Essentials of Sonographic Interpretation

Introduction

When most individuals, including many trained professionals, see a sonogram their first impression or comment is that it is a “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 is the high-frequency acoustic waves emitted from the transducer; the matter is the various layers of human soft tissue through which it travels. Therefore, a sonogram is really a picture that represents the physical phenomena occurring as the ultrasound beam propagates through 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 clinical practice we must first understand the fundamental physical interactions that are being displayed.

Mastering sonographic interpretation skills begins with an understanding of the principles of the physical interactions of ultrasound with human tissue and ends with a description, statement, comment or diagnosis about what is being displayed via the various imaging modalities. The steps between the beginning and the ending points in this process involve the rigorous practice of scientific observation of the displayed information and then relating it to a knowledge base of normal, anomalous, and pathologic human anatomy and physiology. By integrating this interpretation methodology into his/her clinical performance, the sonographer can become highly skilled and adept at making sense out of even the most obscure and abstract-looking “physics picture” (*sonogram*).

Image interpretation involves analyzing the following sonographic characteristics and findings:

- Structural morphology
  - Contour
  - Internal echo pattern
  - Focal vs. diffuse
- Acoustic physical interactions
  - Attenuation
  - Posterior acoustic enhancement
  - Posterior acoustic shadowing
- Classification of structures
  - Cystic
  - Solid
  - Complex

Structural Morphology

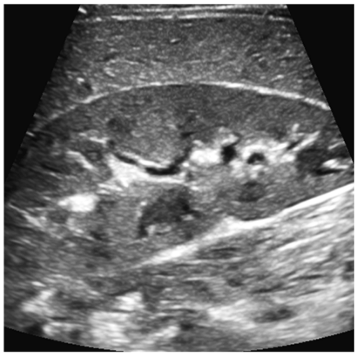
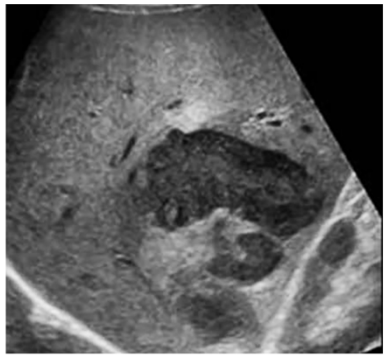
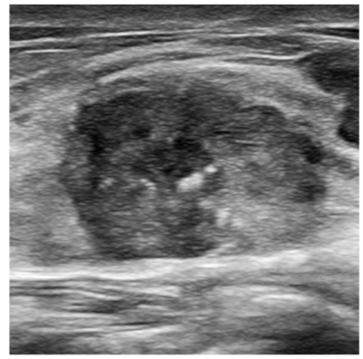
Morphology refers to the overall appearance of an anatomic organ or pathologic structure. The global sonographic appearance of a structure consists of its external boundaries and shape (***contour***) and its interior architecture (***internal echo pattern***). For example, a normal kidney has a reniform (*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 a complex internal echo pattern corresponds to how a pus and fluid-filled inflammatory mass in the adnexa appears the eye (*gross pathology*). In both cases, an analysis and description of the sonographic morphology of the structure being examined provides essential information about its size, shape, and location. Critical data in reaching a final sonographic conclusion and/or diagnosis.

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 anatomical organs in the human body have a fairly well-defined margin owing to the presence of an exterior capsule. For example, the liver, spleen, and kidneys have capsules and subsequently, present smooth, well-defined margins. These borders are portrayed on the ultrasound image as a thin layer of bright specular echoes surrounding the less echogenic parenchymal tissue. Other normal organs, such as the pancreas and thyroid, which do not have connective tissue capsules, generally have a less well-defined sonographic boundary. It must be remembered that the lack of a well-defined specular margin of a structure may indicate some pathologic change, but it may also, and more commonly does, indicate that the ultrasound beam was not directed perpendicularly to the capsular interface. Normal, or perpendicular incidence, is necessary to produce clean, bright specular reflections. Contour boundaries can be described as:

