5 Ultrasound

Objectives:

1. State the function of the transducer used in ultrasonography.
2. Define the term "sonolucent."
3. Give examples of structures that transmit sound well and that transmit sound poorly.

Ultrasound

Ultrasound uses no ionizing radiation and it can image directly in any body plane. In practice, an ultrasonographer (either an ultrasound technologist called a sonographer or a physician) places gel on the patient's skin and moves a transducer across the surface of the patient's body. The gel forms an acoustic seal between the transducer and the skin for better transmission of sound, which results in better images.

The transducer can both send out and receive high-frequency sound waves, which transmit through, or reflect off, structures in the body. The returning sound waves are categorized by their intensity (referred to as echogenicity) and duration of time that it takes for them to return. It is the time that it takes for the echo to return from its encounter with an acoustic interface (a structure within the body which reflects sound) that allows its location within the image to be assigned (Fig. 5.1).

The intensity of the returning echo (echogenicity) of tissues varies greatly. Some tissues, like abdominal fat, are higher in echogenicity than other soft tissues. On the ultrasound image, such structures will appear whiter and are described as being increased in echotexture or "hypERechoic." Tissues/interfaces that return echoes of lower intensity are displayed as darker on ultrasound images and are described as decreased in echotexture or "hypOechoic." By evaluating the echotexture of tissues, we can distinguish one organ from another and look for pathologic processes.

J. Kissane et al. (eds.), *Radiology Fundamentals: Introduction to Imaging & Technology*, https://doi.org/10.1007/978-3-030-22173-7_5

Fluid-filled structures (such as the gallbladder or urinary bladder) have few or no internal acoustic interfaces and hence appear clear black or sonolucent on ultrasound. Look at the simple cyst found when scanning the breast of a patient in Fig. 5.2. Note that the cyst depicted in this image is "anechoic," having no detect-

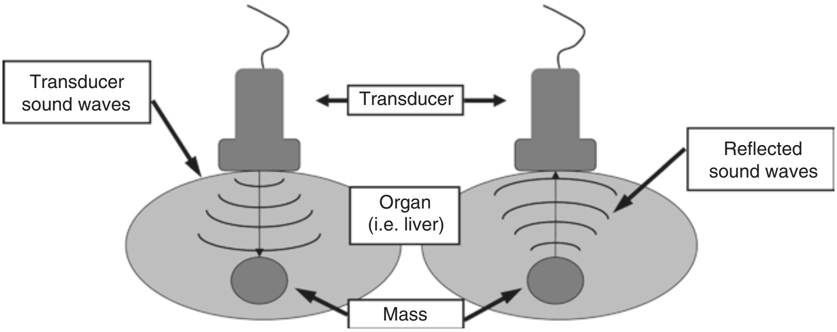

FIGURE 5.1 - ULTRASOUND
The ultrasound transducer acts similar to the sonar on a submarine. The transducer sends a short burst of high-frequency sound into the tissue. Some part of the sound is reflected back by the tissues, the reflected signal is "read" by the transducer, and an image is created

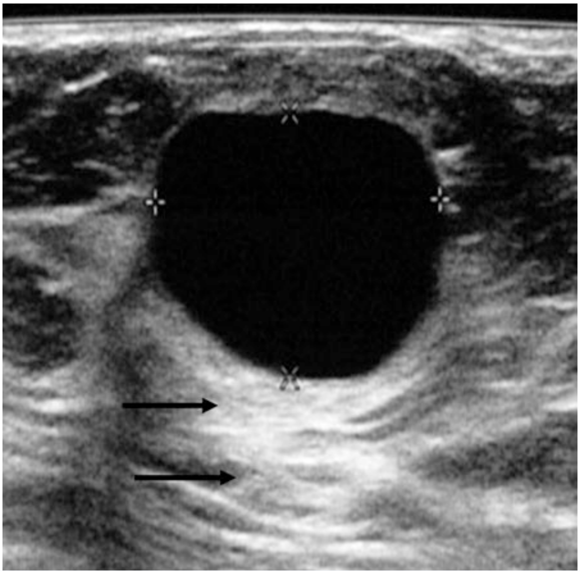

FIGURE 5.2 - SIMPLE BREAST CYST
"Anechoic" cyst having no internal echoes. Note the increased echodensity behind the cyst (*arrows*)

