Chapter-21

ULTRASONOGRAPHY ARTIFACTS

[1]**Adithya G Rao,** Assistant Professor

Department of Medical Imaging Technology, Yenepoya School of Allied Health Sciences,
Yenepoya Deemed to Be University, Mangaluru, Karnataka, India

21.1. INTRODUCTION

Ultrasound imaging has established itself as one of the most important diagnostic tools in modern medicine due to its unique combination of accessibility, portability, non-invasiveness, and absence of ionizing radiation. It provides real-time visualization of internal organs, blood flow, and soft tissues, making it indispensable in fields such as obstetrics, cardiology, abdominal imaging, musculoskeletal assessment, and vascular diagnostics. Despite these advantages, ultrasound is inherently limited by the physical properties of sound wave propagation, reflection, refraction, and attenuation. These limitations manifest in the form of artifacts, which may be defined as image features that do not faithfully represent the true anatomical or physiological structures within the body. Artefacts can appear as structures that are absent in reality, obscure existing structures, or alter the perceived shape, size, and echogenicity of tissues. For this reason, the study of ultrasound artifacts is of profound importance, both from a technical and a clinical perspective. From a definitional standpoint, an ultrasound artifact is any distortion or error in the image that arises due to violations of the assumptions upon which ultrasound imaging systems are designed. The ultrasound machine is programmed to assume that sound waves travel in a straight line, at a constant velocity of approximately 1540 meters per second in soft tissue, and that all echoes arise from the main ultrasound beam and correspond to the most recent transmitted pulse. These assumptions simplify the process of reconstructing echoes into an image; however, human tissues are highly heterogeneous, and acoustic behaviour is often far more complex. When sound interacts with structures of different densities, impedances, or geometries, these assumptions are violated, resulting in image artifacts [1].

The clinical relevance of artifacts cannot be overstated. Artifacts may lead to false-positive findings, in which non-existent structures mimic disease, or false-negative findings, in which true pathology is obscured. A common clinical example of a false-positive artifact is the mirror image artifact near the diaphragm, where structures such as the liver or gallbladder may be duplicated and misinterpreted as lesions or masses. Conversely, posterior acoustic shadowing caused by bowel gas may conceal underlying pathology, such as small gallstones or renal calculi, producing a false-negative interpretation. These diagnostic pitfalls may result in unnecessary investigations, inappropriate treatments, or delayed diagnosis, underscoring the necessity of a thorough understanding of artifact phenomena. At the same time, certain artifacts can be diagnostically advantageous. For instance, posterior acoustic enhancement is a reliable sign of cystic lesions, as sound waves propagate easily through fluid with minimal attenuation, resulting in increased echogenicity behind the fluid-filled structure. Similarly, the presence of clean posterior shadowing behind calcified gallstones serves as confirmatory evidence of their composition. Thus, artifacts are not merely limitations but may also serve as important diagnostic markers when properly recognized and interpreted. The physics underlying artifacts is directly related to the acoustic properties of tissues and the behaviour of sound waves at tissue interfaces. When sound waves encounter

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boundaries of differing acoustic impedance, part of the wave is reflected while the remainder is transmitted. In certain circumstances, repeated reflections occur, leading to reverberation artifacts. Refraction, the bending of sound waves at tissue boundaries, may displace structures laterally from their true position. Variations in the actual velocity of sound through different tissues compared to the assumed constant velocity of 1540 m/s may cause depth misregistration or displacement of echoes, producing speed error artifacts. Similarly, if multiple echoes are mistakenly attributed to a single transmitted pulse, range ambiguity artifacts result. Collectively, these phenomena arise because the imaging system cannot fully account for the complexity of acoustic propagation in heterogeneous biological tissues [2].

For clarity of understanding, artifacts may be categorized into several broad groups: propagation-related artifacts, attenuation-related artifacts, beam-related artifacts, Doppler-related artifacts, and those resulting from operator technique or equipment limitations. Propagation artifacts occur when the assumptions regarding sound travel paths or velocity are violated. These include reverberation, mirror image, refraction, speed error, and range ambiguity artifacts. Attenuation artifacts, such as acoustic shadowing and posterior enhancement, occur due to variations in tissue absorption and scattering. Beam-related artifacts, including side lobes, grating lobes, and beam-width artifacts, are the result of non-ideal beam shapes and off-axis echoes being misrepresented along the main imaging line. Doppler artifacts are unique to vascular imaging and color-flow analysis; examples include aliasing, spectral mirror image, and spectral broadening, which arise from the technical limitations of Doppler sampling. Finally, operator and equipment-related artifacts may occur due to incorrect machine settings, excessive gain, inappropriate probe positioning, or calibration errors. This classification is not merely academic but provides a structured framework for sonographers and radiologists to approach the recognition, interpretation, and correction of artifacts in practice. The clinical implications of these artifact categories are significant across multiple domains of ultrasound practice. In abdominal ultrasound, distinguishing true gallstones from bowel gas is often complicated by shadowing and reverberation artifacts. In obstetric imaging, artifacts such as reverberations may mimic the appearance of multiple gestational sacs, potentially leading to misdiagnosis of multiple pregnancy. In cardiac ultrasound, mirror image artifacts caused by pleural reflections can mimic intracardiac masses, potentially altering clinical management if unrecognized. In vascular Doppler studies, aliasing may lead to false impressions of stenosis, whereas blooming artifacts can exaggerate the diameter of vessels. Therefore, artifact recognition is a vital skill that directly influences the accuracy and safety of diagnostic decision-making. It is also worth noting that the study of artifacts holds not only clinical but also educational significance. Trainees in radiology and sonography must become adept at recognizing artifacts, differentiating them from pathology, and understanding the technical modifications required to reduce or eliminate their impact. Training programs frequently emphasize artifacts using side-by-side examples of true pathology and artifactual appearances, simulation-based teaching, and hands-on scanning sessions where learners can manipulate machine settings to produce and correct specific artifacts. This process cultivates technical expertise, critical thinking, and diagnostic confidence.

Historically, artifacts have been both a challenge and a source of insight. In the early decades of ultrasound development during the 1950s and 1960s, artifacts were often misinterpreted as true anatomical structures, which contributed to skepticism about the reliability of ultrasound as a diagnostic modality. Over time, with advances in ultrasound physics, transducer technology, and computing power, strategies to reduce artifacts were developed. The introduction of harmonic imaging, spatial compound imaging, adaptive beamforming, and sophisticated Doppler algorithms has reduced—but not eliminated—the prevalence of certain artifacts. Despite technological progress, artifacts remain inherent to ultrasound, and their recognition depends largely on the experience and skill of the operator.

