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REVIEW

Artifacts in diagnostic ultrasound

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Abstract: Ultrasound artifacts are encountered daily in clinical practice and may be a source of confusion on interpretation. Some artifacts arise secondary to improper scanning techniques and may be avoidable. Other artifacts are generated by the physical limitations of the technique. Recognition of artifacts is important, as they may be clues to tissue composition and aid in diagnosis. The ability to recognize and correct potential ultrasound artifacts is important for image-quality improvement and optimal patient care. In this article, we review common ultrasound artifacts that occur in B mode, spectral and color Doppler, and elastography.
Keywords: artifacts, ultrasound, Doppler artifacts, B-mode artifacts

Introduction

Ultrasound (US) artifacts are encountered daily in clinical practice and arise secondary to errors inherent to the US beam characteristics, the presence of multiple echo paths, velocity errors, and attenuation errors. US imaging artifacts are commonly encountered in clinical US and may be a source of confusion on interpretation. Some artifacts arise secondary to improper scanning technique and may be avoidable. Other artifacts are generated by the physical limitations of the technique. Understanding the physical properties of US, propagation of sound in tissues, and the assumptions used in image processing allow for a better understanding of US artifacts and why they arise.[1]

There are a number of assumptions used to generate US images. These include that sound travels in a straight line and at a constant speed, the only source of sound is the transducer, that sound is attenuated uniformly throughout the scan plane, each reflector in the body will only produce one echo, and the thickness of the slice is assumed to be infinitely thin. When these assumptions are not accurate, artifacts are produced that display the tissue scanned inaccurately.

Recognition of artifacts is important, as they may be clues to tissue composition and aid in diagnosis. The ability to recognize and correct potential US artifacts is important for image-quality improvement and optimal patient care.

Gray-scale artifacts

Reverberation

Appearance

Multiple equidistantly spaced linear reflections (Figure 1).

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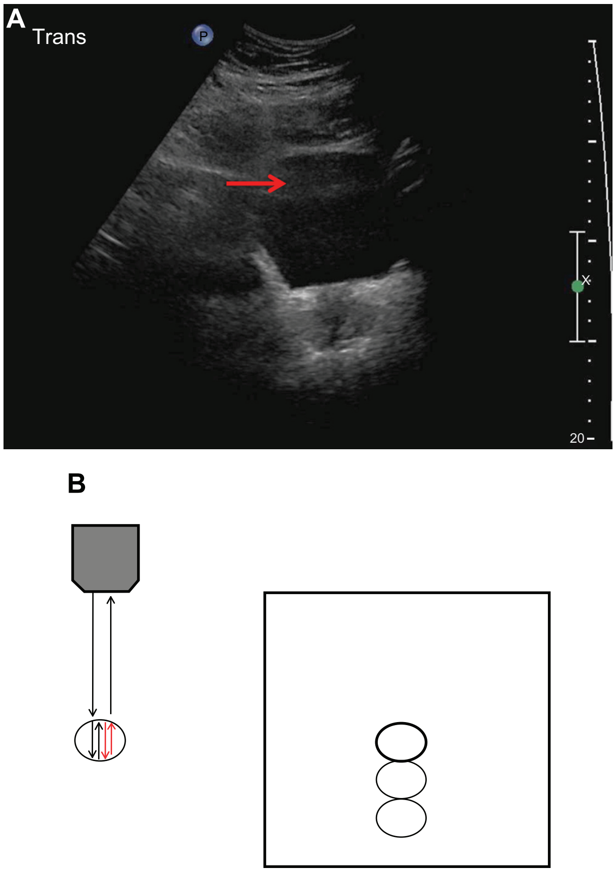

Figure 1 (**A**) Reverberation artifact in the anterior portion of the urinary bladder (red arrow). (**B**) Diagram demonstrating reverberation artifact. The black arrows represent the sound-wave path as expected. The red arrows demonstrate the sound waves that reverberate between the two secular reflects. The red arrows can repeat multiple times. The increased time taken by the reverberations is interpreted as a similar structure more distal than the real object.

Physics

The US image algorithm assumes that an echo returns to the transducer after a single reflection and that the depth of an object is related to the time for this round trip. In the presence of two parallel highly reflective surfaces, the echoes generated from a primary US beam may be repeatedly reflected back and forth before returning to the transducer for detection.[2,3] When this occurs, multiple echoes are recorded and displayed. The echo that returns to the transducer after a single reflection will be displayed in the proper location. The sequential echoes will take longer to return to the transducer, and the US processor will erroneously place the delayed echoes at an increased distance from the transducer. In an image, this is seen as multiple equidistantly spaced linear reflections.

Artifact due to

Propagation assumption.

Where it commonly occurs

Between two specular reflectors along the US beam path (eg, in cysts).

Ring-down artifact

Appearance

A line or series of parallel bands extending posterior to a gas collection (Figure 2).

Physics

When the transmitted US beam encounters a small air bubble, the transmitted US energy causes resonant vibrations (resonance) of the air bubbles. These vibrations create

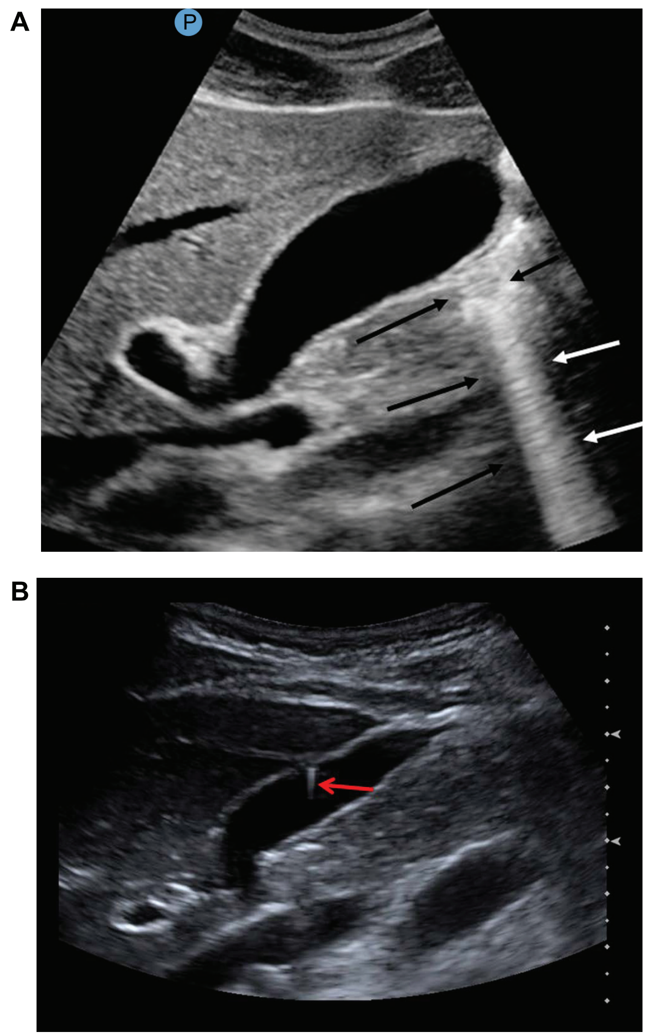

Figure 2 (**A**) In this patient with acute emphysematous cholecystitis, the series of linear spaced lines (arrows) behind air in the gallbladder wall represents ring-down artifact. (**B**) Ring-down artifact arising from gallbladder wall (red arrow) in a patient with adenomyomatosis. Reverberation of sound in the Rokitansky–Aschoff sinus in this disease process leads to ring-down artifact.

a continuous sound wave that is transmitted back to the transducer. This phenomenon is displayed as a line or series of parallel bands extending posterior to a gas collection.

Artifact due to

Propagation assumption.

Where it commonly occurs

Posterior to collections of gas (eg, pneumobilia, portal venous gas, gas in abscesses, bowel).

Note

The banding associated with the comet-tail artifact is not seen.

Comet-tail artifact

Appearance

Series of multiple, closely spaced small bands of echoes (Figure 3).

Physics

Comet-tail artifact is a form of reverberation. In this artifact, the two reflective interfaces and thus sequential echoes are closely spaced. The sequential echoes may be so close together that individual signals are not perceivable in the image. The later echoes may have decreased amplitude secondary to attenuation; this decreased amplitude is displayed as decreased width.[1,2] The result is an artifact caused by the principle of reverberation, but with a triangular, tapered shape.

Artifact due to

Propagation assumption.

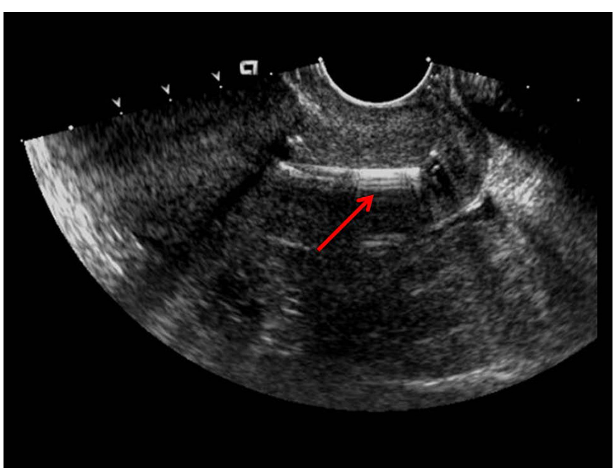

Figure 3 Comet-tail artifact displayed as evenly spaced echogenic bands (red arrows) beyond a copper intrauterine device.

Where it commonly occurs

Gas bubbles, gallbladder polyps, surgical clips.

Shadowing

Appearance

Dark or hypoechoic band deep to a highly attenuating structure (Figure 4).

