B-mode ultrasound artifacts

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Learning objectives

The purpose is to describe, illustrate and explain the physics beyond the more common artifacts in B-mode, how to interpret them or the way to avoid them, improving image quality.

Background

Image artifacts are common in ultrasonography, some are useful, but the majority isn't. Some artifacts can be avoided by a proper technique but others are generated by the physical limitations of the modality.

US artifacts arise secondary to errors of the beam characteristics, attenuation errors, the presence of multiple echo paths, or velocity errors (Fig. 1 on page).

The beam width, side lobe, posterior acoustic shadowing, posterior acoustic enhancement/increased through transmission, reverberation, ring-down, mirror image, speed displacement, and refraction are B-mode artifacts encountered routinely in clinical practice. These artifacts will be described as well as their physics explanation, diagnostic importance and the scanning technique that can be applied to avoid them.

US image processing assumes that:		**US artifacts are secondary to errors of:**
1. The detected echoes are originated from the main ultrasound beam	**However, in clinical sonography, these assumptions usually are not maintained.**	**Beam characteristics**
2. The energy in an ultrasound field is uniformly attenuated		**Attenuation**
3. An echo returns to the transducer after a single reflection		**Multiple echo paths**
4. The depth of an object is directly related to the amount of time for an ultrasound pulse to return to the transducer		
5. The speed of US propagation is constant in human tissue		**Velocity**
6. The sound beam and its echo travel in a straight path		

Fig. 1: US processor's assumptions that are not maintained during clinical sonography, resulting in errors and consequent artifacts.

Findings and procedure details

Some artifacts may cause structures that are present anatomically to be missing from the US image or, on the contrary, simulate a structure that is not real. At the same time, some structures that are present may be incorrect in size, location, or brightness.

ARTIFACTS ASSOCIATED WITH BEAM CHARACTERISTICS

US image processing assumes that the detected echoes are originated from the main ultrasound beam. The ultrasound beam is composed by a main ultrasound beam (that narrows as it approaches the focal zone an then widens again distal to the focal zone), and additional off-axis low-energy beams (side lobes and grating lobes) (Fig. 2 on page 31).

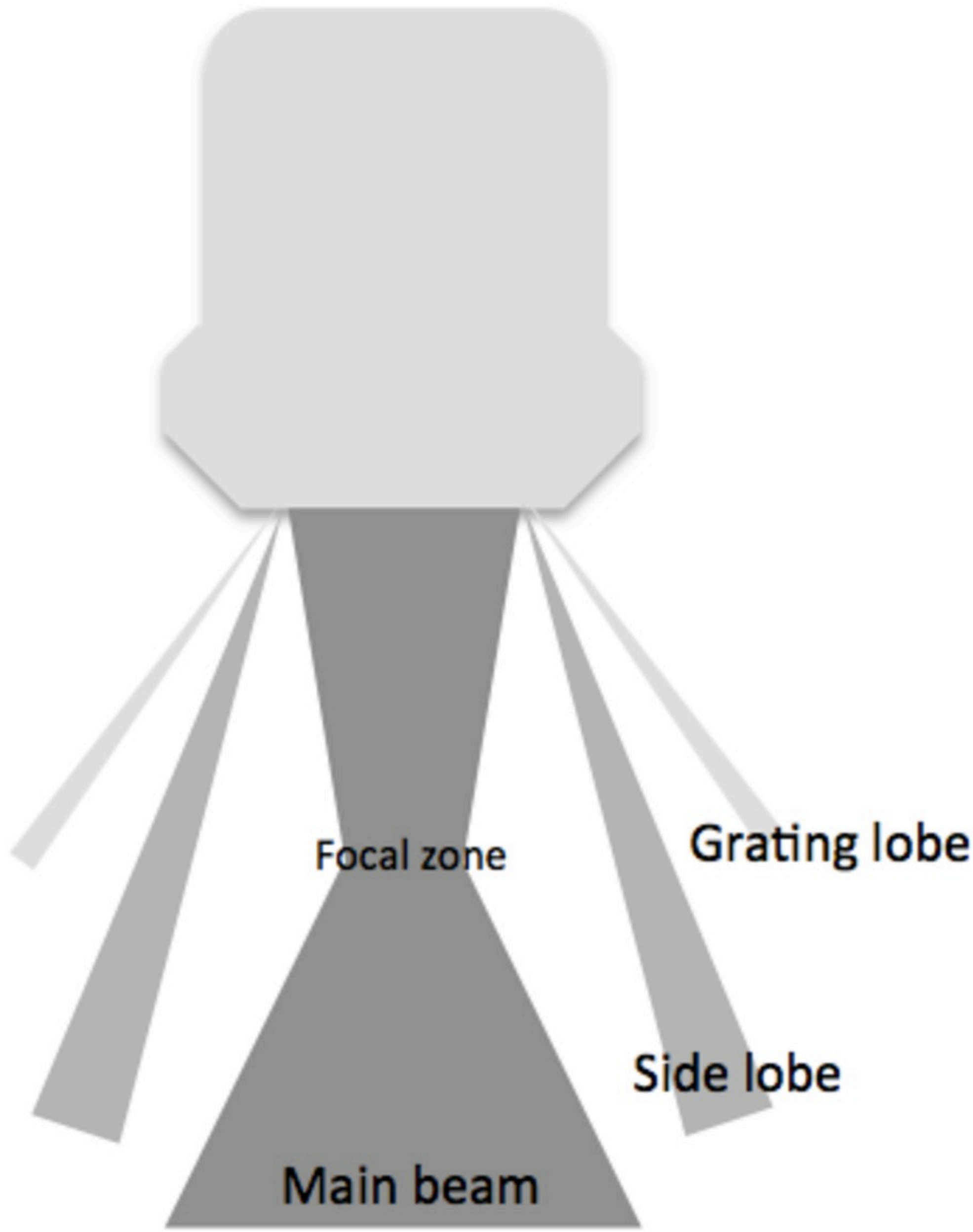

Fig. 2: Diagram of the ultrasound beam. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009
References: Radiology, Centro Hospitalar e Universitário de Coimbra, Centro Hospitalar e Universitário de Coimbra - Porto/PT

A structure that is strongly reflective located outside of the main ultrasound beam may generate echoes that are detected by the transducer and may be interpreted as being originated from within the main beam.

This artifacts are more likely to be recognized when the misplaced echoes overlap an anechoic structure, usualy the gallbladder, the bladder or a cyst.

Beam width artifact

As referred, the main ultrasound beam exits the transducer at approximately the same width as the transducer, narrows as it approaches the focal zone and than diverges (Fig. 2 on page 31). A highly reflective object located within the widened beam beyond the margin of the transducer may generate detectable echoes that may be assumed by the ultrasound display as being originated from within the narrow zone (Fig. 3 on page 32a).

This artifact must be ruled out when a structure that should be anechoic contains peripheral echoes (Fig. 4 on page 23).

Image quality may be improved by adjusting the focal zone to the level of interest and by placing the transducer at the center of the object of interest (Fig. 3 on page 32b).

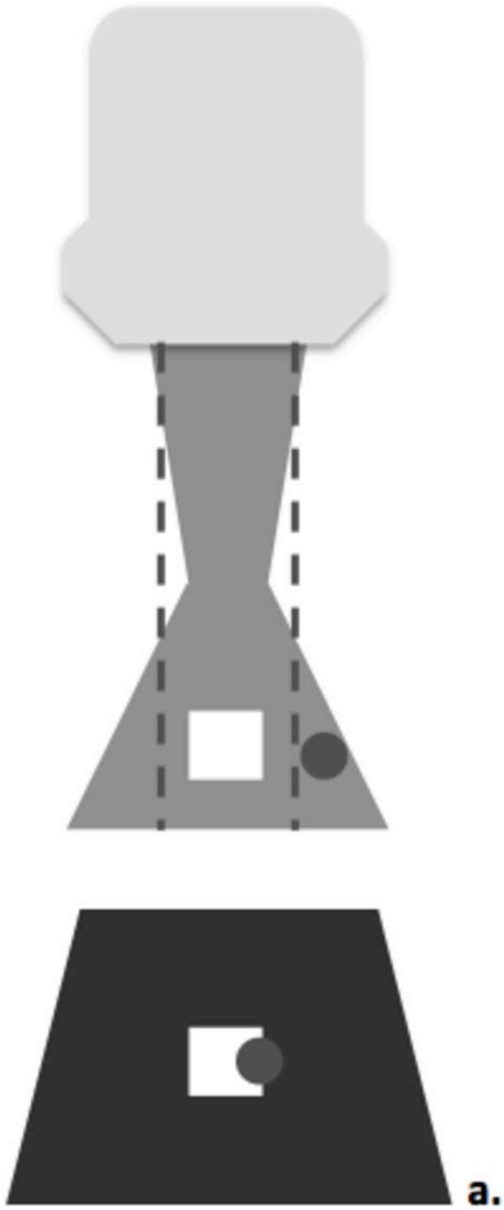

Fig. 3: Diagram of the beam width artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009
References: Radiology, Centro Hospitalar e Universitário de Coimbra, Centro Hospitalar e Universitário de Coimbra - Porto/PT

Side lobe artifact

As illustrated on the Fig. 2 on page 31 , side lobes are off-axis low-energy beams that project radially from the main beam axis. Side lobe energy is generated from the radial expansion of piezoelectric crystals and is more prominent in high frequency linear transducers.

A strong reflective structure that is present in the path of these side lobe beams may create echoes detectable by the transducer. These echoes will be displayed as being originated from within the main beam and may appear duplicated (Fig. 5 on page 33).

This phenomenon is most likely to be recognized as multiple echoes within an expected anechoic structure (Fig. 6 on page 23). Adjusting the focal zone to the level of interest and by placing the transducer at the center of the object of interest will improve image quality, as with beam width artifact.

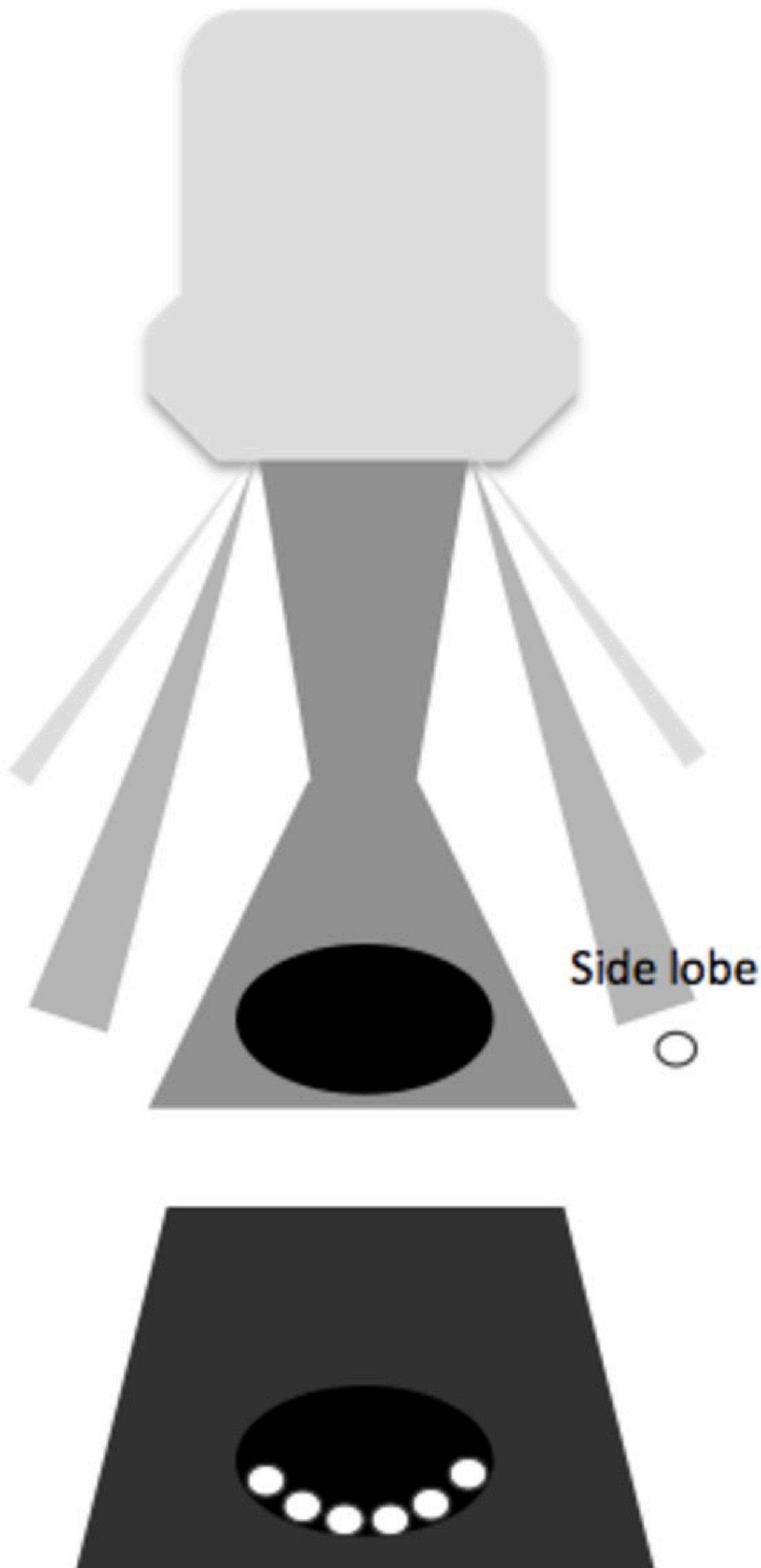
Side lobe

Fig. 5: Diagram of the side lobe artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009
References: Radiology, Centro Hospitalar e Universitário de Coimbra, Centro Hospitalar e Universitário de Coimbra - Porto/PT

ARTIFACTS ASSOCIATED WITH ATTENUATION ERRORS

The energy of an ultrasound beam becomes attenuated as it travels through the tissues, decreasing due to absorption and dissipation. Therefore, an echo that travels a greater distance will be more attenuated than an echo of similar energy that travels a shorter path.

