SECTION 1

DIAGNOSTIC APPLICATIONS

1 Right-upper-quadrant pain in a 10-year-old female

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HISTORY OF PRESENT ILLNESS

A 10-year-old, previously healthy female began to complain of right-upper-quadrant pain approximately 3 weeks prior to her ED presentation. According to her mother, the pain seemed to wax and wane, but had increased in frequency and severity, being particularly noticeable after eating. She had episodic nausea, but no vomiting or diarrhea, and denied other symptoms or inter-current illness.

PHYSICAL EXAMINATION

GENERAL APPEARANCE: Obese female in no obvious distress.

VITAL SIGNS:

Temperature	98.6°F (37.0°C)
Pulse	98 beats/min
Blood pressure	92/60 mmHg
Respirations	18 breaths/min
Oxygen saturation	100% on room air

HEENT: Normocephalic, atraumatic, PERRL, normal TMs, nose and oropharynx.

NECK: Supple neck with no pain to palpation or notable lymphadenopathy.

CARDIOVASCULAR: Regular rate and rhythm. Capillary refill less than 2 s.

LUNGS: Clear to auscultation bilaterally, no wheezes, rhonchi, or retractions.

ABDOMEN: Soft and non-distended. Tenderness to palpation in the right upper quadrant. Murphy's sign was not elicited. No masses were palpated, and there was no rebound tenderness or guarding.

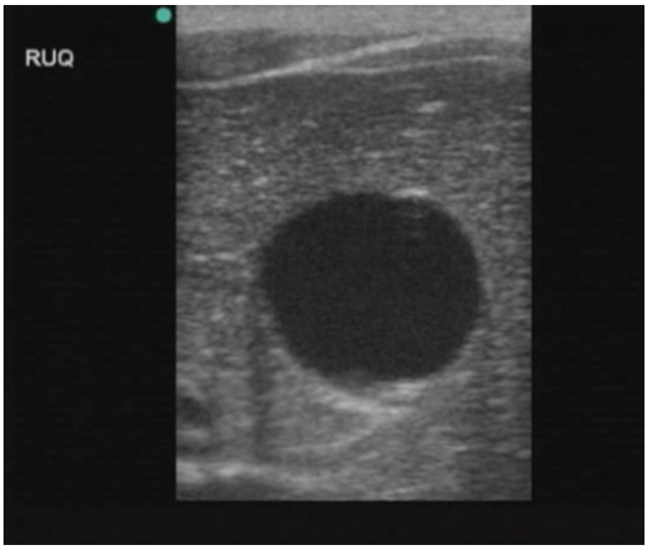

Figure 1.1 Image of the gallbladder in transverse orientation.

The resident evaluating the child appropriately considered the possibility of cholecystitis as the cause of the patient's pain and performed a right-upper-quadrant ultrasound at the patient's bedside. She identified shadowing and some echoes within the gallbladder, and with a look of success, showed her attending physician the images she obtained (Figure 1.1).

What is your diagnosis?

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ANSWER

This case exemplifies the importance of understanding artifacts when performing point-of-care ultrasonography. Artifacts are an important cornerstone of this imaging modality because they can relay imperative information to the sonographer. The shadowing noted in the images obtained by the resident is referred to as **edge-artifact** or **edge-shadow** (Figure 1.2). This artifact occurs when the ultrasound beam contacts a curved structure or crosses the boundary between tissues of different densities. The affected ultrasound beam experiences a change in propagation speed; this refracts (or bends) the beam, causing it to deviate from its initial trajectory.[1] This, in turn, causes an absence of sound wave reflection back to the probe from the area deep to the point of ultrasound beam deviation, causing a shadow.

Edge artifact can be confused with **acoustic shadowing**, which occurs when sound waves strike a highly attenuating structure (e.g. bone, gallstone, or foreign body).[1] In the case of a gallstone, the ultrasound beam will strike the stone and be reflected back to the probe. As the majority of the ultrasound beam energy returns to the probe, there is an absence of echoes generated deep to the stone, hence the appearance of a shadow (Figure 1.3).

Shadowing from edge-artifact or acoustic shadowing gives the appearance of a clean and well-demarcated shadow line. However, when the ultrasound beam encounters a gas–tissue interface, the sound beam scatters and results in a **dirty shadow** appearance (Figure 1.4).[2] This will obscure visualization of any structures in the far-field of this dirty shadow. This type of artifact is often encountered when insonating the abdomen. The application of gentle and sustained pressure can help displace gas and facilitate visualization of abdominal contents when dirty shadowing is encountered.

