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REVIEWS

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Ultrasound imaging artifacts: How to recognize them and how to avoid them

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Echocardiography has become a critical tool in clinical cardiology in evaluating cardiac physiology and diagnosing cardiac disease states. However, imaging artifacts are commonly encountered and often lead to misdiagnoses of life-threatening diseases, such as aortic dissection and ventricular thrombus. It is, thus, critical for clinicians to understand these artifacts to avoid these misdiagnoses and protect patients from undue intervention. Artifacts can be broken down into two categories: those from violation of ultrasound system assumptions and those from interference by external equipment and devices. This review article discusses the most commonly encountered artifacts by category, explains their physical mechanisms, elaborates on their most common presentations, and instructs clinicians on how to avoid their misinterpretation.

KEYWORDS
aliasing, artifacts, beam width, cauterization, comet tail, echocardiography, mirror image, refraction, reverberation, side lobe, ultrasound physics, wave interference

1 | INTRODUCTION

Because of its safety, portability, and cost-effectiveness, echocardiography has become a widely used modality to examine cardiac anatomy and physiology. While, in most instances, echocardiography provides unequivocal diagnostic utility, it is occasionally hampered by imaging artifacts. Thus, it is important for clinicians to recognize and understand the mechanisms behind these artifacts to avoid misdiagnoses. This article summarizes and explains the mechanisms behind the most common artifacts encountered in clinical echocardiography (Table 1).

In general, there are two groups of echocardiographic imaging artifacts—those related to violation of assumptions built into ultrasound imaging equipment and those related to interference by external equipment and devices. Artifacts due to assumption violations occur in a predictable fashion and may result in displacement of image elements, masking or enhancement of image elements, or duplication of image elements. Assumption violation artifacts may occur below the true images (artifacts in axial direction) or to the side of the true image (artifacts in lateral direction) as summarized in Figure 1. Artifacts due to external equipment and devices include those related to cauterization, prosthetic valves, ventricular assist devices, and so forth.

2 | ASSUMPTIONS MADE BY ULTRASOUND SYSTEMS

Echocardiography images are produced from the interaction between an ultrasound wave, which is created by an electric pulse striking piezoelectric crystals to release sound waves, and human tissue. For adult cardiac imaging, a frequency of 4–7 MHz is typically used.[1] As the ultrasound wave interacts with the different media of different tissue densities, parts of the wave are transmitted, reflected, and refracted. The parts that are transmitted pass in a straight line, while the parts that are refracted pass through the tissue at an angle as they cross into the different medium. The parts that are reflected are not absorbed by the tissue and end up traveling back to the wave's origin. These are processed based on the travel time and loss of energy of the returning portions to generate a 2D image.

To create images, all ultrasound systems make the following assumptions in Table 2:[2]

- Pulses and echoes travel along a straight path;
- Echoes return to the transducer after one reflection (ie, a single round trip);

TABLE 1 Artifact classification

Ultrasound assumption violation	Axial direction	Comet tail Simple reverberation Mirror image Acoustic enhancement Acoustic shadowing
	Lateral direction	Refraction Side lobe Beam width
Interference by external equipment and devices	External equipment	Unshielded electrical equipment cauterization Aliasing Click
	Devices	Ultrasound interference Left ventricular assist devices

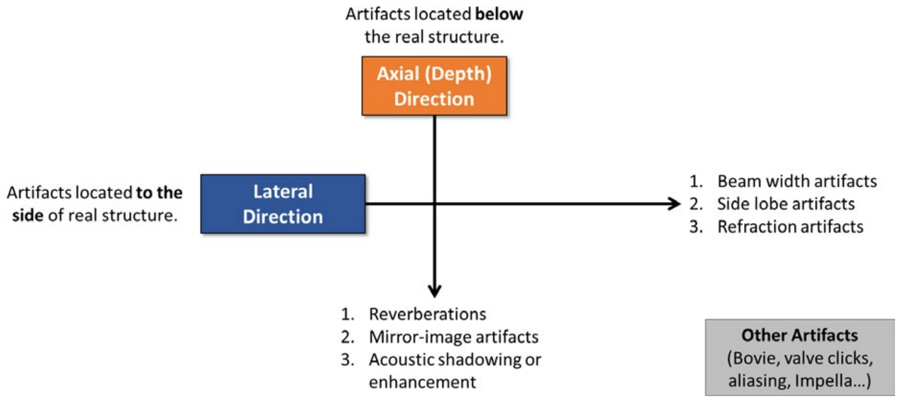

FIGURE 1 Cartoon depicting categories of assumption violation artifacts based on location relative to the true image

TABLE 2 Ultrasound system assumptions

Pulses and echoes travel along a straight path
Echoes return to the transducer after a single reflection
Echoes originate from the main beam
Echoes travel at a uniform speed (1540 m/s)
Pulses and echoes are attenuated uniformly by all tissues (at 0.5 dB/cm/MHz)

- Echoes originate from the main transducer beam;
- Pulses and echoes are attenuated uniformly by all tissues (on average 0.5 dB/cm/MHz); and
- Echoes travel at a uniform speed (1540 m/s).

The last assumption is based on the work by George Ludwig in 1950 at the Naval Medical Research Institute. He embedded gallstones in canine muscles and measured the speed of sound through arm, leg, and thigh muscles as he found them ultrasonically. The average speed was found to be 1540 m/s, which is the standard value we still use today.[3]

3 | ASSUMPTION VIOLATION: ARTIFACTS IN AXIAL DIRECTION

Axial direction artifacts are located below the image of the real structure and consist of simple and complex reverberations, mirror image artifacts, and acoustic shadowing/enhancement.

3.1 | Simple reverberation artifact

The reverberation artifact violates the assumption that an echo returns to the transducer after one reflection. In theory, when the ultrasound wave is emitted from the transducer, it interacts with surface of the structure, and the reflected wave is transmitted directly back to the transducer, making a single round trip (Figure 2). In reality, the reflected ultrasound wave can encounter a closer reflector on its way back to the transducer. One portion of the wave travels back to the transducer as expected, while the other portion is instead reflected back to the original structure.

The portion that was caught by the second reflector essentially makes a second round trip by traveling back to the original structure before eventually making it back to the transducer. Because the ultrasound system assumes that the wave only makes one round trip, the transducer interprets this longer travel time as a reflection coming from a structure that is further away than the original structure. Thus, the transducer produces an artificial image below the original structure at twice the distance between the transducer and the structure (Figure 3). Parallel motion at this distance can usually be seen and is a good indicator of this artifact. The second reflector is often the transducer itself, but can also be other common reflectors, such as the aorta, calcified structures, and implanted devices.[4]

3.1.1 | Examples of simple reverberation artifacts

Two different echo artifacts may lead to misdiagnosis of thoracic aortic dissection: reverberation (typically in the ascending aorta)

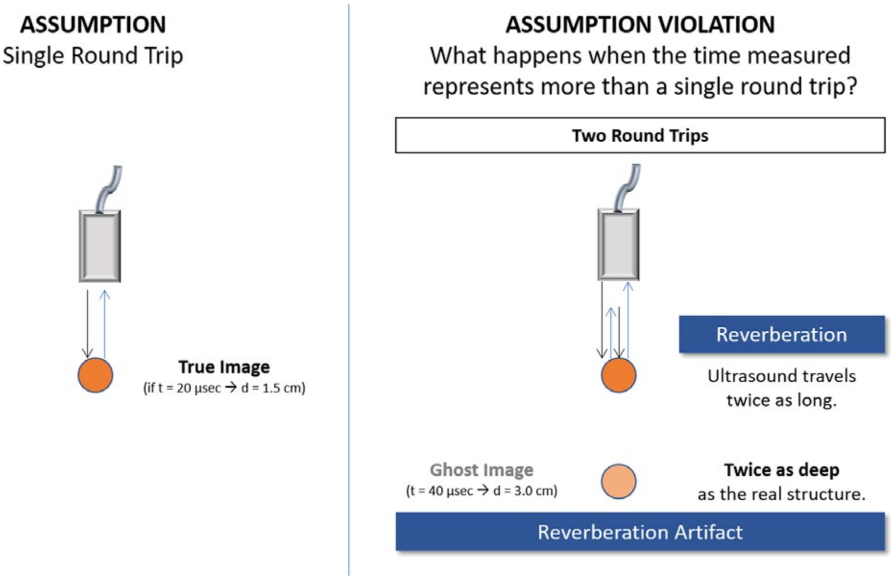

FIGURE 2 Cartoon illustrating the ultrasound assumption and how violation of this assumption results in the reverberation artifact

and side-lobe artifacts (typically in the aortic root). Reverberation artifacts are discussed in this section on axial artifacts, while side-lobe artifacts are discussed in the lateral direction artifacts below.

