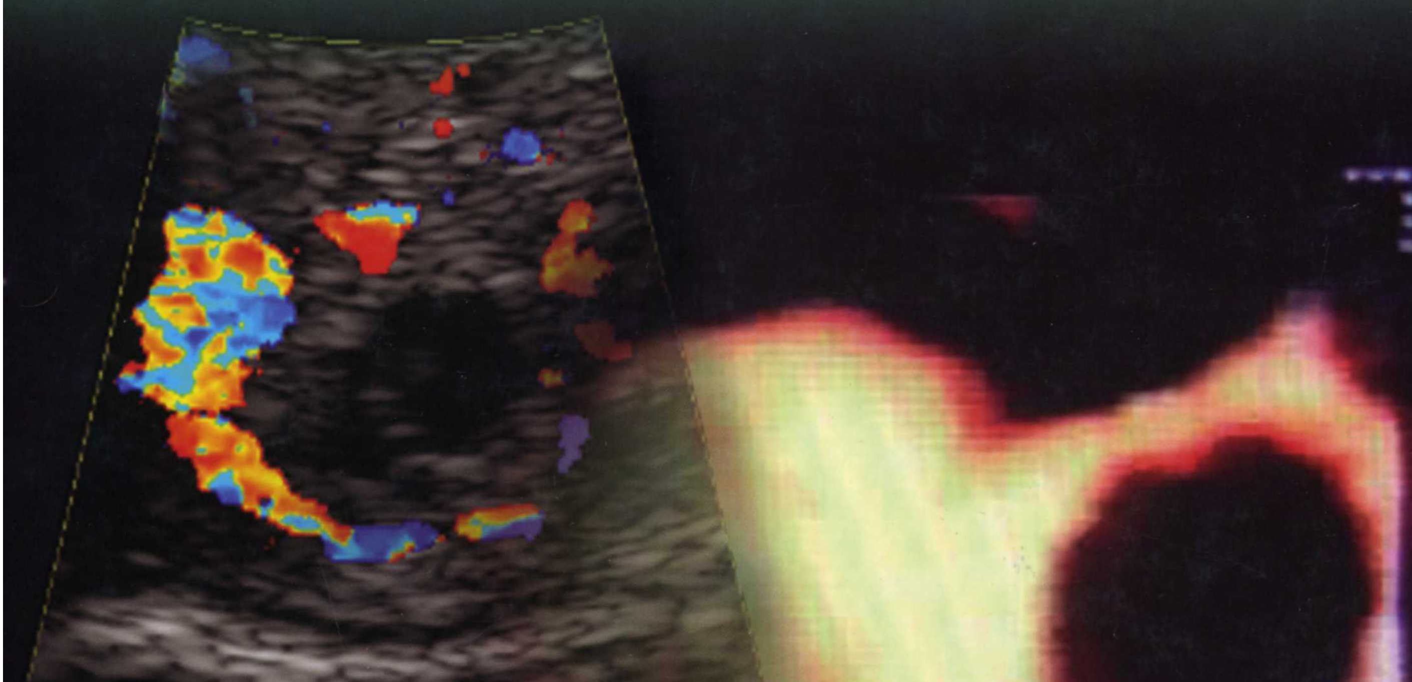
Practical Guide to
EMERGENCY ULTRASOUND



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Fundamentals of Ultrasound

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Introduction

Any textbook on ultrasound has a chapter entitled "Physics," or "Knobology" as it is euphemistically known. In this practical guide to ultrasound, it is important that the fundamentals of ultrasound transmission and image production be covered, because bedside ultrasound is one of the few technologies in clinical practice where the provider both acquires and interprets the image. One must understand the pitfalls and techniques in image acquisition to accurately use ultrasound. This chapter will review the basics of ultrasound transmission, cover the basics of ultrasound equipment, and review basic principles of image acquisition.

Ultrasound Physics

One of the first principles one must understand is that medical ultrasound uses sound energy. Therefore, all of the laws that govern sound transmission apply when using ultrasound. Basic fundamentals of physics can be used to understand and optimize scanning technique. Sound is measured in Hertz (Hz) with human hearing detecting sound in the frequency range of 20 Hz to 20,000 Hz. Diagnostic ultrasound is in the frequency range of 2.5 MHz to 12 MHz. Although ultrasound is well outside the range of human hearing, it behaves no differently than any other sound wave and is subject to all of the effects of mechanical energy.

As sound waves travel through a medium, they cause molecules to vibrate. The molecules vibrate at a given frequency depending on the frequency of the sound. The sound wave then propagates through the medium (tissue) at that frequency. The frequency of these wavelengths determines how they penetrate tissue and affect image detail. The energy of a sound wave is affected by many factors. The spatial pulse length (SPL) is the basic unit of imaging. The SPL is a sound wave packet that is emitted from the transducer. Much like sonar, where the sound wave is sent out at a given frequency and then bounces off an object to localize it, diagnostic ultrasound can use sound waves to generate an anatomic picture. In essence, the sound waves "interrogate" the tissues to create an image. By adjusting various parameters of the sound wave and its production, the ultrasound wave can be used to relay information.

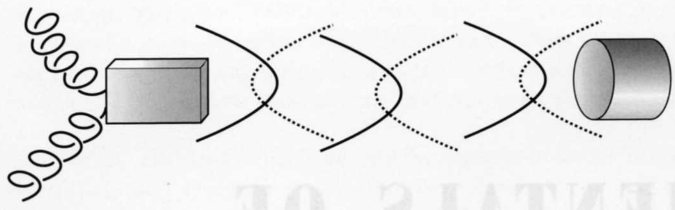


Figure 3.1. *Piezoelectric effect.* Notice that if a current is applied to the crystal on the left a signal is generated. As sound waves return and hit the crystal it will vibrate and generate a current.

The working component of any ultrasound machine that generates the sound wave is the piezoelectric element. Piezoelectric elements are unique crystals that vibrate at a given frequency when alternating current is applied. Similarly, if an ultrasonic wave hits a piezoelectric crystal, it will vibrate and generate an electric current across the dipole (Fig. 3.1). The unique aspects of these crystals enable them to be both a speaker and a microphone. In medical ultrasound, piezoelectric crystals are placed in a sealed container, called a transducer, that comes in contact with the patient to generate an ultrasound image.

