Imaging Artifacts in Echocardiography

Huong T. Le, MD,* Nicholas Hangiandreou, PhD,† Robert Timmerman, MD,* Mark J. Rice, MD,‡ W. Brit Smith, MD,* Lori Deitte, MD,‡ and Gregory M. Janelle, MD, FASE*

Artifacts are frequently encountered during echocardiographic examinations. An understanding of the physics and underlying assumptions of ultrasound processing involved with image generation is important for accurate interpretation of 2D grayscale, spectral Doppler, color flow Doppler, and 3D artifacts and their clinical implications. (Anesth Analg 2016;122:633–46)

Artifacts are common during echocardiography. An artifact is information contained in a displayed image that leads to an incorrect depiction of the true anatomy. The increased complexity in the interpretation of artifacts has been part of the ongoing debate on the importance of proper training and credentialing for echocardiography.[1,2] For example, artifacts in the ascending aorta occurred in 46% of patients with suspected aortic dissections studied by transesophageal echocardiography (TEE).[3] The misinterpretation of an artifact as a true finding may lead to unnecessary or omitted interventions, including medical treatment and surgery.[4,5] This review is intended to discuss artifacts by providing examples, reviewing the ultrasound physics behind their generation, and suggesting how to reduce or eliminate them.

TWO-DIMENSIONAL IMAGE FORMATION

Piezoelectric elements constitute the basic building blocks of ultrasound transducers. These elements convert electrical energy into mechanical vibrations that propagate through tissue as pulsed sound waves during the transmission phase. The distance between the beginning and the end of a pulse is called the "spatial pulse length," and the pulse repetition frequency is defined as the number of pulses emitted per unit time (Fig. 1). Typical echocardiography transducers transmit in the frequency range of 2 to 7 MHz. When transmitted pulses strike tissue interfaces with different acoustic impedances, some of their energy is reflected back to the transducer. The echoes returning to the transducer during the "listening" phase are converted into an electrical signal and processed into an image displayed on the monitor. When the difference in acoustic impedance is high (e.g., bone/soft tissue interface), more of the transmitted ultrasound wave is reflected. Current echocardiography systems assume that the ultrasound travels uniformly at a speed of 1540 m/s through soft tissues, such as the heart. This speed is derived from the mean velocity through various human tissues consisting primarily of muscle[6] and does not represent the speed of sound through all tissues (Table 1).

However, not all the transmitted energy is reflected back to the transducer. Attenuation is the gradual loss of energy because of reflection and absorption[7] (Table 2; Fig. 2). The ultrasound system accounts for the depth-dependent effects of attenuation by amplifying the signals returning later. This can also be done manually via the time gain compensation controls.

Resolution allows the operator to distinguish closely spaced objects in the image display as separate structures rather than as a single one. In 2D imaging, spatial resolution consists of axial and lateral resolution. Axial resolution improves as the spatial pulse length shortens. Lateral resolution is maximum at the narrowest part of the beam (i.e., focal zone). Echocardiography systems allow for adjustment of the depth of the focal zone.

Two-dimensional grayscale imaging artifacts arise when the data acquisition and signal-processing assumptions made by the ultrasound imaging system are violated (Table 3); these were recently discussed by Pamnani and Skubas.[8] In evaluating artifacts, the importance of obtaining multiple views of the same object cannot be stressed enough, because the persistence of a finding in multiple views decreases the likelihood that it is an artifact (Table 4).

TWO-DIMENSIONAL ULTRASOUND ARTIFACTS

Shadowing and Enhancement Artifact

Anechoic or hypoechoic regions may be the result of shadowing. Conversely, hyperechoic areas on an image display may be the result of enhancement. In both instances, the assumption that the ultrasound is attenuated uniformly is violated. Enhancement artifacts resulting in the appearance of extra-anatomic features may occur when the ultrasound beam travels through tissue that attenuates less than its surroundings.[9] Shadowing occurs when the transmitting beam encounters a structure with high attenuating properties.[10] For example, the highly reflective portions of prosthetic or heavily calcified valves prevent the comprehensive evaluation of left ventricular wall motion in the midesophageal views by displaying anechoic regions distal to the valves (Fig. 3; Supplemental Digital Content 1, Supplemental Video 1, http://links.lww.com/AA/B289). VIDEO+ Evaluating the left ventricle from the transgastric or deep transgastric views will remove the reflector (i.e., valve) from the path of the area of interest and eliminate shadowing (Supplemental Digital Content 2, Supplemental Video 2, http://links.lww.com/AA/B290). VIDEO+

From the *University of Florida, Gainesville, Florida; †Mayo Clinic, Rochester, Minnesota; and ‡Vanderbilt University, Nashville, Tennessee.

Accepted for publication September 28, 2015.

Funding: None.

The authors declare no conflicts of interest.

Supplemental digital content is available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's website (www.anesthesia-analgesia.org).

Reprints will not be available from the authors.

Address correspondence to Huong T. Le, MD, University of Florida, P.O. Box 100254, Gainesville, FL 32610. Address e-mail to hle@anest.ufl.edu.

DOI: 10.1213/ANE.0000000000001085

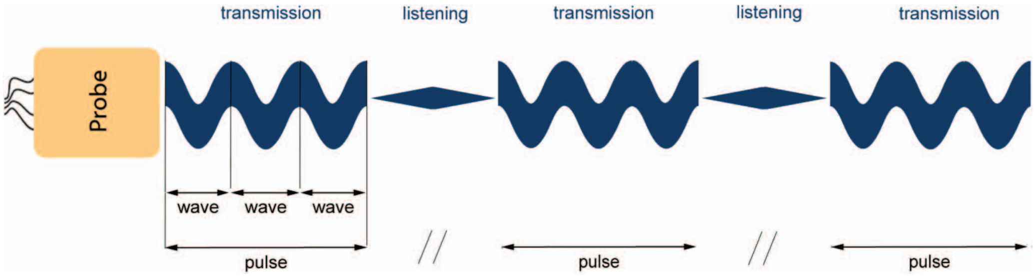

Figure 1. Pulses are a train of ultrasound waves. Each pulse in the figure is made of 3 waves. Each pulse represents the transducer's transmission phase. The transducer's listening phase is between the pulses (time line not in scale, as the listening phase is >95% of the transmission phase).

Table 1. Speed of Sound Through Tissues[6]

Tissue	Speed (m/s)
Air	330
Lung	604
Fat	1450
Soft tissue	1540
Blood	1570
Bone	4080

Table 2. Definitions in Ultrasound[7]

Acoustic impedance	It is determined by the tissue density multiplied by the velocity of sound waves in the tissue. Differences in acoustic impedance cause reflections (echoes).
Absorption	The conversion of sound energy to heat as it travels through a medium.
Attenuation	The gradual loss of ultrasound energy as the wave propagates through tissue; it is caused by reflection, scattering, and absorption.
B-mode	Brightness mode, which is most commonly referred to as 2D grayscale mode.
Reflection	The redirection of a transmitted sound wave, usually at an interface between 2 media with different acoustic impedance.
Refraction	The change of propagation direction (bending) of ultrasound wave as it travels through media with different propagation speeds. This can only occur when the incident angle is different from 90°.
Scattering	The reflected echoes propagate at various directions; it occurs when the reflector has a small surface (i.e., red blood cells).

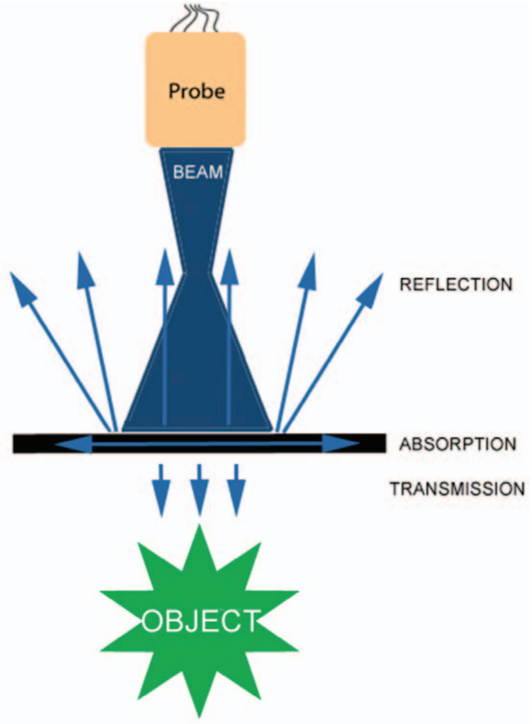

Figure 2. Echoes are created from the reflected energy of an ultrasound beam after it strikes a tissue interface (black line). However, the energy that is reflected away from the probe or absorbed by the tissue is lost. This loss of energy is referred to as attenuation.

Reverberation Artifact

Reverberation results in a pattern of regularly spaced artifacts; the spacing represents the distance between the proximal and the distal reflector (Fig. 4, left). The intensity of the reverberation is directly related to the difference in acoustic impedance between the reflector and its surroundings[11] and, when intense, reverberations may obscure imaging of anatomic structures distal to the reflectors. When the distance between the reflectors is small, the artifact appears as a smear of signal rather than a discrete anatomic feature. In this case, these reverberations are referred to as "comet-tail" or "ring-down" artifacts.[11,12] In reverberations, the assumption that the ultrasound has returned to the transducer after only a single reflection is violated. With reverberation artifacts, the ultrasound beam bounces multiple times between 2 highly reflective surfaces during the listening phase before returning to the transducer.[9] Changing the probe position (e.g., from mid-esophageal to transgastric views) will eliminate these artifacts.