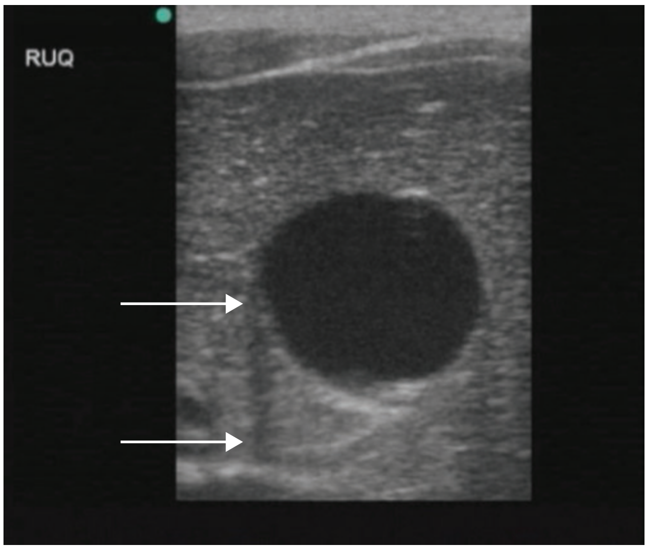

Figure 1.2 Image of the gallbladder in transverse view, demonstrating an edge artifact.

PAE is the opposite of acoustic shadowing. An echogenic far wall is characteristically noted when a cystic/fluid-filled structure is insonated. There is very little dampening (attenuation) of ultrasound beams as they travel through a homogenous fluid medium prior to striking the far wall, which acts as a highly reflective interface, causing it and the area immediately deep to it to appear much brighter than surrounding tissue (Figure 1.5).[2] The posterior wall of a fluid-filled structure may therefore have a very different sonographic appearance when compared to the side and anterior walls of the same structure, when in reality the tissue densities may be the same. As the far wall of the gallbladder may appear thickened due to PAE, it is important to measure the near wall to obtain the most accurate assessment of wall thickness.

While PAE can be a helpful tool, excessive PAE can prevent the ability to visualize structures in the far-field. Figure 1.6

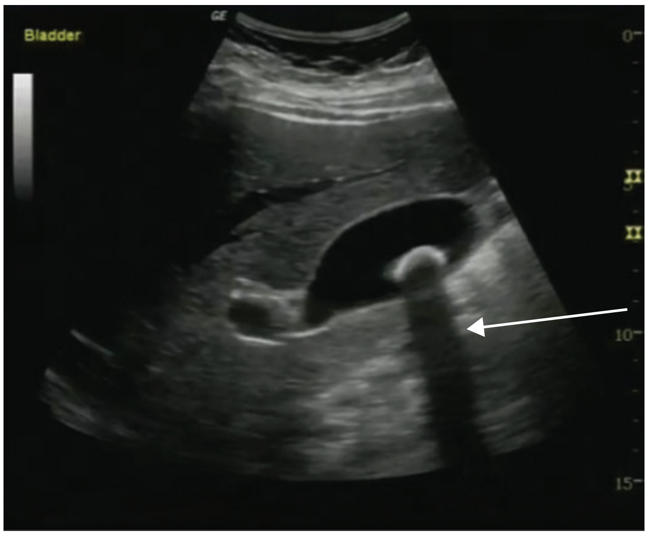

Figure 1.3 Image of the gallbladder in longitudinal view; the arrow points to acoustic shadowing from the gallstone above.

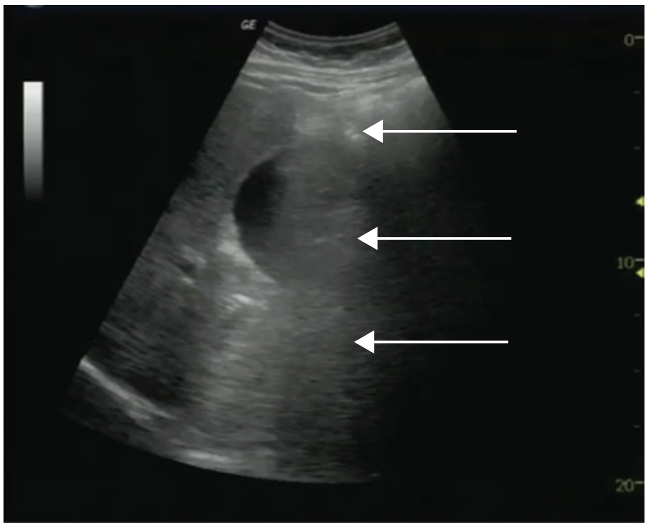

Figure 1.4 Dirty shadow from the bowel (arrows) obscures the gallbladder in this image.