Impedance

Once a sound wave leaves the transducer, the work begins. As the sound wave travels through tissue, several things occur that affect the generation of an image. As a sound wave travels through a medium of one density and crosses into a medium of another density, it encounters impedance at the interface between the two media. Impedance is the resistance to propagation of sound. Reflection of the sound occurs at this interface (Fig. 3.2). The amount of reflection is proportional to the difference in the acoustic impedance between the two media. In general, objects that have very high acoustic impedance, such as bone, reflect much of the signal. In contrast, liquid has much lower impedance and therefore, reflects very little. Liver has moderate impedance, so a portion of the sound is reflected back to the transducer and the remainder is transmitted to deeper structures. An image is generated from the signal that is reflected back to the transducer. If the body had only one uniform density with tissues of similar or identical impedance, then no image could be generated because no reflection would occur. The fact that different tissues have differing impedance allows detailed imaging by ultrasound. For tissue with greater impedance, the reflected signal that returns to the transducer is greater and therefore produces a brighter (more echogenic) image on the monitor. For tissues with lower impedance, more of the signal continues unchanged and less is returned, generating less of a reflected signal and creating a darker, grayer image. If no reflection occurs, a black (echo-free) image is seen on the monitor.

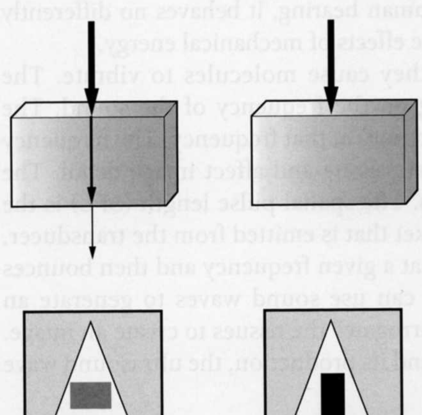


Figure 3.2. *Impedance.* The illustration on the left demonstrates that as the sound waves hit an object, impedance causes some signal to return to the transducer and some to continue. The continuing signal is attenuated. The amount of reflected signal depends on the impedance of the object. In the illustration on the right, if the object is very dense, the entire signal is attenuated and there is acoustic silence or an anechoic signal on the monitor. The top images illustrate a sound wave striking an object. The bottom figures illustrate the image generated on the monitor.

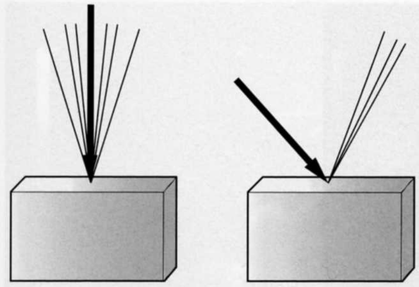


Figure 3.3. Perpendicular scanning. The figure on the left demonstrates good perpendicular scanning. The entire signal is returning to the transducer. The signal on the right is hitting the object of interest at an angle causing poor signal return, resulting in a less sharp image.

Attenuation

Attenuation is the loss of signal energy as it passes through tissue. Higher impedance generally causes more attenuation. Attenuation is partly a function of the intrinsic impedance of the tissues; it is also affected by scanning technique. Only sound that returns to the transducer produces an image. The initial sound signal sent out from the transducer can be returned as an echo and register as a signal; however, some sound waves may be reflected away from the transducer (scatter). Scatter can by caused by a variety of factors. Gas, skin density, and scanning angle all contribute to scatter. To help minimize scatter, it is important to keep the ultrasound beam as perpendicular as possible to the object of interest (Fig. 3.3). Scanning at an angle can cause sound to bounce off an object and not return to the transducer. You will notice that when you scan at a more acute angle, the image appears less sharp. The more perpendicular to the object of interest the beam is, the sharper the image. *It is very important that you try to scan perpendicular to the object of interest to optimize the ultrasound image.*

Resolution

"Resolution" refers to the ability of the sound waves to discriminate between two different objects and generate a separate image for each. There are two types of resolution. "Axial resolution" is the ability to resolve objects that are parallel to the ultrasound beam (Fig. 3.4A). The size of the wavelength is the major determinant of axial resolution. High frequency wavelengths are better able to resolve objects close together and provide good axial resolution. High frequency waves, though, are more subject to attenuation and therefore lack tissue penetration. Lower frequency signals have lower axial resolution, but deeper tissue penetration. The second type of resolution is lateral resolution. Lateral

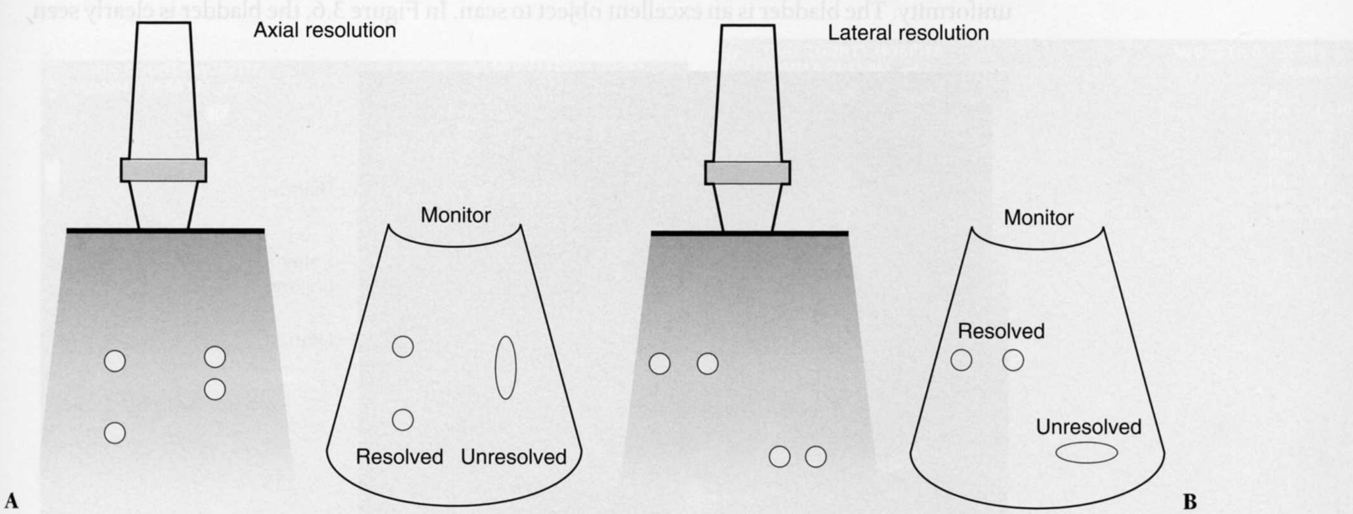


Figure 3.4. Resolution. Examples of axial and lateral resolution. Axial resolution is in line with the scanning plane (A). Lateral resolution is perpendicular to the scanning plane (B). (Redrawn from Simon and Snoey, eds. *Ultrasound in Emergency and Ambulatory Medicine.* St. Louis, MO: Mosby-Year Book, Inc., 1997.

