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Ultrasound in Emergency Medicine

AIR AND ITS SONOGRAPHIC APPEARANCE: UNDERSTANDING THE ARTIFACTS

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☐ Abstract—Background: Although air has traditionally been considered a barrier to sonographic imaging, when encountered in unusual settings it can serve as an important indicator of various pathologic states as well. Clinician recognition and thorough understanding of the characteristic pattern of artifacts generated by air are critical for making a number of important diagnoses. Case Series: We present five emergency department cases in which air was visualized in a pathologic location. Pneumothorax, pneumoperitoneum, necrotizing fasciitis, or Fournier's gangrene, and subcutaneous emphysema and pneumomediastinum, can be rapidly and easily identified on ultrasound by the presence of air artifacts. The relevant sonographic findings are described and discussed in this article. Why Should an Emergency Physician Be Aware of This?: Due to its inherent impedance mismatch with other human tissues, air has a characteristic appearance on ultrasound that includes irregular hyperechoic structures, "dirty shadowing," A-lines, and decreased visualization of deeper structures. Knowledge of the sonographic appearance of air artifacts can assist the physician in making a diagnosis, selecting appropriate additional imaging, and enlisting specialist consultation. © 2017 Elsevier Inc. All rights reserved.

☐ Keywords—ultrasound; bedside ultrasound; sonographic artifact; air artifact; point of care ultrasound

INTRODUCTION

While air has traditionally been considered a barrier to sonographic imaging, when encountered in unusual settings it can serve as an important indicator of various pathologic states as well. Clinician recognition and thorough understanding of the characteristic pattern of artifacts generated by air are critical for making a number of important diagnoses.

Air has extremely low acoustic impedance relative to body tissues. The extent of reflection at an interface between two sonographic media is determined by the difference in the acoustic impedance between them. This is termed *impedance mismatch*. Therefore, when ultrasound waves strike a tissue−air interface, they are mostly reflected, limiting further tissue penetration secondary to a large impedance mismatch. This is easily demonstrated by attempting to perform ultrasound without conducting gel. The significant impedance mismatch generated by the presence of air in between the probe and skin causes significant ultrasound wave reflection, resulting in decreased further penetration of the ultrasound waves and ultimately poor or nonexistent image resolution. Using gel as a medium for ultrasound wave transmission eliminates air, reduces the impedance mismatch between the more similar gel and tissue media, allows better wave penetration, and results in successful image aquisition.

When a tissue−air interface is visualized within the body, it usually has a distinct sonographic appearance, termed *dirty shadowing*. This is primarily related to air being a strong ultrasound wave reflector, which creates an irregular hyperechoic image with reverberation artifacts that form deep to the air−tissue interface. This is

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in contrast to the regular, hypoechoic "clean shadowing" created by ultrasound wave-absorbing structures, such as bone (1). In both cases, shadowing is a result of the failure of ultrasound waves to penetrate into deeper structures and return to the probe.

While many sonographers are adept at interpreting air when it is imaged where it is expected to be encountered, such as in the trachea, lungs, and gastrointestinal tract, its presence in pathologic locations can degrade image quality, obscure underlying anatomy, and disorient even skilled sonographers. Thus, it is important for the sonographer to be familiar with the normal sonographic appearance of these structures in order to recognize normal versus pathologic states.

We present five emergency department (ED) cases in which air was visualized in a pathologic location and the knowledge of the sonographic appearance of air artifacts allowed the physician to make the diagnosis, select appropriate additional imaging, and enlist specialist consultation. Institutional Review Board approval was not obtained, however, all patients signed a written consent for the use of images for educational purposes.

