impact of POCUS on patient outcomes has not consistently been demonstrated in a randomized, controlled trial for many reasons.^{28 29} First, POCUS is used as a diagnostic or monitoring tool. It is not a procedural intervention that can be easily randomized and directly attributed to improved patient outcomes. Second, POCUS is only one part of the complex sequence of medical care. As such, it is challenging to show that a single intervention can either lead to a meaningful outcome or overtreatment, overdiagnosis or potential iatrogenic injury. Finally, POCUS findings as an extension of the physical examination are heavily dependent on proper education and training, maintenance of competency, personal skills and experience and individual interpretation of the operator. With that said, what follows is the current best evidence supporting the clinical indications for POCUS.

Airway ultrasound

Point-of-care airway ultrasound can aid in the assessment and planning of perioperative or periprocedural airway management. Airway US can be used to predict potential difficult airway management. The measurement of the anterior neck has shown that the distance from the skin to the hyoid bone is highly predictive of difficult mask ventilation and intubation.³⁰ In a patient with a concern for a 'cannot intubate, cannot ventilate' scenario, front of neck airway sonographic identification of the cricothyroid membrane is more accurate than palpation alone^{31–34} and more rapid for emergency airway access.^{35 36} Of note, the cricothyroid membrane is highly dependent on neck position; therefore, one must maintain the same position or (following any movement of the neck) rescan to confirm location before attempting an emergency airway.

Airway ultrasound assessment of the cricoid cartilage compared with palpation has improved accuracy, facilitating the correct application of cricoid pressure.^{37 38} Additionally, the efficacy of cricoid pressure can be assessed by visualization of esophageal compression.

Confirmation of endotracheal intubation compared with endobronchial intubation with airway ultrasound was more sensitive and specific than chest auscultation when tracheal cuff dilation and bilateral pleural sliding was seen.^{39 40} In the event of decreased or absent end-tidal carbon dioxide, as seen in cardiac arrest or other low output states, lung sliding can be used as a surrogate for endotracheal tube confirmation.⁴¹ And finally, it can facilitate nasogastric tube placement.^{30–40} Multiple studies have shown the benefit of ultrasound imaging in the correct placement of nasogastric tubes.^{42–44} See [figure 1](#) for an

example of airway ultrasound probe placement, anatomy and sonoanatomy.

There are advanced procedural applications of point-of-care airway ultrasound that we will briefly mention as they are beyond this document's scope. Ultrasound-guided nerve blocks for airway anesthetization should be reserved for those with expertise in their performance.⁴⁵ Landmark-based glossopharyngeal and superior laryngeal nerve blocks have been associated with higher plasma concentrations of local anesthesia, a higher incidence of local anesthetic systemic toxicity (LAST) and lower patient comfort than less invasive techniques.⁴⁵ While ultrasound-guided techniques may provide more favorable results over traditional landmark-based approaches, the current evidence is insufficient to recommend them over non-invasive mucosal topicalization.

Additionally, a thorough ultrasound assessment of the neck for pathologies such as esophageal (Zenker) diverticulum or an aberrant vertebral artery before performing a stellate ganglion block can avoid potential complications.^{46 47}

The Indication, Acquisition, Interpretation, and Medical Decision-Making (I-AIM) Framework is a standardized, step-by-step guide for clinicians learning a new POCUS skill to identify the appropriate clinical scenarios where it can be used.^{48 49} As airway ultrasound is an emerging skill for the regional anesthesiologists and pain physicians, [table 2](#) provides a review of clinical case examples in the I-AIM Framework to facilitate knowledge comprehension, integration and translation into the clinical arena.

Lung ultrasound

Point-of-care LUS can be used to assess an acute or critically ill patient with respiratory distress as an extension to physical examination.⁵⁰ LUS has superior diagnostic accuracy (both sensitivity and specificity) over many traditional imaging. Furthermore, LUS is faster to execute and allows repeated dynamic bedside assessment to monitor disease progression or regression (response to treatment) without radiation exposure.

Overall, LUS excels in its accuracy in detecting lung pathologies such as pneumothorax and pleural effusion ([table 3](#)). Additionally, LUS has the advantage of differentiating pleural effusion from lung consolidation, which is not always possible with a chest radiograph.⁵¹

Two large meta-analyses found the sensitivity and specificity of LUS for diagnosis of pneumonia to range between 85%–93% and 72%–93%, respectively.^{52 53} For diagnosis of lung contusion, LUS has a higher degree of diagnostic accuracy than chest radiography with greater sensitivity (95% vs 27%) but similar specificity (96% vs 100%).^{54 55} LUS is also superior to auscultation in confirming tracheal versus bronchial intubations with higher sensitivity (93% vs 66%) and higher specificity (96% vs 59%).⁴⁰ A recent meta-analysis suggests a higher sensitivity (94%) and specificity (92.4%) with LUS to diagnose heart failure than routine clinical workup, including chest radiography and natriuretic peptides.⁵⁶ B-lines are consistently accurate in the diagnosis and monitoring of pulmonary edema and other lung conditions such as acute respiratory distress syndrome, lung infection,⁵⁷ connective-tissue disorders and lung fibrosis.⁵⁸

LUS has been used for decades as a means to assess diaphragmatic function.⁵⁹ The most common methods image the right and left hemidiaphragm by using the liver and spleen as acoustic windows to record diaphragmatic movement in motion mode. The subcostal method, however, can be challenging, particularly on patients with large body habitus. An alternate approach is

A. Probe Position



B. Anatomy/Sonoanatomy

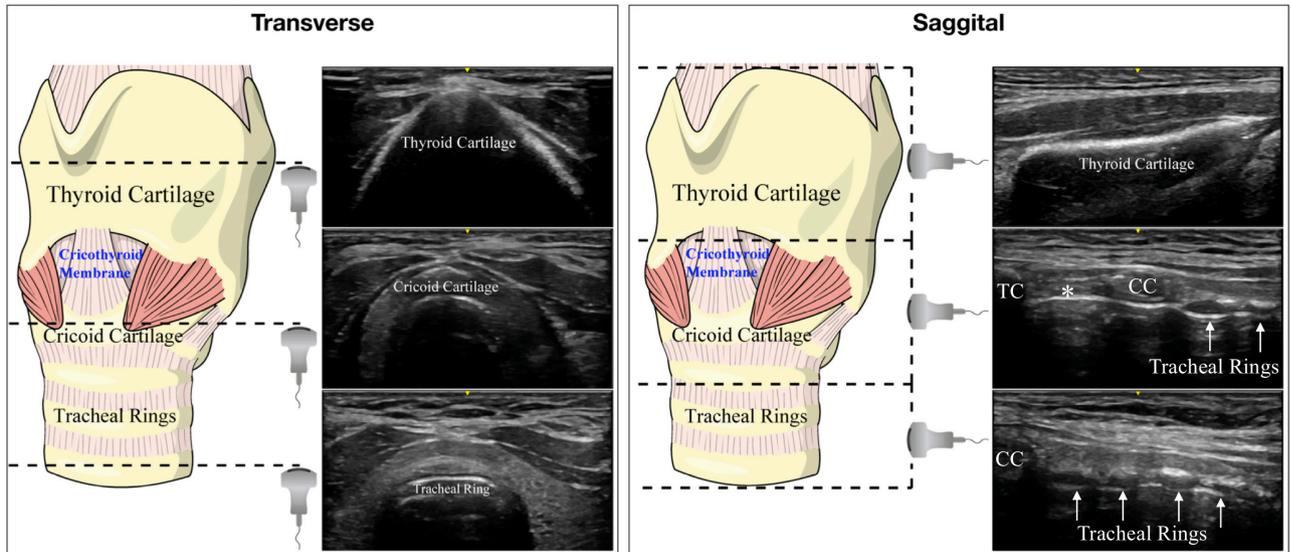


Figure 1 Airway ultrasound (US) probe placement, anatomy and sonoanatomy. (A) Probe placement for airway US scanning. (B) Anatomy of the thyroid cartilage, cricoid cartilage and tracheal rings with corresponding sonoanatomy in transverse and sagittal planes. CC, cricoid cartilage; TC, tracheal cartilage. *Cricothyroid membrane.

to assess diaphragmatic function at the zone of apposition by observing diaphragm muscle thickening during the respiratory cycle.^{60 61} The zone of apposition is defined as the area of the diaphragm close to the lower rib cage where the diaphragm separates from the rib cage.

LUS is based predominantly on the interpretation of artifacts derived by air/tissue interface (eg, pleural line) and real anatomical images in the absence of air/tissue interface (eg, effusion and consolidation). Several lung artifacts (A-lines and B-lines) and signs (lung sliding and pulse) are commonly observed and are highlighted in figure 2.¹¹ Interpretation of lung and pleural artifacts or 'signs' has led to the development of standardized protocols to evaluate the lung. These diagnostic protocols follow a step-by-step approach based on particular US profiles.⁶² In the bedside LUS in emergency protocol,⁶² profiles have been designed to assess pneumonia, congestive heart failure, chronic obstructive pulmonary disease (COPD), asthma, pulmonary embolism (PE) and pneumothorax with an accuracy >90%. The fluid administration limited by lung sonography protocol⁶³ sequentially rules out an obstructive, cardiogenic, hypovolemic and distributive (usually septic) shock.⁶⁴

LUS is a valuable tool for diagnosing and monitoring a variety of pulmonary and pleural complications after regional anesthesia and interventional pain procedures. Pneumothorax⁵⁴ has been reported as a potential complication of regional anesthesia procedures such as interscalene⁶⁵ and supraclavicular⁶⁶ brachial plexus block, erector spinae plane block,⁶⁷ thoracic paravertebral block⁶⁸ and pain procedures such as trigger point injection,⁶⁹ intercostal nerve block,⁷⁰ thoracic facet joint injection, radio-frequency lesioning⁷¹ and celiac plexus block.⁷² Respiratory symptoms may develop within minutes following these

procedures but more commonly develop over several hours. Hemidiaphragmatic paresis is a known complication of above the clavicle brachial plexus blocks (interscalene and supraclavicular) due to a secondary phrenic nerve block.^{59 73} LUS can be used to help determine pre/post block diaphragmatic function, monitor the return of diaphragmatic function and differentiate between a block complication versus another potential cause of respiratory insufficiency. Also, pleural effusion and hemothorax have been described after supraclavicular block⁷⁴ and thoracic epidural⁷⁵ and during interscalene brachial plexus infusion.^{76 77} Diagnostic LUS can also guide management in acute respiratory failure,⁷⁸ circulatory shock and cardiac arrest states,⁷⁹ interstitial syndrome,⁸⁰ lung consolidation,⁵² acute decompensated heart failure⁸¹ and endobronchial intubation.^{40 82}

FAST examination

The FAST is a well-validated POCUS examination with broad applications in the fields of regional anesthesiology and chronic pain medicine.⁸³ See figure 3 for the four FAST views—subcostal, right upper quadrant, left upper quadrant (LUQ) and pelvic views.