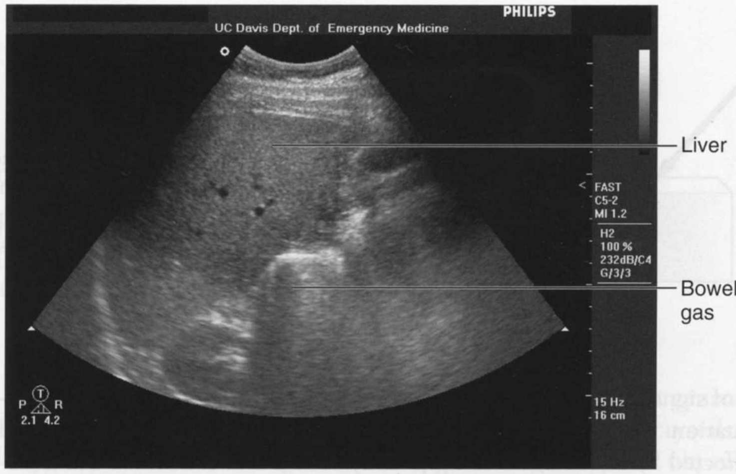


Figure 3.5. Liver and bowel gas. Note the well-defined liver but poorly defined bowel gas. Bowel gas causes scattering of the signal and loss of resolution.

resolution is the ability of sound waves to discriminate between objects that are perpendicular to the ultrasound beam. Lateral resolution is a function of beam width. Beam width is a function of the focus control on the ultrasound machine (Fig. 3.4B).

Ultrasound and Tissue

As sound travels through different media, it interacts in different ways. The ultrasound wave travels through tissue causing molecules to vibrate. The density of the tissue affects the transmission of the sound waves. Tissue that has molecules that are organized and relatively close together transmit better than those that are disorganized or farther apart. In looking at different tissue, this relationship can be seen.

Solid parenchymal organs provide good ultrasound images since they are compact and have some fluid density. The liver is a good example of an organ with excellent transmission properties. A uniform density makes it a superior organ for scanning. Notice how sharp and defined the image of the liver is in Figure 3.5 compared to the surrounding structures that are less defined.

Fluid densities are ideal for imaging with ultrasound because the molecules have some uniformity. The bladder is an excellent object to scan. In Figure 3.6, the bladder is clearly seen

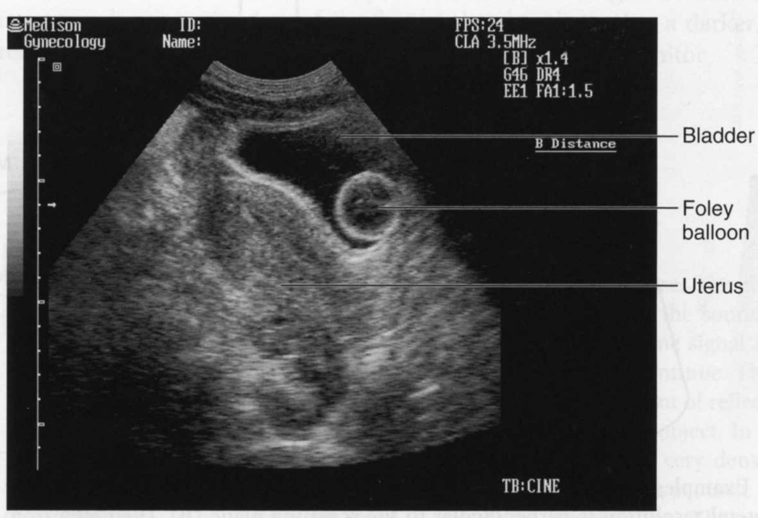


Figure 3.6. Acoustic window. The bladder displaces bowel gas and gives a clear acoustic window to the uterus. (Note the inflated Foley balloon in the bladder.)

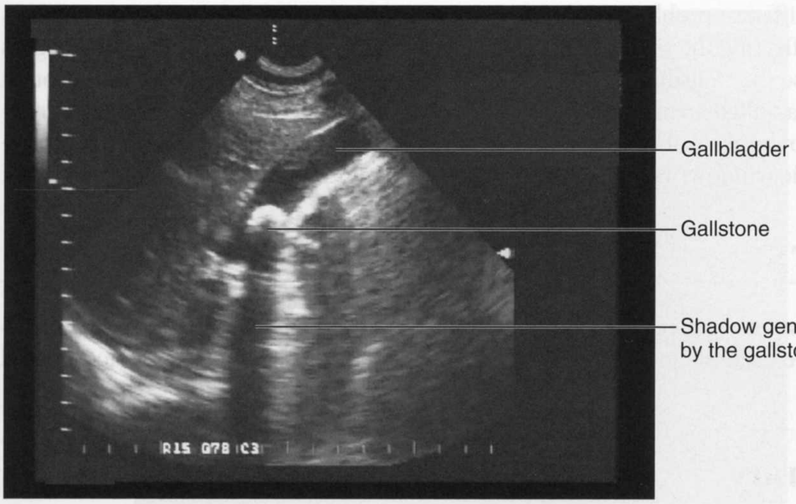
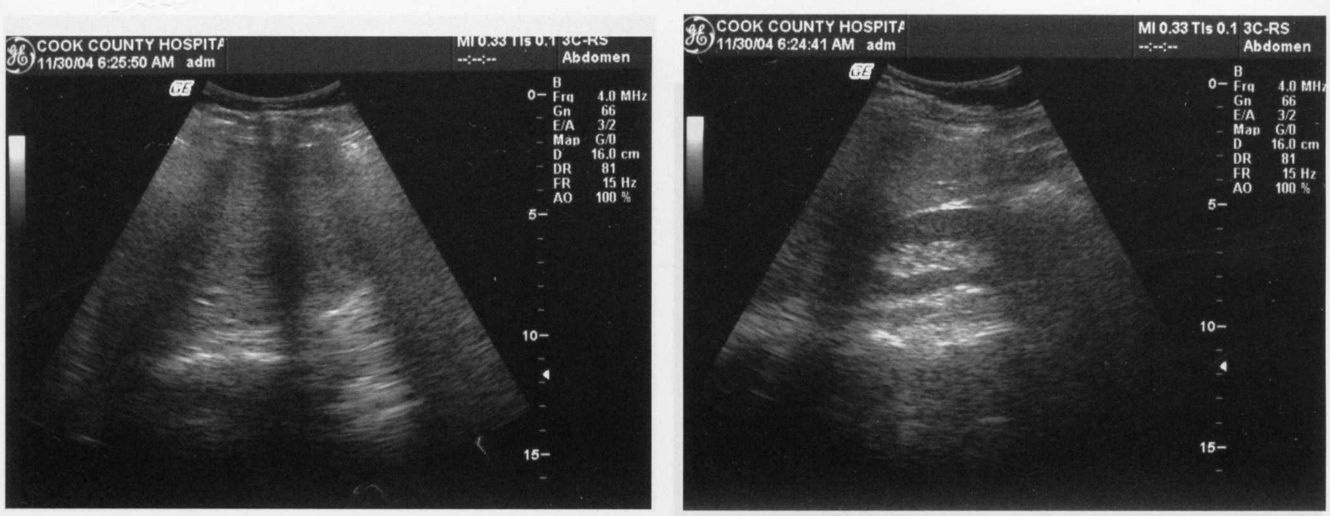