CASE REPORTS

Case 1

A 71-year-old man with history of diabetes, hypertension, cerebral vascular accident with residual right-sided weakness, and on aspirin, presented to the ED with Emergency Medical Services after a mechanical fall down 20 stairs. The patient denied head trauma or loss of consciousness but complained of right shoulder and right rib pain. Initial vital signs were blood pressure 133/81 mm Hg, heart rate 74 beats/min, respiratory rate 22 breaths/min, temperature 36.6°C (98°F), and 94% oxygen saturation on room air. Physical examination revealed decreased breath sounds on the right and tenderness to palpation over the right lateral ribs. An extended focused assessment with sonography for trauma demonstrated lack of lung sliding in B-mode (Figure 1A, B) and a stratosphere sign—a laminar tissue pattern—in M-mode, consistent with pneumothorax (Figure 2A, B). This was not noted on the subsequent supine chest x-ray study. The emergency physician discussed the sonographic findings with the trauma service, who expedited computed tomography (CT) imaging; a large right-sided pneumothorax was confirmed. The patient was emergently returned to the ED for tube thoracostomy placement.

Diagnosis: Pneumothorax

A pneumothorax is an abnormal collection of air between the parietal and visceral layers of pleura. While CT scan is considered the gold standard for diagnosis, ultrasound is an ideal modality in the ED, given its rapid availability, portability, and reproducibility in assessing clinical status changes. Sensitivity and specificity are reported to be 100% and 99%, respectively (2,3).

Either a low frequency (5-1 MHz) or linear array high-frequency probe (10-5 MHz) may be used to clearly visualize the superficial pleural interface. As trauma patients are generally supine patients, pleural free air should rise to the anterior apical regions of the pleural space, making this the location with greatest sensitivity for the diagnosis of pneumothorax. For each hemithorax, the probe marker is oriented cephalad and the probe is placed in the second or third intercostal spaces in the mid-clavicular line. The "bat wing" pattern is a normal finding and is created by the posterior shadowing of ribs on either side of a bright white, hyperechoic line that represents the interface of the visceral and parietal pleura (Figure 1B). When the pleural layers are in contact, this interface shimmers with respiration as the layers slide past each other, producing an appearance described commonly as "ants marching on a string" (4).

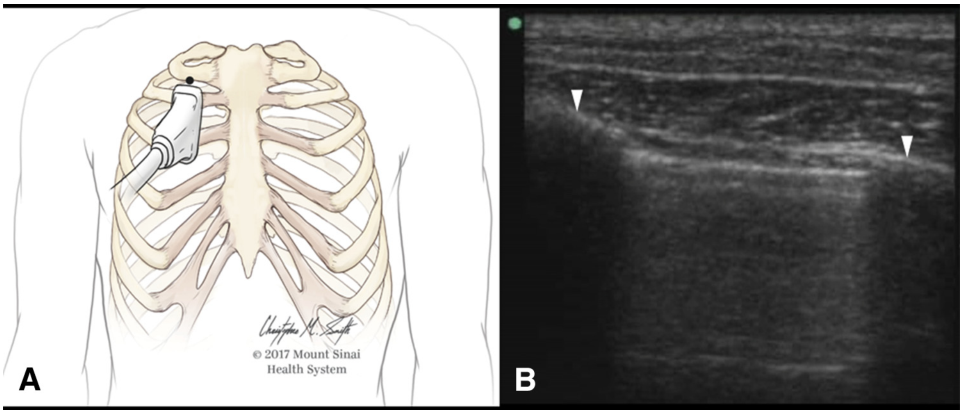

Figure 1. (A) Correct high-frequency linear probe positioning with the probe indicator oriented cephalad in the mid-clavicular line over the second intercostal space. (B) Resultant image demonstrating the "bat wing" pattern of two ribs (arrowheads) on either side of the intercostal space.