Several studies have shown that the sensitivity of transesophageal echocardiography (TEE) for the diagnosis of aortic dissection is high (ranging from 97% to 100%), but that the specificity can be as low as 68%.[5–7] This low specificity is mainly attributed to false positive diagnoses of Stanford type A dissections due to misinterpretation of simple reverberation artifacts (Figure 4).

Reverberation artifacts are very common in the ascending aorta, being observed in 44%–55% of studies, and have continued to lead to discrepancies in diagnosis and unnecessary procedures.[8] This is exemplified in multiple case reports, which describe patients undergoing unnecessary sternotomies due to misinterpretation of aortic dissection on echocardiography.[9,10]

Simple reverberation artifacts are also clinically significant in diagnosing left atrial appendage thrombi (LAAT). Echocardiography is the method of choice for evaluation of LAAT. However, multiple studies have recognized that a significant portion of cases contained reverberation artifacts that were misinterpreted as thrombi.[11,12] Moreover, even with multiplane echocardiography, these artifacts significantly increase inter-observer variability in the diagnosis of LAAT.[12] If this artifact is not recognized, patients can end up receiving undue anticoagulation therapy or even undue surgery.[13]

3.1.2 | How to mitigate simple reverberation artifacts

In addition to maintaining awareness of possible artifact, several studies suggest the use of M-mode echocardiography to differentiate between an intimal flap and a reverberation.[14,15] Other studies suggest turning to different types of imaging, such as CT or MRI,

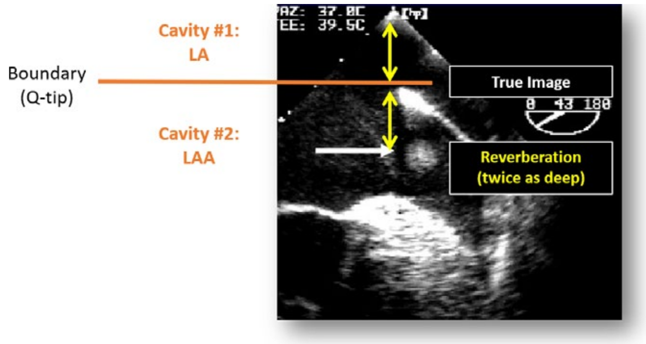

FIGURE 3 (Corresponds to Movie S1). Reverberation artifact in the left atrial appendage (white arrow) that could be mistaken for a thrombus. LA = left atrium; LAA = left atrial appendage

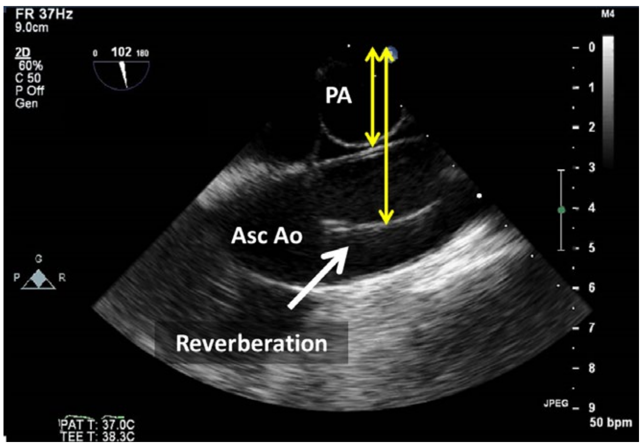

FIGURE 4 (Corresponds to Movie S2). Reverberation artifact (white arrow) in ascending aorta at approximately twice the distance from the transducer (yellow arrows) that could be mistaken for aortic dissection. Asc Ao = ascending aorta; PA = pulmonary artery

for complementary use or as the initial diagnostic procedure if the patient is stable enough.[16,17] To decrease false positive diagnosis of LAAT, one should utilize multiplane TEE with a systematic approach of imaging from multiple windows and at multiple angles.

3.2 | Complex reverberation artifact: comet tail

The complex reverberation artifact, also known as the comet tail artifact, is produced in the same fashion as the simple reverberation artifact. In this case, though, there are usually two or more reflectors that are very close together, and the process involves multiple round trips. With each subsequent round trip, the artificial image produced is moved further below the original structure, and the signal intensity becomes progressively weaker. The characteristic appearance of the artifact is shown in Figures 5 and 6.

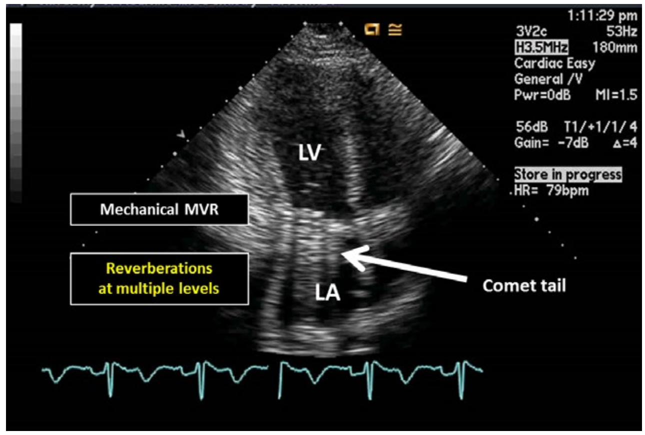

FIGURE 5 (Corresponds to Movie S3). Comet tail artifact (white arrow) originating from a mechanical St. Jude mitral prosthesis. LA = left atrium; LV = left ventricle

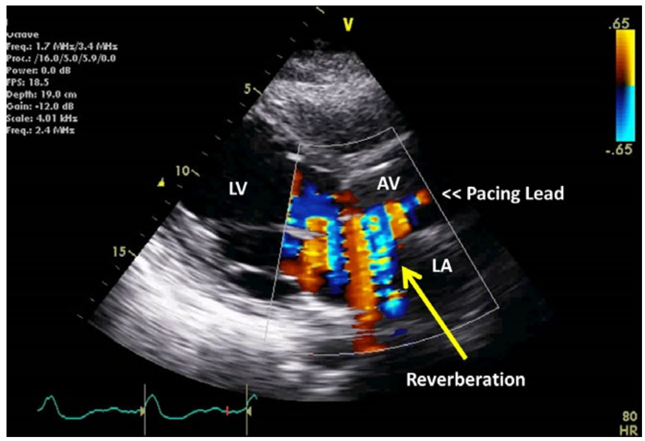

FIGURE 6 (Corresponds to Movie S4). Reverberation artifact (yellow arrow) due to a pacing wire in the right heart. AV = aortic valve; LA = left atrium; LV = left ventricle

3.2.1 | Examples of comet tail artifacts

External devices

Because the comet tail artifact can occur with any closely spaced reflector, it is often compatible with a normal scan. It is commonly seen in patients with mechanical valves and can lead to difficulty in assessing cardiac anatomy. For example, a comet tail artifact from a mechanical mitral valve has been shown to mask the contents of the left atrium.[18] It is also important to recognize that comet tail artifacts are also seen with surgical clips and catheter tips and should not be misinterpreted.