Figure 3.7. Gallbladder with stone. The liver is an excellent acoustic window for the fluid-filled gallbladder. The large gallstone creates a dark shadow. In addition, the tissue behind the gallbladder is more echogenic than surrounding tissue. This is enhancement artifact.

but the surrounding bowel is less defined. Notice that objects far field to the bladder are also clear. A fluid-filled structure allows for the uniform transmission of sound waves to deeper tissue. This is one example of an acoustic window. In an acoustic window an object is used as an acoustic filter for a deeper object. The bladder is often used in scanning to provide an acoustic window; it provides a uniform tissue that allows most of the signal to penetrate deeper tissue and also displaces the bowel allowing for the clearer visualization of the uterus that lies deeper. Fluid-filled organs surrounded by solid organs are also examples of acoustic windows and excellent scanning mediums. The gallbladder is another good example (Fig. 3.7). The liver parenchyma acts as an acoustic window for the fluid-filled gallbladder.

If the structure is too dense it may interfere with the transmission of sound waves. Structures that lie deep to bone cannot easily be imaged because most of the signal is reflected and is not able to penetrate deeper. Scanning over a rib produces a shadow or anechoic space beyond the rib (Fig. 3.8). Adjusting the transducer to move away from the rib allows for the signal to reach deeper structures. However, just because bone is dense doesn't mean it is excluded from all clinical applications for ultrasound. In musculoskeletal ultrasound, the near field cortex can be visualized in order to find a joint space for arthrocentesis.



A B

Figure 3.8. Rib shadow. Ribs cause the complete attenuation of signal and generate a shadow. Rib shadows interfere with scanning through an intercostal approach for the liver (A). Ribs commonly interfere with imaging the kidneys (B).

Gas gives a different problem. Molecules in gas (air) are randomly placed. Sound waves disperse in air, reflecting the signal in different directions. When gas is scanned, the image is ill-defined because the transducer sees a random array of signals. Consequently, ultrasound protocols avoid gas-filled areas such as bowel and lung. In fact, in ultrasound, *air is your enemy*. Excessive bowel gas, subcutaneous air, and lung fields are all impediments to effective scanning. Acoustic windows take advantage of good scanning locations that avoid air or gas.

Artifacts

Artifacts are commonly generated from tissue interfaces. Many artifacts are just an annoyance but some are used diagnostically. The following section lists commonly encountered artifacts.

Reverberation

Reverberation is an artifact created when an object is imaged more than once from repeated reflections by an interface near the transducer. Reverberation gives numerous horizontal lines on the monitor (Fig. 3.9). Reverberation can be limited by changing the angle of the transducer.

Mirror

Mirror artifact is produced when an object is located in front of a very strong reflector. In essence, a second representation of the object is placed at the incorrect location behind the strong reflector in the image. If a sonographic structure has a curved appearance, it may focus and reflect the sound like a mirror. This commonly occurs at the diaphragm (Fig. 3.10).

Ring Down

Ring down is an image artifact created when an object vibrates at a characteristic resonance frequency. This artifact resembles a comet tail artifact without the specific banding seen with the comet tail. The terms *comet tail* and *ring down* are used interchangeably even though they are technically different. Ring down is commonly seen from bowel gas, especially just after a meal. One can take advantage of ring down artifact to locate a needle when doing an ultrasound-guided procedure (Fig. 3.11).

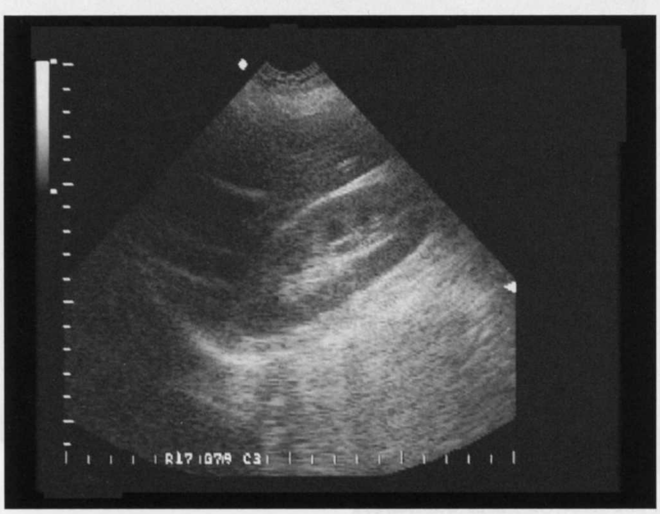


Figure 3.9. *Reverberation.* Note the lines on the left of the image. This is a reverberation artifact.

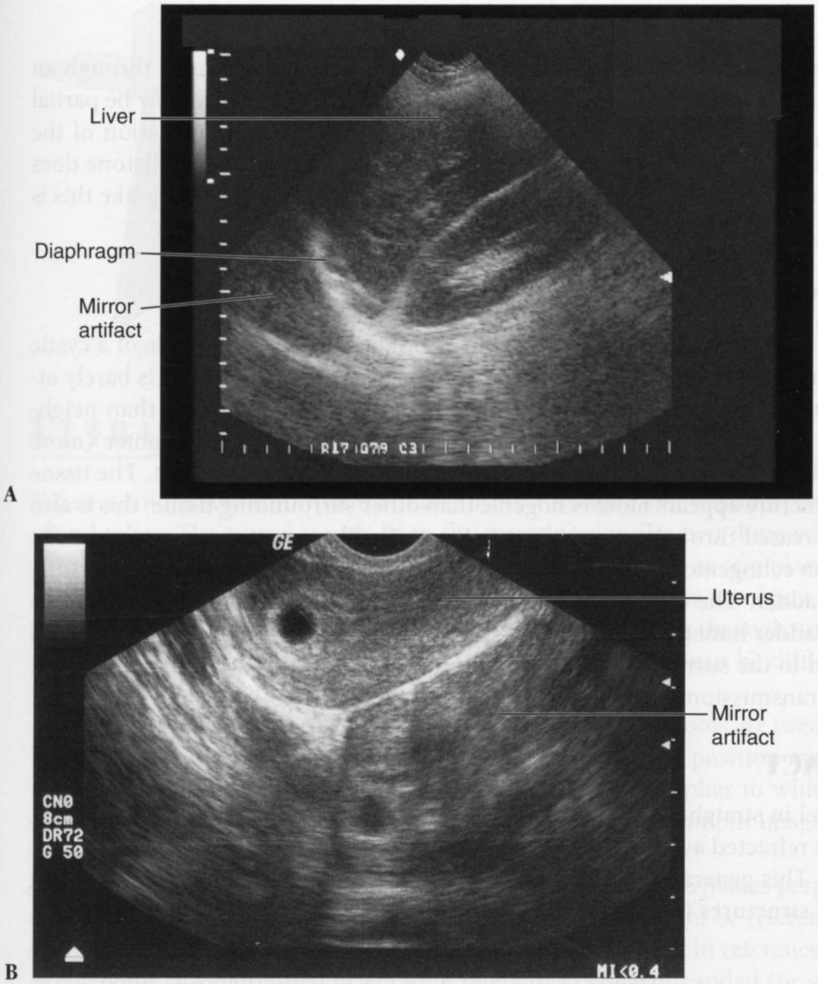


Figure 3.10. *Mirror artifact.* In A, there appears to be liver parenchyma on both sides of the diaphragm. This represents a mirror artifact caused by reflected signal. In B, identical images of the uterus are seen side by side. Image B courtesy of Karen Cosby, MD.

