Fact or Artifact in Two-Dimensional Echocardiography: Avoiding Misdiagnosis and Missed Diagnosis

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Two-dimensional transthoracic echocardiography is the most widely used noninvasive imaging modality for the evaluation and diagnosis of cardiac pathology. However, because of the physical properties of ultrasound waves and specifics in ultrasound image reconstruction, cardiologists are often confronted with ultrasound image artifacts. It is particularly important to recognize such artifacts in order to avoid misdiagnosis of conditions ranging from aortic dissection to thrombosis and endocarditis. This overview article summarizes the most common image artifacts encountered in routine clinical practice, along with explanations of their physical mechanisms and guidance in avoiding their misinterpretation. (J Am Soc Echocardiogr 2016;29:381-91.)

Keywords: Echocardiography, Ultrasound physics, Artifacts

Two-dimensional transthoracic echocardiography is the cornerstone in the evaluation and diagnosis of cardiac pathology. However, echocardiograms sometimes present cardiologists with images of false, missing, mislocated, or distorted structures that are the consequence of artifacts that arise from the interaction of ultrasound waves with tissues, the physical properties of the ultrasound beam, or the image reconstruction algorithms.[1-3] It is particularly important to recognize such artifacts and avoid misdiagnosis on the basis of their presence.[4] Furthermore, some artifacts can be avoided by altering the imaging settings or by changing the imaging position and angulation.[1,3]

This overview article summarizes the most common echocardiographic image artifacts encountered in routine clinical practice, along with physical explanation of the mechanisms, clues to a correct diagnosis, and how to avoid these artifacts and misdiagnoses.

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BASIC PRINCIPLES OF ULTRASOUND IMAGING

Echocardiography uses the physical properties of ultrasound waves to construct images of cardiac tissue and structures.[5-7] Ultrasound waves traveling through biological tissue typically obey the laws of reflection and refraction. Because different tissues have different acoustic impedances, boundaries between two tissues represent acoustic interfaces or reflectors at which one portion of the ultrasound energy is reflected back to the transducer while the remainder continues in the original direction of transmission with or without refraction (Figure 1A). At interfaces that are large relative to the ultrasound wavelength, the reflection angle relative to the interface equals the angle of incidence. The refraction angle is determined by the difference in acoustic impedance between the tissues. Unlike large reflectors, small reflectors do not generate a specular (consistent unidirectional) reflection but instead scatter ultrasound in all directions. Consequently, for small reflectors, the proportion of energy returning to the transducer is independent of the angle of incidence. Typical examples of large specular reflectors include the pericardium, endocardial and epicardial surfaces, aortic wall, and heart valves. Myocardial tissue, on the other hand, contains large numbers of small reflectors that scatter ultrasound and create the myocardium's speckled appearance.[5-7]

The echocardiographic machine maps cardiac structures on the basis of the travel time and intensity of the ultrasound waves returning to the transducer from a given direction. These ultrasound waves are generated by a piezoelectric transducer in the form of an ultrasound beam.[8] Current phased-array transducers allow electronic steering and focusing of the beam by adjusting the timing of excitation of individual piezoelectric crystals.[9] These ultrasound beams have a finite (three-dimensional) beam width that is smallest in the region of focus and diverges in the far field. In addition, not all energy produced by the elements remains focused within a central beam. Smaller amounts of the emitted energy are directed to the sides of the central beam and may form so-called side lobes (or grating lobes in the case of array transducers) of ultrasound energy that propagate off axis[8,10] (Figure 1B).

The most common image artifacts encountered in clinical practice are due to the physics of reflection and refraction or to ultrasound beam properties and equipment (Table 1). Advances in

Abbreviations

LAA = Left atrial appendage

LVOT = Left ventricular outflow tract

MR = Mitral regurgitation

transducer design (further decreasing element size and increasing the number of elements per transducer) and greater image processing power have the potential to overcome some of the issues of finite beam width and side lobes,[11] for example, by allowing parallel beam forming with massive parallel processing and/or unfocused plane wave beam forming with software synthetic focusing. Nevertheless, in current clinical practice both beam width and side lobes remain important sources of echocardiographic image artifacts, as described below.

ARTIFACTS RELATED TO WAVE REFLECTION AND/OR REFRACTION

In the interval between emitting an ultrasound beam and receiving its reflected waves, the transducer is relatively "blind" to what happens to the beam as it travels through the tissue. Certain assumptions with respect to wave propagation are made when processing the returning ultrasound waves to construct an image: (1) that ultrasound propagates in a straight line in the direction of the central beam, (2) that a given structure will reflect the beam only once, (3) that only structures located within the intended path of the beam will generate reflections back to the transducer, and (4) that the position of this structure along the scan line is proportional to the travel time of the transmitted wave. But these assumptions are not in fact always correct, and when they are not, reverberations, acoustic shadowing, mirror artifacts, and refraction artifacts may appear.

Reverberation (Figure 2, Videos 1–3; available at www.onlinejase.com)

A reflected ultrasound wave on its way back to the transducer can encounter a closer reflector in its path that reflects a portion of this returning energy back to the first reflector again. The portion of sound energy that was not interrupted by the closer reflector returns to the transducer as expected, and the first reflector's structure is mapped accurately. However, the portion of sound energy that makes a second round trip to the first reflector and back to the transducer will have had a longer travel time. Because of the assumption of wave propagation, the transducer interprets this artifactual reflected structure as being at a further distance from the transducer because of the additional ultrasound travel time and thus maps a structure below the first reflector (at a distance below first reflector equal to the distance between first and second reflectors). This process can repeat itself each time the returning signal crosses a second reflector, causing multiple reflections between the two reflectors with progressively weaker signal intensity. This appears as a characteristic "stepladder" artifact in the echocardiographic image, with successive reverberations gradually diminishing in intensity; importantly, these reverberations do not respect anatomic boundaries. In clinical practice, the second reflector is often the ultrasound transducer itself, generating an artifact at a distance twice that of the first reflector. Other examples of strong reflectors in the near field include the walls of the aorta and pulmonary arteries, calcified structures, and implanted devices. During the cardiac cycle, the motion of the artifact parallels that of the true structure but with a greater (typically double) amplitude (Videos 2 and 15; available at www.onlinejase.com). Decreasing gain and using alternative imaging planes are possible strategies for reducing, eliminating, and recognizing reverberation artifacts; the basic recognition comes from appreciating doubling of distances for single reverberations and the stepladder appearance of multiple reverberations.

Reverberations caused by two or more reflectors at very close distance from each other (mostly within the same structure; e.g., prosthetic valves, aortic plaques) typically present as a "comet tail" of diminishing reverberations below the reflectors.[12] This is a frequently observed artifact in clinical practice behind a multilayered strong reflector. Similarly, a "ring-down" artifact is a series of reverberations below "trapped" air bubbles due to excitation of the bubbles caused by the ultrasound wave; this occurs frequently in abdominal ultrasound but is rather uncommon in echocardiography.