- Smoothly marginated
- Irregularly marginated
- Well-defined
- Poorly defined

Contour - Margins

Smoothly marginated Well-defined	Irregularly marginated Well-defined	Irregularly marginated Poorly-defined
		
Renal capsule	Liver abscess	Breast malignancy

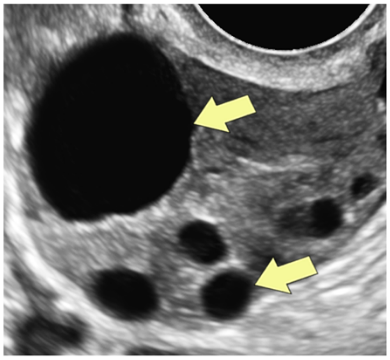
Internal Echo Pattern

The internal echo pattern of a structure is a particularly important characteristic in interpreting a sonographic image. The relative amplitude, or ***echogenicity***, is fundamental. The amplitude of echoes coming from a structure can be adjusted by the operator using overall gain, TGC and other imaging control parameters. Because of this subjective variation, the internal echo pattern of structures is typically 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 described as relative 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.

Echogenicity - Terminology	
Echogenic	Producing echoes (*returning acoustic data*)
Anechoic Sonolucent	**Absence** of echoes (*acoustic data*) in a structure
Hyperechoic	A relative **increase** in amplitude of returning echoes (*acoustic data*)
Hypoechoic Echopenic	A relative **decrease** in amplitude of returning echoes (*acoustic data*)

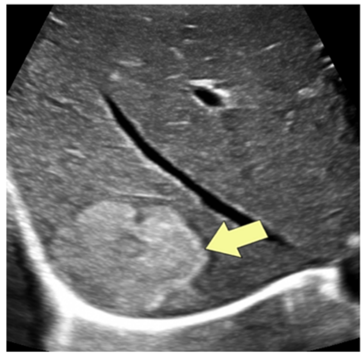
Echogenicity - Image Examples

Anechoic - Sonolucent



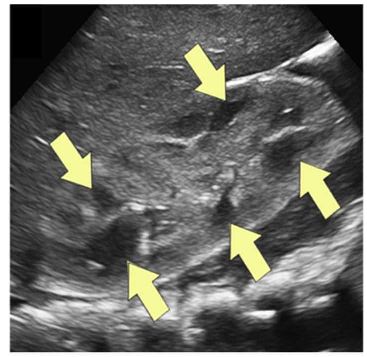
Ovarian follicles

Hyperechoic



Hepatic hemangioma

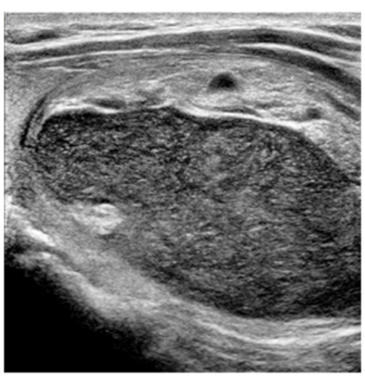
Hypoechoic - Echopenic



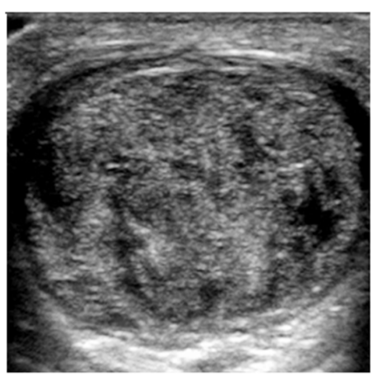
Renal pyramids

It is also important to characterize the distribution and arrangement of the internal echoes within a structure. Generally, a structure that contains a mix of hyperechoic and hypoechoic areas, would be described as ***heterogeneous.*** Heterogeneous structures may also contain anechoic areas and specular reflections arranged in a seemingly random pattern. If a structure appears uniformly echogenic (*hypoechoic or hyperechoic*) then it is described as ***homogeneous***. In organs or structures with a homogeneous internal echo pattern, the histological (*tissue*) appearance is very uniform. Heterogeneous areas in an otherwise homogeneous organ usually represent areas with different underlying tissue architecture such as areas of hemorrhage, necrosis, fat, or fibrin deposition. Typical sonographic examples of heterogeneous appearance correlating with pathological appearance include uterine myomata (*fibroids*) and teratomas.