US image processing assumes that the energy in an ultrasound field is uniformly attenuated. However, the loss of ultrasound intensity per distance (attenuation coefficient) differs from one medium to another.

Ultrasound processing does automatic compensatory amplification of echoes that return later. They are more amplified than those that return earlier, to uniform the US image. There's also a user-adjustable form of compensation.

Shadowing

When the US beam encounters a strongly attenuating structure, the amplitude of the beam distal to this structure is diminished and the echoes returning from structures beyond the highly reflective structure will be strongly diminished (Fig. 7 on page 35).

At imaging, this phenomenon is recognized as a dark ("shadow") deep to a highly attenuating structure (Fig. 8 on page 24).

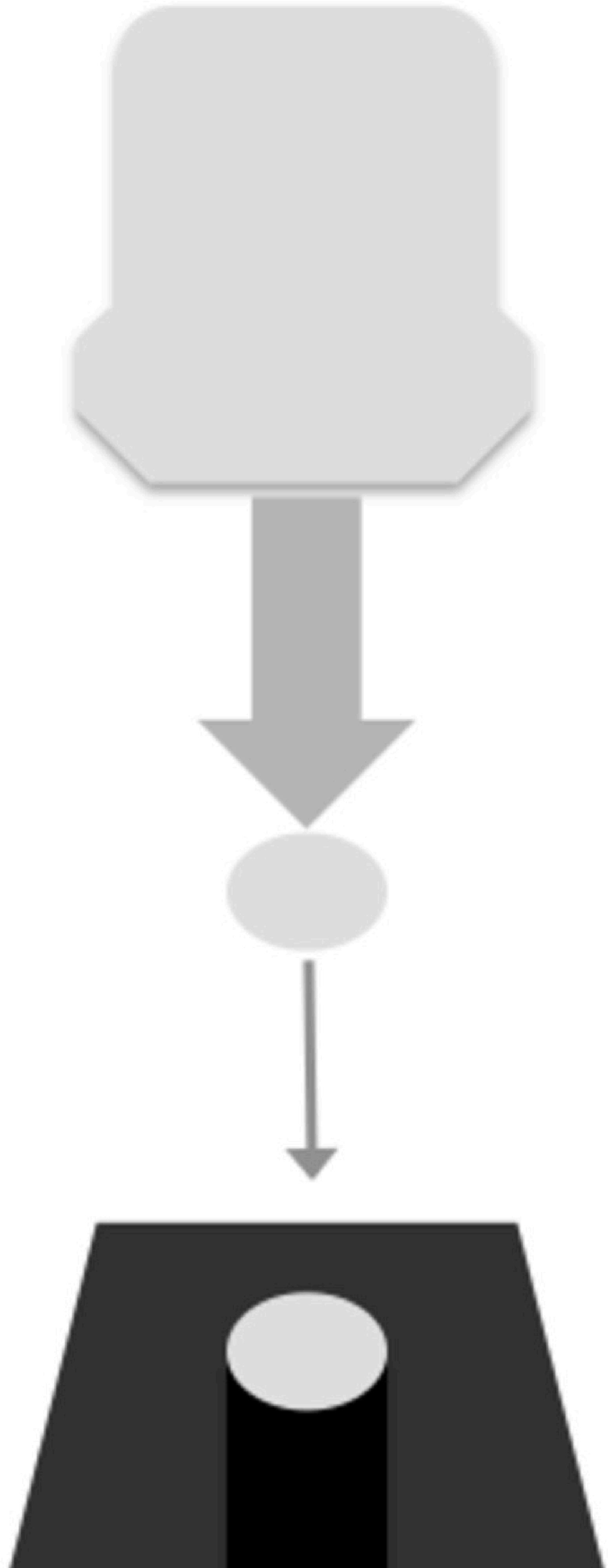

Fig. 7: Diagram of the shadowing artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009
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Increased through transmission

On the contrary, as the ultrasound beam encounters a weakly attenuating structure, the amplitude of the beam beyond this structure becomes greater (Fig. 9 on page 37).

The echoes returning from structures deep to the weak attenuating structure become of higher amplitude and are displayed as a bright band (Fig. 10 on page 25).

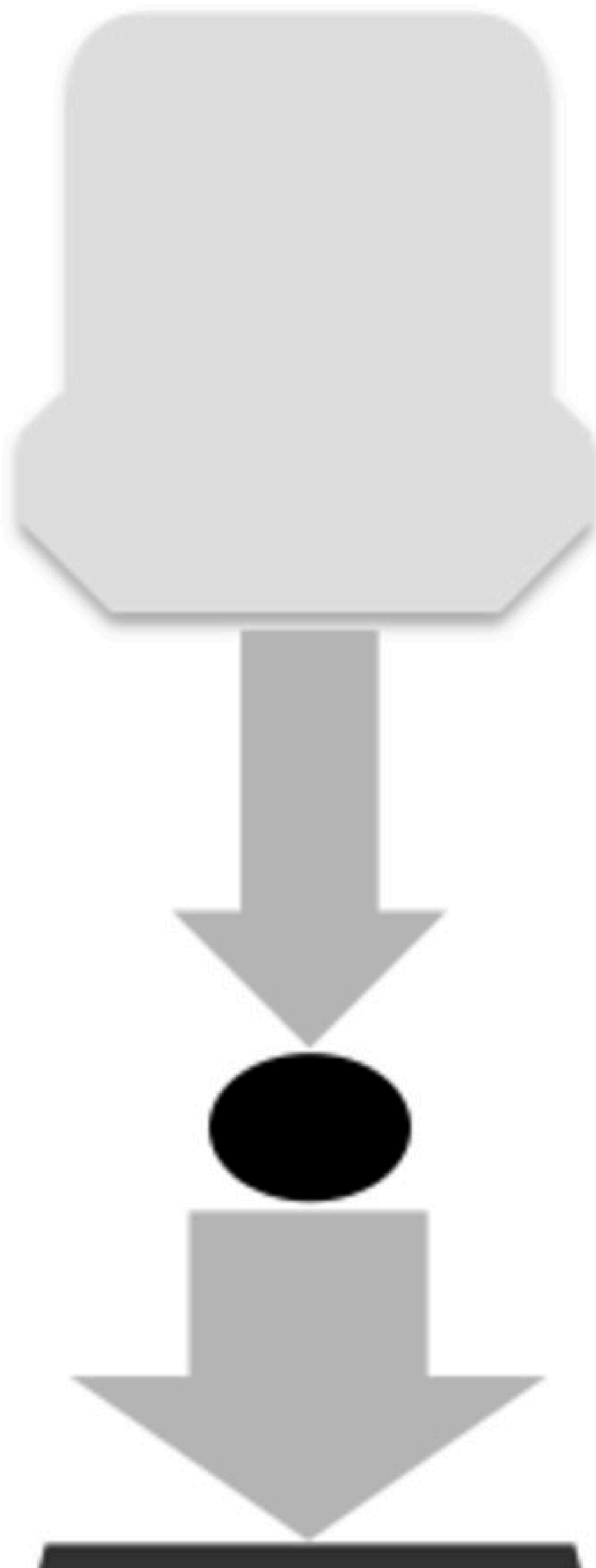

Fig. 9: Diagram of the increased through transmission artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009
References: Radiology, Centro Hospitalar e Universitário de Coimbra, Centro Hospitalar e Universitário de Coimbra - Porto/PT

Attenuation also depends on the frequency of the ultrasound, it is stronger with increase in frequency.

The relationship between attenuation and frequency is linear in soft tissues. In bone and water, attenuation increases as the square of the frequency.

If the attenuation coefficient for a material is high, such as with fat (Ex.: hepatic steatosis), then the beam may not fully penetrate the imaging field and deep structures can't be visualized. Adjusting the frequency or changing to a transducer of lower frequency can optimize penetration, permitting the visualization of deeper structures.

Understanding the attenuation characteristics of materials, US artifacts can be used in our favor to determine the composition of a structure.

ARTIFACTS ASSOCIATED WITH MULTIPLE ECHOES

US image processing assumes that an echo returns to the transducer after a single reflection and that the depth of an object is directly related to the amount of time that an ultrasound pulse takes to return to the transducer. However, in the presence of two parallel highly reflective surfaces, the echoes generated from a primary ultrasound beam may be repeatedly reflected back and forth before returning to the transducer. Therefore, multiple echoes are received and displayed.

Reverberation artifact

The echo that returns after a single reflection will be displayed in its correct location but the sequential echoes will take longer to return, and the ultrasound processor will recognize them as falsely deeper in the US field (Fig. 11 on page 39a).

In clinical imaging, this is seen as multiple linear reflections (Fig. 12 on page 26).

The comet tail artifact is a form of reverberation. In this case, the two reflective structures are very close and thus sequential echoes are close together (Fig. 11 on page 39b).

The sequential echoes may be so close that individual signals are not dissociable. At the same time, the later echoes may have decreased amplitude that is displayed as decreased width, resulting in a reverberation artifact with a triangular shape (Fig. 13 on page 27).