Table 3. Violations of Ultrasound Assumptions that Lead to Artifacts

Assumptions	Artifacts
1. Pulses and echoes travel in straight lines	Refraction
2. Waves are infinitely thin or pulses are extremely small	Beam width
3. Echoes return to the transducer after a single reflection	Reverberation, mirror image
4. Echoes originate from the main beam	Side-lobe, grating lobe
5. The depth of an object is directly related to the travel time for an ultrasound pulse to return to the transducer; speed of sound = 1540 m/s	Refraction
6. Pulses and echoes are attenuated uniformly by all tissues	Shadowing, enhancement

Table 4. Two-Dimensional Grayscale Ultrasound Artifacts

Artifact	Characteristics	How to eliminate
Shadowing	Hypoechoic or anechoic areas distal to strong reflectors	Change the probe position to remove reflector from path of the area of interest
Enhancement	Hyperechoic areas distal to weak reflectors	Change the probe position to remove reflector from path of the area of interest
Reverberation	Multiple regularly spaced duplicated images	Change the probe position to remove reflector from path of the area of interest
Refraction	Misregistration, duplication, or omission of an object	Change the probe position to remove structures with large propagation speeds from the path of the area of interest
Mirror image	Duplicated image deep and equidistant from a reflector	Change the probe position to remove reflector from path of the area of interest
Beam width	Lateral blurring of image that may result in the overlapping of 2 images, thus appearing as one	Move the focal zone to the area of interest
Side and grating lobes	Blurring of edges of an image	Adjusting the harmonic frequency will minimize side lobes

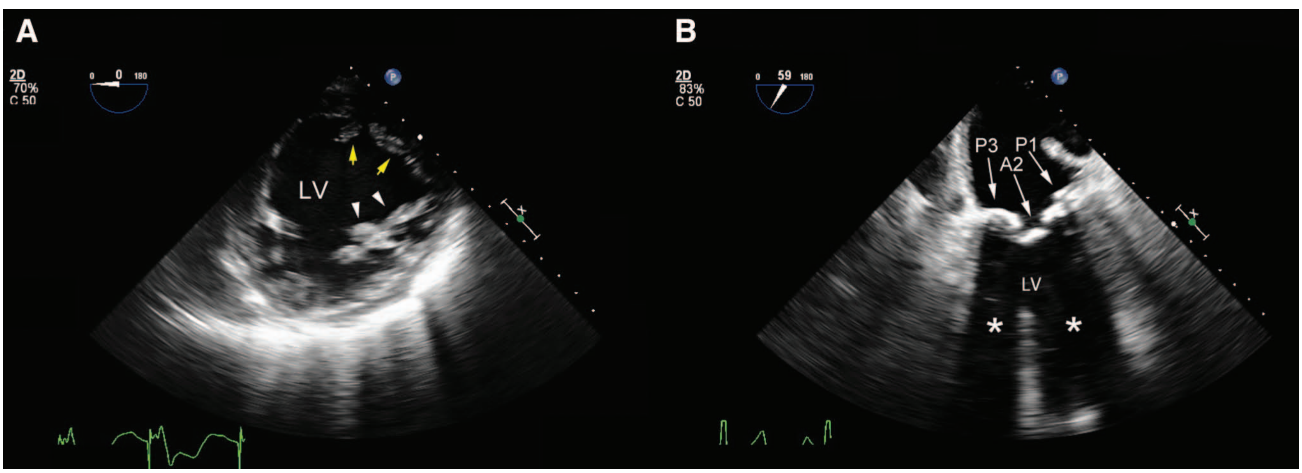

Figure 3. The left ventricle (LV) is shown in the midesophageal transgastric short-axis view (A). The posteromedial papillary muscle (yellow arrows) is displayed with the correct grayscale. Propagation of the ultrasound inside the fluid-filled LV results in a relatively brighter anterolateral papillary muscle (white arrowheads) because of enhancement. B, Shadowing (white asterisks) from heavily calcified posterior (P1 and P3) and anterior (A2) mitral valve leaflets. The anechoic area distal to these structures prevents a thorough assessment of LV wall motion.

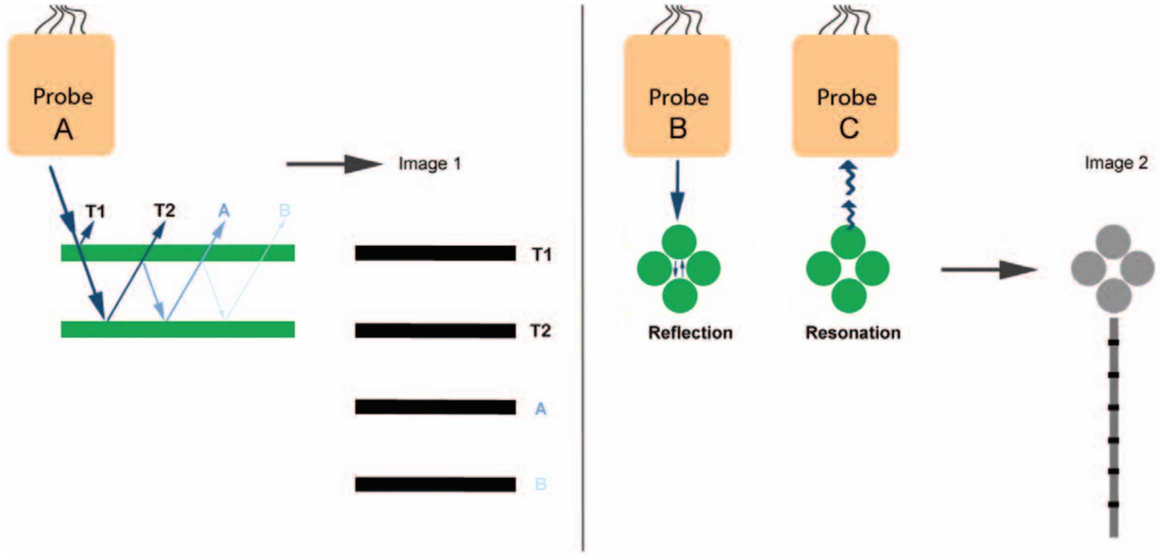

Figure 4. The mechanism of reverberation is shown using probe A. T1 and T2 represent the borders of the reflective object and their corresponding image on the display. Image 1, line A occurs when the ultrasound pulse makes 1 additional reflection after T2. Image 1, line B occurs when the ultrasound pulse makes 2 additional reflections. Ring-down artifacts occur in the presence of gas collections, from reverberation of the ultrasound within or between the gas collection (probe B) or resonation as the ultrasound beam passes through them (probe C).

Ring-down artifacts occur when bubbles within a fluid background reflect or resonate sound waves (Fig. 4, right).[12] The appearance of ring-down artifacts should alert the echocardiographer to the presence of gas (e.g., air embolism or post-cardiopulmonary bypass air; Fig. 5; Supplemental Digital Content 3, Supplemental Video 3, http://links.lww.com/AA/B291). In patients who may benefit from electrical cardioversion for atrial fibrillation, the distinction between left atrial appendage thrombi and a reverberation artifact is an important one to make.[13,14] Similarly, many linear artifacts mimicking aortic dissections have been attributed to reverberation of the posterior wall,[15–24] particularly in a dilated ascending aorta,[22] and may result in unnecessary interventions. Comet-tail artifacts have been reported in association with left atrial catheters[25] but can occur in the presence of any closely spaced reflectors, such as pacing wires or pulmonary artery catheters. They are often seen radiating from the distal wall of a descending aorta (Fig. 6; Supplemental Digital Content 4, Supplemental Video 4, http://links.lww.com/AA/B292).

VIDEO+

VIDEO+

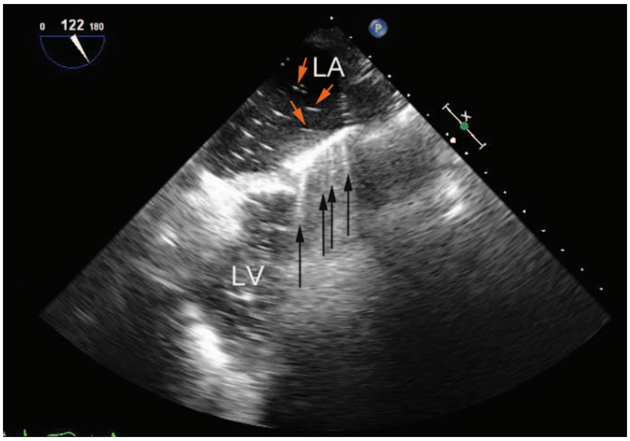

Figure 5. Ring-down artifacts (black arrows) are seen from the midesophageal long-axis view before separation from cardiopulmonary bypass. Residual air bubbles (red arrows) inside the left atrium (LA) before separation from bypass create a ring-down artifact that appears as a series of rays radiating from the anterior wall of the left atrium. LV = left ventricle.

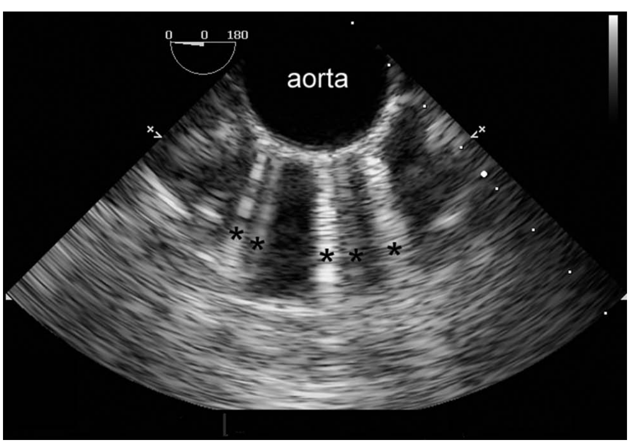

Figure 6. Multiple comet-tail artifacts (black asterisks) radiate from the anterior wall of the calcified descending aorta.

Mirror-Image Artifact

Mirror-image artifacts create the appearance of additional structures on the monitor display. Typically, the duplicated structure is deeper, equidistant, and occasionally lateral to the reflector. Similar to reverberation artifacts, mirror-image artifacts occur when the assumption that the ultrasound echo returns to the transducer after only a single reflection is violated. Instead, the ultrasound beam first hits a large, smooth (mirror-like) reflector during the transmission phase, which directs it to a second reflector (i.e., target). The beam then bounces from the target back to the mirror-like surface on its return to the probe (Fig. 7). Identifying the smooth reflector using multiple imaging planes will help to differentiate true extra structures from mirror-image artifacts. Similar to the artifacts discussed earlier, changing the probe position (e.g., from midesophageal to transgastric views) to remove the reflector from the path of the area of interest will eliminate these artifacts. Examples of mirror-image artifacts are foreign objects in the left ventricle[26,27] or dissections in the descending aorta.[22]

Beam Width Artifacts

Lateral resolution refers to the ability to distinguish 2 or more structures side-by-side on the monitor as separate. When the ultrasound beam widens distal to the focal zone, 2

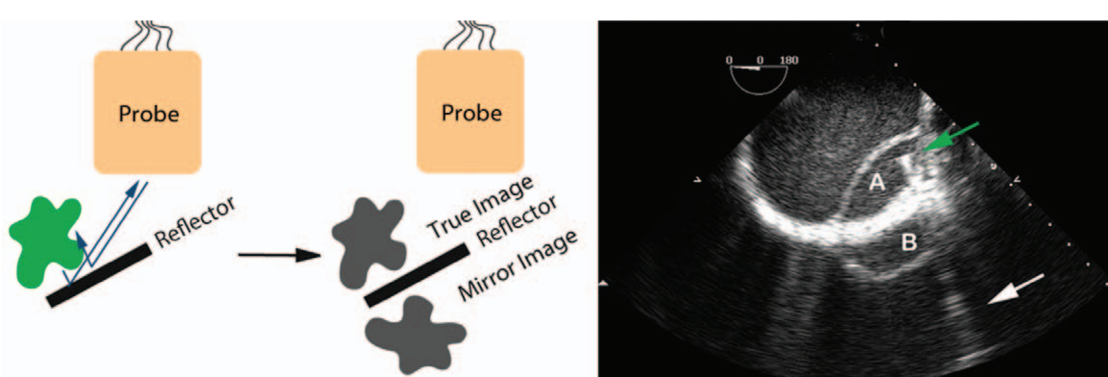

Figure 7. Duplicated structures can occur through a variety of mechanisms. True mirror-image artifacts are opposite but equidistant from the reflector. A dissection flap (A) in the descending aorta with its mirror image (B) outside the aorta. The mirror surface is likely the thickened wall of the aorta. The green arrow points to a guidewire placed in the true lumen of the aorta with a comet-tail artifact (white arrow) radiating away.