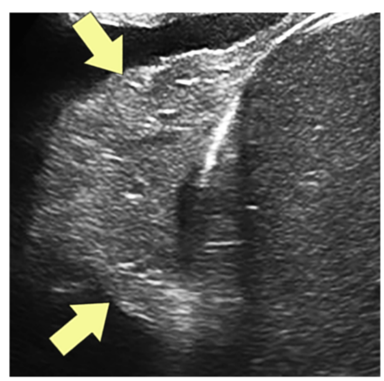
Heterogeneous - Image Examples



Thyroid nodule



Inflamed Achille's tendon

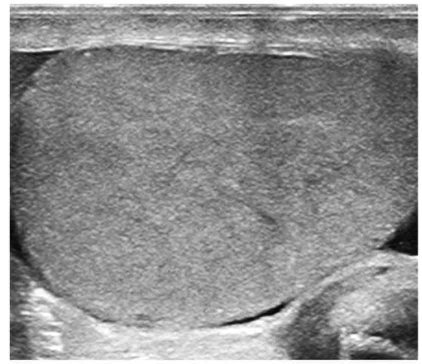


Consolidated lung

Homogeneous - Image Examples

Normal liver tissue

Normal placenta



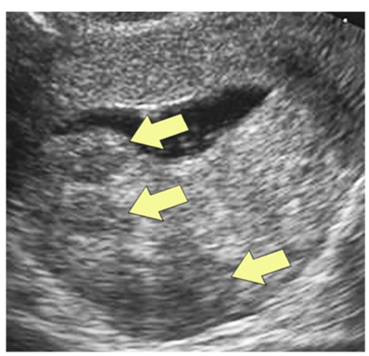
Normal testicular tissue

Focal vs. Diffuse

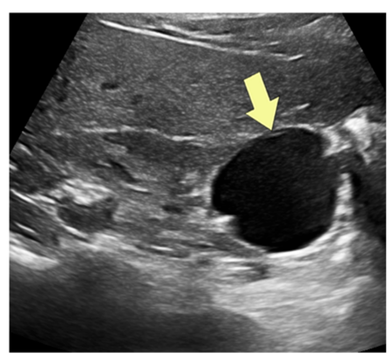
Alterations in the contour and internal echo pattern associated with a solid structure can further be described as either focal or diffuse. This distinction provides significant information about pathological changes that may be present, particularly in solid parenchymal organs. In a **diffuse** presentation, alterations in sonographic appearance are dispersed evenly throughout a structure and typically represent histological changes that affect the entire organ. Examples include fatty infiltration or cirrhotic changes in the liver, testicular microlithiasis, and diffuse inflammatory diseases. A **focal** sonographic finding describes a region in a solid structure that is discrete, well-marginated and of differing echogenicity than that of the surrounding tissue. Focal changes may present as hyper-, hypo-, anechoic or any combination thereof. As one would expect, they are associated with localized alterations in tissue composition. Examples include benign and malignant liver tumors, uterine fibroids, and cysts.

Focal Imaging Findings

Liver tumor
(*Hepatocellular carcinoma*)