Physics

When the US beam encounters a tissue that attenuates the sound to a greater or lesser extent than in the surrounding tissue, the strength of the beam distal to this structure will be either weaker or stronger than in the surrounding field. Thus, when the US beam encounters a strongly attenuating or highly reflective structure, the amplitude of the beam distal to this structure is diminished. The echoes returning from

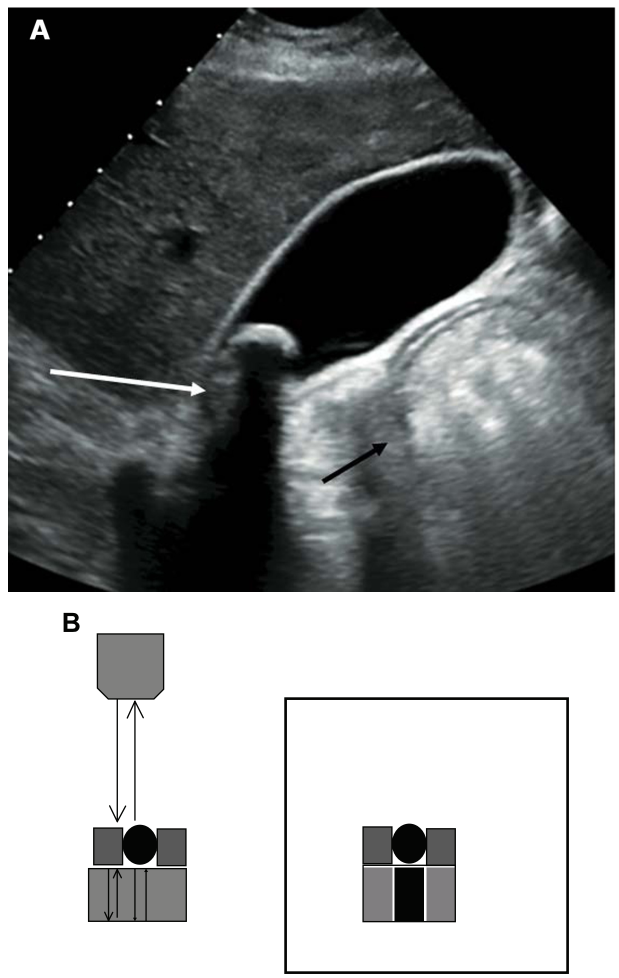

Figure 4 (**A**) Clean shadowing (white arrow) behind a large gallstone and dirty shadowing (black arrow) from an adjacent loop of bowel. (**B**) The black object attenuates sound greater than the adjacent grey boxes. The resultant image has a hypoechoic area behind the black object compared to the adjacent areas.

structures beyond the highly attenuating structure will also be diminished. The hypoechoic or anechoic band occurring deep to a highly attenuating structure is called shadowing.

Artifact due to

Attenuation of sound.

Where it commonly occurs

Calcified lesions, dense tumors.

Clean shadowing

Appearance

Uniformly anechoic signal behind a structure (Figure 4).

Physics

The shadowing (described above) that occurs behind stones, calcifications, and bones are caused primarily by sound attenuation by these structures. Because most of the sound is absorbed by these structures, much less energy is available for the generation of secondary reflections, and the associated shadow tends to be more anechoic and "clean shadowing."

Artifact due to

Attenuation of sound.

Where it commonly occurs

Stones or calcifications $>$0.5 mm, bones.

Partial shadowing

Appearance

Hypoechoic signal behind a structure.

Physics

This shadowing (described above) can occur behind highly attenuating soft tissues. It also occurs behind calcifications and stones if the cross section of the US beam at the depth of the stone is greater than the diameter of the stone (approximately $<$0.5 mm). By adjusting the focal zone of the transducer at the level of the stone, the greatest focusing occurs at the level of the stone producing more pronounced shadowing. Because higher-frequency probes can be focused more drastically and because high-frequency sound is less penetrating, it is usually easier to show shadowing with high-frequency probes.

Artifact due to

Attenuation of sound.

Where it commonly occurs

Behind calcifications and stones $<$0.5 mm, behind fat-containing structures when surrounded by other soft tissues.

Dirty shadowing

Appearance

Low-level echoes in the shadow deep to gas (Figure 4).

Physics

The shadowing that occurs behind gas is due to the high degree of reflection at gas/tissue interfaces. Because the energy of a sound pulse reflected off gas is essentially the same as the transmitted pulse, the reflected pulse will interact with the interfaces in front of the gas and produce secondary reflections that travel back to the gas surface and then reflect from this surface back to the transducer. These secondary reflections produce low-level echoes in the shadow deep to the gas, accounting for the "dirty" appearance.

Artifact due to

Attenuation of sound.

Where it commonly occurs

Behind gas collections.

Increased through-transmission

Appearance

Hyperechoic area behind a structure (Figure 5).

Physics

As sound passes through solid tissues, it is gradually attenuated. Fluid-containing structures attenuate the sound much less than solid structures, so the strength of the sound pulse is greater after passing through fluid than through an equivalent amount of solid tissue. Therefore, interfaces deep to cystic structures will produce stronger reflections and appear brighter than identical interfaces deep to solid tissues. In the image, we recognize the increased through-transmission as a bright band extending from an object of low attenuation.

This artifact produced by increased through-transmission can be used to distinguish cystic from solid lesions. However, it is important to realize that solid masses that attenuate sound less than adjacent soft tissues may also be associated with increased through-transmission.

Artifact due to

Attenuation of sound.

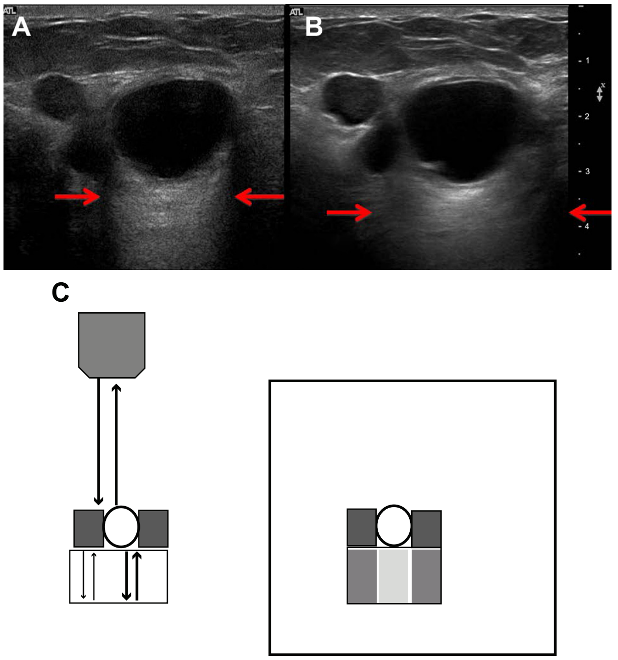

Figure 5 (**A**) Increased through-transmission (red arrows) in a breast cyst demonstrated by the linear increased signals distal to the cyst. (**B**) The same cyst is imaged using spatial compounding, which diffuses the artifact (red arrows) due to the multiple angles of insonation. (**C**) The schematic C depicts increased through transmission. There is less attenuation of the sound waves through the cyst leading to increased returning signals from the tissue behind the cyst.

Where it commonly occurs

Behind fluid-filled structures and occasionally behind solid lesions that attenuate sound less than surrounding tissue (eg, fibroadenoma).

Note

When using spatial compounding, the through-transmission is diffused over a wedge-shaped area corresponding to the angles of insonation used in the spatial compounding.

Refraction "ghosting"

Appearance

Duplication of a structure or structures appearing wider on the US image (Figure 6).

Physics

The speed of sound varies in different tissues. It is slowest in adipose tissue (~1450 m/second), faster in fluid (~1480 m/second), and fastest in soft tissues (~1540 m/second). Sound is refracted (changes direction) when it passes obliquely through an interface between two substances that transmit sound at different speeds.[1] The degree of this change in direction is dependent on both the angle of the incident US beam and the difference in velocity between the two media, as governed by Snell's law. The US display assumes that any returning beam travels in a straight line and thus was reflected from a structure in the direction from which it returned. In refraction artifact, echoes return from a structure that is located along a path different than that of the returning beam. In other words, a structure that is anatomically located lateral to the path of the returning beam is interpreted by the machine as being located in the path of the returning beam. Refraction artifact may cause structures to appear wider than they actually are or may cause an apparent duplication of structures.[2]

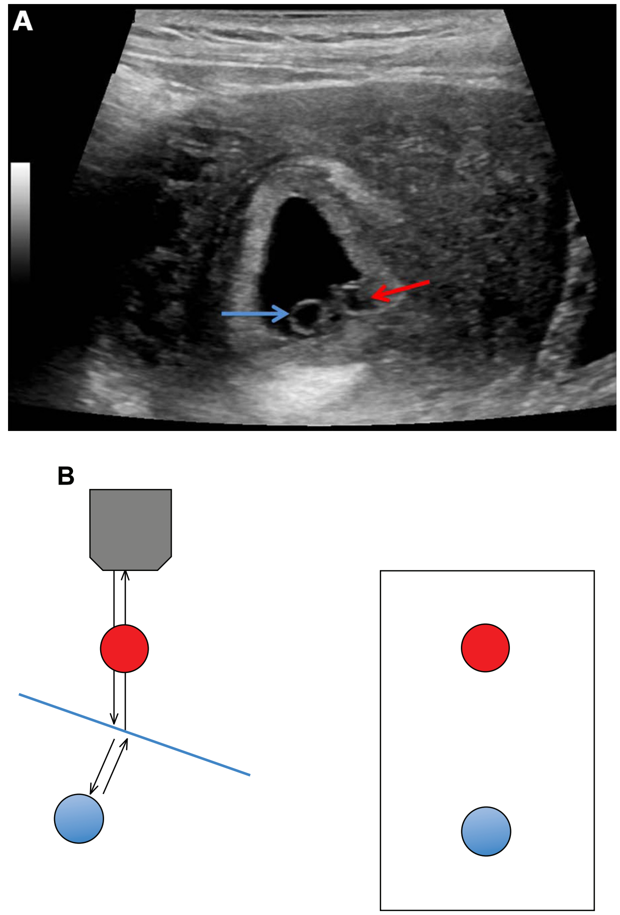

Figure 6 (**A**) Transabdominal scan of first-trimester pregnancy with a single intrauterine gestation. Refraction artifact from the rectus abdominis muscle causes appearance of a duplicate yolk sac (red arrow) adjacent to the actual yolk sac (blue arrow). (**B**) In this schematic depicting refraction, the blue line represents the interface of tissues with different acoustic properties. The red lesion is placed appropriately in the diagram. The blue lesion is displaced because of the refraction at the interface.

Artifact due to

Propagation assumption.

Where it most commonly occurs

At the interface between the rectus abdominis muscles and abdominal wall adipose tissue; at the interface between liver or spleen and adjacent adipose tissues.