B-lines

In evaluating pulmonary anatomy on ultrasound, comet tail artifacts are also known as B-line artifacts. They arise from the pleural line and move synchronously with lung sliding.[19] Thus, displacement or deviation of this artifact is an indicator of a myriad of pulmonary diseases. For example, this artifact has been historically studied as a way to rule out pneumothorax.[20] One study also suggests that the presence of multiple, diffuse, and bilateral comet tail artifacts can be used to make the diagnosis of alveolar-interstitial syndrome in the emergency setting.[21] Variations of the artifact can also indicate other causes of interstitial disease, such as interstitial pneumonia, pulmonary fibrosis, and so forth, but cannot differentiate the cause without clinical correlation.

Studies have also explored using B-lines as an indirect measure of pulmonary wedge pressure. As the number of artifacts responds quickly to changes in lung water content, it is possible to track the reduction in artifacts as the patient is dialyzed.[22] This allows for a noninvasive method of evaluation of response to therapy for decompensated diastolic heart failure patients.[23,24]

Evaluation of the arterial system

Comet tail artifacts have also shown to be useful in the setting of color Doppler in evaluating intimal plaques in the arterial system and accurately measuring aortic aneurysms.[25]

These examples illustrate how an imaging artifact can actually be used as a valuable clinical marker.

3.3 | Mirror image artifact

The mirror image artifact violates the assumptions that the ultrasound wave moves in a linear path and that the echo returns to the transducer after a single reflection. In this scenario, the ultrasound wave from the transducer is initially reflected from the desired object at an angle (angle of reflection = angle of incidence) and then encounters a highly reflective structure that is between the transducer and the initial object (Figure 7). The wave then travels back to the initial object before traversing to the transducer. The transducer does not recognize that the wave took an indirect path on its way back. Instead, it assumes that the longer travel time indicates that the intervening structure must be along a straight path below the initial object, and thus maps a false image of the intervening structure as such. The false image acts as a mirrored object: inverted and moving in the opposite direction as the true intervening structure. These artifacts are usually easy to identify as one can usually see both the original structure and its mirror image in the same frame.

3.3.1 | Examples of mirror image artifacts

Normal physiology

The mirror artifact can be compatible with a normal scan. The pleura is a strong reflector and is often the source of the mirror artifacts of the mitral valve.[4] This is typically seen in the parasternal long-axis view and should not be misinterpreted as a disease process.

Pseudo mitral regurgitation (MR)

When mirror artifacts lead to misdiagnosis, they are often found leading to confusion about the flow in two adjacent vessels in spectral and color Doppler (Figure 8). For example, in patients with mitral valve prostheses, mirroring of the left ventricular outflow tract flow (LVOT) can result in misdiagnosis of MR. One group observed that in patients with tilting disk mitral valve prostheses, color Doppler images from transthoracic echocardiography (TTE) apical views, which suggested significant MR, differed greatly from images from TEE or angiography, which showed only trace physiologic MR.[26] Another study examined a similar cohort and found that 12% had a discrepancy between echocardiographic and operative findings of the degree of MR. In 3.4%, no abnormalities were found at the time of operation even though they had a preoperative echocardiographic diagnosis of prosthetic dysfunction.[27] These studies thus show that a misdiagnosis of MR can be problematic, leading to further evaluation, more imaging, and even unwarranted cardiac catheterization or surgery.

Vessel duplication

Mirror artifacts can also complicate the evaluation of major vessels. For example, the artifact can produce a complete vessel duplication (Figure 9), which can confound sonographers' interpretations of the subclavian region.[28] These artifacts have also been commonly found in the carotid arteries and have led to problems in diagnosing stenosis and plaques.[29] One of the most important consequences of misinterpretation of this artifact is a false diagnosis of dissection, which has been demonstrated in both the carotid artery and abdominal aorta.[30,31] As mentioned above, misdiagnosis of dissection often leads to further imaging and even unnecessary procedures.

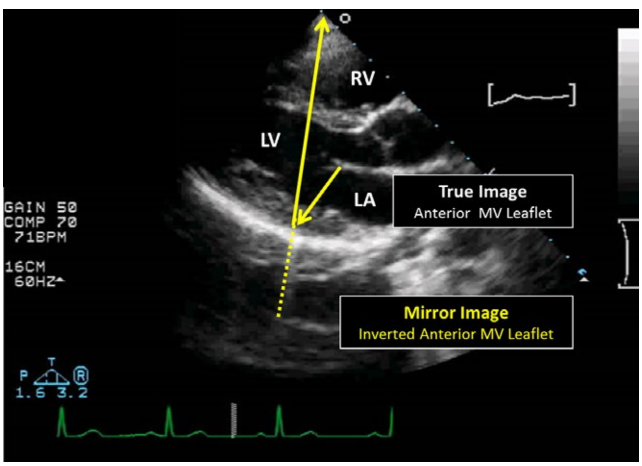

FIGURE 7 (Corresponds to Movie S5). Trajectory of the ultrasound wave as it travels back to the transducer (solid line), bouncing off a reflective object and producing a mirror artifact of the anterior mitral valve leaflet (dotted line). LA = left atrium; LV = left ventricle; RV = right ventricle

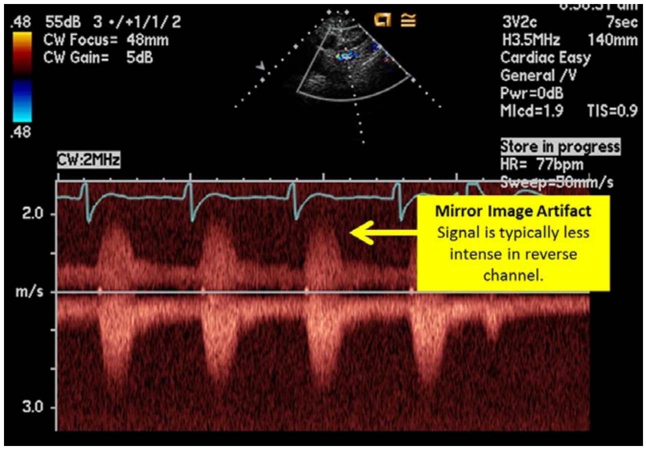

FIGURE 8 Mirror image artifact shown in Doppler of the subclavian artery of a patient with a functioning left-arm dialysis shunt

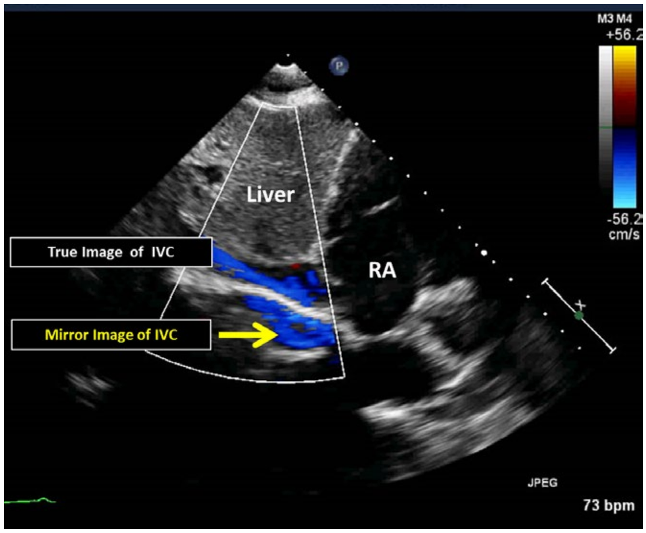

FIGURE 9 (Corresponds to Movie S6). Mirror artifact producing an inverted inferior vena cava (yellow arrow). RA = right atrium

