

FOCUSED—BASIC ULTRASOUND PRINCIPLES AND ARTIFACTS

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Introduction

Turn on the machine. Apply coupling gel. Start scanning. In the realm of the busy veterinary general practice, emergency clinic, or intensive care unit, that statement really sums up the basic use of ultrasound. Just as natural as it is for us to take the stethoscope from around our neck and place it on a patient's thorax, so should be picking up the ultrasound probe and placing it on the patient. No wonder that ultrasonography has been appropriately dubbed both "an extension of the physical exam" and the "modern stethoscope" (Rozycki 2001; Filly 1988). Really, one doesn't need a whole lot of instruction to start scanning; however, as for a lot of things in life, the devil is in the details. Proper imaging technique and understanding its limitations are the keys to accurate image interpretation of diagnostic ultrasound.

The focus of this chapter is a fairly brief review of the basic physics and principles of ultrasound including the more common problematic artifacts. For interested readers, there are more comprehensive textbooks dedicated to the physics and interpretation of ultrasound imaging (Nyland 2002; Penninck 2002).

What Focused Basic Ultrasound Principles and Artifacts Can Do

- Provide a basic review of ultrasound physics, image formation, common artifacts, and ultrasound systematics
- Provide a basic understanding of how artifacts are formed to allow better interpretation of the ultrasound image

What Focused Basic Ultrasound Principles and Artifacts Cannot Do

- Cannot provide an in-depth discussion of ultrasound physics, principles, and artifacts

Indications

- Provide a basic understanding of ultrasound physics, principles, and artifacts for the non-radiologist veterinarian

Objectives

- Provide an understanding of the basic fundamentals of ultrasound physics and how they relate to image formation
- Provide an understanding of how basic ultrasound artifacts are formed to avoid misinterpretation
- Provide a review of basic ultrasound systematics including image orientation and storage and machine and probe care

Basic Ultrasound Principles

The ultrasound (US) machine consists of two main parts, the probe and the processor. The probe is the "brawn" and the processor the "brains" of the operation. The probe has two main functions: first, to generate a sound wave (acts as a transmitter); second, to receive a reflected sound wave (acts as a receiver). The processor, located within the mainframe, takes these incoming signals and turns them into a useful image.

The transmitter and receiver functions of the transducer do not occur simultaneously, but rather sequentially. When placed under mechanical stress the ceramic crystals in the transducer generate a voltage. This process, known as the piezoelectric effect, occurs during the receiving phase, which is when returning sound waves strike the transducer. When an external voltage is applied to the crystals they exhibit the reverse phenomenon and undergo a small mechanical deformation. The subsequent release of this energy generates the ultrasound wave. This is known as the reverse piezoelectric effect. World War I saw the first practical use of the piezoelectric effect in the development of sonar using a separate sound generator and detectors (Coltera 2010).

The sound waves generated by diagnostic US machines are typically in the 3- to 14-megahertz (MHz) range and are thus too high pitched to be perceived by the human ear. We can hear sounds in the range of 20 Hz (cycles/second) to 20,000 Hz. In contrast, our average canine patient hears sounds in the range of 40 Hz–60,000 Hz. The high frequencies are in the realm of what is termed the “ultrasonic” range—basically any sound above our ability to hear—and hence the name for this clinical tool (Nyland 2002).

The sound waves produced by the transducer penetrate the body tissues and are subject to all the rules surrounding any sound wave including reflection, refraction, reverberation, attenuation, and impedance. The processor analyzes the transmitted signals and the returning waves, including their quantity, strength, and the time they took to return. By applying pre-programmed algorithms, the processor translates this information into a pixel, gives it an appropriate intensity (its echogenicity), and places it on the monitor screen to give us the image (sometimes being “fooled” into creating artifacts).

Between the transducer and the processor, it is easy to see why the equipment for this modality can be rather pricey. However, by using the variety of focused or COAST³ ultrasound exams outlined in this textbook, we hope that your US machine will become an asset not only with improved patient care, but also with a return on investment.

Velocity

Sound travels at specific known velocities through various materials. Remember from physics that sound travels faster through solids than it does through liquid or gas, and its velocity through various body tissues is known (Figure 1.1). Notice that velocity is similar through most of the soft tissues; however, current US machines cannot determine what tissues are being penetrated. Therefore, all US machines use an average velocity of 1540 m/sec for their imaging algorithms averaging the speed of sound through fat, liver, kidney, blood, and muscle (Coltera 2010).

The first and last columns in the table illustrate that sound passes relatively slowly through air and relatively quickly through bone. Anyone who has picked up an US probe knows that bone (solid) or lung (air) cannot be adequately imaged using US. To address the issue, the sonographer must understand the principle of acoustic impedance.

Remember the saying: Ultrasound hates bone or stone and is not too fair with air.

Acoustic Impedance

Acoustic impedance refers to the reflection and transmission characteristics of a substance. It is a measure of absorption of sound and the ratio of sound pressure at a boundary surface to the sound flux. Sound flux is

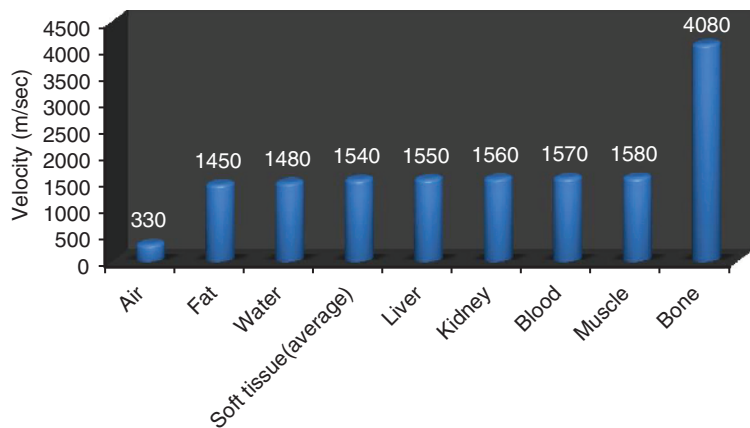


Figure 1.1. Velocity (m/sec) of sound through common body tissues or substances. Note the similar velocity through most soft tissues. This is the basis for using 1,540 m/sec as the number in depth calculations by the ultrasound processor. (Coltera 2010)

flow velocity multiplied by area. If we draw an analogy to electronic circuits, acoustic impedance is like electrical resistance through a wire, sound pressure is like voltage, and flow velocity is like current. The equation that brings it all together is:

$$Z = p/v$$

where Z =acoustic impedance, p =sound pressure (or tissue density), and v =velocity (Nyland 2002). The amplitude of a reflected sound wave is proportional to the difference in acoustic impedance between two different tissues. Air has a low impedance and bone has a high impedance when compared to soft tissue (Reef 1998) (Figure 1.2). Therefore, when a sound wave comes across a soft tissue-bone or a soft tissue-air interface (large difference in acoustic impedance), nearly all of the sound waves are strongly reflected (and a bright white echogenic line is formed at either interface). Reflection is why the sonographer cannot image through bone (solid) or lung (air), and strikes up one of the most common misnomers used in clinical ultrasonography: When imaging through the liver into the thorax, we believe the bright, curved cranial border is the diaphragm. In reality, the diaphragm is rarely imaged except in bicavitary effusions. The bright white (hyperechoic), curved line is actually the strongly reflective surface of the lung (air) at the soft tissue-air boundary or interface serving as a strong reflector.

In conclusion, by comparing the acoustic impedance of most tissues in the body—other than bone (solid) and lung (air)—we see that they are very similar (there is little difference in acoustic impedance among them). This similarity makes US a great imaging tool for examining into and through soft tissues (their parenchyma). On the other hand, due to the large difference in acoustic impedance between soft tissue-air and soft tissue-bone interfaces, US is not an effective

tool for examination beyond the surfaces of either aerated lung or bone (Reef 1998).

