ULTRASOUND

Understanding how ultrasound works; its uses, strengths, and weaknesses

Objective questions:

1. What is ultrasound?
2. How does ultrasound work?
3. How is an image created with ultrasound?
4. When is ultrasound most useful?
5. What are the regions of the body and/or diagnoses best imaged with ultrasound?
6. What are safety considerations with ultrasound?
7. What are 3D and 4D ultrasound?

What is ultrasound?

Ultrasound is defined as high-frequency sound waves of 20 thousand to 1 million Hz (cycles per second) or greater. (Each peak in a sound wave represents one cycle.) Diagnostic ultrasound operates between 3.5 and 10 million Hz (3.5 and 10 MHz).

How does ultrasound work?

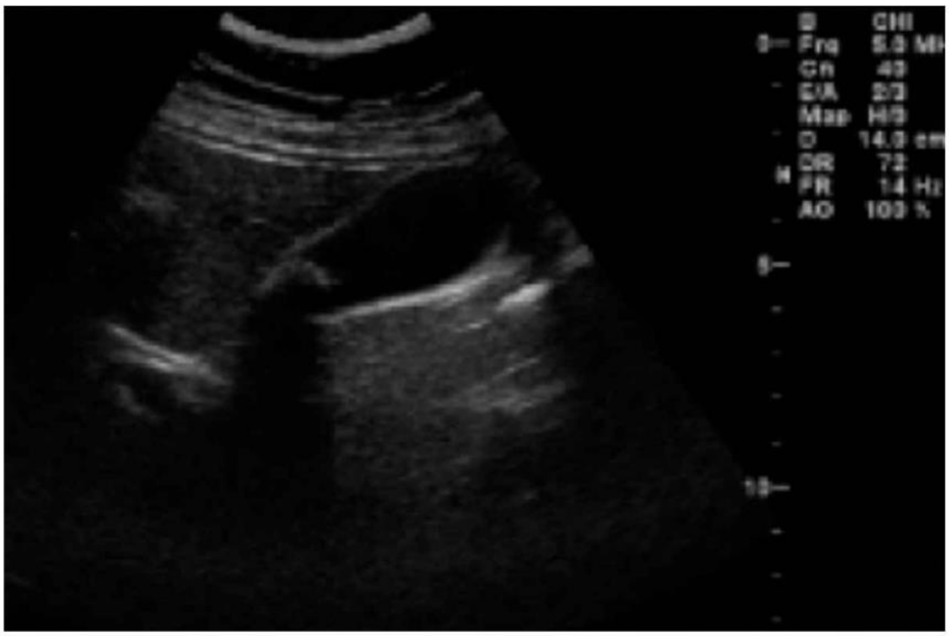
Ultrasound is created by the high-frequency vibration of a crystal located in the ultrasound transducer, which is a piece of equipment about the size of a small cell phone that fits easily into the hand. The soft, curved end of the transducer is placed on the patient, and gel is used to improve its contact with the skin. During the scanning process, the crystal is stimulated electronically to vibrate. This occurs in an instant, and the crystal then becomes a listening device for the returning echoes from ultrasound reflected back by body tissues. These returning echoes are converted to a gray scale for the creation of an ultrasound image.

How is an image created with ultrasound?