21.2. CLASSIFICATION OF ULTRASOUND ARTIFACTS

The classification of ultrasound artifacts is fundamental for systematic understanding, accurate recognition, and clinical management of these phenomena in diagnostic imaging. Artifacts in ultrasonography arise from a wide spectrum of physical principles, instrumentation limitations, and operator-dependent variables. For clarity, these artifacts are broadly grouped into five main categories**:** (1) artifacts related to sound–tissue interaction, (2) artifacts due to propagation speed errors, (3) artifacts linked with attenuation phenomena, (4) Doppler-related artifacts, and (5) machine- or operator-dependent artifacts. Each group encompasses a range of specific phenomena that can significantly alter image appearance and potentially mislead interpretation if not properly recognized. This structured classification allows sonographers, radiologists, and medical physicists to systematically analyze the origin of image errors and employ corrective measures during real-time imaging.

21.2.1. Artifacts Related to Sound–Tissue Interaction

Ultrasound artifacts are phenomena that result from deviations in the behaviour of sound waves as they travel through, reflect from, or scatter within human tissues. The ultrasound imaging system is designed based on a series of fundamental assumptions: (1) sound waves travel in straight lines, (2) echoes arise only from the central axis of the beam, (3) each pulse reflects only once before returning to the transducer, (4) sound travels at a constant speed of approximately 1540 m/s in soft tissue, and (5) attenuation is uniform across tissues. However, biological tissues rarely conform perfectly to these assumptions. Interfaces with large differences in acoustic impedance, complex tissue boundaries, or highly reflective surfaces can alter the propagation pathway of ultrasound waves. As a result, images may contain structures that are misplaced, duplicated, or distorted. These artifacts, while sometimes confusing, may also provide diagnostic clues if properly recognized. The most important artifacts in this category include reverberation, comet-tail, ring-down, mirror image, side lobes, and refraction artifacts. Each arises from specific physical interactions between the ultrasound wave and tissue interfaces. Understanding their underlying mechanisms, appearance, and clinical implications allows radiologists and sonographers to avoid misinterpretations and, in some cases, to utilize these artifacts as diagnostic markers.

1. Reverberation Artifact

Reverberation artifact is one of the most common artifacts observed in ultrasound imaging. It occurs when the ultrasound beam becomes repeatedly reflected between two highly reflective surfaces, such as the pleura, bladder wall, gallstones, or metallic implants. As the sound waves bounce back and forth between these interfaces, each successive echo takes a longer time to return to the transducer. The ultrasound system interprets these delayed echoes as signals from progressively deeper structures, producing multiple, equally spaced, parallel horizontal lines on the image. These lines do not represent real anatomical structures but are instead false echoes created by repeated reflections. The distance between the parallel lines corresponds to the separation between the reflective surfaces, while the brightness of the echoes diminishes with depth due to sound attenuation [3].

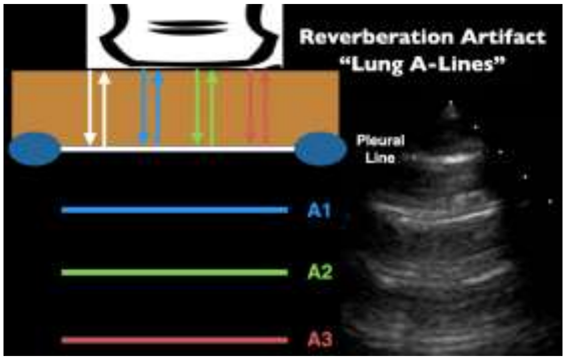

Fig: 21.1. Reverberation Artefact

Clinically, reverberation artifacts are commonly encountered in thoracic, abdominal, and vascular ultrasound examinations. In chest imaging, reverberation between the visceral and parietal pleura generates characteristic A-lines, which appear as parallel horizontal echoes and serve as a normal sign of aerated lung. In abdominal scans, reverberation behind gallstones can simulate multiple calculi or obscure deeper biliary or hepatic structures. Similarly, in the urinary bladder, catheters may produce reverberation patterns that mimic septations or internal echoes. Metallic prostheses and vascular catheters can also cause reverberation, sometimes masking underlying vessels or soft tissues. Recognition of reverberation artifacts is essential for accurate image interpretation, as they may lead to misdiagnosis if mistaken for pathological findings. However, in certain cases, such as lung ultrasound, the presence of reverberation artifacts like A-lines provides useful diagnostic information about the presence of air within the lungs and the absence of fluid or consolidation [4].

Table: 21.1. Clinical Examples of Reverberation Artifact

Clinical Site	Example	Appearance of Reverberation	Clinical Relevance
Lung / Pleura	A-lines	Horizontal, equally spaced lines below pleural line	Indicator of normal aerated lung
Abdomen	Gallstones	Multiple bright echoes posterior to stones	Mimics multiple calculi, obscures posterior anatomy
Urinary Bladder	Catheter / bladder wall	Parallel bands posterior to catheter	May be misinterpreted as septations
Vascular Imaging	Metallic stents or catheters	Repeated parallel echoes	Can obscure vascular lumen assessment
Musculoskeletal	Orthopedic prostheses	Strong parallel lines behind metal	Limits visualization of adjacent soft tissue

Remedial Actions for Reverberation Artifact: Reverberation artifacts, though common, can often be minimized or eliminated through appropriate technical adjustments and scanning techniques. The following remedial actions can help reduce their occurrence and improve image accuracy:

1. Change the Angle of Insonation: Since reverberation occurs when the ultrasound beam strikes a reflective surface perpendicularly, slightly altering the angle of the transducer can redirect the sound waves, preventing multiple reflections between interfaces. This is one of the simplest and most effective corrective measures.
2. Adjust Transducer Position or Orientation: Moving the probe to a different location or changing its orientation can help bypass highly reflective surfaces such as bone, air, or metallic objects, thereby reducing the likelihood of reverberation echoes.
3. Use a Different Acoustic Window: Scanning through an alternative acoustic window—such as a different intercostal space in thoracic imaging or a subcostal approach in abdominal imaging—can help avoid strong reflectors responsible for the artifact.
4. Apply Harmonic Imaging: Tissue harmonic imaging (THI) reduces reverberation artifacts by utilizing higher harmonic frequencies generated within tissues. Since harmonics are less affected by superficial reflections, this technique enhances image clarity and contrast resolution.
5. Modify Gain and Time-Gain Compensation (TGC): Lowering the overall gain or adjusting the near-field TGC can help suppress the brightness of reverberation echoes, making them less prominent without compromising visualization of deeper structures.
6. Use Spatial or Frequency Compounding: Compounding techniques combine images acquired from different beam angles or frequencies, which tend to cancel out artifacts like reverberation while preserving real anatomical details.
7. Apply Appropriate Depth and Focus Settings: Setting the correct imaging depth and placing the focal zone at or just below the region of interest can optimize beam convergence, reducing the visibility of spurious echoes.
8. Avoid Scanning Over Air or Metal: Whenever possible, minimize scanning over air-filled regions or metallic prostheses, as these are strong reflectors that frequently cause reverberation artifacts.