Refractive shadowing (edge artifact, lateral cystic shadowing)

Appearance

Shadow occurring at the edge of a curved surface (Figure 7).

Physics

Because refraction (described above) is also accompanied by defocusing and loss of beam energy, shadowing may also occur at the edge of cystic structures.[1] Sound waves encountering a cyst wall or a curved surface at a tangential angle are scattered and refracted. The result is a lack of echoes returning from the lateral cyst wall and anything in a direct path posterior to it. This has an appearance of a linear shadow. Sound waves encountering a cystic wall or a curved surface at a tangential angle are scattered and refracted, leading to energy loss and the formation of a shadow. This artifact may disappear when changing the angle of the US beam clarifying the nature of the artifact.

One such clinical scenario one should be aware of is upon imaging the urinary bladder. Refractive shadowing may give a spurious appearance of a defect in the bladder wall. The presence of this artifact can be definitively determined by changing the angle of the US beam.[3] Occasionally, it will trap the unwary into thinking there is a defect in the urinary bladder or diaphragm (generally only if there is fluid on either side).

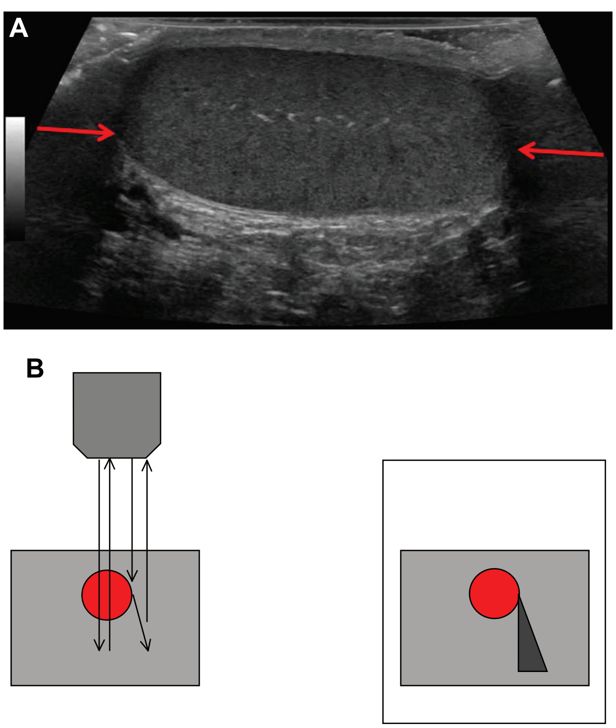

Figure 7 (**A**) Edge-effect refractive shadowing emanating from the superior and inferior edges of the testicle (red arrows). (**B**) Diagram depicting the cause of refractive shadowing. At the curved surface of the lesion, the ultrasound beam is deflected. This leads to a rectangular area where no sound waves are returned to the transducer, leading to an area of shadowing.

Artifact due to

Propagation assumption.

Where it commonly occurs

Cysts, urinary bladder (appearance of a defect in the bladder wall), diaphragm if there is fluid on either side (appearance of a defect in the diaphragm).

Speed propagation

Appearance

Artificial widening of a structure (Figure 8).

Physics

Conventionally, US systems form images assuming the speed of sound in tissue is uniform at 1540 m/second.[2,3] However, the speed of sound varies across tissue types and among different patients. For example, the speed of sound in muscle is about 1560–1600 m/second, while the speed of sound in fat is about 1430–1470 m/second.[4] The default assumption of an incorrect value for the speed of sound leads to broader US beams, potential calculation inaccuracies, and poorer image quality, including degraded point and contrast resolution due to increased acoustic clutter.[5,6]

US systems traditionally create images based on the assumption that the speed of sound travels through all tissues of the body at a uniform rate of 1540 m/second. US imaging of the breast or any other tissue without a corrected speed of sound clearly impacts the resolution of the image (Figure 8B). Chen and Zagzebski reported that imaging at an incorrect speed of sound setting not only causes misregistration of the position of a point target but also causes the dynamic receive focus to miss the target.[6] This ultimately leads to a significant decrease in point and lateral contrast resolution. Anderson et al[7] claim that this decreased imaging quality is especially important in tissue such as the breast, because the distortions arising from speed-of-sound error are inversely proportional to the imaging system's frequency and wavelength. Additionally, Anderson and Trahey[8] reported that they expect sound-speed error would degrade the quality of any image relying on high spatial and/or contrast resolution, such as the visualization of spiculation or capsules, the differentiation of lesions and cysts, and US-guided biopsy.[7] All of these functions are extremely important in clinical sonographic imaging of the breast. With the speed of sound corrected, lateral resolution is

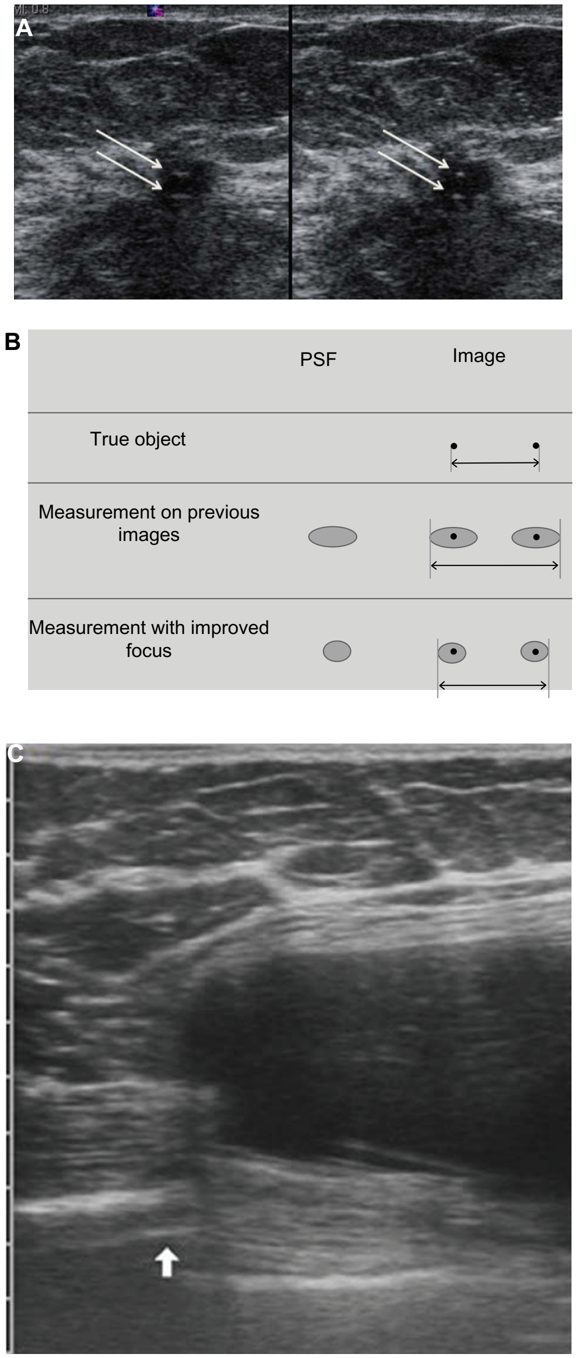

Figure 8 (**A**) This pair of images taken in the same location in a patient with calcifications in a breast mass was processed using different speed-of-sound assumptions. The image on the left was generated with 1540 m/second as the speed of sound, whereas the right image uses a corrected speed of sound for breast tissue. With correction of the speed of sound, calcifications are more discrete and less artificially elongated. (**B**) This diagram depicts how the size of an object is affected by the changes in lateral resolution with different speed-of-sound assumptions. The measurement on previous images occurs when conventional speed of sound is used in breast imaging, causing decreased lateral resolution. Measurement with improved focus occurs when a corrected speed of sound for the tissue is used, improving lateral resolution. (**C**) In this patient with a silicone breast implant, the speed of sound through the silicone is significantly less than in breast tissue. The sound waves distal to the implant therefore return to the transducer delayed compared to those through normal breast tissue. The ultrasound system interprets the delay as the object being deeper in the scan, leading to the apparent disruption of the underlying muscle (arrow).
Abbreviation: PSF, Peak Systolic Velocity.

improved, as previously discussed, so uncertainties in lateral measurement are reduced, as illustrated in Figure 8B. We can assume therefore that measurements in the lateral direction would better represent the true measurement of the object. Axially, the measurement accuracy remains unchanged from that of a conventional system, as the altered speed of sound is only used in beam-forming calculations and does not affect the axial measurement scale. It can therefore be postulated that optimal US images can be generated if a speed-of-sound measurement is obtained in individual patients and the speed then customized to their unique tissue properties. This is not possible at this time. Until this can be performed in real time, a fixed average corrected value(s) as used in this study can be utilized.

Artifact due to
Propagation assumption (incorrect speed of sound).

Where it commonly occurs
In tissues in which the speed of sound is not near the equipment-set speed of sound (breast if speed-of-sound correction is not utilized).

Note
Most US phantoms are calibrated to 1540 m/second. If one uses a speed-of-sound correction (common in breast imaging) on a phantom, erroneous results will occur.[9,10]

Side lobes and grating lobe artifacts
Appearance
Hyperechoic rounded object within an anechoic or hypoechoic structure such as the urinary bladder or gallbladder lumen (Figure 9).

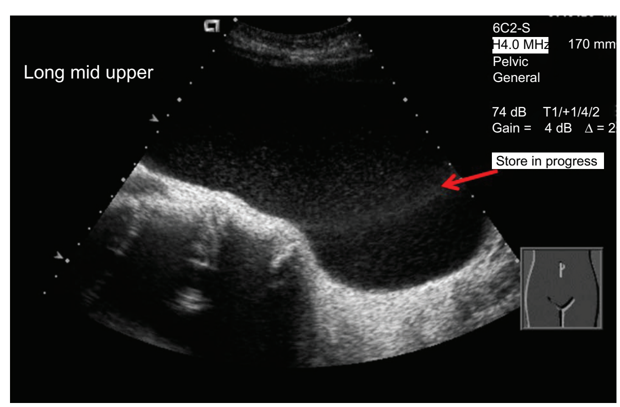

Figure 9 Side lobe/grating lobe artifact (red arrow) seen in a mucinous ovarian tumor.