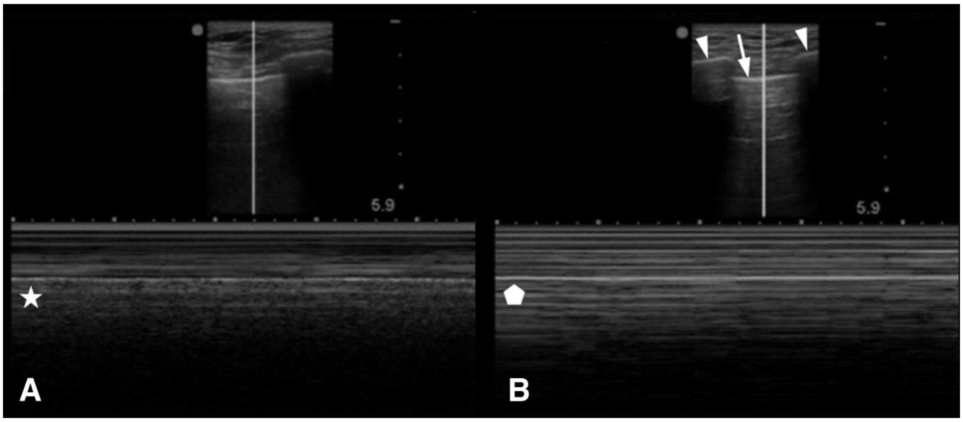

Figure 2. (A) M-mode image of the "seashore sign" (star) below the bright pleural line. (B) M-mode image of the "barcode sign" (pentagon) below the bright pleural line. The two ribs (arrowheads) on either side of the pleural line (arrowhead) create the "batwing" pattern.

The pleural interface can be further evaluated using M-mode, which provides an image of the movement of tissue over time. Normal lung movement will create a "seashore sign," with the stationary subcutaneous tissue at the top of the screen appearing as parallel lines representing the still water, and the moving lung in the lower part of the image appearing more granular or pixelated, representing the sandy beach (Figure 2A). A pneumothorax, by definition, is air between the pleural layers. The resultant increased impedance mismatch prevents ultrasound wave penetration beyond the layer of air in the pleural space. Absent lung sliding in B mode translates to a series of horizontal parallel lines across the entire M-mode image. This is known as the "barcode" or "stratosphere" sign (Figure 2B). Because ultrasound can only give information about what is occurring directly underneath the probe, multiple rib spaces should be evaluated along the anterior and lateral chest bilaterally to increase the sensitivity of the examination (5,6).

Certain patient populations and clinical circumstances may present challenges to the performance of this examination. Ultrasound waves are markedly attenuated by subcutaneous fat, making it difficult to identify the pleural line in obese patients. Patients with poor pulmonary function (e.g., chronic obstructive pulmonary disease) move relatively small volumes of air or may have bullae or blebs, all of which can diminish the degree of noticeable pleural sliding. Visualization of the same intercostal space with M-mode on the contralateral side can help to establish the patient's baseline pleural movement, and may aid in differentiating a chronic disease state from pneumothorax. Finally, in intubated patients with unilateral pleural sliding, consideration of a mainstem intubation is important before making a diagnosis of pneumothorax.

Case 2

A 55-year-old woman with no significant medical history presented to the ED with a complaint of abdominal pain 8 h after undergoing a routine screening colonoscopy. She reported symptoms of nausea without vomiting or diarrhea and had not yet passed flatus since the procedure. Vitals signs were significant only for tachycardia at 112 beats/min. Physical examination revealed a soft, nondistended abdomen with diffuse tenderness to palpation and hypoactive bowel sounds on auscultation. A bedside ultrasound of the abdomen was performed using a low-frequency phased array probe (Figure 3A). Repetitive artifactual horizontal stripes ("A lines") were seen deep to the hyperechoic bright line of the peritoneum consistent with free air in the peritoneal space. An image from the lateral abdomen, with a normal-appearing peritoneal stripe (Figure 3B) is included for comparison. A plain x-ray study was expedited as a result, confirming the findings. Emergent surgical consultation was obtained and the patient underwent an exploratory laparotomy, which revealed a 1.5-cm perforation in the sigmoid colon.

Diagnosis: Pneumoperitoneum

The rate of large bowel perforation after colonoscopy is low, with an incidence of 0.06% in diagnostic colonoscopy to 0.2% in therapeutic colonoscopy (7,8). The normal sonographic findings of the abdomen are peristaltic bowel motion and irregular "dirty shadowing" from intraluminal air mixed with stool, deep to the peritoneal line. Free intra-peritoneal air appears as horizontal reverberation artifacts that occur at regular intervals immediately below a more hyperechoic peritoneal line (Figure 3A), known as the "enhanced peritoneal stripe sign" (9). Peritoneal A-lines may be found

