Focus on abnormal air: diagnostic ultrasonography for the acute abdomen

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Emergency ultrasonography is a frequently used imaging tool in the bedside diagnosis of the acute abdomen. Classic indications include imaging for acute abdominal aneurysm, acute cholecystitis, hydronephrosis, and free intra-abdominal fluid in patients with trauma or suspected vascular or ectopic pregnancy rupture. Point-of-care sonographic imaging often emphasizes the diagnostic utility of fluid and edema, both as a significant finding and as a desirable adjunct for improved imaging. Conversely, the finding of sonographic intra-abdominal air is commonly 'tolerated' as a necessary evil that can foil image acquisition. This is in stark contrast to the accepted diagnostic utility of air in other imaging modalities for the acute abdomen, such as computed tomography and conventional radiography. Countering the bias against air as a deterrent for diagnostic ultrasound's accuracy are several published studies suggesting that abnormal air patterns can be used with high precision to diagnose pneumoperitoneum. These studies advocate that sonographic findings of abnormal air can be straightforward and can become crucial for increasing the diagnostic yield of bedside ultrasound of the acute abdomen. They suggest that practitioners should familiarize themselves with the findings and techniques to gain the experience required to make the diagnosis with confidence. This article will discuss four groups of abnormal air patterns found in the abdomen and the retroperitoneum and the respective scanning techniques, with a focus on the use of ultrasound for diagnosing pneumoperitoneum and a suggested scanning approach in the emergency setting. *European Journal of Emergency Medicine* 00:000–000 © 2012 Wolters Kluwer Health | Lippincott Williams & Wilkins.

European Journal of Emergency Medicine 2012, **00**:000–000

Keywords: abdominal pain, abscess, acute abdomen, bedside ultrasound, emergency ultrasound, free air, free intra-abdominal air, pneumatosis intestinalis, pneumoperitoneum

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Received 6 February 2012 **Accepted** 29 March 2012

Introduction

Ultrasonography is widely recognized as an indispensable tool in the bedside diagnosis of the acute abdomen [1–5]. Even for practitioners with limited ultrasound training, initial assessment of the peritoneal patient often includes a bedside FAST examination to document the presence of free fluid, both for traumatic and for medical presentations. Similarly, bedside ultrasound of the gallbladder, kidneys, aorta, and uterus may prove diagnostic and are within the purview of residency-trained emergency physicians. For all these studies, traditional teaching emphasizes the diagnostic utility of fluid, both as a significant finding (as in FAST scanning, ruptured aortic aneurysm, or ectopic pregnancy) and as a desirable adjunct for improved imaging (as with bladder filling for uterine imaging). Conversely, intra-abdominal air is commonly 'tolerated' as a necessary evil that often foils image acquisition. This is in stark contrast to the accepted diagnostic utility of air in other imaging modalities for the acute abdomen, such as computed tomography (CT) scanning and radiography. Countering the bias against air in ultrasound are several published studies suggesting techniques and documenting the successes and accuracy of sonography for the diagnosis of pneumoperitoneum [6–23]. Despite this, many textbooks and lecturers, especially in the field of emergency and critical care sonography, skip the topic entirely, effectively narrowing the scope of bedside ultrasound. Inclusion of an assessment for pathologic air will increase the diagnostic yield of bedside ultrasound of the acute abdomen, and practitioners should familiarize themselves with the findings and techniques to gain the experience required to make the diagnosis with confidence.

Background

To appreciate the presence of pathological air within the abdomen, one must first recognize the appearance of physiologic air within abdominal and thoracic structures, including the gastrointestinal tract and the lung parenchyma as it descends during inspiration. Air is a medium posing high resistance and impermeability to ultrasound waves, making it a strong reflector. Larger air bubbles may appear as bright, highly echogenic lines with distal reverberation and shadowing artifacts (Fig. 1a, b and d). Smaller air bubbles can appear as bright punctuate foci without ring-down artifacts and shadowing within the intestinal lumen (Fig. 1c). Normal air present within the lumen of the gastrointestinal tract should be recognizable by its association with the bowel and will move with peristalsis. Air artifacts emanating from the lungs into the