In clinical practice, recognition of reverberation artifacts is important to avoid misdiagnosis of thrombi or mobile atrial or ventricular masses in parasternal imaging windows; reverberations from right ventricular intracardiac devices (catheters, pacemaker leads) or from a bright aortic root interface (Figure 2C, Video 2; available at www.onlinejase.com) mimic masses in the left atrium or ventricle. The parallel motion at double distance from the more proximal strong reflector is a typical clue to the presence of a reverberation artifact. In transesophageal imaging, especially when imaging the thoracic aorta or the left atrial appendage (LAA), reverberations are common causes of confusion, as described below.

Acoustic Shadowing

In contrast to reverberations presenting as a series of echoes behind a reflector, acoustic shadowing results in the absence of echoes behind a reflector. This is due to a strong reflector or refractor preventing ultrasound wave propagation beyond that reflector.[13] Color Doppler signals are shadowed as well, causing potential masking of valvular regurgitation jets behind a strong reflector that may in turn lead the reader to underestimate the severity of the regurgitation. Typical examples in clinical practice include prosthetic valves (see below) pacemaker or implantable cardioverter-defibrillator wires, and dense calcifications; of note, only the sewing rings and struts of a bioprosthetic valve cause shadows, whereas the leaflets themselves do not. Alternative imaging windows are needed to visualize the regions in the shadow of the reflectors (e.g., imaging the left atrium from the right parasternal or subcostal four-chamber window to avoid shadowing by a mitral prosthesis).

Mirror Artifact (Figure 3, Videos 4 and 5; available at www.onlinejase.com)

A mirror artifact typically appears below a strong reflective surface that acts much as a mirror does with light, producing a duplicate image behind the mirror of the real structures in front of the mirror; the mirrored images move in the opposite direction from the mirror, as do the real structures.[3,14] The reflection mechanism is similar to that of a reverberation: ultrasound waves hitting a strong reflector are reflected (angle of reflection = angle of incidence) toward objects closer to the transducer than the reflector. These intervening objects reflect the waves back to the strong reflector, which in turn sends them back to the transducer. Because of the assumption of wave propagation (that all the returning sound comes from objects in the initial direction of the sound beam), the scanner displays these objects below the strong reflector, at a distance equal to the distance between strong reflector and the true intervening objects. The most common strong (specular) reflector that causes mirror

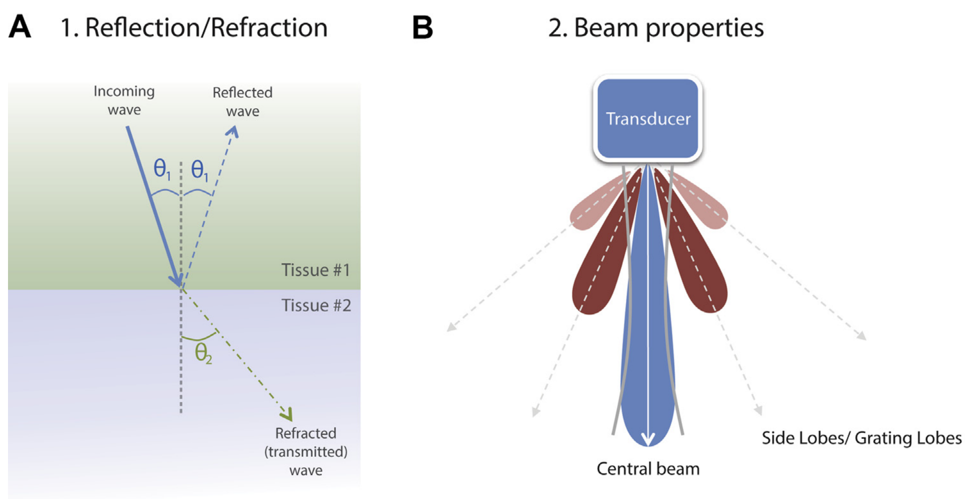

Figure 1 Basic principles of ultrasound imaging. **(A)** Ultrasound waves obey the physical laws of reflection and refraction. The boundary of two tissues with different acoustic impedance acts as a specular reflector if significantly larger than the wavelength of the ultrasound waves. A portion of ultrasound wave energy will be reflected, with a reflection angle equal to the angle of incidence. Another portion will be transmitted, with a reflection angle dependent on the magnitude of difference in acoustic impedance between both tissues. **(B)** Ultrasound beam forming is associated with small parts of ultrasound energy traveling off axis in so-called side lobes or grating lobes.

Table 1 Overview of two-dimensional echocardiographic artifacts

Artifact	Characteristic features	How to avoid
Reflection- and/or refraction-related artifacts		
Reverberation	• More distant than true object • Parallel motion • Comet tails/ring down: on straight line through center of probe	• Decrease gain • Alternative imaging planes
Acoustic shadowing	• Pie-like hypo- or anechogenic segment • Distal to strong reflector, on straight line through center of probe	• Alternative imaging planes • Increase gain/adjust time gain compensation
Mirror artifact	• More distant than true object • Opposite motion	• Decrease gain
Refraction artifact	• Double image • At same distance from probe	• Alternative imaging planes/avoid “refracting” structure • Decrease gain
Ultrasound beam property–related artifacts		
Side-lobe artifact	• Linear • Symmetric at both sides of object • At same distance from probe (“arc-like” in radial direction)	• Decrease gain • Apply color Doppler
Beam-width artifact	• At same distance from probe • Tue object/Doppler signal outside of imaging plane	• Adjust focal zone • Alternative imaging planes
Equipment-related artifacts		
Near-field clutter	• Noise (“clutter”) in near field • No relation with anatomic structures	• Apply color Doppler, reducing scale • Alternative imaging planes

artifacts is the lung, best appreciated in the parasternal long-axis view (Figure 3B) and apical four-chamber view on transthoracic echocardiography and in the midesophageal view of the descending thoracic aorta on transesophageal echocardiography. Mirror artifacts are usually easy to identify in two-dimensional images as copies of structures located above a reflective surface. However, the three-dimensional shape of a reflective surface can sometimes mirror structures that are not located in the respective scanning plane, thereby complicating correct interpretation.[15]

Mirror images commonly seen in clinical transthoracic echocardiography include “double-barreled” aortas from the suprasternal window and “double-barreled” inferior venae cava from the subcostal window.[16] Spectral and color Doppler flow is mirrored as well because of the mirroring mechanism, further enhancing confusion of two adjacent vessels instead of one. A special case of Doppler flow mirroring is so-called pseudo–mitral regurgitation (MR) in mechanical mitral valve prostheses due to mirroring of left ventricular outflow tract (LVOT) flow, as discussed later.[17-19]