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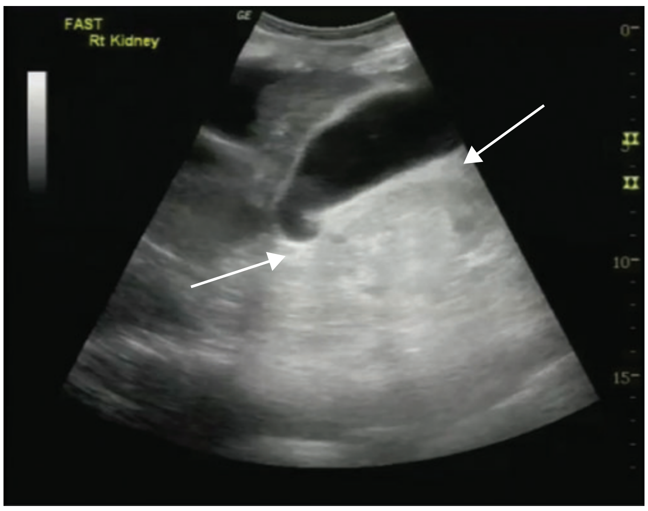

Figure 1.5 This image of the gallbladder in longitudinal view is an example of posterior acoustic enhancement (between arrows). Notice how bright the area below the gallbladder is compared to the area to the left of the image.

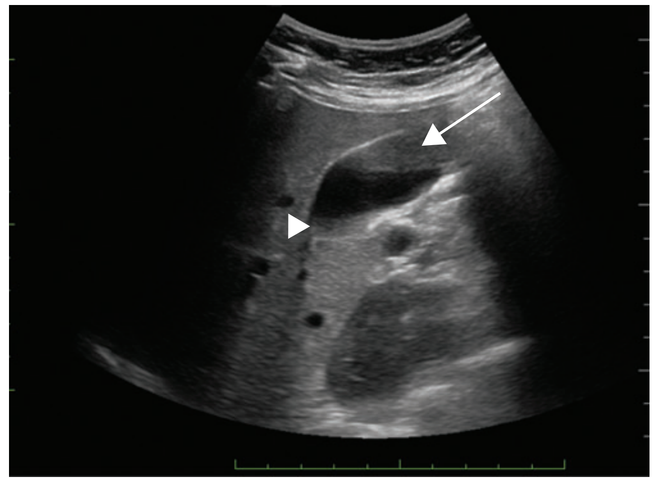

Figure 1.7 Longitudinal image of the gallbladder shows reverberation artifact (arrow). Noting how the artifact defies gravity helps identify it. Side-lobe artifact is noted at the arrowhead and is often confused with sludge.

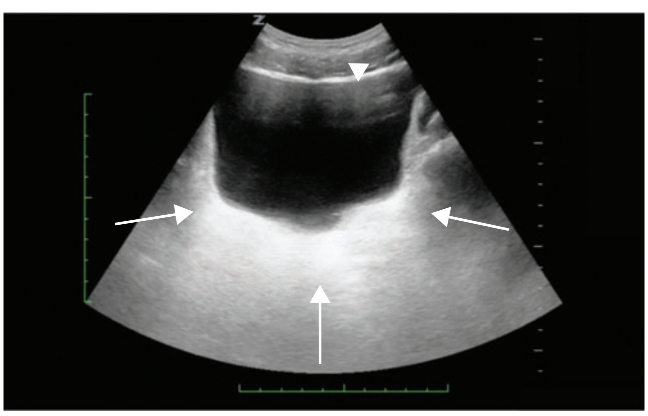

Figure 1.6 This image of the bladder shows extreme posterior acoustic enhancement (arrows). Subtle free fluid may be missed when the image is too bright; turning down the gain will help reduce this. Also note the reverberation artifact at the top of the bladder (arrowhead).

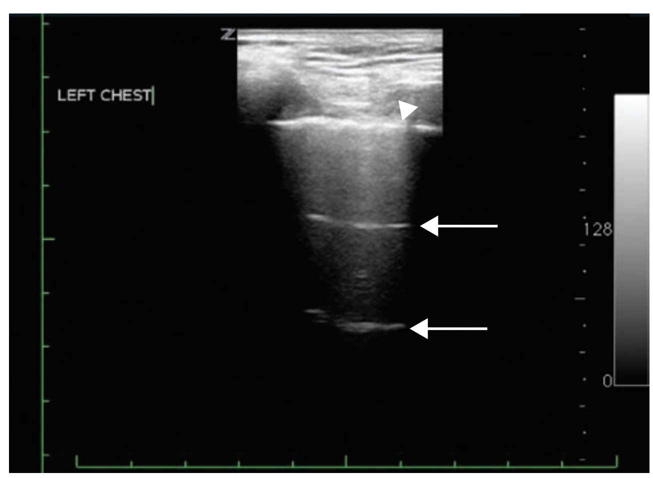

Figure 1.8 A-lines, a type of reverberation artifact, seen in the lung.

depicts an image where there is too much PAE behind the urinary bladder. It is apparent that a small amount of free-fluid in the posterior cul-de-sac could be obscured.