able internal echoes. Sound waves traveling through the fluid-filled cyst retain their energy (since they encounter fewer acoustic interfaces). For this reason, they can pass through with more intensity when they reach the far wall of the cyst. This phenomenon is referred to as "acoustic enhancement" (arrows).

Some structures that are very dense, such as calcified structures or bone, will prevent sound waves from passing beyond them. As a result, there is no imaging information that can be obtained deep to those structures. A dark band-like "shadow" is produced beyond the echodense structure. This dark shadow can be quite prominent, helping identify even very small calcifications, such as kidney stones. This is known as the headlight sign as is seen in Fig. 5.3.

The orientation of the plane of the section on an ultrasound image is indicated by the sonographer, who annotates the plane of the section on images, either with text or with an indicator image.

Scans are normally viewed in "real time." This means that structures can be seen to move in the image (e.g., cardiac valves) and structures can pass into and out of the field of view. The images that the ultrasonographer records are only selected "frozen" images from an extensive examination. In some situations, it may be advantageous to record the examination in real time, known as a video or cine clip.

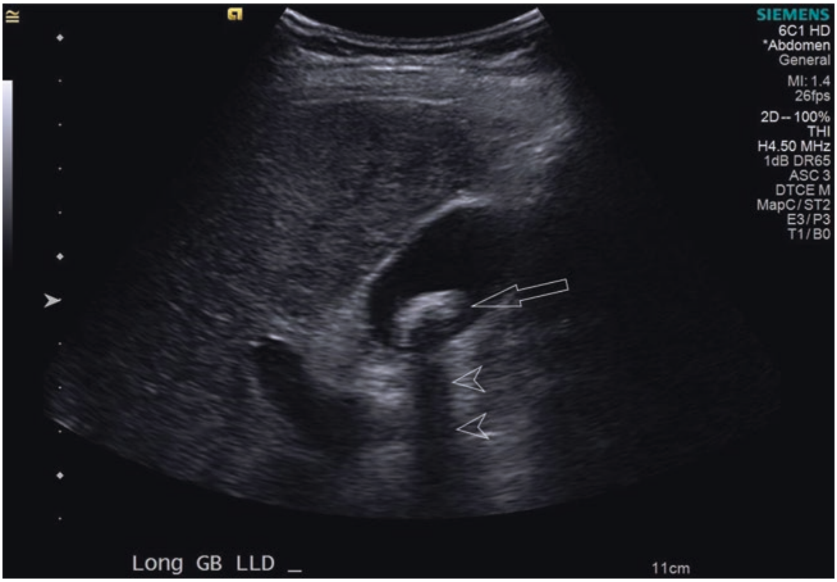

FIGURE 5.3 - HEADLIGHT SIGN
Note the band-like "shadow" (*white lined arrowheads*) beyond the bright echogenic gallstone (*white lined arrow*) due to inability of the sound waves to travel through the dense stone

$$X \propto \left(\frac{1}{D}\right)^2$$

FIGURE 5.4 - INVERSE SQUARE LAW
This is the inverse square law, as it applies to radiography, where X is the exposure at a given distance, D, from a radiation source. If, for example, the distance is doubled, the exposure would be one-fourth of its original strength. The same law applies to the strength of the ultrasound beam

Ultrasound weakens or attenuates rapidly by the inverse square law with distance from the transducer; therefore, structures closer to the transducer are better visualized. Many transducers have been adapted to get them close to the imaged structures. Transducers are included on endoscopes, allowing assessment of the duodenum, common bile duct, and pancreas. An endovaginal transducer provides very detailed imaging of the uterus and ovaries. Endorectal transducers allow high-resolution imaging of the prostate and rectum. By placing the transducer closer to the imaged object, you can also use higher wavelengths of ultrasound, improving detail (Fig. 5.4).