Physics

Every transducer has a main-beam axis along which the main beams are transmitted parallel to the long axis of the transducer. In linear array transducers, multiple other low-amplitude beams project radially at different angles away from the main-beam axis. These are termed side lobes. Side lobes occur relatively close to the primary beam, as opposed to grating lobes that have the same origin, but are farther removed from the central beam. Side-lobe and grating lobe beams may be reflected back (from a strong reflector) to the transducer and sometimes detected. The transducer/machine cannot differentiate between reflected beams returning from the main beam versus those returning from off-axis lobes. It considers any detected beam as originating from the main axis. Off-axis lobes are lower in amplitude than the main axis beam, and therefore in order to be detected by the transducer, they must be reflected by a highly reflective (ie, highly echogenic) structure. Off-axis lobe artifacts have the appearance of a hyperechoic object within an anechoic or hypoechoic structure, such as the urinary bladder or gallbladder lumen. Also, this artifact may be seen with needle biopsy when the needle is a strong reflector.[11] Off-axis lobe artifacts can also be seen on color and spectral Doppler imaging.[11]

Artifact due to

Propagation.

Where it occurs

Urinary bladder, gallbladder, needle biopsy.

Volume averaging (section thickness, slice thickness)

Appearance

False sludge or debris within anechoic cystic structures (Figure 10).

Physics

The thickness of the main US beam as it exits the transducer is equal to the thickness of the transducer array. The finite beam width creates a partial-volume artifact related to slice or section thickness. When the beam includes both a cystic structure and a solid structure, the scan line consists of echoes from both the cystic and solid structure. The accumulation of scan lines of this nature produces filling in of the cystic structure. As the beam propagates away from the transducer, it narrows gradually until it reaches the focal zone. It then gradually widens again. Structures that are proximal to and distal from the focal zone are more prone to artifacts resulting from volume averaging between adjacent objects that both fall within the thickness of the beam. In other words, the thicker the image slice, the more likely that two different adjacent objects will fall within that image slice. This artifact can be minimized by placing the focal zone at the level of the tissue/structure of interest.[12]

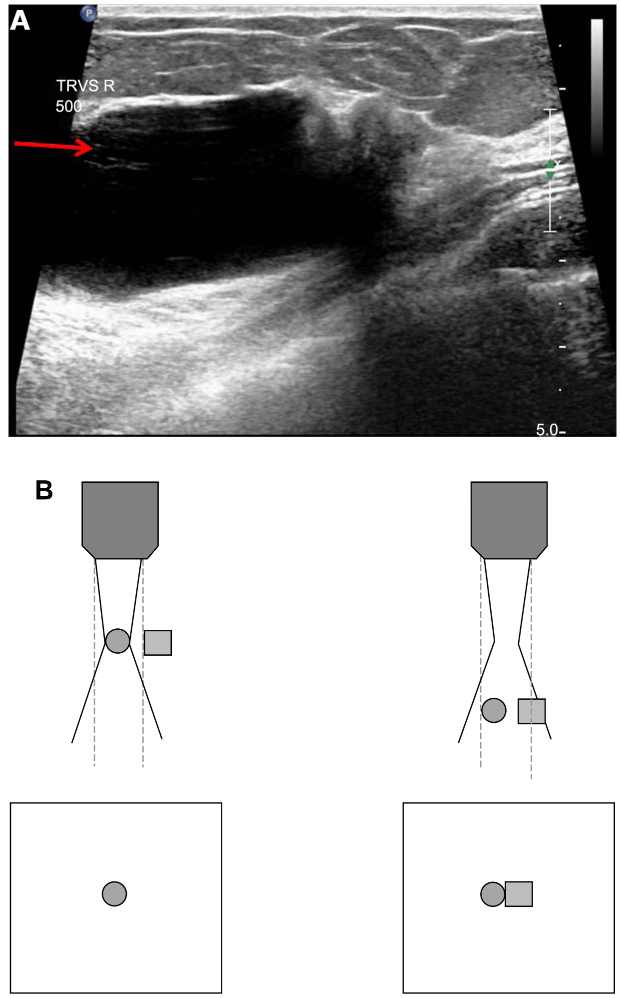

Figure 10 (**A**) Volume-averaging artifact demonstrated in a saline breast implant (red arrow) due to lack of finite thickness of the beam slice. Increased through-transmission is also demonstrated as increased echogenicity behind the implant. (**B**) In this schematic demonstrating volume averaging, the solid lines represent the ultrasound beam transmitted and the dashed lines represent the received sound waves. When the focal zone is placed at the depth of the lesions, only the circle is insonated with the transmit beam leading to an image with only the circle. In the image on the right, the lesions are distal to the focal zone and both the circle and square are insonated, leading to the image having received signals from both the circle and square in the image.
Abbreviation: TRVS, transverse.

Artifact due to

Propagation assumption.

Where it commonly occurs

Urinary bladder, gallbladder, and cysts.

Range ambiguity

Appearance

Structures deep to the scanning range are depicted in the image.

Physics

The US system assumes that all received echoes are formed from the most recent transmitted pulse. A short US pulse is sent out from the transducer, and the transducer is silent for a time to receive the returning echoes. All echoes received during this sampling period are assigned a depth based on the time interval between the transmitted pulse and the detected echo. A second pulse is then sent out, and the transducer is again silent to receive returning echoes. At high pulse-repetition frequency (PRF), echoes from deep structures interrogated by the first pulse arrive at the transducer after the second pulse has been transmitted. These echoes are interpreted as having originated from the most recent transmitted pulse and are incorrectly placed near the transducer in the image.[13]

Artifact due to

Improper scanning parameters.

Where it commonly occurs

Small parts, endosonography.

Mirror-image artifact

Appearance

Duplicated structure equidistant from but deep to a strongly reflective interface (Figure 11).

Physics

The depth at which each structure is displayed on a US image is proportional to the amount of time it takes for a US beam to return to the transducer from the time when it leaves the transducer. Normally, this amount of time would be primarily dependent upon the depth of a tissue from which the beam reflects. This would result in an image with an anatomically accurate depth. In mirror-image artifact, the return of sound beams is delayed, and therefore the structures from which these delayed beams are reflected are displayed at a greater depth than their true anatomic depth. This delay occurs in the presence of highly reflective interfaces, such as the diaphragm/lung base interface on a right upper quadrant scan. The diaphragm/lung base interface is highly reflective because gas reflects almost 100% of the sound that hits it and is therefore the best acoustic mirror in the body.[1] The prototypical example is in the setting of a liver lesion that produces a mirror image at the right lung base. A pulse from the main beam travels through the liver and is reflected off the diaphragm. This reflected echo reaches the liver lesion and reflects back to the diaphragm.[14] From the diaphragm, the echo finally reaches the transducer.[12]

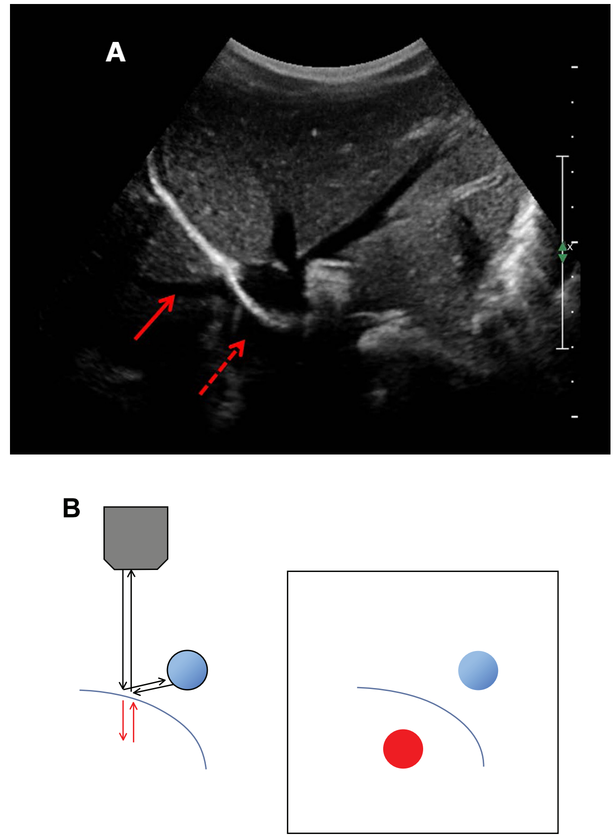

Figure 11 (**A**) Mirror-image artifact demonstrating the appearance of a hepatic vein (red arrow) and IVC (dotted arrow) above the diaphragm. (**B**) Diagram demonstrating the cause of the mirror-image artifact. The black arrows are the true path of the transmitted and received sound waves. The red arrows are how the ultrasound interprets the sound waves. In the image, the blue object is correctly placed and the red mirror image occurs on the opposite side of the secular reflector.
Abbreviation: IVC, inferior vena cava.

Because color Doppler scanning creates images with marked contrast between vascular structures and soft tissues (ie, color vs gray scale), mirror-image artifacts are particularly common on color Doppler scans. As with gray-scale imaging, color Doppler mirror images occur most frequently around the lung. However, the increased contrast also allows weaker acoustic interfaces, such as bone or even the back wall of the carotid, to act as mirrors for color Doppler imaging.

Artifact due to

Propagation assumption.

Where it commonly occurs

Diaphragm with liver lesions or the liver itself being duplicated, trachea.

Electronic interference/spiking

Appearance

Bands of noise (Figure 12).

Physics

When spurious electronic signals are detected by the US system, bands of noise are displayed in the image. This can occur when there is not a dedicated electrical outlet that is appropriately grounded. If a non-dedicated electrical outlet is used and another piece of equipment is turned on, electric signals may enter the US machine, eg, if the US machine is connected to an outlet with a respirator and the respirator turns on.

Artifact due to

Electronic interference.

Where it commonly occurs

Use of a non-dedicated electrical outlet.

Banding

Appearance

A band of increased brightness.

Physics

The focusing characteristics of the transducer may create a banding artifact, which is a band of increased brightness caused by greater intensity, usually in the focal zone. This is more noticeable with systems with fixed transmit focusing and dynamic receive focusing. This artifact can also be created by improper time-gain compensation settings.[13]

Artifact due to

Improper scanning technique.