The resident proceeded to present the image in Figure 1.7, and described how she thought the internal echo noted might have represented gallbladder sludge. The attending physician reviewed the image and pointed out another important artifact: reverberation. **Reverberation artifact** occurs when large-amplitude ultrasound beams bounce between two highly reflective surfaces. This results in bright horizontal lines which are equidistant from the transducer.[5]

Reverberation artifact is also frequently seen in aerated lung when the bouncing back and forth of the sound waves between the transducer and the highly reflective pleura results in the appearance of horizontal lines recurring at a constant interval deep to the pleura within the lung parenchyma (Figure 1.8). This finding, referred to as an A-line, is another example of reverberation artifact.

Referring back to Figure 1.7, the resident was also concerned that the patient had a stone in her gallbladder (arrowhead). This actually represents **side-lobe artifact**. The attending physician explained that while most of the energy emanating from the transducer travels in the center beam, some weak side-beams are also emitted, travel in the periphery of the ultrasound beam and are referred to as side-lobes. Side-lobe beams, upon encountering a reflector, will generate an echo and return to the transducer, as do larger-amplitude ultrasound waves emanating from the center of the probe. The ultrasound machine processor, however, operates under the assumption that the reflection came from the center beam, and a low-level echo is generated on the image produced. As the respective distances traveled from transducer to reflector and back by side-lobe versus central probe-generated ultrasound waves are

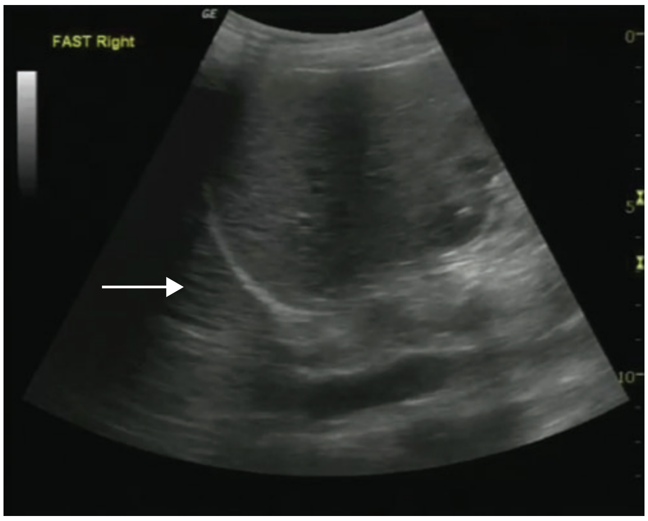

Figure 1.9 This image represents mirror artifact. The liver is mirrored above the diaphragm (arrow). Notice how there appears to be the same tissue above and below the diaphragm.

slightly different, the low-level returning echoes may misrepresent the precise location of highly reflective tissue interfaces.

Side-lobe artifact is primarily encountered in fluid-filled structures such as the gallbladder or urinary bladder. This artifact can be differentiated from actual sludge in that the artifact extends beyond the wall of the gallbladder and is often noted to be floating, rather than sinking to the most dependent portion of the organ, as would be expected of a gallstone or sludge.

The resident also mentioned that it appeared as though liver tissue was both above and below the diaphragm in the right-upper-quadrant view (Figure 1.9). This artifact is referred to as mirror artifact. **Mirror artifact** occurs when ultrasound waves interact with a highly reflective curved surface, such as the hemidiaphragm.[2] The ultrasound machine processor performs distance calculations based on the assumption that sound waves travel in a straight line, at a determined velocity. Mirror artifact occurs when a portion of the ultrasound waves are delayed in their return to the transducer. The re-reflected waves will re-contact the curved surface (e.g. the diaphragm) and only then return to the transducer. The ultrasound machine processor will account for this alteration in signal and timing by creating a duplicate image deep to the original image.[2]

The resident also inquires about the artifact seen along the bowel wall (Figure 1.10) and how it resembles what he has seen when visualizing a foreign body, such as a needle tip. This artifact is called ring-down. **Ring-down artifact** can be helpful or hindering depending on the particular exam and is produced when the ultrasound beam encounters a collection of gas bubbles. Fluid between the gas bubbles, when struck by the ultrasound beam, resonates and reflects a continuous sound wave back to the transducer.[6] This is seen as a series of short, bright parallel bands with straight margins distal to the gas bubbles. The length of the ring-down artifact depends on the duration of the ringing. If the structure rings for a long