Initially, the FAST examination was intended to rapidly identify trauma patients who need surgical intervention.⁸² In the perioperative setting, the indications are an ongoing assessment of trauma patients, critical patients recovering postoperatively, hip arthroscopy patients with severe postoperative pain or showing signs of hemodynamical instability, patients with ascites, patients with peritoneal dialysis and patients following any abdominal surgery.^{14 84} Additionally, there is a role in gynecologic and obstetrics procedures in the form of

Table 2 Examples of cases in airway POCUS following an I-AIM Framework

Clinical scenario	Indications	Image acquisition	Image interpretation	Medical decision-making
Awake cricothyroidotomy	Location of the cricothyroid membrane Location of the cricoid cartilage Location of tracheal rings	Patient supine with the neck extended Linear high-frequency transducer Scan in transverse and sagittal planes Identify: Thyroid cartilage Cricothyroid membrane Cricoid cartilage Tracheal rings Thyroid gland Surrounding vasculature	Localization of cephalocaudal level, mid-point and size of the cricothyroid membrane Localization of the cephalocaudal level and mid-point of the cricoid cartilage Localization of the cephalocaudal level, mid-point and number of tracheal rings	Determine and mark the skin for the correct location of cricothyroid membrane puncture Determine and mark the skin for the correct location of cricoid force (pressure)
Confirmation of correct endotracheal tube placement	Unclear endotracheal intubation Real-time confirmation of endotracheal intubation Rule out esophageal intubation	Patient supine Linear high-frequency transducer Scan in transverse and sagittal planes Identify: Tracheal rings Esophagus Thyroid gland Surrounding vasculature Bilateral lung sliding	Verification of endotracheal tube position (double-bullet sign) Diagnosis of endobronchial intubation (double-bullet sign and unilateral lung sliding (left) Verification of esophageal position (double-tract sign)	Determine the safety of utilization of a tracheal tube for ventilation Reintubation if in the esophagus
Confirmation of orogastric or nasogastric tube placement	Orogastric or nasogastric tube placement without aspiration of gastric content by suction	Patient supine Linear high-frequency transducer, potentially curvilinear probe for verification of orogastric or nasogastric tube in the stomach Scan in transverse and sagittal planes Identify: Tracheal rings Esophagus Thyroid gland Surrounding vasculature	Verification of small, round structure in esophagus or stomach	Determine the safety of use of orogastric or nasogastric tube Replacement/adjustment of the position of orogastric or nasogastric tube

I-AIM, Indication, Acquisition, Interpretation, and Medical decision-making; POCUS, Point-of-care ultrasound.

the focused assessment with sonography for obstetrics examination.^{85 86} A positive examination indicates that the patient has at least 300–500 mL of free fluid in the peritoneal space.⁸⁷ This amount of fluid following abdominal surgery is rarely benign and almost always indicates ongoing hemorrhage. An exception to this situation is intra-abdominal fluid extravasation (IAFE) following hip arthroscopy. IAFE occurs in up to 15% of hip arthroscopy cases and is highly associated with increased pain.⁸⁴

Chronic pain procedures, such as celiac plexus block, have a risk for bleeding and intra-abdominal hemorrhage.⁸⁸ Additionally, patients will rarely have a positive FAST examination except in cases of chronic pathology. It is essential to recognize that cirrhotic patients will commonly accumulate enough ascites to produce a positive FAST examination. The same applies to end-stage renal patients treated with peritoneal dialysis.

Table 3 Comparison of sensitivity and specificity between LUS versus CXR

	Sensitivity	Specificity
Pneumothorax ^{84 85}	LUS–88% CXR–52%	LUS–100% CXR–99%
Pleural effusion ¹⁸³	LUS–94% CXR–51%	LUS–98% CXR–91%

CXR, chest X-ray; LUS, lung ultrasound.

Gastric ultrasound

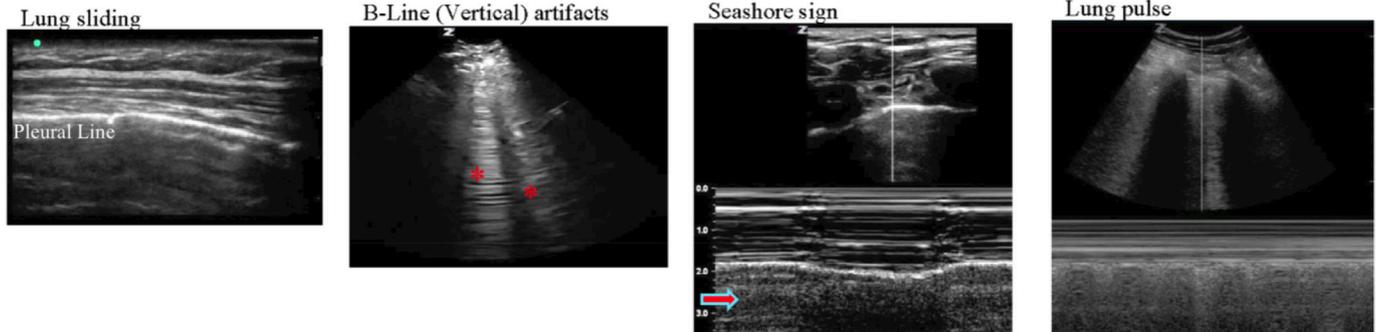
Gastric POCUS is used to evaluate stomach contents as they relate to aspiration risk.^{13 89} Pulmonary aspiration of gastric contents has significant perioperative morbidity and mortality.⁹⁰ Regional anesthesia and pain management procedures are commonly performed under various degrees of sedation. Chronic pain patients frequently require sedation because of increased sensitivity to needling, opioid-induced hyperalgesia and anxiety. Additionally, deep sedation can be crucial for interventions where patient movement during the procedure may lead to devastating complications, including, for example, inadvertent administration of brain stem injection with trigeminal nerve block or radiofrequency ablation, or pneumothorax with intercostal, or paravertebral nerve blocks.⁹¹

The ASA's recommendations for nil per os (NPO) status are routinely observed in anesthesia and pain medicine practice.⁹² However, the guidelines are for healthy patients undergoing elective procedures and does not apply to the many complex patients receiving anesthesia or sedation. Opioid dependency, labor, diabetic gastroparesis, advanced renal or liver dysfunction, neuromuscular disorders, ileus, trauma or urgent surgery may prolong gastric emptying, leading to a 'full stomach' despite prolonged periods of fasting.^{93 94} Morbidly obese, pregnant and pediatric patients may also be at increased risk of aspiration.^{93 94} Additionally, the prandial status may be difficult to assess in patients with a language barrier, altered cognition (such as delirium or dementia) and inconsistent clinical history.

A. Probe Position



B. Normal Lung



C. Pneumothorax

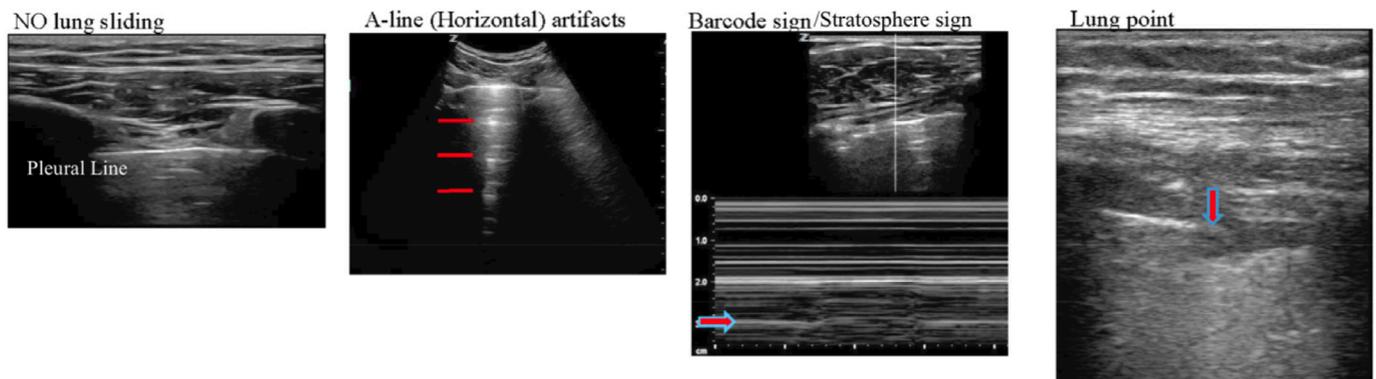


Figure 2 Lung ultrasound (LUS) with normal findings and pathology to rule out and diagnose a pneumothorax. (A) Probe placement for LUS scanning. (B) Normal lung sonoanatomy to rule out a pneumothorax, including lung sliding, B-lines (red asterisks) vertical reverberation artifacts, the seashore sign with arrow pointing to the ‘sandy beach’ visible with normal lung sliding and lung pulse with asterisk showing intermittent movement synchronous with the cardiac rhythm. (C) Sonoanatomy with LUS to diagnose a pneumothorax, including absence of lung sliding, A-lines (red lines) horizontal artifact pattern seen with absence of lung sliding, a barcode sign or stratosphere sign with the arrow pointing to the pattern of parallel horizontal lines continuing beyond the pleural line visible with lack of movement and a lung point.

Therefore, gastric US should be considered before sedation to verify gastric content for patients with these conditions or when fasting status is unclear.⁹⁵

Gastric POCUS is most useful when there is clinical uncertainty regarding the status of stomach contents, in other words, when the pretest probability of a ‘full stomach’ is close to 50%.^{13 96 97} In a prospective study with a simulated clinical scenario with a pretest probability of ‘full stomach’ of 50%, a positive gastric ultrasound examination increased the post-test probability of a full stomach to over 95%, and a negative test decreased the post-test probability to 0.1%.⁹⁸ Additionally, bedside gastric ultrasound has been shown to change anesthetic management in two-thirds of patients who have not followed fasting instructions before elective surgery^{99 100} and in pediatric patients undergoing urgent surgery.^{101 102}

Gastric ultrasound has been studied in adult,^{103–105} pediatric,^{101 106 107} obstetric^{108 109} and morbidly obese^{110 111} patients.

A systematic assessment of the gastric antrum provides information about the entire organ’s contents (figure 4).^{103 104 112 113} Based on qualitative and quantitative findings, the results of a gastric ultrasound examination may be summarized in a binary manner as an ‘empty’ or a ‘full’ stomach.^{13 89 96 97 103 104 114} An ‘empty’ stomach has no appreciable content or there is a low volume (≤ 1.5 mL/kg) of hypoechoic fluid consistent with baseline gastric secretions.^{13 89 96 97 103 104 114} A ‘full’ or ‘not empty’ stomach has evidence of solid particulate content (mixed echogenicity), thick (hyperechoic) fluid or a volume of clear fluid in excess of normal baseline gastric secretions (>1.5 mL/kg) (figure 5).^{13 96 97 103 104 114}

Patient position affects antral size as the stomach’s contents pool in the most dependent areas. A more accurate evaluation of the antrum and gastric content is obtained in the right lateral decubitus (RLD) or the semirecumbent position with the head elevated at 45°, as the supine position can underestimate gastric