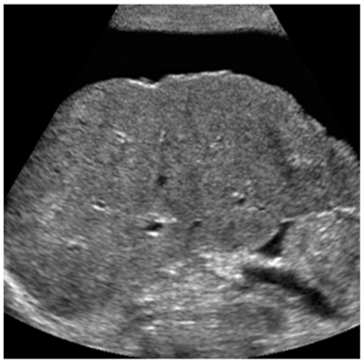


Focal uterine fibroids

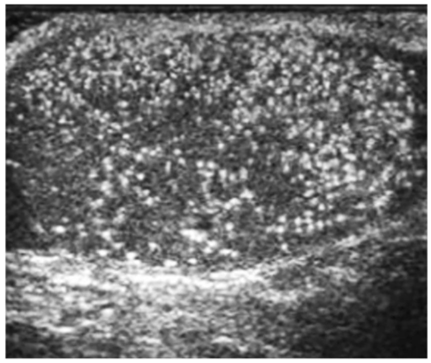


Renal cyst

Diffuse Imaging Findings



Cirrhotic liver



Testicular microlithiasis

Abdominal lymphoma

Acoustic Physical Interactions - Attenuation

It is the predictable interaction of acoustic energy with human soft tissue that generates the input used in creating sonographic images. Specular and non-specular reflection, speckle, and scattering provide the myriad data points that form the foundation of each individual imaging frame. Other phenomena, usually considered undesirable in sonographic imaging, also provide useful information when interpreting grayscale images. They are all related to the process of attenuation, or lack thereof, whereby the magnitude of acoustic energy is either diminished or enhanced as it propagates through the human body.

Attenuation is the decrease in amplitude and intensity of a sound wave as it is transmitted through a medium. While the conversion of acoustic energy into heat (*absorption*) accounts for about 80% of the attenuative process, reflection, refraction, and scattering contribute the remaining 20%. Normal soft tissues demonstrate a predictable degree of attenuation, a process compensated for by the use of imaging system gain controls. However, changes in the histological composition of a particular tissue type are frequently associated with a significant alteration in the degree of attenuation. To accurately characterize a structure sonographically, it is important to recognize these diffuse or focal changes. Several phenomena contribute to this effect and include:

- **Absorption:** of significant amounts of the acoustic energy
- **Reflection:** both specular and non-specular
- **Refraction**: portions of the beam bent away from incident transmission
- **Scattering:** occurs when the acoustic wavefront encounters rough, irregular interfaces or structures smaller than the wavelength

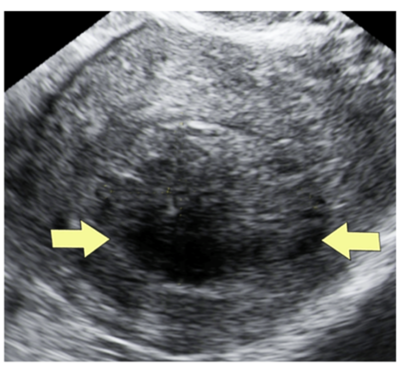
There are two variations on how tissue types affect the attenuative process: those that increase attenuation (*hyperattenuation*) and those that reduce it and enhance acoustic transmission (*increased through transmission*).

Hyperattenuation

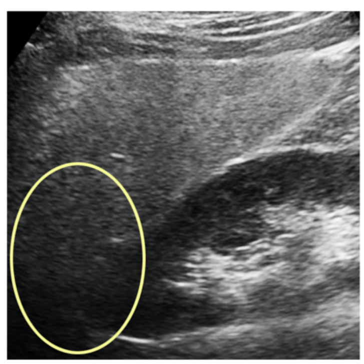
If there is an excessive loss of acoustic energy as it propagates through a tissue bed it is described as being highly attenuative or **hyperattenuating**. The notable characteristic, then, of hyperattenuating structures is that they appear “darker” on a grayscale image. It seems harder to penetrate the region of interest and overall image quality suffers. Observation of this effect provides information about the histological nature of the tissue. First, it is not normal. There is some obvious alteration in the architecture of the tissue that augments the physical phenomena noted above.

An excellent example of a hyperattenuating structure is a uterine fibroid. While the gross pathology of a fibroid is that of bundles of striated muscle fibers arranged and running in random directions, the sonographic appearance is not consistent with that seen in the normal uterine myometrium (*muscular layer*). In fact, in most fibroids, it is impossible to obtain any sonographic detail about the internal architecture of the mass at all. Rather, fibroids appear as hypoechoic masses that attenuate ultrasound rapidly. This appearance is the result of the abnormal and eccentric muscle-tissue bundles, running randomly and frequently in arcs or circles, reflecting, refracting, and scattering significant quantities of the ultrasound beam at these curved interfaces. This increased internal refraction contributes to an overall increase in attenuation with a resultant hypoechoic, solid appearing mass. Other common clinical examples of hyperattenuating structures include fatty infiltration of the liver and solid neoplastic lesions.