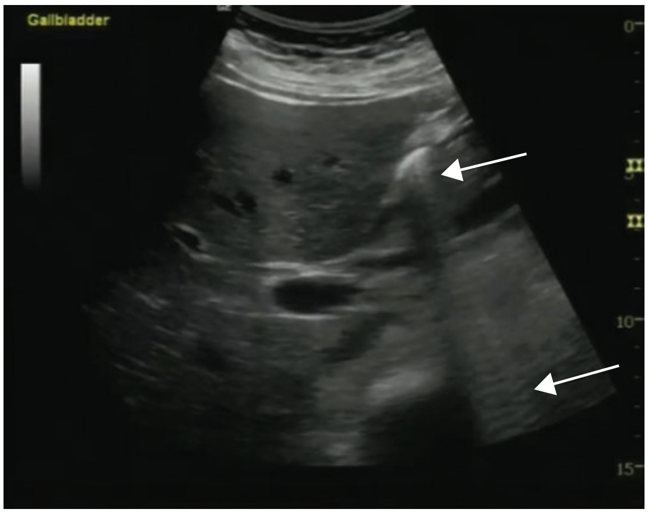

Figure 1.10 Ring-down artifact is seen from the bowel (arrows). Note how the ringing pattern can be traced to the end of the image.

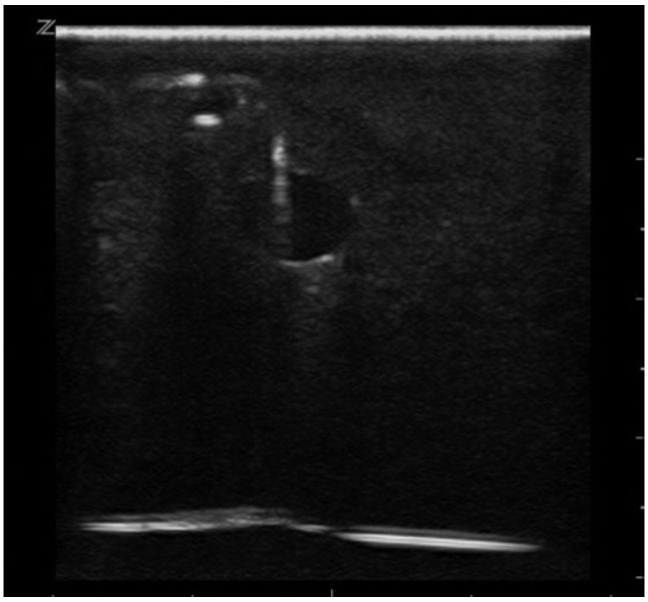

Figure 1.11 Ring-down artifact seen from a needle in a vessel; again, note the repeated horizontal lines of the ringing.

period of time, ring-down artifact may be seen to the bottom of the image. Conversely, a short-duration ringing will only produce a short artifact. Because of its characteristic appearance, ring-down artifact is helpful in localizing a needle tip when performing procedures like central line placement (Figure 1.11). On occasion, ring-down from the bowel can obscure images distal to it and hinder image acquisition.

Comet-tail artifact is encountered when an ultrasound beam strikes cholesterol stones or metallic foreign bodies such as surgical clips, staples, or needle tips (Figure 1.12).[1] Although the terms comet-rail and ring-down artifact are often used interchangeably and have similar appearances, comet-tail artifact is technically different as the reflecting object is the vibrating foreign body itself. Comet-tail artifact is characterized by very

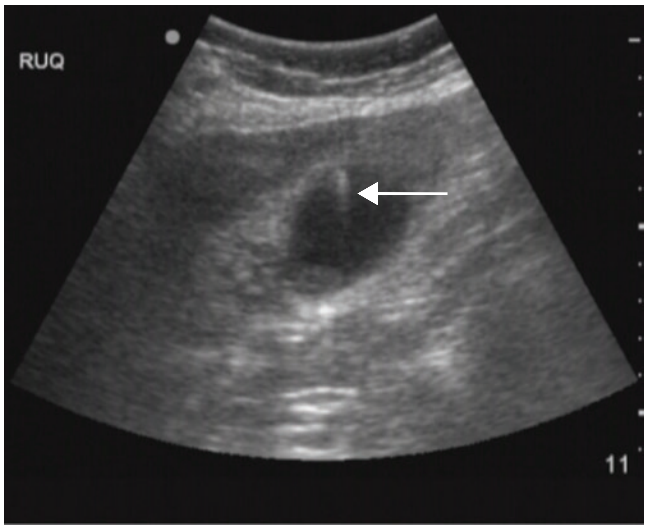

Figure 1.12 Short comet-tail artifact (arrow) from a cholesterol stone in the wall of a gallbladder.