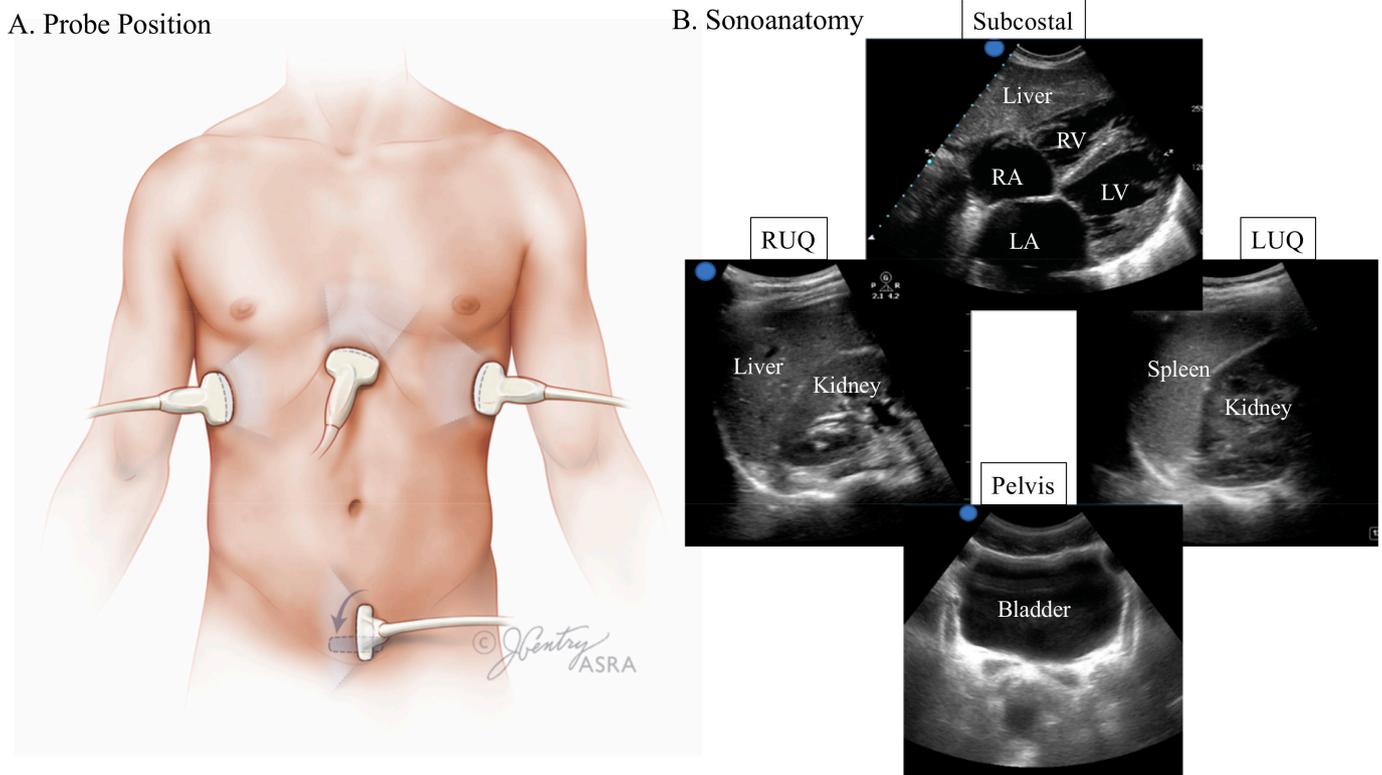


Figure 3 FAST examination probe placement and corresponding sonoanatomy. (A) Probe placement. (B) Sonoanatomy for FAST views including subcostal four-chamber view, RUQ (Morison's pouch/hepatorenal space), LUQ (perisplenic space) and pelvic view (transverse view). FAST, focused assessment with sonography for trauma; LA, left atrium; LUQ, left upper quadrant; LV, left ventricle; RA, right atrium; RUQ, right upper quadrant; RV, right ventricle.

content.^{103 104 112 115} Given these positional differences, a semi-quantitative three-point grading system can be used to assess the presence or absence of clear fluid in the supine and/or RLD positions.^{104 112} In a grade 0 antrum (empty stomach), fluid is absent in both positions. A grade 1 antrum only has visible fluid in the RLD position, consistent with baseline gastric secretions. Grade 0 and 1 antrums are commonly seen in the fasting state. Alternatively, a grade 2 antrum appears distended with clear fluid in both the supine and RLD positions, and it correlates with gastric volumes >100 mL.^{104 112} A grade 2 antrum is uncommonly seen in the fasting state. Gastric ultrasound has been shown to be reliable and accurate to identify a 'full stomach'.^{98 116}

Quantification of gastric antrum volume has been validated against endoscopically guided gastric suctioning^{110 112} for a wide range of gastric volumes (0–500 mL), patient's body mass index (19–60) and ages (18–85 years). By placing the patient in the RLD position and measuring the cross-sectional area (CSA) of the gastric antrum at the level of the aorta, the following statistical model can be used to measure gastric volume. Gastric volume (mL) = $27.0 + 14.6 \times \text{RLD CSA} - 1.28 \times \text{age}$.¹¹² This statistically robust model has the benefit of only one covariate (age) and has been shown to have high intrarater and inter-rater reliability.

Focused cardiac ultrasound

FoCUS has been used in critical care for over 25 years, with the earliest example being the focus assessed transthoracic echocardiography (FATE) protocol.¹¹⁷ While echocardiography was, for decades, the exclusive domain of the cardiologist, those days have passed. Both the American Society of Echocardiography¹¹⁸ and the World Interactive Network Focused on Critical Ultrasound¹¹⁹ have published recommendations for the utility of

FoCUS at the bedside for specific clinical indications. With the availability of high-quality, hand-carried devices, as well as the expansion of training and expertise, the perioperative setting has been ushered into a new era of bedside ultrasound. Specifically, this evidence has been supplemented by several review articles describing the value of FoCUS in the broad practice of anesthesiology,^{120 121} regional anesthesia and pain medicine.^{12 122} Although there are no controlled studies on the utilization of FoCUS in pain practice at this time, there are several scenarios where it could be clinically relevant.

FoCUS aids with patient assessment and clinical optimization, and it can help guide the management of procedural complications. Patients presenting urgently or emergently in the perioperative or periprocedural setting can have undiagnosed and potentially significant cardiac comorbidities. FoCUS can be used to screen high-risk patient populations for undiagnosed cardiac disease when formal echocardiography is not promptly available.¹¹⁸ One clinical example is the elderly patient presenting with a hip fracture.¹²³ In a prospective study, hip fracture patients who received routine bedside cardiac ultrasound screening found that 31% of patients with no audible murmur had aortic stenosis (AS).¹²⁴ Diagnosis of significant pathologies, such as AS, should alter anesthetic technique, monitoring and postoperative care.¹²⁵ Additionally, bedside cardiac ultrasound on high-risk hip fracture patients did not delay entry into the operating room and may have improved short-term and long-term mortality.¹²³

FoCUS can differentiate among intraoperative and periprocedural complications. In the setting of refractory hypotension following a procedure, FoCUS can differentiate among decreased preload seen with a high spinal, poor contractility related to LAST to the myocardium and other complications associated

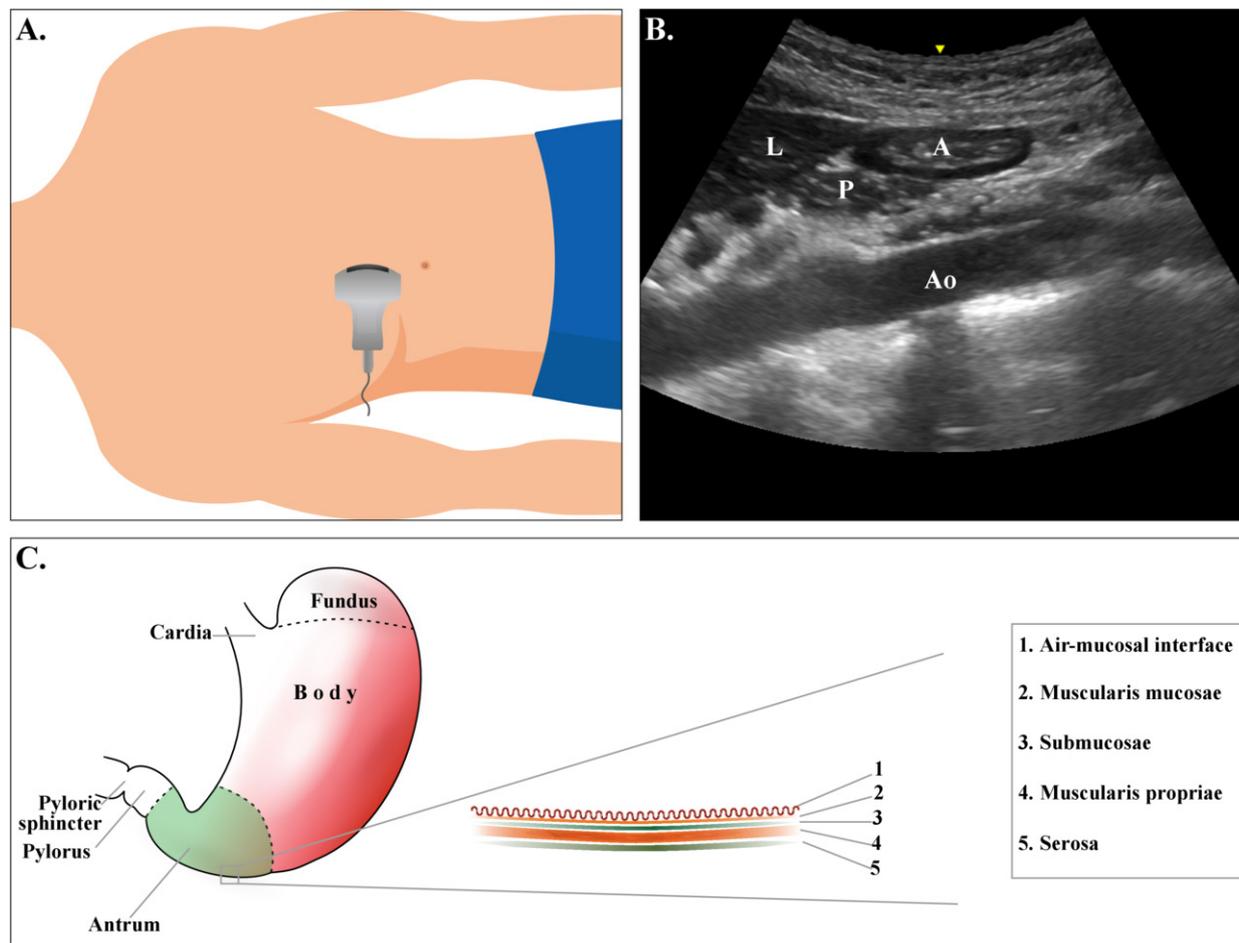


Figure 4 Gastric ultrasound probe placement and anatomy: (A) Probe placement for gastric ultrasound. (B) Basic sonoanatomy of the gastric ultrasound view at the level of the gastric antrum. (C) The five sonographic layers of the gastric wall. Note that with a low-frequency curvilinear transducer, the resolution is decreased and only the muscularis propria is evident. A, antrum; Ao, aorta; L, liver; P, pancreas.

with more complex cardiac pathologies (eg, myocardial infarction (MI), PE, undiagnosed pericardial effusion).¹²⁶

FoCUS can also provide repeated evaluation of volume status and ventricular function, which is often not logistically feasible with formal echocardiography^{118 127–129}; additionally, FoCUS may prompt further testing or consultation. For example, although FoCUS has a low sensitivity for PE,^{130 131} when there is a high level of clinical suspicion and visualization of a dilated right ventricle (RV), it might lead to a more urgent pursuit of definitive imaging like CT angiography (CTA).¹¹⁸ Similarly, while FoCUS should not be used to detect wall motion abnormalities,^{118 119} global left ventricle (LV) systolic dysfunction in a patient with ECG changes and other supportive symptoms may prompt more rapid cardiology consultation. Of note, negative findings with FoCUS in a clinical situation suspicious for the above pathologies should not discourage pursuing more conclusive investigations, such as ordering advanced imaging, for example, CTA or a complete transthoracic echocardiogram.