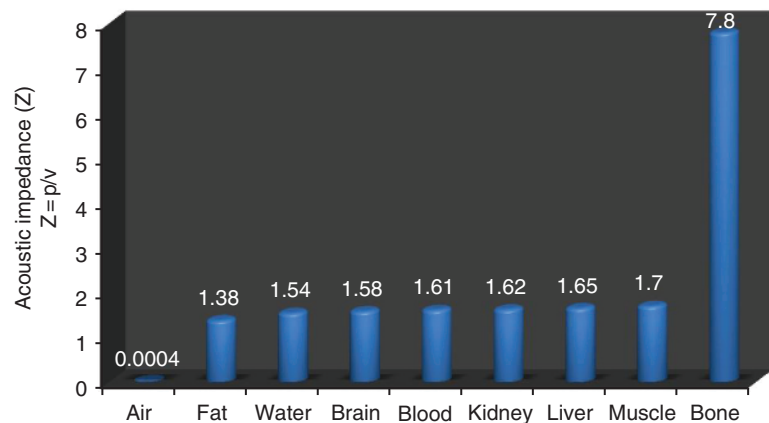
Absorption, Scatter, and Reflection

Other US principles that affect our image include absorption, scatter, and angle of reflection. As the sound waves enter the body, some of them are absorbed by the tissues and are never reflected back to the probe. These waves are lost and do not contribute to the image. Furthermore, many of the waves are scattered by the tissues and their surface irregularities and either return to the probe (receiver) in a distorted path or do not return at all. As a result, the US waves are “misinterpreted” by the processor and the image and its resolution are affected. The ideal angle of US reflection for generating the best image is 90 degrees; this is why linear probes (not used by most small animal practitioners) provide superior detail when compared to curvilinear probes (more commonly used among small animal practitioners). Interestingly, a deviation of as little as 3 degrees from this ideal causes US waves to be lost and not returned to the receiver, thus decreasing the detail of the US image.

Attenuation

All sound beams become attenuated, or lose energy, during transmission through tissues; therefore, the returning sound wave is weaker than when it started. Different frequencies (MHz) are attenuated to different degrees. Low frequency is attenuated less than high frequencies and therefore allows deeper tissue penetration. Conversely, high frequency gives better resolution but undergoes more attenuation. Strategies that include lowering the MHz for better penetration (depth) come at the expense of detail. Conversely, using higher frequency for more detail comes at the

Figure 1.2. Acoustic impedance ($10^6 \text{ kg/m}^2\text{sec}$) of common body tissues or substances. This figure illustrates the degree of difference in acoustic impedance between substances that helps determine sound wave transmission. The greater the difference, the greater reflection or loss of transmission. You can see how ultrasound is ideally suited for most soft tissue and why it is not suited for imaging bone or air-filled structures. (Reef 1998)



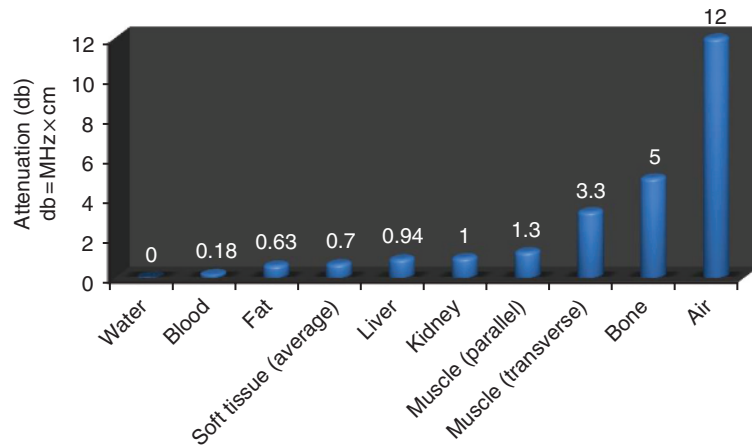


Figure 1.3. Attenuation (db/cm/MHz) in common tissues. Attenuation of sound energy within tissues varies with the frequency of the sound and is affected by reflection, scattering, and absorbance. Note how bone and air have the greatest attenuation values. (Reef 1998)

cost of less penetration (depth). Furthermore, high-density tissues attenuate the sound waves more than low-density tissues (Figure 1.3). These principles will be further discussed in Basic Artifacts.

The analogy of hearing a boom box from a distance can help you remember which MHz penetrates more. The bass dominates (low MHz) over higher frequencies (high MHz); thus, low MHz penetrates deeply at the expense of detail, and high MHz gives better detail at the expense of penetration.

Basic Artifacts

Now we'll take the fundamental laws governing wave dynamics and see how artifacts are created. Artifacts may be grouped by the most important principles leading to their formation including attenuation, velocity, or propagation, and artifacts associated with multiple echoes.

Artifacts of Attenuation, Strong Reflectors (Bone, Stone, Air)

Shadowing, "Clean" and "Dirty"

Clean shadows and dirty shadows result from strong reflectors (bone, stone, and air). We know from differences in acoustic impedance at soft tissue-air and soft tissue-bone (stone) interfaces that most of the sound waves will be reflected, albeit in different degrees (Figures 1.4 and 1.5A).

Bone (or Stone) Interface

When the US wave strikes bone (and stone), most of the waves are reflected back thus there will be an area of intense hyperechogenicity (whiteness) at the soft

tissue-bone (stone) interface. Because the surface of bone is often smooth, there is little scattering or reverberation of the US wave and a nice, clear-cut, anechoic (blackness) "clean shadow" is produced beyond the reflector (bone or stone) (Figure 1.4B, also see Figures 15.1, 15.2, 15.6, and 15.7).

Air Interface

On the other hand, soft tissue-air interfaces are more variable in their degree of reflection with some of the US waves incompletely moving through the air-filled structure unlike the complete reflection at bone (or stone); thus reverberations occur distal to the air interface creating a "dirty shadow." (Penninck 2002) (Figure 1.4A, 1.5A).

Artifacts of Attenuation (Fluid-Filled Structures)

Edge Shadowing (Fluid-Filled Structures)

When the US waves strike the edge of a fluid-filled structure with a curved surface (its wall), such as the stomach wall, urinary bladder, gallbladder, or cyst, US waves change velocity and bend, resulting in the physical process of refraction. As a result, a thin hypoechoic (darker) to anechoic (black) area lateral and distal to the edge of the curved structure is formed. The novice may mistake this artifact as a "rent" in the urinary bladder wall when in fact it is an artifact created by the US machine (Nyland 2002) (Figure 1.5).

Acoustic Enhancement (Fluid-Filled Structures)

When the sound beam passes through a fluid-filled structure, such as the gallbladder, urinary bladder, fluid-filled stomach, or a cyst, US waves do not become

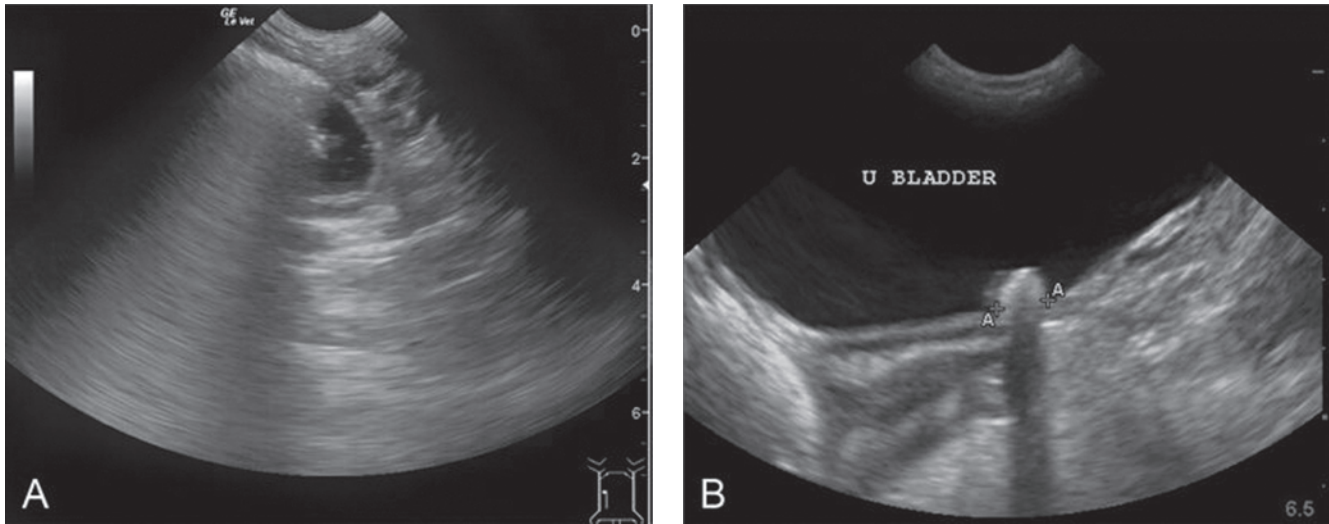


Figure 1.4. Clean versus dirty shadowing. (A) “Dirty” shadow. A gas bubble within a fluid-filled distended loop of small bowel generates a dirty gas shadow (image on the left) because some US waves pass through the structure. Contrast the dirty shadow with the “clean” shadow of the cystourolith (urinary bladder stone) in (B). Note how a body icon was used to show the approximate location of the probe because there are no anatomical landmarks within the image itself. (B) “Clean” shadow. The smooth surface of the cystourolith (urinary bladder stone) generates the clean shadow typical of bone or stone with a hyperechoic (bright white) reflective surface in the near field, completely blocking all echoes and thus resulting in an anechoic (dark or black) shadow extending from it. Courtesy of Dr. Sarah Young, Echo Service for Pets, Ojai, California.