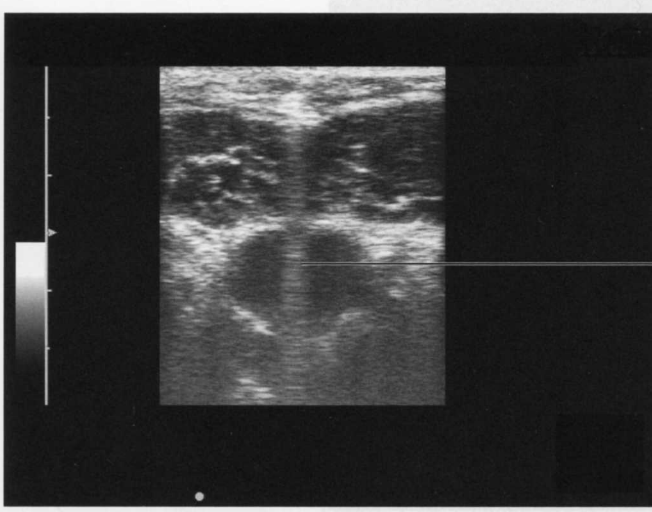


Figure 3.11. *Ring down artifact.* This is an excellent example of ring down artifact from a needle during central line cannulation.

Shadowing

Shadowing is an anechoic signal caused by failure of the sound beam to pass through an object. This blockage is caused by reflection or absorption of the sound and may be partial or complete. For example, air bubbles in the duodenum allow poor transmission of the sound beam because most of the sound is reflected. In addition, a calcified gallstone does not allow any sound to pass through and shadowing is pronounced. Shadowing like this is used to help diagnose gallstones (Fig. 3.7).

Enhancement

Enhancement is commonly seen as a hyperechoic or bright area on the far side of a cystic structure. It is caused because sound traveling through a fluid-filled structure is barely attenuated; the structures distal to a cystic lesion appear to have more echoes than neighboring areas. The back wall of a cystic structure will appear thicker and brighter (more echogenic) than the anterior wall; this is known as *posterior* wall enhancement. The tissue behind a cystic structure appears more echogenic than other surrounding tissue; this is also referred to as "increased through transmission" (Fig. 3.7). These properties are especially noticeable when an echogenic structure, such as a gallstone, is imaged in a cystic structure, such as the gallbladder. The echogenic gallstone is especially noticeable in the echo-free space of the gallbladder lumen. In addition, the echo-free shadow produced by the stone is sharply contrasted to the surrounding area behind the gallbladder that is enhanced by increased through transmission.

Edge Artifact

Sound waves travel in straight lines. When they encounter a rounded or curved structure, the sound wave is refracted away from the original line of propagation, leaving an acoustically silent space. This generates a shadow. This distorted image is commonly seen along the sides of cystic structures (Fig. 3.12).

Side Lobe

Side lobe artifact is generated from secondary intensity lobes displaced from the main ultrasound beam that are created by interference. Side lobe artifact can be seen especially around the bladder. Side lobes can misrepresent interface locations in the image.

Figure 3.12. *Edge artifact.* Shadows are seen along the curved sides of cystic structures, caused by refraction of the sound wave along the curved interface. In this image, an oblique view of the inferior vena cava is seen.

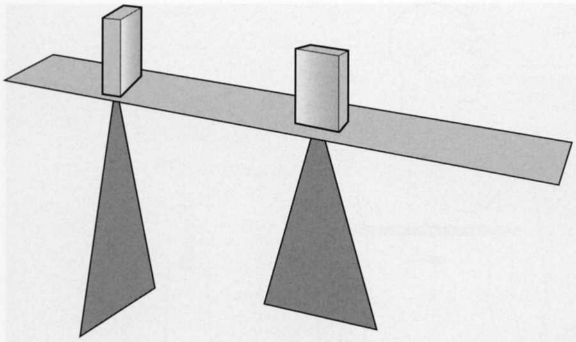


Figure 3.13. *Two dimensional planes of imaging.* This figure illustrates the 2-D signal that comes out of the transducer. Note that the transducer needs to be rotated to visualize the object in two planes perpendicular to each other.

Ultrasound and 2-D

When sound is sent out from the transducer, it is important to conceptualize the form the sound takes. The sound travels from the transducer in flat two-dimensional (2-D) planes (Fig. 3.13). At any one moment objects are only visualized in one plane. The transducer can be "fanned" or tilted from side to side to better visualize an object (Fig. 3.14). Scanning in two planes perpendicular to each other and fanning through an object allows for more of a three-dimensional (3-D) conceptualization. This can be difficult to see from a two-dimensional textbook page.

In order to keep our relationships consistent, reference tools are used. Each transducer has a position marker (indicator) that corresponds with the position marker on the ultrasound monitor. This is a guide to help remind the sonographer to which orientation the transducer is positioned. Scanning protocols are not just random images; rather they are accepted views of a particular anatomic area.

If possible, the object of interest should be scanned in two planes perpendicular to each other to give the best 3-D representation available. Images can be referenced in one of two ways. Some organs have an orientation conveniently imaged in reference to the major axis of the body. A longitudinal orientation refers to a cephalad-caudad (or sagittal) view (Fig. 3.15A). A transverse orientation refers to a cross-sectional view similar to that produced by conventional computed tomography (CT). If an object lies in an oblique plane relative to the body (e.g., kidney), it is best referenced by its own axis. These objects are typically imaged in their long and short axes. When a longitudinal orientation is desired, by convention, the transducer indicator is positioned toward the patient's head (Fig. 3.15A). The

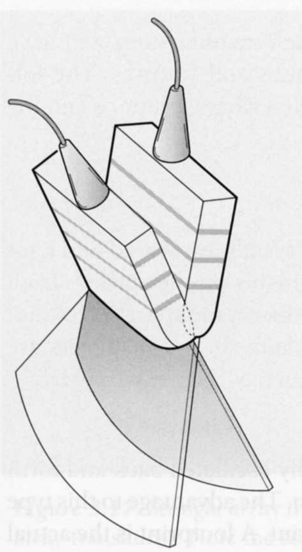


Figure 3.14. *Fanning.* Rocking or fanning the transducer produces a 3-D perspective of the object of interest. (Redrawn from Simon and Snoey, eds. *Ultrasound in Emergency and Ambulatory Medicine.* St. Louis, MO: Mosby-Year Book, Inc., 1997.)