2. Comet-Tail Artifact

The comet-tail artifact is a distinctive form of reverberation artifact seen in ultrasound imaging, characterized by a bright, tapering trail of echoes that resemble the tail of a comet. Unlike conventional reverberation, which produces multiple discrete, evenly spaced parallel lines, the echoes in comet-tail artifact are so closely spaced that they blend into a continuous, dense, and highly echogenic band. This artifact typically arises when the ultrasound beam interacts with very small but strongly reflective interfaces, such as cholesterol crystals, metallic objects, or gas bubbles, which cause rapid back-and-forth reflections between the interfaces. Because the spacing between these reflectors is extremely small, the returning echoes overlap, creating a solid bright line that diminishes in intensity with depth.

Fig: 21.2. Comet-tail artifact in Adenomyomatosis

Clinically, the comet-tail artifact often provides useful diagnostic information rather than being a source of error. In hepatobiliary imaging, it is a hallmark feature of adenomyomatosis of the gallbladder, where cholesterol crystals within Rokitansky–Aschoff sinuses produce the characteristic tail-like echoes. It is also commonly observed behind metallic surgical clips, retained foreign bodies, and small intraluminal gas bubbles, serving as a reliable indicator of these highly reflective structures.

Table:21.2. Clinical Examples of Comet-Tail Artifact

Clinical Site	Example	Appearance	Clinical Relevance
Gallbladder	Adenomyomatosis (cholesterol crystals in Rokitansky-Aschoff sinuses)	Bright tapering tail extending from gallbladder wall	Classic diagnostic marker of adenomyomatosis
Surgical Sites	Metallic clips / foreign bodies	Dense tapering bright trail posterior to object	Helps confirm presence of clip or foreign body
Gastrointestinal Tract	Intraluminal gas bubbles	Comet-tail echoes posterior to small gas pockets	Differentiates gas from pathology
Soft Tissue / MSK	Retained metallic fragments	Tapering bright echoes posterior to fragment	Assists in localization of foreign material

3. Ring Down Artefact

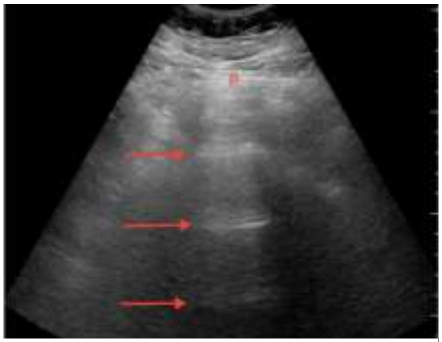

Fig: 21.3. Ring Down Artefact

The ring-down artifact is a distinctive type of ultrasound artifact that appears as a continuous bright echo extending downward (distally) from a structure containing gas. It is often confused with the comet-tail artifact because both appear as bright, tapering trails on the image. However, the underlying cause of the ring-down artifact is different. Instead of resulting from multiple reflections between closely spaced interfaces, as in the comet-tail artifact, the ring-down artifact occurs due to the resonance of gas bubbles within tissues or fluid. When the ultrasound beam strikes a small collection of gas bubbles, these bubbles begin to vibrate or "ring," continuously emitting sound waves even after the original ultrasound pulse has passed. This ongoing vibration produces a continuous, bright, vertical echo that appears as a solid, flame-like band extending downward from the site of the gas collection. On the ultrasound image, the ring-down artifact typically appears as a bright, continuous line or band that gradually tapers in intensity with depth. It is most commonly seen in areas where gas is present, such as the gastrointestinal tract, abscess cavities, or the biliary system. For example, it may be observed in conditions like pneumobilia (air in the biliary tree), emphysematous cholecystitis (gas in the gallbladder wall), or gas-forming infections in soft tissue. The presence of a ring-down artifact is therefore a useful indicator of gas within a region that may not normally contain it, alerting clinicians to possible infection, perforation, or other pathology. In comparison to the comet-tail artifact, the ring-down artifact differs both in mechanism and appearance. The comet-tail artifact arises from multiple reflections between solid, closely spaced interfaces such as cholesterol crystals or metallic clips, producing a short, discrete series of bright echoes. In contrast, the ring-down artifact arises from the resonance of gas bubbles that continuously emit sound, resulting in a longer, solid, and more uniform band. Recognizing the difference between these two artifacts is important in clinical practice, as it helps accurately identify the nature of the underlying tissue and avoid diagnostic confusion [5].

Table: 21.3. Differentiation from Comet-Tail Artifact

Feature	Comet-Tail Artifact	Ring-Down Artifact
Cause	Multiple reverberations between closely spaced reflectors	Resonance of gas bubbles emitting continuous sound
Appearance	Series of short, bright, discrete echoes	Continuous, bright, tapering vertical band
Source	Solid or metallic interfaces (cholesterol crystals, surgical clips)	Gas bubbles or air–fluid interfaces
Common Locations	Gallbladder (cholesterolosis), surgical sites	Biliary tree, abscesses, bowel loops

Clinical Importance: The clinical importance of the ring-down artifact lies in its ability to signal the presence of gas within tissues or structures where it is not normally found, serving as a valuable diagnostic clue in medical imaging. Recognizing this artifact allows clinicians to identify pathological conditions associated with gas formation, such as abscesses, biliary infections, or gas-producing bacterial infections. For instance, the presence of a ring-down artifact within the liver or biliary system may suggest pneumobilia (air in the bile ducts) or emphysematous cholecystitis, while in soft tissues it can indicate gas-forming infections or necrotizing fasciitis. By accurately identifying the ring-down artifact, radiologists and sonographers can differentiate between gas-related pathology and normal anatomical structures, helping prevent misinterpretation of the ultrasound image. This distinction is particularly important because gas within tissues can mimic other echogenic interfaces, potentially leading to diagnostic errors. Therefore, understanding and recognizing this artifact not only enhances diagnostic accuracy but also supports timely clinical decision-making, especially in emergency and infectious conditions [6].

4. Mirror Image Artifact

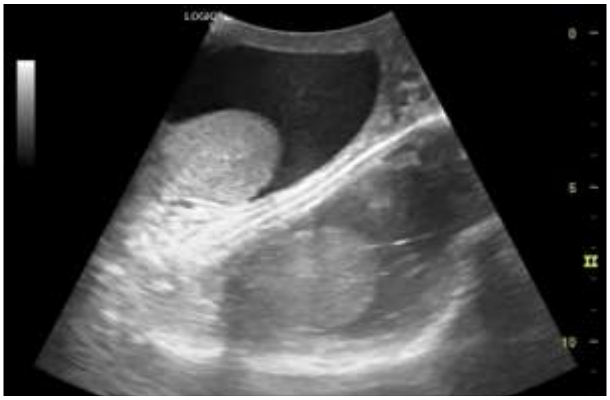

Fig: 21.4. Mirror Image Artifact

The mirror image artifact in ultrasound (USG) is a common type of image duplication artifact that occurs when the ultrasound beam encounters a strong reflective interface, such as the diaphragm or pleural surface**.** When sound waves strike this highly reflective surface, a portion of the echo is redirected toward another structure before returning to the transducer. As a result, the ultrasound system assumes the returning echoes have traveled in a straight line from deeper structures, leading to the appearance of a duplicated (mirror) image of the structure on the opposite side of the reflective interface. This artifact typically appears as a reversed or duplicated copy of an organ or structure, located deeper than the real one and across the reflective boundary. A classic example is seen in liver imaging, where the diaphragm acts as the mirror. The liver tissue located just above the diaphragm may appear duplicated into the thoracic cavity, giving the impression of hepatic tissue “floating” above the diaphragm. Similar effects can also be observed with other strong reflectors, such as the bladder wall or lung surfaces. The mirror image artifact arises because the ultrasound system is built on the assumption that sound waves travel in a straight line and at a constant speed. When this assumption is violated by reflection and redirection of the beam, the system incorrectly interprets the path length, resulting in the false appearance of duplicated anatomy. Clinically, recognizing the mirror image artifact is important because it helps avoid misinterpretation of duplicated structures as real pathological findings, such as cysts, masses, or lesions. Understanding its mechanism and appearance allows sonographers to correctly identify the artifact, often confirmed by changing the angle of insonation or scanning position, which causes the mirror image to disappear or shift.