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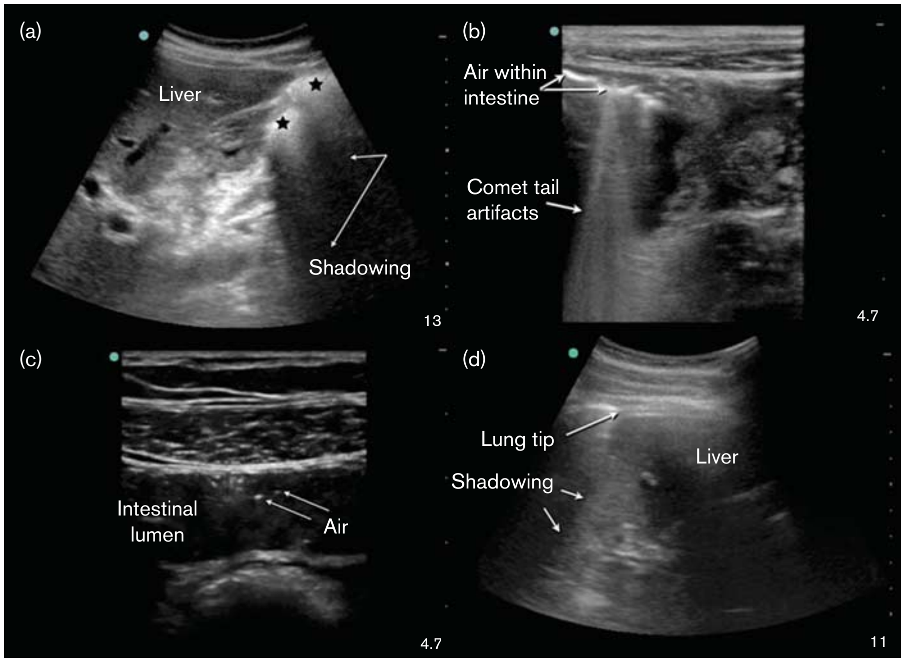
Fig. 1

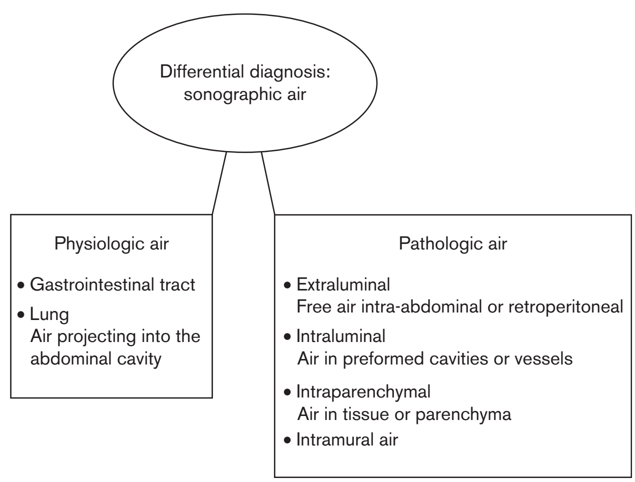


Appearance of physiologic air in the abdomen: (a) air within the intestinal lumen (stars) with shadowing, (b) larger air bubbles appearing as hyperechoic stripes generating comet tail artifacts, (c) smaller air bubbles within the intestinal lumen, and (d) air artifacts emanating from the thoracic cavity and the lung over the liver. Sonography equipment used for all figures was an M-Turbo (Sonosite, Bothell, Washington, USA) with either 3–5 MHz curvilinear or 5–10 linear probe.

abdomen will show characteristic respiratory movements and originate from the thoracic cavity (Fig. 1d).

Findings of pathologic intra-abdominal air can be divided into several categories: (a) 'free air', seen in the peritoneal and retroperitoneal space, (b) air seen in the lumen of preformed intraperitoneal or retroperitoneal structures or cavities, such as the bladder and the gallbladder, biliary tree, common pancreatic duct, portal vein, hepatic veins, and other blood vessels. Air may also form (c) within the abdominal wall tissues or organ parenchyma, as in kidney, liver, and abdominal wall abscesses. Finally, the finding of (d) intramural air, as seen in pneumatosis of the bladder wall or in pneumatosis intestinalis, can be a crucial finding in a patient with abdominal complaints (Fig. 2) [6–24]. Once the concept of normal versus abnormal air patterns is established, the sonologist can utilize this information to diagnose the potential causes of pathologic abdominal air. This article will discuss the aforementioned four groups of abnormal air patterns found in the abdomen and the retroperitoneum, with a focus on the use of ultrasound for diagnosing pneumoperitoneum.