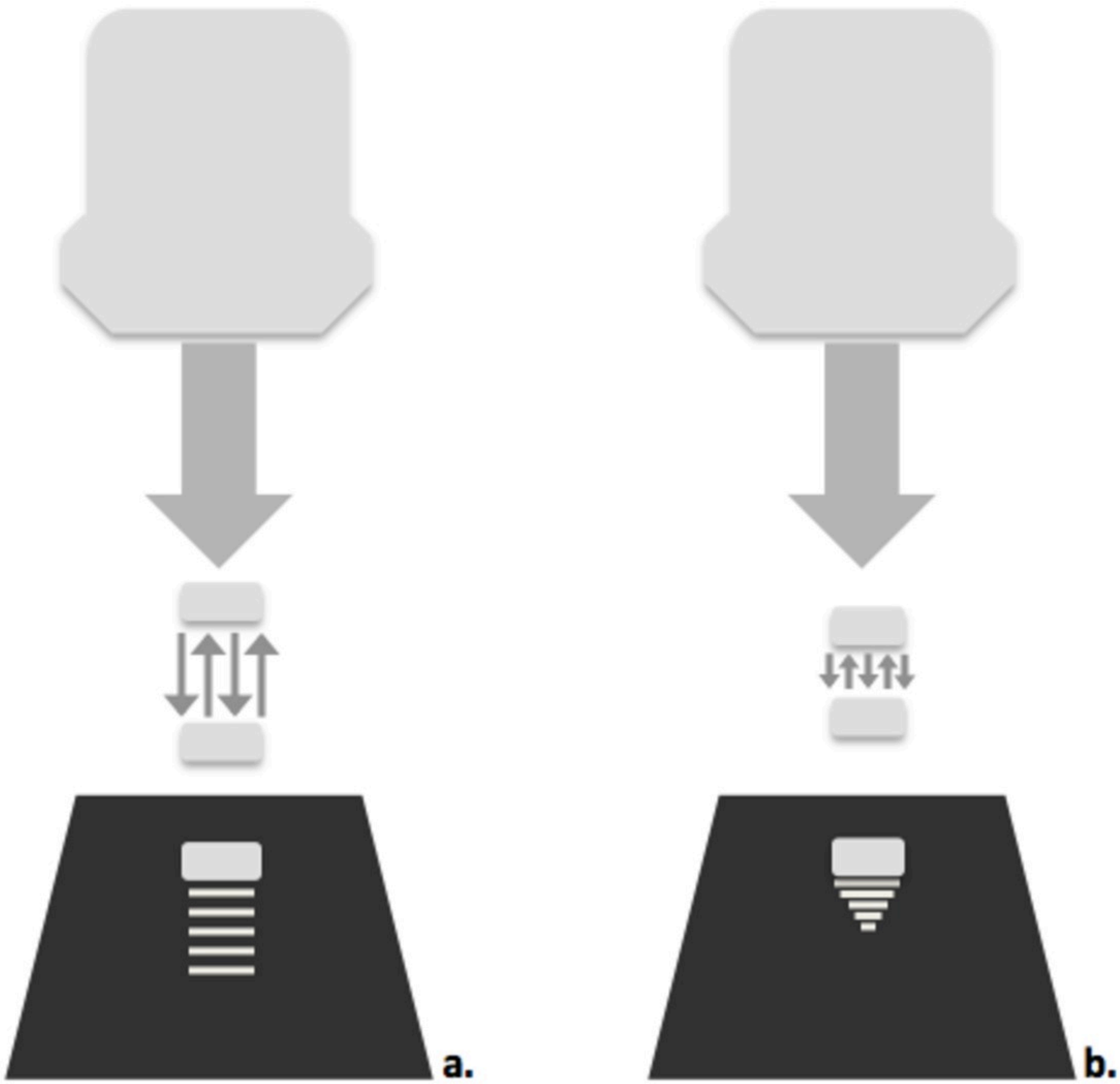

Fig. 11: (a) Diagram of the reverberation artifact. (b) Diagram of the comet tail artifact (a subtype of reverberation artifact). Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009
References: Radiology, Centro Hospitalar e Universitário de Coimbra, Centro Hospitalar e Universitário de Coimbra - Porto/PT

Ring-down artifact

The ring-down artifact is often similar in appearance with the comet tail artifact, and in the past they were thought to be the same. Currently they are known to have separate mechanisms.

The ring-down artifact results of the resonant vibrations within fluid trapped between a tetrahedron of air bubbles (Fig. 14 on page 39). These vibrations create a continuous sound wave that is transmitted back and is displayed as a line or series of parallel bands extending deeper to a gas collection (Fig. 15 on page 28).

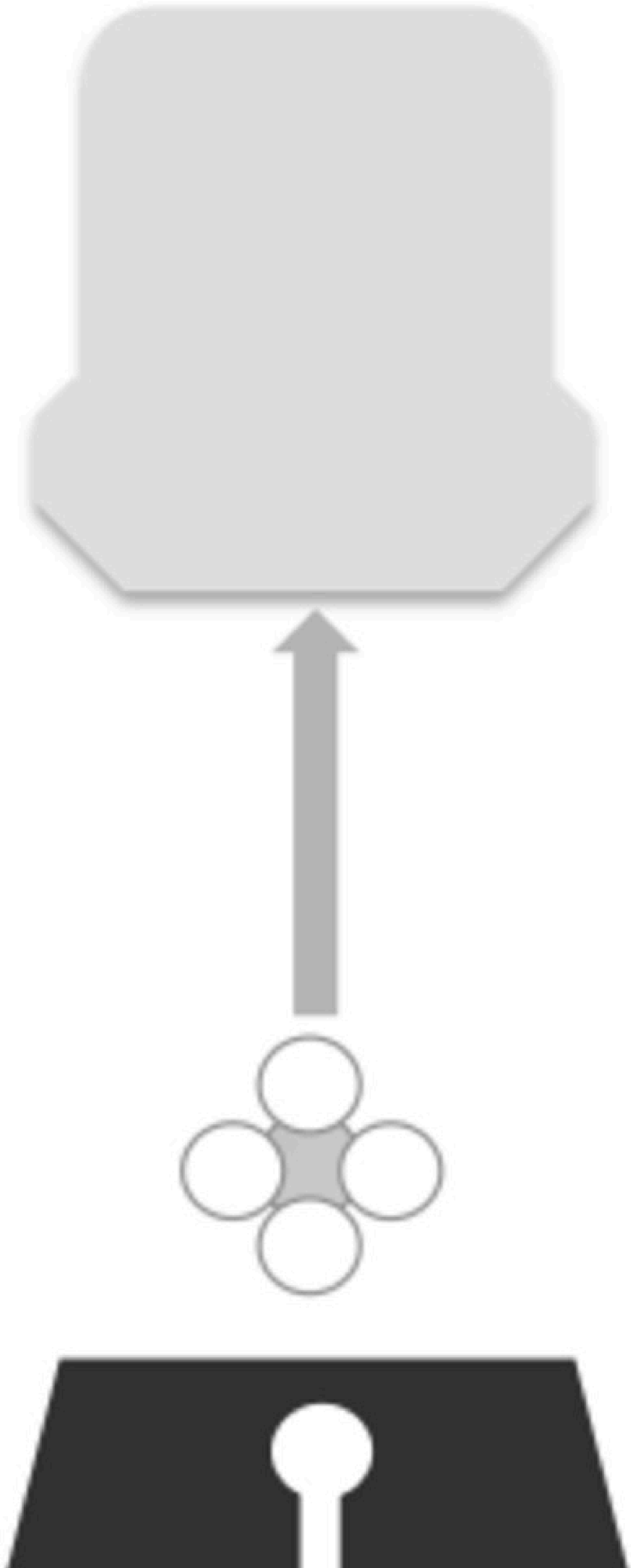

Fig. 14: Diagram of the ring-down artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

References: Radiology, Centro Hospitalar e Universitário de Coimbra, Centro Hospitalar e Universitário de Coimbra - Porto/PT

Mirror artifact

This artifact is also generated by the same assumption that an echo returns to the transducer after a single reflection. In this case, the main US beam encounters a highly reflective interface (usually the pleural-air interface), then the reflected echoes encounter the end of a structure and are reflected back toward the reflective interface before being reflected to the transducer. The image processor displays a duplicated structure equidistant from but deep to the strongly reflective interface (Fig. 16 on page 41).

At imaging, this usually happens at the level of the diaphragm, with the pleural-air interface acting as the strong reflector (Fig. 17 on page 29).

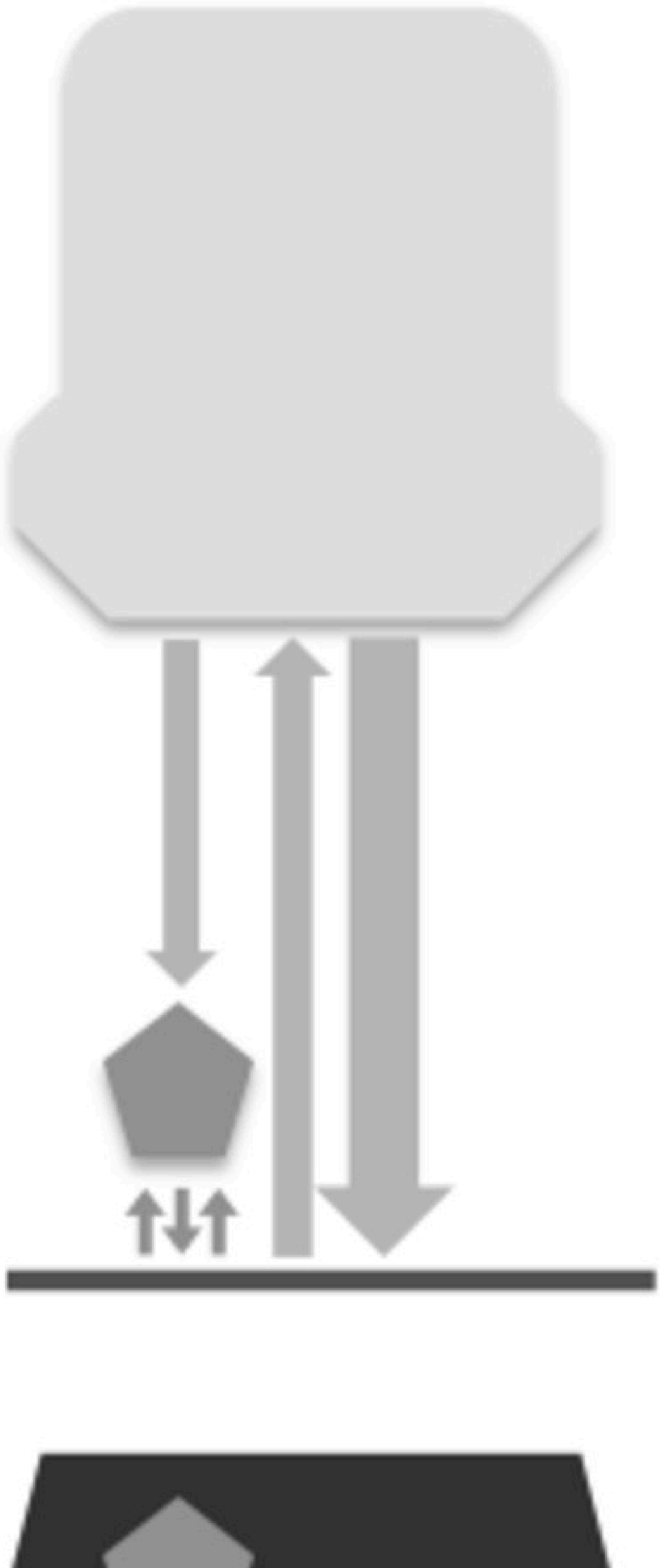

Fig. 16: Diagram of the mirror artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009
References: Radiology, Centro Hospitalar e Universitário de Coimbra, Centro Hospitalar e Universitário de Coimbra - Porto/PT

ARTIFACTS ASSOCIATED WITH VELOCITY ERRORS

The US processing assumes that the speed of ultrassound propagation is constant (1540 m/sec) in human tissue. However, speed of sound depends on density and elastic properties of a tissue and it differs as the US beam encounters air, fluid, fat, soft tissue, or bone.

Speed displacement artifact

The US image processor assumes that the length of time for a single round trip of an echo is related only to the distance traveled by the echo, but in a material with a speed of US propagation that is significantly lower than the 1540m/sec, the returning echo will be also slower. Therefore, this echoes are displayed falsely deeper (Fig. 18 on page 43, Fig. 19 on page 30). It is often recognized when the ultrasound beam encounters an area of focal fat.