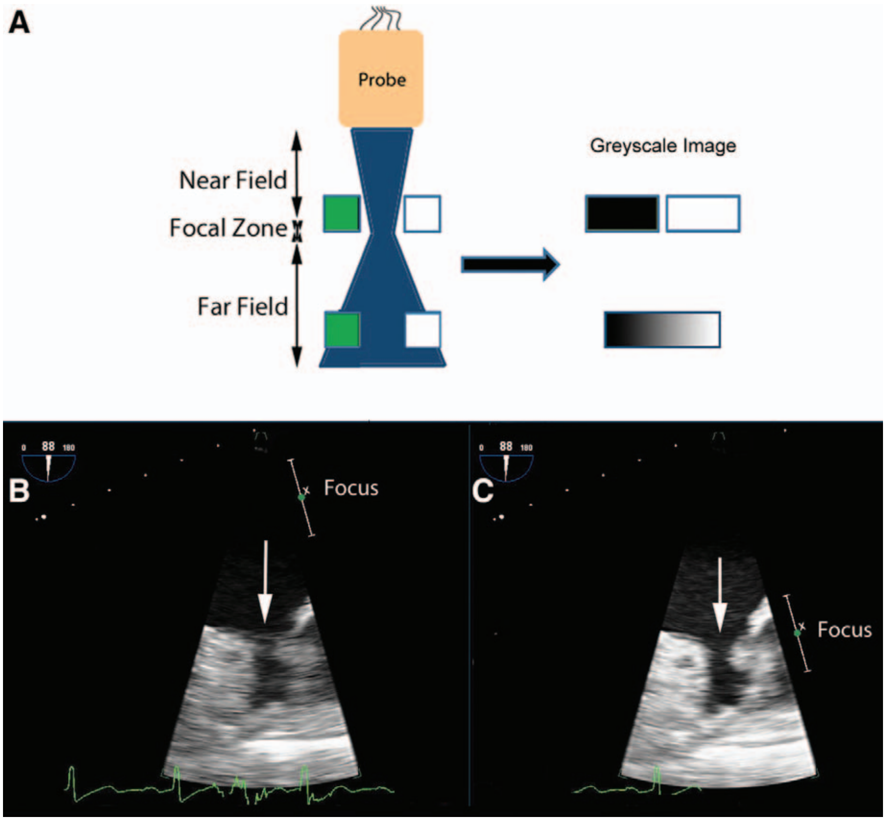

Figure 8. Mechanism of beam width artifact formation is shown (A). In the near field, the pair of targets is displayed as separate objects. The pair of targets in the far field is imaged at a depth where the ultrasound beam is wide. It is not clear in the displayed image if there are 2 targets or a single wide one. Panel B shows how beam width artifacts may be misdiagnosed as a thrombus in the left atrial appendage. The area of interest (white arrow) is in the far field of the ultrasound beam (B). As a result, the left atrial appendage may appear blurred and thrombus cannot be excluded. When the beam is narrowed by repositioning the focus to the level of the appendage, the echogenic material disappears (C, white arrow).

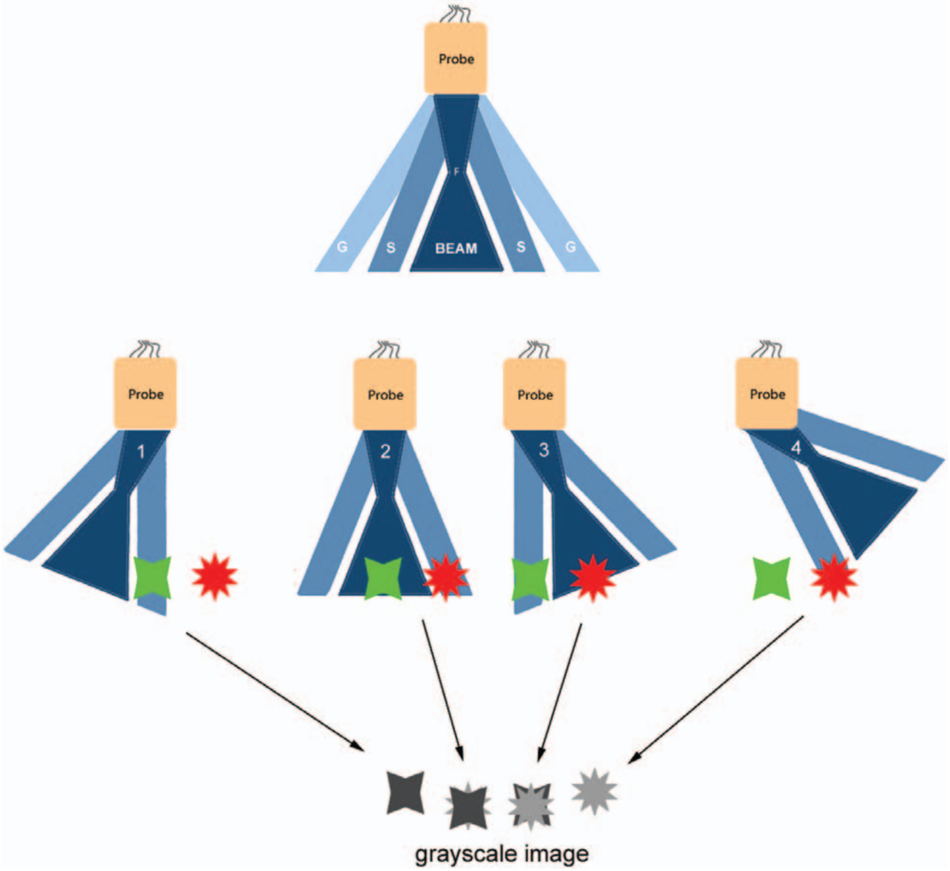

Figure 9. In the far field, distal to the focal zone (F), the beam widens (beam). Side lobes (S) and grating lobes (G) are lateral to the main beam. The bottom panel shows how each target may potentially have 2 additional echoes in the display.

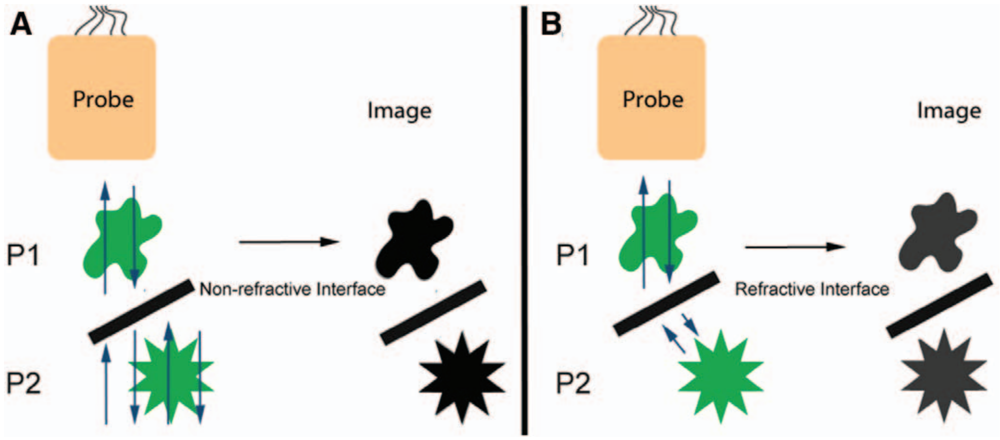

Figure 10. Refraction artifact. When the ultrasound beam travels through a tissue interface and the propagation speeds (P) are equal (P1 = P2) on both sides of the interface, the resulting image shows the objects in their proper positions (A). However, when the ultrasound beam travels through an interface between tissues with different propagation speeds (P1 ≠ P2), its propagation direction is altered, resulting in misregistration of the distal object (green star, B).

Table 5. Spectral and Color Flow Doppler Artifacts

Artifact	Characteristic	How to eliminate
Aliasing	"Wrap-around" of the velocity scale	Decrease the transmitted ultrasound frequency and/or the sector depth while maximizing scale or shifting the baseline
Blooming	CFD velocities extend beyond the region of true blood flow	Reduce gain setting
Spectral Doppler mirroring	Duplicate of Doppler spectrum above and below the baseline	Reduce the gain or power output or reposition the probe so that Doppler angle is as close to 0 or 180° as possible
Pseudoflow	Motion of fluid other than blood	Spectral imaging will not show characteristic arterial or venous waveform
Twinkling	Mosaic of rapidly changing blue and red patches of color near strongly reflective, surfaces	Spectral Doppler of this artifact will produce a pattern consistent with noise

separate side-by-side structures may appear as 1 continuous structure on the image display. Poor lateral resolution may be the result of beam width artifacts. These artifacts occur when the assumption that ultrasound waves are infinitely thin throughout is violated. Adjusting the focal zone with the focus knob may help to eliminate these artifacts (Fig. 8). Beam width artifacts have been attributed to false positives for thrombus in the left atrial appendage for patients undergoing TEE with atrial fibrillation.[28]

Side and Grating Lobe Artifacts

Side and grating lobe artifacts result in the blurring of the edges of a displayed object (reduce lateral resolution); the assumption that the ultrasound waves are infinitely thin is violated. Grating and side lobes appear similarly around the main beam, but their mechanisms of origin differ (Fig. 9).[29] Side and grating lobes are secondary beams around the central ultrasound beam and are produced by nonaxial vibrations of the piezoelectric elements.

