

# Essentials of Sonographic Image Interpretation

FOUNDATIONS FOR CONFIDENT,  
CLINICALLY RELEVANT ULTRASOUND ANALYSIS

ANATOMY  
PHYSICS  
CLINICAL INSIGHT



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SonoScholar Publishing

Educational Resources for Sonography Professionals



## Introduction

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When most individuals, including many trained professionals, first view a sonogram, their immediate impression is that they are looking at a “picture” of a liver, a baby, or a blood vessel. In reality, that is not what a sonographic image is. A sonographic image is a visual display of the interaction of energy with matter. The energy is the high-frequency acoustic wave emitted by the transducer; the matter is the multiple layers of human soft tissue through which that wave travels.

Therefore, a sonogram is best understood as an image that represents the physical phenomena occurring as the ultrasound beam propagates through the tissues of the human body. What is displayed is not anatomy or pathology directly, but a pattern of acoustic information produced by tissue interaction. In this sense, a sonogram is a **physics picture**. To understand this picture, and to use it accurately and competently in clinical practice, the sonographer must first understand the fundamental physical interactions being displayed.

Mastering sonographic interpretation begins with an understanding of the physical interaction of ultrasound with human tissue and progresses toward a meaningful description, statement, impression, or diagnosis of what is displayed by the various imaging modalities. The steps between these beginning and ending points require the disciplined practice of scientific observation: assessing the displayed information, recognizing patterns, and relating those patterns to a knowledge base of normal, anomalous, and pathologic human anatomy and physiology. By integrating this interpretive methodology into clinical performance, the sonographer develops the ability to make sense of even complex or unfamiliar images and to contribute meaningful, clinically relevant findings to the diagnostic process.

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. In sonography, the global appearance of a structure is determined by two broad features: its external boundaries and shape, or **contour**, and its internal architecture, or **internal echo pattern**. For example, a normal kidney has a reniform, or ovoid, shape with smooth echogenic borders. Its internal architecture grossly resembles textbook renal anatomy, with an echogenic renal sinus and collecting system surrounded by relatively echo-poor renal pyramids. This sonographic appearance is consistent with the kidney's gross anatomic structure and is therefore a description of its **structural morphology**.

Similarly, an abscess can be described in sonographic terms that correspond to its gross pathologic appearance. For example, an irregularly marginated mass adjacent to the ovary with a complex internal echo pattern is consistent with the expected appearance of a pus- and fluid-filled inflammatory mass in the adnexa. In this case, the sonographic morphology reflects the underlying pathologic structure. In both normal and abnormal findings, analysis of structural morphology provides essential information about the size, shape, contour, internal architecture, and location of the structure being examined. These observations provide critical data used in forming a final sonographic impression, conclusion, or diagnosis.

### Contour

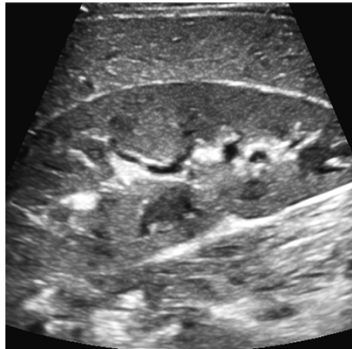
The contour of a structure refers to its shape, outline, and boundaries. This includes the general shape of the structure, such as round, oval, or elliptical, as well as the appearance of its margins. Most anatomic organs in the human body have fairly well-defined margins because they are surrounded by an external capsule or connective tissue covering. For example, the liver, spleen, and kidneys have capsular surfaces and therefore tend to demonstrate smooth, well-defined borders. On the ultrasound image, these boundaries are often displayed as a thin layer of bright specular echoes surrounding the less echogenic parenchymal tissue. Other normal organs, such as the pancreas and thyroid, do not have the same type of well-defined connective tissue capsule. As a result, their sonographic boundaries may appear less distinct, even in the absence of disease.