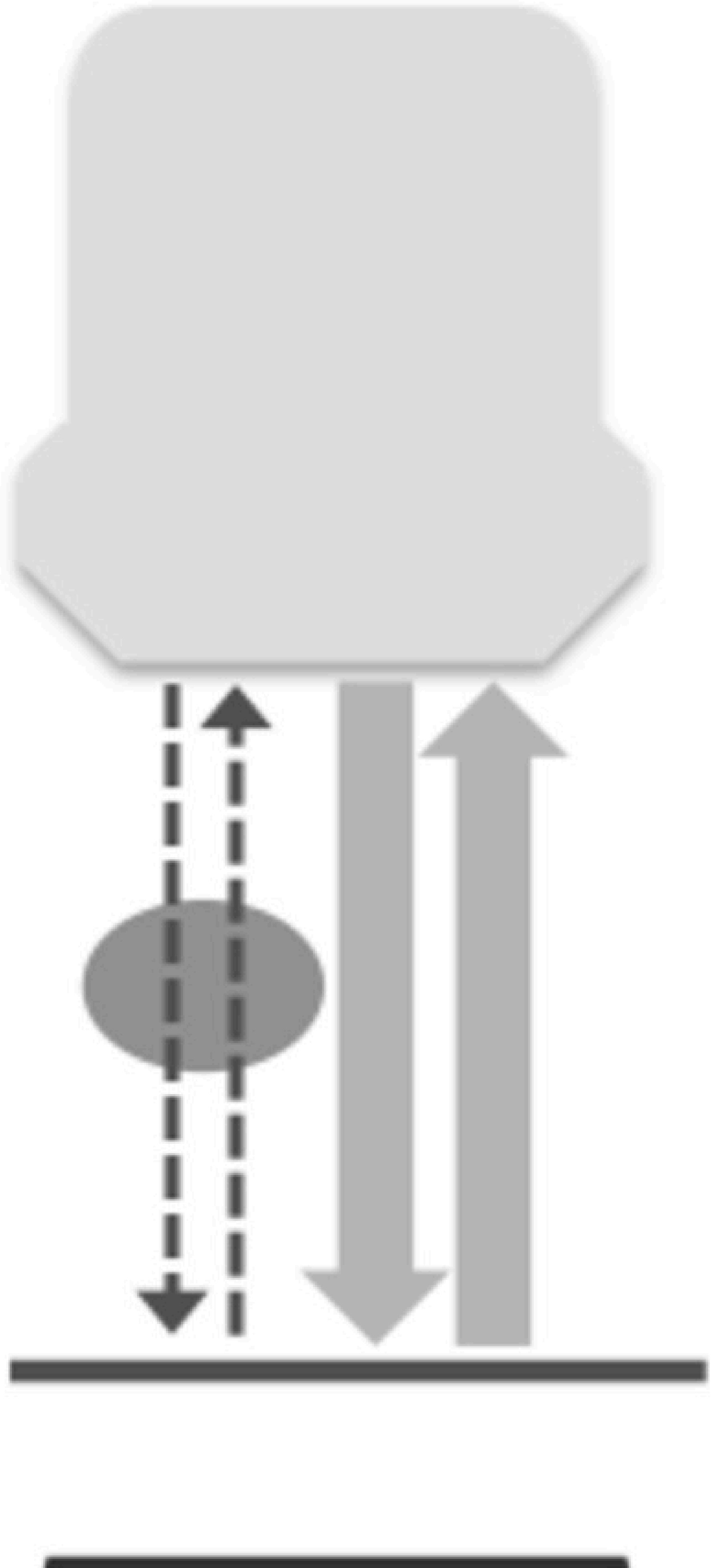

Fig. 18: Diagram of the speed displacement artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009
References: Radiology, Centro Hospitalar e Universitário de Coimbra, Centro Hospitalar e Universitário de Coimbra - Porto/PT

Refraction artifact

The ultrasound display assumes that the beam travels in a straight line, but when a nonperpendicular incident ultrasound energy encounters an interface between two materials with different speeds of sound, it changes direction. The degree of this change depends on both the difference in velocity between the two media and the angle of the incident ultrasound beam.

The US image processor misplaces the returning echoes, assuming that the beam traveled in a straight line (Fig. 20 on page 45).

Refraction artifact may cause structures to appear wider or duplicated. This artifact may be recognized in pelvic structures deep to the junction of the rectus muscles and midline fat.

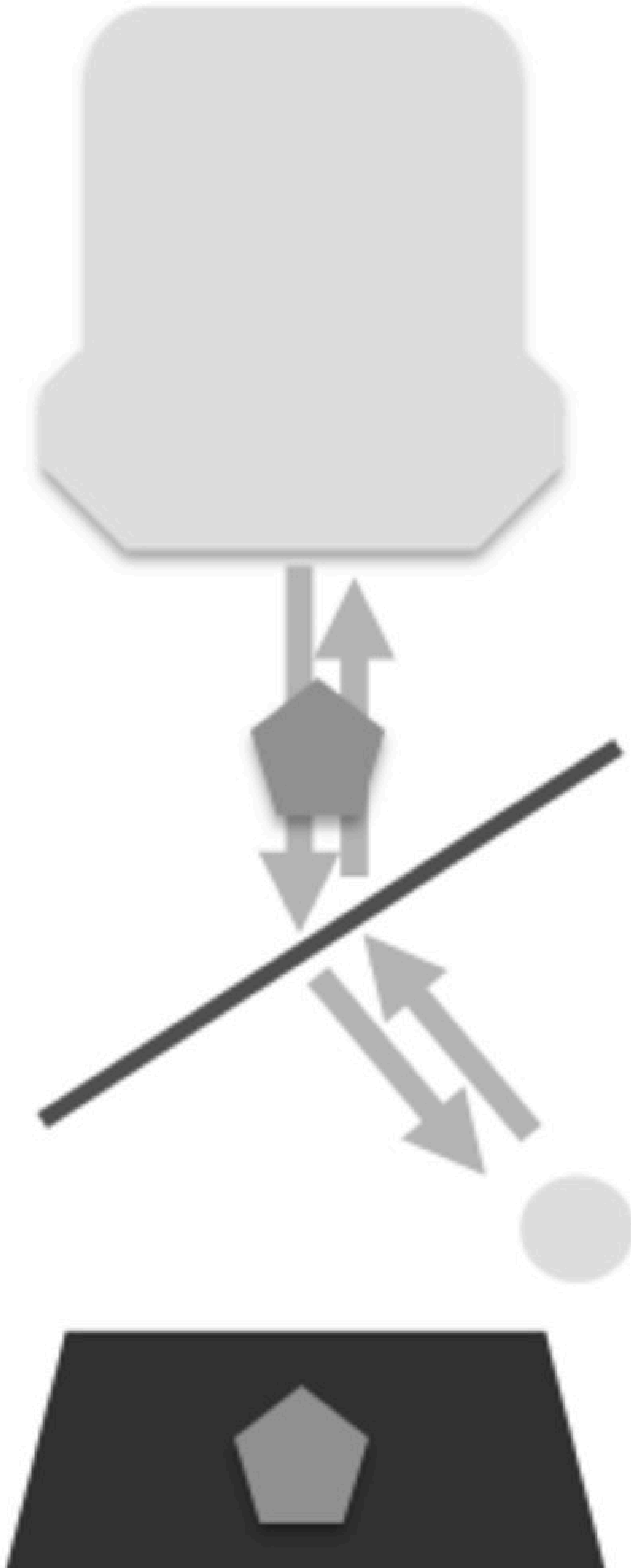

Fig. 20: Diagram of the refraction artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009
References: Radiology, Centro Hospitalar e Universitário de Coimbra, Centro Hospitalar e Universitário de Coimbra - Porto/PT

Images for this section:

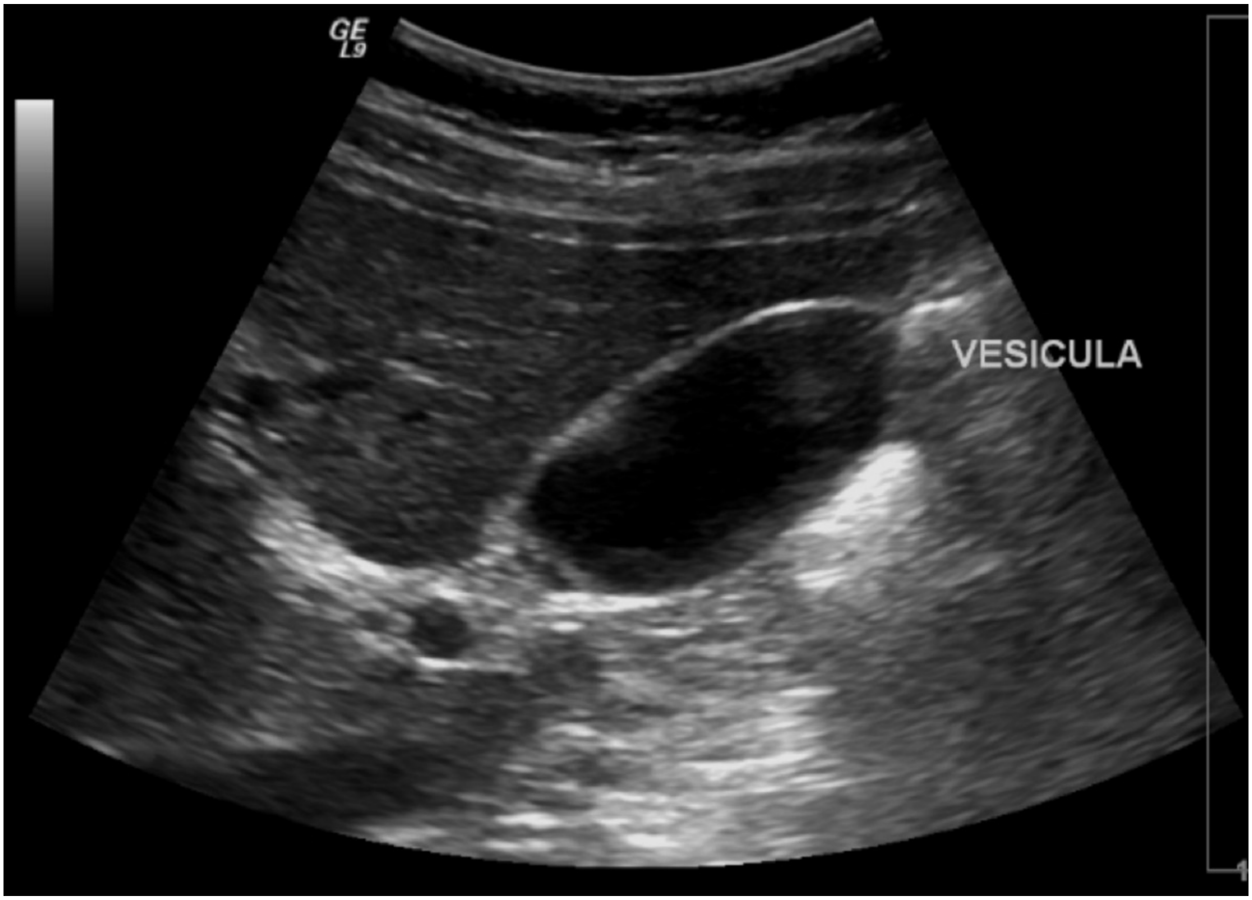

Fig. 4: Beam width artifact. US image shows peripheral echoes in a filled gallbladder with expected anechoic bile.

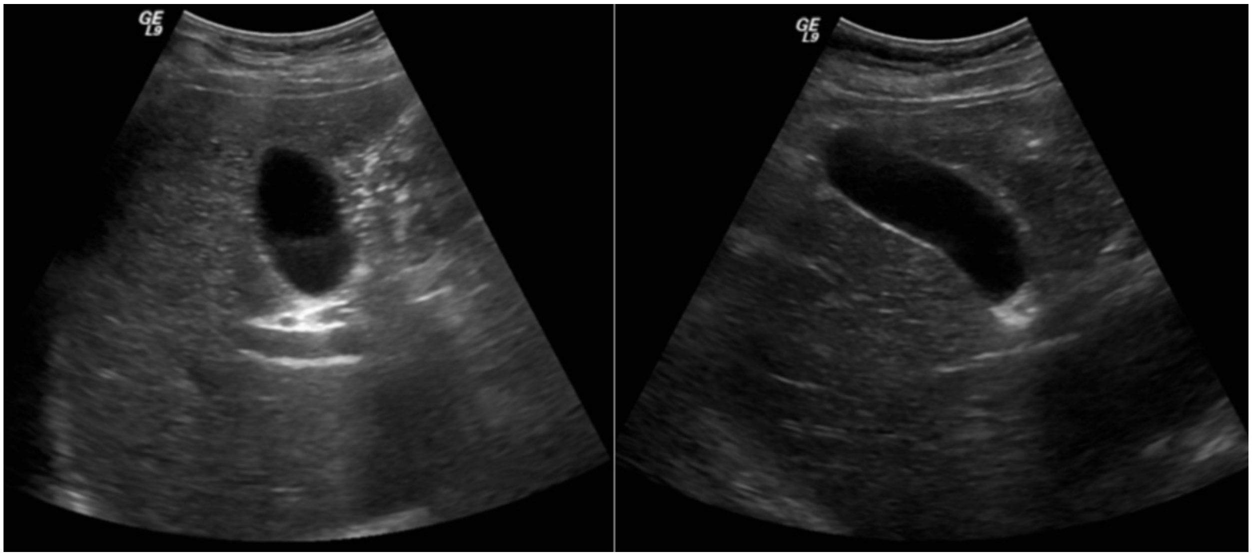

Fig. 6: Side lobe artifact. The display assumes that the echoes returning from a off-axis object came from the main beam and misplaces and duplicates the structure, in this case inside the gallbladder and simulating sludge. Adjusting the focal zone and replacing the transducer improve image quality with resolution of the artifactual echoes.