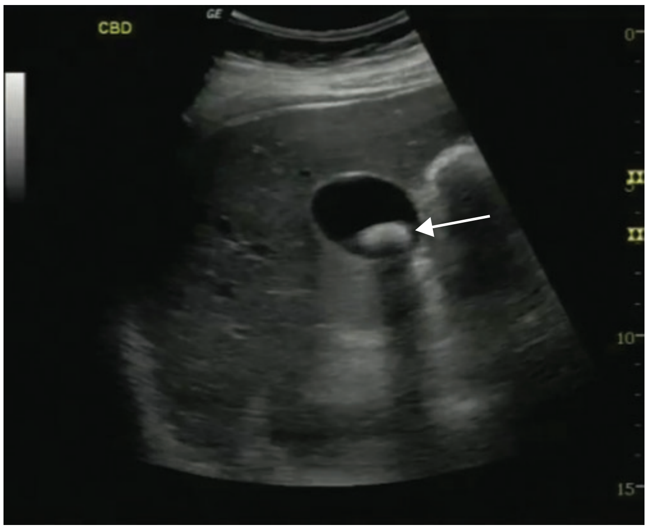

Figure 1.13 Gallstone (arrow) producing a hypoechoic clean shadow below it.

narrow and closely spaced sound wave reverberation. This artifact, visualized deep to the insonated foreign body, not only confirms its presence but assists in localization.

The laboratory results returned on the 10-year-old girl with right-upper-quadrant pain and were entirely normal. The resident physician repeated the right-upper-quadrant ultrasound on this patient and returned to show her attending physician non-obstructing gallstones with shadowing (Figure 1.13). The child underwent laparoscopic cholecystectomy and recovered uneventfully.

KEY TEACHING POINTS

1. Understanding ultrasound artifacts is essential to the performance of clinician-performed sonography. Artifacts are often generated at echogenic tissue interfaces.
2. Edge-artifact occurs when ultrasound waves experience refraction causing an absence of reflection back to the probe from the area deep to the point of sound-beam deviation.
3. Acoustic shadowing refers to the absence of sound waves deep to a highly reflective structure.
4. Posterior acoustic enhancement occurs when sound waves experience relatively little attenuation while traveling through a cystic structure, causing the far wall and the area immediately deep to it to appear much brighter than surrounding tissue.
5. Reverberation artifact is produced by a bouncing of large-amplitude ultrasound waves between two highly reflective surfaces (tissue interface and transducer) and produces horizontal lines deep to the reflective tissue.
6. Side-lobe artifact occurs as a result of low-intensity echoes returning to the ultrasound probe following initial generation in the lateral portion of the transducer and may distort interfaces in cystic structures.
7. Mirror artifact refers to echoes and images appearing distal to a highly reflective interface and occur as a result of delayed sound wave return to the transducer.
8. Ring-down artifact appears as a series of short parallel bands with straight margins distal to gas–fluid interfaces and can enhance ultrasound-guided procedures involving a needle.

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2 Motor vehicle accident evaluation in a 5-year-old male

Annie Heffernan Rominger and David J. McLario

HISTORY OF PRESENT ILLNESS

A 5-year-old male was transported to the Pediatric ED by EMS following a motor vehicle accident. He was a car-seat-restrained passenger in the rear of a vehicle that sustained moderate front-end damage after striking the side of another vehicle ticketed for failure to yield at an intersection. The estimated speed at impact was 30 mph. He was not ejected and was found by EMS within the vehicle, strapped in the non-displaced car seat, awake, and crying. His 17-year-old brother, the driver of the vehicle in which he had been riding, was transported to the adjacent Adult ED for suspected minor injuries.

He arrived immobilized on a backboard with a cervical collar in place. According to the EMS report, he was alert during transport, with complaints of right shoulder and forearm pain. In view of the mechanism of injury, trauma team activation occurred in advance of his arrival.

PHYSICAL EXAMINATION

GENERAL APPEARANCE: Patient was crying but spoke clearly with c-collar applied appropriately.

VITAL SIGNS:

Temperature	97.5°F (36.4°C)
Pulse	122 beats/min
Blood pressure	105/62 mmHg
Respirations	21 breaths/min
Oxygen saturation	100% on room air

HEENT: Normocephalic, PERRL, tympanic membranes normal, nose atraumatic, oropharynx normal.

NECK: No cervical spine tenderness nor pain with active motion.

CARDIOVASCULAR: Normal color, heart sounds and pulses, capillary refill 2 s.

LUNGS: Equal breath sounds bilaterally without retractions or nasal flaring.

ABDOMEN: Non-tender, no lap-belt or other ecchymosis, no bruising.

GENITOURINARY: No blood at the urethral meatus, exam otherwise normal.

EXTREMITIES: Right forearm deformity, abrasion right shoulder.

NEUROLOGICAL: Alert, GCS 15, normal motor and sensory evaluation.

Following the primary survey, the Emergency Medicine fellow proceeded with a FAST examination (Figure 2.1).

What is your diagnosis?