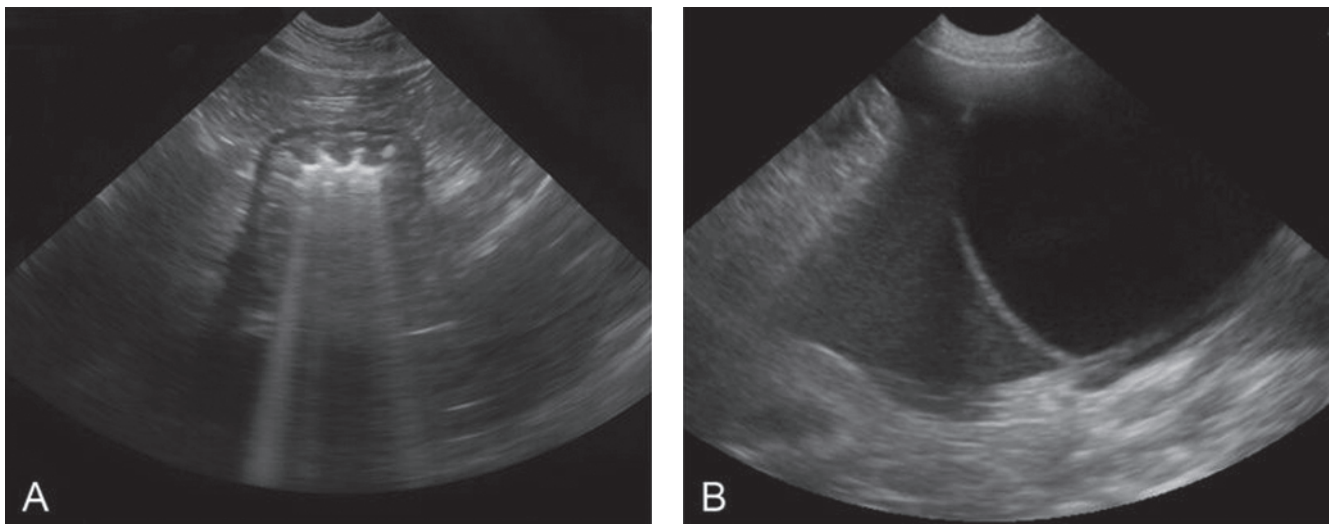


Figure 1.5. Edge shadow artifact. (A) An edge shadow artifact is seen arising from the curved edge on the left side of the stomach wall in this image, making its wall appear to extend distally as an anechoic (dark or black) line. A dirty gas shadow is also produced from gas within the stomach lumen. (B) An edge shadow artifact at the apex of the urinary bladder makes it falsely appear to have a rent which can fool the novice into thinking the free fluid is from a ruptured bladder. Courtesy of Dr. Sarah Young, Echo Service for Pets, Ojai, California.

as attenuated as the neighboring waves passing through more solid tissues to either side of the structure. Therefore, the tissues on the far side of the fluid-filled structure appear much brighter than the neighboring tissues at the same depth. Acoustic enhancement is

obvious, looking past the fluid-filled gallbladder and urinary bladder (Figure 1.6). On the other hand, by realizing how the artifact is formed, the acoustic enhancement artifact can be advantageously useful to the savvy sonographer in determining if a structure of interest is

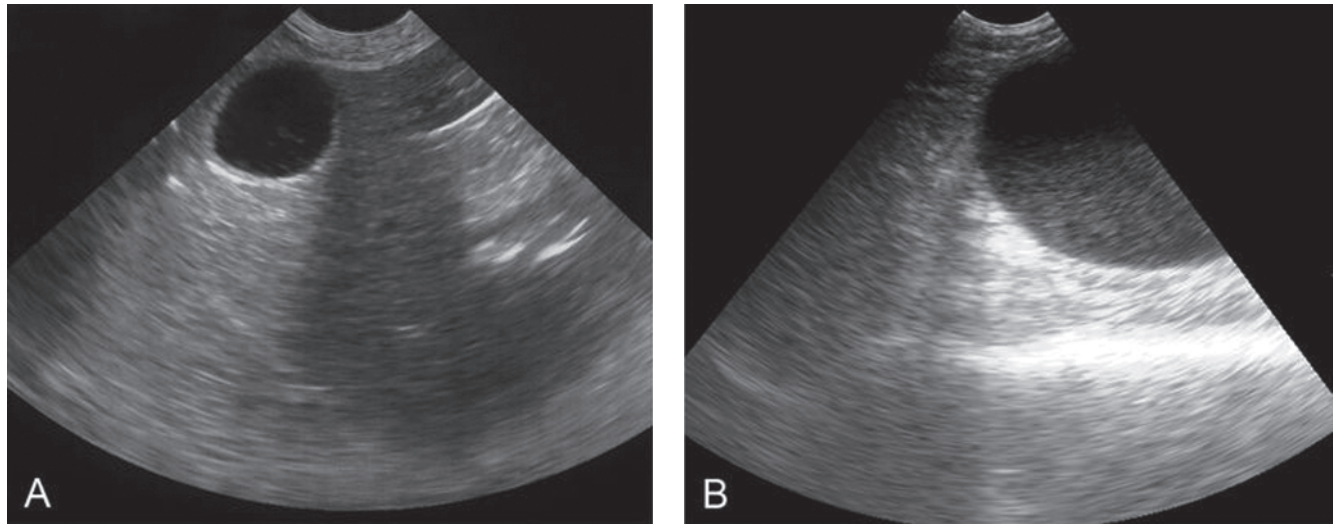


Figure 1.6. Acoustic enhancement artifact. Because there is less attenuation when sound moves through liquid, the area distal to a fluid-filled structure will appear hyperechoic (brighter or whiter) to the surrounding tissue. Note the hyperechoic region distal to the gallbladder (A) and distal to the urinary bladder (B).

fluid-filled (brighter through the far field having acoustic enhancement) or soft tissue (lacking acoustic enhancement) (Penninck 2002) (Figure 1.6).

Artifacts of Velocity or Propagation

Mirror Artifacts (Strong Reflector [Air])

When we image a structure that is close to a curved, strong reflector such as the diaphragm (actually the lung-air interface following the curve of the diaphragm), a sound beam can reflect off the curved surface, strike adjacent tissues, reflect back to the curved surface, and then reflect back to the transducer. Because the processor only uses the time it takes for the beam to return home and cannot "see" the ongoing reflections, it will be fooled into placing (mirroring) the image on the far side of the curved surface. The classic place for a mirror artifact is at the diaphragm, and the classic mistake is interpreting the artifact as a diaphragmatic hernia (Penninck 2002) (Figure 1.7).

Reverberation or A-Lines (Strong Reflector [Air])

Reverberation occurs when sound encounters two highly reflective layers. The sound is bounced back and forth between the two layers before traveling back. The probe will detect a prolonged traveling time and assume a longer traveling distance and display additional reverberated images in a deeper tissue layer. The reverberations can get caught in an endless loop and extend all the way to the bottom of the screen as parallel equidistant

lines, referred to as A-lines (also see chapters 9 and 10). This artifact most commonly extends beyond air-filled structures within the thorax (e.g., lung) and within the abdomen (e.g., gastrointestinal tract), with varying width (Penninck 2002) (Figures 1.8A, Figure 1.5A).

Comet-Tail or Ring-Down Artifact (Strong Reflector [Usually Metal or Bone but Can Be Air])

A comet-tail artifact, also called a ring-down artifact, is similar to reverberation. It is produced by the front and back of very strong reflectors with high acoustic impedance, such as metallic foreign bodies or implants, needles, and stylets during US-guided procedures (chapters 12 and 17), or strong reflectors with very low acoustic impedance, relative to their adjacent soft tissues, such as gas in the lung, gas bubbles, or gas in the bowel. The reverberations are spaced very narrowly and blend into a small band. The greater the difference between the acoustic impedance of the reflecting structure and the surrounding tissues, the greater the number of reverberation echoes (Reef 1998) (Figure 1.8B).