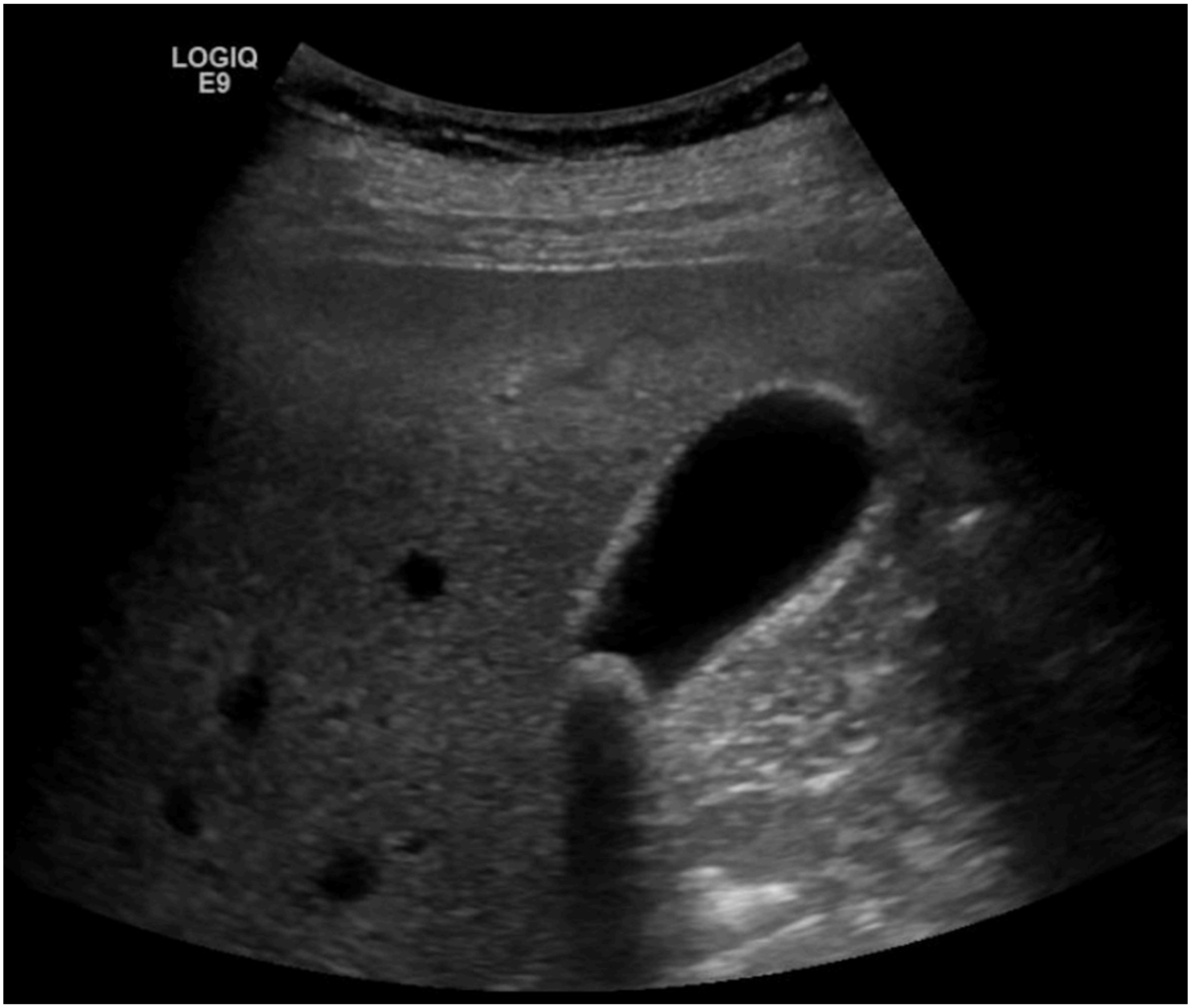

Fig. 8: Shadowing artifact. US image of the gallbladder shows shadowing posterior to an echogenic gallstone.

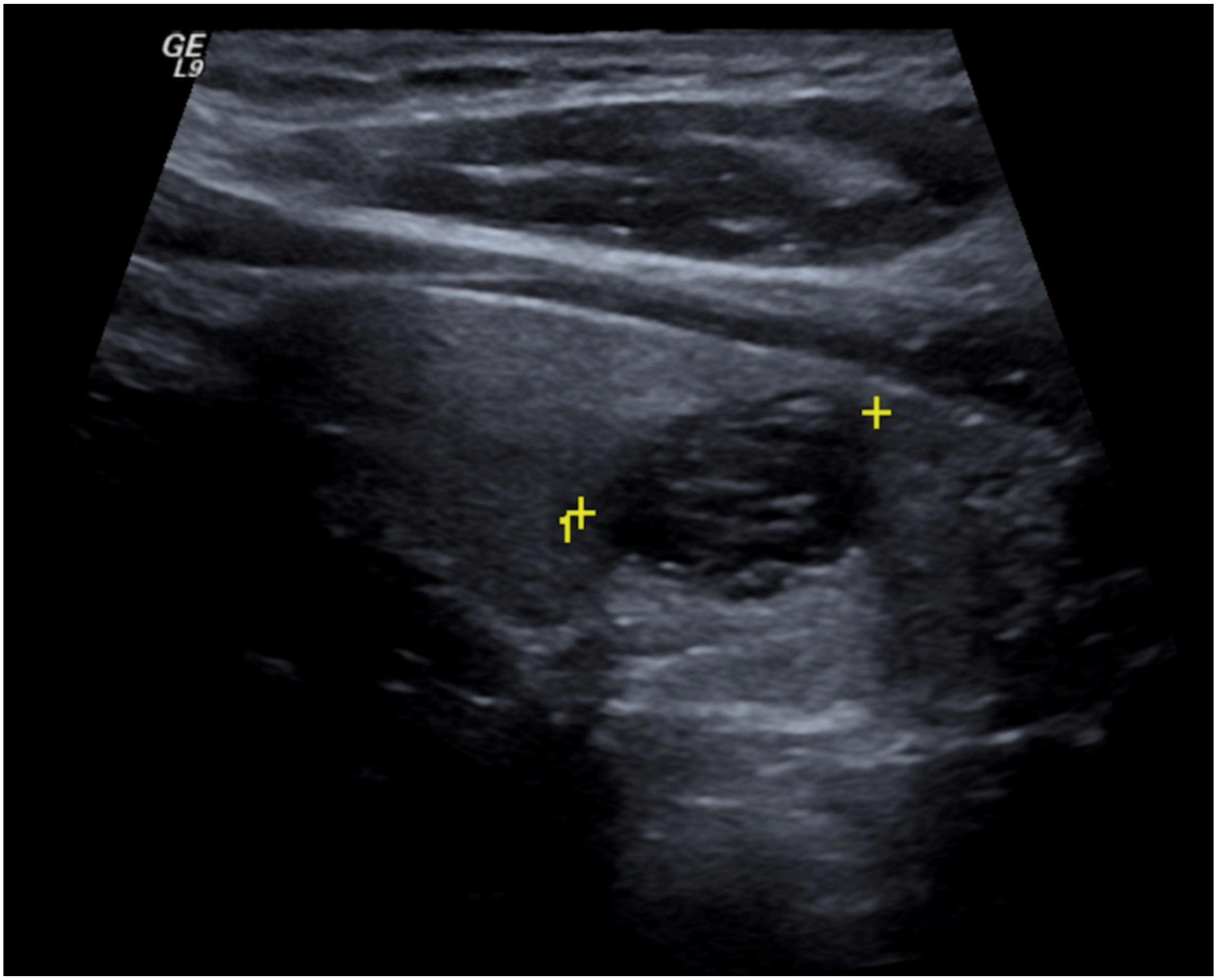

Fig. 10: Increased through transmission artifact. Transverse US image of the thyroid shows an hypoechoic and heterogeneous nodule associated with increased through-transmission artifact, demonstrating that it is cystic in origin.

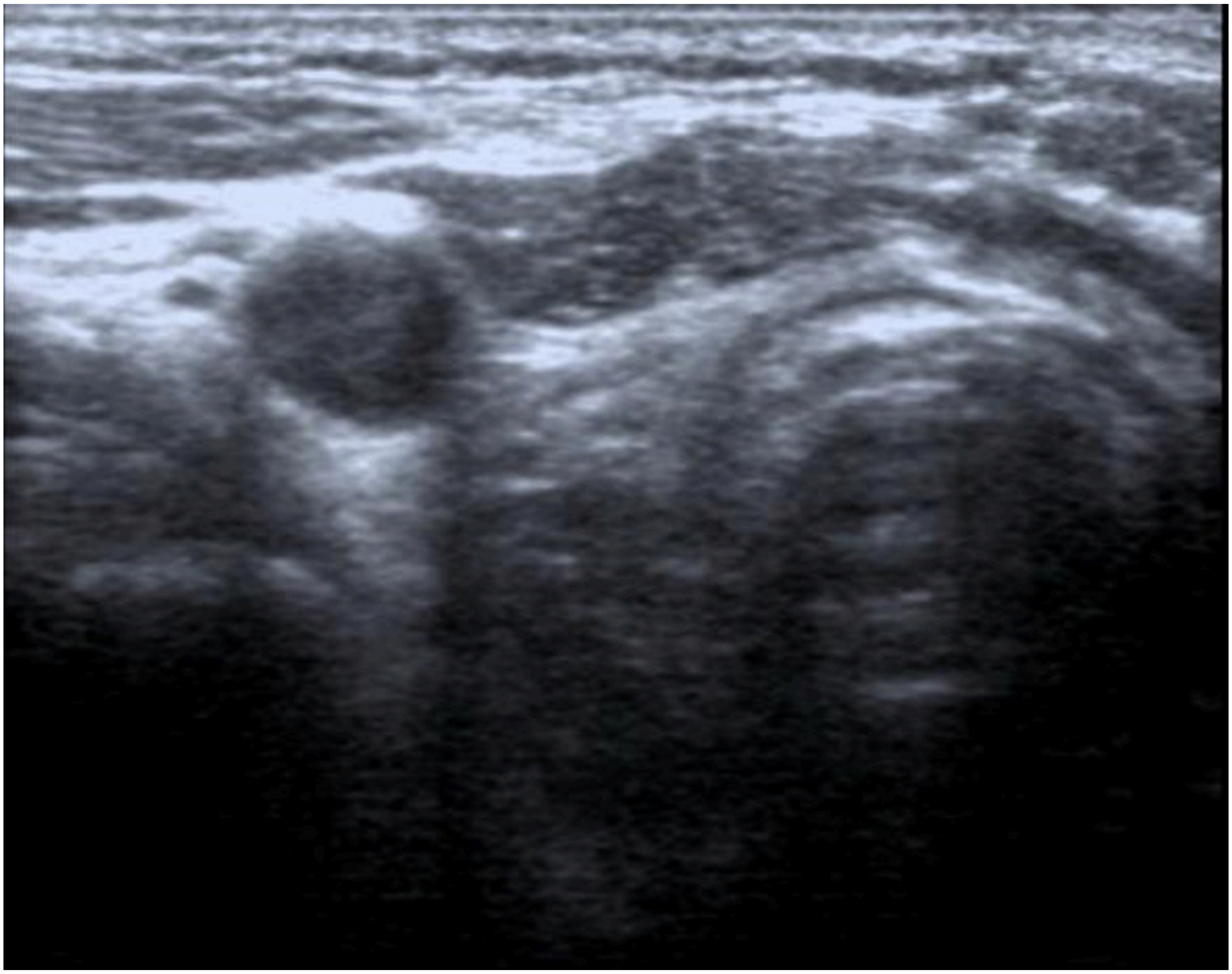

Fig. 12: Reverberation artifact. Multiple equally spaced signals extending into the deep field caused by the air inside the trachea.