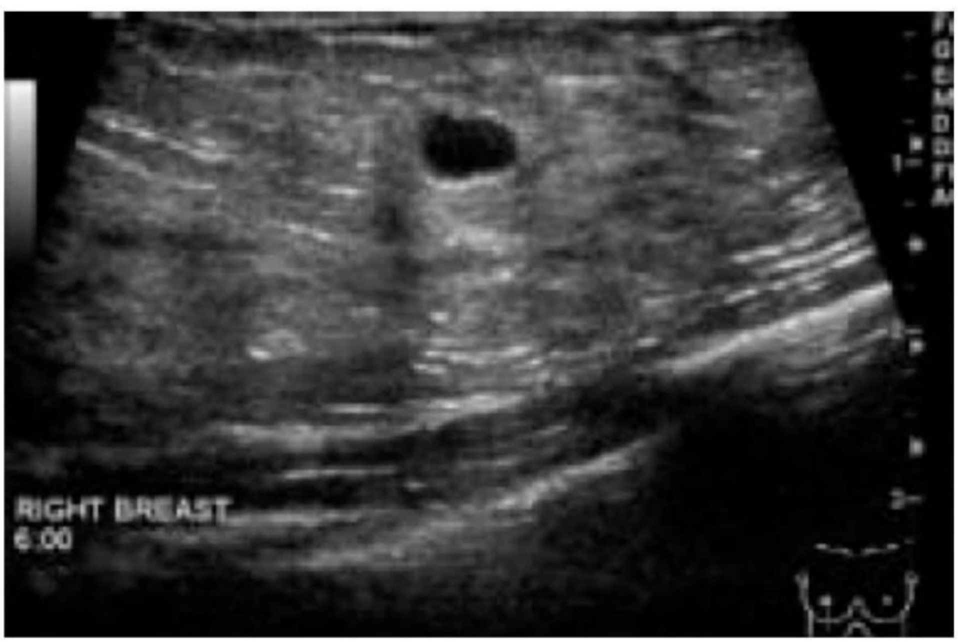
As the ultrasound energy travels through tissues of the body, it is scattered, transmitted, or reflected back to the transducer. Ultrasound that is scattered does not help to create an image. Ultrasound that is transmitted produces an echo-free area on the image. Fluid such as ascites, bile within the gallbladder, and serous water within a cyst all appear as sonolucent (echo-free and black on the film) areas on the ultrasound image. Reflected ultrasound creates a density on the ultrasound image (gray or white on the film). The difference in how much ultrasound a given tissue reflects allows us to see individual structures. For example, the pancreas reflects more ultrasound (is more echogenic) than the liver, the liver reflects more than the spleen, and the spleen reflects more than the kidneys.

Important term 1 "Increased through transmission"
When ultrasound passes through a fluid medium, the intensity of the sound energy is not diminished. Therefore, tissues behind the fluid collection are more echogenic (brighter because there is more acoustic power to reflect back to the transducer).

Important term 2 "Posterior acoustical shadowing"
When ultrasound hits a dense object such as a gallstone and is completely reflected, a posterior acoustical shadow is formed. The gallstone is bright and echogenic. Because no ultrasound energy is left to go beyond the stone, an echo void is created, which appears as a wedge-shaped dark area posterior to the dense object.



Posterior acoustical shadowing (gallstone)



Breast cyst with increase through transmission

When is ultrasound most useful?

As a general rule, ultrasound is best at distinguishing the characteristic echo-free appearance seen in fluid collections or cysts. It works best on thin patients and on body parts closest to the skin. Ultrasound does not work well in the presence of gas or air or in larger patients.

What are the regions of the body and/or diagnoses best imaged with ultrasound?

> Appendicitis
> Breast
> Female pelvis
> Gallbladder
> Heart
> Kidneys
> Neonatal brain
> Pleural effusion
> Pregnancy
> Scrotum
> Soft tissue masses
> Thyroid
> Upper abdomen
> Vascular structures (venous and arterial)

Cyst—right ovary

Solid left breast nodule

What are the safety considerations for ultrasound?

Ultrasound is the safest of all current imaging modalities. There is no magnetic field and no radiation to be concerned about. No harmful effects have been proven when ultrasound is performed at diagnostic frequencies.

What are 3D and 4D ultrasound?

Three-dimensional ultrasound uses the same principles as 2D ultrasound but adds a position-sensing component to produce the effect of a 3D image. As with CT, 3D imaging is helpful to examine contour. Currently, 3D ultrasound is used primarily in pregnancy ultrasound to provide a snapshot of the fetus. The detail possible with 3D ultrasound is incredible, especially in the delicate facial area, but also in the heart chambers and valves. Four-dimensional ultrasound adds the fourth dimension of time. It is essentially a motion video of the three-dimensional fetus. Diaphragm activity, limb movement, and cardiac motion can be seen clearly in real time.

MRI/PET

Understanding how MRI and PET scanning work: their uses, strengths, and weaknesses

Objective questions:

1 How does MRI work?
2 What is being imaged with MRI?
3 What is meant by "MRI signal"?
4 How do I begin to interpret MRI?
5 What are the benefits of MRI compared to plain radiography, CT, and ultrasound?
6 What are the regions of the body and/or diagnoses best imaged with MRI?
7 What are the safety considerations with MRI?
8 How does PET scanning work?
9 When should a PET scan be requested?
10 Are there contraindications to PET scanning?
11 What is PET/CT?

How does MRI work?

Although it is not critical that the student understand the complex physics of MRI, it does help to have a few very basic concepts in mind when analyzing MR images. The following statements are oversimplifications that I have found helpful. Anyone interested in studying radiology as a vocation is encouraged to learn the true properties and physics in greater detail.

