Sonographic Image Interpretation

Sonograms are two-dimensional gray-scale images that allow assessment and diagnosis of many anatomic and pathologic changes that can occur in the human body. When most individuals, including many trained professionals, see a sonogram their first impression or comment is that the “picture” is of a liver, or of a baby, or of a blood vessel. In fact, that is not what a sonographic image is at all. A sonographic image is a visual display of the interaction of energy with matter; the energy being used is high-frequency sound waves, the matter that it interacts with are the various acoustic media through which it travels. Therefore, a sonogram is really a picture representing the physical phenomena occurring as the ultrasound beam propagates through and interacts with tissues in the human body. What we are seeing is not anatomy or pathology at all, what we are seeing is a “physics picture”. To understand this picture and to be able to accurately and competently make use of it in medical practice we must first understand the fundamental physical interactions that have been displayed and recorded.

Mastering sonographic interpretation skills begins with mastering the principles of the physical interactions of ultrasound with human tissue and ends with an assessment, statement, comment or diagnosis about what is happening in a particular patient. The steps between the beginning and the ending points in this process involve the rigorous practice of scientific observation of the information displayed and then relating it to a knowledge base of normal, abnormal and pathologic human anatomy and physiology. By integrating this interpretation methodology into his or her clinical performance, a sonography professional can become highly skilled and adept at making sense out of even the most obscure and abstract-looking sonogram. And this skill is indispensable in correctly laying out differential diagnoses when an abnormality is detected during a real-time sonographic examination.

It is important to note at the beginning of the study of sonographic interpretation, that sonography as a sole modality is rarely capable of making a specific histologic diagnosis in most cases of pathology.
**Morphology**

Morphology refers to the overall architectural appearance of an anatomic organ or pathologic structure. Overall appearance of such a structure consists of its external boundaries and shape (contour) and its internal architecture (echo pattern). For example, a normal kidney has a reniform (ovoid) shape with smooth, echogenic borders and an internal architecture that grossly resembles textbook kidney anatomy, i.e., echo-rich renal calyces and collecting system and echo-poor renal pyramids. This description of the sonographic appearance of a normal kidney is consistent with its gross anatomical appearance, or structural morphology. Similarly, an abscess can be described in sonographic terms that are consistent with its gross pathological appearance. For example, an irregularly marginated mass adjacent to the ovary with complex internal architecture might be how a pus and fluid-filled inflammatory mass in the adnexa would appear sonographically. In both cases, an analysis of the overall morphology represented on the sonogram provides essential information about the size, shape and location of the structure under scrutiny.

**Contour**

The contour of a structure refers to its shape, outline or boundaries. This includes not only the general shape of a structure, such as round, oval, or elliptical, but also the appearance of the margin of the structure. Most of the organs of the body have a fairly well-defined margin owing to the presence of a capsule. For example, both the liver and spleen have capsules and smooth, well-defined margins. These are portrayed on the ultrasound image as specular echoes surrounding the less echogenic parenchymal mass. Other normal organs, such as the pancreas, which do not have a capsule, do not have as well-defined margins, and thus normally have a poorly defined sonographic boundary. It must be remembered that the lack of a well-defined specular margin of an organ may indicate some pathologic change, but it also may, and more commonly does, indicate that the ultrasound beam was not aimed perpendicularly to that interface so that the specular echo was not recorded. In addition to terms describing the general shape of a particular structure, such terms as smooth-walled, irregular-walled, well-defined, or poorly-defined can describe the boundary.

In addition to contributing to the assessment of normal and anomalous anatomical structures, contour information also is essential in providing information about the
gross appearance of isolated pathologic structures or those seen within the parenchyma of an organ. Focal, well-marginated hyperechoic areas in the otherwise smooth appearing liver parenchyma may represent metastatic lesions or hemangiomas; indistinct, poorly marginated hyperechoic regions in the same liver may represent focal fatty infiltration. Many other examples of the importance of contour observations exist in interpreting a sonographic image, however, what is of general note is the overall shape and border configuration. This information frequently forms the basis for further investigation of a structure.