Ultrasound Lung Rockets or B-Lines (Air Immediately Next to Water)

Ultrasound lung rockets (ULRs), more recently termed B-lines (Volpicelli 2012), are vertical, narrow-based lines arising from the near field's pulmonary-pleural line, extending to the far edge of the ultrasound screen, always obliterating A-lines, and moving "to and fro" in concert with inspiration and expiration. Although ULRs

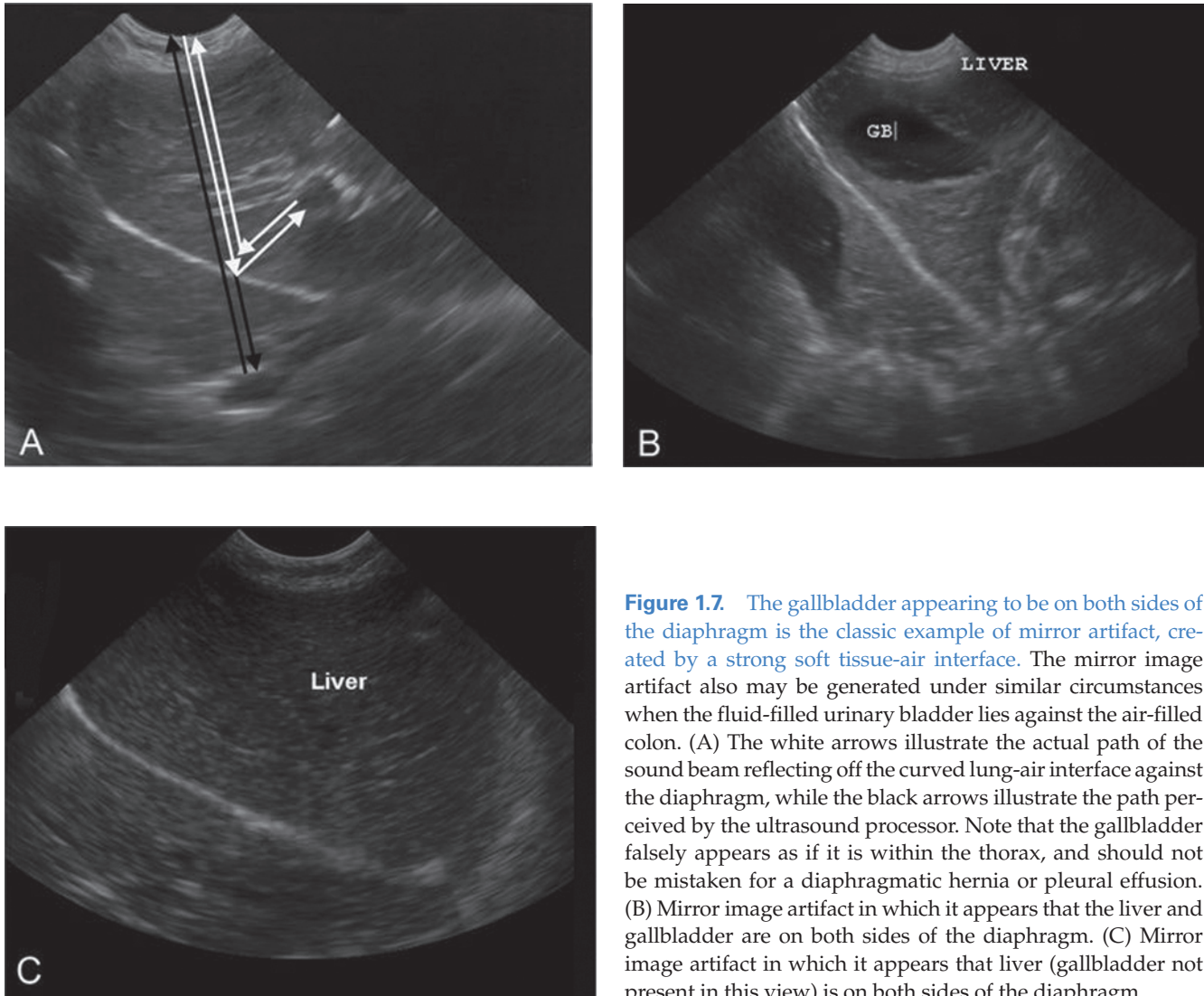


Figure 1.7. The gallbladder appearing to be on both sides of the diaphragm is the classic example of mirror artifact, created by a strong soft tissue-air interface. The mirror image artifact also may be generated under similar circumstances when the fluid-filled urinary bladder lies against the air-filled colon. (A) The white arrows illustrate the actual path of the sound beam reflecting off the curved lung-air interface against the diaphragm, while the black arrows illustrate the path perceived by the ultrasound processor. Note that the gallbladder falsely appears as if it is within the thorax, and should not be mistaken for a diaphragmatic hernia or pleural effusion. (B) Mirror image artifact in which it appears that the liver and gallbladder are on both sides of the diaphragm. (C) Mirror image artifact in which it appears that liver (gallbladder not present in this view) is on both sides of the diaphragm.

are similar to comet-tail artifacts, they are specifically created by the strong impedance of air adjacent to a small amount of water, and are the ultrasound near equivalent of radiographic Kerley B lines (representing interlobar edema). Their clinical relevance is very important and explained later (chapters 9 and 10) (Lichtenstein 2008, 2009, Lisciandro 2011, Volpicelli 2012) (Figure 1.9).

Artifacts of Multiple Echoes

Side-Lobe Artifact

We like to think of the ultrasound beam as extending from the probe in a very thin fan or rectangle, and this is exactly what the processor thinks it sees. In reality, there are smaller beams that travel laterally to the main beam. When one of these smaller side beams is of sufficient strength and bounces off a highly reflective

surface, such as the wall of the urinary bladder, it will be interpreted as coming from the main beam and the processor will place the resulting image within the bladder, mimicking sediment. The resulting image is usually weaker in intensity than the main image. It is possible that the artifact can be altered by changing probes or dropping the focal point, or that it will disappear with lower gain settings—all things that will not happen with true pathology (i.e., bladder sediment, bladder stones, etc.) (Penninck 2002) (Figure 1.10).

Slice-Thickness Artifact

Slice-thickness artifact is somewhat similar to the side-lobe artifact. Particularly in the gallbladder and urinary bladder, this artifact mimics sludge or sediment. It occurs when part of the beam's thickness lies just outside of a fluid-filled structure. These artifacts

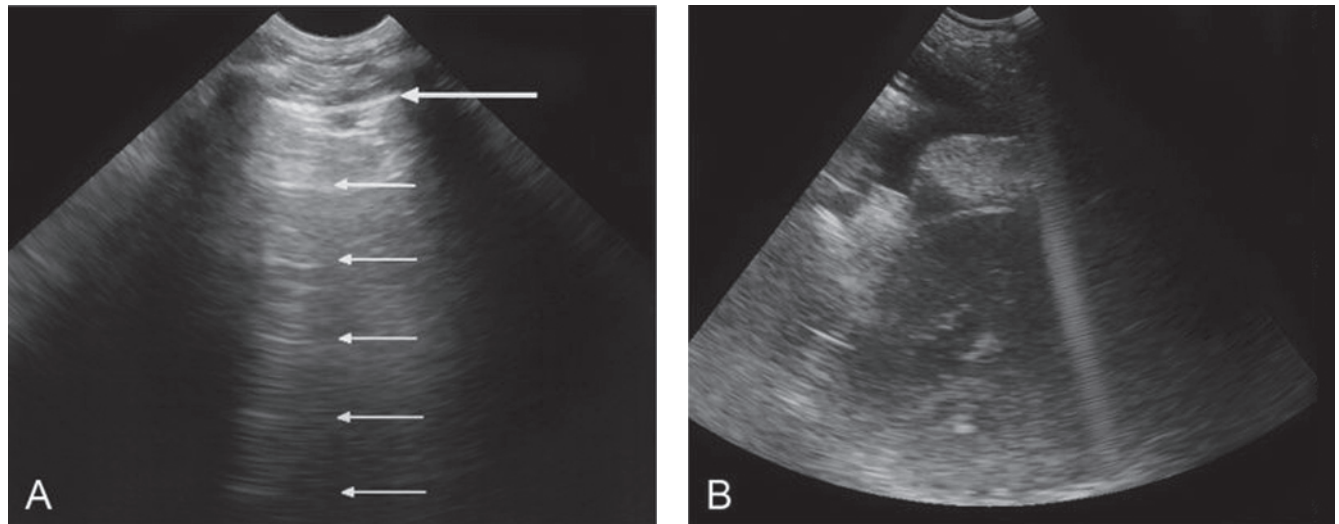


Figure 1.8. Reverberation artifacts of strong reflectors, A-lines, comet-tail, and ring-down artifacts. (A) A reverberation artifact, also known as A-lines (think of it as “A” for air), is seen as regularly spaced parallel lines illustrated by the small white arrows. The larger arrow in the near field denotes the lung’s pleural surface, evident in the intercostal space between two ribs [bone] creating the clean shadowing through the far field. (B) The very tight and distinct reverberation artifact, referred to as a comet-tail or ring-down artifact, is caused by sound waves reflecting off a metal needle used during abdominocentesis. Any strong reflector of US waves produces this artifact; this typically involves bone, stone, or metal, such as implants, needles, and foreign bodies.