Fig. 2



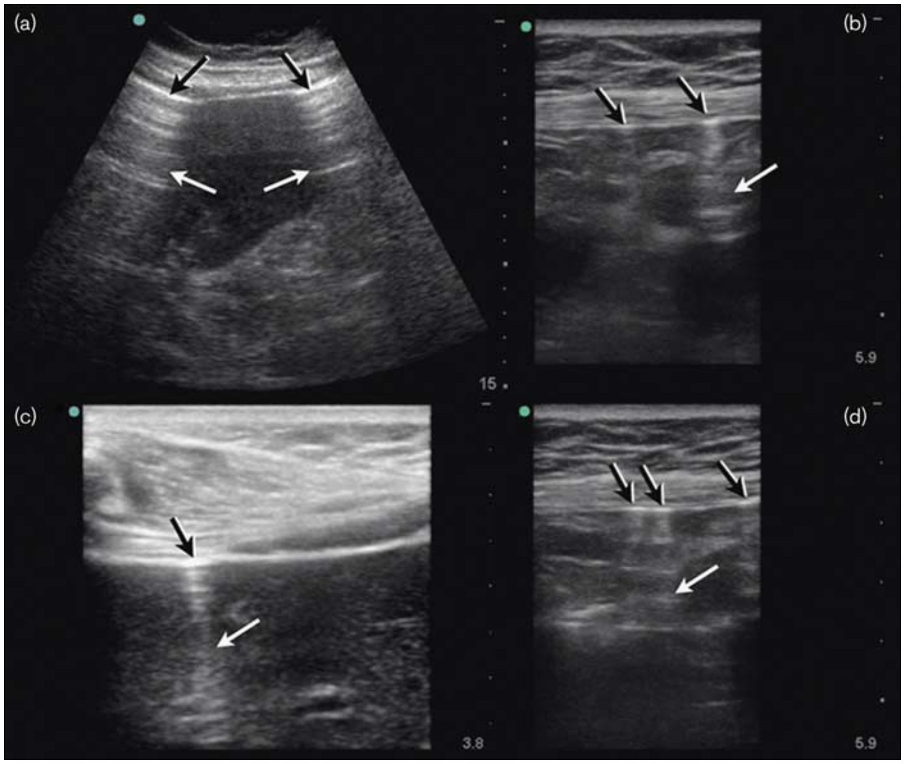
Differential diagnosis of air found with abdominal sonography. Adapted with permission from [24].

Abnormal findings and sonographic technique

Extraluminal free air: pneumoperitoneum and pneumoretroperitoneum

Pneumoperitoneum: is an expected finding after certain procedures including abdominal laparoscopy or laparotomy, percutaneous needle biopsy, peritoneal dialysis, culdocentesis, or paracentesis. Free air after surgery may be absorbed within a few days, but can last as long as 18 days, with incidence and quantity declining over time [20]. In patients with postoperative acute abdominal pain, a common diagnostic dilemma centers on whether postoperative intra-abdominal air represents benign residual air from the surgery or a pathologic condition such as anastomotic failure.

Fig. 3



(a) Large amount of free air superficial to the liver in the hepatoperitoneal space with enhanced peritoneal stripe (black arrows) and reverberation artifacts (white arrows). The patient had a colon biopsy 5 days ago and presented with acute severe abdominal pain and hypotension. Normal peritoneum is visualized lateral to the enhanced areas. (b and d) Several small air collections in the mid-abdominal area causing the Enhanced Peritoneal Stripe Sign (EPSS) phenomenon (black arrows) and reverberation artifacts posteriorly (white arrow). This patient presented from a nursing home with abdominal pain, change in mental status, and hypotension after a recent colon surgery. The intraoperative diagnosis was perforated viscous at surgical site and peritonitis. (c) Small amount of free air anterior (small air bubble) ventral to the liver causing EPSS (black arrow) and reverberations with a ring-down artifact (white arrow). This patient presented with several days of mild-to-moderate abdominal pain and normal vital signs, and was diagnosed with perforated diverticulitis. Free air was also found in the left lower abdomen.