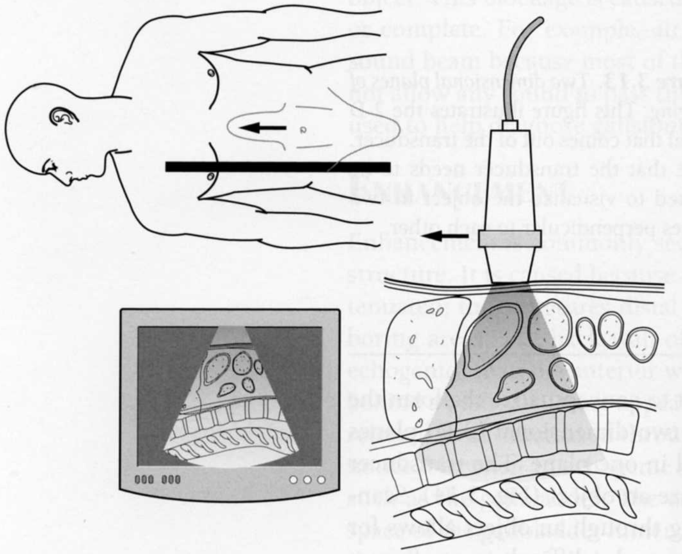


Figure 3.15A *Longitudinal axis.* Long axis scanning with the position marker (indicator) towards the patient's head. The arrow notes the indicator position.

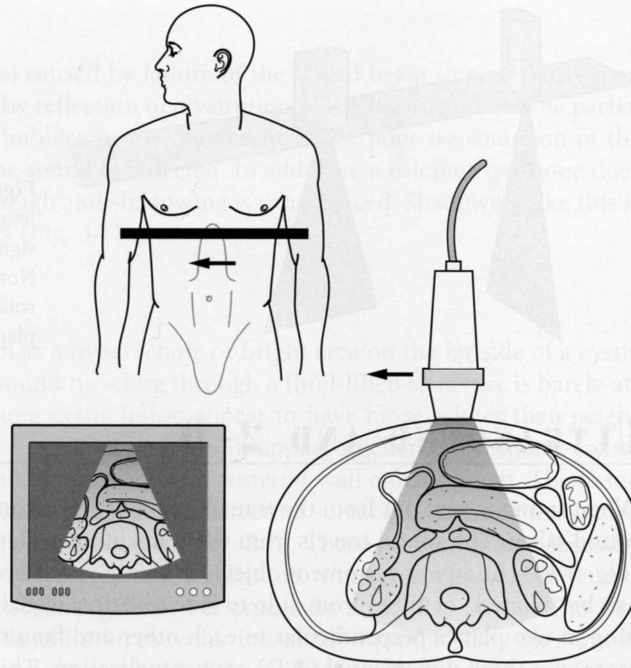


Figure 3.15B *Transverse axis.* Short axis scanning with the position marker (indicator) towards the patient's right side. (Redrawn from Heller and Jehle, eds. *Ultrasound in Emergency Medicine.* Philadelphia, PA: W.B. Saunders, 1995.)

ultrasound monitor projects the image closest to the patient's head on the left side of the ultrasound monitor; the image closest to the patient's feet toward the right. When a transverse orientation is desired, the transducer indicator is placed toward the patient's right side (Fig. 3.15B). In this position the ultrasound monitor projects the patient's right side to the left of the monitor, the image closest to the patient's left side toward the right. Clinicians will recognize this view because it is the same orientation provided on traditional CT cuts. In most common applications the position marker on the monitor is on the left side. This differs from classic echocardiography orientation where it is placed on the right side of the image. The guides help develop a better image when scanning in two dimensions.

Primer on Equipment

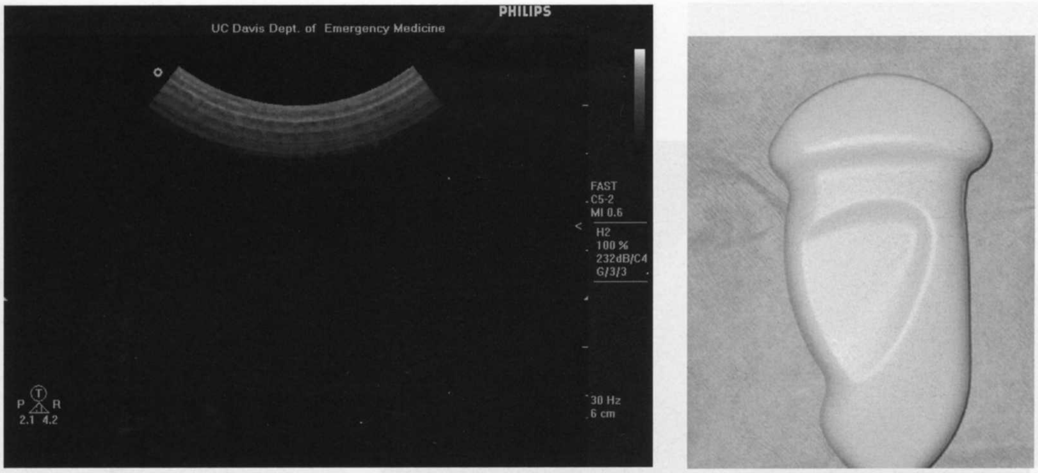
All ultrasound units share some common features. Although each manufacturer will have certain specific components, all machines have some basic knobs and features. The following section explores the basics of each of these features and describes variations and the practical nature of each.

Transducers

The transducer is the scanning device where the piezoelectric crystals are stored and emit and receive sound. There are four main types of transducers available on the market. Each type has its advantages and disadvantages. Generally, most transducers today are sealed and have limited serviceability. In addition, many manufacturers claim their transducers are multifrequency. A transducer may have a range or effective frequency (i.e., 3.5–5.0 MHz).

Mechanical transducer

In a mechanical transducer the piezoelectric crystals are physically oscillated back and forth to produce the scanning field. The transducer has a slight vibration. The advantage to this type of transducer is that it can be designed to have a very small footprint. A footprint is the actual



A B

Figure 3.16. *Curvilinear array transducer.* Image A illustrates the image footprint generated by a curvilinear transducer. Note the curved image at the top of the screen.

transducer surface that comes in contact with the patient. Small footprint transducers allow for scanning through intercostal spaces with limited shadowing. In addition, they tend to be less expensive compared to electronic transducers. Their primary disadvantage is that the mechanism can be easily broken with any blunt force against the transducer. This is generally a disadvantage in a busy emergency department where objects can inadvertently hit a transducer. Mechanical transducers can be a good value and give excellent scanning resolution.