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Many qualities should be assessed when describing the internal echo pattern of a particular structure. The relative amplitude, or echogenicity, is very important. The amplitude of echoes coming from a structure can be varied by the settings of the gain, TGC and other imaging control parameters on the scanner. Because of this, the internal echo pattern of structures is primarily described relative to the echo pattern of adjacent structures. For example, if a patient is being examined to characterize the appearance of a mass lesion within the liver, the internal echo pattern of the mass would be related to the normal echo pattern in the liver. If the mass were more echogenic than the liver, i.e., the amplitude of the echoes within the mass were greater than the amplitude of the internal echoes of the liver, it would be described as hyperechoic. If the lesion contained lower-amplitude echoes than the normal liver, it would be described as hypoechoic or echopenic. If the lesion contained no echoes at all, it would be described an anechoic or sonolucent. These terms are used to describe the amplitude of internal echoes relative to some other reference structure.

It is also important to characterize the distribution of the internal echoes within a structure or mass. Not all structures have a uniform internal echo pattern. Referring to the example of a mass lesion within the liver, if the mass contains hyperechoic and hypoechoic areas, it would be described as a heterogeneous mass. If the mass is
uniformly hypoechoic or hyperechoic, then it is described as a **homogeneous** mass. When one examines the pathology of organs or structures that have a homogeneous internal echo pattern, the histological (tissue) appearance is usually very uniform. Heterogeneous lesions typically contain areas that differ from the basic underlying structure such as areas of hemorrhage, necrosis, fat or fibrin deposition within the mass itself or areas of different tissue types. Typical sonographic examples of heterogeneous appearance correlating with pathological appearance include uterine myomata (fibroids) and teratomas.

**Acoustic Physical Interactions**

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### Attenuation Characteristics

**INCREASED ATTENUATION**

To accurately characterize a structure sonographically, it is important to identify what happens to the intensity of a sound beam as it passes through the structure. If there is very poor transmission of sound through a mass, it is described as **highly attenuative** or **hyperattenuating**. This occurs in structures or masses that either reflect much of the sound back toward the transducer and allow very little sound to penetrate beyond the mass; that scatter the sound away from the transducer and thus inhibit further transmission of the sound beyond the mass; or that absorb significant amounts of the sound energy.

An excellent example of a hyperattenuating mass is a uterine fibroid. While the gross pathology of a fibroid is that of bundles of striated muscle fibers running in random directions, it’s sonographic appearance is not consistent with that found in other normal muscular structures. In fact, in most fibroids, it is impossible to obtain any sonographic detail about the internal architecture of the mass; rather, they appear as hypoechoic masses that attenuate ultrasound rapidly. This is the result of the excess muscle bundles, running randomly and frequently in arcs or circles, refracting significant quantities of the ultrasound beam. This increased internal refraction contributes to an overall increase in attenuation with a resultant hypoechoic, solid appearing mass.
POSTERIOR ACOUSTIC ENHANCEMENT

Structures, which allow a sound beam to pass through relatively unimpeded, give the appearance of *enhanced transmission* or posterior acoustic enhancement behind the mass. This quality is characteristic of fluid-filled or cystic structures. Ultrasound, upon entering a fluid filled structure, speeds up slightly and passes through the structure with virtually no attenuation. As a result, the intensity of the ultrasound beam impinging upon the back wall of the enhancing structure is almost as great as it is when entering it. The ultrasound energy passing through tissue adjacent to the fluid-filled structure is attenuated at a normal rate, therefore, at the same depth it appears less echogenic than the area behind the fluid. The presence of this bright, hyperechoic region behind any structure, normal or pathologic, is strong evidence that the structure has a significant fluid component to it.