3.3.2 | How to mitigate mirror image artifacts

Fortunately, in the Doppler setting, it is easy to recognize this artifact by using pulse Doppler sampling to confirm that the velocity and timing are similar to those of the adjacent vessel (in the aforementioned example, this would be the LVOT flow).[26] In order to avoid misdiagnosis of dissection due to vessel duplication, clinicians can change the scanning plane and manipulate the incident angle of the sound beam in order to expose this artifact in ambiguous cases.[32]

3.4 | Acoustic shadowing and enhancement

Acoustic shadowing and enhancement are violations of the assumption that echoes are attenuated uniformly by all tissues. In this scenario, if a tissue attenuates the transmitted ultrasound wave to a significantly greater or lesser extent than the surrounding tissue, the strength of the beam distal to this structure will be either much weaker or stronger than that in the surrounding field.[33] The ultrasound system determines image settings based on this assumption of uniform attenuation by all tissues. Thus, if the ultrasound beam encounters a very strong or weak attenuating ($\gg$ or $\ll$0.5 dB/cm/MHz) structure, the produced image beyond the structure will appear too dark (a shadow) or too bright (an enhancement), respectively.

3.4.1 | Examples of acoustic shadowing artifacts

Acoustic shadowing (Figures 10 and 11) can be found with any calcium-containing structure, prosthetic valves, and even silicone breast implants. This artifact has been known to be particularly problematic in evaluating paravalvular leaks in patients with prosthetic valves due to shadowing from the prosthesis material.[33] The anterior feature of the aortic ring is especially difficult to visualize because of shadowing from the posterior valve ring.[34]

Often, this artifact leads to underestimation or displacement of regurgitant jets. For example, one study described a case where a TTE gave an impression of a MR jet, but the acoustic shadow did not allow adequate evaluation of the regurgitation. TEE demonstrated a small periprosthetic leak. However, because the patient's symptoms were disproportionate to the patient's symptoms, an intra-cardiac ultrasound was performed and revealed significant periprosthetic regurgitation.[35] Another study portrayed the difficulty in determining whether a jet was the result of aortic regurgitation or mitral inflow because there was significant shadowing from a patient's mechanical mitral valve.[36] These reports are worrying because misinterpretation can result in insufficient treatment or unjustified surgery for a significant disease process.

3.4.2 | How to mitigate acoustic shadowing artifacts

To avoid underestimation or displacement of regurgitant jets caused by acoustic shadowing, some studies suggest increasing the aliasing velocity of color flow Doppler to allow for closer examination of the jet, using a deep transgastric long-axis view for better imaging of the LVOT and aortic valve, and repositioning of the short-axis view of the aortic valve to better examine the aortic leaflets.[36,37] Other studies also suggest the adjunctive use of cardiac CT and intracardiac echocardiography, especially in ambiguous cases or in those with a contraindication to transesophageal imaging.[34,36]

3.4.3 | Examples of acoustic enhancement artifacts

Acoustic enhancement (Figure 12), also known as posterior enhancement, is mainly seen while evaluating fluid filled abdominal organs, such as the gallbladder and the urinary bladder. However, it is also commonly seen in echocardiography in the subxiphoid window, which includes the liver. Cystic lesions and cavernous hemangiomas are the most common liver lesions that present with this artifact.[38] Other studies have also seen this artifact in hepatocellular carcinoma. These groups found that almost half of carcinoma cases demonstrated acoustic enhancement and suggest that the artifact may be more frequently associated with advanced cancers.[39,40] This artifact does not usually impede evaluation of cardiac anatomy, but it should be recognized so that it is not misdiagnosed.

3.4.4 | How to mitigate acoustic enhancement artifacts

For acoustic enhancement, changing the angle of the ultrasound beam can eliminate the artifact if it interferes with evaluation of cardiac anatomy.[41]

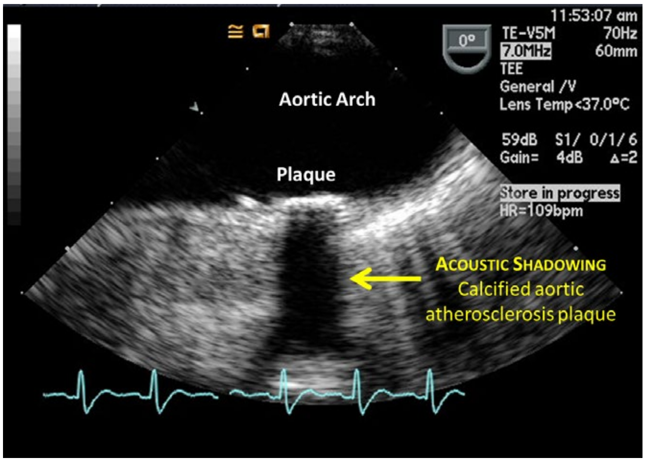

FIGURE 10 (Corresponds to Movie S7). Calcified aortic atherosclerosis plaque causing acoustic shadowing artifact (yellow arrow)

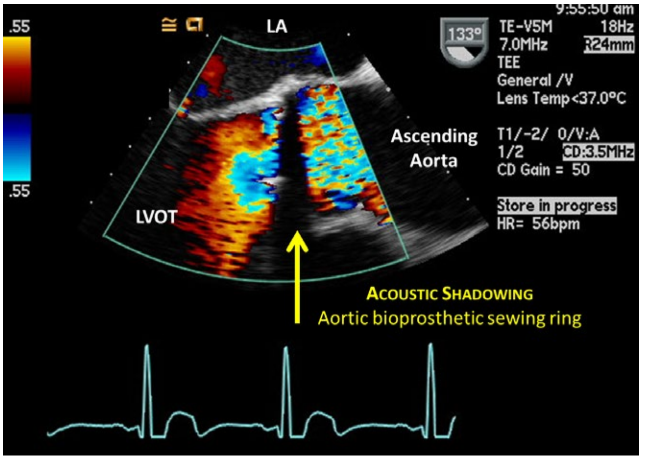

FIGURE 11 (Corresponds to Movie S8). Shadowing artifact (yellow arrow) caused by aortic bioprosthetic sewing ring. LA = left atrium; LVOT = left ventricular outflow tract

4 | ASSUMPTION VIOLATIONS: ARTIFACTS IN LATERAL DIRECTION

Lateral direction artifacts are located to the side of the image of the real structure and consist of refraction artifacts, beam width artifacts, and side-lobe artifacts.

4.1 | Refraction artifact

The refraction artifact violates the assumptions that the path of the ultrasound wave is straight and that the speed of the ultrasound wave is uniform. In this scenario, instead of the ultrasound wave traveling directly to the cardiac object and back to the transducer, the wave encounters a structure that acts as a wave refractor. This structure essentially behaves as a lens.[42] As the wave goes through the structure, the path of the wave is bent at the interface, and the speed of the wave is changed depending on material of the structure. This results in duplication (often partial) of the cardiac object that appears as a sort of ghost image to the side of the true image (Figure 13). The produced image is similar to that of the mirror image artifact, but it appears next to instead of underneath the true image. Common inducers of refraction artifacts are costal cartilage, fascial structures and fat, and pleural and pericardial surfaces.[43,44]

4.1.1 | Examples of refraction artifacts

These artifacts are most often seen on the short-axis view of the aortic valve and left ventricle, but they are described only a few times in literature. When reported, they are commonly found depicting duplications of the mitral, aortic, or pulmonary valve.[44,45]

4.1.2 | How to mitigate refraction artifacts

Fortunately, these artifacts are also easily recognizable as the ghost image usually depicts an anatomically impossible structure. Moreover, these artifacts are easily eliminated by altering the transducer's angle and position.