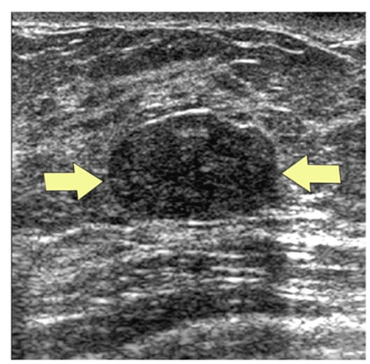
Hyperattenuation - Image Examples



Uterine fibroid



Fatty liver



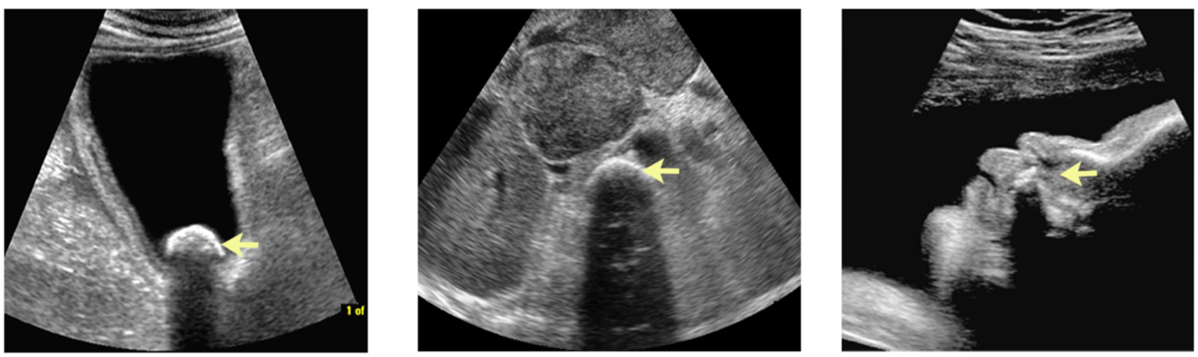
Solid breast lesion

Posterior Acoustic Shadowing

An exaggerated manifestation of hyperattenuation is a phenomenon called **posterior acoustic shadowing.** When the sound beam encounters an interface that both absorbs and reflects a significant proportion of the transmitted acoustic energy, little energy remains to travel beyond the interface. Other physical phenomena, such as refraction and redirection of transverse waves, also contribute to the drop in transmitted energy. As a large quantity of acoustic energy is consumed at these strong interface surfaces, little energy remains to travel deeper into tissue and continue the imaging process. The result is an area of acoustic drop-out distant to the interface which appears on the image as a shadow.

The presence of an acoustic shadow provides useful information about the composition of the structure from which it originates. The most common source of a shadow is the presence of calcium or other highly attenuative materials such as cholesterol, lipids, and uric acid crystals. Calcium is universally present in bony structures and is a common component of some types of calculi (*stones*) in the kidneys and gall bladder. It is also a frequent component of various neoplastic and chronic inflammatory processes. Some clinical examples of pathologic entities that cast a posterior acoustic shadow include atheromatous arterial plaques, teratomas, chronic abscesses, and chronic pancreatitis.