Getting an image from MRI depends upon the presence of protons in the body. Protons are free hydrogen atoms (proton without electrons). They are abundant in the body. With their net positive charge, protons are small magnets, each having a north and a south pole. When placed in a strong magnetic field, enough of these tiny proton magnets align to form a single magnetic vector. A radiofrequency pulse is added to this steady state and tips the net magnetic vector off axis. As the vector returns to its alignment in the magnet, energy is released. It is this energy that is used to create the image.

What is being imaged with MRI?

In general, MRI is water imaging. Most pathologic conditions in the body are associated with edema, or water formation. MRI is excellent for detecting this water. T1 and T2 are the basic MR imaging sequences (although there are now many more variations in clinical use). With T1, water has no signal and is black. With T2, water has high signal and is white. Proton density (PD) imaging, which is midway between T1 and T2, has some of their advantages. This sequence is very helpful in evaluating the menisci of the knee. For most MRI examinations, two to eight imaging sequences are performed. The faster sequences can be obtained in about two minutes, while more complex sequences can take about 15 minutes. You will hear such terms as *spin echo*, *fast spin echo*, *gradient echo*, *inversion recovery*, *diffusion weighting*, *T2**, and *fat saturation*. Each of these sequences carries advantages and disadvantages. Radiology departments may vary in the MRI imaging sequences they utilize. Most departments follow a manual as a general guideline and make modifications as needed depending on factors such as the strength of the magnet, the pathology being studied, and the preferences of the radiologists.

The terms *open* and *closed magnets* refer to the enclosure that patients are placed in for the examination. Open MRI, in general, provides more room for patient comfort but takes longer because of lower field strength. Closed MRI is more confining but is often faster because it typically has higher field strength. Although debate continues about the relative sharpness and image quality (many believe that the difference between open and closed MRI for most examinations is negligible), either system can provide beautiful diagnostic images of the body.

An MRI machine may use a fixed magnet or a superconducting magnet. A detailed discussion of the differences between the two is beyond the scope of this handbook, but in general a fixed magnet has a lower field strength (lower tesla) and is used in open MRI, while a superconducting magnet has a higher field strenght and is found in most closed MRI units.

Surface coils are important tools for MRI. A surface coil is an antenna that fits closely around the body part to be examined. It increases the radiofrequency signal produced by the body during an MRI.

What is meant by “MRI signal”?

Whereas in CT and X-ray we use terms such as *density* and *attenuation*, in MRI the term is *signal;* it de-scribes the shades of gray between bright white and black. Describing a white area on MRI, we say that there is high signal. Describing a dark gray or black area, we say that there is low or no signal.

T1 is often referred to as the *anatomy sequence* because water or edema is less conspicuous and anatomy is usually clearly delineated. T2 is known as the *pathologic sequence* because the high signal (white) occurring when there is edema is very easy to see. A good example is effusion in the knee joint. The fluid in the joint is very obvious as white or bright signal on T2-weighted images. Today, there are many variations in MRI imaging sequences, and more are being discovered all the time. These sequences can be used to suppress signal from fat or from free fluid.

T1 lumbar MRI

T2 lumbar MRI

How do I begin learning to read an MRI?

Begin by learning imaging anatomy. There are many excellent reference texts and Web sites. If you can recognize normal anatomy, pathology becomes easier to detect. If you have access to MRI films, labeling structures with a wax pencil reinforces your learning. Specifically look for normal structures with the signal characteristics of T1 and T2. In other words, when examining an MRI of the brain, first examine the fluid-filled ventricles. The fluid will be black on T1 and white on T2. After mastering imaging anatomy, learn the signal characteristics of normal structures, and finally the signal characteristics of pathologic conditions.

What are the benefits of MRI compared to plain radiography, CT, and ultrasound?

MRI is a superior imaging modality. No radiation is used, and the anatomic detail it provides is exquisite. The imaging parameters can be varied in multiple ways that continue to evolve, bringing us closer to achieving tissue specificity.

MRI is superior to X-ray and CT in the evaluation of soft tissues such as cartilage, ligaments, soft tissue tumors, fluid collections, neuronal tissue such as the spinal cord, and the white matter tracts of the brain. MRI eliminates overlapping shadows, which are a problem with plain X-rays.