The distinction between benign and pathologic etiologies should be made on a case-by-case basis. Acute pneumoperitoneum in nonpost-operative scenarios can be caused by pathologic findings such as ruptured viscous, peritonitis with gas-forming organisms, intra-abdominal abscess rupture, bowel obstruction with permeation of gas through the bowel wall, cardiopulmonary resuscitation, mechanical ventilation, cocaine use, and extension of pneumothorax or pneumomediastinum [25–27].

The concept of visualizing free intra-abdominal air using B-mode sonography is not new. In fact, one of the most comprehensive and detailed studies on the topic was published nearly 30 years ago [6]. In this landmark publication, Seitz and Reising [6] reported many of today's known qualitative and quantitative aspects of free intraperitoneal air sonography. Ultrasound consistently detected as little as 1 cm^3 of free air [6]. Their study was triggered by their observation that in patients with recent cholecystectomy, distinct posterior hyperechoic reverberation and shadowing artifacts emanating from an enhanced peritoneal stripe impeded postoperative hepatobiliary sonography. They suspected that this phenomenon was caused by free air (Dr K. Seitz, personal communications, August 2011) and found it most prominent over the ventral aspect of the liver or when the patient was in the semileft lateral decubitus position. They also described 'shifting' of air to the highest point of the cavity when the patient was repositioned [6]. An initial qualitative study confirmed corresponding free air on the chest radiograph and ultrasound in study participants who had small amounts of free air injected after paracentesis. Muradali *et al.* [11] later validated this finding and termed the phenomenon 'Enhanced Peritoneal Stripe Sign (EPSS)'. EPSS consists of a superficial single or double echogenic line that marks the abutment of the abdominal wall with the peritoneal contents (Fig. 3a–c). A double line is commonly seen in patients with excess abdominal fat, in whom identification of the peritoneal stripe may be more difficult. Muradali's experimental trials in pigs (whose abdomens were infused with degassed water) showed that a single bubble of air could lead to a focal thickening of the peritoneal stripe [11]. When more air was introduced, the superficial focal thickening of the peritoneal stripe was associated with dirty shadowing or multiple reflection artifacts. Dirty shadowing occurs when multiple layers of air bubbles create multiple bright overlapping echo tails; this is commonly seen with normal bowel gas during routine abdominal scanning. Comet tail artifacts may appear posterior to a single row of bubbles, with tapered periodic echogenic lines or reverberations [12]. When the reverberation echoes retain their width, the artifact is termed as 'ring-down'.

Sonographic technique for pneumoperitoneum: Most authors suggest using higher frequency linear probes to best visualize the superficial peritoneal layer and associated free air [6]. One author, however, achieved high sensitivity and specificity (100 and 99%, respectively) with curved array transducers in the 2.6–5 MHz range [19]. However, in that study, evaluation for free air was included in a systematic abdominal ultrasound examination using a curved array transducer and was performed by a radiologist in a dedicated ultrasound suite. The entire comprehensive ultrasound exam lasted 20–35 min, and it is unclear how much time was spent on the evaluation for free air.

Today, most authors agree that the best initial place to look for pneumoperitoneum is in the right hypochondrium, superficial to the liver, with the patient in the supine position with the thorax slightly elevated or in a semilateral decubitus position [6,9,11–13]. When the patient is positioned in semileft or semiright lateral decubitus, free air frequently collects in the ventral hepatoperitoneal space (right) or at the lower pole of the spleen (left) [6,9]. One study of 600 patients with abdominal pain referred for ultrasound (21 of whom ultimately had pneumoperitoneum) showed that the finding of EPSS was observable in all quadrants of the abdomen with varying frequency, with 83% being observable in the right hypochondrium, 75% in the umbilical region, and only 8.3% noted in the right lumbar region [19]. Another study suggests that optimal positioning is achieved with the supine patient at 10–20° inclination. Alternatively, an intercostal view was obtained with the patient in the left lateral decubitus position, with the abdomen and thorax elevated to 30–40° [13].