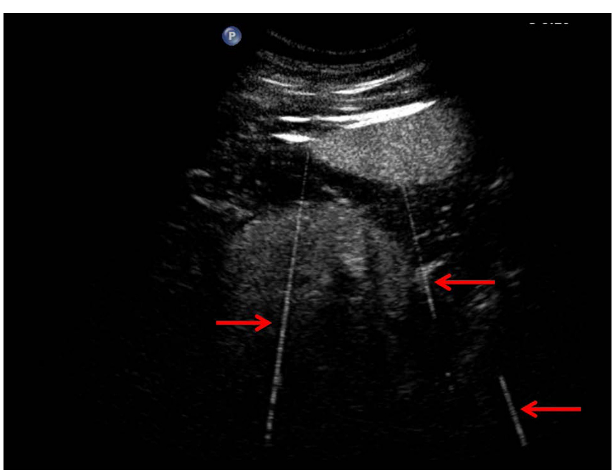

Figure 12 Electronic interference creating spiking artifact (red arrows).

Where it commonly occurs

With improper time-gain compensation settings, or improper focal zone placement.

Speckle

Appearance

The random granular texture that obscures anatomy in US images (noise) (Figure 13).

Physics

Speckle is created by a complex interference of US echoes made by reflectors spaced closer together than the US system's resolution limit. Speckle or acoustic noise occurs throughout the image. Speckle degrades spatial and contrast resolution and obscures the underlying anatomy. Speckle is a major cause of image degradation in US. Speckle interferes with the ability of a US system to detect low-contrast objects. Speckle can be reduced using techniques that reduce noise (ie, higher-frequency transducer, real-time compounding, adaptive post-processing, and harmonic imaging).

Artifact due to

Propagation assumption.

Where it commonly occurs

Everywhere; speckle is inherent in US images.

Beam-width artifact

Appearance

Fine, grainy echoes distributed along the inside of cystic structures whose wall is struck obliquely by the US beam (Figure 14).

Physics

The origin of beam-width artifact is similar to that of side-lobe artifact. The main US beam exits the transducer at

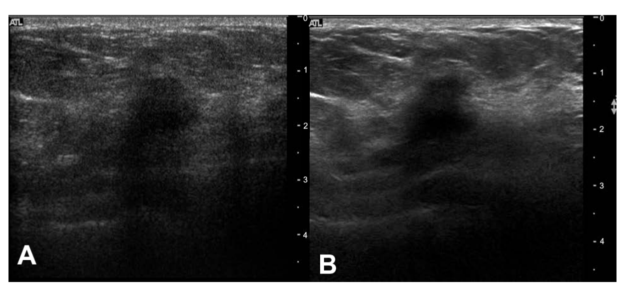

Figure 13 Speckle or noise is present on all ultrasound images and leads to degradation of the image. Techniques can be used to decrease speckle and therefore improve image quality. (**A**) Fundamental image of an invasive ductal breast cancer. The same image in (**B**) uses special compounding and adaptive post-processing to reduce speckle, improving image quality.

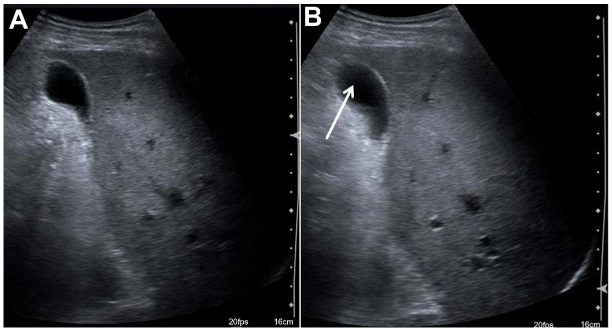

Figure 14 Images of the gallbladder taken with the focus in an appropriate location (**A**) and deep in the far field (**B**). The increased echoes adjacent to the gallbladder wall (arrow) are beam-width artifact.

approximately the same width as the transducer, then narrows as it approaches the focal zone and widens again distal to the focal zone.[1] The distal beam may widen beyond the actual width of the transducer. A highly reflective object located within the widened beam may generate detectable echoes.[2] The transducer cannot differentiate between echoes, whether they originate from within the narrow imaging plane or originate from a location within the widened beam. The transducer falsely interprets objects located in the widened beam to be located within the narrow beam. This can be minimized or eliminated by adjusting the focal zone, such that it is placed at the level of the target organ/structure that is being examined.

Artifact due to

Propagation assumption.

Where it commonly occurs

Urinary bladder, gallbladder, and other cystic structures.

Attenuation artifact

Appearance

Nonvisualization of deep structures (Figure 15).

Figure 15 Images of a liver obtained with a 4 MhZ (**A**) and 6 MhZ transducer (**B**) demonstrate the loss of signal in the far field with the higher-frequency transducer, due to the increased attenuation of the tissues with the higher-frequency transducer.

Physics

The different tissues a US beam encounters attenuate the beam differently. If the attenuation coefficient for a material is great, such as with fat, then the beam may not fully penetrate the imaging field. In this situation, deep structures may not be visualized. An appropriate frequency transducer should be selected to optimize penetration. Attenuation is also dependent on the frequency of the US. Attenuation increases with increase in frequency. In soft tissues, the relationship between attenuation and frequency is linear. In bone and water, attenuation increases as the square of the frequency.[3]

Artifact due to

Attenuation of sound.

Where it commonly occurs

High-frequency transducers, in tissues which significantly attenuate sound (fat, bone).

Anisotropy

Appearance

Hypoechoic area in a structure that has anisotropy (Figure 16).

Physics

When a tendon (highly anisotropic) is imaged perpendicular to the US beam, a characteristic hyperechoic fibrillar appearance is displayed. In structures with anisotropy (having properties that differ according to the direction of measurement) and when the transducer's angle of incidence is not perpendicular to the structure, fewer returning echoes to the transducer results in a hypoechoic area. This can occur when the US beam is angled as little as 5° relative to the long axis of such a structure. This phenomenon can lead to misinterpretation and can be overcome by changing the transducer position (heel-to-toe movement to make the transducer

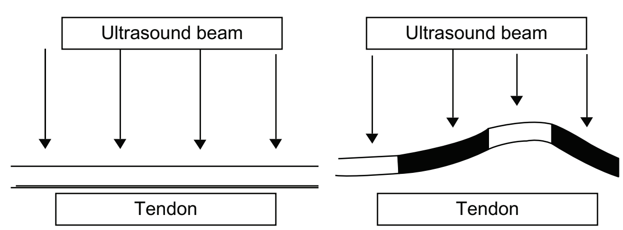

Figure 16 In the image on the left, the ultrasound beam is perpendicular to the tendon throughout its course. The tendon is uniformly hyperechoic. In the image on the right, the tendon is curved. Where the ultrasound beam is perpendicular to the tendon, the tendon is hyperechoic. Where the ultrasound beam is not perpendicular to the tendon, the tendon is hypoechoic.

perpendicular to structure). The artifactual hypoechoic area of the structure will disappear with perpendicular transducer positioning.

Artifact due to

Anisotropy of structure.

Where it commonly occurs

Tendons, and to a lesser extent muscles, ligaments, and nerves.

Spectral and color Doppler

Mirror image (cross talk)

Appearance

Mirror image of the spectral display on the opposite side of the baseline (Figure 17).

Physics

When a strong sound signal in one direction channel leaks into another, a mirror image of the spectral display on the opposite side of the baseline occurs. This is called mirror image or cross talk. Cross talk distinguishes the condition of undesired crossover of transmitted sound waves into the receiving transducer in continuous-wave Doppler.

Artifact due to

Propagation assumption.

Where it commonly occurs

Any spectral Doppler waveform in which the Doppler (receiver) gain is too high.

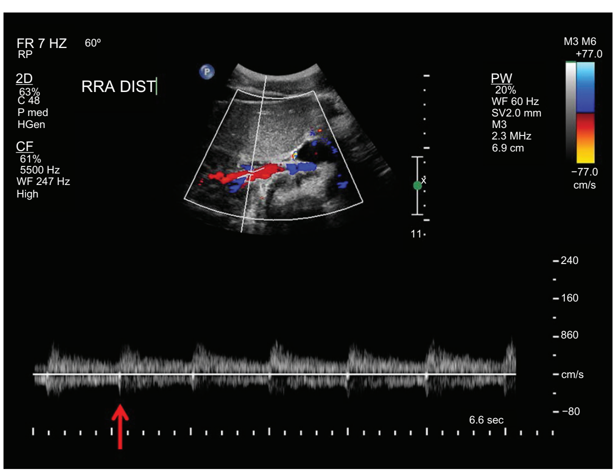

Figure 17 Artifactual display of flow beneath the baseline (arrow) in this image is due to improper Doppler gain setting.
Abbreviation: RRA DIST, right renal artery distal.

Aliasing

Appearance

On waveforms, the high-frequency component is wrapped around to the negative extreme (Figure 18).

Physics

An artifact occurring when the velocity of the sampled object is too great for the Doppler frequency to be determined by the system. Governed by the Nyquist limit, the blood-flow direction appears to be reversed. This artifact occurs when the Doppler sampling rate (PRF) is less than twice the Doppler frequency shift. Aliasing causes the high-frequency components to wrap around from the positive extreme of the scale to the negative extreme or vice versa. The change in color assignment can be distinguished from true flow reversal because the change is between light color shades rather than dark color shades. Aliasing can be diminished or eliminated by increasing the PRF.[11]

Velocity information in spectral and color Doppler is derived from pulsed sound beams that are used to sample