It is important to remember that the absence of a clean, bright specular margin does not automatically indicate pathology. A poorly defined boundary may reflect pathologic change, but more commonly it may simply indicate that the ultrasound beam was not directed perpendicular to the capsular interface. Normal, or perpendicular, incidence is required to produce a strong specular reflection. When the beam strikes a smooth boundary obliquely, much of the reflected sound is redirected away from the transducer, and the margin may appear less distinct. Contour boundaries are commonly described as:

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

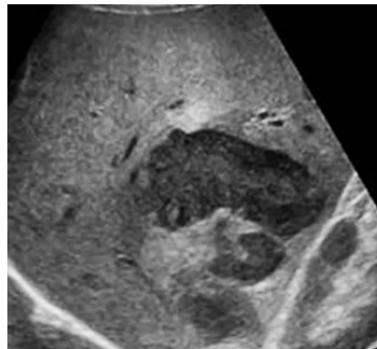
### Contour - Margins

Smoothly marginated  
Well-defined



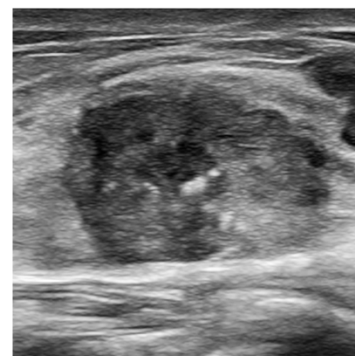
Renal capsule

Irregularly marginated  
Well-defined



Liver abscess

Irregularly marginated  
Poorly-defined



Breast malignancy

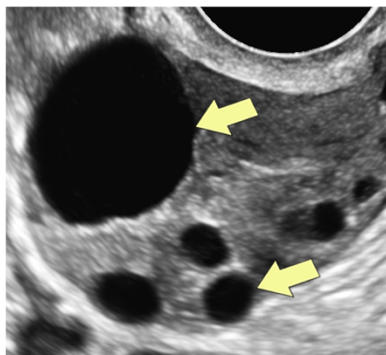
### Internal Echo Pattern

The internal echo pattern of a structure is one of the most important characteristics used in sonographic image interpretation. A fundamental component of this pattern is **echogenicity**, which refers to the relative amplitude of echoes returning from within a structure. The amplitude of displayed echoes can be influenced by the operator through overall gain, time gain compensation, and other imaging control settings. Because these adjustments can alter the apparent brightness of a structure, internal echo patterns are usually described **relative to adjacent tissue or another appropriate reference structure**. For example, when characterizing a mass within the liver, the internal echo pattern of the mass is described in relation to the surrounding normal liver parenchyma. If the mass produces echoes of greater amplitude than the adjacent liver tissue, it is described as **hyperechoic**. If the lesion produces echoes of lower amplitude than the surrounding liver, it is described as **hypoechoic**, or **echopenic**. If the lesion produces no internal echoes, it is described as **anechoic**, or **sonolucent**. These terms are used to describe the relative amplitude of internal echoes and should always be understood in comparison to a reference tissue or structure.

| Echogenicity - Terminology |                                                                                      |
|----------------------------|--------------------------------------------------------------------------------------|
| Echogenic                  | Producing echoes ( <i>returning acoustic data</i> )                                  |
| Anechoic<br>Sonolucent     | <b>Absence</b> of echoes ( <i>acoustic data</i> ) in a structure                     |
| Hyperechoic                | A relative <b>increase</b> in amplitude of returning echoes ( <i>acoustic data</i> ) |
| Hypoechoic<br>Echopenic    | A relative <b>decrease</b> in amplitude of returning echoes ( <i>acoustic data</i> ) |