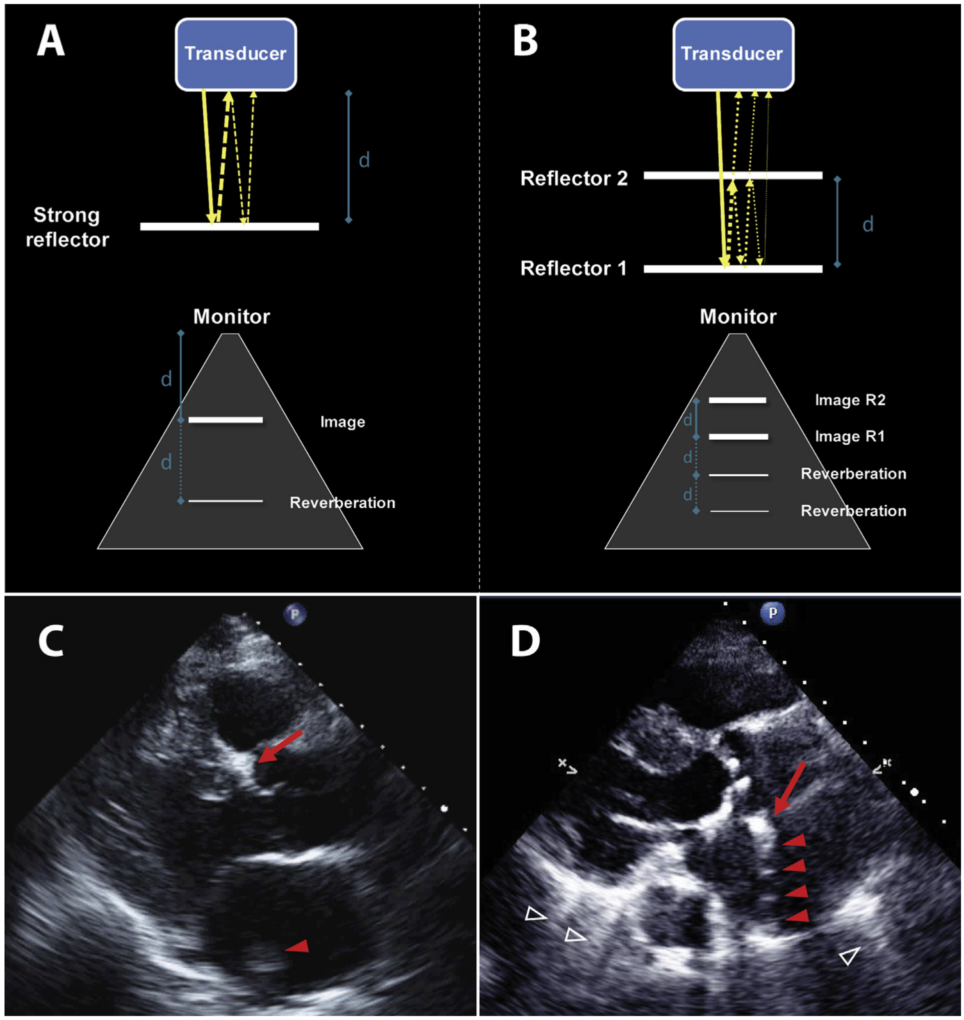

Figure 2 Reverberation artifact. **(A,B)** The theoretical genesis of a reverberation artifact (animation in Video 1; available at www.onlinejase.com). The second reflector can either be the transducer itself **(A)**, leading to a reverberation at twice the distance to the probe, or another strong reflector **(B)** located above the first reflector. **(C)** Reverberation artifact in the parasternal long-axis view mimicking a mass in the left atrium *(arrowhead)*. Detailed analysis of the mass shows that it is a reverberation of the calcified aortic annulus *(arrow)*, with the mass presenting at exactly twice the distance from the transducer (Video 2; available at www.onlinejase.com). **(D)** Typical "stepladder" of reverberations *(full arrowheads)* below a "multilayered" aortic calcification *(arrow)* acting as the first and second reflectors (Video 3; available at www.onlinejase.com). Comet-tail reverberations below a strongly reflecting pericardium can be observed as well *(empty arrowheads)*.

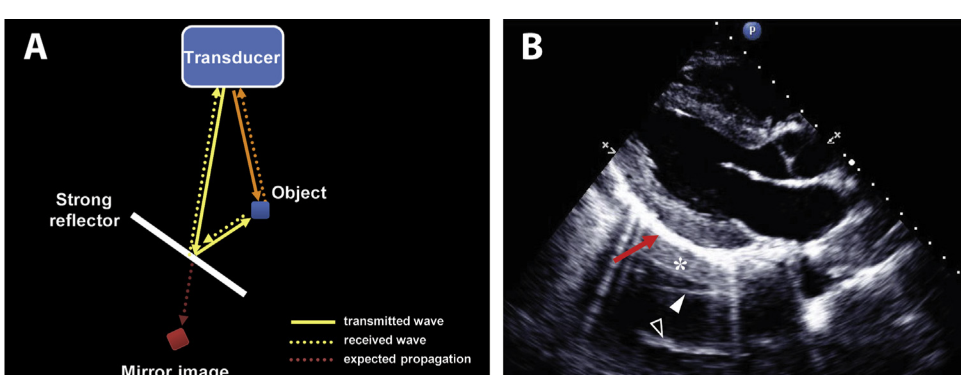

Figure 3 Mirror artifact. **(A)** The theoretical genesis of a mirror artifact (animation in Video 4; available at www.onlinejase.com). **(B)** Parasternal long-axis image showing a mirror artefact below the pericardium-lung interface *(red arrow)* (moving images in Video 5; available at www.onlinejase.com). Notice the mirror image of the posterior myocardial tissue *(asterisk)*, the posterior mitral leaflet *(full arrowhead)*, and the anterior mitral leaflet *(empty arrowhead)*. Comet-tail reverberations below the pericardium due to the strongly reflecting lung interface can be observed as well.

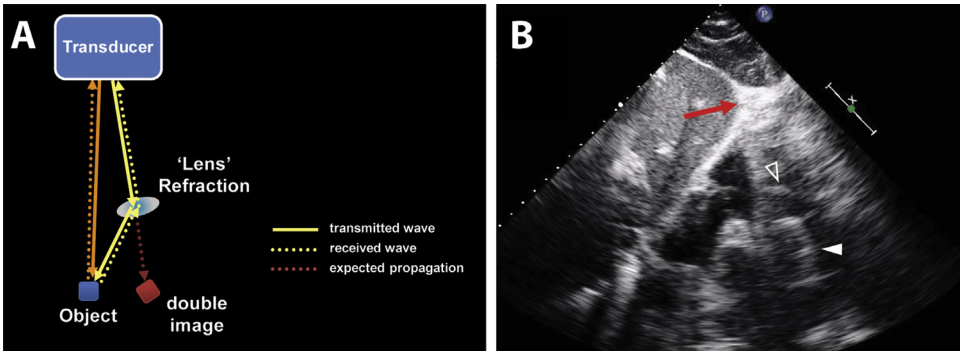

Figure 4 Refraction artifact. **(A)** The theoretical genesis of a refraction artifact. Ultrasound waves directed through a "lens" are refracted toward the respective cardiac object and back, resulting in a duplicate of this object in the initial beam direction (animation in Video 6; available at www.onlinejase.com). **(B)** Double image of the aorta *(full arrowhead)* in a subcostal short-axis image of the heart, due to refraction of the ultrasound beam at perihepatic fatty tissue *(arrow)*. A Swan-Ganz catheter in the right ventricular outflow tract is doubled as well *(empty arrowhead)*. Moving images in Video 7 (available at www.onlinejase.com).