Array or electronic transducers

The vast majority of transducers on the market are of the array or electronic type. In these transducers, the crystals are fixed in an array and fire electronically to generate the field of view. There are different arrays available. Array transducers are described based on the positioning of the crystals. Most array transducers have the crystals in a line and are thus called linear arrays. The face of the transducer can be curved to give a wider field of view. This type is termed a curvilinear array transducer (Fig. 3.16). The array may be in a straight line for a more perpendicular field. These are termed straight linear arrays (Fig. 3.17). In both types of linear arrays, the crystals are fired sequentially to produce the field of view.

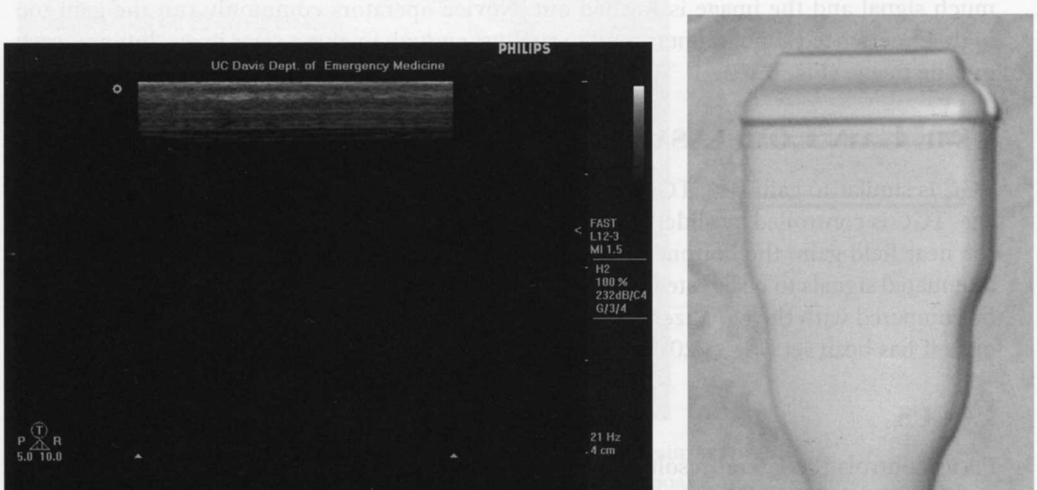


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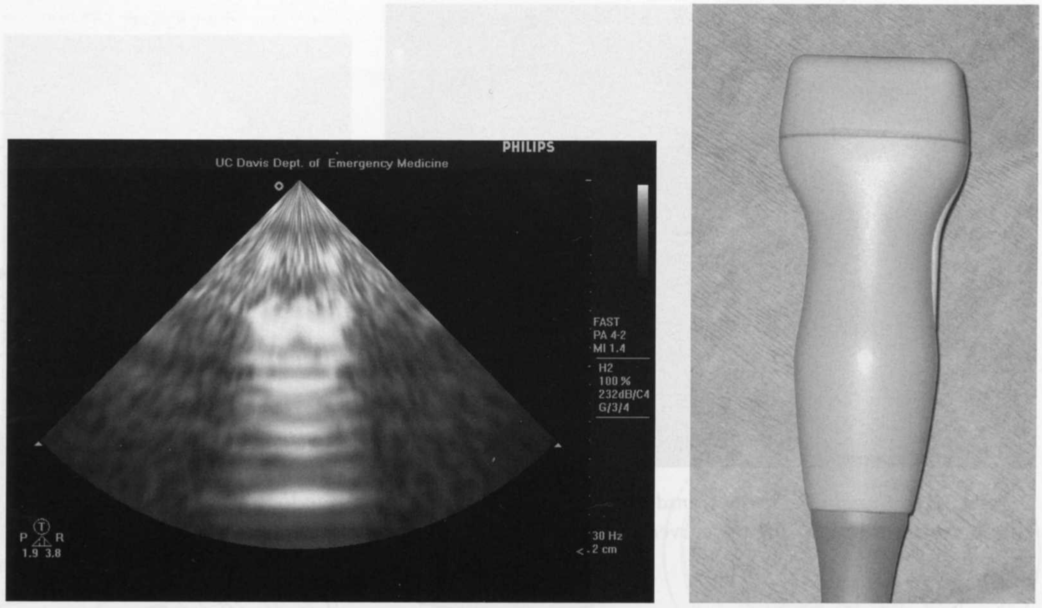
Figure 3.17. *Straight array transducer.* Image A illustrates the image footprint generated by a straight array transducer. Note the straight image at the top of the screen.



A B

Figure 3.18. Phased array transducer. Note the small footprint and very small image footprint on the screen.

A more sophisticated array is the phased, or sector array, transducer (Fig. 3.18). In this type of array, the crystals are not in a line, they are layered in a staggered fashion. This allows for a very small footprint. The computer in the ultrasound machine then fires the crystals in phase to electronically oscillate the ultrasound and generate a wide field of view. These types of transducers tend to be more expensive. They are commonly used in echocardiography where a small footprint transducer is required.

Gain

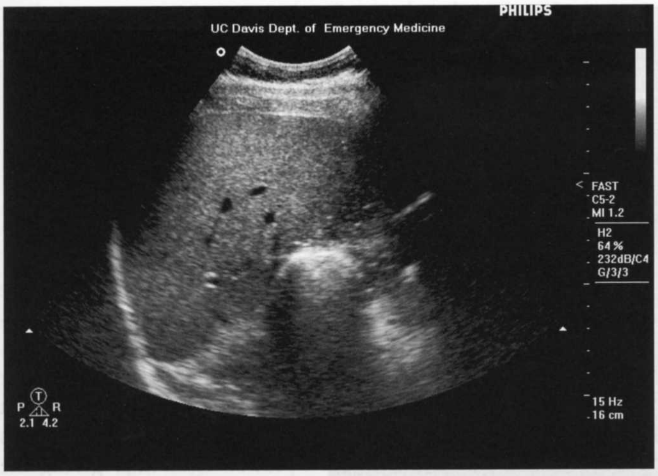
The gain control adjusts the signal that returns to the unit. It can be compared to the volume knob on a stereo system. The intensity of the reflected sound wave is amplified to produce a visual image. As the volume is turned up on a stereo, the music becomes clearer until it is too loud and there is too much signal to noise. Similarly, as gain is increased, the amount of signal processed is increased and the image becomes brighter until there is too much signal and the image is washed out. Novice operators commonly run the gain too high. Experienced sonographers tend to run just enough to give a clear image but not wash out the image (Fig. 3.19).

Time Gain Compensation (TGC)

TGC is similar to gain. The TGC controls the gain at different levels of the ultrasound image. TGC is controlled by slider controls on most ultrasound units. The top control adjusts the near field gain; the bottom control adjusts the far field gain. The TGC controls allow attenuated signals to be boosted at specific levels rather than overall. The TGC controls can be compared with the equalizer on a stereo. Generally the TGC is not adjusted very much once it has been set (Fig. 3.20).