Posterior Acoustic Shadowing

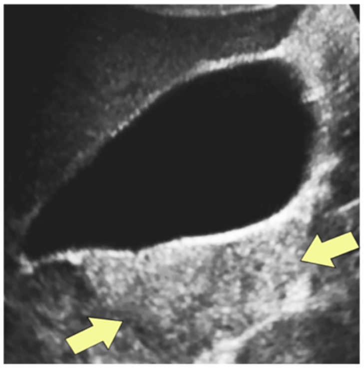


Gall stone   Vertebral body   Fetal maxilla

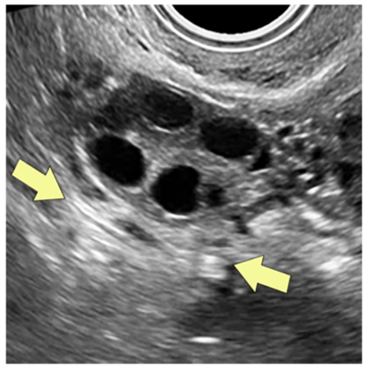
Posterior Acoustic Enhancement

Posterior acoustic enhancement is a physical phenomenon opposite to shadowing. As an acoustic beam of given amplitude encounters a structure that is less attenuating than adjacent soft tissue, it continues to propagate through the structure unimpeded. As the beam exits the structure, the intensity remains strong enough to produce high amplitude echoes as it encounters interfaces deep to the structure. As a result, the echogenicity of the area behind the structure appears increased compared to adjacent tissue areas. This area of increased echogenicity is called an area of posterior acoustic enhancement or of “enhanced through-transmission”. Posterior acoustic enhancement is strong evidence of the presence of a fluid-filled structure and is normally seen, for example, behind the gall bladder or a simple cyst. The presence of enhancement behind other complex or echo-filled masses is evidence that the mass has a definite fluid component or significant water content. Other common examples of structures that enhance include normal follicle-filled ovaries, hematomas, and abscesses.

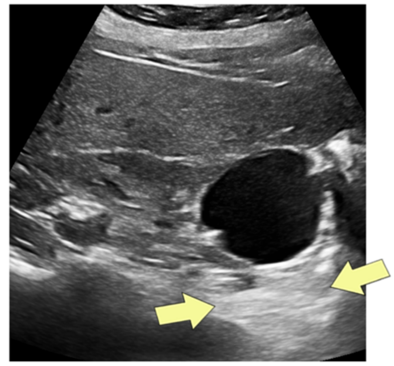
Posterior Acoustic Enhancement



Behind the gall bladder



Behind a normal follicle-containing ovary



Behind a renal cyst

Acoustic Physical Interactions – Image Artifacts

As a rule, artifacts can degrade the quality of a sonographic image or confuse its proper interpretation. However, there are two specific artifacts that can be useful in identifying and differentiating certain substances that are not normally present in human soft tissue.

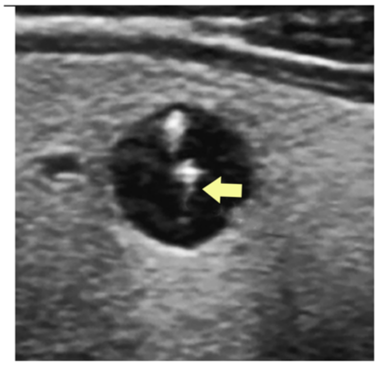
Comet-tail Artifact

Comet-tails are a variant of conventional reverberation artifacts. They originate from small, highly reflective interfaces that are too closely spaced to be resolved individually. As a result, the displayed "ringing" from these robust reflectors appears as a high amplitude "tail", not the equally spaced, linear artifacts associated with reverberation. Additionally, attenuation of the continued ringing results in a progressive diminution of both amplitude and width creating the tapering, echogenic triangle that resembles a comet tail. They are more frequently seen in otherwise anechoic areas on an image. Comet-tail artifacts are clinically useful, particularly in identifying cholesterol crystals in adenomyomatosis of the gallbladder or inspissated colloid in benign colloid nodules of the thyroid. They may also be seen with small calcifications and metal objects, such as foreign bodies and surgical clips.