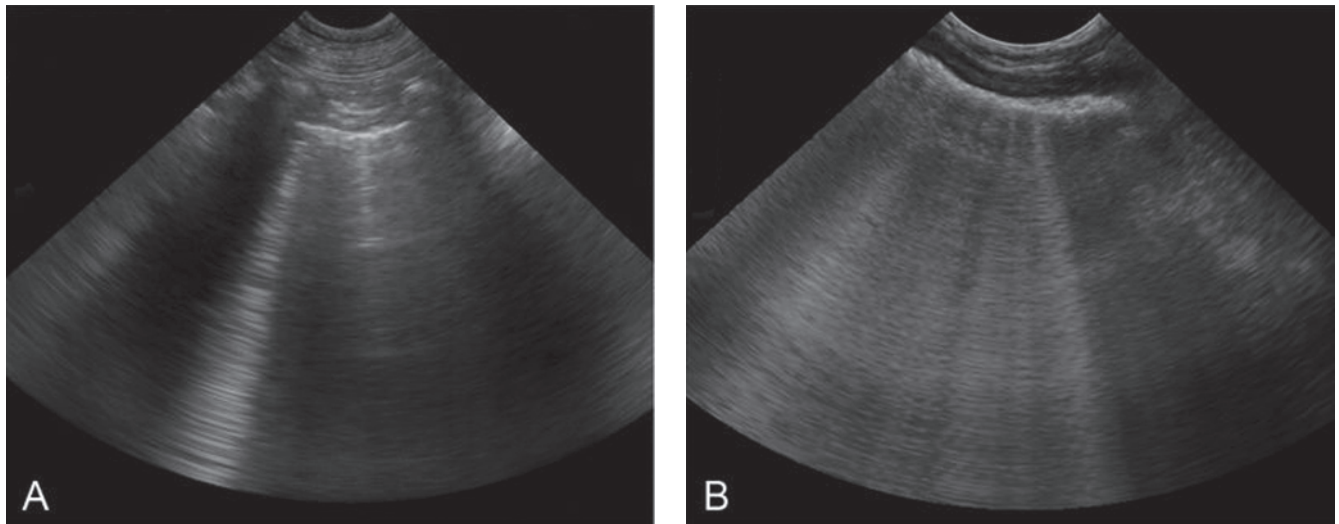


Figure 1.9. Recently the nomenclature for this lung ultrasound artifact has been changed from comet-tail artifact to ultrasound lung rockets (URLs), also called B-lines. URLRs are generated from the lung’s most outer (1- to 3-mm) pleural surface when a small amount of interstitial fluid (e.g., water) is immediately next to air. The ULR artifact begins at the lung’s pleural surface and continues without loss of intensity through the far field of the image as a hyperechoic (bright white) streak that obliterates A-lines. In real-time, ULRs must oscillate with the to-and-fro motion of inspiration and expiration. (A) Single ULR. (B) Multiple ULRs. Courtesy of Dr. Greg Lisciandro, Hill Country Veterinary Specialists, San Antonio, Texas.

typically appear within the lumen of these structures and are somewhat hyperechoic (bright) and curved. They can be differentiated from real sediment by several methods or clues. First, gravity dependent sediments have a flat surface, whereas the artifact will be rounded. Second, by changing the position of the

patient, the relative position of true sediment will change as gravity pulls it to the new lower point. Third, the sonographer can use the US probe to ballot the bladder and stir the sediment up a bit; the artifact will not yield a “snow globe” effect (sediment will) (Penninck 2002) (Figure 1.10).

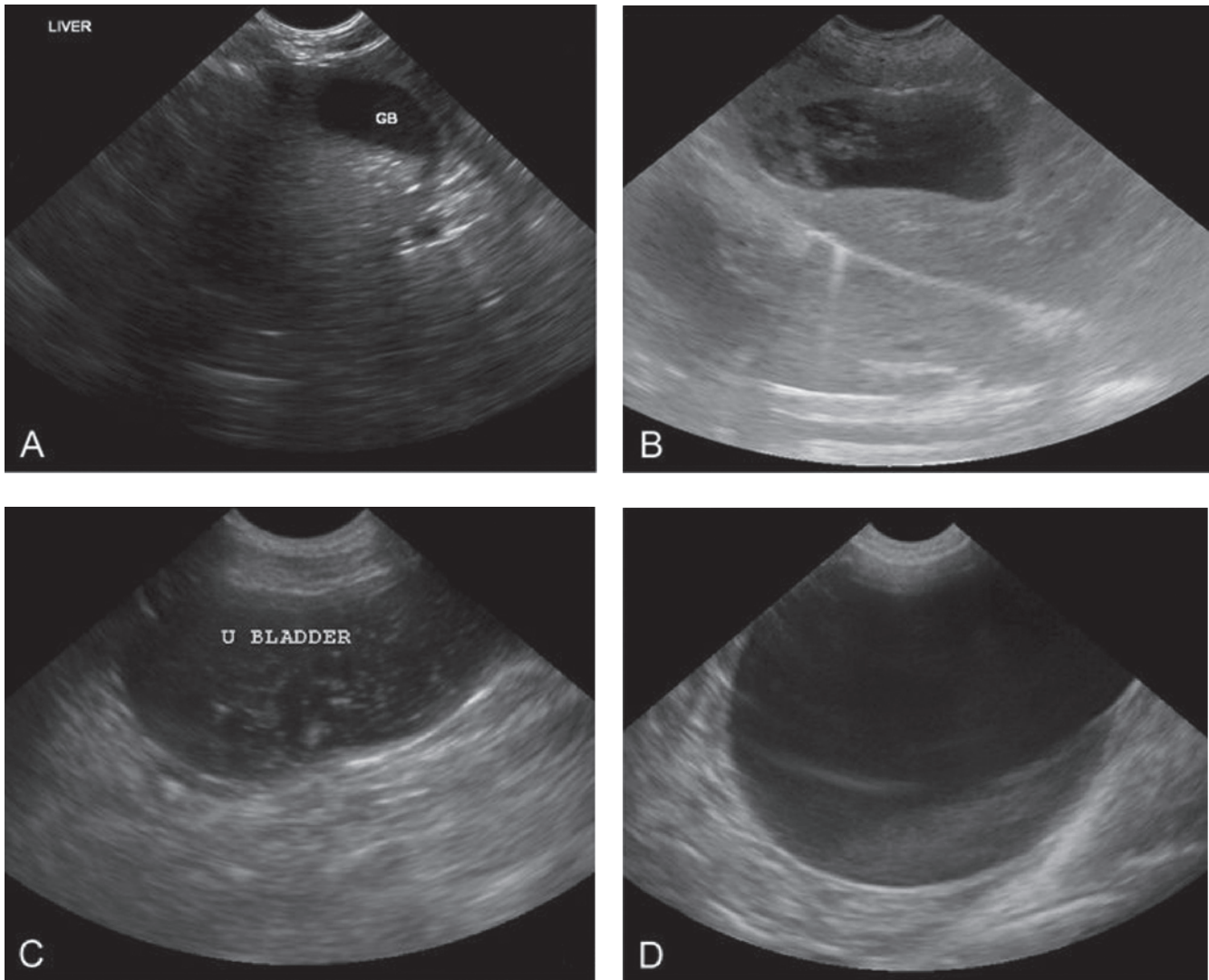


Figure 1.10. Sediment vs. side-lobe and slice-thickness artifact. (A) Sediment is affected by gravity and leads to a flat surface, as seen with the sludge within this gallbladder's lumen. True sediment can be stirred up by repositioning the patient or through ballottement with the ultrasound probe, whereas artifacts mimicking sediment cannot. (B) Slice-thickness and side-lobe artifacts mimic sediment in the gallbladder shown here; however, the artifact will not be altered by moving the patient's position or by ballottement. (C) True sediment in a urinary bladder with ballottement gives a snow globe appearance. (D) In contrast, the slice-thickness and side-lobe artifacts mimicking sediment shown here will fail to ballot (will not give the snow globe effect) or change position to the gravity dependent side of the urinary bladder when the patient is moved. Other helpful tricks that discriminate true sediment from artifact include lowering the gain and/or moving the focus cursor. Generally speaking, artifacts can be eliminated by these maneuvers, but true sediment cannot.