The classic example of posterior acoustic enhancement is found behind the full urinary bladder. (This is one of the reasons, in fact, a full bladder is required prior to trans-abdominal gynecologic ultrasound examinations.) After passing through a full bladder, ultrasound enters the posterior pelvic structures with sufficient intensity to provide enough echo information to create diagnostic quality images. Without such an acoustic window, a significant proportion of the sound beam would be attenuated by anterior abdominal cavity structures and good quality images of the pelvic organs would be impossible. Another good example of the usefulness and importance of recognizing posterior acoustic enhancement is in sonographically identifying the ovaries. During the menstrual years, both ovaries produce small cystic follicles in varying size and number throughout each cycle. Since the follicles contain serous fluid they are, by physics standards, cysts. Even though the individual follicles may not be discernible, or resolvable, on the sonographic image, the presence of acoustic enhancement behind an avoid structure in the adnexa lends strong evidence to the conclusion that it is an ovary. Bowel loops, on the other hand, will not demonstrate posterior acoustic enhancement.
This Chapter has addressed some of the basic principles of sonographic image interpretation. One of the most difficult areas of ultrasound interpretation is the identification and characterization of image artifacts. **Ultrasound artifacts are defined as sonographic display anomalies caused by complex physical interactions between ultrasound, human soft tissue and the inherent limitations of imaging technology.** Failure to appreciate ultrasound artifacts can lead to confusion and errors in diagnosis. However, a basic understanding of artifacts and of the physical principles of their origin will not only allow their identification, but also, in some cases, will be essential to make the correct diagnosis. The importance of a good understanding of ultrasound artifacts cannot be overemphasized, and for this reason discussion of artifacts is included in this chapter.

**REVERBERATION**

Reverberation artifacts occur when sound is reflected back to the transducer from a very strongly reflective surface or from any two strongly reflective surfaces in close apposition in the body.

The initial sound wave emitted from the crystal is reflected from the strong reflector back to the transducer face. This causes an appropriate electric signal to be generated in the crystal which is recorded on the image. However, part of the reflected sound wave is, in turn, reflected from the transducer face back into the body. When it strikes the strongly reflective surface, it again reflects back to the transducer face, where another electric signal is recorded. If the sound wave is strong enough at this point, the phenomenon will repeat itself, with the beam reflecting off the transducer face, back into the body; reflecting off the reflective surface in the body, and back to the transducer again, where a third electric signal will be generated. This reverberation, or rebounding phenomenon, results in multiple linear echoes which parallel the transducer face/scan plane. These artifactual echoes are equally spaced, and the distance between each artifactual echo is equal to the distance between the transducer face and the strong reflector. The amplitude of each of the reverberatory echoes decreases as they are displayed distally.

Reverberation echoes are very common artifacts. They are most easily identifiable in cystic structures, since fluid-filled structures are anechoic. They can occur in solid structures as well, but are frequently masked by the inherent internal echo pattern of the solid structure. Reverberations are so common in superficial cystic structures that
they can be used to help characterize cystic masses and, more importantly, should not be misinterpreted as echoes generated from inside the cyst.

By far the greatest acoustic mismatch in the body occurs at soft tissue-air interfaces. When scanning the abdomen, this is most noticeable at the interface between the abdominal wall and air-containing bowel. Essentially all the sound is reflected at this interface, and the echoes that are seen beyond this interface are reverberatory in origin. The accompanying figure shows an example of reverberatory artifact due to air within the bowel. It is important to realize that the echoes located beyond the soft tissue-bowel interface are artifactual in origin and do not represent echoes generated from any structure beyond the interface. The soft tissue-bone interface encountered when scanning near the ribs can also produce reverberatory echoes, owing to the relatively superficial location of this interface within the body and the large acoustic impedance mismatch. The repetitive nature of the reverberatory artifact must be discriminated from internal echoes that are actually generated from the structures located beneath the ribs.

**POSTERIOR ACOUSTIC SHADOWING**

An acoustic shadow occurs when there is absence of sound distal to a reflector. Although acoustic shadows can obscure the sonographic visualization of structures, this artifact is an important diagnostic finding.

There are probably several physical phenomena which cause acoustic shadowing, including reflection, attenuation, and refraction. Acoustic shadows can result from ribs, calcified masses, or barium in the gastrointestinal tract. The acoustic shadow is caused both by the reflection of a large percentage the sound beam back to the transducer and by the absorption of the sound by the structure itself. These two mechanisms inhibit sound transmission through the structure, resulting in an acoustic shadow.