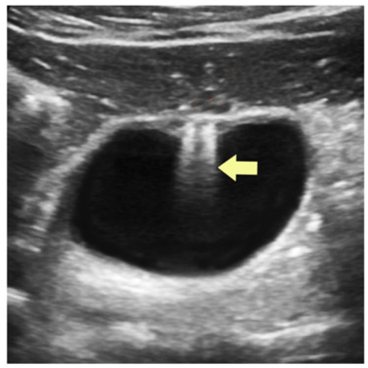
Ring-down Artifact

Ring-down artifact is similar in nature to comet-tails, but the causative mechanism is completely different. When an acoustic wavefront encounters small air bubbles trapped within a fluid collection, the bubbles begin to oscillate. This physical response is similar to that which occurs between acoustic energy and the microbubbles used in contrast-enhanced ultrasound. The resonating air bubbles create both nonlinear and harmonic responses which, in contrast-enhanced ultrasound applications, can be captured, processed, and put to good use. In grayscale imaging, however, these resonant vibrations produce a continuous, though decaying, stream of acoustic energy displayed on the image as a fuzzy streak deep to the point source. Ring-down artifact is only associated gas bubbles enclosed within a fluid collection. As such, they can be useful in identifying the abnormal presence of air that may be associated with pathological conditions such as pneumoperitoneum, portal venous gas, and emphysematous (*gas-forming*) infections and abscesses.

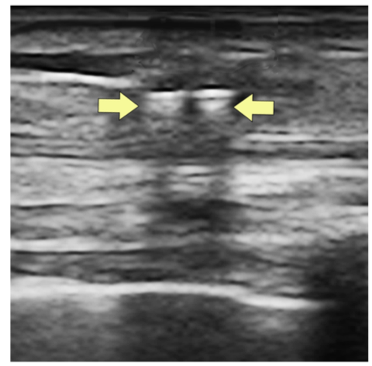
Comet Tail Artifact



Thyroid colloid cyst

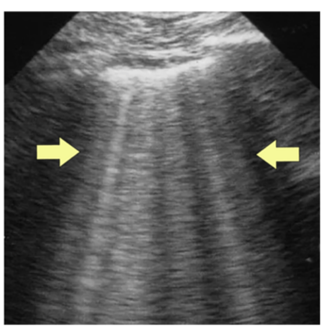


Gall bladder adenomyomatosis

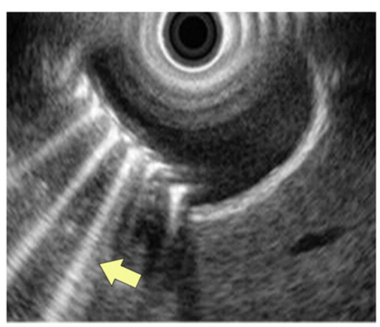


Subcutaneous surgical clips

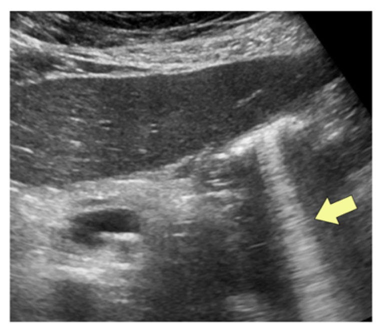
Ring-down Artifact



Lung/pleura interface



Gall stones - endoscopic



Gas in duodenum

Classification of Structures

A useful tool in interpreting an ultrasound image is the use of a system of classification based the various sonographic characteristics. These terms will incorporate three sonographic qualities: contour, internal echo pattern and attenuation, which have already been discussed. While these classification terms are admittedly broad, they represent a basic interpretive vocabulary.

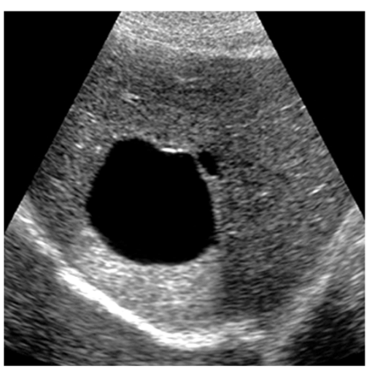
Cystic

Cystic structures are fluid-filled. Examples of normal cystic anatomical structures in the body include the urine-filled bladder, the eye, and a normal gallbladder. Cystic structures are usually smooth-walled and have well-defined borders. The content of simple cystic structures in the body is essentially water-based regardless of whether the source is exudate, transudate, or an excretory by-product. There may be biochemical variations in the composition of these fluids, but they all behave acoustically like water. Because the content of a cystic structure is by nature a homogenous fluid, there are no acoustic interfaces within to generate echoes leaving the structure echo-free or anechoic. The presence of posterior acoustic enhancement behind the cyst confirms the fluid-filled nature of the structure being imaged.