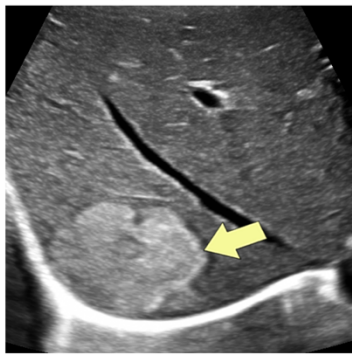
## Echogenicity - Image Examples

Anechoic - Sonolucent



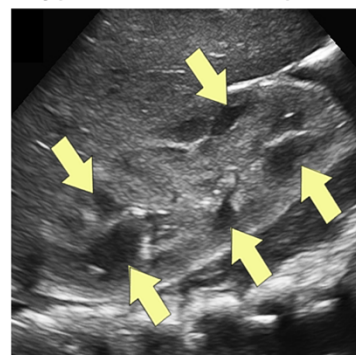
Ovarian follicles

Hyperechoic



Hepatic hemangioma

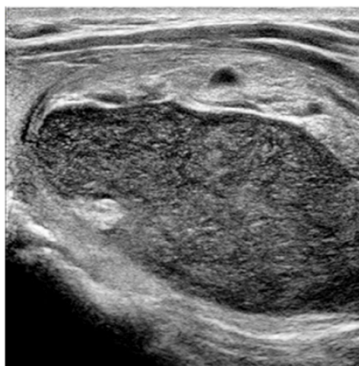
Hypoechoic - Echopenic



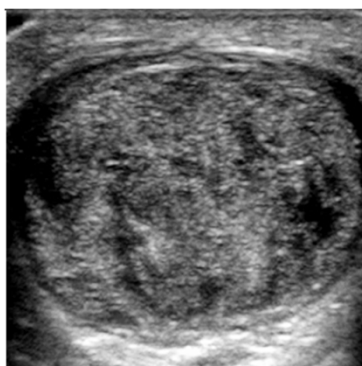
Renal pyramids

It is also important to characterize the **distribution and arrangement** of the internal echoes within a structure. This aspect of the internal echo pattern is commonly described in terms of **texture**. A structure that contains a mixture of hyperechoic and hypoechoic areas is described as **heterogeneous**. Heterogeneous structures may also contain anechoic areas, specular reflections, or irregular echo components arranged in a seemingly random or nonuniform pattern. In contrast, a structure that demonstrates a uniform internal echo pattern is described as **homogeneous**. A homogeneous structure may be uniformly hypoechoic, isoechoic, or hyperechoic relative to a reference tissue, but the key feature is that the echogenicity and echotexture remain consistent throughout the structure. In organs or structures with a homogeneous internal echo pattern, the underlying histologic architecture is typically uniform. Heterogeneous areas within an otherwise homogeneous organ usually represent regions with different tissue composition or organization. These may include areas of hemorrhage, necrosis, fat deposition, fibrin deposition, inflammation, or other structural change. Common sonographic examples of heterogeneous lesions that correlate with complex underlying pathology include uterine myomata, or fibroids, and teratomas.

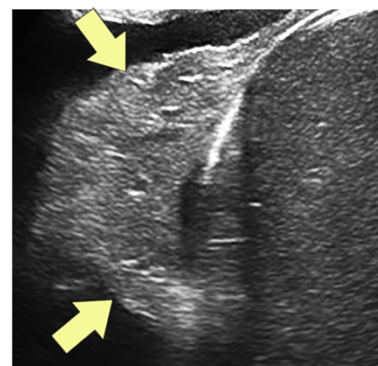
## Heterogeneous - Image Examples



Thyroid nodule



Inflamed Achille's tendon



Consolidated lung

## Homogeneous - Image Examples



Normal liver tissue



Normal placenta

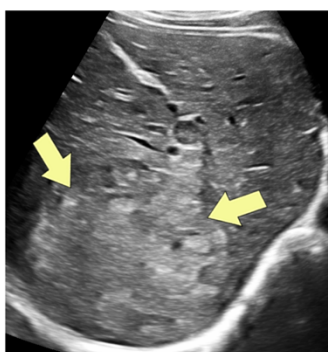


Normal testicular tissue

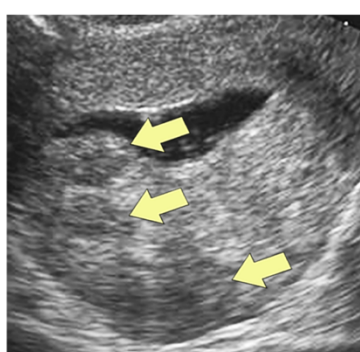
## Focal vs. Diffuse

Alterations in contour and internal echo pattern within a solid structure may be further described as either **focal** or **diffuse**. This distinction provides important information about the type and distribution of pathologic change, particularly in solid parenchymal organs. A **diffuse** sonographic presentation describes alterations that are distributed broadly and relatively evenly throughout a structure. Diffuse changes typically reflect histologic alterations that affect most or all of the organ. Examples include fatty infiltration or cirrhotic change in the liver, testicular microlithiasis, and diffuse inflammatory disease. A **focal** sonographic finding describes a localized, discrete region within a solid structure that differs in echogenicity or architecture from the surrounding tissue. Focal findings may be hyperechoic, hypoechoic, anechoic, or mixed in appearance. As expected, they are associated with localized changes in tissue composition or organization. Examples of focal findings include benign and malignant liver tumors, uterine fibroids, and cysts. In each case, the distinction between focal and diffuse involvement helps the sonographer describe not only what is seen, but how the abnormality is distributed within the organ or structure being examined.