5. Refraction Artifact

The refraction artifact in ultrasound imaging occurs when the ultrasound beam changes direction (bends) as it passes through tissues that have different propagation speeds or acoustic properties. This bending is most commonly observed at interfaces where tissues of different densities, speeds, or stiffness meet—for example, at the junction between fat and muscle, tendon and fluid, or soft tissue and bone. When the sound beams bends, the ultrasound machine incorrectly assumes that the returning echoes have traveled in a straight line. As a result, the system miscalculates the position of the reflecting structure, producing lateral displacement, duplication, or distortion of the true anatomical structures on the image [7].

A common clinical example is seen when imaging curved or oblique interfaces, such as the rectus abdominis muscle, bowel loops, or gallbladder wall. In these cases, a structure may appear shifted sideways or duplicated, creating the illusion of an additional object adjacent to the real one. Refraction artifacts are particularly prominent when scanning structures with smooth curved surfaces, where the beam enters at an oblique angle and exits at a different path, exaggerating the displacement of echoes. The refraction artifact occurs because the ultrasound system is built on the assumption that sound waves travel in a straight line at a uniform speed of 1540 m/s. When this assumption is violated, as happens when sound bends through tissues with differing speeds, the machine misplaces the location of echoes on the display, leading to inaccurate imaging. Recognizing refraction artifacts is clinically important to prevent misinterpretation of false structures as real pathology, such as cysts, masses, or foreign bodies. Simple corrective measures include changing the angle of insonation, repositioning the transducer, or scanning from a different acoustic window, which often eliminates or reduces the artifact.

Fig: 21.5. Refraction Artifact

6. Side-lobe and grating-lobe artifacts

Side-lobe and grating-lobe artifacts occur when ultrasound energy is emitted outside the main beam axis and interacts with strong reflectors located off-axis. In an ideal system, all the transmitted sound energy should travel along the main beam; however, in reality, some energy leaks laterally (side lobes) or at specific angles due to phased-array or linear-array transducer designs (grating lobes). When these off-axis beams strike a highly reflective structure, such as the diaphragm, bowel gas, or gallbladder wall, they produce echoes that are falsely interpreted as originating from the main beam. This leads to the appearance of spurious or “ghost” echoes on the image, which do not correspond to actual anatomical structures. Side-lobe artifacts are most common in single-element or mechanically scanned transducers, whereas grating-lobe artifacts are more prominent in array transducers with multiple active elements. On the image, these artifacts may appear as false echoes adjacent to or within fluid-filled structures, potentially mimicking lesions, stones, or foreign bodies. For example, a small hyperechoic line or dot may appear within a cyst or the bladder, even though no actual structure is present there. The artifact arises because the ultrasound system assumes that all returning echoes come from the path of the main beam, so it incorrectly places echoes from off-axis reflections into the displayed image. Recognizing side-lobe and grating-lobe artifacts is clinically important to avoid misdiagnosis of nonexistent structures. They can often be reduced by adjusting the scanning angle, changing transducer position, or using harmonics imaging, which suppresses off-axis energy [8].

7. Acoustic Shadowing Artifact in Ultrasound (USG)

Acoustic shadowing is a commonly encountered ultrasound artifact characterized by a dark or anechoic area appearing behind a structure that strongly attenuates the ultrasound beam. This artifact occurs when the ultrasound waves are either absorbed or reflected by a highly dense or highly reflective object. Such structures prevent the ultrasound waves from penetrating deeper into the tissues. Because the ultrasound system relies on returning echoes to form an image, the area distal to the attenuating structure receives little or no echoes, resulting in a dark or black region on the image. This gives rise to the characteristic "shadow" effect, which can be used as a diagnostic clue in various clinical settings. On ultrasound, acoustic shadowing appears as a dark or anechoic region directly posterior to the structure causing attenuation.

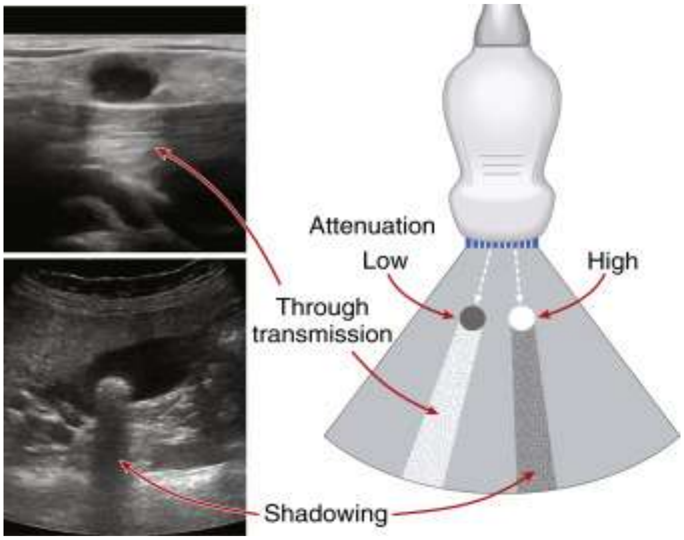

Fig: 21.6. Acoustic Shadowing Artifact

The edges of the shadow are usually sharp and well-defined, particularly when produced by highly reflective structures such as bones or stones. The intensity and extent of the shadow can vary depending on several factors, including the density and composition of the attenuating object and the frequency of the ultrasound transducer used. Higher-frequency transducers generally produce more pronounced shadows, while denser structures generate deeper and darker posterior shadowing, making the artifact both visible and diagnostically useful.

Table: 21.4. Common Causes and Examples

Structure	Example	Clinical Relevance
Bone	Vertebra, ribs, skull	Helps identify fractures and cortical margins
Gallstones	Cholelithiasis	Confirms presence of stones, differentiates from polyps or sludge
Calcifications	Breast, thyroid	Detects microcalcifications suggestive of malignancy
Metallic objects	Surgical clips, prostheses	Locates implants or foreign bodies

Types of Acoustic Shadowing: Acoustic shadowing can be classified into two main types: clean (dense) shadowing and dirty shadowing.