4.2 | Beam width artifact

The beam width artifact violates that assumption that echoes are generated only from reflectors located within the main ultrasound beam. To comprehend this artifact better, one must understand the actual shape of the ultrasound beam. As the beam exits the transducer, it maintains approximately the same width as the transducer. It then narrows to a certain point (called the focal zone) and then widens again as it continues to move further from the transducer to a width often beyond that of the transducer.[46] This gives the ultrasound beam a sort of hourglass appearance (Figure 14). If there is a highly reflective object in the widened base of the beam, the ultrasound system will think that the echo from this object originates from the focal zone. Thus, ghost images of these highly reflective objects can become visible along the same plane of the real image.

4.2.1 | Examples of beam width artifacts

This artifact can lead to intra-cavitary clutter and has been misinterpreted in previous studies as thrombi and pseudomasses.[47,48] Implantable cardiac devices, such as prostheses and pacemaker/ICD leads, are particularly prone to generating these artifacts and can complicate interpretation of echocardiographic images. One group, for example, documented an artifact that mimicked the appearance of a pacemaker lead inside the left atrium.[49] Fortunately, in this case, further imaging and evaluation elucidated the nature of the artifact, and the patient did not undergo any unnecessary clinical intervention.

The beam width artifact is also clinically important in the setting of color and spectral Doppler because it makes it difficult to interpret the flow of adjacent vessels. For example, in a patient with MR, the flow can be directed toward the left atrial appendage and be misunderstood as disturbed systolic flow in the pulmonary artery.[4] Another

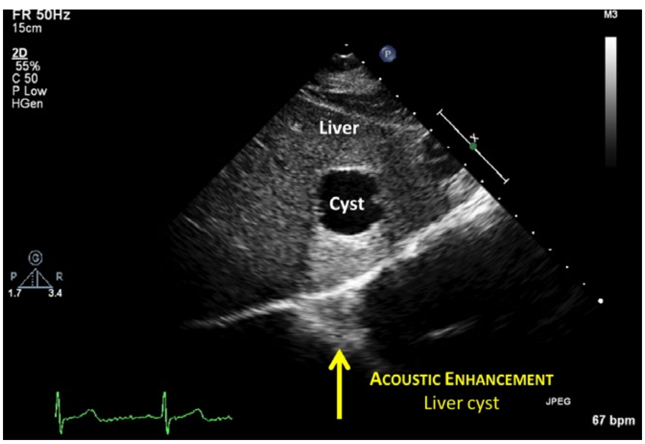

FIGURE 12 (Corresponds to Movie S9). Acoustic enhancement artifact (yellow arrow) from liver cyst

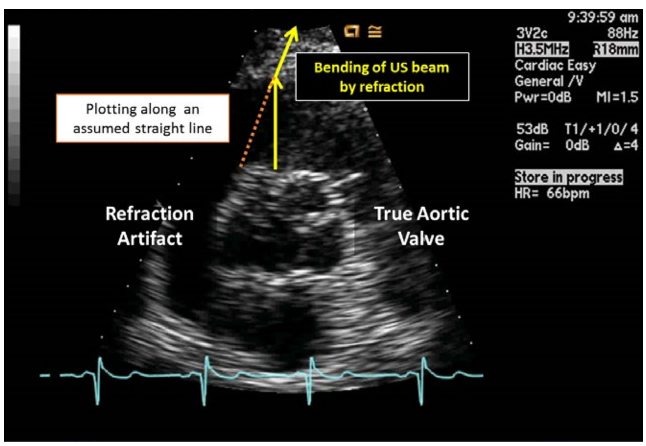

FIGURE 13 (Corresponds to Movie S10). Demonstration of the altered path of the wave (dotted line), leading to refraction artifact showing duplication of the aortic valve

example is portrayed in Figure 15. The mitral flow is projected onto the aortic regurgitant flow, creating the illusion of a significant degree of aortic regurgitation. Confusion about valvular flow can lead to incorrect diagnoses and potentially unjustified surgery depending on the indication.

4.2.2 | How to mitigate beam width artifacts

To reduce these artifacts, one can adjust the focal zone toward the level of interest, diminish gain settings so that the reflections from the widened base are decreased, and view the same structure in different acoustic windows and at different angles as an artifact is usually not reproducible in multiple echocardiographic planes.[48,49]

4.3 | Side-lobe artifact

The side-lobe artifact also violates the assumption that echoes are generated only from reflectors located within the main ultrasound beam. While most of the energy produced by the ultrasound is concentrated in the center, smaller amounts of emitted energy are directed to the sides and form side lobes of energy. These smaller energies usually disperse throughout the tissue without emitting any prominent echoes. If a strong reflector resides in these side lobes, however, the reflections produced are interpreted as originating from the central beam.[50] These images often overlap with each other and merge, producing a linear, arc-like artifact next to the real image.[46,51]

4.3.1 | Examples of side-lobe artifacts

Like beam width artifacts, side-lobe artifacts (Figure 16) have been shown to greatly confuse the interpretation of left ventricular thrombosis and vegetations as they can mimic these masses, especially when using fundamental frequency imaging.[52] They are also the leading cause of intra-cavitary clutter. Despite its high sensitivity and specificity, TTE has been rendered limited in studying these masses in the left ventricle because of these artifacts. One study even noted that, in daily practice, poor image quality occurs in about 10%–20% of patients because of ultrasound artifacts and clutter.[53]

Side-lobe artifacts are also often misinterpreted as dissection flaps in the aorta.[54,55] As previously noted, two completely different echo artifacts may lead to misdiagnosis of aortic dissection: reverberation (discussed earlier) and side-lobe artifacts.

The artifact is usually a reflection of the sinotubular junction and results in a curvilinear image within the lumen of aorta. Fortunately, there are many ways to distinguish this artifact from a true dissection.[56,57] First, a true dissection flap will display random mobility, whereas the artifact will have a more fixed location with respect to the aortic wall. Second, a true dissection flap will have constant echo intensity, while the artifact's intensity will progressively diminish toward the lumen of the aorta. Color Doppler can also reveal the artifact because the artifact will not affect the distribution of the color flow signal. A true dissection will show margination of flow. Finally, the artifact often ignores normal anatomic boundaries and may be seen crossing the aortic wall in some images.

4.3.2 | How to mitigate side-lobe artifacts

Side-lobe artifacts appear more commonly with fundamental than harmonic imaging. Tissue harmonic imaging has been shown to significantly improve the visualization of endocardial borders and to decrease the side-lobe clutter.[58] This is a result of the nonlinear relationship of the generation of harmonics and the energy of the original ultrasound wave.[59] When a high-frequency harmonic wave is used, the signals from high-energy beams are amplified more significantly than those from the low-energy beams. Because the side-lobe artifact originates from a much weaker beam than the central imaging beam, this dramatic difference in signal intensity effectively eliminates the artifact from the produced image.