Focus

Focus controls the lateral resolution of the scanning beam. The focus is generally set for each application, although it may need to be adjusted for specific scanning situations. Adjustments in focus won't be dramatic so don't expect the focus to be the difference between making a diagnosis and not making a diagnosis.



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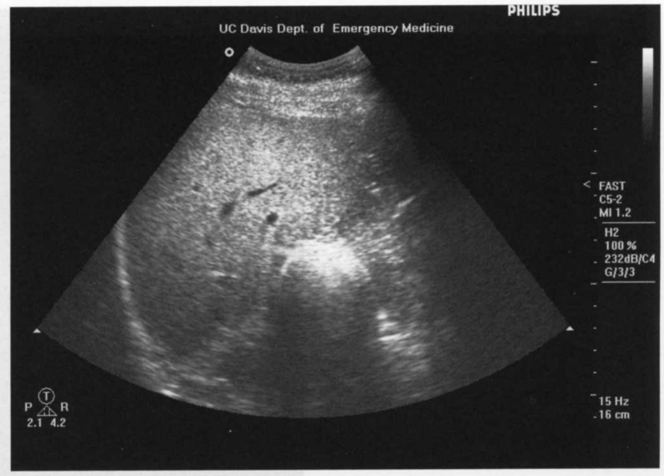

B

C

Figure 3.19. *Optimizing gain.* In A, the gain is too low and the image is too dark. In B, the image has too much gain and the image is washed out. In C, gain is optimal, resulting in excellent contrast.

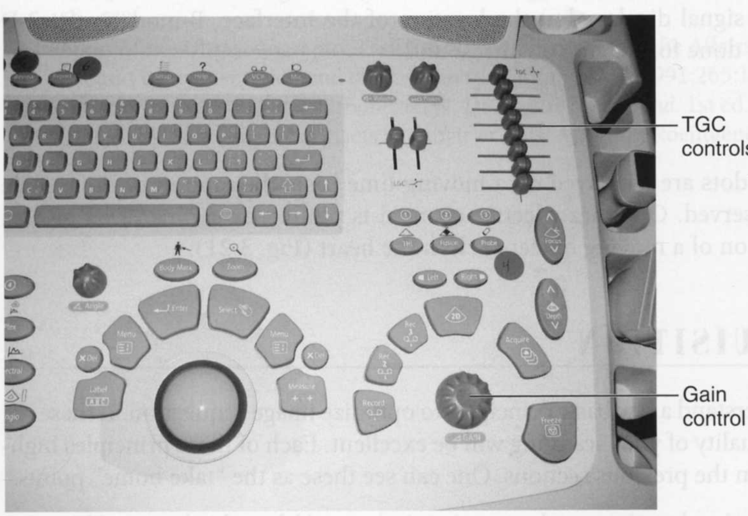

Figure 3.20. *Gain and time gain compensation (TGC).* Note the gain knob in the lower right. The TGC levers are in the upper right of the keyboard.

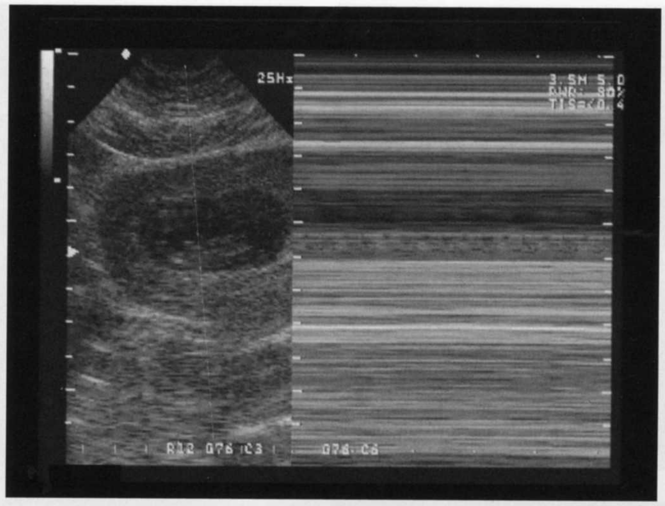

Figure 3.21. *B- and M-mode image.* A B-mode scan of an 8-week fetus is seen on the left. The reference channel cursor is aligned with the fetal heart rate. This single channel is plotted over time giving the M-mode screen on the right.

Freeze

A selected image in the real-time acquisition is designated for continuous display until this mode is turned off. The freeze button holds an image still and allows printing, measuring, and manipulation.

Calipers

These markers are available to measure distances. Some ultrasound units add a feature for ellipsoid measurement. This feature provides a dotted line that can be drawn around the outline of a structure to calculate either the circumference or the area.

B-Mode

This is termed "brightness mode scanning"; it modulates the brightness of a dot to indicate the amplitude of the signal displayed at the location of the interface. B-mode is the 2-D scanning customarily done for diagnostic ultrasound.

M-Mode

If a series of B-mode dots are displayed on a moving time base, the motion of the mobile structures can be observed. One piezoelectric channel is plotted over time. This gives a real-time representation of a moving object such as the heart (Fig. 3.21).

Image Acquisition

It is important to understand a few basic principles to optimize image acquisition. If these are adhered to then the quality of your scanning will be excellent. Each of these principles highlights topics covered in the previous sections. One can see these as the "take home" points.

1. Use accepted scanning locations and acoustic windows. Although ultrasound images may appear random at the beginning, each protocol has standard images that need to be acquired. Just as an electrocardiogram has standard lead placement, ultrasound images

for a given application are standardized so that those reviewing the images can make an accurate interpretation. Most accepted applications take advantage of acoustic windows such as a full bladder, liver, or spleen.

2. Scan perpendicular to the object of interest. Only sound that returns to the transducer is processed. A scan perpendicular to an object provides the best return of signal and optimizes detail. It is important to recognize that a transducer that is placed perpendicular to a deeper tissue object may not necessarily be perpendicular to the skin surface.
3. Obtain at least two views perpendicular to each other through any object of interest. Looking at an object in two perpendicular planes is critical for proper ultrasound interrogation. A few studies will not fully allow this practice, such as the critically injured trauma patient, but most applications will. Do not come to any conclusions until you have scanned in at least two planes. Sometimes what appears to be edge artifact in one plane can be a clear gallstone in another plane.
4. Scan through an object of study to give a 3-D view. This is important clinically to avoid misinterpreting the artifact. Fanning the transducer through the object of study will give the best 3-D detail.

This chapter briefly covers some basics in ultrasound fundamentals. As one scans, more details will become clear. Ultrasound is unique because the image acquisition component is as important as the interpretation. Take time to understand the components of your particular machine and enjoy scanning!

Recommended Reading

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