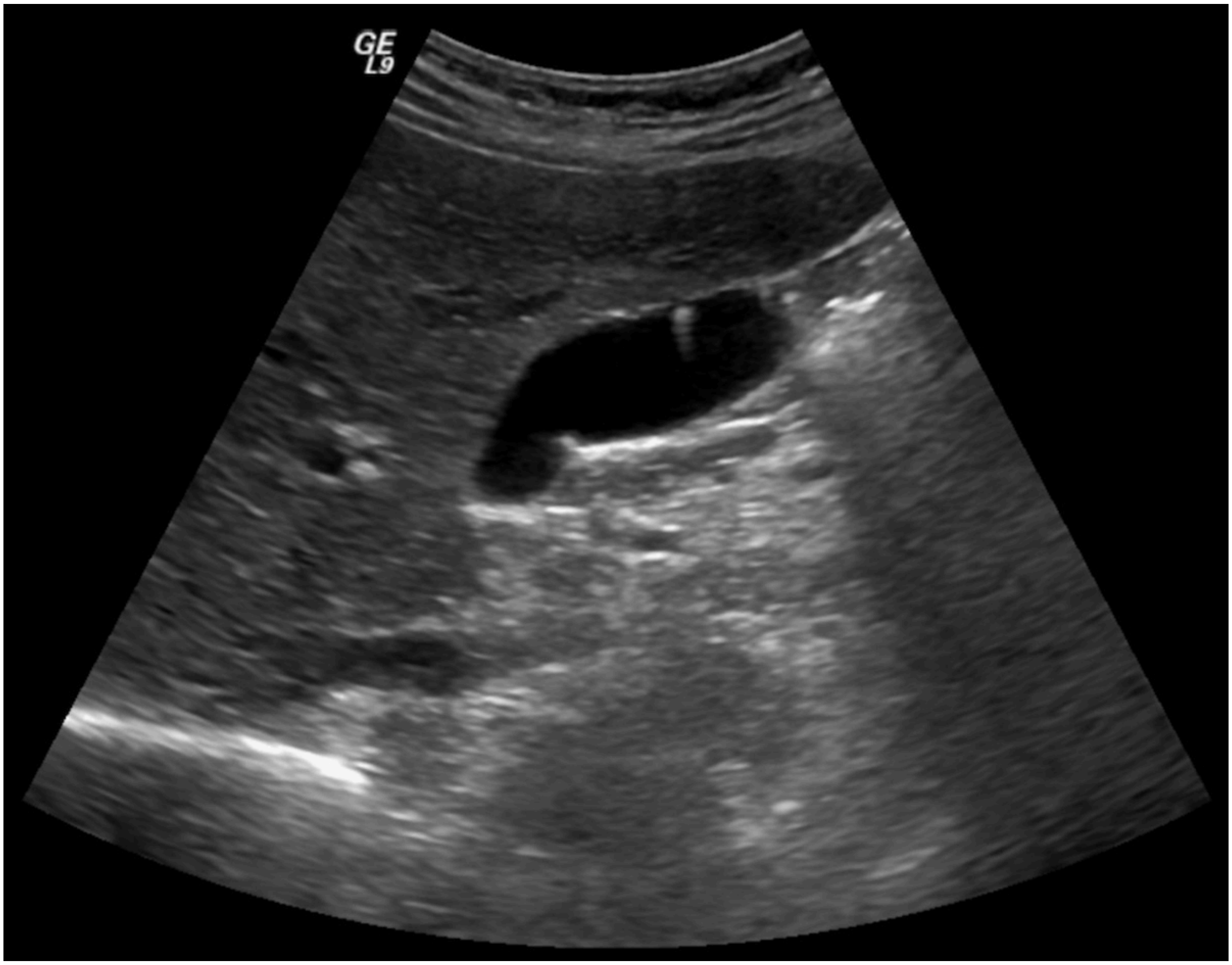

Fig. 13: Comet tail artifact in adenomyomatosis, caused by cholesterol crystals in Rokitansky-Aschoff sinuses.

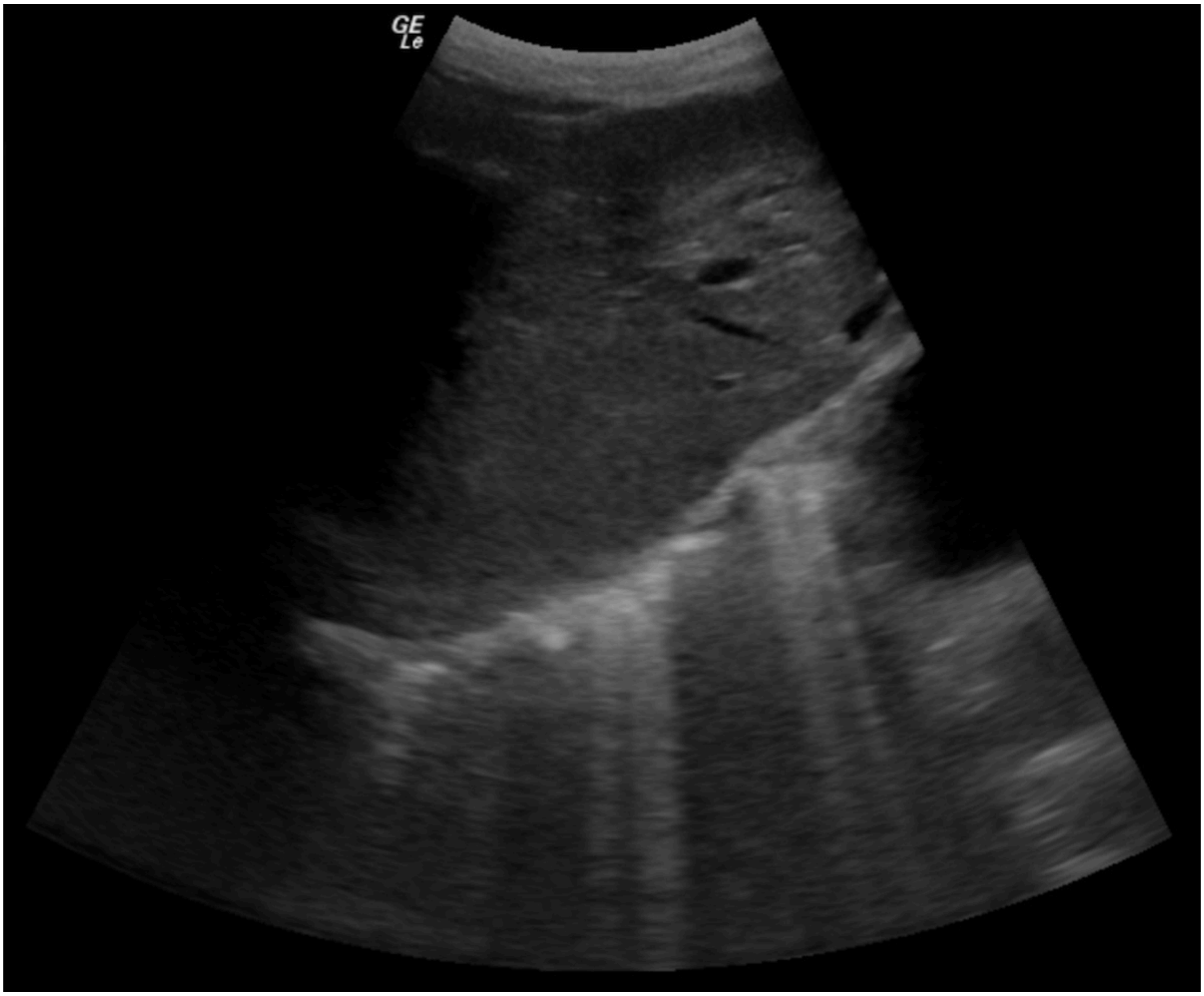

Fig. 15: Ring-down artifact. The US display shows a bright reflector with an echogenic line extending posteriorly.

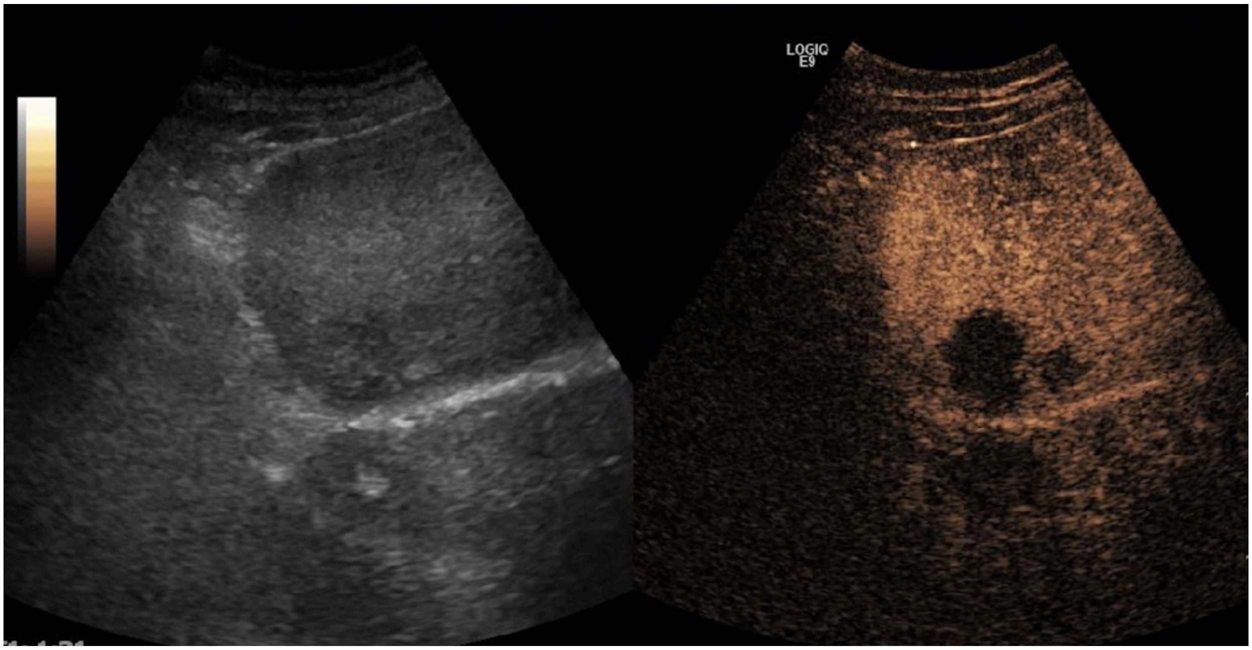

Fig. 17: Mirror artifact. US image obtained at the level of the right hepatic lobe shows an hypoechogenic and heterogeneous lesion and a duplicated lesion equidistant from the diaphragm overlying the expected location of lung parenchyma. This lesion have been thermoablated, therefore after IV contrast (SonoVue) it does not enhance.

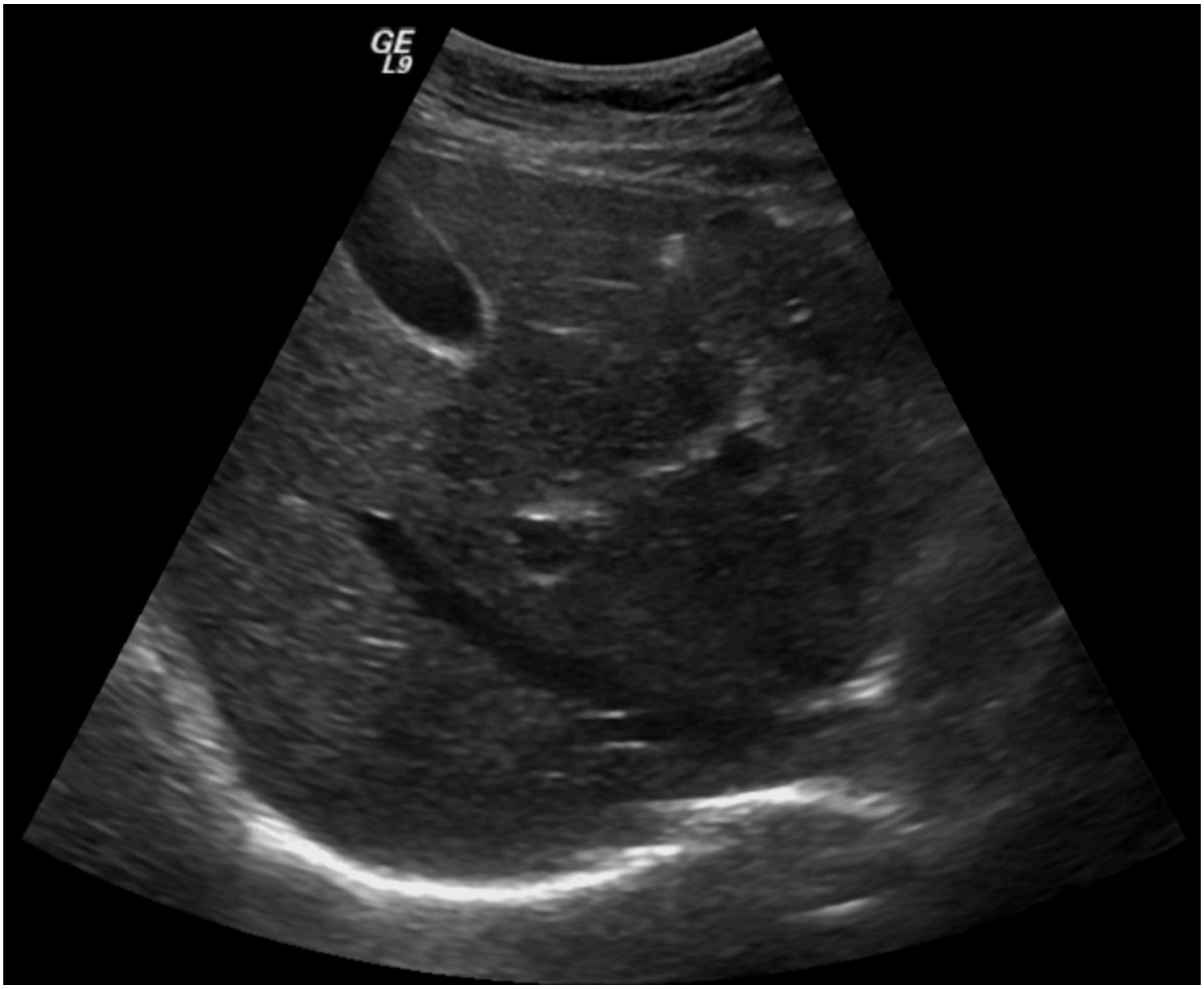

Fig. 19: Speed displacement artifact. US image of the liver show that the interface between the liver and the diaphragm is discontinuous and focally displaced. This appearance may be explained by areas of focal fat within the liver.