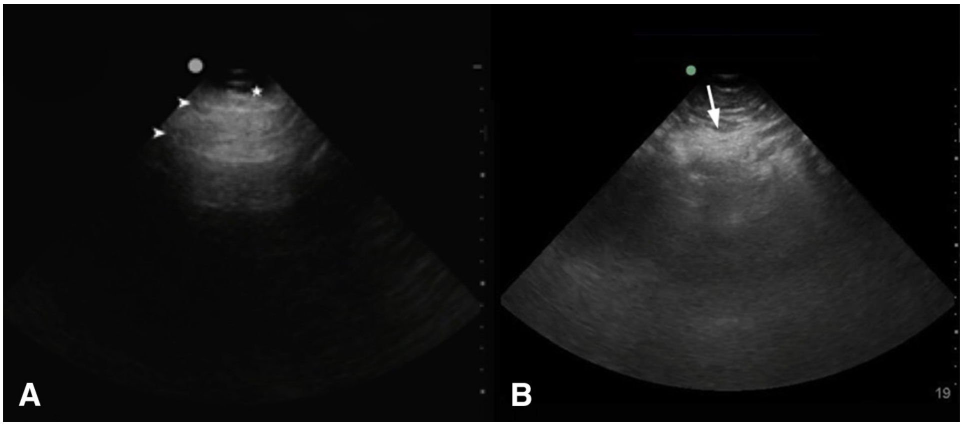

Figure 3. (A) Image of the abdomen demonstrating "A" lines (arrowheads) deep to the peritoneal line (star). (B) Image of a normal peritoneum-bowel interface (arrow).

incidentally during abdominal ultrasound examination and only noticed when normal landmarks fail to appear. They may be seen in various areas of the abdomen; however, they would be expected in the least dependent portion of the abdomen in a supine patient. Ultrasound has been reported to be 95.5% sensitive and 81% specific for the diagnosis of pneumoperitoneum (10).

There are several instances in which the sonographer may encounter potentially false-positive findings of free intraperitoneal air. In the epigastrium, the right lower lobe of the lung may be seen entering into the subxiphoid region during inspiration, giving rise to A-lines. To avoid this pitfall, a careful search for intact pleural sliding, which is absent at the peritoneal line, would confirm probe positioning over lung tissue. Alternatively, images obtained in the left upper quadrant may demonstrate air that is actually within the stomach. A simple method to avoid this potential pitfall would be to compress the area, which would demonstrate the movement of the air artifacts with swirling of gastric contents.

Cases 3 and 4

A 49-year-old man with history of morbid obesity and diabetes presented to the ED with increasing pain of the perianal and scrotal area. He had been evaluated the previous day for a 1-week history of perianal pain, and had undergone incision and drainage by the general surgery consultant for a perianal abscess. He was given prescriptions for oral antibiotics. At the repeat presentation, his vital signs were: blood pressure 100/60 mm Hg, heart rate 105 beats/min, and a rectal temperature of 38.3°C (101.0°F). Physical examination reflected significant scrotal swelling with purulent drainage from the incision and drainage site. A bedside ultrasound was performed and demonstrated significant thickening of the soft tissues, "cobblestoning" of the scrotal skin, and a hydrocele (Figure 4A). Additionally, there was evidence of air in the left hemiscrotum (Figure 4B). The surgery and urology services were emergently consulted. The findings were confirmed by subsequent CT scan and the patient was taken to the operating room for Fournier's gangrene with necrotizing soft tissue infection extending from the perianal abscess to the scrotum. Wide debridement of the left scrotum was performed without complications.

Diagnosis: Fournier's Gangrene

Fournier's gangrene is a critical, rapidly progressive, necrotizing fasciitis with a high mortality that affects the external genitalia and perineal or perianal regions (11). Plain films can be limited in identifying subcutaneous air, and CT has the significant downsides of requiring intravenous contrast, exposing the patient to ionizing radiation, and often mandating that the patient leave the critical care area.

To perform an ultrasound evaluation for Fournier's gangrene, a high-frequency (10-5 MHz) transducer is utilized in a supine patient. Towels may be placed under the scrotum for support as needed and the conducting gel can be warmed for comfort. The unaffected hemiscrotum is evaluated in the longitudinal plane, scanning through the entire area of interest. Transverse images are then performed, scanning from the superior to the inferior pole of the testicle. The affected side is scanned for comparison, with additional imaging of the perineal region.