Basic Scanning

Image Orientation

Any part of a medical record must contain the essentials of basic medical communication to have value. As veterinarians, we are taught how to communicate with each other in such a way that regardless of our individual personality and training, one veterinarian can describe a lesion to another half a world

away and pass along vital information. Ultrasound exams likewise need to have standard image orientation and recording of findings to give the study meaning.

For standard plain radiography, the lateral film is oriented with the patient's head to the left, and the spine is dorsum and at the top of the viewer. This is the same for either a right or left lateral image. For the

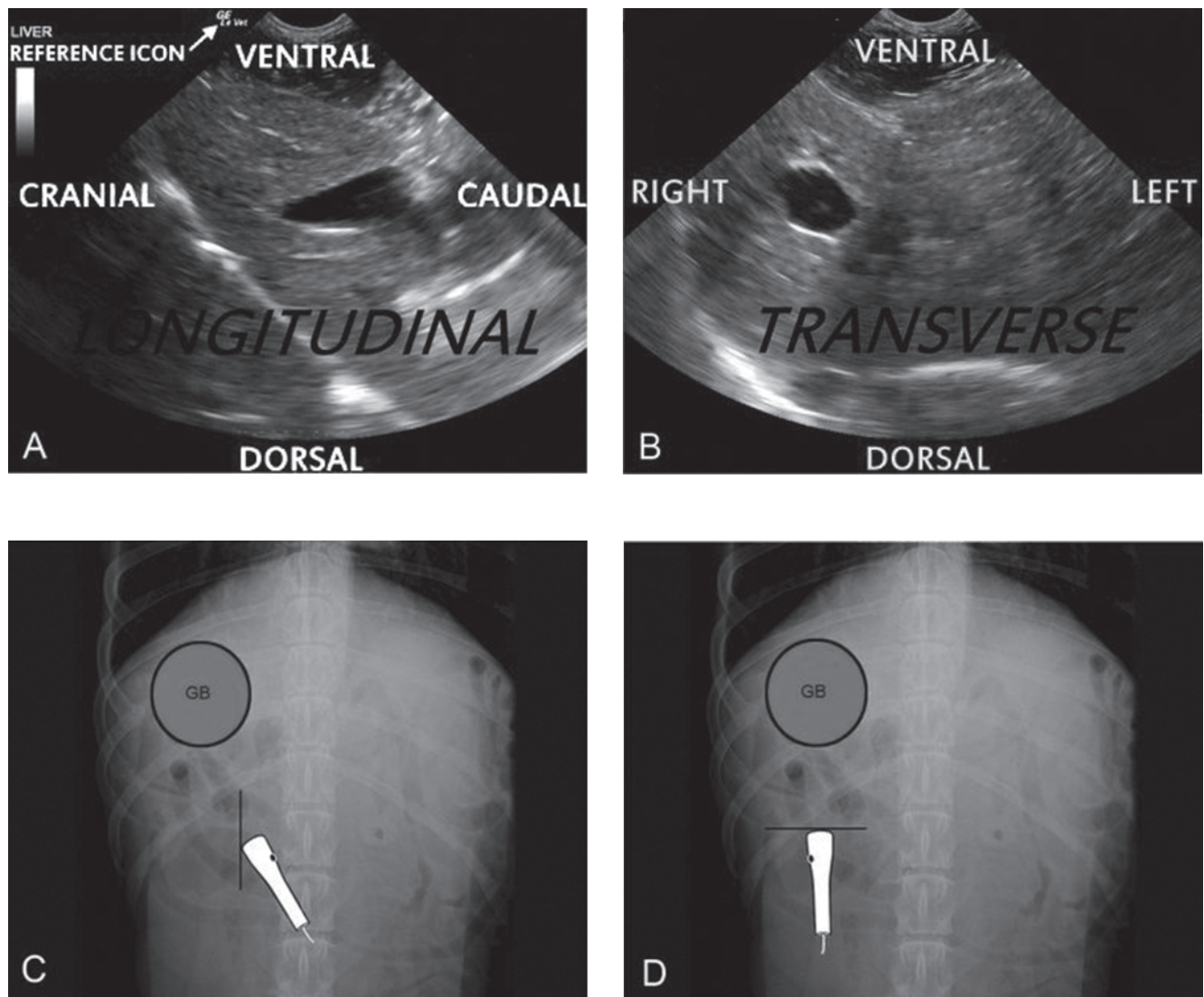


Figure 1.11. Standard ultrasound screen orientation, longitudinal (sagittal) and transverse. The radiograph for each orientation is located below the respective ultrasound image. Figures (A) and (C) illustrate longitudinal (or sagittal) and (B) and (D) transverse orientation with the corresponding probe position during interrogation of the liver and gallbladder via the subxiphoid region of a dog. Note that the reference icon (GE_{Le}) corresponds with the probe reference marker (dot on the probe) with the GE_{Le} reference icon (labeled with arrow in (A) to the left on the US image). The best way to make standard ultrasound imaging a habit is to have the probe marker toward the head for longitudinal (or sagittal) orientation (black dot on the probe in (C) and turn (the probe head) left or counterclockwise for transverse orientation (black dot on the probe in (D) with the reference icon (in this case the GE_{Le}) to the screen's left (shown at the top of the US image in (A) and (B)). If your reference icon is to the right of the US image, most US machines have a "reverse" button feature on their keyboard to flip the reference icon back to the standard left side (with the exception of echocardiography orientation; see Chapter 11).

ventrodorsal or the dorsoventral view, the radiograph is positioned with the head pointed up, and the patient's right side toward the left-hand side of the view box.

Ultrasound follows similar convention. When we scan from the ventral aspect (as when the patient is in dorsal recumbency), the following orientations applies:

Longitudinal image: The ventrum is on the top of the screen, dorsum on the bottom. Cranial is to the left, and caudal is to the right (Figure 1.11A).

Transverse image: Ventral and dorsal remain top and bottom, respectively, and the patient's right side is represented on the left side of the screen, and the patient's left side is represented on the right side of the screen (Figure 1.11B).

This US image orientation convention is the most intuitive if the patient is positioned in dorsal recumbency with its head facing the same way the sonographer is facing (toward the machine). Many emergent patients are not stable enough to be placed in dorsal recumbency and all FAST³ scans actually prescribe lateral or sternal recumbency, so the sonographer may need to do a little mental gymnastics at times to orient the image on the screen with the patient.

When scanning from the lateral aspect of the patient (i.e., in a dorsal plane), the following convention applies:

Longitudinal image: Non-recumbent side is on top of the screen, recumbent side is on the bottom. Cranial is to the left side of the screen, and caudal is to the right (Figure 1.11A).

Transverse image: Non-recumbent side is still on top of the screen, recumbent side still on screen's bottom. Ventral is on the left, dorsal is on the right (Figure 1.11B).

Develop the habit of having the marker toward the patient's head (longitudinal imaging) and turning left for transverse imaging to maintain proper orientation etiquette.

All US probes have a reference mark to allow for proper orientation. The marker may be a raised dot or line molded into the plastic, or possibly a small LED light. On the image screen, there will be a symbol (often the company's logo) that corresponds with the probe's reference mark. The marker on the screen is commonly referred to as the "reference icon" (Figure 1.11). Sonographers should familiarize themselves with the various types of US probes—phase array, linear, and curvilinear—and know that by looking at the shape of the US image the probe is readily apparent—pie-shaped pointed near field (phase array or sector), rectangular (linear), and pie-shaped with curved concave near field (curvilinear) (Figure 1.12).