In clinical practice, it can be difficult to differentiate between side and grating lobe artifacts.[30] A blurred pacemaker wire or pulmonary artery catheter is considered either a beam width or a side-lobe artifact.[31]

Side-lobe artifacts are echoes extending lateral of their targets across the arc of the sector scan. They are also part of the differential diagnosis for masses in the left atrial appendage.[32] Side-lobe–generated artifacts may contribute to making normal, stented bioprosthetic aortic valves appear abnormally bent.[33] Harmonic imaging may reduce the echoes from the side and grating lobes of the ultrasound beam (Supplemental Digital Content 5, Supplemental Video 5, http://links.lww.com/AA/B293).[7,34] VIDEO+

Refraction Artifact

Refraction occurs rarely in TEE and appears as the misregistration, omission, or side-by-side split imaging of an object (Fig. 10). Refraction occurs when the ultrasound beam propagates at a different angle from its original path as it travels through tissue interfaces with different propagation speeds. In refraction, the assumption that the ultrasound pulses travel in a straight line is violated. It may disappear when the probe is moved toward areas with similar propagation speeds (e.g., blood next to soft tissue) or by changing the imaging plane. This artifact has been noted to mimic a pseudoaneurysm of the aorta.[35] It occurs more frequently during transthoracic echocardiogram[36–39] because the ultrasound wave is more likely to travel through tissue interfaces with large differences in propagation speed (e.g., fat versus muscle) compared with TEE.

SPECTRAL AND COLOR FLOW DOPPLER ARTIFACTS

Doppler Shift

When a pulse emitted from the transducer strikes a moving red blood cell, the difference between the transmitted and the reflected frequency (i.e., Doppler shift) is proportional

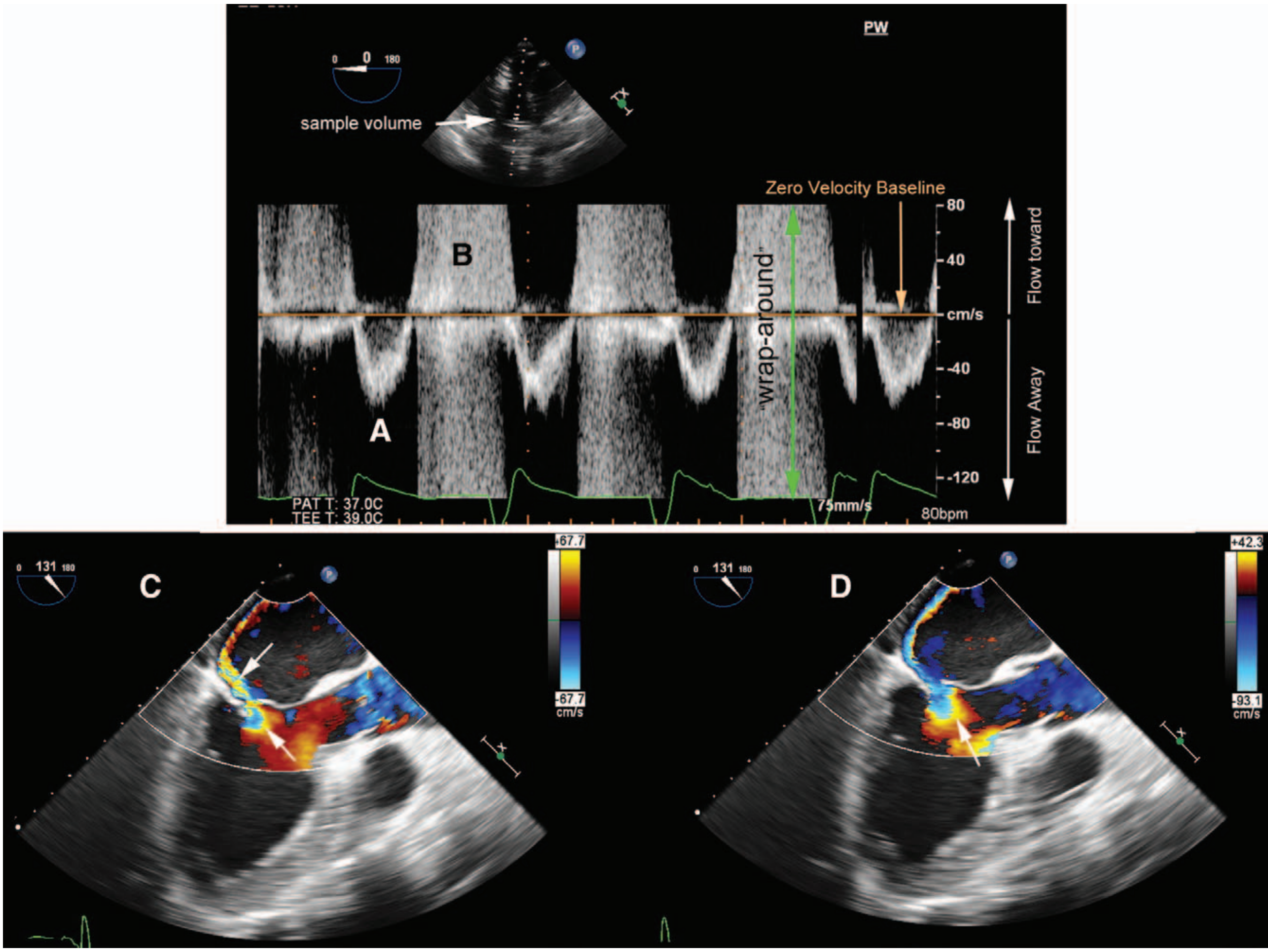

Figure 11. The top image shows aliasing in the pulsed wave Doppler. The sample volume (deep transgastric view) is over the aortic valve and measures the systolic velocity (away from the probe, A). During diastole, the aortic regurgitation velocity "wraps-around" (green double arrow) the velocity scale because of aliasing (B). C and D show aliasing in color flow Doppler (white arrows). Shifting the color baseline (D) will create aliasing in the proximal LVOT area. LVOT = left ventricular outflow tract.

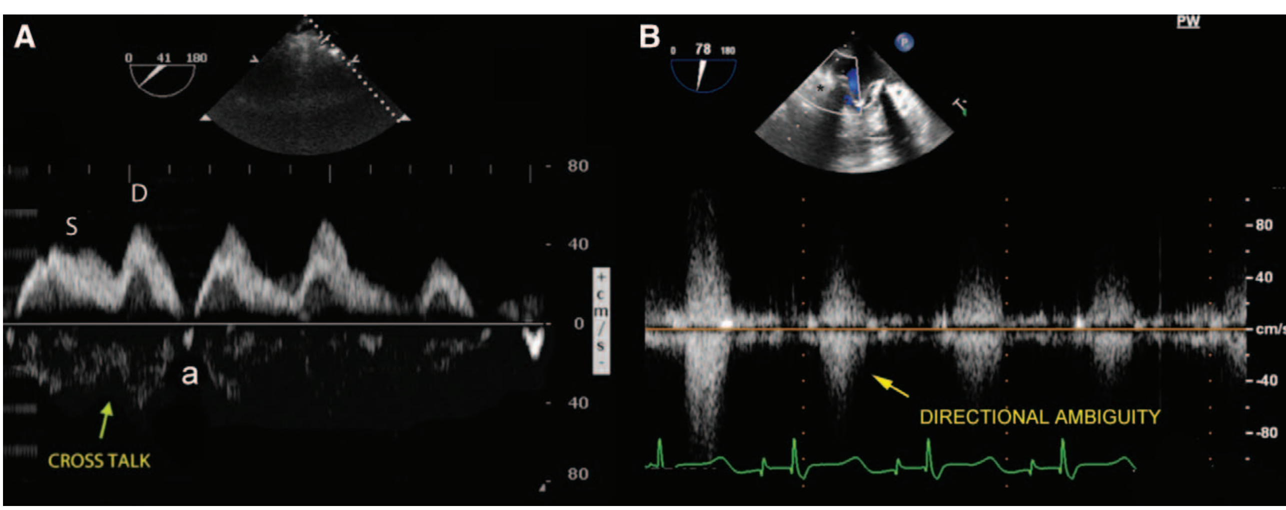

Figure 12. Doppler spectral mirroring. A, Electronic cross talk below the zero baseline in the spectral display of the left upper pulmonary vein blood flow. B, Directional ambiguity: the velocity of the coronary sinus (asterisk) blood flow (midesophageal view of the left ventricle) above and below the baseline is similar. S = systolic wave; D = diastolic wave; a = atrial wave.

to the speed of the red blood cell. This is expressed in the mathematical formula for Doppler shift where the blood flow velocity (vel) is vel = [(Fr − Ft) × (C)]/[2Ft × cosine θ] and Ft = frequency of transmitted ultrasound beam, Fr = frequency of reflected ultrasound beam, C = velocity of sound in human tissue, assumed to be constant at 1540 m/s,