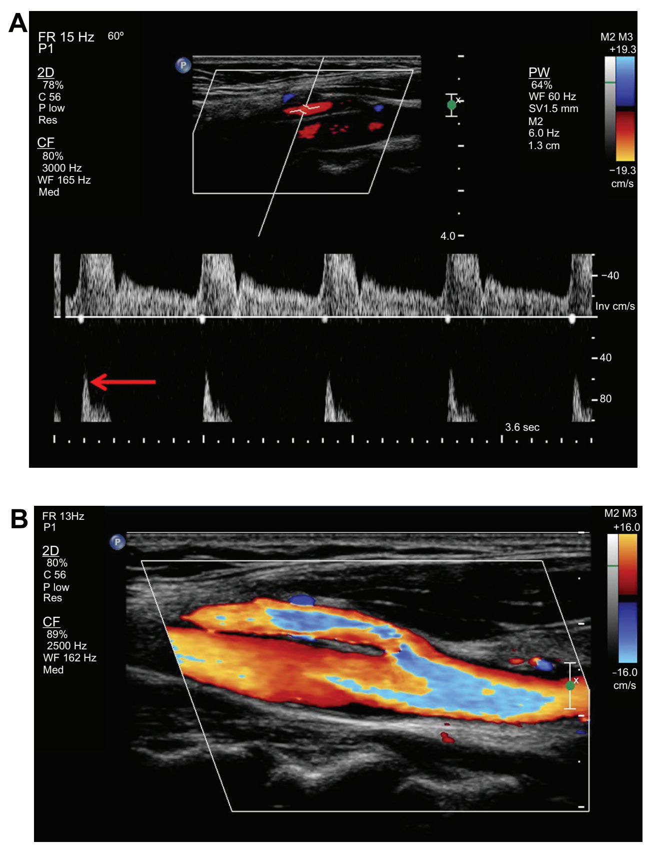

Figure 18 (**A**) Aliasing displayed on a spectral Doppler waveform (red arrow). When the Nyquist limit is exceeded, the waveform "wraps around," resulting in an inability to measure velocity accurately. (**B**) Aliasing displayed in color Doppler. Due to the Nyquist limit being exceeded, the "wrapping around" of velocity causes the fastest flow (centrally in the vessel in laminar flow), displayed as blue in this example.

the blood flow in vessels of interest.[11] A minimum of two pulses per cycle of Doppler shift frequency is required to determine the corresponding velocity.[12] When there is an insufficient sampling rate (PRF) relative to the Doppler signals generated by moving blood, aliased signals occur, ie, when the velocity scale is set too low relative to the velocity of flow in a vessel. On spectral Doppler images, this manifests as wraparound of the highest flow velocities into the negative part of the graph.[15] On color Doppler images, this manifests as reversed flow within central areas of higher laminar velocity. This gives the false appearance of reversal of flow within the vessel. True reversal of flow versus spurious reversal from aliasing can be differentiated on color Doppler as follows: in true flow reversal, the velocity must gradually decrease (or increase) and pass through zero velocity, whereas with aliasing this does not occur. The point at which the velocity reaches zero manifests on color Doppler as a black stripe.[11] Thus, the absence of the black stripe indicates aliasing. If aliasing persists despite turning up the velocity scale, then the velocity within that vessel is beyond the limit of that scale. This can be a useful indicator of abnormally elevated velocities, such as occur distal to an arterial stenosis.

Aliasing can be reduced or eliminated by increasing the velocity scale (which increases the PRF), increasing the Doppler angle (which decreases Doppler shift), changing the baseline setting, or using a lower US frequency (by manually decreasing the frequency or switching transducers).[11]

Artifact due to
Improper settings.

Where it commonly occurs
Inappropriate velocity scale (set too low), inappropriate PRF setting.

Tissue vibration
Appearance
Red and blue Doppler signal in perivascular soft tissue (Figure 19).

Physics
Tissue-vibration artifact is produced in nonflow areas by bruits, arteriovenous fistulas, and shunts. Turbulence causes pressure fluctuations in the lumen of the vessel that can produce vibration of the vessel wall and the adjacent soft tissues. When the tissue interfaces vibrate, they may produce

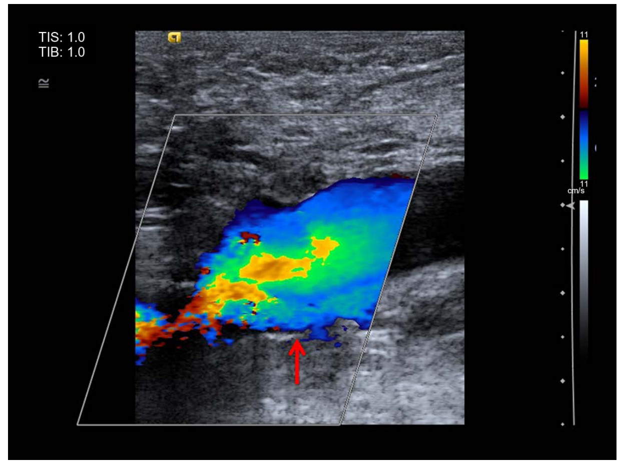

Figure 19 Tissue vibration (red arrow) in tissues adjacent to common femoral vein during augmentation. The appearance of flow outside of the vessel is due to signal detection of tissue movement, rather than motion of actual blood flow.

a detectable Doppler frequency shift that will be assigned a color. The vibrational motion is both towards and away from the transducer, resulting in a color-assignment mixture or red and blue.

Artifact due to
Patient factors.

Where it commonly occurs
Arteriovenous fistulas and shunts.

Twinkle
Appearance
A discrete focus of alternating colors with or without an associated-color comet-tail artifact (Figure 20).

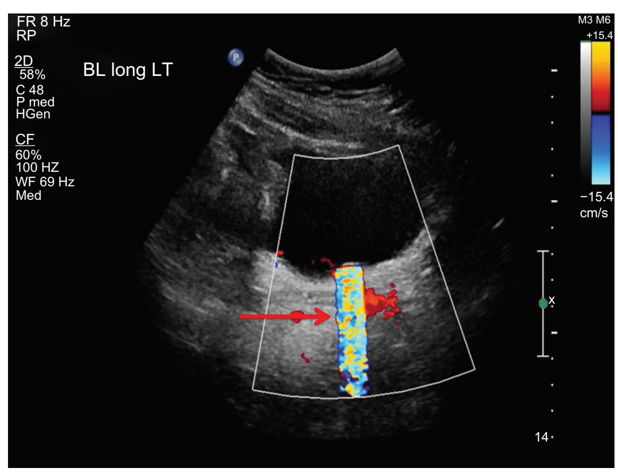

Figure 20 Twinkle artifact (red arrow) behind a stone at the ureterovesicular junction. The stone was not visible on gray-scale ultrasound, and visualization of the twinkle artifact made the diagnosing of urolithiasis possible.

Physics

Twinkle is a phenomenon dependent on US machine settings (color-write priority, gray-scale gain, and PRF), motion of the object scanned with respect to the transducer, and equipment used. Presence of this artifact is sometimes beneficial, such as in cases of detection of urinary tract stones with indistinct echogenicity and poor posterior acoustic shadowing. In prenatal fetal scans, it can imitate aberrant vessels or flows behind echogenic structures or give the impression of cardiac activity in fetal demise. Because this artifact is dependent on US machine settings it is possible to distinguish it from real vessels by changing some parameters. For instance, when the focal zone is above the source of the artifact (such as a urinary stone), the artifact disappears, but when the focal zone is under the hyperechoic area, it occurs. This could be an easy distinguishing maneuver in assessment of this phenomenon.

When a large number of reflectors (and therefore Doppler shifts) are included in the analysis, the resulting phase shift provides a correct estimation of velocity. Furthermore, the velocity estimation is unchanged by faint motion. When the number of reflectors is small (as occurs in calcifications), the velocity estimation can be affected by any faint motion.[16]

The twinkling artifact is probably generated through slight variations in path length of the transmitted and reflected US. Focusing an US array transducer depends on precise phasing among the elements in the scan-head array. Even minor phase errors could produce fluctuations in the US field generated by a transducer. These fluctuations could easily alter the effective beam path slightly from firing to firing, although the beam will be pointed in the correct direction on average. The same types of errors only increase on reception of the reflected wave in which the same phasing issues also occur. If there is a strong reflector with a rough surface, these slight variations in beam direction could be magnified to produce apparent aliased Doppler shifts. Multiple reverberations would further magnify this effect by projecting the artifact below the reflecting surface. The effect is most commonly seen in urinary stones, and the rougher the surface, the greater the twinkling artifact.[17]

Artifact due to

Noise generated in calcification.

Where it commonly occurs

Urinary stones.

Flash artifact

Appearance

Spurious appearance of blood flow (Figure 21).

Physics

Vascular motion artifact and flash artifact have similar underlying physical causes. In flash artifact, motion of the patient's body, motion of the probe, or motion of an anatomic structure secondary to an external force (such as the pulsation of an adjacent artery or the heart) can cause motion of the reflectors within a structure of interest without the presence of blood flow. The motion of the reflectors results in a Doppler shift, giving a spurious appearance of blood flow. Hypoechoic and anechoic structures are more susceptible to flash artifact, and therefore it is seen more commonly in cysts, the gallbladder, dilated bile ducts, and ascites. This stems from limitations of the motion discriminator function that can be found in most US machines. The motion discriminator functions to eliminate false flow, but is less effective in doing so in areas of low echogenicity.[11]

Artifact due to

Patient factors.

Where it commonly occurs

Around the heart, patient motion (breathing, gas movement).

Vascular motion artifact

Appearance

Artifactual increase and decrease of spectral Doppler velocity pattern in a cyclical fashion (Figure 22).

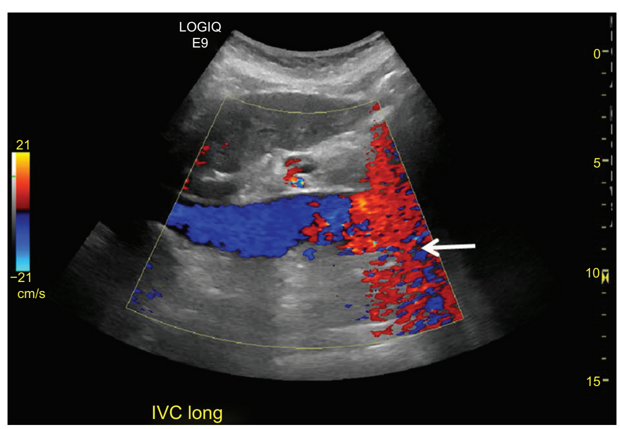

Figure 21 Flash artifact (arrow) visualized due to motion of bowel gas anterior to IVC (inferior vena cava).