There are several clinical scenarios where the utilization of FoCUS can be considered for the chronic pain or interventional pain physician. Radiographic contrast is routinely used in interventional pain management to help detect an intravascular spread of the injectate. While adverse reactions are rare, they can be life-threatening.¹³² Therefore, pain physicians should be equipped with tools allowing timely management of an anaphylactic reaction or other complications. FoCUS can be potentially used to treat other rare complications of pain management

procedures, including hypotension after sympathetic blocks or respiratory and cardiovascular collapse resulting from brainstem anesthesia after trigeminal blocks.^{133 134}

Cardiac arrest

FoCUS is emerging as an important tool to assist with diagnosing and managing patients in cardiac arrest.¹³⁵ FoCUS plays a role in the asystole and pulseless electrical activity (PEA) pathway in the advanced cardiac life support (ACLS) algorithm. FoCUS can help diagnose treatable pathologies such as hypovolemia, PE, LV failure and pericardial tamponade. FoCUS can also provide insight into prognosis and survivability based on the presence or absence of LV wall motion.¹²⁶ The focused echocardiographic evaluation in life support protocol describes the optimal timing and FoCUS views to assist in diagnosis and management during ACLS while avoiding interference with other essential treatments.¹²⁶

FoCUS views

The fundamental FoCUS views are the parasternal long axis, parasternal short axis, apical four-chamber, subcostal four-chamber and the subcostal-inferior vena cava view. These views are sufficient to obtain the qualitative information needed to diagnose gross and potentially life-threatening pathology. This article will not detail view acquisition as there are multiple resources available in publications and online.^{12 121 136} However,

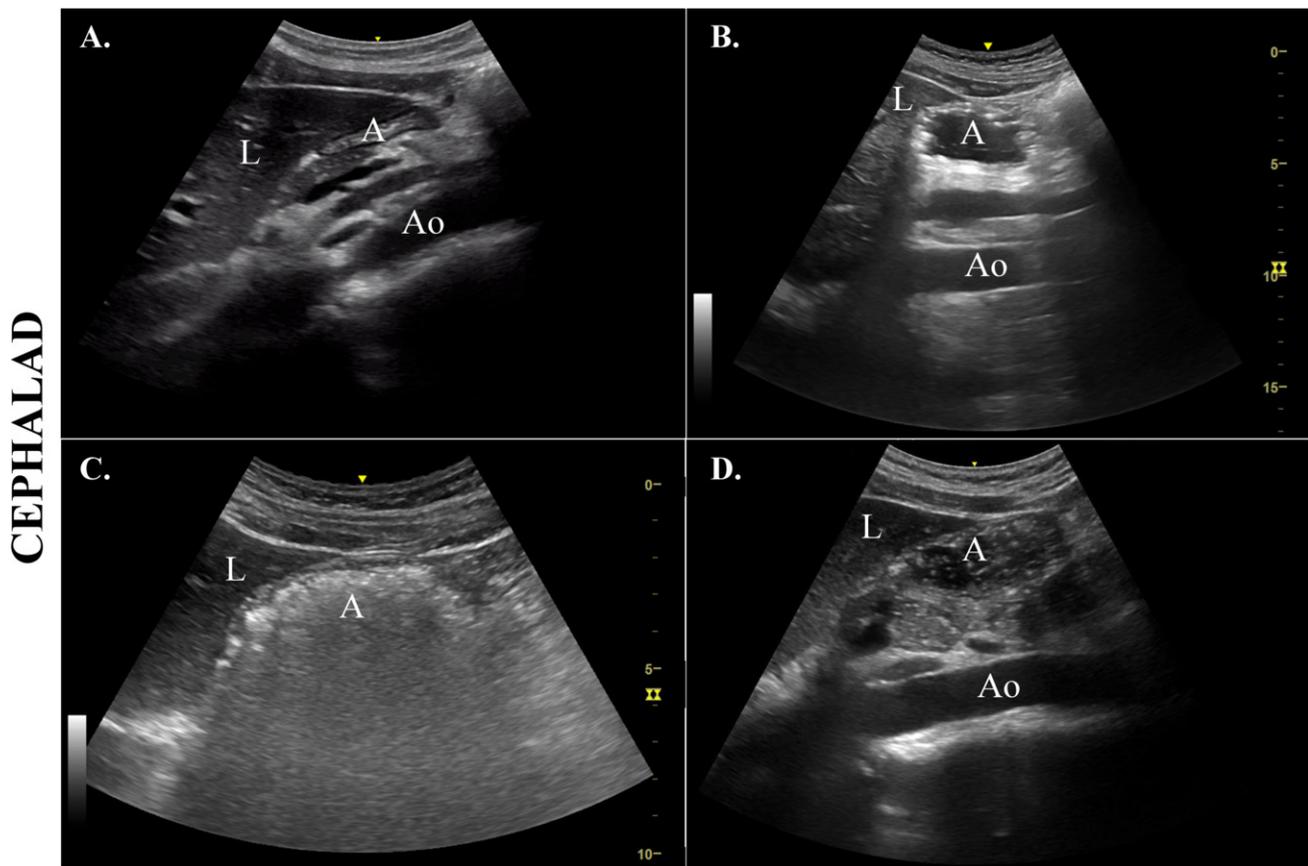


Figure 5 Gastric ultrasound sonoanatomy. (A) Sonographic appearance of the antrum in an empty stomach. (B) Appearance with clear fluid. (C) Appearance soon after a solid meal (early stage solid) with significant air content. (D) Appearance with mixed solid and fluid content (late stage solid). A, antrum; Ao, aorta; L, liver.

figure 6 highlights the basic views as initially described with the FATE protocol.

Relevant pathology

FoCUS can identify specific gross pathologies, and the following section will highlight some of the most pertinent pathologies for regional anesthesiologists and pain medicine physicians. Before implementing a new clinical skill, it is essential to understand the indications and subsequent steps required to practice this skill both safely and correctly. The I-AIM Framework is a standardized, step-by-step guide for clinicians learning a new POCUS skill to identify the appropriate clinical scenarios where it can be used.^{48 49} table 4 has a summary of each cardiac pathology using the I-AIM Framework.

Local anesthetic systemic toxicity

Although LAST is a rare complication for regional anesthesiologists and pain specialists, it is one of the most critical complications to assess and manage appropriately. LAST resulting from peripheral nerve blocks or neuraxial anesthesia can be devastating, causing severe ventricular arrhythmias, myocardial depression and cardiovascular collapse. There is a complex algorithm for the assessment and management of LAST,¹³⁷ which is particularly relevant when LAST is detected immediately following local anesthetic injection. However, FoCUS can be essential with a delayed presentation of LAST, which can mimic other cardiac pathologies such as MI¹³⁸ and cardiogenic shock.¹³⁹ For example, in an otherwise healthy patient presenting with delayed hemodynamic instability following either neuraxial or

peripheral nerve block, FoCUS can reveal new-onset myocardial dysfunction suggesting LAST.

Aortic stenosis

AS is often of concern for a patient presenting for urgent or emergent surgery (for example, hip fracture surgery) without a recent medical workup and an audible systolic murmur on auscultation. Hip fracture patients can benefit significantly from neuraxial technique depending on their comorbidities; however, a patient with severe AS is at risk for significant hemodynamic changes and potential complications following induction with neuraxial technique. Although the definitive diagnosis and grading of valvular AS require advanced technical skill and knowledge, FoCUS can be used to detect morphologic signs that suggest AS and prompt additional diagnostic imaging as well as changes in management.^{118 119 125 140}

Hypovolemia

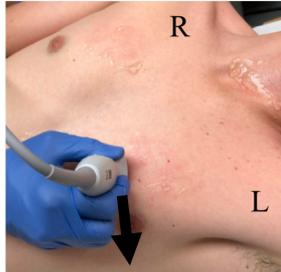
Assessment for hypovolemia before a neuraxial blockade can add considerable value and help guide management. For example, a trauma patient presenting for emergent surgery with an occult bleed or a patient with end-stage renal disease who has recently undergone dialysis may have inadequate preload at baseline, resulting in significant hemodynamic changes and potential cardiac arrest following induction with neuraxial technique. Alternatively, hypovolemia may result from low vascular resistance and reduced afterload, as seen in pathologies such as sepsis or septic shock.

A. Probe Position

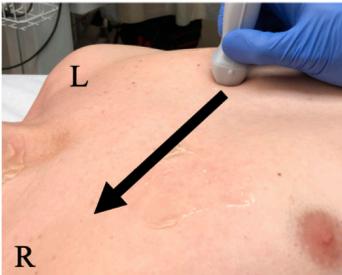
Pos 1: Subcostal 4-C



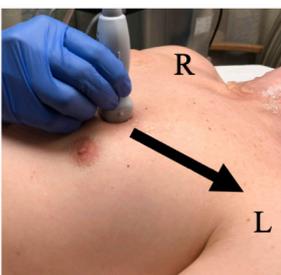
Pos 2: Apical 4-C



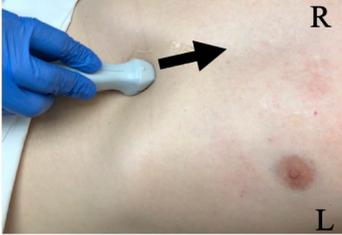
Pos 3: PS LAX



Pos 3: PS SAX



Position 1: Subcostal IVC



B. Modified FATE Card

Focus Assessed Transthoracic Echo (FATE)

Scan position 1-3 in the most favorable sequence

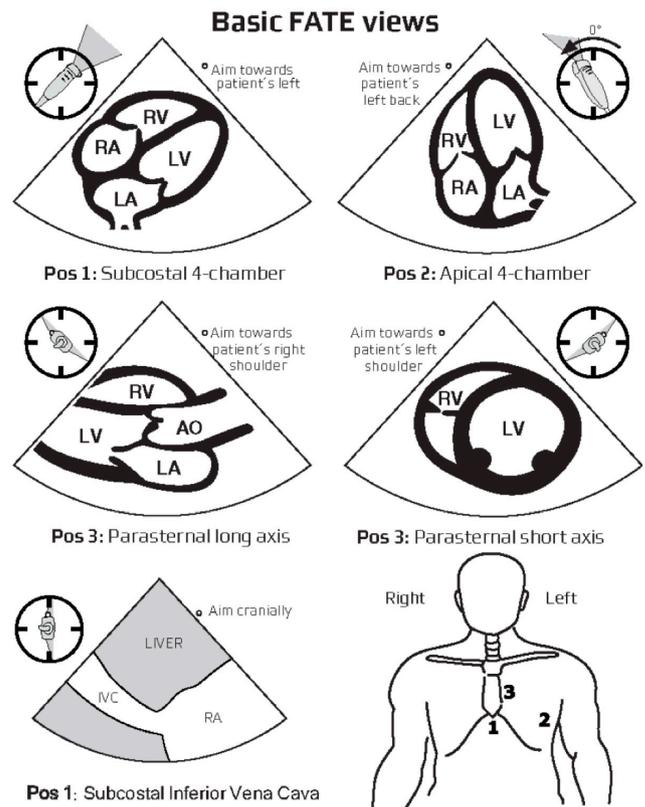


Figure 6 Probe placement for a focus cardiac ultrasound examination and modified basic FATE card to include subcostal IVC view. (A) Probe placement for each FATE view with arrow demonstrating orientation marker direction. (B) Modified basic FATE card with IVC view. 4-C, four-chamber; Ao, ascending aorta; IVC, inferior vena cava view; L, left; LA, left atrium; LV, left ventricle; R, right; RA, right atrium; RV, right ventricle; PS LAX, parasternal long axis, PS SAX, parasternal short axis.

Pulmonary embolism

PE is a relatively common complication following orthopedic procedures (~1.7%)¹⁴¹ and is a significant cause of death following trauma surgery (~1.6%).¹⁴² Regional anesthesiologists routinely manage patients at risk for this complication, and it should be high on our differential diagnosis in the perioperative setting of hemodynamic instability and cardiovascular collapse. PE is a time-sensitive emergency that requires a rapid diagnosis to ensure adequate intervention and management. Although FoCUS has a low sensitivity for PE,¹³⁰⁻¹³¹ it has been shown to have high specificity in the setting of massive PE, particularly in patients without any known preexisting cardiovascular disease.¹⁴³⁻¹⁴⁴ Occlusion of the pulmonary vasculature, as seen with massive PE, causes an acute elevation in RV pressure resulting in RV dilation and failure. Although emboli are not always visible, multiple FoCUS findings significantly increase suspicion for PE and should direct further evaluation and/or management.

Summary of clinical indications

Based on the evidence presented, there are multiple clinical applications for POCUS; however, to provide additional examples to guide training, this group has provided several educational case-based clinical scenarios (online supplemental file 1 part I—Case-Based Clinical Scenarios) for review that can be implemented into a training program.