## Focal Imaging Findings



Liver tumor  
(Hepatocellular carcinoma)

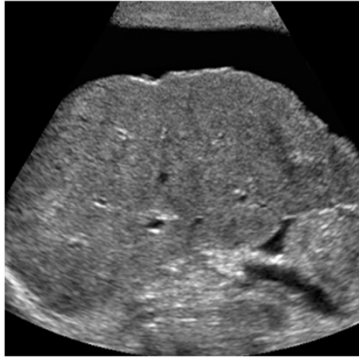


Focal uterine fibroids

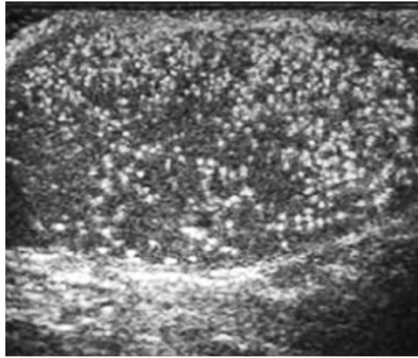


Renal cyst

### Diffuse Imaging Findings



Cirrhotic liver



Testicular microlithiasis



Abdominal lymphoma

## Acoustic Physical Interactions - Attenuation

The predictable interaction of acoustic energy with human soft tissue generates the acoustic information used to create sonographic images. Specular reflection, non-specular reflection, speckle, and scattering provide the numerous data points that form the foundation of each individual imaging frame. Other acoustic phenomena, often considered undesirable in routine image formation, also provide useful information when interpreting grayscale images. Many of these effects are related to attenuation, or to differences in attenuation, as acoustic energy propagates through the human body.

**Attenuation** is the decrease in amplitude and intensity of a sound wave as it is transmitted through a medium. Absorption, the conversion of acoustic energy into heat, accounts for most of the attenuative process. Reflection, refraction, and scattering also contribute to the overall loss of transmitted acoustic energy. Normal soft tissues demonstrate a predictable degree of attenuation, which is partially compensated for by the use of imaging system gain controls. However, changes in the histologic composition of a tissue are frequently associated with a significant alteration in the degree of attenuation. To accurately characterize a structure sonographically, the sonographer must recognize these focal or diffuse changes and understand how they affect the appearance of the displayed image.

- **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

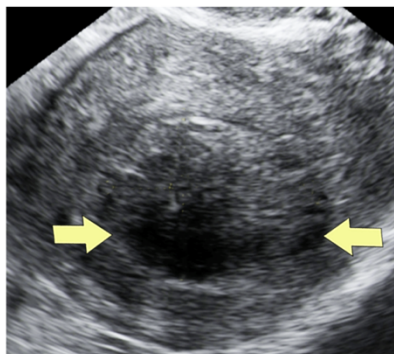
Together, these interactions influence how much acoustic energy returns to the transducer, how much continues deeper into the body, and how tissues and structures are represented on the grayscale image. There are two variations on how tissue types affect the attenuative process: those that increase attenuation (*hyperattenuation*) and those that reduce it and enhance acoustic transmission (*increased through transmission*).

## Hyperattenuation

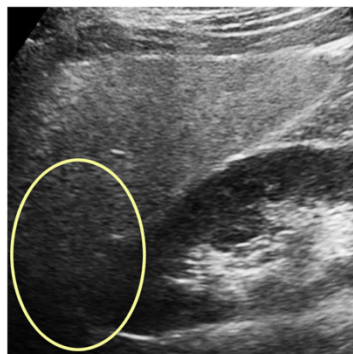
When there is excessive loss of acoustic energy as the ultrasound beam propagates through a tissue bed, the tissue is described as **highly attenuative** or **hyperattenuating**. The most notable sonographic characteristic of a hyperattenuating structure is that it appears relatively “dark” on the grayscale image. The region may seem difficult to image at depth, and overall image quality is often reduced. Recognition of this effect provides important information about the histologic nature of the tissue being examined. Hyperattenuation is not a normal imaging behavior for most soft tissues. It indicates some alteration in tissue composition or architecture that increases absorption, reflection, refraction, scattering, or some combination of these interactions.