- **Clean (Dense) Shadowing:** This type is produced by highly reflective structures, such as stones or bone. It appears on ultrasound as a uniform, sharply defined dark region directly posterior to the attenuating object. The clarity and consistency of the shadow make it easy to identify and often serve as a useful diagnostic clue.
- **Dirty Shadowing**: This occurs when the ultrasound beam encounters gas-containing structures, such as bowel gas. Unlike clean shadowing, dirty shadowing appears as a heterogeneous, less well-defined dark area. The irregular appearance results from scattering of the sound beam by the gas, causing the shadow to have a more diffuse and patchy quality. This type of shadowing can help differentiate gas-filled structures from solid or calcified ones.

Table: 21.5. Comparison of clean (dense) shadowing and dirty shadowing in ultrasound

Feature	Clean (Dense) Shadowing	Dirty Shadowing
Cause	Highly reflective structures (e.g., stones, bone, metallic objects)	Gas-containing structures (e.g., bowel gas)
Appearance	Uniform, sharply defined dark area	Heterogeneous, poorly defined dark area
Echogenicity	Completely anechoic posterior to the object	Partial or patchy anechoic region due to scattering
Diagnostic Clues	Confirms presence of stones, bone margins, or metallic objects	Indicates gas-filled structures, helps differentiate bowel loops or gas from solid lesions
Mechanism	Strong reflection or absorption of sound waves prevents penetration	Scattering and absorption of sound waves by gas bubbles prevent clear transmission

Fig: 21.7. Dirty and Clean Shadowing

8. Enhancement Artifact in Ultrasound (USG)

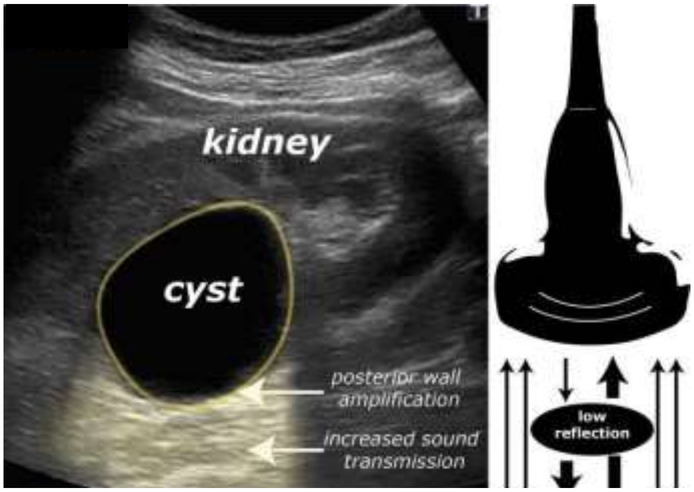

Fig: 21.8. Posterior Enhancement Artifact

The enhancement artifact, also referred to as posterior acoustic enhancement, is a key ultrasound phenomenon characterized by increased brightness or echogenicity in tissues located immediately posterior to fluid-filled structures. Common examples of such structures include simple cysts, the urinary bladder, gallbladder, bile ducts, or blood vessels. The underlying mechanism is based on the low attenuation of ultrasound waves by fluid. Unlike solid tissues, which absorb or scatter a significant portion of the sound energy, fluid allows the majority of the ultrasound beam to pass through with minimal energy loss. Consequently, tissues located beyond the fluid receive a higher intensity of ultrasound waves, producing stronger returning echoes and resulting in a brighter or hyperechoic appearance on the image. The artifact is most pronounced when the fluid collection is anechoic and homogeneous, such as in a simple cyst, because the ultrasound beam is transmitted efficiently without internal scattering. In contrast, complex cysts containing septations, debris, or haemorrhage may produce partial enhancement or irregular posterior brightness. The frequency of the transducer also influences the degree of enhancement: higher frequencies produce more noticeable echogenicity due to their greater sensitivity to variations in beam attenuation. Similarly, the size and depth of the fluid-filled structure affect the artifact's appearance; larger or deeper cystic structures tend to produce more prominent posterior enhancement. Clinically, posterior acoustic enhancement is highly useful in differentiating cystic from solid lesions. For example, a simple renal or hepatic cyst will appear anechoic with marked posterior enhancement, whereas a solid tumour or mass will not generate this artifact and may even produce posterior acoustic shadowing due to higher attenuation. Enhancement artifacts are also valuable in vascular imaging, aiding in the visualization of fluid-filled vessels and differentiating them from surrounding tissues. Recognition of this artifact is essential for accurate ultrasound interpretation, as it provides critical diagnostic information while preventing misidentification of posterior bright echoes as pathological lesions.

21.2.2. Artifacts Due to Propagation Speed Errors in Ultrasound (USG)

Ultrasound imaging assumes that sound travels at an average speed of 1540 m/s in soft tissues. When the actual propagation speed differs from this assumed value, the system miscalculates the distance to the reflecting structures, leading to propagation-related artifacts. These artifacts can result in misplacement, distortion, or duplication of anatomical structures on the ultrasound image, potentially affecting diagnostic interpretation.

A. Propagation Speed Error in Ultrasound

Propagation speed errors occur when ultrasound waves travel at speeds that differ from the assumed average of 1540 m/s used by the imaging system. Tissues with different acoustic properties can either slow down or accelerate sound propagation. For instance, fatty tissue tends to slow the transmission of sound, while dense fibrous tissue, calcifications, or metallic objects can increase the speed. The ultrasound machine calculates the depth of structures based on the time taken for echoes to return, assuming a constant speed of 1540 m/s. When the actual speed differs, the system misregisters the true location of structures, causing them to appear either too deep or too shallow on the image. This type of artifact is particularly noticeable in areas with significant variations in tissue composition, such as the breast with fatty layers, scarred or fibrotic liver tissue, or regions with calcifications. Recognizing propagation speed errors is crucial, as they can distort anatomical relationships and potentially lead to misinterpretation of lesion depth or size.

B. Range Ambiguity Artifact in Ultrasound

The range ambiguity artifact occurs when echoes originating from deeper structures are received after the next ultrasound pulse has already been transmitted. Because the ultrasound system assumes that each returning echo corresponds to the most recently emitted pulse, echoes from deeper structures can be misplaced at a shallower depth on the image. This overlap of pulse cycles leads to false or duplicated structures, potentially mimicking anatomical features or pathology that do not actually exist. Range ambiguity is particularly prevalent in imaging situations with a high pulse-repetition frequency (PRF) or when scanning deep structures with strong reflectors, as the returning echoes from these deep targets arrive after the subsequent pulse has been sent. Recognizing this artifact is crucial, as it can distort the perceived depth of structures, affecting measurements and potentially leading to diagnostic errors. Adjustments in PRF settings or imaging depth can help minimize the occurrence of range ambiguity artifacts.