Classic sonographic characteristics of a simple cystic structure are:

- Distinct borders
- Anechoic interior
- Posterior acoustic enhancement

Cystic - Image Findings



Liver cyst

Dilated renal pelvis
(hydronephrosis)

Breast cyst

Solid

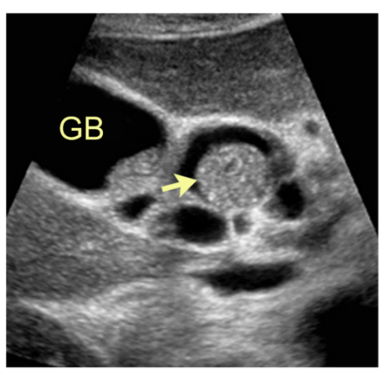
Generally speaking, solid structures contain varying numbers and intensities of internal echoes. These echoes are generated by the myriad acoustic interfaces present within. When ultrasound interacts with these diffuse reflectors, echoes are dispersed omni-directionally in a process known as **scattering**. Only the echoes that are reflected back toward the transducer are used in imaging. This is called **backscatter**. The effects of these two processes, reflection and scattering, is the attenuation of the acoustic beam. Unlike cystic structures, there is no posterior acoustic enhancement seen behind a solid structure. In fact, most, but not all, solid structures attenuate ultrasound energy at a higher rate than adjacent soft tissue. This increased internal attenuation may result in a "drop-out" of acoustic energy creating an echopenic area behind the structure.

The accompanying images demonstrate sonographic findings associated with several different solid structures. It is the appearance of internal echoes and the absence of posterior acoustic enhancement that characterize a solid structure on sonographic images. Solid structures come in all shapes, sizes, and contours. 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 some tumors in the liver*) can sometimes be discriminated only by the difference in texture between the normal liver parenchyma and the tumor.

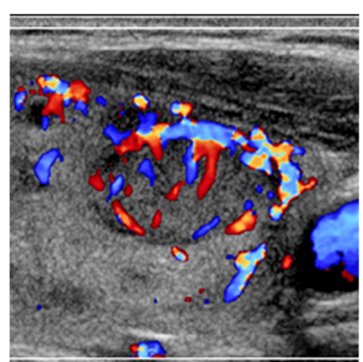
It is worth noting that the generalizations used to sonographically discriminate cystic and solid structures are not always straightforward. There are solid structures or lesions that have a very homogeneous, low-amplitude internal echo pattern that can mimic cystic structures. Enlarged lymph nodes caused 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. In defining cystic or solid structures, all of the criteria—contour; echo pattern, and attenuation—must be evaluated.

Solid - Image Findings


Normal prostate gland
(*transrectal imaging*)



Solid bile duct tumor

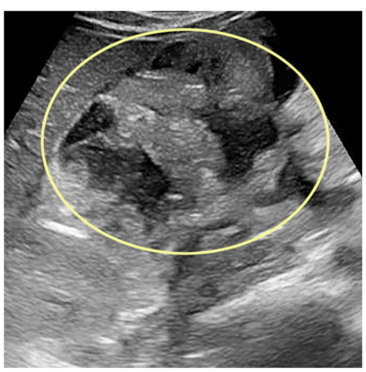

Vascularized thyroid nodule

Complex

Complex structures are generally described as containing both cystic and solid elements. From a clinical perspective, 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 called 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 dermoid tumors, 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 posterior acoustic enhancement of the acoustic energy sound behind to the mass in this area, while there may be evidence of acoustic attenuation distant to another area of the mass that is composed primarily of solid tissue.

Complex - Image Findings



Ruptured gall bladder

Hematoma in splenic capsule

Necrotic metastatic tumor in the liver