A common example of a hyperattenuating structure is a uterine fibroid. Grossly, a fibroid is composed of bundles of smooth muscle fibers arranged in a disorganized and often whorled pattern. This pathologic architecture differs from the more uniform appearance of normal uterine myometrium. Sonographically, many fibroids provide little internal architectural detail. Instead, they often appear as hypoechoic solid masses that attenuate the ultrasound beam rapidly. This appearance is produced by the abnormal arrangement of muscle-tissue bundles within the fibroid. These bundles run in irregular directions and frequently form curved or circular interfaces. As the sound beam encounters these interfaces, significant portions of the beam are reflected, refracted, and scattered. The resulting increase in internal beam redirection contributes to greater attenuation and produces the characteristic hypoechoic, solid appearance of many fibroids. Other common clinical examples of hyperattenuating tissues or structures include fatty infiltration of the liver and some solid neoplastic lesions.

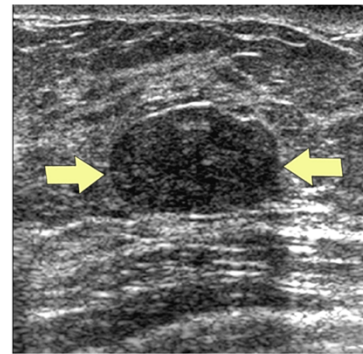
### Hyperattenuation - Image Examples



Uterine fibroid



Fatty liver

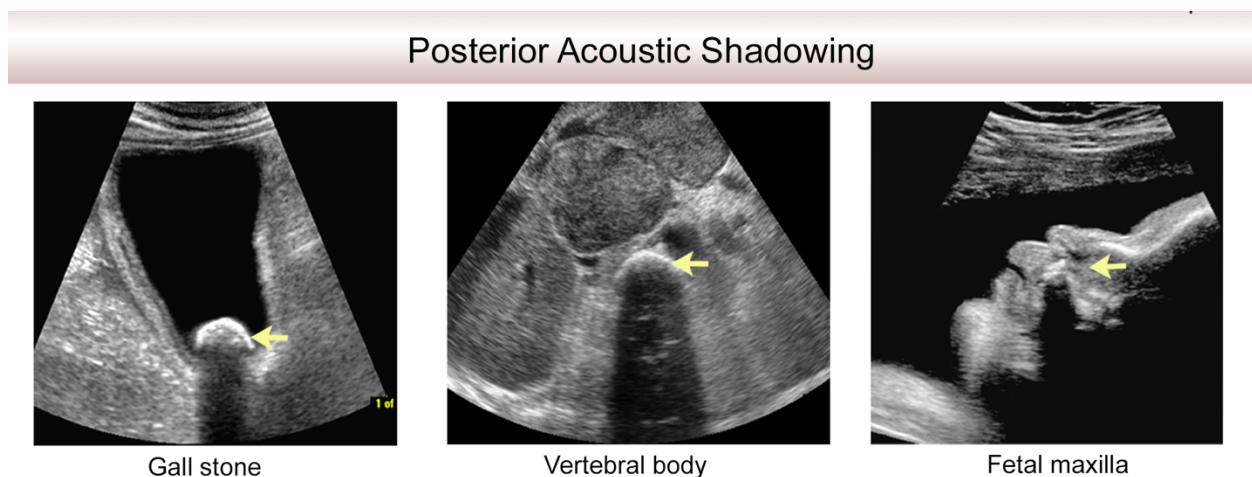


Solid breast lesion

## Posterior Acoustic Shadowing

An exaggerated manifestation of hyperattenuation is the phenomenon known as **posterior acoustic shadowing**. Shadowing occurs when the sound beam encounters a structure or interface that absorbs, reflects, redirects, or otherwise removes a significant proportion of the transmitted acoustic energy. As a result, little energy remains available to travel beyond the interface and continue the imaging process. Other physical phenomena, including refraction and redirection of the beam at strong or curved interfaces, may also contribute to the reduction in transmitted energy. When a large amount of acoustic energy is lost at or within a highly attenuative structure, the tissue distal to that structure receives markedly less sound energy. The result is an area of reduced or absent acoustic data beyond the interface, displayed on the image as a **posterior acoustic 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 posterior acoustic shadowing is calcium or another highly attenuative material. Calcium is universally present in bone and is a common component of some types of calculi, including renal and gallbladder stones. Highly attenuative materials such as cholesterol, lipids, and uric acid crystals may also contribute to shadowing, depending on their concentration and structural arrangement. Posterior acoustic shadowing may also be associated with neoplastic or chronic inflammatory processes that contain calcification, dense fibrous tissue, or other highly attenuative components. Clinical examples of pathologic entities that may cast a posterior acoustic shadow include atheromatous arterial plaque, teratomas, chronic abscesses, chronic pancreatitis, renal calculi, and gallstones.