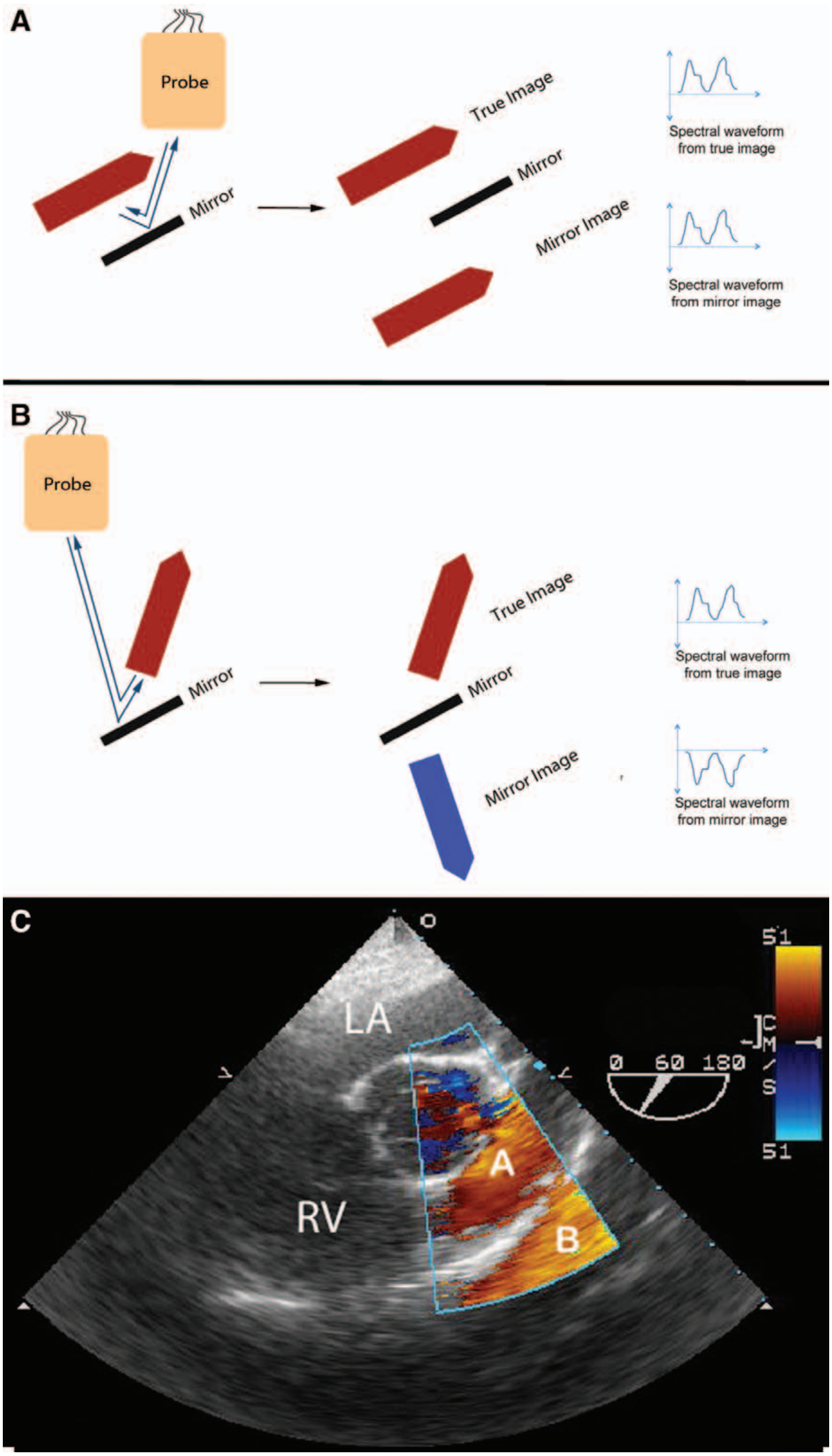

Figure 13. In color Doppler mode, the flow inside a mirrored vascular structure depends on the relative directions of the flow in the true vessel and the pulse after its reflection in the mirror. The color of the mirror-image vessel may be the same as the true vessel (A, red arrow) or opposite (B, blue arrow). In the mirror-image artifact (midesophageal right ventricle inflow-outflow view), both true ("A") and mirror ("B") color flows are the same color (direction). LA = left atrium; RV = right ventricle; C = mirror image of right ventricle.

θ = angle between the Doppler beam and the direction of blood flow. In continuous wave Doppler (CWD) and pulsed wave Doppler (PWD), the velocity calculated from the Doppler shift is graphed against time in the x-axis. The velocities above the zero velocity baseline correspond to blood flowing toward the transducer, whereas velocities below the zero velocity baseline correspond to blood flowing away from the transducer. In color flow Doppler (CFD), a sector is superimposed on the 2D image, and the velocity range within this sector is depicted with a preset gradation, with the lightest colors representing highest velocities. Most ultrasound systems have default CFD settings, such that

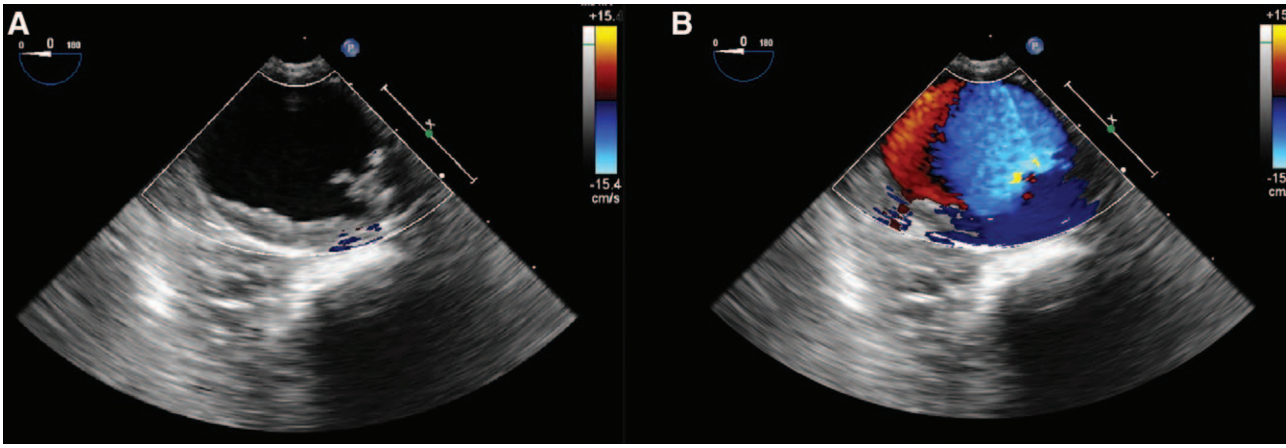

Figure 14. A, High-grade atherosclerotic disease in the descending aorta. When color flow is added to the image (B), the lesion is obscured as a result of blooming.

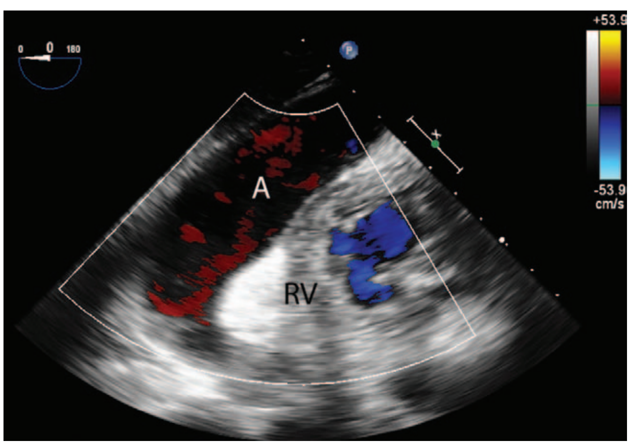

Figure 15. Transgastric short-axis view of the right ventricle (RV) in a patient with a large pericardial effusion (A) shows pseudoflow (red color Doppler). The pericardial effusion consisted of serosanguinous and purulent fluid. True blood flow is seen inside the right ventricle (blue color Doppler).

blue represents flow away from the transducer and red represents flow toward the transducer (mnemonic: blue away, red toward [BART]).[40]

The physics of each modality have been thoroughly reviewed.[41,42] In terms of clinical application, CWD measures all blood velocities along the ultrasound beam, whereas PWD and CFD detect velocity information at a specific location. Artifacts in spectral Doppler and CFD are summarized in Table 5 and will be discussed in more detail later.

Aliasing

Aliasing, also called Doppler shift ambiguity, appears as a "wrap-around" of the velocity in PWD and CFD. In PWD, the velocity continues beyond the limit of the scale and reappears at the opposite part of the scale. In CFD, the wrap-around is displayed as patches of light blue adjacent to patches of bright yellow (Fig. 11). In the presence of aliasing, the displayed velocities cannot be resolved.

Aliasing occurs because the velocity that can be measured accurately by PWD and CFD is limited; this maximum resolvable velocity corresponds to a Doppler shift equal to half of the pulse repetition frequency (i.e., Nyquist limit).[42] Aliasing may be reduced by shifting the baseline, maximizing the velocity scale, decreasing the sector depth, decreasing the transmitted ultrasound frequency, or decreasing the sector.[43]

The ability to use aliasing may be clinically useful in detecting a turbulent lesion across valves and vessels,[44–46] as well as in diagnosing diastolic dysfunction and the severity of valvular regurgitation. When aliasing is used for the subjective grading of regurgitation or stenosis, using a low-velocity scale (i.e., setting the Nyquist limit too low) will make the flow appear worse than it is (Supplemental Digital Content 6, Supplemental Video 6, http://links.lww.com/AA/B294).

VIDEO+

Aliasing does not occur with CWD because separate elements on the probe transmit while others simultaneously "listen." This eliminates the limitation set by the pulse repetition frequencies (i.e., pulses emitted per second).

Spectral Doppler Mirroring

Spectral Doppler mirror-image artifacts appear as a duplicate of the velocity spectrum above and below the baseline. Causes of spectral Doppler mirror-image artifacts are cross talk and directional ambiguity. Cross talk results from erroneous signal transfers when the echo exceeds the operating range of the circuit and results in the appearance of velocity on both sides of the baseline. On one side, the velocity is usually more intense and brighter (i.e., true Doppler shift) than the one on the other side (Fig. 12A). Reducing the Doppler gain or output power may eliminate the artifact. Directional ambiguity occurs when the Doppler angle is near 90°. Also known as "indeterminate flow direction,"[47] the intensity on both sides of the baseline is relatively uniform (Fig. 12B). When Doppler spectral mirroring is related to directional ambiguity, gain and power have little effect on reducing the artifact.

Artifacts in CFD

Artifacts in CFD are due to the same mechanism as in B-mode imaging. Mirror-image artifacts also occur in CFD images. Reflections from a mirror surface do not alter the Doppler shift, but the apparent flow direction (and color coding) may be affected. If the transmitted and reflected

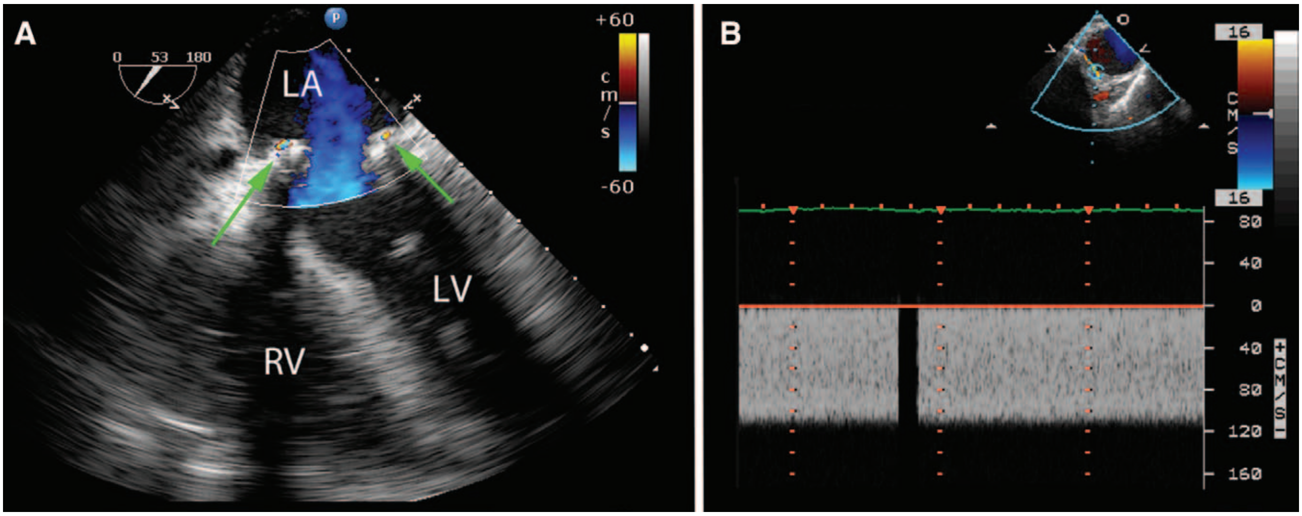

Figure 16. Midesophageal commissural view shows a bioprosthetic mitral valve with twinkling artifacts (green arrows) near the struts (A). B, An example of noise in spectral Doppler in the midesophageal view of the descending aorta. LV = left ventricle; LA = left atrium; RV = right ventricle.