Acoustic shadows may also be identified at the margins of cystic or other curved structures. The mechanism of producing this type of acoustic shadowing, or edge effect, is probably a combination of refraction and reflection. When the sound passes through a cystic structure near its lateral border, it is refracted or its path is altered, owing to the differences in the velocity of sound in soft tissue and fluid. The beam is also diverted from its axial course by reflection at the margins of the cyst. The net
effect of the refraction and reflection is an acoustic shadow at the margin of the cyst. This type of shadow occurs with structures such as the gallbladder and cystic masses within solid organs.

Acoustic shadowing can be identified at the margins of round, non-cystic structures as well. This is most commonly demonstrated in obstetric scanning when acoustic shadows are identified at the margins of a transverse section of the fetal head. This type of acoustic shadow is probably due to reflection of the sound off the curved surface away from the transducer (critical angle). It has been shown that to demonstrate an acoustic shadow behind a gallstone, the gallstone must lie at a depth within the focal zone of the transducer; i.e., where the width of the beam is small relative to the size of the gallstone. If the gallstone lies proximal or distal to the focal zone of the transducer, the wide beam at these locations will mask the acoustic shadow. For this reason, it is particularly important to use a transducer of the appropriate focal length, or to position the patient so that the gallbladder is within the focal zone of the transducer to diagnose gallstones accurately.

SLICE THICKNESS ARTIFACT

The width of the beam at a particular depth can also create an artifact in the dependent area of fluid-containing spaces that may simulate debris. This has been termed slice-thickness artifact. This artifact is caused by the increased width of the beam beyond the focal zone of the transducer. The width of the beam is such that at the margins of curved fluid-containing spaces, portions of the wall as well as portions of the fluid are within the beam simultaneously. This creates meniscus-shaped artifactual echoes in the dependent areas of the fluid. This artifact is particularly identifiable on longitudinal scans of ascitic fluid in the pericolic gutters and on longitudinal scans along the lateral aspect of the urinary bladder. The meniscus-like appearance is a tip-off that these echoes are not real. In the image above, the arrow points to slice thickness artifact projected into the amniotic fluid near the curved uterine fundus. Slice-thickness artifact can be reduced or eliminated using newer probe designs, such as elevation array technology.
Classification of Structures

It is useful when evaluating ultrasound images to use a system to classify the various sonographic characteristics of structures. Doing this will provide semi-quantitative data that can be useful in arriving at a differential diagnosis. The classification system presented here, will be kept brief, realizing that the terms used will be used to describe a wide variety of both normal and pathologic sonographic appearances. These terms will incorporate three sonographic qualities: contour, internal echo pattern, and attenuation, which we have already discussed. While these classification terms are admittedly broad, they represent a basic interpretive vocabulary.

Cystic

Cystic structures are fluid-filled. Examples of normal cystic structures in the body include the urine-filled urinary bladder and the normal gallbladder. Cystic structures are usually smooth-walled and have well-defined borders. Because liquids are homogenous, there are no acoustic interfaces to generate internal echoes. Therefore, cystic structures are anechoic. The accompanying image demonstrates the sonographic findings of a cystic structure.

There is little or no attenuation of the sound as it passes through a cystic structure. This characteristic, combined with the amplification of sound as determined by the TGC curve, creates the appearance of enhanced transmission of the sound at the distal aspect of a cystic mass. This commonly used term, enhanced transmission (or posterior acoustic enhancement), is actually a misnomer. Cystic masses do not enhance the sound transmission, they simply do not attenuate the sound compared with adjacent solid structures. The TGC curve provides increased amplification of echoes as a function of distance from the transducer. The attenuation through the distance of the cystic structure compared with the attenuation through adjacent solid structures is much less. Therefore, the echoes originating from the area immediately distal to a cystic mass appear amplified disproportionately to the echoes of an adjacent solid structure at the same depth from the transducer.
is the phenomenon of lack of attenuation of sound in a cystic structure that leads to the appearance of enhanced through transmission.