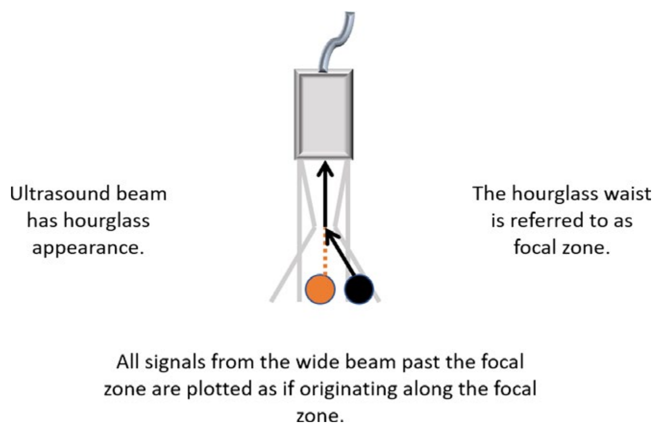

FIGURE 14 Cartoon demonstrating the mechanism behind beam width artifact

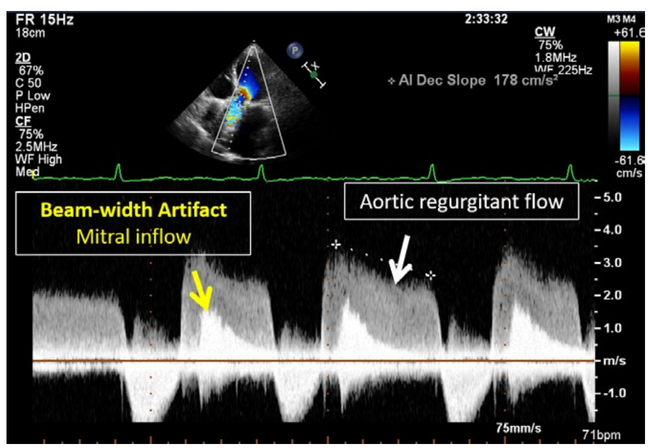

FIGURE 15 Beam width artifact of mitral inflow (yellow arrow) projected onto the aortic regurgitant flow (white arrow)

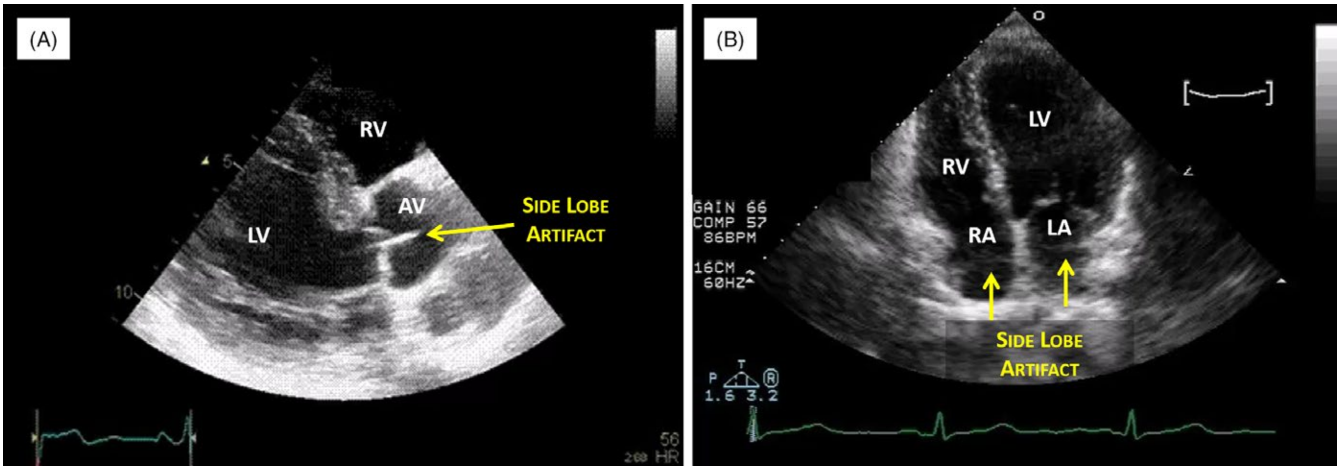

FIGURE 16 (Panel A corresponds to Movie S11, and Panel B corresponds to Movie S12). Two examples of how side-lobe artifacts (yellow arrows) can lead to intra-cavitary clutter and be mistaken for thrombus or vegetations. AV = aortic valve; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle

5 | ARTIFACTS DUE TO EQUIPMENT

Artifacts due to equipment include artifacts from unshielded electrical equipment, cauterization artifacts, aliasing, and click artifacts.

5.1 | Artifacts from unshielded electrical equipment

This artifact can be seen with a malfunctioning ultrasound probe, but it mainly occurs when other unshielded pieces of electrical equipment are turned on near the ultrasound machine. The external electronic signals are detected by the ultrasound system and these result in a band-like pattern over the normal ultrasound image.[60] This artifact is easily recognizable because it has a geometric shape and appears in all windows while the electrical equipment is still on or unshielded (Figure 17). Hence, there have not been any reported cases of this artifact leading to misdiagnoses.

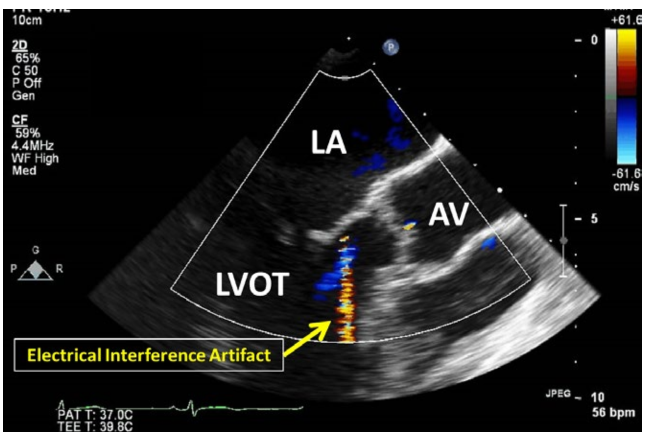

FIGURE 17 (Corresponds to Movie S13). Electrical interference artifact (yellow arrow) from unshielded electrical appliance or broken probe. AV = aortic valve; LA = left atrium; LVOT = left ventricular outflow tract

5.1.1 | How to mitigate artifacts from unshielded electrical equipment

One can simply avoid this artifact by shielding or turning off all electrical equipment to ensure that the artifact does not hinder proper examination of the cardiac anatomy.

5.2 | Cauterization artifact

Cauterization artifact is another example of how external electrical equipment can cause distorted ultrasound images. The artifact produced has a characteristic image of a geometric fan-shaped interference pattern, masking any resemblance of an anatomic structure in the displayed image (Figure 18).

5.2.1 | How to mitigate cauterization artifact

This artifact only appears during electrocautery use and disappears as soon as the electrocautery stops.[61] Moreover, the newest generation of Siemens ultrasound systems automatically removes this artifact.

5.3 | Aliasing artifact

This artifact occurs in the setting of pulsed-wave spectral and color Doppler. In these imaging modalities, pulsed sound beams are used to sample blood flow or tissue movement in a desired location (sample volume) and derive velocity information.[62] This calculation is possible with the Doppler shift, which is a change in the frequency of sound due to the motion of the blood or tissue. The maximum Doppler shift frequency is known as the Nyquist limit and is equal to half of the pulse repetition frequency (PRF, ie, the sampling frequency) of the transducer.[63]