Like CT, MRI uses slices of anatomy that allow us to focus in on specific anatomy and pathology. Unlike CT, MRI can obtain these slices in any imaging plane while the patient remains supine. MRI does not contend with artifacts that can plague CT, such as bone artifacts in the posterior fossa of the brain.

MRI is not limited by bone and air, two limitations of ultrasound.

What are the regions of the body and/or diagnoses best imaged with MRI?

- Abdomen (to clarify CT or ultrasound findings)
- Bile ducts and pancreatic duct (magnetic resonance cholangiopancreatography [MRCP])
- Brain (especially the posterior fossa, nuclei, cranial nerves, and white matter tracts)
- Cervical, thoracic, and lumbar spine
- Female pelvis (to clarify ultrasound or CT findings)
- Joints
  - Elbow
  - Fingers
  - Foot and ankle
  - Hip
  - Knee
  - Shoulder
  - Temporomandibular joint
  - Wrist
- Staging endometrial cancer
- Staging prostate cancer
- Vascular structures (magnetic resonance arteriography and venography)

What are the safety considerations for MRI?

Magnets that are used in diagnostic imaging are strong and potentially dangerous. Most MRI machines operate between 0.3 and 3.0 tesla. The magnetic field of the earth is approximately 1 gauss, or one ten-thousandth of a tesla.

Death and injury have occurred when metal objects became projectiles in a magnetic field. Never enter the MRI scan room with scissors, hemostats, stethoscopes, or anything else that is ferromagnetic. The magnetic strips on credit cards are erased by the magnetic field, pacemakers malfunction, aneurysm clips dislodge, and oxygen tanks can hurtle through the air.

MRI personnel try very hard to screen patients for potential hazards. Never order an MRI without first considering the potential risks to the patient. When in doubt, ask the radiologist or technologist if it is safe for the patient to be scanned. Be particularly careful of pacemakers, metal workers who may have metal shavings in their eyes, and any patient who has had recent surgery. Emergency code situations can occur in the MRI scan room. Stop and think before springing into action. Remember, in an emergency, your first action should be to check your pockets carefully and remove any metal objects before entering the scan room.

Note: Most postoperative patients can be safely imaged with MRI. Hip-replacement surgery, cholecystectomy, hysterectomy, and many other surgeries do not preclude MRI. The Web site http://MRIsafety.com is a good source for further information.

How does PET scanning work?

Positron emission tomography (PET) scanning is a branch of nuclear medicine or nuclear imaging, which means that it utilizes radioactive materials to create an image. Nuclear imaging generally depicts physiologic activity and provides less anatomic detail. PET involves the imaging of the metabolic activity of cells within the body. Cancer cells, having rapid and unchecked growth, have much greater metabolic activity than normal cells. When a radioactive substance is tagged to a glucose derivative known as fluorodeoxyglucose (FDG), areas of the body containing such cells can be imaged. When positrons, which are subatomic particles attached to FDG, decay, gamma rays are produced. These rays are detected by a “gamma camera.” The image that is created is composed of a background of gamma rays coming from normal cells, reflecting normal metabolic activity, and a highly intense concentration of gamma rays coming from cells with an extremely high metabolic rate—cancer cells.

When should a PET scan be requested?

Medicare currently covers the following PET indications:

Evaluation of the solitary pulmonary nodule
Staging of non-small cell lung cancer
Detection and localization of recurrent colon cancer
Staging and characterizing of Hodgkins and non-Hodgkins lymphoma
Identification of metastatic disease from melanoma
Diagnosis and staging of esophageal cancer
Detection of head and neck cancer (excluding CNS and thyroid)
Restaging of breast cancer and distinguishing of scar from recurrent cancer
Presurgical evaluation of refractory seizures
Assessment of myocardial viability

Source: Medicare press release, http://www.cms.hhs.gov/media/press/release.

The indications for PET continue to expand.

Are there contraindications to PET scanning?

There are only a few contraindications to PET. Pregnancy is a relative contraindication. Always check with the radiologist before ordering a test that utilizes radiation on a pregnant patient.

What is PET/CT?

PET/CT is positron emission tomography combined with computed tomography. PET has the advantage of sensitivity for rapidly growing cancer cells, but it provides limited anatomic information. CT is excellent for clearly depicting anatomy, assessing tumor size, and accurately localizing the cancer, and is especially important for evaluating vital structures adjacent to the cancer. But CT cannot detect metabolic activity. PET/CT allows clinicians to see a fused image of physiologic and anatomic information.