Pediatric POCUS

POCUS is becoming an essential tool for diagnostic and procedural purposes in pediatric acute care medicine, similar to its use in adult populations.¹⁴⁵⁻¹⁴⁹ Evidence documents the benefits of gastric,¹⁰⁶⁻¹⁵⁰⁻¹⁵¹ cardiac,¹⁴⁷⁻¹⁴⁸ airway and lung¹⁵²⁻¹⁵⁶ ultrasound use in children. While there are many similarities between POCUS imaging for adults and children, the differing size, physiology, common injury patterns and distribution of comorbidities in children create aspects of POCUS that are unique to pediatric patients.¹⁵

When considering the various categories of the I-AIM model, most of the technical aspects of image acquisition are quite similar between children and adults. In general, smaller footprint, higher frequency transducers are used on children, and the depth and focus settings need to be adjusted to size. Otherwise, the views are acquired through the same windows with similar transducer orientations. Obtaining intraoperative images can be easier given that there is a shorter distance to the target structures. However, when infants and children are draped and positioned for surgery, their smaller size limits access to sonographic windows. Indications, interpretation and directed medical management differ due to the pathophysiologic characteristics of pediatric patients. The following sections summarize the distinct aspects of POCUS applications in children to supplement the didactic information already included in the previous sections.

Table 4 FoCUS I-AIM framework for the regional anesthesiologist

Pathology	Clinical indication	Acquisition—optimal FoCUS view(s)	Interpretation	Medical decision-making
Local anesthetic systemic toxicity (LAST)	Delayed onset of hemodynamic instability following neuraxial or PNB in a patient with no known cardiac disease (\pm arrhythmias)	PSAX Alternative Acceptable Views: PLAX, A4C, SC4C	PSAX Sluggish, poorly contracting and potential dyssynchronous LV	Provide hemodynamic support (\pm inotropes or vasopressors) Follow LAST guidelines, including the use of lipid emulsion
Aortic stenosis	Urgent or emergent surgery (eg, hip fracture surgery) with inadequate medical workup and an audible systolic murmur on auscultation	PLAX PSAX at the level of AV*	PLAX and PSAX at level of AV* \downarrow AV cusp mobility \uparrow AV cusp thickness/calcification	Urgent Case Formal TTE and cardiology consultation Emergent case Adjust perioperative management: +arterial line, maintain hemodynamics with vasopressors \pm inotropes throughout induction, escalate postoperative care to stepdown or ICU
Hypovolemia	Urgent or emergent surgery with concern for hypovolemia (eg, trauma patient or ESRD following dialysis)	SCIVC PSAX	SCIVC IVC diameter <1.5 cm, >50% collapse with 'kissing wall sign' PSAX Hyperdynamic LV with underfilled end-diastolic volume and end-systolic 'touching' of the myocardium Note: Emptying depends on afterload	Fluid resuscitation prior to induction Consider gradual induction with epidural over a subarachnoid block
Pulmonary embolism (PE)	Suspected massive PE in high-risk patient population (eg, orthopedics or trauma patient)	PSAX A4C or SC4C	PSAX D-shaped septal shift, RV>LV A4C or SC4C RV and RA dilation >LV Intraventricular septal bowing toward LV during systole	Cardiopulmonary resuscitation when necessary Initiate thrombolytic therapy and/or embolectomy

*Advanced view not discussed in the recommendations.

A4C, apical four-chamber view; AV, aortic valve; ESRD, end-stage renal disease; FoCUS, focused cardiac ultrasound; I-AIM, Indication, Acquisition, Interpretation, and Medical Decision-Making Framework; ICU, intensive care unit; IVC, inferior vena cava view; LAST, local anesthetic systemic toxicity; LV, left ventricle; PLAX, parasternal long axis view; PNB, peripheral nerve block; PSAX, parasternal short axis view; RA, right atrium; RV, right ventricle; SC4C, subcostal four-chamber view; SCIVC, subcostal inferior vena cava view; TTE, transthoracic echocardiogram.

Airway and LUS

Infants and children have an increased risk of endobronchial intubation due to relatively short tracheal length.¹⁵⁷ The ASA Closed Claims Project shows that bronchial intubations account for 4% of respiratory claims in children compared with 2% in adults.¹⁵⁸ Point-of-care LUS correctly identifies endobronchial intubation in 95%–100% of children.^{153 159 160} Diagnosis of an interstitial syndrome and pneumothorax is similar to adult data.

The proportionally large head, small mouth opening, bigger tongue and anterior position of the larynx in infants¹⁵⁷ predisposes them to accidental esophageal intubation, which occurs in up to 21% of infants.¹⁶¹ Those patients with esophageal intubation have a 4% incidence of hypotension and a 3% incidence of initiation of chest compression.¹⁶¹ Real-time tracheal ultrasound imaging using a high-frequency linear transducer placed transversely just above the sternal notch has a sensitivity and specificity of 98.5%–100% and 75%–100%, respectively, for correctly diagnosing esophageal intubation.^{153 159 160} Airway ultrasound has the potential to eliminate the need for test ventilation and speed the diagnosis of esophageal intubation.

Abdominal ultrasound

In response to hypovolemia, children have greater hemodynamic compensatory mechanisms to maintain blood pressure until 40% of the blood volume is lost, making a timely diagnosis of intra-abdominal bleeding via abdominal ultrasound advantageous.^{162–164} The smaller caliber of Foley catheters makes

kinking and plugging common, and ultrasound of the bladder can help to differentiate causes of anuria.

Gastric ultrasound

The gastric volume is measured in pediatric patients in mL/kg with a volume greater than 1.5 mL/kg suggesting greater than baseline secretions.¹⁰⁷ Children may not understand the importance of remaining NPO and may violate NPO guidelines when not directly observed. Comorbidities placing them at risk for delayed gastric emptying are short gut syndrome and pyloric stenosis. In infants presenting for a repair of pyloric stenosis, pre gastric and post gastric suctioning imaging can be used to direct the anesthetic induction technique.¹⁵⁰ Gastric imaging is ideally performed pre induction, but children may not cooperate, making imaging difficult. Clinical applications of gastric ultrasound imaging in children are sparse.^{101 150}

Focused cardiac ultrasound

Given the prevalence of congenital heart disease in children, it is important to realize that bedside cardiac ultrasound has very limited applications in children with congenital heart disease and should not be used to delineate structural abnormalities.^{118 147 165} Ultrasound imaging of the heart adds important information to the physical examination in children and is most commonly indicated in the setting of undifferentiated hypotension or tachycardia.^{147 148 166 167} The use of cardiac ultrasound in the setting of pediatric cardiac arrest is distinct from adult

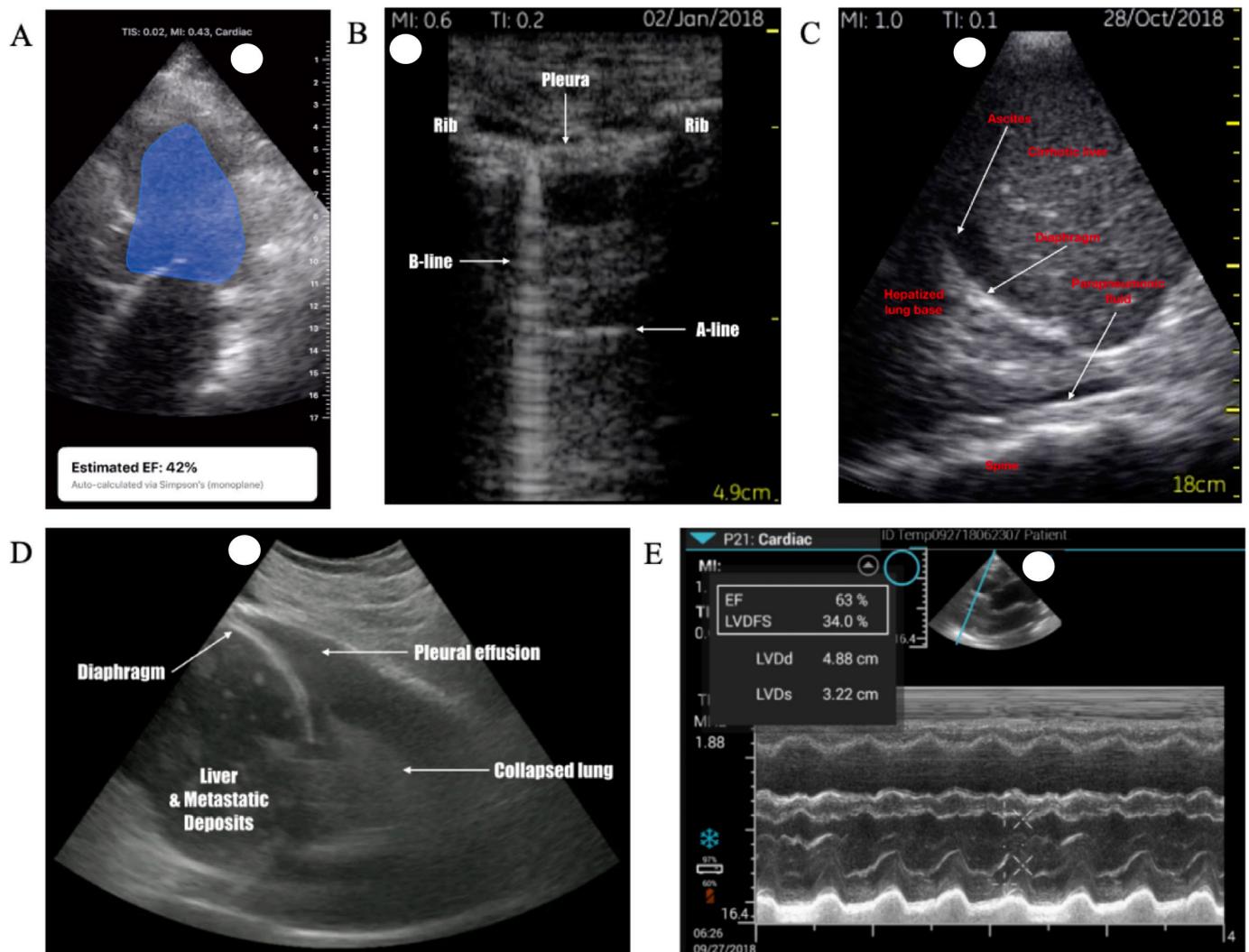


Figure 7 Various images obtained from a range of portable handheld devices. (A) Apical four-chamber view with auto-ejection fraction calculation. (B) LUS—upper zone view demonstrating anatomy and pathology. (C) Right lung base/right upper quadrant view showing cirrhotic liver, ascites and parapneumonic fluid. (D) Right upper quadrant abdominal scan with lung base view, demonstrating metastatic cancer in liver with pleural effusion. (E) Parasternal long axis of the heart, demonstrating calculation of fractional area change. EF, ejection fraction; LUS, lung ultrasound; LVd, left ventricular end-diastolic diameter; LVDFS, left ventricular dimension fraction shortening; LVdS, left ventricular end-systolic diameter.

practice. While insufficient evidence exists to recommend for or against the routine use of FoCUS during pediatric cardiopulmonary resuscitation (CPR), the 2010 International Pediatric Basic and Advanced Life Support guidelines recommend that ‘bedside cardiac echocardiography may be considered to identify potentially treatable causes of a cardiac arrest when appropriately skilled personnel are available, but the benefits must be carefully weighed against the known deleterious consequences of interrupting chest compression’.¹⁶⁸ Ultrasound can be used to identify reversible causes of cardiac arrest, including cardiac tamponade, severe hypovolemia and pulmonary air embolus.^{126 169–172} The diagnosis of cardiac standstill or PEA in children carries a different prognosis and algorithmic sequence compared with adults. Forty per cent of intraoperative cardiac arrests in children occur from a respiratory etiology, and restoration of oxygen delivery alone may lead to a return of spontaneous circulation.¹⁷³ Extracorporeal membrane oxygenation for cardiac resuscitation (E-CPR) as a rescue strategy in children in cardiac arrest is not uncommon.¹⁷⁴ There is evidence that E-CPR for pediatric patients with in-hospital arrest requiring >10 min of standard CPR is associated with improved survival

and neurologic outcomes. There is also evidence that prolonged conventional CPR with ongoing use of epinephrine every 3–5 min (as recommended by pediatric advanced life support protocol) and resultant elevated systemic vascular resistance may have deleterious effects when implementing E-CPR by limiting extracorporeal membrane oxygenation pump flows.¹⁷⁵ More rapid determination of myocardial standstill using cardiac ultrasound may facilitate more rapid progression to E-CPR with improvement in outcomes.