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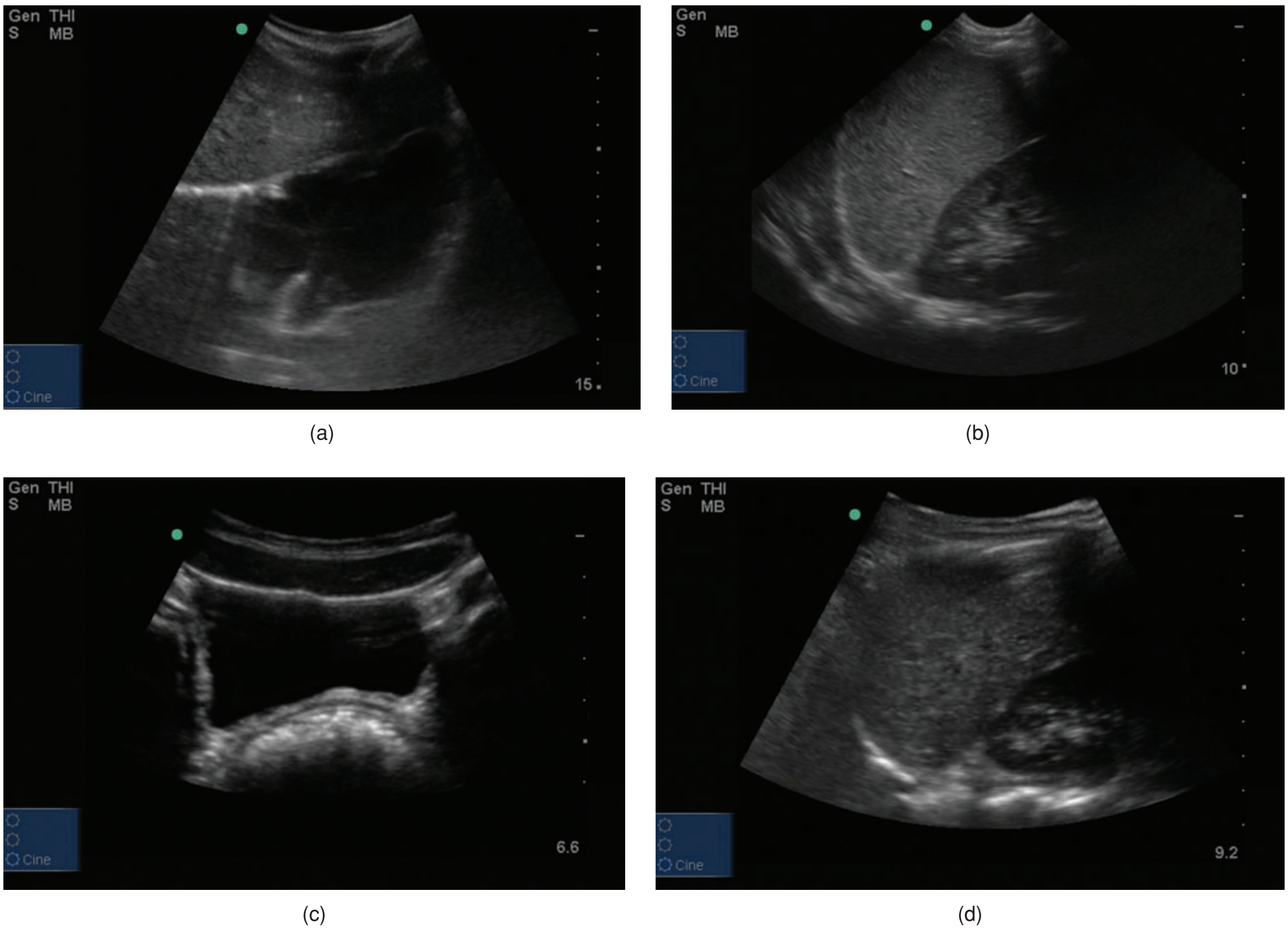

Figure 2.1 The patient's FAST exam (a) subxiphoid, (b) peri-hepatic, (c) suprapubic, and (d) peri-splenic views.

ANSWER

The FAST is negative. Hemopericardium is not present and there is no evidence of IPH. The patient was log-rolled and evaluation of his posterior torso and extremities was normal. He had no TLS-spine tenderness or deformity and was removed from the backboard. Trauma labs were normal, including a bedside hematocrit of 43%.

Plain films of the chest, pelvis, and c-spine were negative. A forearm x-ray revealed displaced fractures of the right radius and ulna. The orthopedic service was consulted and reduced his forearm fracture using a Bier Block. He was admitted for overnight observation where serial FAST and clinical abdominal examinations performed by the trauma team were normal. He was discharged the following afternoon and made a complete recovery.

FAST – focused assessment with sonography for trauma

In 1971, the use of ultrasound in the evaluation of trauma was first reported in the literature.[1] Twenty-five years later, The American College of Surgeons advocated ultrasound use within the ATLS evaluation. Subsequently, FAST has supplanted deep peritoneal lavage as the primary modality for detection of trauma-induced IPH.