The mnemonic "STAFF" has been developed to describe classic ultrasonographic findings in necrotizing fasciitis (12). STAFF refers to evaluating for Subcutaneous Thickening, Air, and Fascial Fluid. As suggested, significant findings on ultrasound include thickened, edematous subcutaneous tissue, peritesticular fluid, and hyperechoic foci with reverberation artifact reflecting subcutaneous gas (Figure 5A, B). This finding implicates

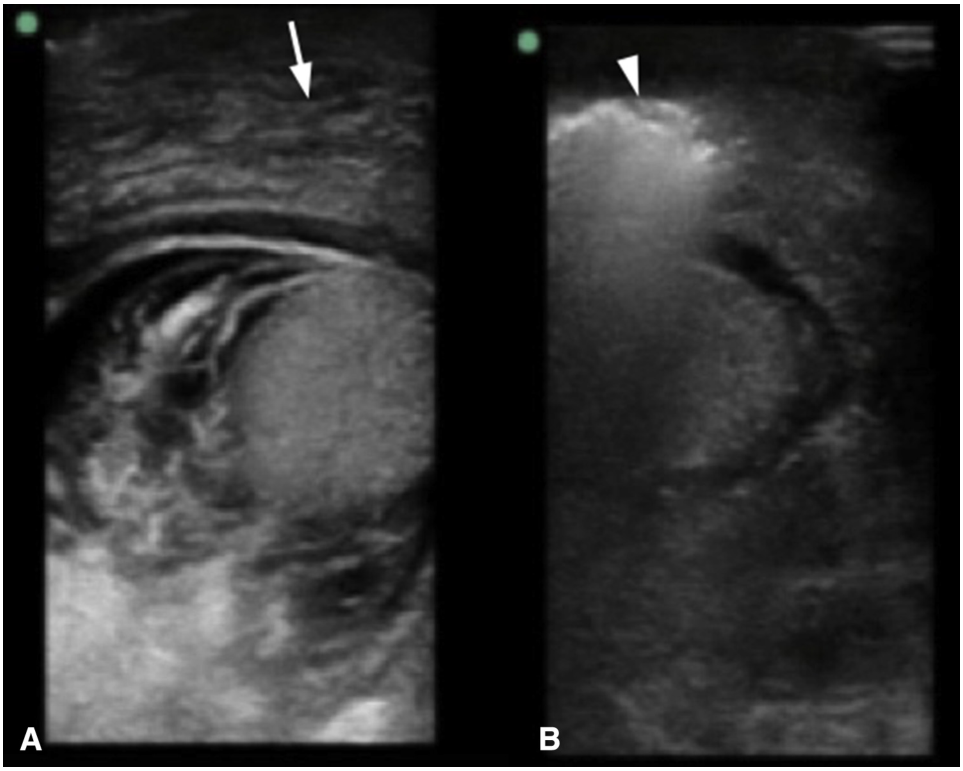

Figure 4. Images of the scrotum demonstrating the findings of the STAFF (subcutaneous thickening, air, fascial fluid) mnemonic. (A) Thickening of soft tissues and interstitial edema (arrow) and (B) air artifact from subcutaneous gas (arrowhead).

gas-forming organisms in the polymicrobial infection, and is pathognomonic for Fournier's gangrene. Unfortunately, its presence is an indication of advanced necrotizing fasciitis. As this is a time-dependent diagnosis, bedside identification of subcutaneous air has the potential for more rapid definitive management and improved outcomes in patients with this condition.

The differential diagnosis for scrotal pain with air on ultrasound includes bowel gas within an incarcerated or strangulated hernia. To avoid misdiagnosis, the operator should thoroughly scan through the area to determine whether the air is located within the bowel or contained within the scrotal soft tissues. The presence of air mixed in with semi-formed stool or visualization of peristalsis would indicate that it is contained within the bowel.