Table 6. Three-Dimensional Artifacts

Artifact	Characteristic	How to eliminate
Stitching	The presence of demarcation lines within the image, making the image appear "sliced" and shifted	Minimize the heart's out-of-plane movement during the electrocardiogram-gated image acquisition period (i.e., eliminate dysrhythmias, cease ventilation or patient or probe movement, or cease electrocautery). High volume rate (high volume rate mode) may minimize stitching
Dropout	Missing data from image structures that are parallel to the ultrasound pulse	Increase gain. Change the probe position to move area of interest from position parallel to ultrasound beam
Railroad	Objects with wide lumens displayed as if they have a railroad track appearance	Optimize spatial and temporal resolution. Change the probe position to move the ultrasound beam to 90° of the area of interest
Blurring	Objects appear thicker than they are in reality	Optimize spatial and temporal resolution

pulse encounters the blood flow from the same direction (relative to the flow direction), then the duplicated (mirrored) color Doppler pattern will be the same as the flow inside the true structure. If they encounter the flow from opposing directions, then the Doppler pattern will have the opposite color (i.e., suggesting flow in the opposite direction; Fig. 13; Supplemental Digital Content 7, Supplemental Video 7, http://links.lww.com/AA/B295). This has been seen as a duplication of the right ventricular outflow tract with parallel flow secondary to a thickened pericardium.[48] Shadowing is commonly seen in CFD as an area of missing velocity information distal to a strong attenuating object such as a prosthetic valve (Supplemental Digital Content 8, Supplemental Video 8, http://links.lww.com/AA/B296).

VIDEO+

VIDEO+

Blooming

In "blooming," soft tissues are color-coded as if they contain true blood flow. Also known as "color bleed," this artifact results from abnormally high-gain settings and the artifact may potentially obscure pathology[47] such as severe atherosclerosis in the aorta (Fig. 14). Doppler gain does not affect the intensity of the transmitted pulse.

Pseudoflow

Motion of fluids other than blood, such as ascites, amniotic fluid, pleural effusion, and urine can be imaged with CFD; this "pseudoflow" is an artifact because spectral imaging will not typically show characteristic arterial or venous waveforms.[47] Pericardial effusions seen during an echocardiographic examination may demonstrate flow because of their proximity to the heart (Fig. 15; Supplemental Digital Content 9, Supplemental Video 9, http://links.lww.com/AA/B297).

VIDEO+

Twinkling

Used for diagnostic purposes in noncardiac imaging,[49–51] "twinkling" artifacts are a mosaic of rapidly changing blue and red patches of color near strongly reflective surfaces resulting in patterns that imitate abnormal flow (Fig. 16; Supplemental Digital Content 10, Supplemental Video 10, http://links.lww.com/AA/B298). Twinkling may be the result of a type of intrinsic scanner noise dubbed "phase" or "clock jitter."[52] Spectral Doppler-mode interrogations in the region of this artifact will produce a spectral pattern consistent with noise (Fig. 16, right). Intracardiac flow that is present throughout the cardiac cycle should also be considered twinkling as part of the differential diagnosis. First described in 1996, this artifact may mimic blood flow,[53] such as a regurgitant jet, paravalvular leak, or shunt. It has been described in association with echogenic intracardiac foci in the fetal heart,[54] as well as calcified and noncalcified cardiac valves.[55] Vena contracta measurements become inaccurate in association with a twinkling artifact.[55]

VIDEO+

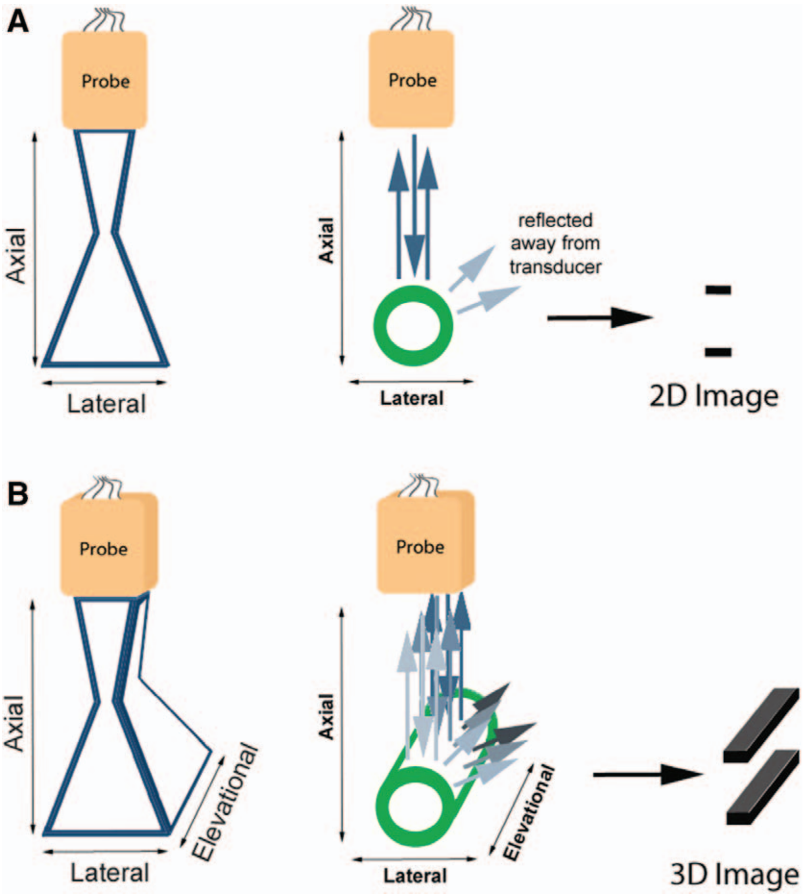

Figure 17. When an ultrasound beam encounters a specular reflector, such as a catheter, only the ultrasound signals reflected from the near and far wall of the catheter are seen. A, A 2D ultrasound image of a catheter (green circle) and (B) a 3D reconstruction of the same catheter. By adding the elevational aspect to the image, the reconstructed data set in all 3 orthogonal planes appear as a "railroad" on the display.

THREE-DIMENSIONAL ULTRASOUND ARTIFACTS

Matrix array transducers allow for real-time acquisition and display of cardiac structures in 3D. These transducers are capable of performing 2D multiplanar and live or electrocardiogram-gated 3D imaging of cardiac structures. Three-dimensional ultrasound imaging is subject to the same types of artifacts seen in 2D grayscale images (Supplemental Digital Content 11, Supplemental Video 11, http://links.lww.com/AA/B299), and the mechanisms of artifact formation are similar.[56,57] The mechanism for artifacts "specific" to 3D imaging, such as poor elevational resolution and anisotropy, is discussed later and summarized in Table 6.

VIDEO+

In all planar imaging modalities (i.e., 2D and 3D), a voxel or volumetric pixel is the base data unit for the image. With (2D) grayscale imaging, only the height (i.e., axial resolution) and length (i.e., lateral resolution) of the image is displayed. In 3D imaging, the height, length, and thickness (i.e., elevational resolution) of the image are displayed as well (Fig. 17). Analogous to how beam width affects the lateral resolution along the length of the 2D image, slice thickness affects the elevational resolution along the thickness of the 3D image. Poor elevational resolution is difficult to identify in 2D images, but in 3D imaging it is more visually apparent.

Dropout and Railroad Artifacts

"Dropout" artifacts may result in the appearance of holes, defective objects, or perforations where none exist. "Railroad" artifacts have a characteristic railroad track-shaped appearance (Fig. 18).[57] These artifacts result from images with areas of missing data, some of which are related to anisotropy.[57] In general, pulses that impact an interface at 90° will be reflected straight back to the transducer where they are detected and rendered in the image. In the case of an oblique incidence, the echo may be reflected away from the transducer, like a billiard ball rebounding from a bumper on a pool table, and will not be detected or included in the image (Fig. 17). This is often seen in 2D musculoskeletal imaging where the interface is large, smooth, and "specular."[58] Increasing gain may reduce dropout artifacts at the expense of overall image sharpness and can also result in greater blood signal obscuring cardiac structures (Fig. 19). Dropout artifacts are commonly seen in the interatrial septum and aortic leaflets.[57] Railroad artifacts refer specifically to artifacts from large catheters with a wide lumen similar to a pulmonary artery catheter or a guide catheter used by interventional cardiology.

