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;■:■-■.)

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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.

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 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

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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.

Abbreviations

LAA = Left atrial appendage

LVOT = Left ventricular outflow tract

MR = Mitral regurgitation

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)

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). 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) 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)

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 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