Although necrotizing fasciitis needs to remain on the differential diagnosis, there are many causes of subcutaneous emphysema, including complications of a pneumothorax or pneumomediastinum, pleural bleb, rupture of the gastrointestinal system, and trauma (13,14). We

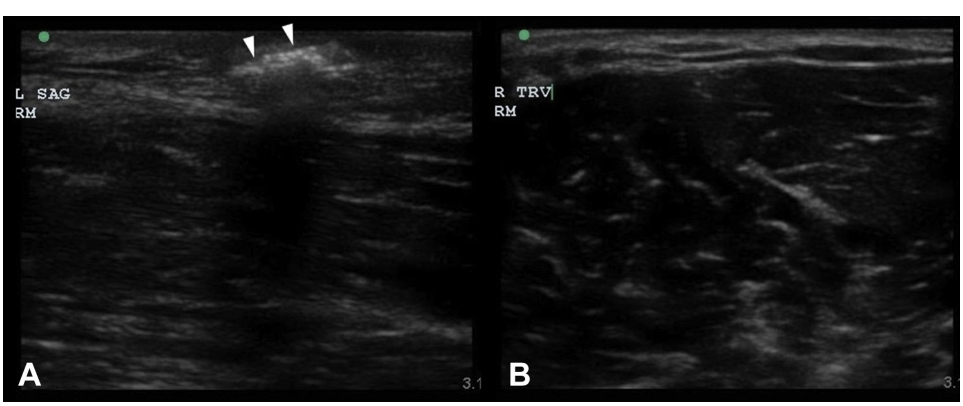

Figure 5. Soft tissue ultrasound demonstrating (A) air artifact from subcutaneous gas (arrowheads) and (B) unaffected side for comparison.

present a second case that highlights a different clinical scenario with different sonographic findings.

A 33-year-old man was using IV drugs and noticed redness, swelling and intense pain at the site of injection. He denied fevers or chills and his vital signs were within normal range. A bedside ultrasound of the affected area was performed and an irregular hyperechoic density was noted just deep to the skin surface with “dirty shadowing” (Figure 5A, B).

Due to its subtle nature, there are several pitfalls when trying to identify subcutaneous emphysema with ultrasound. If the amount of subcutaneous air is small, it can appear as haziness rather than a bright hyperechoic artifact; this can be misinterpreted as normal tissue. Similarly, vague shadowing and haziness can be found in early cellulitis as well. Comparison views of unaffected tissue may aid in avoiding these pitfalls.

Despite the presence of subcutaneous air, the images in this case did not demonstrate other associated findings of necrotizing fasciitis, such as subcutaneous thickening or fascial fluid. While it remained on the differential diagnosis, the finding of subcutaneous emphysema, in this case, was more likely caused by air introduced into the tissue during drug injection. Additionally, a foreign body present in the tissue can also appear as a hyperechoic structure. In such cases, air may be present due to the traumatic introduction of air as the foreign body dissects through the tissue.

Case 5

A 25-year-old man with a history of gastritis presented to the ED with 3 weeks of pharyngeal discomfort described as a foreign-body sensation in the right side of his throat. The patient saw an otolaryngologist 1 week before his visit and he had a normal flexible laryngoscopy. Five days before presentation, his symptoms worsened and included sharp, right-sided chest pain, diaphoresis, and mild odynophagia. Initial vital signs included blood pressure of 133/80 mm Hg, heart rate of 89 beats/min, respiratory rate of 17 breaths/min, and oxygen saturation of 98% on room air. Physical examination revealed an anxious-appearing patient with a clear oropharynx, and no tenderness or crepitus on palpation of the neck and chest wall. The lungs were clear and there was no pain with deep inspiration. The abdomen was soft and nontender. A chest x-ray study revealed no abnormalities. A bedside focused echocardiogram was performed that demonstrated “dirty shadowing” in the parasternal long- and short-axis views that coincided with the respiratory cycle. Specifically, the heart was easily visualized during inhalation; however, artifact obscured the view during exhalation (Figure 6A, B). Due to the concerning findings identified on bedside sonography, a chest CT scan was performed and was positive for air in the mediastinum at the level of the thoracic inlet.