The FAST examination is based on the presumption that free fluid will follow gravity and accumulate in dependent regions of the peritoneal cavity. Also foundational is the fact that blood is sonographically anechoic (black) and contrasts with the more echoic (gray) echo-textures of adjacent solid organs.[2] The FAST exam is not intended to be a detailed multi-organ investigation of all possible abdominal pathology, but rather a screening evaluation for the detection of IPH in the setting of trauma.

IPH is most likely to accumulate in one or more of three compartments – the supra-mesocolic, infra-mesocolic, and para-colic – in the supine patient (Figure 2.2). Specific sites in the supra-mesocolic compartment where free fluid (including IPH) is sonographically identifiable in the supine patient are the hepato-renal fossa and Morison's pouch, a potential space between the caudal border of the liver and Gerotta's fascia of the kidney (Figure 2.3). The slightly less dependent supra-mesocolic recess exists in the left upper quadrant in the vicinity of the spleen, where free fluid is usually noted above the superior spleen convexity and/or around the caudal tip of the spleen (Figure 2.3).

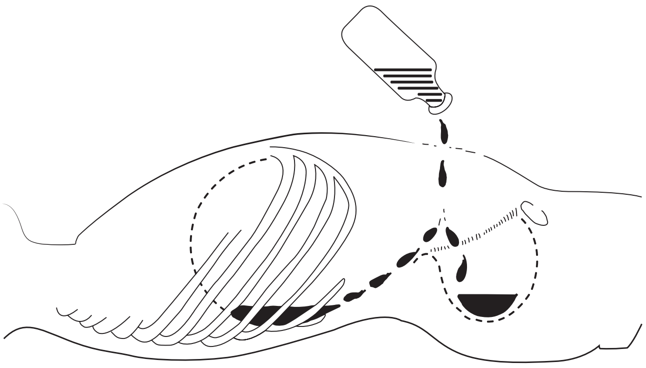

Figure 2.2 A drawing showing the expected flow of free fluid in the peritoneum of a supine person (redrawn from Cosby and Kendall, eds. *Practical Guide to Emergency Ultrasound*. Philadelphia, PA: Lippincott, Williams, and Wilkins, 2006).

The infra-mesocolic compartment houses the recto-vesicular and recto-uterine pouches which are the most dependent areas in the supine male and female, respectively (Figure 2.3).

The para-colic gutters connect the supra- and infra-mesocolic compartments. Free intraperitoneal fluid will tend to gravitate preferentially toward the right upper quadrant via the right para-colic gutter as resistance to flow toward the left upper quadrant via the left para-colic gutter occurs due to interference from the phrenico-colic ligament (Figure 2.4). Also, with cardiac injury, blood may accumulate between the visceral and parietal pericardia, causing hemo-pericardium.

There are many advantages to using FAST in the setting of trauma. It is immediately available at the bedside and is accurate in the assessment of solid organ injury. A FAST exam can be performed in patients who are insufficiently unstable for transport to the CT scanner and can be repeated at the discretion of the caregiver.

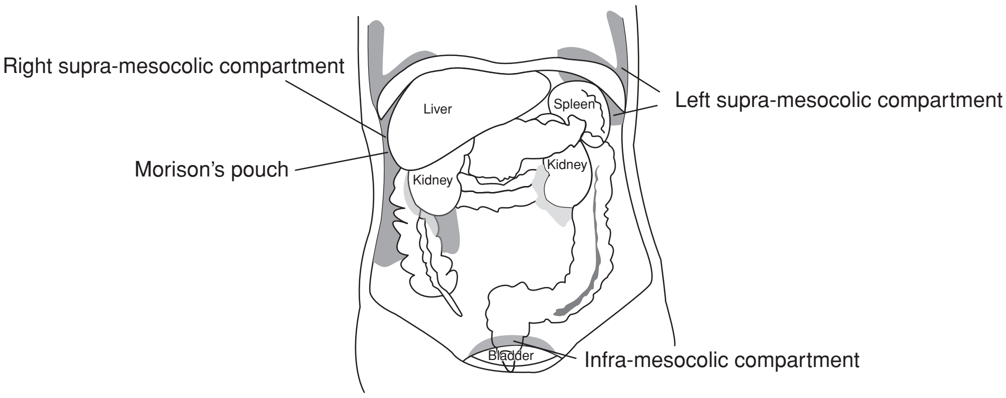

Figure 2.3 Potential spaces within the torso where fluid can collect (redrawn from Cosby and Kendall, eds. *Practical Guide to Emergency Ultrasound*. Philadelphia, PA: Lippincott, Williams, and Wilkins, 2006).