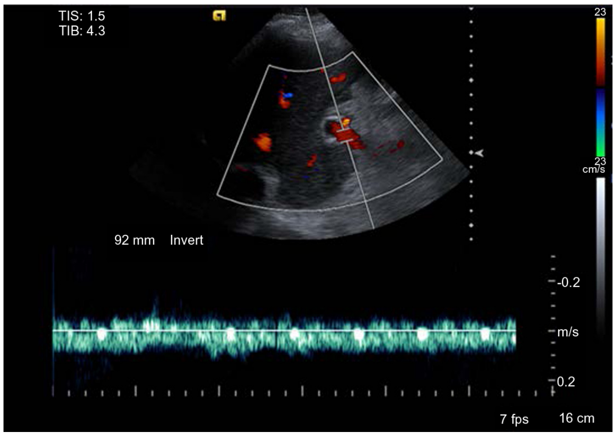

Figure 22 Flow in portal vein seen on both sides of baseline due to vascular motion artifact.

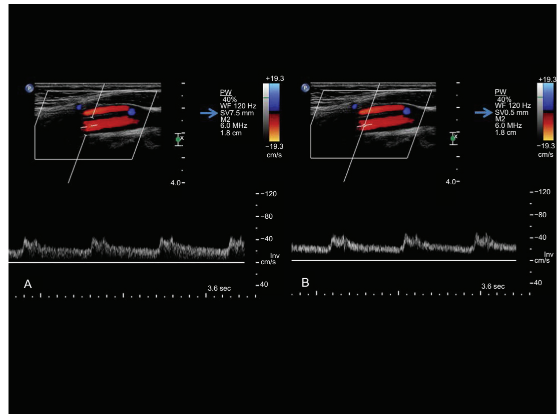

Figure 23 Spurious spectral broadening visualized in (**A**) due to large sample volume. When sample-volume size is reduced, the accurate depiction of flow velocities within the vessel is seen in image (**B**).

Physics

Vascular motion artifact can be encountered most often when interrogating hepatic vessels. Understanding vascular motion artifact depends upon understanding laminar blood flow. In a blood vessel in which the flow is laminar, there is an organized range of velocities from the center of the vessel, where it is highest, gradually decreasing down to the lowest velocity abutting the vessel wall. Ideally, the gate should be set to a small size (2–3 mm), and the spectral Doppler sample should be taken at the center of the vessel. Cardiac motion induces cyclical motion of the liver (and of course motion of the hepatic vessels within it). The vessel thus moves in relation to the fixed location of the sampling box. This results in sampling of a continuum of locations within the cross section of the blood vessel. As the sample box interrogates toward the periphery and back toward the center, the spectral Doppler velocity pattern will artifactually decrease and increase in a cyclical fashion. This appearance can be falsely interpreted as, eg, a cyclical pattern in a portal vein indicating tricuspid regurgitation.[11]

Artifact due to

Patient factors.

Where it commonly occurs

Hepatic vessels.

Spurious spectral broadening

Appearance

Spurious spectral broadening (Figure 23).

Physics

In a blood vessel in which the flow is laminar, there is an organized range of velocities from the center of the vessel, where it is highest, gradually decreasing down to the lowest velocity abutting the vessel wall. In spectral Doppler imaging, increasing the size of the sample volume box (the gate) is helpful in searching for trickle flow or trying to obtain a Doppler signal behind a shadowing calcified plaque. The size of the sample volume box is normally kept between 2 and 3 mm.[18] However, if the sample volume box is set too large (>3.5 mm), it will include a wider range of the velocities within the vessel. This manifests on the spectral waveform as spurious spectral broadening. This is spurious because true spectral broadening indicates the presence of turbulent flow, turbulent flow being present just distal to an arterial stenosis.[19] A small gate of 1.5–2 mm should be used to obtain good central vessel laminar flow information without including the slower-flowing signals from blood near the vessel wall.[19] If the gate is too small (<1.5 mm), the Doppler signal may be missed. Spurious spectral broadening can also result when the sample volume box is located close to the vessel wall and when the gain setting is too high. Lastly, it may result when using a large Doppler angle (close to 90°). Thus, errors can be minimized by keeping the Doppler angle less than 60°.[11]

Artifact due to

Improper scanning technique.

Where it commonly occurs

When a wide gate is used; sample box located close to the vessel wall; gain setting too high.

Spurious thrombosis related to velocity scale, wall filter, and gain

Appearance

Spurious thrombosis (Figure 24).

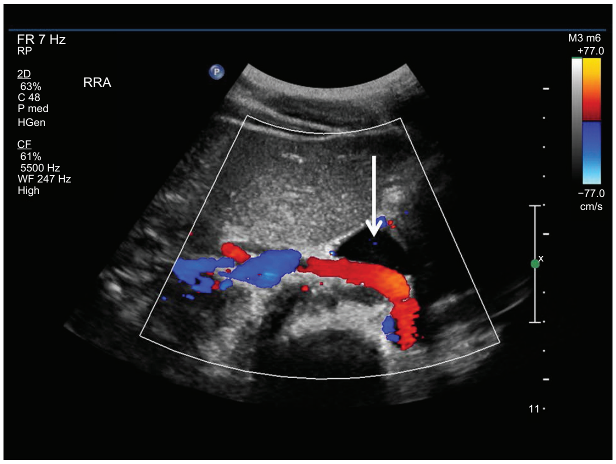

Figure 24 Artifactual appearance of thrombosis in IVC (arrow) due to PRF/velocity scale setting being too high to display low-velocity slow venous flow.
Abbreviations: IVC, inferior vena cava; PRF, pulse repitition frequency; RRA, right renal artery.

Physics

Spurious thrombosis may be seen as a result of setting the velocity scale or wall filter too high or the gain too low. When the velocity scale is set too high relative to the blood-flow velocity in a slow-flow vessel, visualization of flow in such a vessel is decreased. Thus, such vessels may falsely appear thrombosed.

When the gain is set too low, some Doppler information is lost, especially in vessels with slow flow. When the gain setting is too high, this produces random color noise throughout the display. The color gain should be increased until noise is encountered, and then decreased until the noise just clears from the image.[11]

A wall filter is a user-adjustable function of the US machine that allows exclusion of color flow information above or below specified Doppler frequency levels. A high-pass filter includes higher Doppler frequency information (higher velocity) and excludes Doppler frequency information below the user-specified level. A high-pass filter is used when imaging higher-velocity vessels (arteries) and has the effect of removing artifacts related to vessel-wall motion, which is typically a low-frequency signal. Artifacts can arise when there is true slow blood flow in a vessel (which will produce lower-frequency Doppler shifts). If these Doppler shift frequencies are below the level set for the filter, then this will produce a spurious appearance of lack of flow in such vessels (spurious thrombosis).[11] Diagnostically significant information can also be lost in the measurement of resistive index. Arterial diastolic flow is lower in velocity (producing lower-frequency Doppler shifts), and therefore if the low-velocity diastolic flow is filtered out, this will produce a spuriously high resistive index.[11]

Artifact due to

Improper scanning technique.

Where it commonly occurs

Veins.

Directional ambiguity

Appearance

Doppler signal appearing both above and below the spectral zero-velocity baseline.

Physics

Directional ambiguity occurs when the main US beam intercepts a vessel at a 90° angle.[11] The sound wave reflected from flowing blood is neither moving toward nor away from the direction of the wave and does not undergo a Doppler shift. Without a Doppler shift, the direction of flow cannot be deduced. In this situation, spectral Doppler information is displayed as a tracing both above and below the spectral zero-velocity baseline.[11] This artifact is worsened by higher gain settings and is easily corrected when the beam direction is shifted to an angle either side of 90°. When obtaining a sample volume in spectral Doppler imaging, one should avoid the portion of a vessel that intercepts the interrogating beam at 90°; however, the Doppler angle should ideally be kept at less than 60°. Note that electronic angulation, when available, can also be used to adjust the Doppler angle.[11]

Artifact due to

Improper scanning technique.

Where it commonly occurs

When a Doppler beam is 90° to flowing blood.

Elastography

Bull's eye artifact (strain)

Appearance

White central signal within a black outer signal and a bright spot posterior to a lesion (Figure 25).

Physics

A characteristic elastogram is seen with benign simple and complicated cysts with some systems. This artifact is characterized by a white central signal within a black outer signal and a bright spot posterior to the lesion.[20] This artifact has a high predictive value for the lesion being a benign simple or complicated cyst. If there is a solid component in the cyst, it will appear as a solid lesion within the pattern.

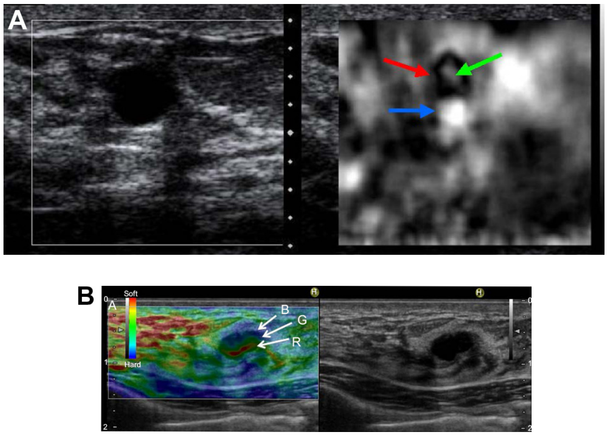

Figure 25 (**A**) The image on the left in the dual-screen display is the B-mode image, whereas the image on the right is the elastogram. The elastogram shows the characteristic artifact, a black area (red arrow) with a central bright spot (green arrow) and posterior bright spot (blue arrow). (**B**) A different artifact is seen in cysts on the Hitachi system. This artifact has three-colored layers with a blue-green-red (BGR) pattern.

This artifact can be used to decrease the number of breast biopsies performed.[20] In one series, 10% of complicated cysts appeared as solid masses on B-mode that could be identified as complicated cysts with this technique. If core biopsies are performed, notifying the pathologist the lesion is a complicated cyst as opposed to a solid mass will lead to better pathology/imaging correlation. If the pathologist is told the lesion is solid, he may not mention that a cyst wall is present and suggest the suspected solid lesion is not in the specimen, leading to nonspecific diagnosis. This useful artifact is seen with Siemens and Philips equipment and may not be seen in other manufacturers' equipment.[20]

The Hitachi system has a different artifact that occurs in cysts (Figure 25B). There is a three-color layering pattern of blue, green, and red (chorine) identified in cystic lesions.[21–23] A detailed study evaluating the sensitivity and specificity of this artifact has not been performed.

Artifact due to
Algorithm.

Where it commonly occurs
Both simple and complex benign cysts.

Note
The artifact is vendor-specific.

Sliding artifact (strain)
Appearance
A bright ring surrounding a lesion (Figure 26).