**Solid**

Generally speaking, solid structures contain varying numbers and intensities of internal echoes. The internal echoes are generated by the multiple acoustic interfaces that exist in solid structures. When sound interacts with one of these diffuse reflectors, echoes are redirected in multiple directions in a process known as **scattering**. Only the echoes that are reflected back to the transducer are used in imaging. This is termed **backscatter**. The effects of these two processes, reflection and scattering, contribute to the overall attenuation of the ultrasound beam. Thus, there is usually no enhanced transmission distal to a solid structure, and, indeed, some solid structures will attenuate the sound greater than other adjacent solid structures. This is displayed as a “drop-out” of sound distally. The accompanying image demonstrates the sonographic findings of solid structures.

It is the appearance of internal echoes that characterizes the nature of a solid structure. Some organs in the body normally have a fine, homogeneous, low-amplitude echo pattern, such as the thyroid or testis. Other organs normally have a higher-amplitude internal echo architecture, such as the pancreas or the renal sinus of the kidney. Only after one has developed a thorough familiarity with the normal sonographic appearances of the organs of the body can one distinguish solid pathologic alterations in normal tissue.

Generally speaking, the term **texture** is applied to the distribution of echoes which are characterized by their amplitude and number within a small area of a structure. **Architecture** refers to the overall composition of an organ or structure. For example, the spleen has a normal texture of medium-amplitude echoes, which are evenly distributed throughout the entire organ, creating a homogeneous architecture. In comparison, the normal breast is composed of multiple tissue elements (fat, fibrous tissue, and glandular tissue). The fat normally has a low-amplitude, relatively homogeneous echo pattern or texture, whereas the fibrous tissue has a high-amplitude appearance and a more linear distribution. Glandular tissue has an echo amplitude level somewhere between that of fat and fibrous tissue, with a different distribution. It is this variety of textural patterns and distribution that produces the normal heterogeneous architecture of the breast.

Solid structures exist in all shapes and sizes and in all varieties of contour. Generally, smooth-walled solid structures have a specular boundary that can be demonstrated, whereas solid structures with irregular, poorly-defined walls or margins do not. The boundary between a solid lesion within a solid organ (such as metastatic tumor in the liver) can sometimes be discriminated only by the difference in texture between the normal liver and tumor.
It is worth noting that the generalizations used to sonographically discriminate cystic and solid structures are not always straightforward. There are solid structures or lesions that have a very homogeneous, low-amplitude internal echo pattern that can mimic cystic structures. Enlarged lymph nodes caused by lymphoma are a classic example. The small degree of reflectivity and the smooth-walled, sometimes round shape of these abnormal lymph nodes cause a “pseudocystic” appearance when compared with adjacent solid structures. However, when the sound transmission distal to a lymphomatous mass is compared with the sound transmission distal to a fluid-filled structure at the same distance from the transducer, one would see reduced sound transmission behind the lymphomatous mass compared with the fluid-filled structure. In defining cystic or solid structures, all of the criteria—contour, echo pattern, and attenuation—must be evaluated.

**Complex**

Complex structures are generally described as containing both cystic and solid elements. It is important to attempt to identify whether the mass or structure is predominantly solid and contains some fluid-filled or cystic areas or is predominantly cystic and contains some solid elements. This distinction will help to consider the diagnostic possibilities in a logical and meaningful manner. A predominantly cystic structure may be termed complex if it contains multiple septations, a dependent debris level, or solid elements projecting into its lumen. An otherwise solid structure may be termed complex if it contains areas of fluid within it due to areas of liquefactive necrosis or liquefied (lysed) hemorrhage. Some lesions have a complex sonographic appearance by their very nature, such as dermoids, which contain multiple tissue elements, some of which may be cystic and others solid. As with cystic and solid masses, it is important to describe the shape and appearance of the boundary of the mass. It is also important to attempt to characterize the boundaries of the cystic or solid elements within a complex lesion. Sound transmission characteristics behind complex masses vary depending on the path of the ultrasound beam. If the beam passes through a predominantly cystic area, there will be enhanced transmission of the sound distal to the mass in this area, while there may be evidence of sound attenuation distal to another area of the mass that is composed primarily of solid tissue.