Refraction Artifact or Double Image (Figure 4, Videos 6 and 7; available at www.onlinejase.com)

A refraction artifact, also called a "lens artifact," is the false duplication of an object behind a structure that acts as a wave refractor and thus behaves as a lens.[20] Ultrasound waves directed through the "lens" are refracted toward the respective cardiac object and then re-refracted back to the original direction of transmission on the return acoustic path, resulting in a duplicate image of this object but in the original direction of the beam. These artifacts occur mostly in subcostal and parasternal imaging planes, with costal cartilage, fascial structures and fat, and pleural and pericardial surfaces acting as the medium inducing refraction of the ultrasound beam.[21,22] Structures behind an ultrasound lens may not be visible in that plane, because the sound beam never reaches them, and instead they are overwritten by the duplicate image of a nearby structure. Adjusting the probe to avoid the lens and using alternative imaging windows are strategies to avoid the double image and assess the structures that were shadowed.

In routine clinical practice, refraction artifacts are typically recognizable because they create impossible anatomic relations, such as intersecting duplicated images of the mitral valve in long-axis imaging[22] or the aortic root and left ventricle in short-axis imaging (Figure 4).[21] However in apical long-axis images, more subtle doubling of the ventricular wall can occur because of refraction at the apex (pericardium, fat), complicating the assessment of left ventricular dimensions and ejection fraction. Adjusting the image settings and changing the probe angulation are possible strategies to avoid refraction in such cases.[7]

ARTIFACTS RELATED TO ULTRASOUND BEAM PROPERTIES AND EQUIPMENT

Side-Lobe Artifact (Figure 5, Videos 8 and 9; available at www.onlinejase.com)

The small portions of ultrasound energy emitted in "side lobes" are mostly dissipated in the tissue, without relevant reflections. However, when this side-lobe energy is reflected by a strong reflector (wires, calcifications, pericardium) in its path, these reflections are interpreted by the scanner as originating from the central beam.[10] As the transducer scans the imaging window by sweeping in a radial direction, numerous side-lobe artifacts can be generated on both sides of the true reflector. When the true reflector is bright and wide, these multiple side-lobe images can overlap and visually merge, producing a linear arc-like artifact at a radial distance of the transducer.[2,23]

Clinical recognition is important to avoid misdiagnosis of thrombi or vegetations generated by side-lobe artifacts from highly reflective annular or prosthetic interfaces. In addition, side-lobe artifacts from highly reflective aortic sinotubular junctions could be mistaken for aortic dissection flaps (Figure 5B).

Beam-Width Artifact (Figure 6)

In most current machines and transducers, the ultrasound beam is able to focus only over a limited distance and increasingly diverges beyond from the focal zone.[8] Within the imaging plane, the wider the beam is, the poorer the lateral resolution (i.e., the minimal lateral distance needed between two objects to be identified as two separate objects by the transducer). However, the finite beam width is even more problematic in the perpendicular direction ("elevation width") out of the scanning plane, because it is less evident to the interpreter. Objects or blood flow out of the imaging plane but within the elevation width of the beam are interpreted as if located in the imaging plane, sometimes leading to diagnostic dilemmas and enigmas.[24-26]

In clinical practice, beam-width artifacts from highly reflective annular or prosthetic interfaces could be confused for thrombi or vegetations (similar to side-lobe artifacts). Furthermore, it is important to recognize out-of-plane artifacts displaying strong Doppler signals in adjacent structures, for example, disturbed LVOT flow in patients with aortic stenosis, producing apparent tricuspid regurgitation (without typical direction or vena contracta) or prominent MR eccentrically directed toward the LAA, producing apparently disturbed systolic flow in the pulmonary artery (Figures 6B and 6C).

Near-Field Clutter

Structures in the near field are sometimes obscured because of the high amplitude of oscillations by the transducer itself, causing so-called near-field clutter.[7] This is especially relevant in case an apical ventricular thrombus is suspected (Figure 7, Video 10; available at www.onlinejase.com). The introduction of harmonic imaging and the technologic advances in transducer design have already reduced the occurrence of this type of artifact. In contrast to a thrombus, clutter is unaffected by ventricular wall motion and appears to pass