Blurring and Blooming Artifacts

"Blurring" and blooming artifacts occur when objects appear thicker than they really are (Fig. 20). They are also referred to as "3D amplification artifacts."[57] The 3D imaging-related blurring artifact is similar to the beam width artifact encountered in 2D imaging; both cause blurring of the lateral edges of known sharp objects. Unlike axial and lateral resolution, which is adjustable, elevational resolution is relatively fixed and is primarily responsible for 3D blurring artifacts. The term "blooming artifact" is used when

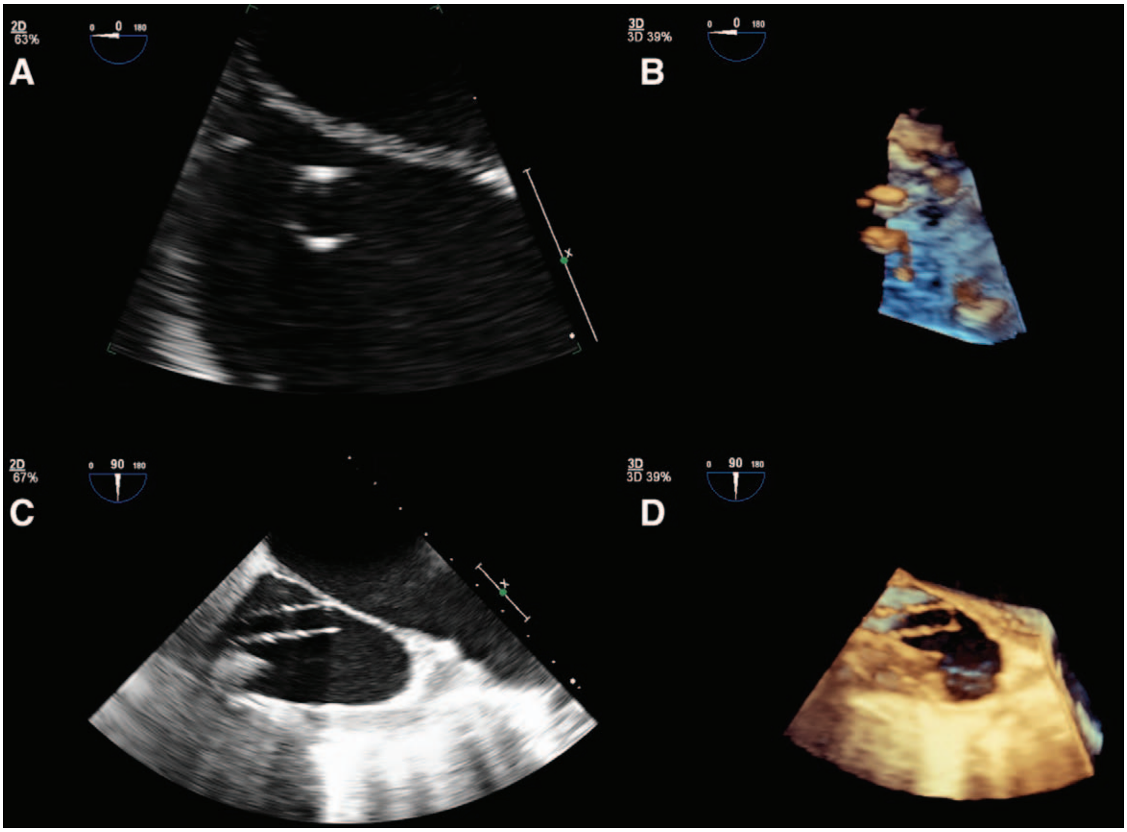

Figure 18. With 2D imaging, an extracorporeal membrane oxygenator venous cannula is seen entering the right atrium from the inferior vena cava (A and C). The portions of the cannula that interface with the ultrasound beam at 90° produce the brightest portions of the image and those that interface with the ultrasound beam at an oblique angle produce weaker or no returning signals. This is also seen in the 3D image and has been named a "railroad" artifact (B and D).

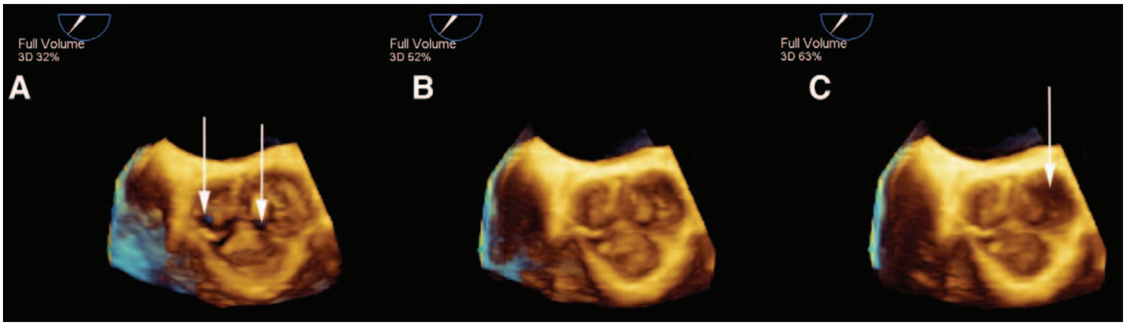

Figure 19. Dropout occurs when the 3D image shows an erroneous absence of data. In this example, it mimics perforation of the aortic valve (A, white arrows). The panels demonstrate the impact of increasing gain to compensate for the dropout artifact from A to C. The gain in panel B is increased relative to panel A. While increasing gain will reduce dropout to a degree, all returning signals are amplified and therefore spatial resolution is decreased (C, white arrows).

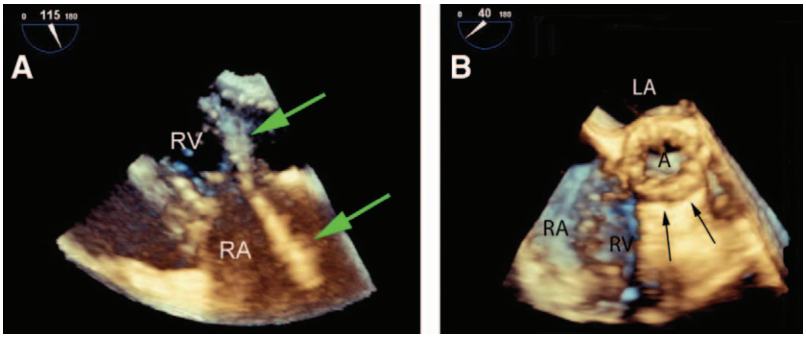

Figure 20. In panel A, the unusually thickened and uneven appearance of a pacing wire is due to 3D blooming (green arrows). In panel B, 3D rendering shows the aortic valve (A) short-axis view after transcatheter aortic valve replacement. The metal rim (black arrows) around the aortic valve appears thickened because of blurring. RV = right ventricle; RA = right atrium; LA = left atrium.

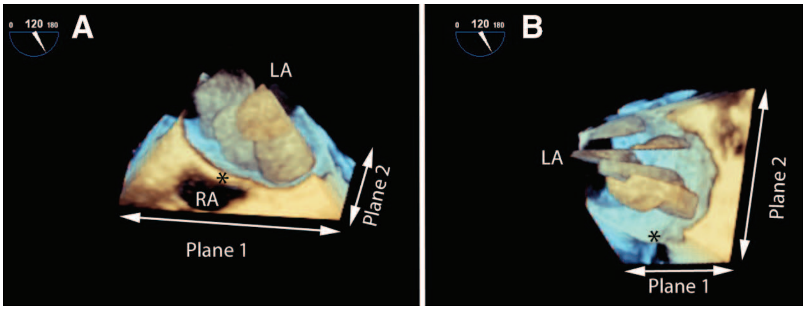

Figure 21. Three-dimensional rendering of left atrial myxoma in a patient with a history of embolic strokes is shown. The side view of the mass appears as if there may be multiple masses in the left atrium (A). However, when the image is rotated, the impact of the stitching artifact is apparent (B). LA = left atrium; RA = right atrium; * = interatrial septum.

VIDEO+ the artifact is specific to metal wires (Supplemental Digital Content 12, Supplemental Video 12, http://links.lww.com/AA/B300).[57]

Stitching Artifacts

"Stitch" artifacts appear as "fault" lines within an image and make it difficult to interpret along the slice thickness direction (Fig. 21; Supplemental Digital Content 13, Supplemental Video 13, http://links.lww.com/AA/B301). The image comprises shifting segments. Three-dimensional volume-gated images are created when 2 or more pyramidal sections (or slices) obtained over the equivalent number of heartbeats are merged.[57] When the pyramidal sections are imprecisely merged during post-processing, stitching artifacts occur. Stitching artifacts can be reduced by minimizing the heart's out-of-plane movement during the electrocardiogram-gated image acquisition period eliminating dysrhythmias, ceasing ventilation or patient or probe movement, or ceasing electrocautery. Although there is some reduction in resolution, a high volume rate (high volume rate mode) on 3D systems minimizes stitching by scanning the subvolumes in an interlocking sparse pattern rather than contiguously. In this way, the ultrasound system is better able to estimate missing data when there is significant out-of-plane motion during data acquisition.

VIDEO+

CONCLUSIONS

Artifacts are commonly seen in TEE but are often misinterpreted. Misinterpretation of echocardiography artifacts can have unintended consequences and may lead to inappropriate operations, extra time on cardiopulmonary bypass, and/or additional interventional procedures. Knowledge of the underlying physics behind image generation gives the echocardiographer the basis for correctly identifying these artifacts and assuring correct interpretation of these studies. In addition, several views should be assessed when one suspects an artifact is present so that the image can be correctly interpreted.

DISCLOSURES

Name: Huong T. Le, MD.
Contribution: This author helped design the study, conduct the study, analyze the data, and write the manuscript.
Attestation: Huong T. Le approved the final manuscript.
Name: Nicholas Hangiandreou, PhD.
Contribution: This author helped write the manuscript.
Attestation: Nicholas Hangiandreou approved the final manuscript.
Name: Robert Timmerman, MD.
Contribution: This author helped write the manuscript.
Attestation: Robert Timmerman approved the final manuscript.
Name: Mark J. Rice, MD.
Contribution: This author helped write the manuscript.
Attestation: Mark J. Rice approved the final manuscript.
Name: W. Brit Smith, MD.
Contribution: This author helped design the study, conduct the study, analyze the data and write the manuscript.
Attestation: W. Brit Smith approved the final manuscript.
Name: Lori Deitte, MD.
Contribution: This author helped write the manuscript.
Attestation: Lori Deitte approved the final manuscript.
Name: Gregory M. Janelle, MD, FASE.
Contribution: This author helped write the manuscript.
Attestation: Gregory M. Janelle approved the final manuscript.
This manuscript was handled by: Martin London, MD, PhD.