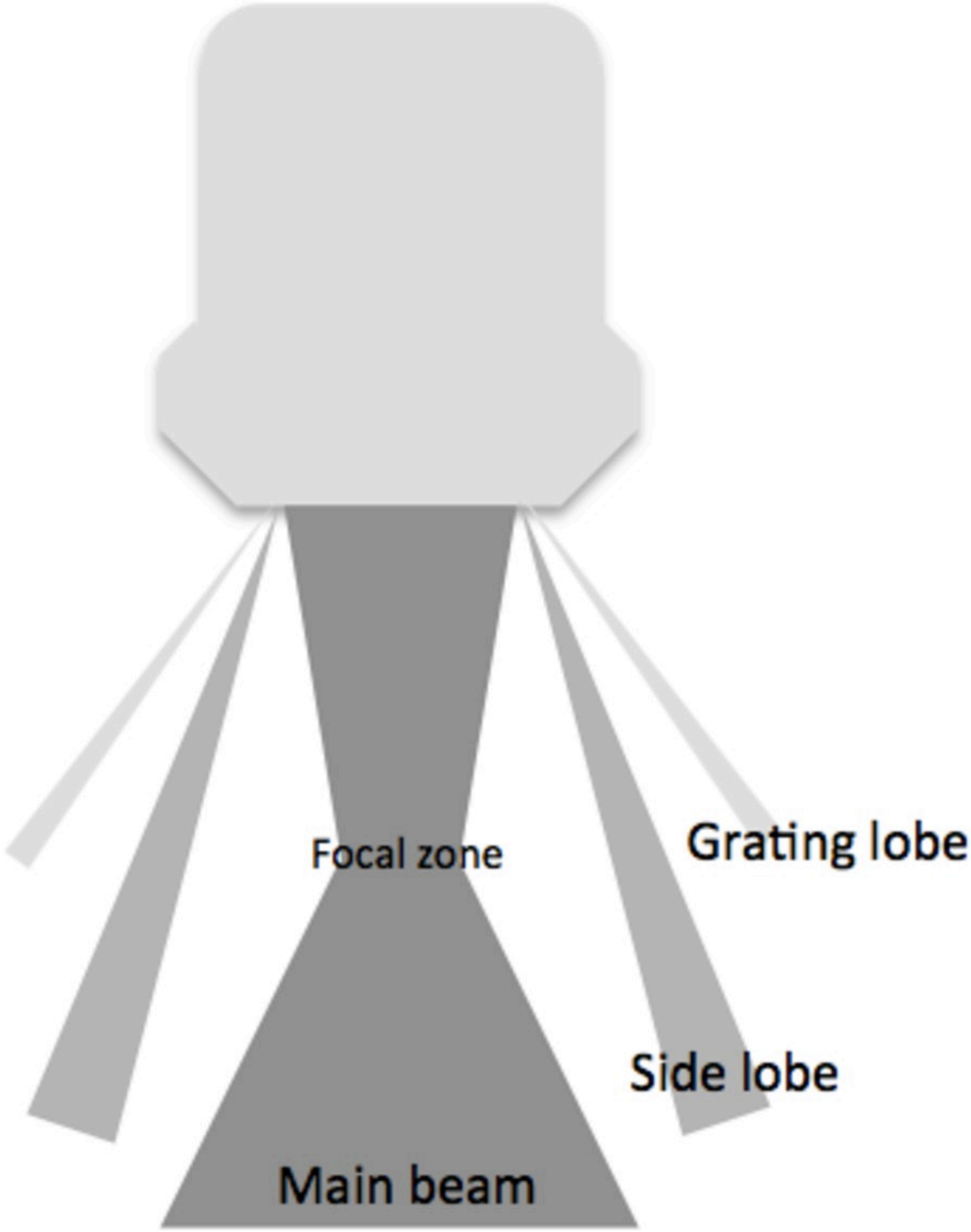

Fig. 2: Diagram of the ultrasound beam. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

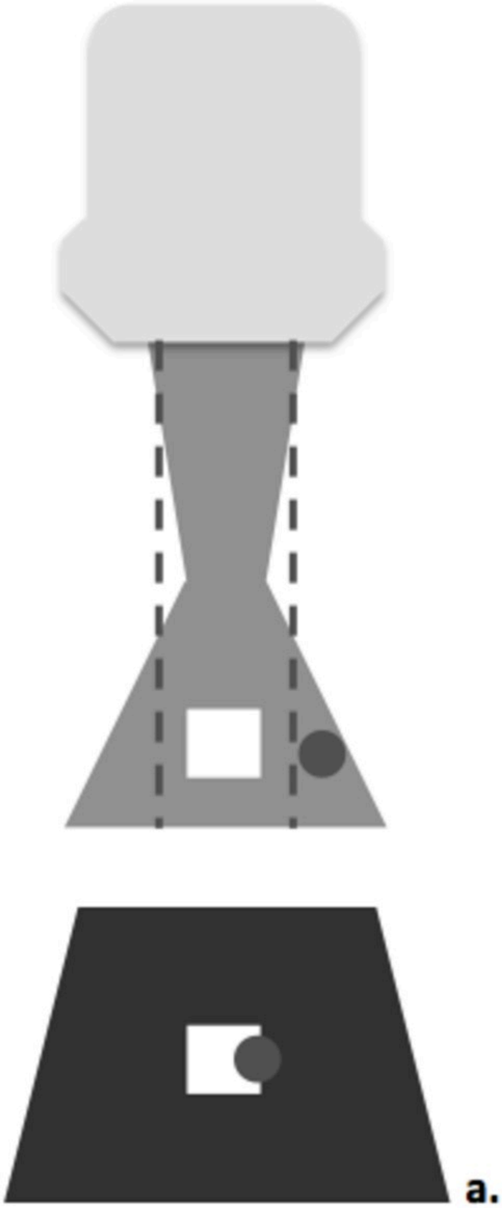

Fig. 3: Diagram of the beam width artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

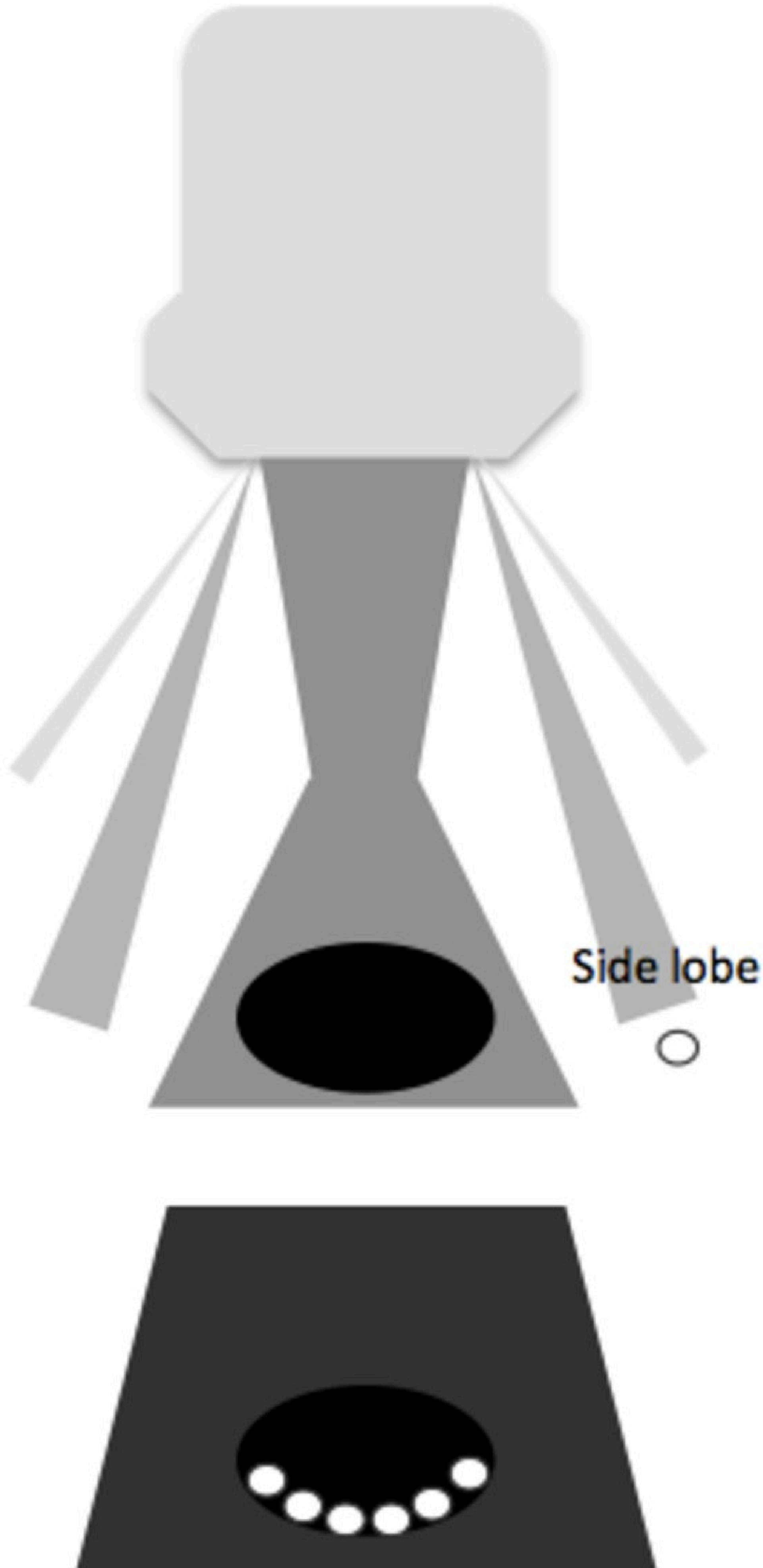
Side lobe

Fig. 5: Diagram of the side lobe artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