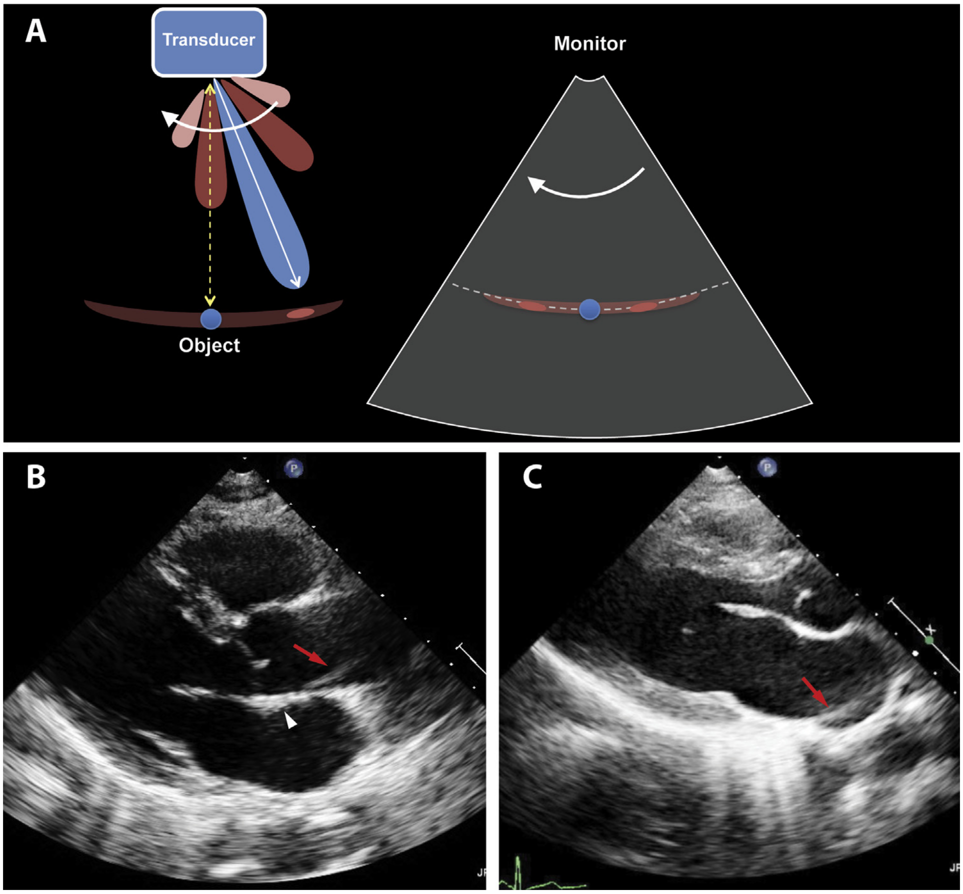

Figure 5 Side-lobe artifact. **(A)** The genesis of a side-lobe artifact. While "interrogating" the imaging plane in a radial direction, side-lobe energy can encounter a strong reflector. Reflections of side-lobe energy are interpreted as if originating from the direction in which the transducer is "looking." Ultimately, this leads to a linear "arc-like" artifact at both sides of the strong reflector (short animation in Video 8; available at www.onlinejase.com). **(B)** Parasternal long-axis view with linear side-lobe artifact *(arrow)* in the aorta ascendens due to a calcified sinotubular junction *(arrowhead)*. This artifact can sometime be misinterpreted as a dissection flap. **(C)** Parasternal long-axis view of a healthy patient with strongly reflecting pericardium, causing a side-lobe artifact in the left atrium *(arrow)*. In moving images (Video 9; available at www.onlinejase.com), comet-tail reverberations, acoustic shadowing, near-field clutter, and a mirror image of the mitral valve leaflets can be observed as well.

through the wall. When uncertain, one can apply color Doppler and reduce the scale in order to demonstrate blood flow through the apex, thus refuting the possible thrombus; alternatively, one can switch to other (parasternal or subcostal) imaging planes or use contrast echocardiography to confirm or refute the presence of an apical thrombus.

CARDIAC DEVICES

Implantable cardiac devices, such as pacemaker and implantable cardioverter-defibrillator leads, catheters, mechanical circulatory support devices, and valve prostheses, typically represent strong reflectors that are prone to the aforementioned reflection-related artifacts (reverberations or comet tails, shadowing, and mirroring) as well as side-lobe and beam-width artifacts.[27,28] Cardiac devices therefore complicate the interpretation of echocardiographic images (Figure 8) and demand careful examination of the devices and surrounding structures from different imaging views.

In addition, devices with specific geometric designs can sometimes generate uncommon artifacts because of the interaction between ultrasound waves and the device geometry, bearing in mind the physical principle that for a specular reflector, the angle of reflection equals the angle of incidence. The figure-of-eight artifact (Figure 9) obtained when imaging a percutaneous disk occluder is a typical example of such a device-specific artifact based on the physics of ultrasound reflection. This artifact occurs in disk occluders (e.g., patent foramen ovale occluders, atrial septum defect occluders, the Amplatzer Cardiac Plug LAA occluder, and similar devices) with a specific epitrochoidal mesh configuration, when imaged from an imaging plane that is coronal relative to the device.[29] Because of the characteristic direction of the nitinol mesh fibers that act as strong specular reflectors, ultrasound waves are mostly reflected or deflected away from the transducer, except where the mesh fibers lie orthogonal to the beam direction. Our mathematical analysis previously demonstrated that those locations constitute a figure of eight, explaining the artifact that is frequently seen in apical five-chamber view after LAA closure using the Amplatzer Cardiac Plug,[29,30] but also in off-axis parasternal long-axis views following atrial septal defect or patent foramen ovale closure procedures.[31] In contrast, three-dimensional echocardiographic imaging with the beam propagating perpendicular to the plane of the device (frontal probe position) will correctly display the rounded extent of the occluder.[29]

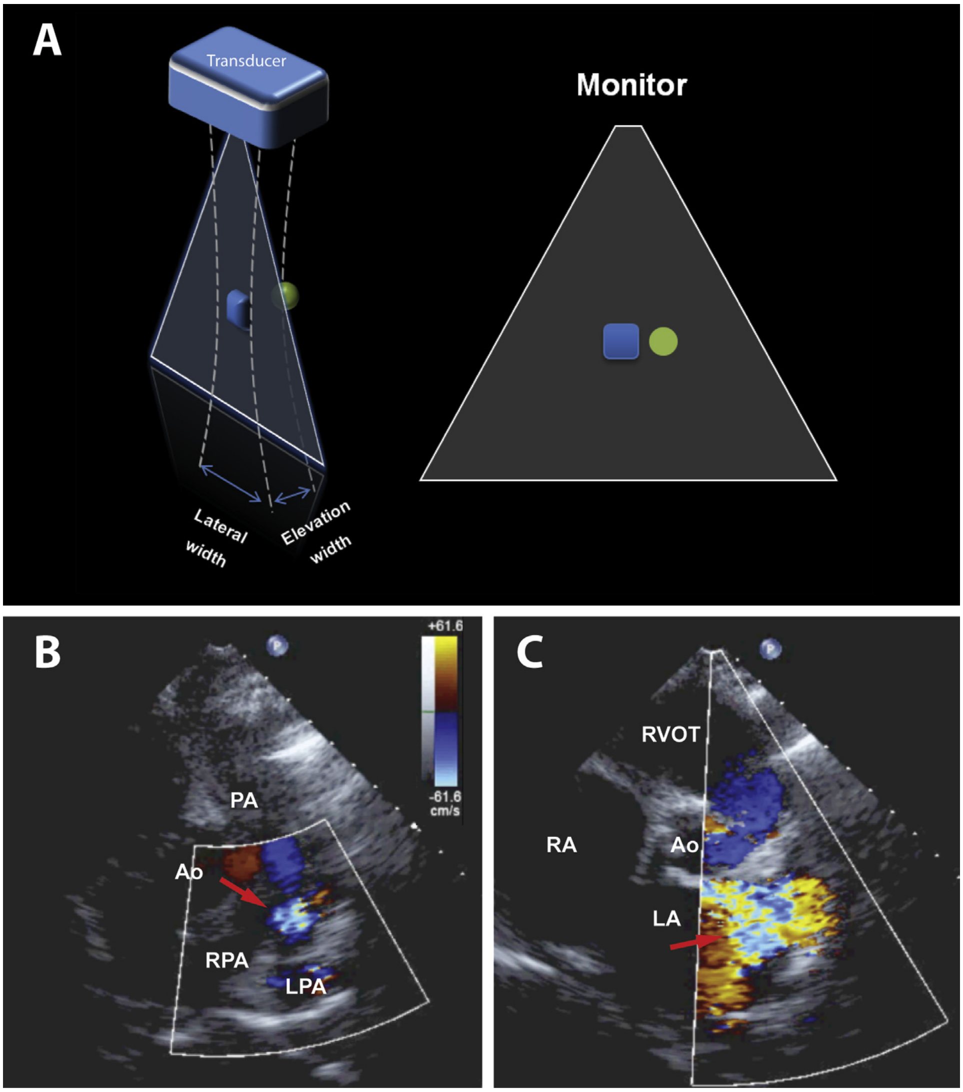

Figure 6 Beam-width artifact. **(A)** The lateral width and elevation width of the ultrasound beam, respectively, cause a decrease in lateral resolution and the occurrence of beam-width artifacts. The blue square object within the scanning plane is correctly identified in the center of the beam. However, because of the elevation width of the beam, the green circular object outside of the imaging plane is incorrectly positioned within the scanning plane. **(B)** Parasternal short-axis image of pulmonary arteries showing unexplained turbulent flow into the left pulmonary artery (LPA; *arrow*), without evidence of shunting or stenosis. **(C)** Tilting of the probe out of the scanning plane reveals massive MR into the left atrium (LA) picked up by the beam as if occurring in the pulmonary artery (PA). *Ao*, Aorta; *RA*, right atrium; *RPA*, right pulmonary artery; *RVOT*, right ventricular outflow tract.