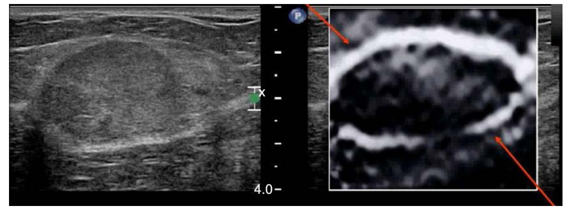

Figure 26 B-mode image and elastogram of a lipoma. Note the white ring (red arrows) surrounding the lesion on the elastogram. This pattern is caused by the lesion moving in and out of the imaging plane during the elasticity image acquisition and is called the sliding artifact. Because this artifact usually occurs with lesions that can move independent of the adjacent tissue, it is usually identified in benign lesions. Keeping the lesion in the same field of view during elasticity image acquisition can eliminate it.

Physics
A white ring or group of waves around a lesion on the elastogram indicates the lesion is moving in and out of the imaging plane while the elastogram is being obtained. This is called a sliding artifact.[23] Having the lesion remain within the imaging plane during the acquisition can eliminate the artifact. Repositioning the patient, using less compression, or having the patient hold their breath may help keep the lesion in the scanning plane. This artifact suggests the lesion is freely moveable within the adjacent tissues and is most likely benign.

Artifact due to
Improper scanning technique.

Where it commonly occurs
Lesions that can slip laterally under the transducer, eg, fibroadenoma, lipoma.

Worm pattern (strain)
Appearance
A pattern of changing stiffness in the image (Figure 27).

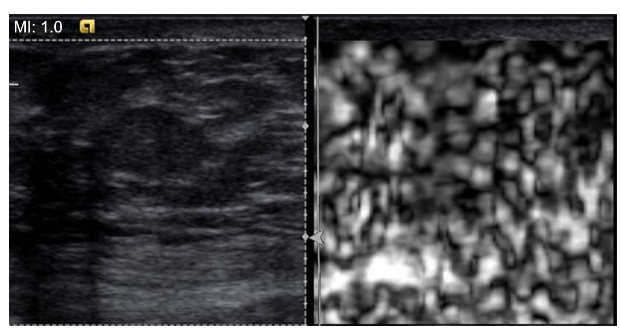

Figure 27 Elastogram of an area of fat under significant precompression has only regions of alternating dots and tubular areas interspersed with similar black areas. On real-time imaging, these are constantly changing form, as this represents noise.

Physics

If there is very little variability in the elastic properties of the tissues within the Field of View (FOV), such as when significant precompression is applied, a pattern of varying signals is noted, representing noise. This has been named the worm pattern.[23] There is no clinical information in these images. This artifact can be eliminated by the use of minimal precompression and including various tissues within the field of view.[23]

Artifact due to

Improper scanning technique.

Where it commonly occurs

When the tissues within a field of view are of equal strain (when moderate precompression is used).

Lack of shear-wave signal (shear wave)

Appearance

No color-coding of a lesion in shear-wave imaging (Figure 28).

Physics

In very hard lesions, such as invasive cancers, the shear wave may not propagate normally. No results are therefore obtained, and the area with no results is not color-coded. In these areas, interpretation is not possible. Shear waves will not propagate through simple cysts, and they will not be color-coded either (Figure 26B). The shear wave is detected by US echo signal. Therefore when areas in B-mode image show extremely low signals, it indicates the echo signal is too low for successful detection. These areas are not color-coded. This will occur in areas with marked shadowing, such as ribs, tumor with significant shadowing, and areas with calcification.[23]

Artifact due to

Patient factors, lesion factors.

Where it commonly occurs

In areas deeper than the shear wave is generated, in hard or disordered structures where the shear wave contains significant noise.

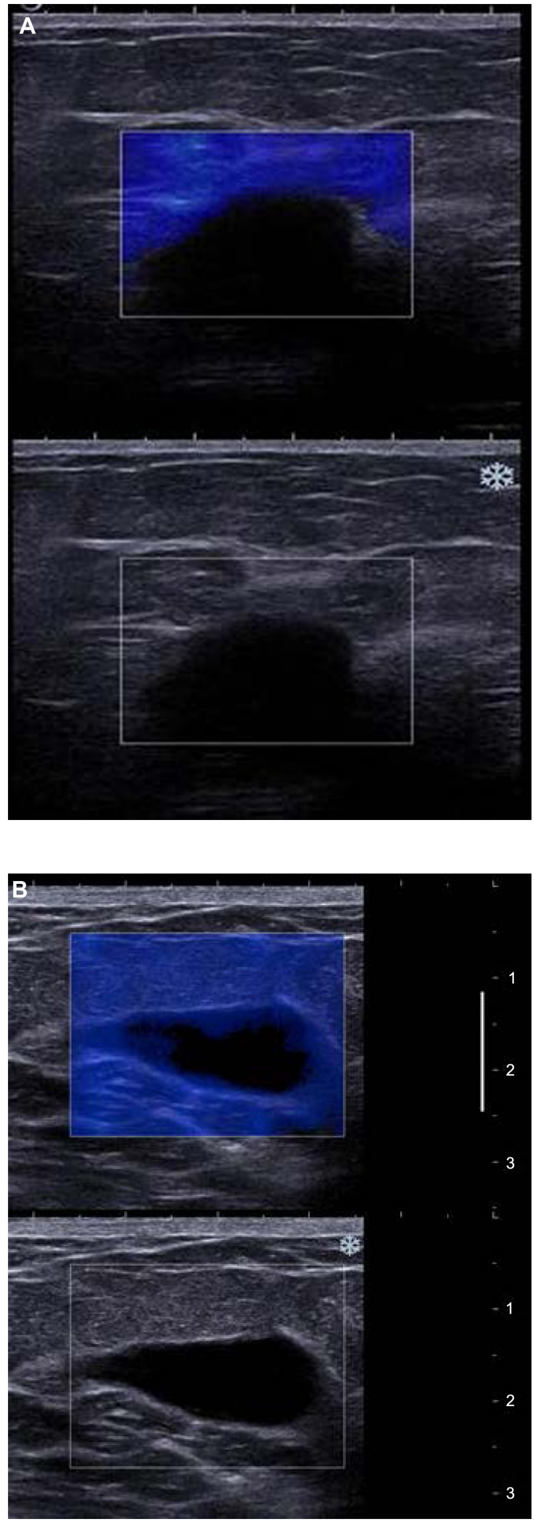

Figure 28 (**A** and **B**) Problems that can be encountered with shear-wave elastography include no signal within the lesion, which can occur because the push pulse does not start a shear wave in the mass because of the lesion depth. (**A**) This invasive ductal carcinoma does not have a shear-wave signal (no color with the lesion) because the shear wave did not form. (**B**) Simple cyst. Shear waves cannot propagate in simple cysts and therefore are not color-coded on the shear-wave elastogram. If the cyst is complicated, the shear wave may propagate and will be color-coded blue (low kPa value). Precompression can markedly affect the kPa value of a lesion. With increased precompression, all lesions become stiffer and therefore code with a higher kPa value.

Precompression artifact (strain and shear wave)

Appearance

Erroneously high shear-wave velocity (shear wave) and increasing noise (strain) (Figure 29).

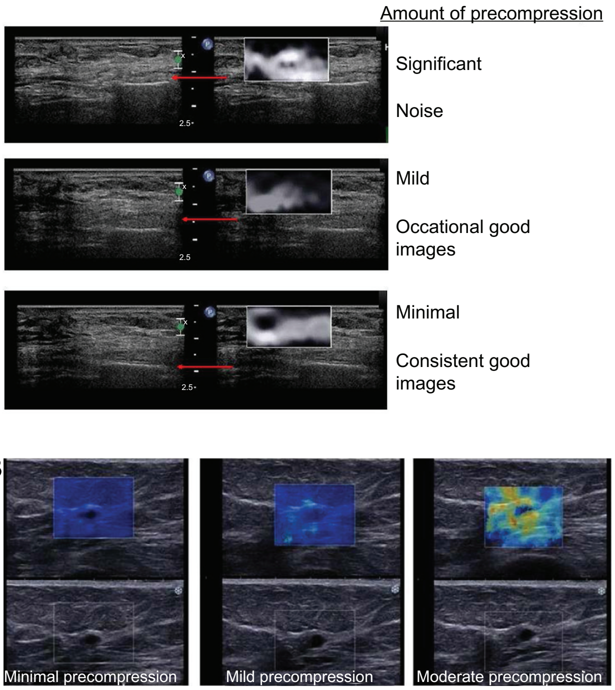

Figure 29 (**A**) Effect of precompression on strain imaging of an epidermoid cyst. In the bottom image, the elastogram is obtained with minimal precompression. The epidermoid cyst is seen as a "hard" (black) lesion and is seen on all frames during the examination. In the middle image, a mild amount of precompression is applied. The elastogram has frames that are of good quality, but others that are of poor quality and nondiagnostic. With substantial precompression, all frames are nondiagnostic, and the images show just noise, as all of the tissues have similar elastic properties. The red arrows point to a rib, which can be used to determine the amount of precompression.[24] (**B**) Cyst with varying degrees of precompression. Note that the cyst has higher kPa values with increasing precompression and with marked precompression has a kPa value indicating malignancy. Precompression must be avoided with both elasticity imaging and shear-wave elastography to obtain accurate results.

Physics

If one uses precompression, there will be a pattern of red in the near field.[23,24] This can be corrected by using minimal pressure from the transducer on the patient. However, in general, the desmoplastic reaction of the tumor will be hard surrounding the tumor and appear as a hard (red) halo surrounding the lesion. Care must be taken with precompression, as this can also create the same appearance in a benign lesion[23] (Figure 29B).

Artifact due to

Improper scanning technique.

Where it commonly occurs

When pressure is applied to tissue by the transducer.

Conclusion

US artifacts are common, and some can be used to aid in diagnosis when the principles of the artifacts are known. Understanding the cause of the artifacts can help to eliminate unwanted artifacts.

Disclosure

RGB has received equipment and research grants from Siemens Ultrasound, Philip Ultrasound and SuperSonic Imagine. He is on an advisory panel for Philips Ultrasound, and is a lecturer for Siemens Ultrasound, Philips Ultrasound, and SuperSonic Imagine.

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