Handheld devices in POCUS applications

Increasingly portable ultrasound machines have led to an exponential uptake in utilization and discussion in the literature¹⁷⁶ with some devices priced for individual purchase.^{177 178} Traditional ultrasound machines have many barriers to use, including size, cost and difficulty to operate. Therefore, handheld devices can be an introductory device before becoming competent in advanced ultrasound applications.¹⁷⁹ For example, the introduction of handheld ultrasound devices in medical schools aids with teaching functional anatomy and with implementing a clinical

Box 1 Summary of advantages and disadvantages to handheld devices using an I-AIM Framework.

Advantages and disadvantages of handheld devices in POCUS applications:

Advantages

- ▶ Portability/convenience.
- ▶ Increased teaching and training opportunities due to portability/affordability.
- ▶ App-based software upgrades offering AI and other increased functionality.
- ▶ Ease of transport.
- ▶ Minimal boot-up time.
- ▶ Practical in confined spaces.
- ▶ Simple and less intimidating to beginners.
- ▶ Cloud-based storage available.
- ▶ WiFi image upload possible with DICOM linkage to existing institution systems.
- ▶ Potential to use existing electronic equipment (Android-based/Apple-based devices).

Limitations and pitfalls

- ▶ Poorer image quality than higher-end systems:
 - More prone to artifacts.
 - Greater risk for image misinterpretation.
- ▶ Small screen size:
 - Limits image acquisition.
 - Prevents multiple functionalities on the screen.
- ▶ Increased phantom scanning (scanning without image capture/record).
- ▶ Limited compatibility with existing image storage system.
- ▶ Limited advanced functionality (ie, pulsed or continuous wave Doppler).
- ▶ Potential for overuse and misinterpretation of incidental findings.
- ▶ Misplacement, theft or loss of the device.
- ▶ Scanning time limited by battery life.
- ▶ Transducer selection is device dependent.
- ▶ Probes overheat.
- ▶ Cloud security/governance challenges
- ▶ Wireless devices prone to drop-out/'jumpy images'/limited image quality on probe movement.
- ▶ Sterility concerns.

AI, artificial intelligence; DICOM, Digital Imaging and Communications in Medicine; POCUS, point-of-care ultrasound; WiFi, wireless fidelity.

POCUS curriculum.^{180 181} Examples of basic images obtained from a selection of these devices are shown in [figure 7](#).

Limitations in image quality, screen size, available memory and data encryption make handheld ultrasound devices better used to extend the physical examination rather than comprehensive diagnostics tools. Sterility is of utmost importance given the potential for frequent use and the ability to attach to personal devices.

Critics of POCUS often express concern that it deprioritizes patient contact during the physical examination; however, handheld ultrasound can bridge the gap between the clinician and diagnostic tests while facilitating communication with visual confirmation of findings in real time.¹⁸² The presentation of pathology can aid compliance and buy-in for additional testing/imaging.

To offer a balanced approach to handheld devices, some of the advantages and disadvantages are shown in [box 1](#).

SUMMARY

POCUS is an essential skill for all regional anesthesiologists and pain physicians to help diagnose relevant complications related to routine practice and guide perioperative management. The growing evidence supporting the clinical utility of POCUS has been outlined to lay the foundation for part II of the recommendations. Part II will provide structured guidelines and strategies for the education of the trainee and postgraduate learner.

The expert panel acknowledges that clinical evidence supporting POCUS is evolving, and certain endpoints, such as improved survival during CPR, require additional validation.^{181 182} All interventions have risks or downsides, including potential false-negative findings, higher rates of interventions or delayed bedside management due to the performance of an examination.^{181 182} Because of these concerns, adequate training and future investigation into applications are essential for the adaptation of POCUS into the perioperative and periprocedural setting.

Regarding POCUS skills that fall outside of the traditional scope of regional anesthesiologists and pain specialists, such as the FAST examination, the expert panel emphasizes learning to perform these skills as well. As these skills are introduced into new clinical practice realms, there is great potential to illuminate novel clinical scenarios in the perioperative and periprocedural setting that can aid in patient assessment and management.

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Supplement 1 – Clinical Cases

Airway US

CASE 1

A 59-year-old male with PMH of obesity, OSA, status post cervical fusion from C3-6, and lumbar T10 to L5 fusion is scheduled to undergo a total hip arthroplasty revision. His neck circumference is 20 inches. He reports that last time he had surgery, they "had to wake me up as they could not get the tube in."

Indication

This patient is high-risk for a difficult airway and/or failed intubation. An ultrasound of the airway allows for assessment and localization of the cricothyroid membrane in preparation for a cannot ventilate, cannot intubate scenario.

Acquisition

The first step is the identification of the tracheal rings with a linear probe in a transverse plane. As you scan cephalad, you identify the thicker, more anterior, and dome-shaped cricoid cartilage before arriving at the triangular thyroid cartilage. Once you have found the thyroid cartilage, you slide caudad into the space to mark the location of the cricothyroid membrane (CTM) in the transverse plane (also known as the "air gap"). Having identified the CTM in the transverse plane, you rotate the probe ninety degrees into the longitudinal plane to mark the midline. Correct midline position is marked by identification of the "string of pearls" consisting of the larger tracheal cartilage, thicker and more anterior cricoid, as well as the slightly thinner and deeper tracheal rings.

Interpretation

Identifying the cricothyroid membrane in both the transverse and longitudinal planes allows for more precise and expeditious localization of the CTM in a difficult airway scenario, particularly in obese patients. (**Supplement 2 - Figure 1**) It is crucial to identify the CTM in both planes to ensure both the correct level and precise true midline.

Medical management

You topicalize the patient's airway with an atomizer to anesthetize the glossopharyngeal nerve, perform an ultrasound-guided superior laryngeal block, and perform a transtracheal recurrent laryngeal nerve block. This topicalization is followed by an uneventful awake fiberoptic intubation with an otolaryngologist on standby in the room to perform a cricothyrotomy if needed.

CASE 2

You are performing a general anesthetic for a total shoulder arthroplasty in an ASA3 patient with moderate CHF and COPD. Upon laryngoscopy, you unexpectedly encounter a grade three Cormack-Lahane view and pass the endotracheal tube down what you believe to be the trachea. The CO2 analyzer is calibrating, breath sounds are minimal, and the misting of the endotracheal tube is minimal.

Indication

Airway ultrasound is highly useful in situations where confirmation by conventional means is not possible, equivocal, or whenever real-time assessment of the correct endotracheal position (non-esophageal and non-endobronchial) is needed.

Acquisition

The image is obtained supine with the ultrasound probe placed left of the midline in a transverse plane. This view allows for real-time visualization of endotracheal or esophageal intubation and the application of paratracheal pressure to decrease or prevent the risk of aspiration on induction. Typically, a linear probe is used with depth settings of about 4-6 cm. With an additional step, endobronchial intubation can be ruled out by visualization of bilaterally pleural sliding in the midclavicular line between the 2nd and 4th intercostal space. If there is endobronchial intubation, then lung sliding will only be seen on one side (typically the right side), while endotracheal intubation will show bilateral lung sliding.

Interpretation

In the above scenario, the suspicion for esophageal intubation is high. Ultrasound imaging demonstrates the double trachea sign confirming the suspicion.

Medical management

Once esophageal intubation is confirmed, the endotracheal tube is removed, and an alternative means of intubation is performed with video laryngoscopy.

Lung US

CASE 1

A celiac plexus block was performed in a patient with severe abdominal pain secondary to terminal pancreatic carcinoma. The procedure was completed uneventfully but on arrival in the post anesthetic care unit (PACU), the patient became short of breath and showed signs of increased work of breathing. Initial supportive measures included increasing the FIO₂, elevating the head of bed and frequent vital signs monitoring. After gathering relevant clinical information and reviewing the anesthetic record, it was decided to perform a LUS.

Indication

This patient has developed acute respiratory distress in the PACU. There are several differential diagnoses that LUS can help to rule-in or rule-out including pneumothorax, pleural or abdominal collections, lung consolidation/atelectasis, and pulmonary edema. In addition, LUS can guide the treatment and evaluate patient response.

Acquisition

With the patient lying supine, a high frequency linear probe (8-12 MHz) is placed on the anterior chest over the 2 intercostal space and moved slowly towards the posterior chest. Confirmation of sliding pleura, seashore sign (M mode), B lines (normal if located predominantly in the posterior thorax and maximum of three), lung pulse (B and M mode) would rule out pneumothorax in the assessed area. The presence of barcode sign (M-mode) or the discovery of a lung point on 2D highly suggests pneumothorax.

The probe should be placed on the anterior chest wall in a cephalad-caudal orientation to allow visualization of at least two ribs with the pleural line in between. This minimizes the risk of mistaking the rib border for a non-moving pleural line. The pleural line should be visualized at multiple interspaces (2nd to 4th) and from medial to lateral in the least dependent zone of the thorax. Comparison with findings on the contralateral side may facilitate interpretation.

In a supine patient with suspected pneumothorax (absence of lung sliding, pulse, and vertical artifacts on one side of the image), the lung point is identified by rotating the probe transversely over an intercostal space and sliding laterally and posteriorly. A lung point can be visualized in a non-complete pneumothorax when the beam insonates the transition between the intra-pleural air and expanded lung adhering to the parietal pleura without interposed air.

Interpretation

Lung sliding, lung pulse, and vertical artifacts (B and Z lines) are all absent over the anterior right hemithorax. Barcode sign and lung point are seen on the anterior right hemithorax. Using the clinical history and the above sonographic findings, the diagnosis of a right pneumothorax is made.

It is worthy to mention that the absence of sliding pleura doesn't confirm the diagnosis of pneumothorax as there are other lung conditions when the visceral pleura doesn't slide against the parietal pleura (e.g., apnea, pleurodesis, inflammatory adherence, over-inflation, severe bullous disease and endobronchial intubation).

Medical management.

Supportive measurements are continued while a right pigtail catheter is inserted for drainage.

CASE 2

A left sided interscalene brachial plexus block was performed in a patient undergoing arthroscopic shoulder surgery. Patient has a history of atrial fibrillation, past CHF and CAD. Patient also underwent general anesthesia without incident. Upon arrival to PACU, the patient was found to low O₂ saturation down to low 80s.

You started appropriate initial supportive measurements (increasing FIO₂, bag mask ventilation), gather relevant clinical information, review the anesthetic record and ordered blood work.

Indication

This patient has developed acute respiratory failure. There are several differential diagnoses that LUS can help to rule-in or rule-out including pneumothorax, pleural collections, diaphragmatic dysfunction, and pulmonary edema. In addition, LUS can guide the treatment and evaluate patient response.

Acquisition

With the patient in the supine position, a high frequency linear probe (8-12 MHz) is placed on the anterior chest and moved slowly towards the posterior chest. Attention is focused on the sliding pleura and the presence of vertical artifacts to rule out pneumothorax. Then over the mid axillary line at the 8th – 9th intercostal space, the diaphragm is accessed to evaluate the change in thickness during end inspiration and end expiration.

Alternatively, a low frequency curvilinear probe (2-5 MHz) can be placed between the midclavicular and anterior axillary lines in the subcostal region (right side) or between the mid and posterior axillary line (left side) to access excursion of the diaphragmatic dome. M-mode can be used to quantify the diaphragmatic excursion during quiet respiration (resting tidal volume), deep inspiration and sniffing.