Clinical Significance of Propagation-Related Artifacts: Artifacts caused by propagation speed errors and range ambiguity can significantly distort the appearance of anatomical structures or mimic pathological findings on ultrasound images. Such artifacts may lead to inaccurate assessment of lesion size, depth, or location, particularly in tissues with variable acoustic velocities, such as fatty tissue, scarred or fibrotic organs, or calcified areas. Misinterpretation of these artifacts can result in diagnostic errors if not recognized. Awareness of their occurrence is therefore essential for accurate image interpretation. In clinical practice, these artifacts can often be minimized or corrected by techniques such as adjusting the scanning angle, employing tissue harmonic imaging, modifying the pulse-repetition frequency, or optimizing other machine settings. Recognizing and accounting for propagation-related artifacts ensures more reliable and precise ultrasound-based diagnoses.

21.2.3. Artifacts Related to Beam Geometry and System Design

Artifacts related to beam geometry and system design arise due to the physical properties of the ultrasound beam and the limitations of the transducer or imaging system. These artifacts occur when ultrasound energy interacts with structures outside the intended main beam, or when the beam characteristics produce misplacement, duplication, or distortion of echoes. Understanding these artifacts is essential for accurate interpretation and avoiding misdiagnosis.

1. Beam-Width Artifact in Ultrasound (USG)

The beam-width artifact arises from the finite thickness of the ultrasound beam. Unlike the ideal concept of an infinitely thin beam, real ultrasound beams have a measurable width, particularly in the lateral plane. When scanning, the beam can encompass adjacent structures in addition to the intended target. As a result, echoes from structures outside the main imaging plane may be included in the image, producing false or misleading echoes. This artifact is particularly noticeable in fluid-filled regions, such as cysts or the urinary bladder, where adjacent echogenic structures (e.g., vessel walls, septa, or stones) may be erroneously displayed within the anechoic fluid. The appearance of these spurious echoes can mimic pathology, such as internal debris, septations, or small masses.

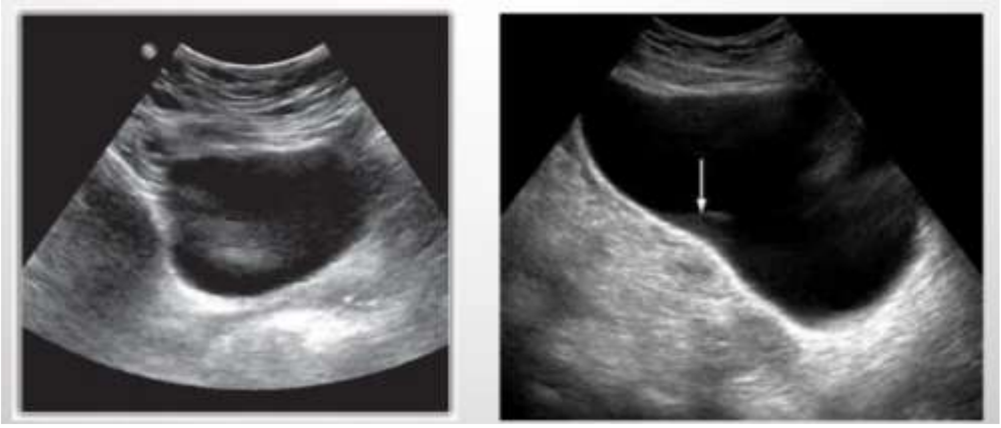

Fig: 21.9. Beam Width Artifact

The severity of beam-width artifact depends on several factors, including the transducer frequency, beam focusing, and depth of imaging. Higher-frequency transducers with better lateral resolution reduce the effect, whereas wide beams or poorly focused transducers are more prone to producing this artifact. Clinically, awareness of the beam-width artifact is essential to avoid misinterpretation of fluid-filled structures and to distinguish true internal features from artifacts.

2. Slice-Thickness Artifact (Partial Volume Artifact) in Ultrasound (USG)

The slice-thickness artifact, also referred to as the partial volume artifact, occurs because real ultrasound imaging planes have a finite elevational thickness rather than being infinitely thin. The ultrasound beam covers not only the intended imaging plane but also a volume of tissue above and below it. When multiple structures within this volume reflect echoes simultaneously, the ultrasound system averages these echoes and displays them as originating from the central imaging plane. This averaging effect can produce false internal echoes within structures that are otherwise homogeneous or anechoic.

This artifact is particularly evident in fluid-filled regions, such as simple cysts in the liver, kidney, or ovary. A cyst that is truly anechoic may appear to contain internal echoes, debris, or septations, mimicking a complex cystic lesion or even a solid mass. The severity of the artifact depends on several factors, including:

- Beam Elevational Thickness: Wider beams increase the volume of tissue sampled, increasing the likelihood of averaging.
- Transducer Frequency: Low-frequency transducers generally produce thicker beams, while high-frequency probes offer better elevational resolution and reduce the artifact.
- Focal Zone Position: Poorly positioned focal zones can exacerbate the artifact, as echoes from outside the plane are less well-resolved.
- Scanning Angle: Off-axis scanning can increase the inclusion of structures from adjacent planes, worsening the artifact.

Fig: 21.10. Slice Thickness Artifact

Clinically, the slice-thickness artifact can lead to misinterpretation of cystic lesions, potentially resulting in unnecessary further imaging or interventions. Recognizing this artifact is critical to distinguish true internal content from spurious echoes. Strategies to minimize its effect include:

- Using high-frequency transducers with narrower slice thickness.
- Optimizing the focal zone to the level of interest.
- Scanning the lesion from multiple planes or angles to confirm its true anechoic nature.
- Utilizing harmonic imaging, which can improve elevational resolution and reduce partial volume effects.

21.2.4. Doppler-Related Artifacts in Ultrasound (USG)

Doppler-related artifacts occur specifically in color and spectral Doppler imaging and result from the motion of blood, surrounding tissues, or limitations in the signal processing algorithms of the ultrasound system. These artifacts can distort the representation of blood flow, produce false flow signals, or obscure true vascular patterns, which may lead to misinterpretation of hemodynamic information. Common causes include high-velocity flow exceeding the Nyquist limit, motion of adjacent tissues, or strong reflectors in the beam path. Recognizing Doppler-related artifacts is critical for accurate assessment of vascular patency, flow direction, and velocity, and for avoiding false diagnoses such as stenosis, turbulence, or reversed flow. Appropriate adjustments in pulse-repetition frequency (PRF), color gain, wall filters, and insonation angle, along with careful scanning technique, are essential to minimize these artifacts and ensure reliable Doppler interpretation.

1. Aliasing Artifact in Doppler Ultrasound

Aliasing is a common Doppler artifact that occurs when the Doppler frequency shift exceeds the Nyquist limit, which is defined as half of the pulse-repetition frequency (PRF). When this limit is exceeded, the ultrasound system cannot correctly represent the true velocity of blood flow, causing the signal to wrap around and be displayed in the opposite direction. In pulsed-wave Doppler, the system measures the time delay between transmitted and received pulses to calculate flow velocity. If the blood flow velocity is too high relative to the PRF, the returning echoes return after the next pulse has already been emitted, causing the machine to misinterpret the direction and magnitude of flow. This results in a reversal of color coding on color Doppler or erroneous velocity readings on spectral Doppler.