Beginning with Seitz and Reising [6], investigators frequently noticed that free air pockets were positioned independent of respiratory movements, but would migrate when pressure from the ultrasound transducer deformed the abdominal wall. This phenomenon was later described as 'scissor's phenomenon' or 'shifting of air' by Karahan *et al.* [18]. 'Shifting' can also be accomplished by moving the patient from a supine to a decubitus position to confirm the free movement of intraperitoneal air, as opposed to intraluminal or alveolar air [17] Proponents of the EPSS method of identifying pneumoperitoneum argue that shifting or elevating the patient may not be possible in cases of critical illness or trauma [11].

The accuracy of sonography for pneumoperitoneum in the clinical setting was found to be high in several large prospective trials. Seitz and Reising [6] reported a sensitivity of 90% and a specificity of 100% for the detection of pneumoperitoneum, evaluating 4000 consecutive patients with nontraumatic acute abdominal pain. A recent study on 487 consecutive patients with blunt trauma and abdominal pain by Moriwaki *et al.* [23] showed that a screening ultrasound for pneumoperitoneum had a sensitivity and specificity of 85 and 100%, respectively. The authors concluded that sonography may be a valuable screening tool for intra-abdominal free air.

Pseudopneumoperitoneum: The practitioner should be aware of several conditions that may mimic pneumoperitoneum. Chilaiditi syndrome is a rare condition in which colonic bowel is interposed between the liver and the diaphragm. Its potential to mimic free air under the diaphragm on upright chest radiography is well known. The dynamic nature of ultrasonography is helpful in this situation; shifting the patient to a different position should show that there is no freely mobile air within the peritoneum. In addition, prolonged scanning may show peristalsis within the hepatodiaphragmatic recess, leading to the diagnosis of this condition. Artifacts distal to an overlying rib may mimic a reverberation artifact suggestive of pneumoperitoneum. In this case, the origin of the artifact should be traceable to a point superficial to the peritoneal stripe and should change with probe position and patient movement. Also, the contrast between rib shadow and the liver can mimic free air, but the distinction should become clearer during respiration. When scanning the right upper quadrant, a ring-down artifact may be seen originating from alveolar air in the lungs. During inspiration, these artifacts may overlap with the reverberations from pneumoperitoneum; however, expiratory scanning will show the separate thoracic and intra-abdominal origins of the artifacts [8]. In addition, the step-off may be noted from the more superficial alveolar artifacts and the pneumoperitoneum artifacts just inside the peritoneum [9]. Intramuscular and cutaneous air may be distinguished by immobility when probe pressure is applied [23].

Pneumoretroperitoneum: This is a rare complication of endoscopic retrograde cholangiopancreatography (0.5%) and other iatrogen-invasive procedures [21], but can also be because of trauma, inflammation, infection, or neoplastic processes [21]. Typical sonographic findings include air collections around the right kidney, causing it to appear 'overcast' or 'veiled' [28], air ventral to the aorta and the inferior vena cava, giving the appearance of 'vanishing great vessels' [29], and air collections around retroperitoneal parts of the duodenum, pancreatic head, and posterior to the gallbladder [21]. In contrast to intra-abdominal free air, the shifting phenomenon is not observed. Rather, air is found in closed relation to an organ or around retroperitoneal viscous [11,12,21].

Intraluminal free air: abnormal air within preformed lumens

Abnormal air within lumens physiologically not containing any gas can be observed within the biliary ducts or the gallbladder, portal venous system, abdominal or retroperitoneal veins and arteries, within the bladder and the urogenital tract, or even within pancreatic ducts [9,12,21,30–32]. The interpretation of findings will depend on the clinical presentation and circumstances, as the two most common etiologies appear to be trauma (including iatrogenic manipulation) and infectious causes [12]. Pneumobilia (air in the biliary system) for instance can be caused by papillotomy, fistulas within the gastrointestinal tract, tumor invasion, or by an ascending biliary infection with gas-producing organisms. Air collections within arteries and veins can be because of iatrogenic vascular manipulations such as a cardiac catheter or hemodialysis and are rare. Air within the portal venous system is associated with a significant mortality (Fig. 4), often stemming from bowel necrosis or thrombosis of the mesenteric artery or veins [8,12].