Most veterinarians are taught that when scanning the abdomen in long-axis, the probe's reference mark is pointed toward the patient's head. Therefore, by convention, the reference icon on the screen will also be positioned on the left side of the screen (left=cranial, right=caudal). When the probe is turned into the transverse orientation, the reference mark is pointed toward the patient's right, making a counterclockwise

motion ("turning left") if one views the probe from its tail, or cable, end (left=right side of patient, right=left side of patient).

Cardiac Orientation

See chapters 9 (TFAST³) and 11 (focused ECHO) for information on cardiac orientation.

Deciding on an Ultrasound Machine

Selecting the Machine

There are three main types of US machines: consoles, portables, and handhelds. The console machines are big and bulky, but they have stronger processors and thus give a better image. The portables, often laptop format, are easy to move to the exam table or cageside and their image quality is constantly improving. There are several small handheld machines now on the market. Some have pretty decent depth and resolution capabilities. Just make sure they don't walk out of your clinic. It's very easy to put these in a lab jacket pocket and forget about them.

You may be limited to whatever you currently have in your veterinary practice, but if you are thinking of buying a new unit, consider what your main use is going to be, and get the best US machine you can afford for that purpose. The axiom holds true—the better the machine, the better the image, and the better the diagnostic information.

Selecting the Probe

Probes, or transducers, come in two basic types, mechanical and electronic. Mechanical probes are by many accounts considered outdated but there are still some around with their working parts visibly rotating or rocking under their translucent covers. Newer ultrasounds come standard with electronic probes. Electronic probes come in various arrangements. Probes are generally described by the size and shape of their face, referred to as their "footprint," which is represented by the gray rubber probe covering (Figure 1.12A). Selecting the right probe is essential to getting good images, although there may be times when more than one probe may be appropriate for a given exam.

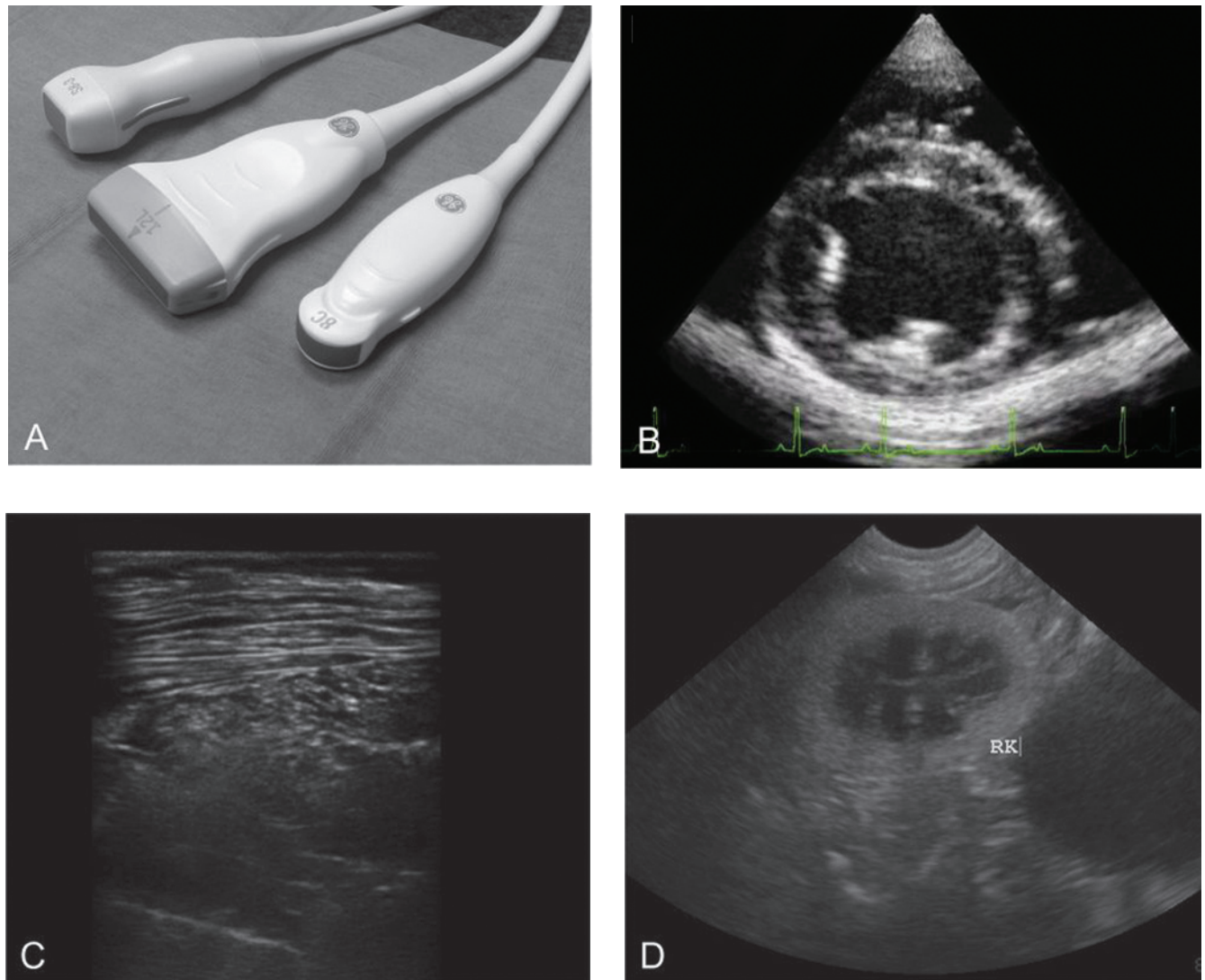


Figure 1.12. Electronic ultrasound probes and their characteristic B-mode images. The probe used for the US image is easily recognized by the US image's shape. (A) Ultrasound probes, from left to right: phased-array (also known as sector), linear, and curvilinear (also referred to as microconvex). A molded reference marker can be seen on all three of these probes. Other probes may use an LED light as the reference marker. The rubber probe heads (gray) represent the "footprint" or contact surface of each probe. (B) The phased-array probe US image is pie-shaped with a near field "point." Phased-array is ideal for echocardiography because it best avoids ribs (note no rib shadow). (C) Linear probe US image with its rectangular shape. Linear is superior in detail because it sends and receives US waves 90 degrees to structure(s) of interest. (D) Curvilinear probe US image is pie-shaped but wide and concave in the near field. Curvilinear (microconvex) is most commonly used by non-radiologist veterinarians because of its versatility.

Three basic types of probes are used in general practice, emergency, and critical care point-of-care ultrasound: linear, curvilinear, and phased-array (also known as sector) (Figure 1.12A). Linear probes are typically of higher frequency and have a rectangular footprint (Figures 1.12A and C). Curvilinear probes are arranged along a convex face and are typically of lower

frequency than the linear probes. A phased-array (sector) probe generates an image from an electronically steered beam in a close array, generating an image that comes from a point and is good for getting between ribs, such as in cardiac ultrasound (Figures 1.12A and B). Both curvilinear and phased-array probes generate sector or pie-shaped images, narrow in the near field

and wide in the far field (Figures 1.12A and D). Phased-array probes are typically lower frequency. Because of their smaller footprint, pie-shaped image, and common frequencies, the curvilinear probes are generally the most versatile and ideal for the focused, COAST³, and FAST³ studies.

Probes are generally named for the primary frequency they emit. For example, a General Electric (GE) 8C probe indicates that 8MHz is its primary frequency and the C represents the probe's curvilinear footprint. Moreover, a GE 9L probe indicates a 9MHz primary frequency in a linear (L) probe, and a GE 7S as having 7MHz as its primary frequency in a sector (S) probe. However, modern probes are capable of emitting a range of frequencies known as bandwidth. In choosing the best frequency, we need to go back to the basics. Remember that higher frequencies are attenuated more, and that means less penetration but better detail. Lower frequencies are attenuated less, and that means deeper penetration but less detail.

For the focused, COAST³, and FAST³ ultrasound scans, begin with an intermediate setting of 8MHz as a general rule of thumb. That being said, most chapters in this textbook provide probe frequency recommendations.

Image Optimization Using the Big 4 Knobs

For an US image to have meaning, it must have adequate detail. The best rule of thumb is that the image should simply look "nice." Pretty or nice may be a little different from one person to another, but they should all be fairly similar. There are numerous buttons and knobs that can be used improve, or worsen, the image. The Big 4 are depth, gain, frequency, and focus position and number.