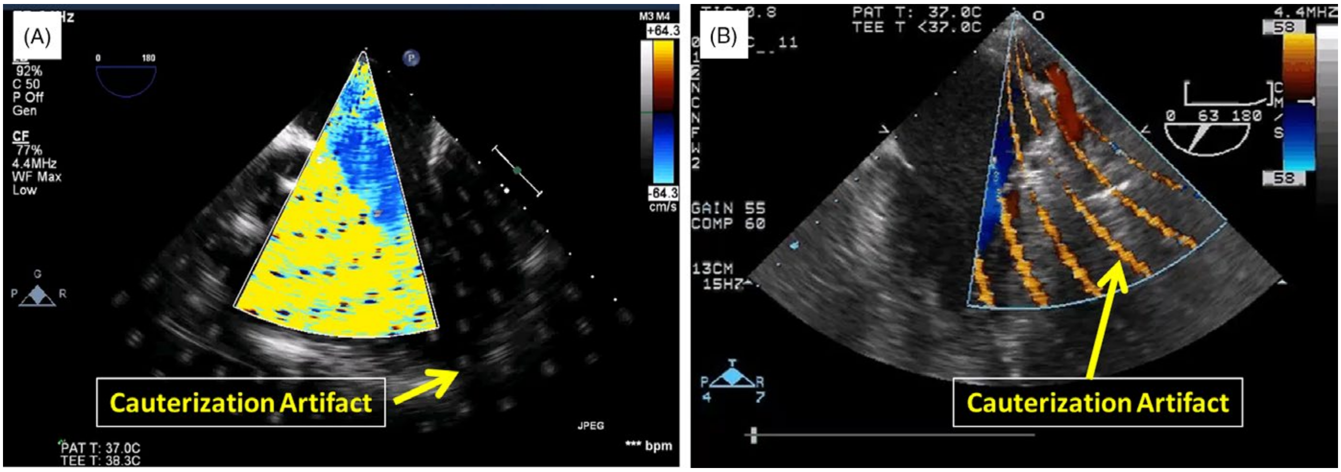

FIGURE 18 (Panel A corresponds to Movie S14, and Panel B corresponds to Movie S15). Fan-shaped cauterization artifacts due to interference from Bovie cauterizer seen on both grayscale (Panel A) and color Doppler imaging (Panel B)

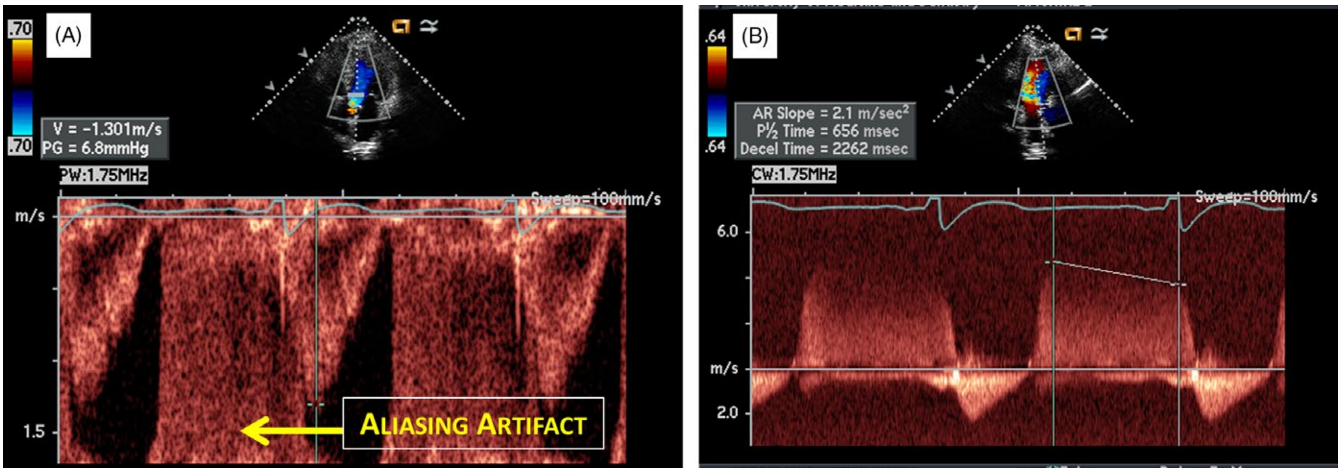

FIGURE 19 Panel A—Aliasing artifact (yellow arrow) of high-velocity aortic regurgitation jet on pulsed-wave Doppler. Panel B—Aliasing artifact eliminated with the use of continuous-wave Doppler

The ultrasound system sets the maximum Nyquist limit based on the depth of the sample volume (typically in cm) and the desired probe frequency (typically in MHz). To set the maximum Nyquist limit, the ultrasound system constantly compares two simultaneous time intervals: time of ultrasound flight (TOF, which is dependent on the depth of sample volume) and pulse repetition period (the time interval between successive ultrasound pulses). The pulse repetition period (PRP) is the inverse of PRF.

To set the maximum Nyquist limit, the ultrasound system:

- Calculates the maximum TOF based on the depth of desired sample volume and known ultrasound velocity (1540 m/s);
- Sets PRP not to exceed maximum TOF; and
- Sets the maximum Nyquist velocity limit using the following equation

$$\text{Aliasing Vmax (Nyquis Limit)} = \frac{\text{PRF}}{4 * F * \cos(\theta)} * c$$

where c = ultrasound velocity (1540 m/s), F = transducer frequency, θ = angle of ultrasound beam, and PRF = pulse repetition frequency, which is calculated as 1/TOF.

From the above equation, one can deduce that aliasing is more likely to occur when using a higher frequency probe and interrogating a deeper structure that moves at a higher velocity.

The aliasing artifact occurs when the velocity of the blood or tissue surpasses the maximum Nyquist limit. The image produced is the result of a wraparound effect where the high-frequency components wrap around to the negative extreme of the scale. On spectral Doppler, the highest flow velocities are mapped onto the negative part of the graph, and on color Doppler, the image gives the illusion of reversal of flow within the sample volume.

5.3.1 | Aliasing artifact examples

Aliasing artifacts are most commonly apparent in vessel and valvular stenosis. In these high flow states, the default PRF is usually set too low on spectral or color Doppler. Thus, the image shows flow reversal (Figure 19), which may confuse a clinician who is unaware of this artifact

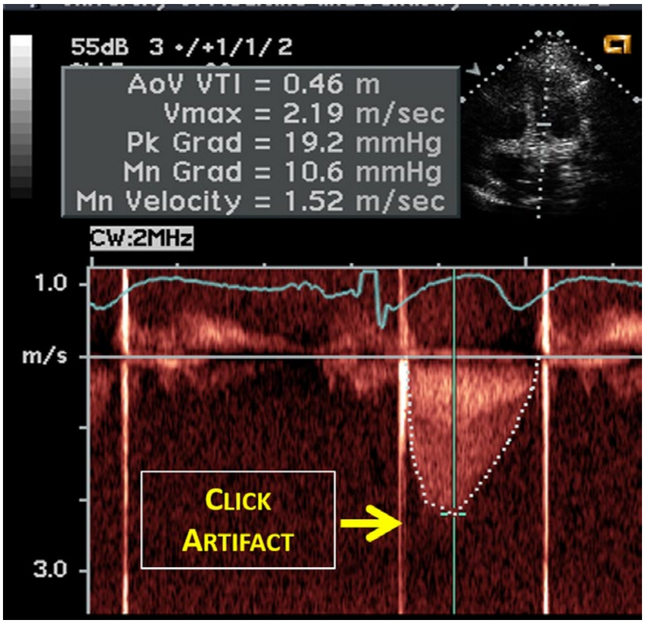

FIGURE 20 Click artifact (yellow arrow) resulting from opening and closing of mechanical aortic valve

and lead to an incorrect diagnosis. Aliasing also makes measurement of the maximum velocity challenging in these disease states. Thus, one may have difficulty measuring peak velocities in patients with aortic stenosis and tricuspid regurgitation using pulsed-wave Doppler.[64]

5.3.2 | How to mitigate aliasing artifact

Given the above equation, reducing aliasing artifact is mainly based on three factors: decreasing transducer frequency, decreasing depth, and choosing an anatomic structure whose velocity is expected not to exceed the Nyquist limit (such as diastolic mitral inflow or pulmonary venous flow). This translates into using a lower frequency probe and finding a window where the structure is close to the probe. When the blood velocity is expected to exceed the Nyquist limit (as with aortic stenosis and mitral or tricuspid regurgitation), aliasing can be avoided using continuous-wave Doppler. In this mode, the transducer uses two crystals to send and receive signals continuously rather than in discrete pulses. While this method allows for measurement of high velocities, it cannot tell the depth at which these velocities come from (range ambiguity).