Diagnosis: Pneumomediastinum

Spontaneous pneumomediastinum (SPM) is caused by a nontraumatic leakage of air, most commonly from ruptured alveoli, which dissects along bronchovascular sheaths and then accumulates in the mediastinum (15). SPM is a rare entity that is more common in children than adults and has an overall incidence of 1/44,000 (16). Traditionally, the diagnosis of SPM is made by physical examination and chest radiography, but there have been several case reports describing the diagnosis of SPM using ultrasound (17–19). The cause of this transient air artifact has been described previously as the “air gap” sign, which occurs as a result of air in the mediastinum that transiently obscures the parasternal view of the heart. During diastole, the relaxed, full left ventricle pushes mediastinal air out of view, allowing for easy sonographic visualization of the heart. During systole, the contracted chamber creates a space for

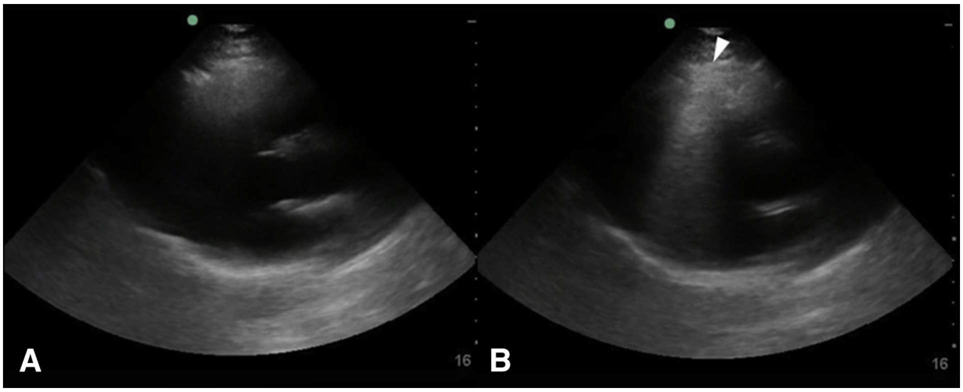

Figure 6. Cardiac ultrasound demonstrating (A) easily visualized parasternal long axis during inhalation and (B) parasternal axis view with “dirty shadowing” obscuring the heart during exhalation (arrowhead).

mediastinal air to re-accumulate between the heart and the chest wall, obscuring the sonographic view (20,21).

Differentiating pneumomediastinum from pneumothorax and pneumopericardium can be difficult. In pneumothorax, the parasternal sonographic views of the heart may be obscured during systole, as air in the pleural space interposes between the heart and anterior chest wall. With diastole, the heart enlarges and displaces air from the pleural space anterior to the heart, allowing for sonographic wave transmission. This is called the "heart point" and is seen as a flickering that varies with the cardiac cycle (22). Therefore, to differentiate between these two, the sonographer should attempt to scan the left anterior chest wall to evaluate for pneumothorax. With the heart's inferior surface resting on the diaphragm, in both disease entities, air cannot interpose, allowing for a clear subxyphoid view of the heart throughout the entire respiratory and cardiac cycles. In pneumopericardium, however, air within the pericardium obscures all views of the heart at all times because, unless extremely minimal, pericardial air cannot be displaced enough for sonographic wave penetration.

DISCUSSION

Due to its inherent impedance mismatch with other human tissues, air has a characteristic appearance on ultrasound that includes irregular hyperechoic structures, "dirty shadowing," A-lines, and decreased visualization of deeper structures. Facile use of ultrasound to identify air is a skill of paramount importance, as identifying it in pathologic locations is a common characteristic of multiple critical diagnoses.

WHY SHOULD AN EMERGENCY PHYSICIAN BE AWARE OF THIS?

Pneumothorax, pneumoperitoneum, necrotizing fasciitis, or Fournier's gangrene and subcutaneous emphysema, and pneumomediastinum can be rapidly and easily identified on ultrasound by the presence of air artifact, but the principles we have described can be applied to any area that is being evaluated in the critical patient. As a widely available, rapid, repeatable, and low-risk diagnostic modality, ultrasound is uniquely suited to aid in these diagnoses and expedite further management.

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