Know the "Big 4" knobs: depth, gain, frequency, and focus position and number.

Depth

When reviewing a radiograph, the clinician can become narrow-sighted by focusing on one area and not looking at the rest of the film. With US, however, the goal is to focus on one area. Adjust the depth to the area of interest. Filling up the screen with the area of interest will result in a better diagnostic US image.

Gain

Gain is the overall brightness of the image. The ideal is not too bright and not too dark. The gain knob is the one knob that will adjust the overall setting. After first setting the overall gain, minimize dark or light bands across the screen by using the time gain compensation (TGC) knobs. These are usually sliders that adjust brightness along discrete bands across the image. The goal is to have a consistent brightness from top to bottom of the screen.

Frequency

Find a happy medium between penetration and resolution. Use the highest frequency (MHz) you can get away with and still see as deeply as needed.

Focal Position and Number

The US beam has a focus position where the beams narrow to give a more detailed image at a certain depth. The beams do not converge, as we may think of light focusing on the retina, because they will again diverge beyond the focal position. The physics of this can be found in additional references (Nyland 2002). Both the focus position and number of focal points can be set by the sonographer. However, the processor can only handle a certain amount of information and by asking it to do more, it will reduce other items, normally the frame rate, or how many times/second the image is refreshed. High frame rates make for a smooth image, but take a lot of processing power. Low frame rates give a choppy image. Ask the processor to do more and it will respond by giving you a lower frame rate.

For the focused, COAST³, and FAST³ scans, generally keep the focal point number at one, and set the focal point's position at, or just deep to, the area of interest.

Presets, Abdominal, Cardiac, Small Parts, etc.

Even with just these four settings, that's still a lot of knobs to be adjusting in the emergent situation. Modern US machines have a collection of imaging presets which the user may select based upon the area of interest (such as cardiac vs. abdomen vs. small parts and others) and patient size (adult vs. pediatric). It is prudent to remember, however, to adjust your depth.

Alternate Imaging Tools

Up until now, we have been talking about B-mode, or standard 2-dimensional, ultrasonography. A-mode has no practical bearing on the emergency scans outlined in this book and therefore will not be discussed. However, M-mode and color Doppler imaging are used in some focused, COAST³, and FAST³ protocols (see chapters 8 and 11).

M-mode

The "M" in M-mode stands for motion. This mode has also been called the "ice pick" mode because it reflects a small column of US waves but follows it over time. Cardiac US is where M-mode is best known. It can be a little challenging to understand what is being displayed on the screen, but using the B-mode view to show just where that "ice pick" is cutting through is helpful. M-Mode is used not only for certain cardiac studies, but also in certain lung studies and fetal imaging (see chapters 8, 10, and 11).

Color Flow Doppler

Color flow Doppler is used in combination with B-mode ultrasonography. It allows you to see flow of blood within a vessel and helps to determine the direction of that flow. Doppler is best when the flow is parallel with the sound beam. Color signatures are usually set up so that flow toward the probe is red and flow away from the probe is blue, although this can be set on most machines to user preference. Color flow Doppler has its limitations with low velocities.

Color signatures are usually set up so that flow toward the probe is red and flow away from the probe is blue (remember "away" and "blue" have the same number of letters). An alternate form of color flow Doppler, called power Doppler imaging (PDI), can be employed. Similar to color flow, this shows flow of fluid but at much lower velocities. The trade-off is a lack of directionality. Blood flowing 0.5 cm/s away from the probe will have the same color signature as blood flowing at 0.5 cm/s toward the probe.

On The Horizon

Single Crystal Probes

Single crystal probes emit a large bandwidth of sound beams instead of just one, thereby combining the benefits of high-frequency resolution and low-frequency

penetration. The learning curve for imaging is generally much different than that of traditional multicrystal US probes.

Smartphone Applications

At the time of this writing, there is at least one smartphone-powered US device approved by the U.S. Food and Drug Administration (FDA). Technology is advancing quickly and one must wonder what the future holds for US imaging.

Recording Ultrasonographic Findings, Labeling Still Images

Documentation of the Focused, COAST³ and FAST³ Ultrasound Exam

Save the images. A medical record is not complete with just a written description of an image, whether that is a radiograph, an ultrasound image, a computerized tomography (CT), or magnetic resonance imaging (MRI). The image must be there to back it up. Furthermore, the other modalities have information to know exactly where an image was obtained. For the radiograph there are anatomic landmarks; for both CT and MRI, there is a pilot image that records where all the remaining images are obtained. For US images there may not be any definitive markers.

An US image that makes sense to the sonographer when it was recorded may make no sense when under review two days or even two hours later. One of the most common mistakes veterinarians make is not labeling their images. Label the organ or structure of interest and label your orientation (longitudinal vs. transverse) if it is not evident from the image. There will be times when there are no anatomic landmarks evident on the image.

Most US machines have some sort of body pattern that can be placed on the image with an icon to show the approximate location of the probe (Figure 1.4A). Put all labels outside the image, too. Placing words across the image can potentially hide diagnostic information. If you must write across the US image, first save a picture of the unadulterated image and then save a second picture of the annotated image. Short video clips can also be saved on most US machines.

For recording US findings in medical records, see Appendix II with suggested goal-driven templates.

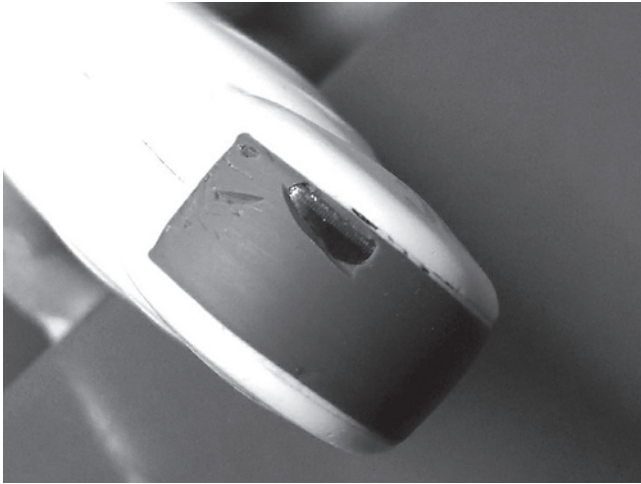


Figure 1.13. The damage to the surface of this probe was attributed to repeated or prolonged contact with isopropyl alcohol. The contact layer is clearly lost over a portion of this probe, negating its ability to serve as an electrical insulator between the probe and patient. It is possible for potentially serious electric shock to occur through the damaged area to the contact area.

Ultrasound Machine and Probe Care

Not all US machines were designed for the battlefield with parts that can sustain a six-foot drop. Most were designed for the relative quiet and safety of a hospital. The US machines and their components can be broken by rough handling and improper use, and replacement can be costly, especially if you drop an US probe and damage its crystals.

The most common misuse of the US machine is probe abuse resulting in probe head damage (Figure 1.13). In the haste of the moment, the attending sonographer will often grab a bottle of isopropyl alcohol, wet down the fur with only the alcohol, and apply the probe. Nearly all US manufacturers list alcohol as an inappropriate liquid to place in direct contact with the probe head because alcohol, over time, can cause probe head damage (Figure 1.13).

Always use acoustic coupling gel on the probe head and be familiar with the US machine's manufacturer guidelines. Importantly, it should be noted that the rubber probe head accomplishes two things. First, it acts as coupling media to transmit the sound wave out of the probe. Second, it is part of an electrical insulator serving as an electrical ground between the patient and the electricity being sent from the US machine to the transducer's crystals. There are no documented electrocutions via a damaged US probe, but theoretically, it's possible.

Avoid probe head damage by using an acoustic coupling media on the probe head as a barrier to alcohol.

Setting up an Ultrasound Program

See Appendix I for information on setting up an ultrasound program.

Pearls and Pitfalls, the Final Say

In summary, this chapter has briefly covered some of the basics. Other textbooks are available that go into more detail regarding US principles and artifacts, and many US courses sponsored by ultrasound companies are available throughout the year to enhance learning (see Appendix V). Also see the editor's website: www.fastvet.com. It is important to be familiar with some of the basic principles, artifacts, and nuances associated with US as an imaging modality for your busy general practice, emergency room, or critical care unit to minimize misinterpretations. It truly is an "extension of the physical examination" and "the modern stethoscope" (Rozycki 2001, Filly 1988).

So there you have it. Turn on your ultrasound machine, apply your coupling medium, and start scanning. Get focused and save lives.

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