Interestingly, the aliasing artifact can also be used to diagnostic advantage, such as with the proximal isovelocity surface area (PISA) method to assess the severity of valvular regurgitation.[65]

5.4 | Click artifact

The click artifact is a normal component of Doppler images. As valve leaflets open and close, they create a peak signal in the same direction as the blood flow. In the setting of mechanical valves, this click artifact is amplified. While there are many types of mechanical valves, the bileaflet valve is the most popular design.[66] This valve is composed of two semicircular leaflets that pivot on a hinge. When the leaflets open, blood flows between one rectangular and two semicircular openings. When closed, some blood leaks back between the two leaflets and between the leaflets and the housing around the valve. Compared to a native heart valve, these mechanical valves demonstrate high turbulent shear stresses at high-velocity gradients immediately distal to the valve leaflets. Moreover, when the valve closes, a high-pressure difference develops and causes a fast-moving flow that leaks around the hinge of the valve.[67] On Doppler, the transducer detects these high velocities and produces a brief, spiked signal that is more intense than that seen on a normal Doppler scan (Figure 20).

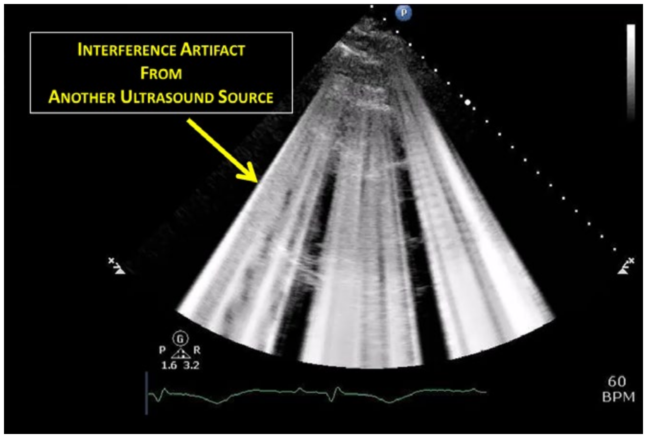

FIGURE 21 (Corresponds to Movie S16). Fan-shaped artifact seen on cardiac ultrasound from the interference of ultrasound waves from another ultrasound source, namely the intra-pulmonary EKOS thrombolysis system

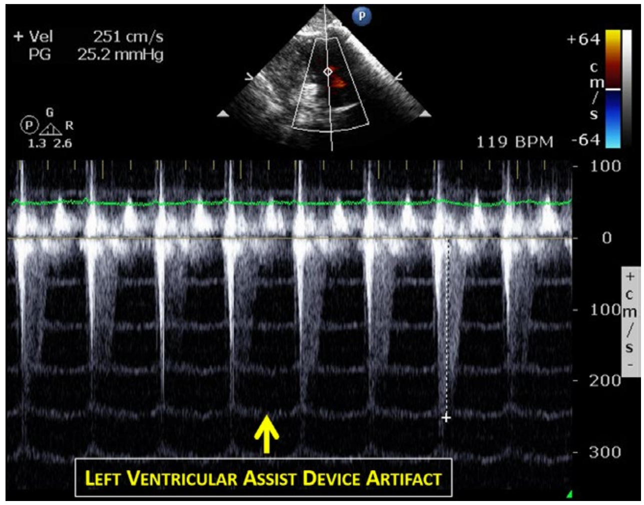

FIGURE 22 Regularly spaced wavy horizontal artifact (yellow arrow) from Impella left ventricular assist device superimposed on continuous-wave Doppler tracing of tricuspid regurgitation

6 | ARTIFACTS DUE TO DEVICES

Artifacts due to devices include artifacts from interference of other ultrasound systems and left ventricular assist devices.

6.1 | Ultrasound interference artifact

This artifact can be seen with either a broken probe or with another ultrasound system in use, such as EKOS. The EKOS system is a form of catheter-based thrombolytic delivery system used to treat pulmonary emboli. It uses acoustic microstreaming and ultrasonic agitation via ultrasound energy from a series of ultrasound transducer elements to alter thrombus structure and allow the thrombolytic therapy to be more effective.[68] The interaction between the frequency from the ultrasound transducer and the pulsations of lower frequencies from the EKOS system ends up creating a sort of fan-shaped, "windshield wiper" artifact (Figure 21).

6.1.1 | How to mitigate ultrasound interference artifact

Removing all devices that use ultrasound waves will eliminate this artifact. Equipment should also be checked to ensure that the artifact is not the result of a broken probe.

6.2 | Left ventricular assist device artifact

Another type of wave interference artifact can be seen with ventricular assist devices, especially those with the continuous flow such as the Impella device (Figure 22). The Impella is a percutaneously inserted ventricular assist device that pumps blood from the left ventricle into the ascending aorta. The instrument has been shown to provide significant hemodynamic support, leading to decreases in pulmonary capillary wedge pressure, increases in cardiac output and mean arterial blood pressure, and improved organ perfusion in patients with severe cardiogenic shock.[69,70] The proximity of the electromagnetic motor of the Impella to the ultrasound transducer allows the waves of the motor to interfere with those of the ultrasound system, inducing the appearance of this wave-like artifact that appears at evenly spaced intervals.[71]

6.2.1 | How to mitigate left ventricular assist device artifact

Removing the left ventricular assist device is the only way to eliminate the artifact. As patients often require these devices for a prolonged period of time, clinicians should be aware of the artifact so that it is not misdiagnosed.

7 | CONCLUSION

Within clinical echocardiography, there are a variety of artifacts that can be categorized by the location in relation to the desired image (axial or lateral), interference from external equipment, and interference from devices. While technological advances have reduced the prevalence of these artifacts, it remains pertinent for clinicians to proactively maintain awareness of these artifacts. This mindset will further provide clinicians with the knowledge needed to avoid crucial misdiagnoses and diminish the influence of these artifacts on patient care.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Movie S1. Reverberation artifact in the left atrial appendage (yellow arrow) that could be mistaken for a thrombus.

Movie S2. Reverberation artifact (yellow arrow) in ascending aorta at approximately twice the distance from the transducer that could be mistaken for aortic dissection.

Movie S3. Comet tail artifact (yellow arrow) originating from a mechanical St. Jude mitral prosthesis.

Movie S4. Reverberation artifact (yellow arrow) due to a pacing wire in the right heart.

Movie S5. Mirror artifact (yellow arrow) of the anterior mitral valve leaflet.

Movie S6. Mirror artifact producing an inverted inferior vena cava (yellow arrow).

Movie S7. Calcified aortic atherosclerosis plaque causing acoustic shadowing artifact (yellow arrow).

Movie S8. Shadowing artifact (yellow arrow) caused by aortic bioprosthetic sewing ring. Abbreviations: Asc Aorta, ascending aorta; LA, left atrium; LVOT, left ventricular outflow tract.

Movie S9. Acoustic enhancement (yellow arrow) from liver cyst.

Movie S10. Refraction artifact (yellow arrow) showing duplication of the aortic valve.

Movie S11. Example of how side-lobe artifact (yellow arrow) can be mistaken for vegetation. Based on a clip from http://folk.ntnu.no/stoylen/strainrate/Ultrasound/, accessed October 6, 2012.

Movie S12. Example of how side-lobe artifact (yellow arrow) can lead to intracavitary clutter and be mistaken for thrombus.

Movie S13. Electrical interference artifact (yellow arrow) from unshielded electrical appliance or broken probe.

Movie S14. Fan-shaped cauterization artifact due to interference from Bovie cauterizer seen on gray-scale.

Movie S15. Fan-shaped cauterization artifact due to interference from Bovie cauterizer seen on color Doppler imaging.

Movie S16. Fan-shaped artifact seen on cardiac ultrasound from the interference of ultrasound waves from another ultrasound source, namely the intrapulmonary EKOS thrombolysis system.

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