DOPPLER ARTIFACTS

In spectral and color Doppler imaging, similar physical principles and limitations apply to the incident and scattered Doppler-shifted sound waves, and thus similar imaging artifacts can be observed in Doppler imaging.[32-36] Mirror artifacts and beam-width artifacts are the most relevant Doppler artifacts. In mirror artifacts, the velocity signal above the reflector is mirrored as well and interpreted by the transducer as originating from below the reflector because of the assumption of wave propagation (Figure 4).[37] Therefore, both color and spectral Doppler signals remain detectable in the mirror image (Figure 10D). Importantly, in patients with mechanical mitral valve prostheses, mirroring of LVOT flow can occur, mimicking MR below the prosthesis (also known as “pseudo-MR”).[17-19] Misdiagnosis of severe prosthetic MR has important consequences, as Faletra *et al.*[38] showed no abnormality in 3.4% (seven patients) of a total of 208 prosthetic valve reoperations. Clues to pseudo-MR include its pulsed Doppler velocity profile, which is that of LVOT flow; the absence of a left ventricular proximal flow convergence region; and an empty distance between the prosthesis and the artifactual flow equal to the distance between the mirroring prosthesis and the LVOT on the other side of the “mirror.” Beam width–like Doppler artifacts (as described earlier and depicted in Figures 6B and 6C) extend to spectral Doppler signals as well. A spuriously elevated tricuspid regurgitation jet velocity in a patient with medially directed MR (wrongfully included in the continuous-wave beam interrogating the tricuspid regurgitation jet) leads to an incorrect diagnosis of pulmonary hypertension and potentially results in MR surgery for the mistaken pulmonary hypertension indication.

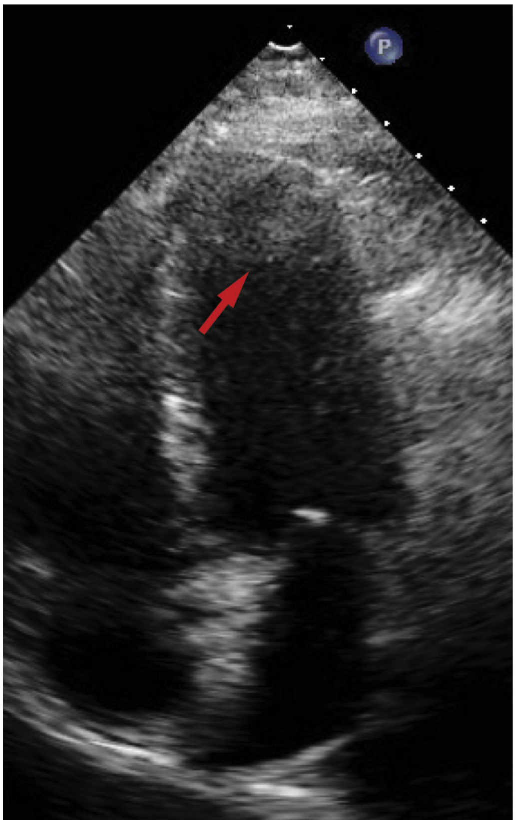

Figure 7 Near-field clutter *(arrow)* in apical four-chamber view, mimicking apical thrombus. Moving images (Video 10; available at www.onlinejase.com) show normal apical myocardial kinetics and no relationship between clutter and myocardial motion.

On the other hand, Doppler color flow imaging can be a powerful tool to help distinguish artifacts, for example, an apparent mass in the LAA that is otherwise filled with flow of a normal and undisturbed velocity. In apical hypertrophic cardiomyopathy, a paucity of intramyocardial specular reflectors can produce the spurious impression of an apical aneurysm (to be distinguished from the occasional true small outpouching of the obstructed apical blood pool), an artifactual dropout that can be remedied by color Doppler (showing a narrow apical flow stream) or left ventricular echocardiographic contrast opacification. It is important to note that artifacts generated by structural reverberations and mirror images will not accelerate or disturb surrounding flows in any way; however, flow may not necessarily be displayed in the same pixels as a structural artifact, because the scanner must select structural versus flow signals for display on the basis of its tissue priority algorithm and the strength of the respective signals.

TRANSESOPHAGEAL ECHOCARDIOGRAPHY

Although this overview article is focused mainly on routine transthoracic echocardiography, the aforementioned artifacts are frequently encountered in transesophageal echocardiography as well.[4,23,39-41] Figure 10 displays a selection of common artifacts in transesophageal echocardiography. The most relevant clinical situations in this respect are (1) excluding thrombus in the LAA (Figures 10E and 10F) and (2) excluding aortic dissection[42] (Figures 10G and 10H). Reverberations, mirror artifacts, and side-lobe artifacts in particular play an important role in these settings because of the often linear aspect of the artifact, resembling a dissection flap in the ascending or descending aorta,[43-47] or mimicking a thrombus in the LAA.[48,49] Historically, lack of recognition of artifacts in transesophageal echocardiography for aortic dissection created the impression that echocardiography lacked specificity for the diagnosis relative to other modalities such as magnetic resonance imaging,[50] a misimpression that can be eliminated by understanding the nature of artifacts. Furthermore, in the early years of transesophageal imaging, occasional patients were being operated on because of artifacts now largely eliminated by our understanding. Even so, to date patients are still receiving anticoagulation rather than undergoing immediate cardioversion for atrial fibrillation because of image artifacts. This again shows the importance of understanding the physics of ultrasound reflection, refraction, and beam formation, a practical consequence of that knowledge.

FACT OR ARTIFACT?

Table 2 summarizes some typical features of true structures versus artifacts, which can aid in the investigation of uncommon echocardiographic findings and offer clues toward a correct interpretation in both transthoracic and transesophageal imaging. One central principle to recall for all forms of artifact is that true structures cannot pass through cardiac or vascular walls and are typically well defined (even thrombi, with their mildly fluctuant borders), unlike the sometimes nebulous borders of artifacts. Furthermore, true structures are seen in multiple imaging views, whereas artifacts typically cannot be reproduced from alternative probe positions (e.g., a reverberation artifact mimicking a thrombus in the left atrium in parasternal imaging windows cannot be reproduced in apical imaging windows). In addition, unlike true anatomic structures, artifacts will not accelerate or disturb surrounding color Doppler flow in any way. In case an artifact is suspected, a logical physical explanation for its presence in that location should be explored on the basis of the principles described here. Careful examination from multiple imaging views, with optimized imaging settings and with the application of color Doppler flow, is mandatory in cases of doubt.