REFERENCES

1. Rudski LG, Picard MH. Artifacts, truths, and consequences. Am J Med 2000;108:589–91
2. Sharma V, Fletcher SN. A review of echocardiography in anaesthetic and peri-operative practice. Part 2: training and accreditation. Anaesthesia 2014;69:919–27
3. Losi MA, Betocchi S, Briguori C, Manganelli F, Ciampi Q, Pace L, Iannelli G, Spampinato N, Chiariello M. Determinants of aortic artifacts during transesophageal echocardiography of the ascending aorta. Am Heart J 1999;137:967–72
4. Faletra F, Constantin C, De Chiara F, Masciocco G, Santambrogio G, Moreo A, Alberti A, Vitali E, Pellegrini A. Incorrect echocardiographic diagnosis in patients with mechanical prosthetic valve dysfunction: correlation with surgical findings. Am J Med 2000;108:531–7
5. Neustein SM, Narang J. Transesophageal echocardiographic artifact mimicking an aortic valve tumor. J Cardiothorac Vasc Anesth 1992;6:724–7
6. Ludwig GD. The velocity of sound through tissues and the acoustic impedance of tissues. J Acoust Soc Am 1950;22:862–6
7. Hangiandreou NJ. AAPM/RSNA physics tutorial for residents. Topics in US: B-mode US: basic concepts and new technology. Radiographics 2003;23:1019–33
8. Pamnani A, Skubas NJ. Imaging artifacts during transesophageal echocardiography. Anesth Analg 2014;118:516–20
9. Hedrick WR, Peterson CL. Image artifacts in real-time ultrasound. J Diagnostic Med Sonography 1995;11:300–8
10. Feldman MK, Katyal S, Blackwood MS. US artifacts. Radiographics 2009;29:1179–89
11. Ziskin MC, Thickman DI, Goldenberg NJ, Lapayowker MS, Becker JM. The comet tail artifact. J Ultrasound Med 1982;1:1–7
12. Avruch L, Cooperberg PL. The ring-down artifact. J Ultrasound Med 1985;4:21–8
13. Schneider B, Stöllberger C, Schneider B. Diagnosis of left atrial appendage thrombi by multiplane transesophageal echocardiography: interlaboratory comparative study. Circ J 2007;71:122–5
14. Maltagliati A, Pepi M, Tamborini G, Muratori M, Celeste F, Doria E, Galli C. Usefulness of multiplane transesophageal

echocardiography in the recognition of artifacts and normal anatomical variants that may mimic left atrial thrombi in patients with atrial fibrillation. Ital Heart J 2003;4:797–802
15. Lanigan MJ, Chaney MA, Gologorsky E, Chavanon O, Augoustides JG. Case 2–2014: aortic dissection: real or artifact? J Cardiothorac Vasc Anesth 2014;28:398–407
16. Ducart AR, Broka SM, Collard EL. Linear reverberation in the ascending aorta: a cause of multiplane transesophageal echocardiographic artifact. Anesthesiology 1996;85:1497–8
17. Vignon P, Spencer KT, Rambaud G, Preux PM, Krauss D, Balasia B, Lang RM. Differential transesophageal echocardiographic diagnosis between linear artifacts and intraluminal flap of aortic dissection or disruption. Chest 2001;119:1778–90
18. Chu VF, Chow CM, Stewart J, Chiu RC, Mulder DS. Transesophageal echocardiography for ascending aortic dissection: is it enough for surgical intervention? J Card Surg 1998;13:260–5
19. Patel S, Alam M, Rosman H. Pitfalls in the echocardiographic diagnosis of aortic dissection. Angiology 1997;48:939–46
20. Keren A, Kim CB, Hu BS, Eyngorina I, Billingham ME, Mitchell RS, Miller DC, Popp RL, Schnittger I. Accuracy of biplane and multiplane transesophageal echocardiography in diagnosis of typical acute aortic dissection and intramural hematoma. J Am Coll Cardiol 1996;28:627–36
21. Nienaber CA, Spielmann RP, von Kodolitsch Y, Siglow V, Piepho A, Jaup T, Nicolas V, Weber P, Triebel HJ, Bleifeld W. Diagnosis of thoracic aortic dissection. Magnetic resonance imaging versus transesophageal echocardiography. Circulation 1992;85:434–47
22. Appelbe AF, Walker PG, Yeoh JK, Bonitatibus A, Yoganathan AP, Martin RP. Clinical significance and origin of artifacts in transesophageal echocardiography of the thoracic aorta. J Am Coll Cardiol 1993;21:754–60
23. Alter P, Herzum M, Maisch B. Echocardiographic findings mimicking type A aortic dissection. Herz 2006;31:153–5
24. Evangelista A, Garcia-del-Castillo H, Gonzalez-Alujas T, Dominguez-Oronoz R, Salas A, Permanyer-Miralda G, Soler-Soler J. Diagnosis of ascending aortic dissection by transesophageal echocardiography: utility of M-mode in recognizing artifacts. J Am Coll Cardiol 1996;27:102–7
25. Pothula AR, Nanda NC, Agrawal G, Kremkau FW, Tirtaman C, Bhatnager S. Mirror image from a left atrial line mimicking a catheter in the left ventricle during transesophageal echocardiography. Echocardiography 1997;14:165–8
26. Neema PK, Singha S, Manikandan S. A rounded image inside the left ventricle: the mechanism of the artifact formation. J Cardiothorac Vasc Anesth 2010;24:384–5
27. Misra S, Koshy T, Sinha PK, Kapilamoorthy TR, Sivadasanpillai H. A ring artifact in the left ventricle on transesophageal echocardiography after mitral valve replacement. Anesth Analg 2010;110:731–3
28. Gersh BJ, Gottdiener JS. Shadows on the cave wall: the role of transesophageal echocardiography in atrial fibrillation. Ann Intern Med 1995;123:882–4
29. de Jong N, Souquet J, Faber G, Bom N. Transducers in medical ultrasound: Part Two. Vibration modes, matching layers and grating lobes. Ultrasonics 1985;23:176–82
30. Kyavar M, Sadeghpour A, Alizadehasl A, Salehi N. Thrombosis on implanted device for atrial septal defect closure or echocardiographic beam width artifact? A diagnostic enigma! Int J Cardiovasc Imaging 2012;28:1851–2
31. Skubas N, Brown NI, Mishra R. Diagnostic dilemma: a pacemaker lead inside the left atrium or an echocardiographic beam width artifact? Anesth Analg 2006;102:1043–4
32. Correale M, Ieva R, Deluca G, Di Biase M. Membranes of left atrial appendage: real appearance or "pitfall". Echocardiography 2008;25:334–6
33. Bach DS. In vitro two-dimensional echocardiographic imaging of a stented porcine bioprosthetic valve: the bent strut artifact. Echocardiography 2009;26:10–4
34. Tranquart F, Grenier N, Eder V, Pourcelot L. Clinical use of ultrasound tissue harmonic imaging. Ultrasound Med Biol 1999;25:889–94
35. Hust MH, Metzler B, Claussnitzer R, Sebold H, Braun B. Transesophageal echocardiographic artifact mimicking pseudoaneurysm of the aorta. J Am Soc Echocardiogr 1994;7:538–41
36. Ozeke O, Ozbakir C, Gunel EN. Double mitral valve imaging. J Am Soc Echocardiogr 2010;23:340.e1–2
37. Austin MJ, Gerscovich EO, Fogata M, Gillen MA, Bijan B. Sonographic duplication artifact of the spinal cord in infants and children. J Ultrasound Med 2004;23:799–803
38. Sauerbrei EE. Duplication of the aortic ring. An artifact in echocardiography. J Ultrasound Med 1989;8:477–80
39. Spieker LE, Hufschmid U, Oechslin E, Jenni R. Double aortic and pulmonary valves: an artifact generated by ultrasound refraction. J Am Soc Echocardiogr 2004;17:786–7
40. Shung KK. Diagnostic ultrasound: past, present, and future. J Med Biol Eng 2011;31:371–4
41. Anavekar NS, Oh JK. Doppler echocardiography: a contemporary review. J Cardiol 2009;54:347–58
42. Boote EJ. AAPM/RSNA physics tutorial for residents: topics in US: Doppler US techniques: concepts of blood flow detection and flow dynamics. Radiographics 2003;23:1315–27
43. Pellett AA, Tolar WG, Merwin DG, Kerut EK. Doppler aliasing. Echocardiography 2005;22:540–3
44. Ender J, Selbach M, Borger MA, Krohmer E, Falk V, Kaisers UX, Mohr FW, Mukherjee C. Echocardiographic identification of iatrogenic injury of the circumflex artery during minimally invasive mitral valve repair. Ann Thorac Surg 2010;89:1866–72
45. Holte E, Vegsundvåg J, Wiseth R. Direct visualization of a significant stenosis of the right coronary artery by transthoracic echocardiography. A case report. Cardiovasc Ultrasound 2007;5:33
46. Ostovan MA, Aslani A. Myocardial bridge in hypertrophic cardiomyopathy: imaging with color Doppler echocardiography. Eur J Echocardiogr 2008;9:72–3
47. Rubens DJ, Bhatt S, Nedelka S, Cullinan J. Doppler artifacts and pitfalls. Radiol Clin North Am 2006;44:805–35
48. Manikandan S, Neema PK, Rathod RC. Double color flow during transesophageal echocardiography in a child with tetralogy of Fallot: is this real or an artifact? J Cardiothorac Vasc Anesth 2008;22:155–6
49. Lee JY, Kim SH, Cho JY, Han D. Color and power Doppler twinkling artifacts from urinary stones: clinical observations and phantom studies. AJR Am J Roentgenol 2001;176:1441–5
50. Ghersin E, Soudack M, Gaitini D. Twinkling artifact in gallbladder adenomyomatosis. J Ultrasound Med 2003;22:229–31
51. Ozkur A, Dikensoy E, Kervancioglu S, Kervancioglu R, Inalöz S, Bayram M. Color Doppler twinkling artifact in intrauterine fetal demise. J Clin Ultrasound 2008;36:153–6
52. Kamaya A, Tuthill T, Rubin JM. Twinkling artifact on color Doppler sonography: dependence on machine parameters and underlying cause. AJR Am J Roentgenol 2003;180:215–22
53. Rahmouni A, Bargoin R, Herment A, Bargoin N, Vasile N. Color Doppler twinkling artifact in hyperechoic regions. Radiology 1996;199:269–71
54. Zhao BW, Yang Y, Pan M, Li P, Wang B, Tang FG. Color Doppler twinkling artifact in fetuses with echogenic intracardiac foci: echocardiographic observation and clinical significance. Ultrasound Obstet Gynecol 2010;35:548–51
55. Tsao TF, Wu YL, Yu JM, Kang RJ, Tseng YH, Huang HH, Hung SW, Gueng MK, Lin YC, Tyan YS, Su CH. Color Doppler twinkling artifact of calcified cardiac valves in vitro: a not well known phenomenon in echocardiography. Ultrasound Med Biol 2011;37:386–92
56. Vegas A, Meineri M. Core review: three-dimensional transesophageal echocardiography is a major advance for intraoperative clinical management of patients undergoing cardiac surgery: a core review. Anesth Analg 2010;110:1548–73
57. Faletra FF, Ramamurthi A, Dequarti MC, Leo LA, Moccetti T, Pandian N. Artifacts in three-dimensional transesophageal echocardiography. J Am Soc Echocardiogr 2014;27:453–62
58. Smith J, Finnoff JT. Diagnostic and interventional musculoskeletal ultrasound: part 1. Fundamentals. PM R 2009;1:64–75