Sonographic technique to detect abnormal air within preformed lumens: In general, the same technique used to examine the preformed lumens, that is, biliary or portal vein or abdominal vessel sonography, will also show abnormal air.

Intraparenchymal free air: abnormal air within organ parenchyma and tissues

A common etiology for this finding is infection and abscess formation (Fig. 5). Trauma (including iatrogenic) or neoplasm eroding into solid tissue from air-containing

Fig. 4

Left: Air bubbles detected within the portal vein (black arrows) and accumulating in smaller portal vessels (white arrows). The patient was found to have bowel necrosis and ischemia from mechanical ileus. Right: Large amount of air in the inferior vena cava and the hepatic venous system of the liver (white arrows). This patient had sustained a gunshot wound to the thigh with an injury to the femoral vein and prolonged cardiopulmonary resuscitation.

Fig. 5

Abscess of the abdominal wall with small air collections on ultrasound (left) and with the corresponding image on computed tomography (right). White arrows show examples of air collection.

structures can also cause gas collections within organs. For instance, air can appear after a biopsy along the needle path, or when a fistula (Crohn's disease) erodes into a neighboring organ, or neoplasms or ulcers penetrate into parenchyma [12]. The clinician should always attempt to distinguish these findings from other locations of air collections or findings mimicking free air, such as microcalcifications or cholesterol deposits [30].

Sonographic technique to detect intraparenchymal free air: is equivalent to the regular ultrasound approach when examining these organs and tissues.

Intramural air

Sonographic intramural air has been described in the gut (pneumatosis intestinalis) [12,33], but also can be found in the wall of the bladder (Fig. 6) or the stomach and the gallbladder [30,34]. It is associated with infection, ischemia, and trauma. Pneumatosis intestinalis is a difficult sonographic diagnosis and should be distinguished from the phenomenon of pseudopneumatosis.

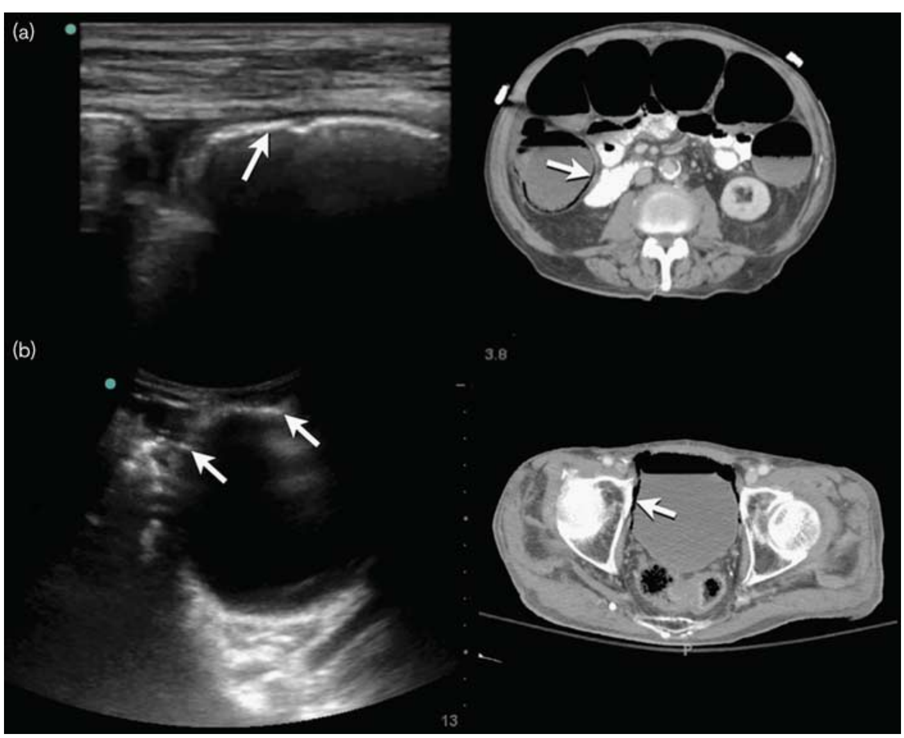
Pseudopneumatosis intestinalis [33]: This is not a pathological condition, but rather an artifact occurring at the non-dependent wall.