## Posterior Acoustic Enhancement

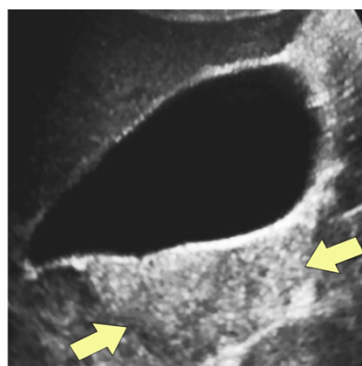
**Posterior acoustic enhancement** is a physical phenomenon opposite to shadowing. As an acoustic beam of given amplitude encounters a structure that is less attenuating than adjacent soft tissue, it continues to propagate through the structure unimpeded. As the beam exits the structure, the intensity 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.

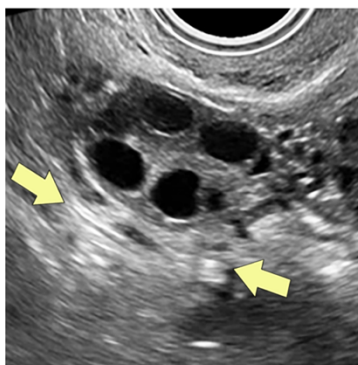
### Acoustic Physical Interactions – Image Artifacts

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.