Appearance and Locations of Aliasing Artifact: On Doppler imaging, aliasing manifests differently depending on the mode used. In color Doppler, it appears as an abrupt reversal of color, often seen as alternating red and blue bands within the same vessel, indicating that the measured flow velocity has exceeded the system’s Nyquist limit. In spectral Doppler, flow velocities beyond the Nyquist limit are “folded” downward, producing a wrapped or aliased waveform that inaccurately represents true velocities. Aliasing is most commonly observed in high-velocity vessels, such as the carotid arteries, aortic stenosis, arteriovenous fistulas, and high-velocity jets across stenotic valves.

Methods to Minimize Aliasing: Several techniques can be used to reduce or eliminate aliasing artifacts. Increasing the pulse-repetition frequency (PRF) raises the Nyquist limit, allowing accurate measurement of higher velocities. Shifting the baseline downward can also accommodate high-velocity flow without color reversal. Using continuous-wave (CW) Doppler is another effective strategy, as CW Doppler does not have a Nyquist limit and can measure very high velocities without aliasing. Additionally, adjusting the insonation angle by reducing the angle between the ultrasound beam and the direction of blood flow can decrease the Doppler shift and minimize the artifact.

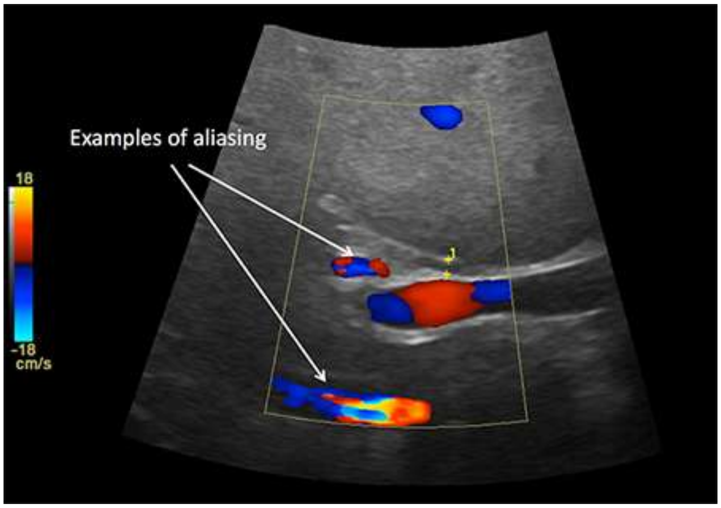

Fig: 21. 11. Aliasing Artifact in Doppler USG

Clinical Significance: Recognition of aliasing is critical for the accurate assessment of high-velocity blood flow, as failure to identify it may lead to underestimation or misinterpretation of stenosis severity, turbulence, or flow direction. Proper understanding of its appearance and implementation of corrective techniques ensures reliable velocity measurement, preventing potential misdiagnosis and allowing clinicians to make accurate hemodynamic evaluations.

2. Flash Artifact in Doppler Ultrasound (USG)

The flash artifact occurs in color Doppler imaging due to sudden motion of the patient, the transducer, or adjacent tissues, which produces transient and random color signals. These signals are not caused by actual blood flow but result from the movement of structures within or near the vessel, leading to a brief display of color on the Doppler image. Flash artifacts can appear as rapid, scattered color changes within the vessel or surrounding tissue, potentially masking true flow or creating a false impression of turbulence. This artifact is commonly observed during respiration, patient movement, or when the sonographer unintentionally moves the transducer. It is more pronounced in low-velocity flow regions or when imaging small vessels, where even minimal tissue motion can generate detectable Doppler shifts. Recognizing flash artifacts is essential to avoid misinterpreting motion-related signals as pathological blood flow or vascular turbulence. Strategies to minimize flash artifacts include ensuring patient immobility, stabilizing the transducer, and adjusting wall filters and color gain to reduce sensitivity to low-frequency motion signals. Proper identification and management of flash artifacts allow for accurate assessment of vascular flow and hemodynamics without interference from motion-induced color signals.

3. Blooming Artifact in Doppler Ultrasound (USG)

The blooming artifact occurs when color Doppler signals are overestimated, leading to an apparent enlargement of the vessel or flow area. This typically happens due to excessive color gain or signal saturation, which causes the Doppler display to spread beyond the actual boundaries of the blood flow. On imaging, the vessel may appear wider than its true diameter, and flow may appear more extensive than it actually is. Blooming artifacts are most common in small vessels or regions with low-velocity flow, where high gain settings exaggerate the color overlay. They can obscure adjacent anatomical structures, distort the perception of flow patterns, and potentially mislead clinicians about vessel size or the extent of vascularization. Recognizing the blooming artifact is essential to avoid misinterpretation of vascular anatomy. Excessive gain should be reduced, and color Doppler parameters optimized to match the actual flow. Proper adjustment of settings ensures that the color overlay accurately represents blood flow, allowing reliable evaluation of vessel caliber, flow distribution, and hemodynamic status.

21.2.5. Equipment-Related and Operator-Induced Artifacts in Ultrasound (USG)

Equipment-related and operator-induced artifacts arise from limitations, malfunctions, or improper use of the ultrasound system rather than from interactions between sound and tissue or blood flow. Equipment-related artifacts can result from transducer defects, electronic noise, or incorrect system calibration, leading to phenomena such as dropout, streaking, speckle, or misregistration of structures. Operator-induced artifacts occur due to improper scanning technique, including incorrect probe positioning, excessive or insufficient pressure, inappropriate insonation angle, or suboptimal machine settings such as gain, dynamic range, or focal zone placement. Unlike tissue-related artifacts, these artifacts are often preventable or correctable with proper technique, calibration, and maintenance. Recognition of these artifacts is essential to avoid misdiagnosis, false-positive findings, and misinterpretation of images, ensuring accurate and reliable ultrasound evaluation.

1. **Electrical Interference Artifact in Ultrasound (USG):** Electrical interference artifacts occur when external electronic devices or power sources disrupt the normal functioning of the ultrasound system, producing noise patterns or spurious signals on the image. These artifacts can appear as random speckling, horizontal or vertical streaks, flickering, or fluctuating brightness, which are unrelated to the patient’s anatomy or tissue characteristics. Common sources of interference include nearby monitors, mobile devices, electrosurgical units, or other medical equipment operating in close proximity to the ultrasound machine. Electrical interference can obscure critical anatomical details, mimic pathology, or degrade image quality, potentially leading to misdiagnosis or repeated scanning. Awareness of the potential for such artifacts allows operators to identify their source, often by turning off nearby electronic devices, ensuring proper grounding of equipment, or relocating the ultrasound system away from interference sources. Proper maintenance of the ultrasound system, including shielding and grounding, is also essential to minimize these artifacts and maintain high-quality imaging standards.
2. **Motion Artifact in Ultrasound (USG):** Motion artifacts occur when there is movement of the patient, the ultrasound probe, or internal structures during scanning. Such motion can produce blurred, distorted, or duplicated images, reducing spatial resolution and making anatomical structures appear elongated, smeared, or displaced. This artifact is particularly noticeable in slow-flow or small vessels, fetal imaging, and organs affected by respiration or peristalsis, where even slight motion can significantly degrade image quality. Motion artifacts can obscure important anatomical details, mimic pathology, or complicate measurements, potentially leading to misinterpretation. To minimize motion artifacts, operators should ensure patient comfort and immobilization, use proper probe handling techniques, and, when necessary, coordinate scanning with the patient’s breathing or cardiac cycle. Adjusting frame rate, image acquisition speed, and transducer pressure can also help reduce motion-related distortions and improve the overall diagnostic quality of the ultrasound study.
3. I**mproper Gain or TGC (Time-Gain Compensation) Settings Artifact in Ultrasound (USG):** Artifacts due to improper gain or TGC settings occur when the ultrasound system’s overall gain or depth-specific amplification is set too high or too low. Excessive gain can make normally anechoic structures appear echogenic, creating false internal echoes or exaggerated structures, while insufficient gain can render real anatomical or pathological features difficult to visualize or entirely invisible. Similarly, incorrect TGC adjustments, which control echo brightness at different depths, can cause uneven image intensity, with deeper tissues appearing too dark and superficial tissues too bright, potentially mimicking focal lesions, fluid collections, or tissue heterogeneity. Recognition and correction of gain and TGC-