In addition to artifacts, it is important to recognize causes of apparently abnormal myocardial motion such as pseudodyskinesis, in which external compression of the left ventricular diaphragmatic surface causes characteristic diastolic flattening, while the normal systolic contraction causes outward epicardial motion, similar to paradoxical septal motion when the interventricular septum is flattened in right ventricular volume overload.[51]

CONCLUSIONS

Image artifacts in clinical echocardiography are related to the physics of reflection and refraction (reverberation, acoustic shadowing, mirror artifact, refraction artifact) or to ultrasound beam properties and equipment (side-lobe artifact, beam-width artifact, near-field clutter). It is particularly important to recognize such artifacts and avoid misdiagnoses on the basis of their presence, keeping in mind the need to avoid the production of artifacts or confirm their artifactual nature by altering imaging settings and by changing imaging position and angulation, an important part of the sonographer's art. A physical explanation of artifact mechanisms and a recognition of the most

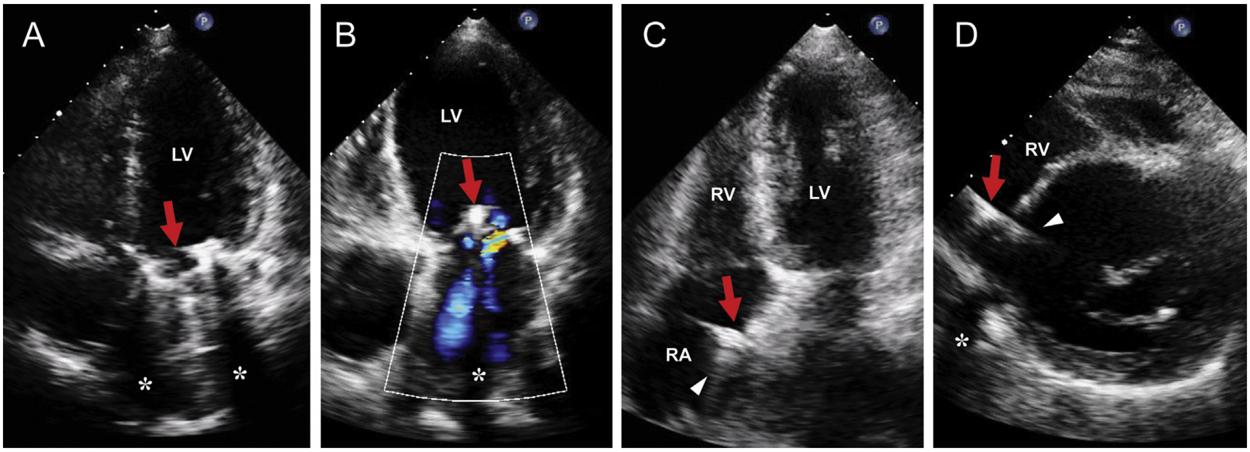

Figure 8 Cardiac devices as sources of image artifacts. **(A)** Mechanical mitral valve prosthesis causing multiple reverberations and comet tails below the prosthesis *(arrow)* as well as two acoustic shadowing regions below the prosthesis frame *(asterisk)* (Video 11; available at www.onlinejase.com). **(B)** Acoustic shadowing *(asterisk)* distal from an implanted MitraClip device *(arrow)*. Notice the shadowing of the color flow signal as well, potentially leading to underestimation of residual MR after clip placement. **(C)** Pacemaker wire in the right atrium (RA) *(arrow)* with linear comet-tail reverberation *(arrowhead)* below the wire and side-lobe artifact extending in the radial direction. **(D)** Defibrillator wire in the right ventricle (RV) *(arrow)* with linear arc-like side-lobe artifact crossing the anatomic borders (interventricular septum). This should not be misinterpreted as a dislocated (perforated) wire into the left ventricular cavity (Video 12; available at www.onlinejase.com). *LV*, Left ventricle.