Interpretation

Lung sliding and lung pulse are present bilaterally, scarce B-lines are seen only on the posterior hemithorax and there are no pleural effusions. B and M-modes reveal paradoxical upward motion of the left hemidiaphragm during inspiration. There is less than 12% change in left diaphragmatic thickness between end inspiration and end expiration. Together with the clinical history and these sonographic findings, the diagnosis of unilateral diaphragmatic paresis is made.

Medical Management

Supportive measurements are continued and non-invasive mechanical ventilation is started. After a few hours, a follow up LUS exam shows no evidence of left hemidiaphragm paradoxical movement, excursion is more than 2 cm and the change in left diaphragmatic

thickness is more than 25%, confirming resolution of left hemi diaphragmatic paresis.
(Supplement 2 - Figure 2)

CASE 3

A right supraclavicular brachial plexus catheter was placed in a patient undergoing extensive elbow reconstruction. Patient was involved in a high speed car accident 24h ago. During the procedure the patient had an incomplete block, necessitating small doses of opioids, ketamine and field infiltration. Upon completion of surgery, the patient was transferred to the PACU where he started to develop tachypnea, hypotension (BP 85/50) and decreased LOC.

Appropriate initial supportive measurements were initiated including placing a non-rebreathing mask, crystalloid bolus and phenylephrine to maintain SBP > 90 mmHg. After gathering relevant clinical information and reviewing the anesthetic record it was decided to perform a LUS.

Indication

This patient is in decompensated shock. LUS can help to rule-out life threatening pathologies including pneumothorax, pleural or abdominal collections, lung contusion/atelectasis, and diaphragmatic paresis. In addition, LUS can guide the treatment and evaluate patient response to medical interventions.

Acquisition

With the patient in the supine position, a high frequency linear probe (8-12 MHz) is placed on the anterior chest over the 2 intercostal space and moved slowly towards the posterior chest. Presence of sliding pleural, lung pulse or vertical artifacts is evaluated. Then a low frequency curvilinear probe (2-5 MHz) is placed between the midclavicular and anterior axillary line on the right side and between the mid and posterior axillary line on the left side to access diaphragmatic excursion and thickening.

Finally, a low frequency curvilinear probe is placed in a cephalad-caudal orientation between the 8 -10 intercostal spaces in the mid-axillary line. The probe is rotated slightly counterclockwise and directed posteriorly towards the vertebral column to ensure visualization of the most dependent portion of the pleural space. The image should display lung artifacts and diaphragm to the left with the liver/spleen and the vertebral column, and potentially the kidney to the right. Visualization of the spine and kidney provides confirmation that the beam is interrogating the most dependent region of the thoracic cavity.

Interpretation

Lung sliding and lung pulse are present bilaterally, scarce B-lines are seen only on the posterior hemithorax. Diaphragmatic dome excursion is reduced on the right side. An anechoic collection above the right diaphragm is visualized. This collection is occupying 2/3 of the right

hemithorax causing collapse of the ipsilateral lung. (**Supplement 2 - Figure 3**) Using the clinical history and the above sonographic findings, the diagnosis of a right hemothorax is made.

Medical Management

Crystalloid and blood transfusion were started. A right chest tube is inserted for drainage of hemothorax.

Gastric US

CASE 1

A 46-year-old man with type 2 diabetes mellitus presents for an open fixation of a fifth metacarpal fracture under brachial plexus blockade and intravenous sedation. The patient had a cup of tea with milk and biscuits six hours ago.

Indication

This patient carries a risk of delayed gastric emptying due to his co-morbid status (diabetes), as well as a recent injury. Delayed gastric emptying may increase the risk of pulmonary aspiration following induction of general anesthesia or deep sedation despite adhering to fasting guidelines. Point-of-care gastric ultrasound is indicated in this case to determine the risk of pulmonary aspiration with intravenous sedation.

Acquisition

The patient is placed in the right lateral decubitus position and a low-frequency, curved array ultrasound transducer is used to scan the epigastrium. After sweeping from left to right, you find the key sonographic landmarks at the level of the aorta demonstrating the gastric antrum posteriorly to the left lobe of the liver.

Interpretation

The gastric antrum is small, with a thick muscularis propria layer. There is minimal fluid in the antrum, consistent with a Grade 0 antrum and an empty stomach (**Supplement 2 – Video 1**).

Medical Decision-Making

In the clinical context of an elective procedure with the history and time-interval since last ingestion of food and fluids, and an adequate image acquired, you determine that it is safe to proceed with the anesthetic plan of a regional anesthetic and intravenous sedation.

CASE 2

A 71-year-old woman with a history of severe aortic stenosis with left ventricular diastolic dysfunction and preserved systolic function presents for an open reduction and internal fixation of a fractured neck of femur in the supine position. She is confused, has received intravenous opioids for analgesia and believes she has not eaten for more than six hours. You plan to perform a femoral nerve block for analgesia and a general anesthetic. You would like to proceed with a slowly titrated induction of anesthesia with tight hemodynamic control and a supra-glottic airway device.

Indication

There is a potential conflict in anesthetic goals between her cardiac condition which would dictate a slowly titrated induction of general anesthesia and could include management with a supra-glottic airway device versus the possibility of a “full stomach” which would require a rapid sequence induction of anesthesia and endotracheal intubation. This patient carries a risk of delayed gastric emptying due to pain and the use of opioid analgesia. The patient is also confused, and you cannot be certain about her fasting status. To determine the risk of pulmonary

aspiration and guide you to choose the safest anesthetic technique, you perform point-of-care gastric ultrasound.

Acquisition

After performing a femoral nerve block, you place the patient in the semi-recumbent position and use a low-frequency, curved array ultrasound transducer in the exposed epigastrium. After sweeping from left to right, you find the key sonographic landmarks at the level of the aorta demonstrating the gastric antrum posterior to the left lobe of the liver.

Interpretation

The gastric antrum is distended, with a thin muscularis propria layer. There is active peristalsis noted and both anechoic (fluid) and hyperechoic (solid) content within the antrum, consistent with a full stomach (**Supplement 2 – Video 2**).

Medical Decision-Making

In the clinical context of an urgent procedure with the history and sonographic findings (adequate image acquired), you determine that the safest option is to proceed with a general anesthetic using a modified rapid sequence induction technique and endotracheal intubation. You also decide to place an arterial line prior to induction to best monitor her hemodynamic state and quickly respond to possible changes.

Focused Assessment with Sonography for Trauma (FAST)

CASE 1

A 22-year-old otherwise healthy female is scheduled for R total hip arthroscopy. Induction of anesthesia is uneventful, and a 4cc 1.5 mepivacaine spinal is placed. Sedation is maintained with propofol, and the surgery is uncomplicated. Near the end of the operation, the patient becomes restless; blood pressure is 78/40, and the propofol is discontinued. A fluid bolus is initiated, and 10mg ephedrine is given.

The procedure is quickly finished, and over the next five minutes, she begins to complain of severe diffuse abdominal pain, and the blood pressure remains borderline low. Based on her presentation, a decision is made to perform a FAST exam.

Indication

This patient has severe abdominal pain and hypotension at the end of a surgical procedure. A FAST exam can be used to identify and/or narrow the differential diagnosis, which includes hematoma formation versus fluid extravasation. The FAST exam can also be used to get a general view of the pericardium to evaluate for pericardial effusion.

Acquisition

A diagnosis can be made from the right upper quadrant and pelvic views. In general, a large curvilinear abdominal probe with low frequency is preferred, but a cardiac probe can be used as well. The patient should be positioned supine. To obtain the right upper quadrant view, the transducer should be placed at the mid-axillary line at around the 10th or 11th rib. The orientation marker should be faced towards the patient's head. If only the liver is seen, slide the probe caudad until the kidney is seen. If only the kidney is seen then the probe should be slide cephalad until the liver is seen. The ideal view reveals both the liver and the kidney, and the space between them is known as the hepatorenal space or Morrison's pouch. Usually, the liver and kidney are right next to each other, and the hepatorenal space is more of a potential space that appears hyperechoic.

The pelvic views are obtained with the curvilinear probe as well; note that urine in the bladder makes evaluation of the pelvis much easier. To obtain views of the pelvis, the probe should be placed midline superior to the pubic symphysis with the orientation marker facing the patient's right. If the bladder is not seen it can become visible by aiming the probe towards the patient's feet, but this assumes that the bladder has urine. Once the bladder is identified, sweep caudad and cephalad to view the structure of the pelvis. Rotating the probe ninety degrees counterclockwise so that it faces the patient's head will give a cross-sectional view. In general, in males, free fluid tends to pool just below the bladder between the bladder and prostate. In females, however, fluid often can collect posterior to the uterus initially but given more volume will expand to the space between the bladder and the uterus.

Interpretation

The right upper quadrant view reveals significant fluid building in the hepatorenal space. In the pelvis views, there is a considerable amount of fluid with multiple pouches between the bladder and the uterus. Based on these findings, a diagnosis of intraabdominal fluid extravasation is made.

Medical Management

Supportive care is initiated; the patient is started on a phenylephrine infusion to maintain blood pressure, and the patient is started on an IV PCA and admitted for overnight observation. The phenylephrine is weaned over the next three hours. The patient is discharged home the following day, and the rest of her post-operative course is uneventful.

CASE 2

A 54-year-old male with a past medical history of chronic pancreatitis is scheduled for a neurolytic celiac plexus block. Following an uncomplicated procedure, the patient transferred to the PACU. In the PACU, he begins to complain about Left greater than right-sided abdominal pain. Over the next 10 minutes, the patient becomes hypotensive with a blood pressure of 79/42. You are called to the bedside, and following standard resuscitative measures decide to perform a FAST exam.

Indication

This patient has hypotension and abdominal pain following an invasive procedure. A FAST exam will help to elucidate new pathology such as hematoma versus chronic pathology such as ascites. In addition, it can be further used to guide care. The patient is complaining of left-sided abdominal pain, and so the initial focus should be in the left upper quadrant views.

Acquisition

A large curvilinear abdominal probe with low frequency is preferred, with the patient in the supine position. Note that if there is a concern for hematoma, placing the patient in the Trendelenburg position can assist in allowing fluid to pool in the right upper and left upper quadrant (RUQ and LUQ) views. Likewise, if there is a concern for fluid in the pelvis, the patient can be placed into reverse Trendelenburg, but keep in mind that this may exacerbate hypotension.

To obtain the LUQ view, note that the spleen is a little more posterior and superior to the liver. Thus, the transducer should be placed in the posterior axillary line around the eighth rib. The orientation marker should be pointing towards the patient's head. Finding the correct landmarks can be more challenging than the RUQ view. In the optimal situation, one can visualize both the kidney and the spleen. If only the kidney is seen, slide the probe more cephalad until the spleen is seen. If nothing can be seen, consider sliding the probe even more posteriorly.

Once the spleen and kidney are located, fanning the probe in multiple directions can help to examine the area thoroughly. As with the RUQ, the interface between the kidney and the spleen appear hyperechoic. Cephalad to the spleen, the diaphragm will appear as a thick hyperechoic line.

Note that unlike the RUQ view where the fluid is predominantly in the hepatorenal recess, in the LUQ view, fluid is most likely to be found between the spleen and the diaphragm (subphrenic space). However, fluid can still appear in the splenorenal recess as well.

Interpretation

A sizeable hypoechoic fluid collection is found in the subphrenic space. Other views revealed fluid in multiple views. Given the new-onset hypotension and severe abdominal pain, a diagnosis of hemorrhage was made.

Medical management

Aggressive resuscitation measures were initiated, including the placement of large-bore IVs and activation of the massive transfusion protocol. The patient was transferred to the OR for abdominal exploration, and a large liver laceration was identified and repaired. Serial FAST exams were performed in the post-op period showing no further evidence of significant hemorrhage.