Sonographic technique for intramural air: The ultrasonic beam should be aligned perpendicular to the intestinal wall and the use of a high frequency may show a better resolution of bowel wall layers. When the probe is angulated, intraluminal air bubbles may be falsely projected within the inner wall layers because of tangential effects. This artifact can also occur in areas of the intestine in which gas bubbles may be trapped in prominent intestinal folds. The appearance of air should change from intramural to intraluminal with probe angulation and the phenomenon should not be visible in the lower part of the intestinal wall. It is important that other sonographic findings mimicking intramural air, such as adenomyomatosis or calcifications within the gallbladder wall, are distinguished from pathological air. The clinician should rely on history and examination findings, and have a high clinical index of suspicion.

Conclusion

Although sonographic detection of abnormal free air has been described and recognized for decades, it is often overlooked in traditional ultrasound teaching, especially in the emergency medicine and critical care communities. This is unfortunate, given evidence that, in experienced hands, ultrasound may be as effective as radiography or perhaps even CT at diagnosing pneumoperitoneum [6,19,23].

Fig. 6



(a) Intramural air in pneumatosis coli with the corresponding computed tomography image on the right. White arrows show air collections. (b) Intramural air in a patient with severe bladder infection causing pneumatosis of the bladder wall (white arrows) and air fluid level in the bladder.

A scanning protocol used in our emergency department to screen for pneumoperitoneum suggests placement of the patient in either a semilateral left decubitus or a supine position with a slightly elevated thorax. A systematic evaluation of the right hypogastric and epigastric area for EPSS is performed, beginning with a curvilinear transducer, at depth settings of about 9–11 cm. Areas of interest are further evaluated using a high-frequency linear probe. The exam includes an assessment for pleuroperitoneal step-off sign, nonmovement of EPSS with respirations, scissors maneuver, and shifting and usually lasts no longer than 3–5 min for trained emergency physicians.

However, to what length should the emergency physician go in search of EPSS? The authors believe that the answer might be similar to other, already established emergency ultrasound indications: it depends. In a patient with a high suspicion for perforated viscous and with both radiograph and CT imaging or surgical resources readily available, care might suffer if the physician spends too much extra time with an additional imaging tool. The opposite might be true for care provided in resource-poor environments, where ultrasound becomes the imaging tool of choice, or if the physician is faced with a long list of potential differential diagnosis in a stable patient with significant but undifferentiated symptoms. Here, an additional sonographic view of the ventral peritoneal anatomy could be combined with acute abdominal aneurysm or renal colic sonography. In our institution, which is a tertiary medical center, the critically ill patients represent another target group for pneumoperitoneum sonography. These very ill patients can challenge the physician with their limited ability to provide a history but may present with suspicious physical exam findings such as abdominal tenderness. Here, if too unstable to be transported to CT – incorporating sonographic evaluation for pneumoperitoneum into bedside imaging can provide the physician with expedited care diagnosis. Of course, large studies focusing on outcome metrics would be needed to substantiate these assertions. The finding of abnormal free air, with or without other associated ultrasonographic findings (such as free fluid, ileus, or bowel necrosis), may allow for a definitive diagnosis at the bedside within minutes for the patient with an acute abdomen. The advantages are worthy of the efforts required to accurately perform assessments for pathologic air using the techniques described above, especially as these patients are often already undergoing bedside ultrasound. Abdominal ultrasound instruction should include the teaching of techniques described above to detect pneumoperitoneum, so that the next generation of practitioners may routinely acquire the skill necessary to make the diagnosis with confidence. Large prospective trials will be needed to validate the accuracy and the inter-rater reliability of sonography for pneumoperitoneum performed by diverse groups of trained emergency or critical care physicians.

Acknowledgements

Conflicts of interest

There are no conflicts of interest.

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