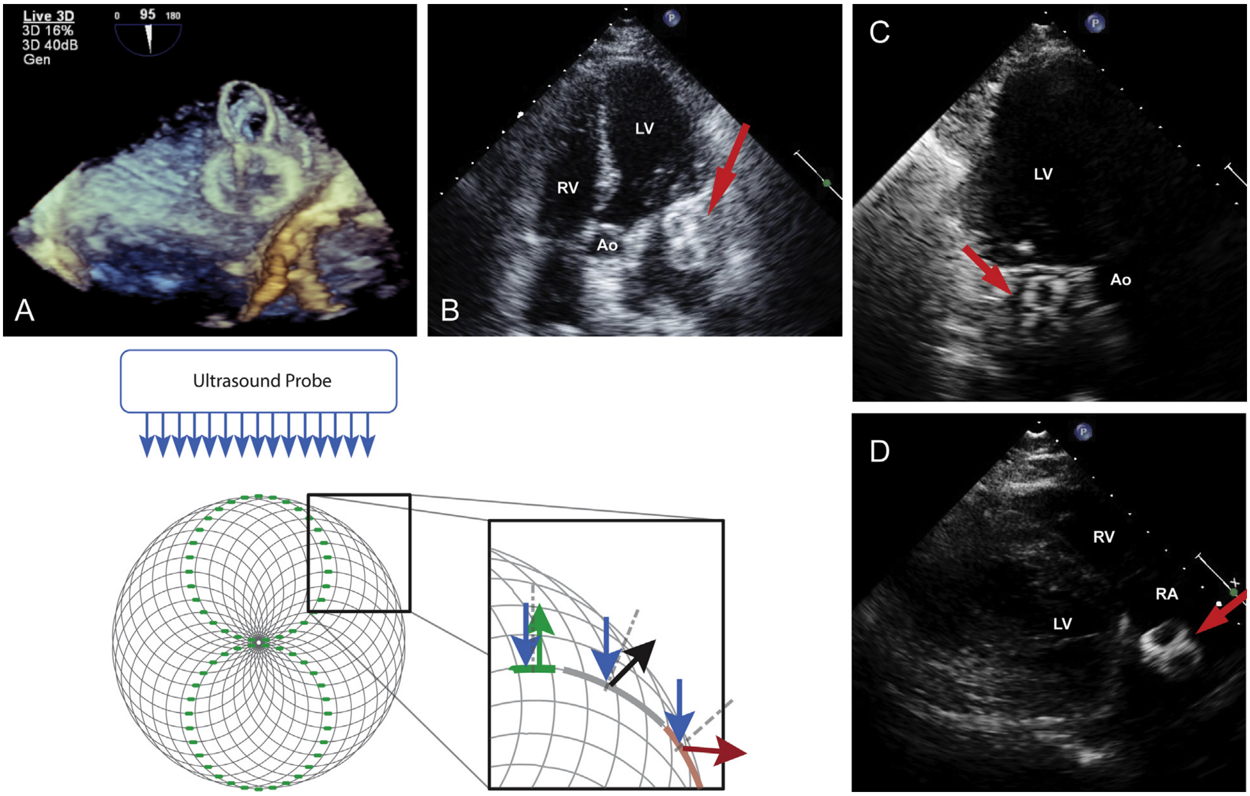

Figure 9 Figure-of-eight artifact in the echocardiographic assessment of disk occluders. **(A)** Three-dimensional echocardiography of an Amplatzer Cardiac Plug after successful implantation in LAA. **(B)** Apical five-chamber view in the same patient, with an Amplatzer Cardiac Plug in the correct position presenting as a figure-of-eight (Video 13; available at www.onlinejase.com). **(C)** Apical three-chamber view (slightly off axis) in a patient following LAA occlusion. **(D)** A patent foramen ovale (PFO) occluder device in a parasternal off-axis image of the interatrial septum in a patient a few years after PFO occlusion (Video 14; available at www.onlinejase.com). Central image: because of the epitrochoidal mesh geometry of the disk occluders, sound is reflected back to the probe only by the small segments of mesh with fibers orthogonal to the beam direction. These align in a figure of eight (as shown by the green lines on the figure). Adapted from Bertrand *et al*.[29] with permission. *Ao*, Aorta; *LV*, left ventricle; *RA*, right atrium; *RV*, right ventricle.

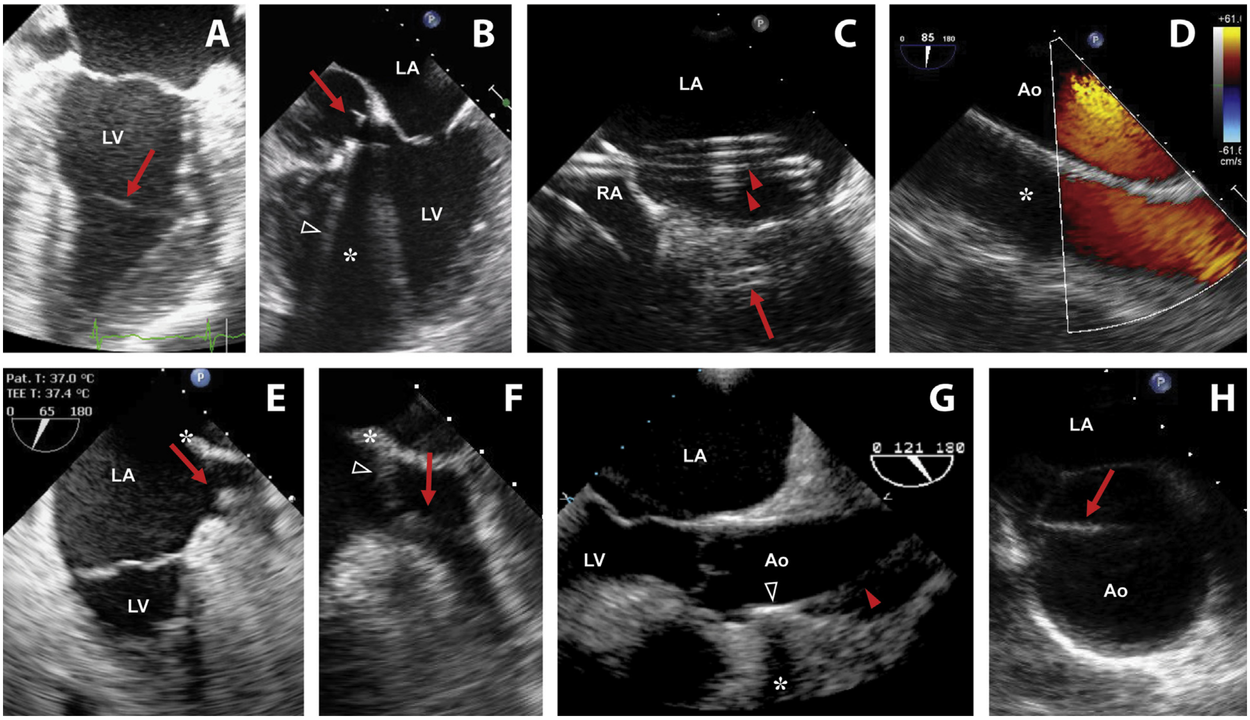

Figure 10 Transesophageal image artifacts. **(A)** Reverberation artifact of mitral valve leaflet at exactly twice the distance from the probe, presenting as a wire in the left ventricular cavity (Video 15; available at www.onlinejase.com). **(B)** Mechanical aortic valve casting an acoustic shadow over the majority of the right ventricle (RV) *(asterisk)* and a reverberation (comet tail) to the side *(arrowhead)* (Video 16; available at www.onlinejase.com). **(C)** Transseptal guiding catheter during pulmonary vein isolation procedure presenting with a series of closely spaced reverberations *(arrowheads)* due to reflections at the upper and lower side of the *(hollow)* catheter and one reverberation at twice the distance to the probe due to reflection at the transducer itself. **(D)** Mirror artifact *(asterisk)* of the ascending aorta (Ao) mimicking two parallel aortas. Notice the mirroring of the color flow in the mirror image as well, the mechanism being similar (i.e., the assumption of wave propagation) (Video 17; available at www.onlinejase.com). **(E)** Reverberation artifact in the LAA mimicking thrombus. Detailed analysis from multiple angles **(F)** and applying color flow imaging in the respective region confirms the presence of a reverberation from the warfarin ridge *(asterisk)* rather than true thrombus (Videos 18–20; available at www.onlinejase.com). **(G)** Side-lobe artifact *(arrow)* from a calcified sinotubular junction *(arrowhead)* extending in the ascending aorta (Video 21; available at www.onlinejase.com) should not be misinterpreted as a dissection flap. **(H)** Similarly, a reverberation in the ascending aorta might be misinterpreted as being a dissection flap. *LA*, Left atrium; *LV*, left ventricle; *RA*, right atrium.

Table 2 Clues to the correct interpretation of common echocardiographic artifacts

	Favors real structure	Favors artifact
Morphology	• Distinct edges (unless thrombus)	• Linear • Lacks well-demarcated borders
Motion	• Independent motion	• Identical to other real structure (parallel or mirror) • Appears to pass through other solid structures
Attachments	• Attached to other structures	• No clear attachments
Reproducibility	• Consistently seen in multiple views	• May not be reproduced in other imaging views
Color Doppler flow	• Affected by real structure	• Not affected by artifact
Others	• Logical anatomic relationships	• Logical physical explanation for its presence in that specific location

common image artifacts encountered in routine clinical practice is important, for it will provide clues to correct diagnosis and approaches to avoid the production of artifacts.

SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.echo.2016.01.009.

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