related artifacts are essential to ensure accurate visualization of anatomy and pathology. Operators should optimize overall gain so that anechoic regions (e.g., cysts or vessels) remain truly anechoic while echogenic tissues are properly visualized. TGC should be adjusted to achieve uniform brightness throughout the field of view. Proper settings prevent false-positive findings and improve diagnostic confidence, particularly in studies assessing small lesions, fluid collections, or low-contrast structures.

4. **Calibration Errors in Ultrasound (USG):** Calibration errors occur when the ultrasound system's measurement settings or internal software are not correctly adjusted, resulting in inaccurate distance, area, or velocity calculations. For example, if the system's spatial calibration is incorrect, the size of anatomical structures may appear larger or smaller than their true dimensions, potentially affecting volume or lesion assessments. Similarly, in Doppler imaging, miscalibration of velocity settings can lead to overestimation or underestimation of blood flow velocities, which may misrepresent the severity of stenosis or turbulence. Calibration errors can significantly impact diagnostic accuracy, particularly in vascular studies, fetal biometry, and lesion measurements, where precise quantification is crucial. These errors are typically systematic and reproducible, allowing them to be identified and corrected through routine quality control, system calibration, and verification with phantoms or known reference standards. Regular equipment maintenance and adherence to manufacturer-recommended calibration protocols are essential to ensure accurate, reliable ultrasound measurements and to prevent misdiagnosis due to technical inaccuracies.

Operator-Induced Artifacts in Ultrasound (USG)

Operator-induced artifacts arise from improper scanning technique or suboptimal machine settings, rather than inherent tissue or flow interactions. Common causes include incorrect probe positioning, excessive or insufficient transducer pressure, improper insonation angle, and inappropriate gain or time-gain compensation (TGC) settings, all of which can distort anatomy or obscure pathology. Additionally, patient movement or failure to coordinate with respiration or cardiac cycles can introduce motion artifacts, while poor handling can exaggerate Doppler signals or create false echoes. These artifacts are preventable with proper training, careful technique, and real-time adjustment of scanning parameters. Recognizing operator-induced artifacts is essential for accurate image interpretation, ensuring that observed findings reflect true anatomy or pathology rather than technical errors.

Remedial actions for operator-induced artifacts focus on correcting scanning technique, optimizing machine settings, and ensuring proper patient cooperation. To minimize artifacts caused by improper probe handling, the operator should maintain steady and consistent transducer pressure, ensure correct orientation and alignment, and adjust the angle of insonation to optimize visualization of structures and flow. Motion artifacts can be reduced by stabilizing the patient, coordinating imaging with breathing or cardiac cycles, and using supportive devices or cushions when necessary. Artifacts related to gain or TGC misadjustment can be corrected by optimizing overall gain and depth-specific compensation to produce uniform image brightness and avoid false echoes. Finally, continuous training, experience, and real-time feedback are essential to recognize and promptly correct operator-induced errors, ensuring accurate image acquisition and reliable diagnostic interpretation.

21.3. USEFUL AND NON-USEFUL ARTIFACTS IN ULTRASOUND

Artifacts in ultrasound arise because the ultrasound system makes assumptions about tissue properties, sound speed, and echo behavior, which are sometimes violated. The fundamental principle is that ultrasound assumes a uniform propagation speed of 1540 m/s, linear propagation, and straight-line travel of sound waves. When these assumptions are violated by tissue heterogeneity, gas, fluid, or system limitations, artifacts appear. Some artifacts are clinically useful, as they provide indirect information about tissue composition or pathology, while others are non-useful, as they obscure true anatomy or mimic disease.

Useful Artifacts: Useful artifacts in ultrasound occur when deviations from the ideal assumptions of sound propagation provide meaningful diagnostic information about tissue characteristics. For example, acoustic enhancement, also known as posterior enhancement, arises because fluid attenuates sound less than solid tissue, resulting in stronger echoes from deeper tissues and a brighter appearance, which helps distinguish cysts (anechoic) from solid masses. Similarly, the ring-down or comet-tail artifact is caused by the resonance of gas microbubbles, producing continuous echoes that are valuable for detecting air in tissues, biliary sludge, or microbubbles in contrast-enhanced ultrasound, based on the principle of resonant scattering. Posterior shadowing occurs when dense structures such as bone or stones strongly attenuate the ultrasound beam, preventing echoes from reaching deeper tissues and producing a dark shadow; this artifact is clinically useful for identifying calculi and calcifications, relying on absorption and reflection physics. Additionally, edge or refraction artifacts arise from the bending of the sound beam at tissue interfaces, producing bright or shadowed edges that help in delineating cyst or vessel margins. Collectively, these useful artifacts leverage fundamental physical principles to enhance diagnostic accuracy in ultrasound imaging.

Non-Useful Artifacts: Non-useful artifacts in ultrasound arise when physical or system limitations produce misleading images, potentially obscuring true anatomy or mimicking pathology. For instance, aliasing in Doppler imaging occurs when high-velocity blood flow exceeds the Nyquist limit, resulting in a false reversal of flow direction due to the sampling limitations of pulsed Doppler systems. Flash artifacts are caused by sudden patient or probe movement, generating transient Doppler signals that do not reflect true blood flow, making them motion-induced artifacts. Blooming artifacts occur when excessive color gain exaggerates the apparent size of vessels, a result of signal processing limitations. Side-lobe and grating-lobe artifacts arise from off-axis energy reflecting from adjacent structures, producing false echoes due to beam geometry constraints. Motion artifacts in B-mode imaging occur when patient or probe movement blurs structures because of temporal averaging and echo displacement. Finally, electrical interference from external electronic sources introduces random noise into the image, which is system-related rather than tissue-related. Recognizing and understanding these non-useful artifacts is crucial to avoid misinterpretation and ensure accurate diagnostic evaluation.

End of Chapter

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