Color and Power Doppler Imaging in Ultrasound

When an ultrasound beam encounters a moving structure a change in the pitch or frequency of the returning echo, compared to the echo sent out by the transducer, occurs. This is called the Doppler shift and it is encountered in real life when you hear a siren from a police car as it drives past you; the pitch or frequency of the sound you hear changes as the vehicle passes.

By using the information generated by this Doppler shift, images can be generated, giving information about the speed and direction of the moving structure. This is most commonly used in evaluating blood vessels and blood flow. In conventional color Doppler, the displayed color identifies the direction of flow as well as the speed of flow. Power Doppler, which measures the concentration of moving structures, is more sensitive to low-flow states, but does not allow an evaluation of direction or speed.

Calculating the velocity of moving red blood cells numerically can allow an estimation of the diameter of the vessel in which the cells are flowing. This is the basis of a vascular spectral (duplex) assessment of vessels such as the carotid arteries. A spectral Doppler study will display grayscale images, color images, and waveform images of the vessel being evaluated. As the vessel lumen narrows, generally the velocity of red cells moving through it increases. By using multiple calculations along the path of the vessel, multiple velocity measurements and ratios of velocities can be calculated, allowing one to diagnose, quantify, and monitor focal areas of vascular narrowing.

Color/power Doppler and spectral imaging are used to assess for possible clot in veins, to evaluate areas of arterial narrowing/stenosis, and to determine if masses and organs have increased blood flow. You might see increased blood flow in a malignant tumor or reduced blood flow in a torsed testicle or ovary. Doppler imaging is also used to diagnose vascular malformations and assess for the presence of varicose veins.

Indications for Ultrasound Use

Ultrasound is most efficient in thinner individuals or when evaluating structures closer to the transducer. It does not require the use of ionizing radiation, but still should be used cautiously. Studies have shown that prolonged exposure to ultrasound can increase the temperature of tissue and that cavitation can occur when sound waves pass through a structure containing a gas bubble or air pocket (such as bowel and lung). Like any other imaging modality, ultrasound should be used judiciously, only when necessary, and by someone appropriately trained in the modality.

Ultrasound is most commonly used to image specific organs such as the liver, gallbladder, kidneys, spleen, uterus/adnexa, and scrotum. Despite knowing the limitations of ultrasound when evaluating air- and fecal-filled bowel loops (and structures around them), ultrasound is being used increasingly to evaluate diseased bowel (which tends to be thicker and often fluid-filled). With appropriate training, point-of-care ultrasound can aid in the detection of pneumothorax, pleural effusions, and peritoneal fluid and in guiding the placement of central lines.

S: Unlike conventional radiography, CT scanning and angiography, ultrasound does not use ionizing radiation to generate images. However, ultrasound does deposit energy into tissue and so must be used safely. Think about therapeutic uses of ultrasound such as lithotripsy and ultrasound for physical therapy. Anyone using ultrasound for diagnostic and therapeutic purposes should have proper ultrasound safety training.

A: Ultrasound is best used to answer specific questions, in appropriate organs and locations, and in proper patients. Ultrasound is not a good modality to use to just "look around" for pathology. Ultrasound may provide limited diagnostic images in the obese patient, the uncooperative patient and the patient with thick bandages or large scars.

F: Obtaining ultrasound images is aided by knowledge of anatomy and experience to conceptualize what you are seeing. Tissue display is unique to ultrasound such as adipose tissue which is dark on CT and bright on ultrasound.

E: Ultrasound can provide quick real-time assessment and information to answer a clinical question and direct treatment. For example, ultrasound can be used to identify large amounts of free fluid in the abdomen after trauma, directing the next steps in patient care.