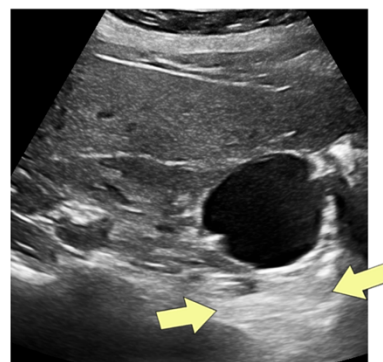
#### Posterior Acoustic Enhancement



Behind the gall bladder



Behind a normal follicle-containing ovary

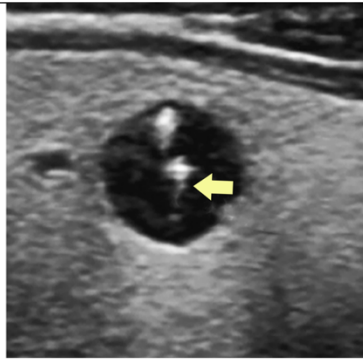


Behind a renal cyst

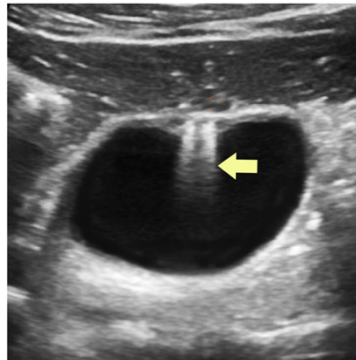
### Comet-tail Artifact

**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.

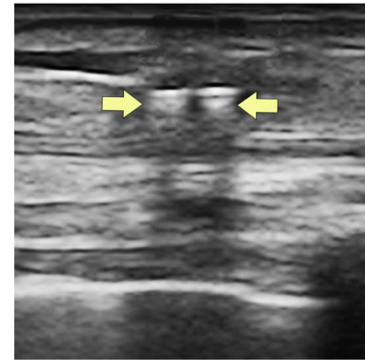
### Comet Tail Artifact



Thyroid colloid cyst



Gall bladder adenomyomatosis

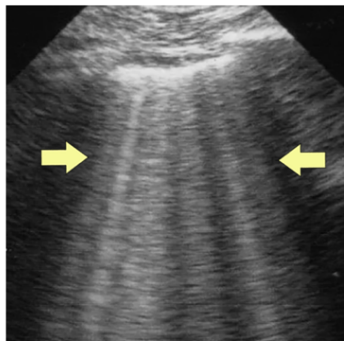


Subcutaneous surgical clips

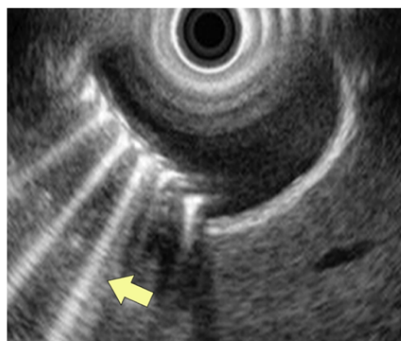
### Ring-down Artifact

**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 with 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.

### 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 on 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.

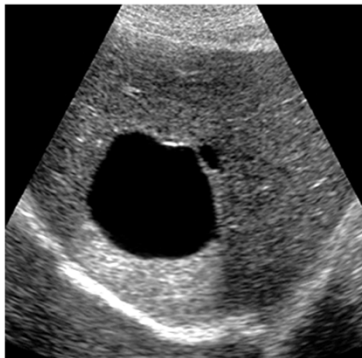
### Cystic

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.

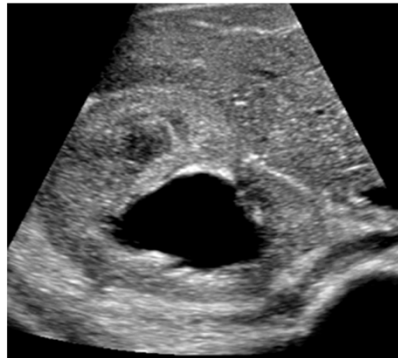
Classic sonographic characteristics of a simple cystic structure are:

- **Distinct borders**
- **Anechoic interior**
- **Posterior acoustic enhancement**

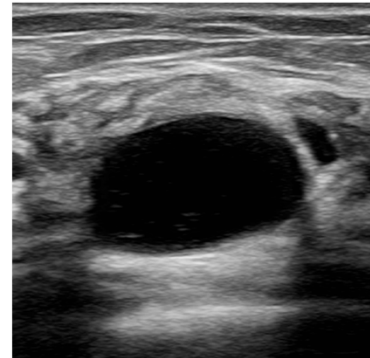
### Cystic - Image Findings



Liver cyst



Dilated renal pelvis  
(hydronephrosis)



Breast cyst

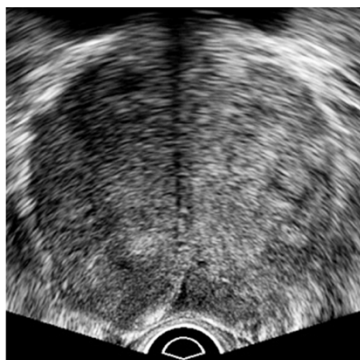
## Solid

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.

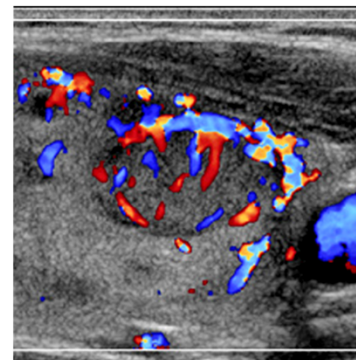
### Solid - Image Findings



Normal prostate gland  
(*transrectal imaging*)



Solid bile duct tumor



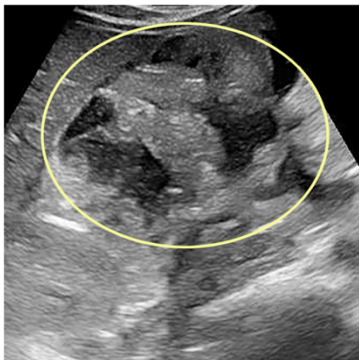
Vascularized thyroid nodule

## 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.

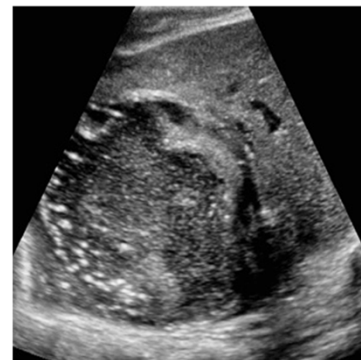
### Complex - Image Findings



Ruptured gall bladder



Hematoma in splenic capsule



Necrotic metastatic tumor  
in the liver