Focused Cardiac Ultrasound (FoCUS)

CASE 1

A previously healthy 40-year-old woman is scheduled for a cervical plexus block for treatment of somatic pain referred to the mandible. An uneventful block is performed with 5cc of 0.5% Bupivacaine (25mg total). Approximately 20 minutes later, in the post-anesthetic care unit, the patient becomes short of breath and hypotensive, with a noninvasive blood pressure of 74/40.

Initial supportive measures include applying a face mask and increasing the FO2, placing the patient in Trendelenburg, and giving a 500cc lactated Ringer's bolus. After a quick chart review is performed, a focused cardiac ultrasound exam is conducted, including a parasternal short-axis view is obtained.

Indication

The patient has developed respiratory distress and hypotension in the PACU. A focused cardiac exam can be used in this situation to help narrow the differential and potentially identify etiologies such as hypovolemia, right ventricular failure, pericardial effusions, and cardiac tamponade. Moreover, we can use the exam to help guide and optimize further treatment.

Acquisition

Ideally, the patient should be lying in the left lateral decubitus position, but in emergent situations, adequate views can be obtained with the patient in the supine position. A cardiac probe (phased array) is used and is initially placed between the third and fourth intercostal space immediately left of the sternum. The orientation marker should be facing towards the left shoulder. Slide the probe back and forth between the intercostal spaces and towards/away from the sternum until the optimal scanning window is obtained.

To evaluate the cardiac chambers, the depth should be adjusted to include the entire heart as well as the pericardium. The subcostal view requires the most depth, and the depth should be decreased when scanning the more shallow apical and parasternal views.

In this view, the myocardium of the ventricles will typically appear as a hyperechoic (light or grey circular shape), while the blood within the ventricular chamber will be hypoechoic (dark). Look for a hypoechoic area outside of the ventricular wall, as this may be indicative of pericardial effusion. The right ventricle can also be seen, and one should take note of its size. At the basal level, the mitral valve will appear in a cross-sectional view. The ventricular walls can be examined from this point, and special attention should be given to the septal wall to evaluate for the right ventricular pressure and volume overload. This will be seen as a septal wall flattening in systole, diastole, or both. In addition, the ventricular walls can be examined for symmetrical movement and thickening.

From the basal level, the tail of the probe can be tilted toward the right shoulder to further evaluate the ventricular walls. In the mid-papillary short axis view of the heart, the papillary muscles will appear and decreased preload would appear as a kissing papillary sign. This view is ideal for qualitatively estimating left ventricular systolic function (normal, mildly reduced, moderately reduced, severely reduced). Tilting the tail further up will present the apical segments of the heart where one can continue to look for specific wall motion abnormalities.

Rotating the probe counterclockwise with the orientation marker towards the right shoulder will allow one to obtain the parasternal long-axis views. These views can be useful to help narrow down the differential diagnosis or further rule out other cardiac abnormalities.

Interpretation

The parasternal short axis, long axis and apical views reveals severely reduced global left ventricular systolic function without any evidence of specific wall motion abnormalities. **(Supplement 2 – Video 3-5)** Given the recent procedure, a diagnosis of bupivacaine-induced local anesthetic toxicity with subsequent severe myocardial depression is made.

Medical management

The patient was transferred to the cardiac critical care unit, and hemodynamics were aggressively managed. By post-op day three, the patient's symptoms had improved significantly. And repeated bedside cardiac exam revealed grossly normal left ventricular function.

CASE 2

A 62 yo male with a history of hypertension and diabetes is scheduled for a total knee replacement. Surgical anesthesia is achieved with a 4cc 1.5% mepivacaine spinal. A propofol infusion is started at 25mcg/kg/min. Fifteen minutes after placement of the spinal blood pressure is 68/35, and the heart rate is 84. The patient is given a 10mg ephedrine bolus with nominal improvement. In order to elucidate the cause of hypotension, a decision is made to perform a focused cardiac ultrasound exam.

Indication

The patient has developed an acute onset of hypotension following the induction of anesthesia. The differential diagnosis is broad includes ischemia versus infarction, pulmonary embolism, and hypovolemia. After narrowing the diagnosis, we can use FoCUS to both guide treatment and evaluate for appropriate patient response.

Acquisition

Evidence can be obtained from the subcostal IVC and the parasternal long-axis views. To obtain the subcostal view, a cardiac probe is placed approximately 2cm below the xiphoid process with the patient in the supine position. A view of the heart should be seen below the liver margin at a depth of 16-20cm. A traditional subcostal view can be obtained with the orientation marker directed towards the left; however, to obtain the IVC long axis view, the orientation marker should be rotated ninety degrees counterclockwise so that it faces up towards the head. At this point, one should see the IVC, but make sure that the IVC is coming into the right atrium as it may be confused with the descending aorta, which runs below. Measurement of the IVC is typically done 2 cm inferior to the junction of the IC and the right atrium.

For the parasternal long-axis view, the patient should be placed in the left lateral decubitus position if possible to avoid lung artifact and put the heart closer to the probe. However, in an emergent situation, this may not be possible, and one can often obtain adequate imaging in the supine position. A cardiac probe and is placed between the third and fourth intercostal space immediately left of the sternum. The orientation marker should be facing towards the right shoulder. From there, slide the probe back and forth between the intercostal

spaces and towards/away from the sternum until the optimal scanning window is obtained. As with the PSAX view, to evaluate cardiac chambers, the depth should be between 12-16cm.

In this view, the left ventricle will typically appear as a hyperechoic(light or grey circular shape, while the chambers will be hypoechoic(dark). Posteriorly the descending aorta can be seen in the cross-sectional view. Anterior to this is the left atrium and AV junction. The left ventricular outflow tract, including the aortic valve, are seen, and the right ventricle is seen closest to the probe.

In this view, the apex of the left ventricle should not be visualized; this indicated that the probe is too far out from the sternum, and it should be slide back to near the sternum.

Interpretation

In the subcostal IVC view, the IVC walls are found to be touching(kissing wall sign) during the respiratory cycle. (**Supplement 2 – Video 6**) In spontaneously ventilating patients, IVC collapse of greater than 50% is highly suggestive of low RA pressure. In the parasternal long-axis view, the patient is found to have grossly normal contractility, but the heart appears empty in diastole consistent with decreased preload and hypovolemia.

Medical management

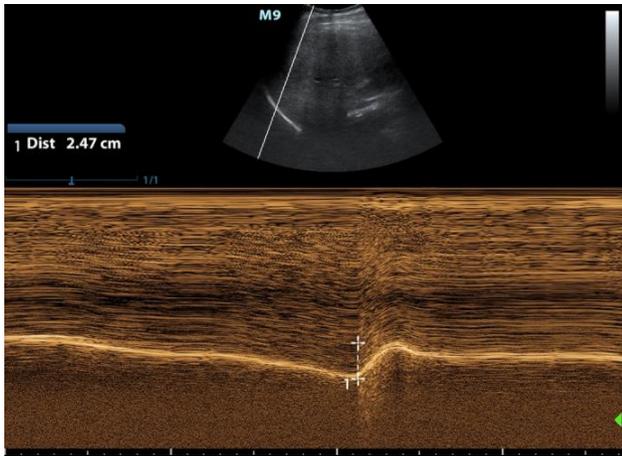
The patient was given a bolus of 1000cc of lactated ringers and later 500cc 5% albumin. An arterial line was placed, and a temporary infusion of phenylephrine was initiated. Following the albumin bolus, the patient's blood pressure improved to 107/68, and the phenylephrine infusion was stopped. The patient had no further issues during the perioperative course.

Surface Markings for Airway Ultrasound

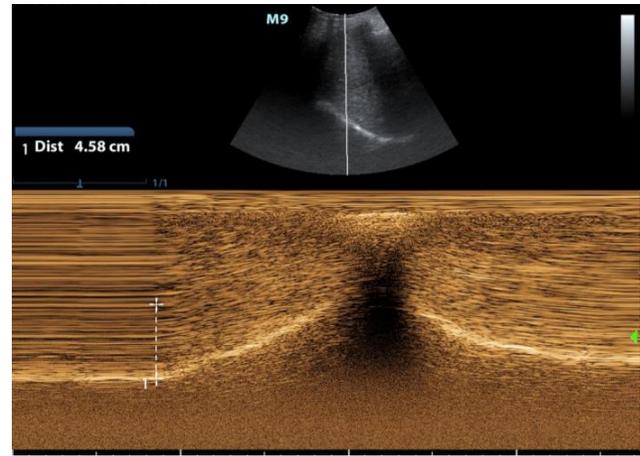


Diaphragmatic US Assessment

Dome movement



Quiet breathing > 1.6 cm

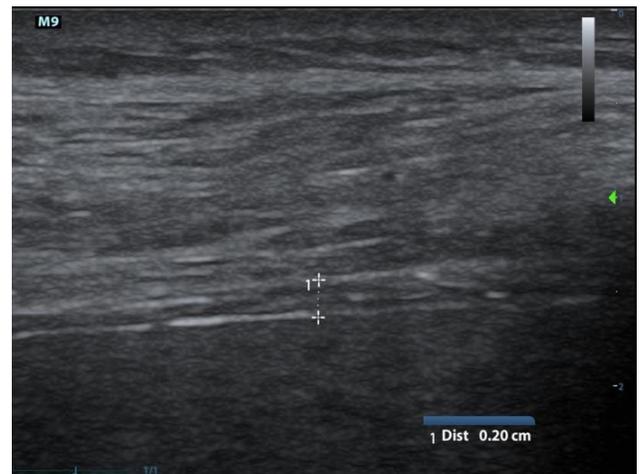


Deep breathing > 4.4 cm

Diaphragm Thickness (Δtdi)



End inspiration



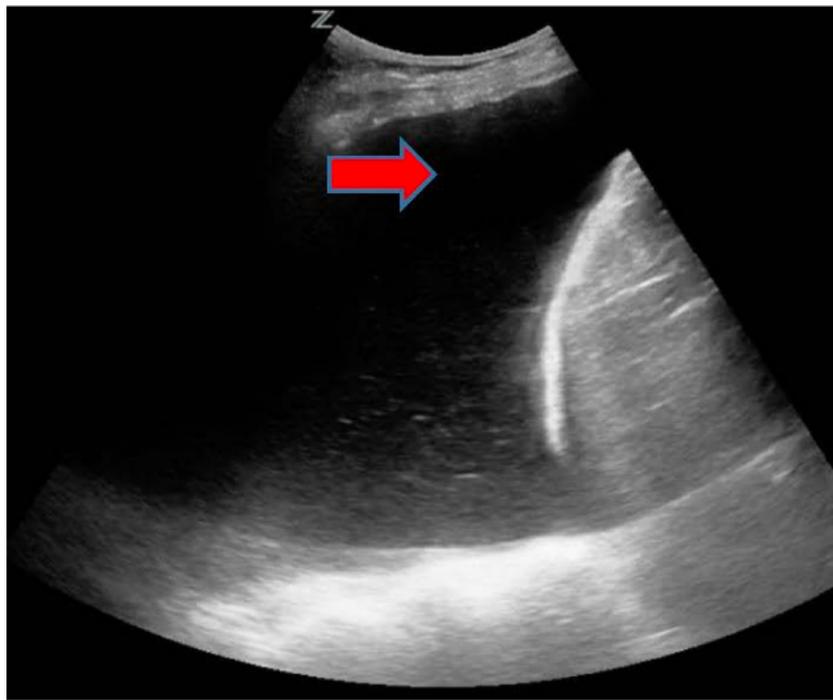
End exhalation

$$\Delta tdi = \frac{tdi \text{ end insp} - tdi \text{ end exhal}}{tdi \text{ end exhal}}$$

Normal > 20%

Pleural collection

Anechoic collection



Spine sign