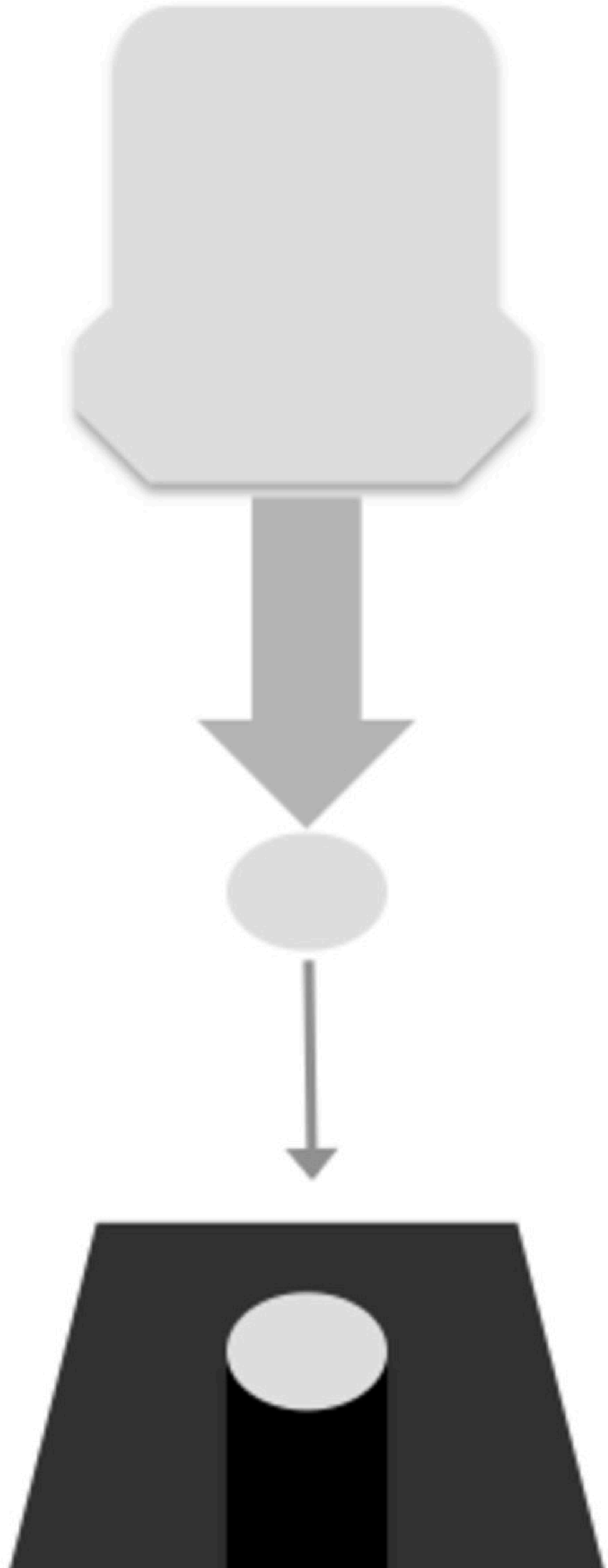

Fig. 7: Diagram of the shadowing artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

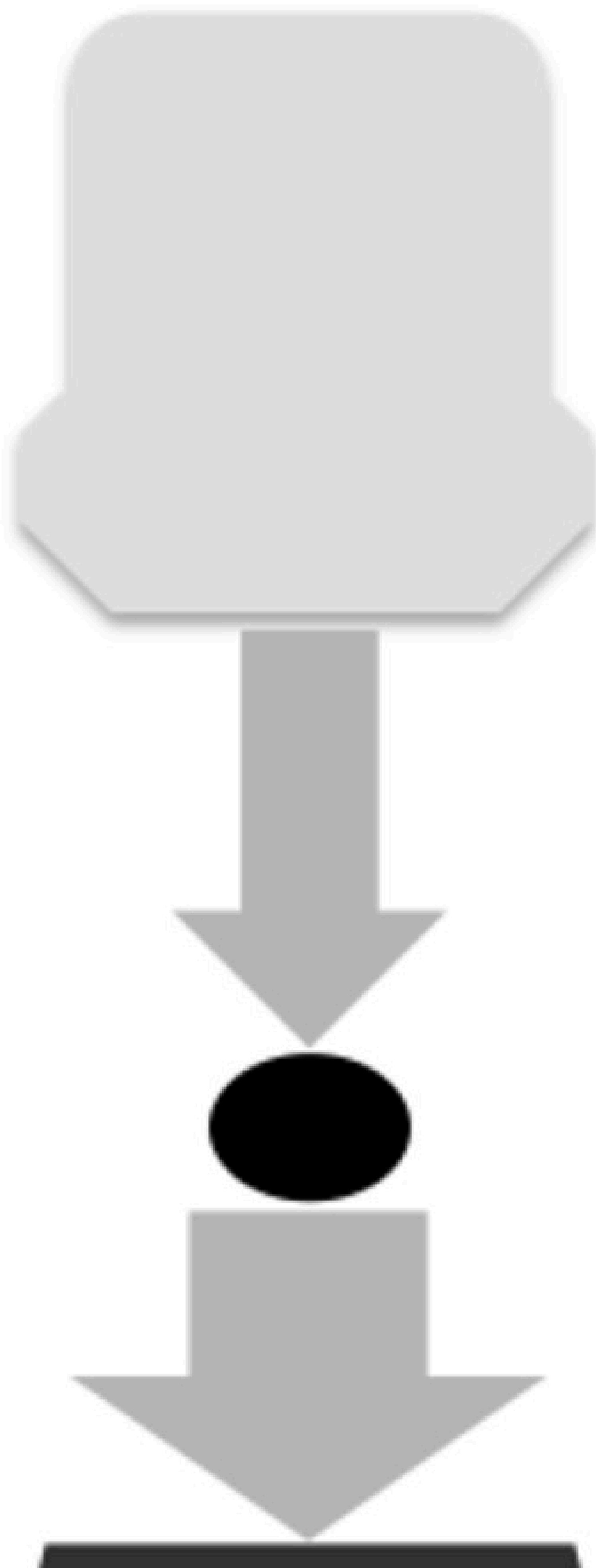

Fig. 9: Diagram of the increased through transmission artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

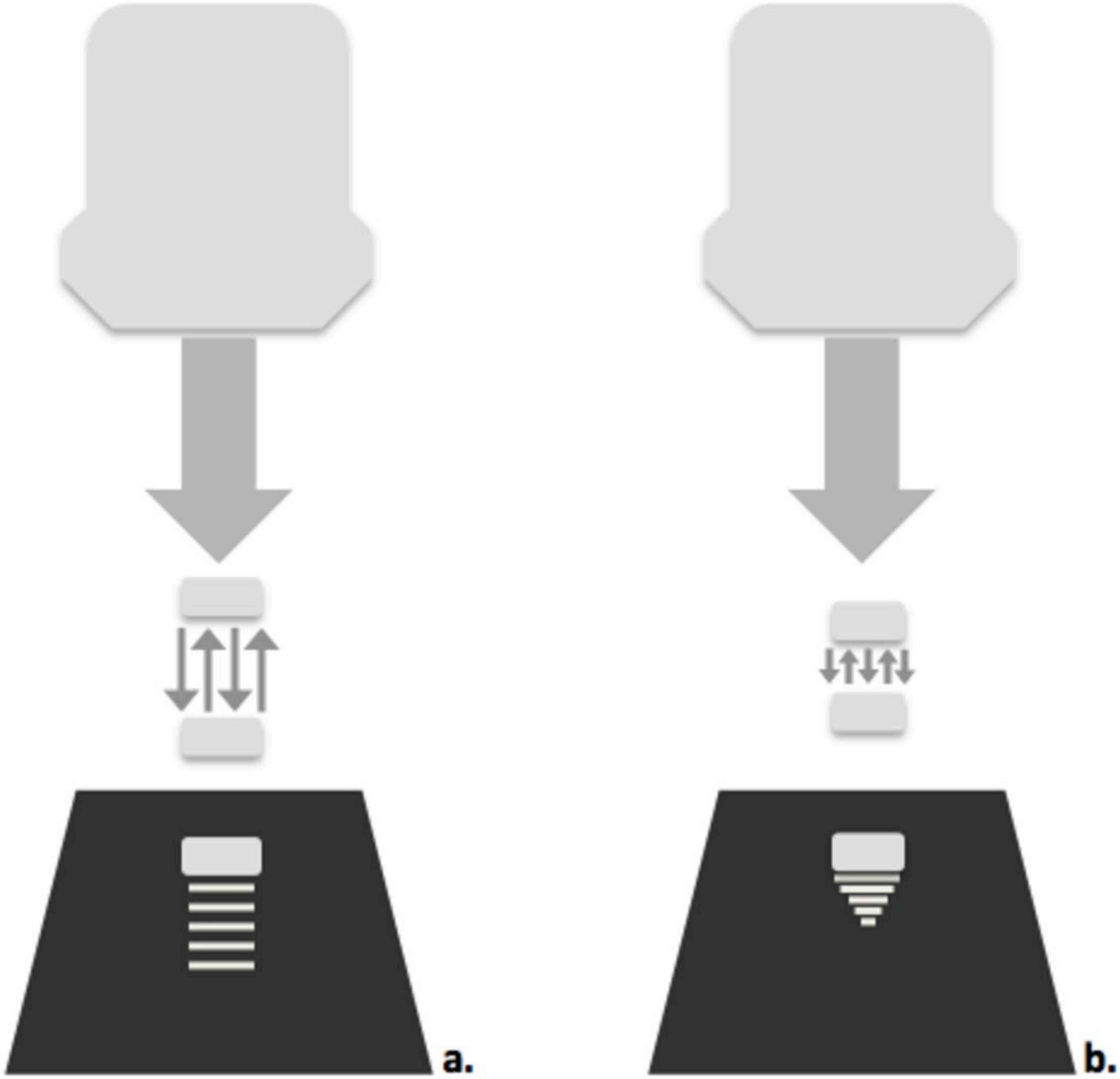

Fig. 11: (a) Diagram of the reverberation artifact. (b) Diagram of the comet tail artifact (a subtype of reverberation artifact). Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

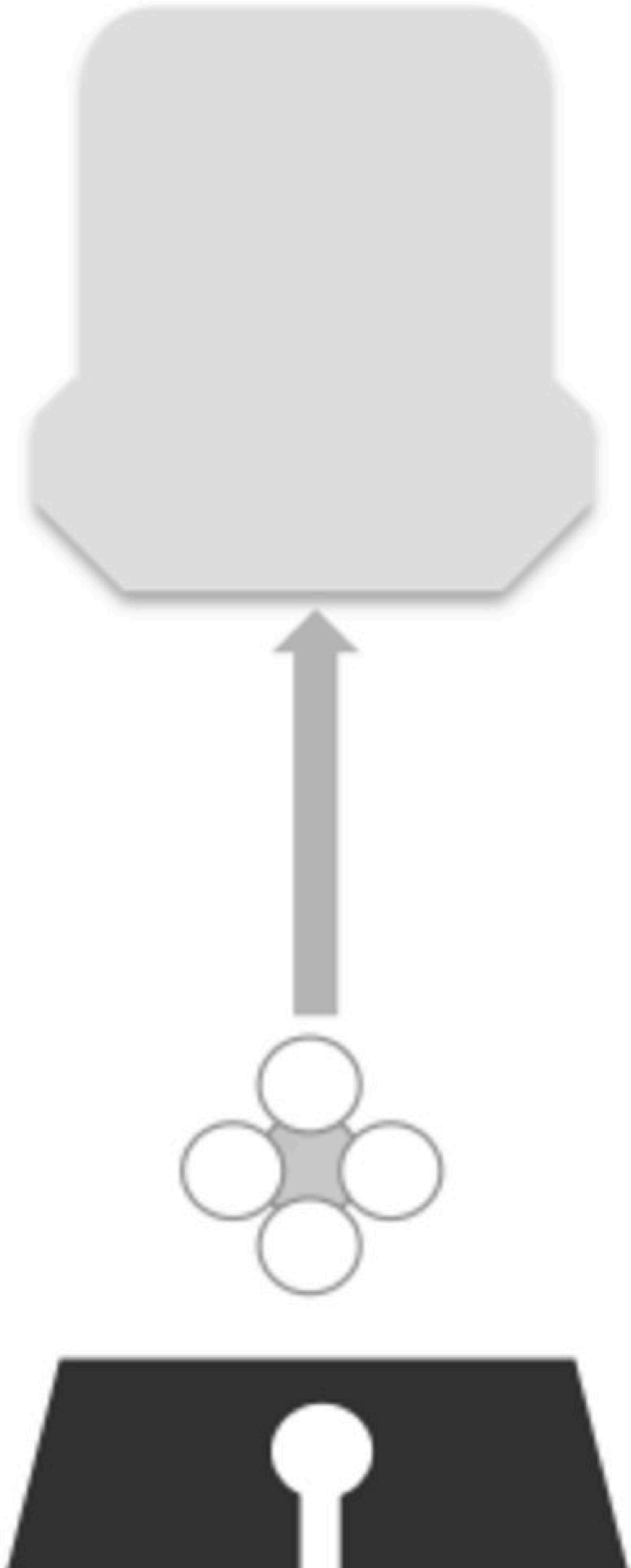

Fig. 14: Diagram of the ring-down artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

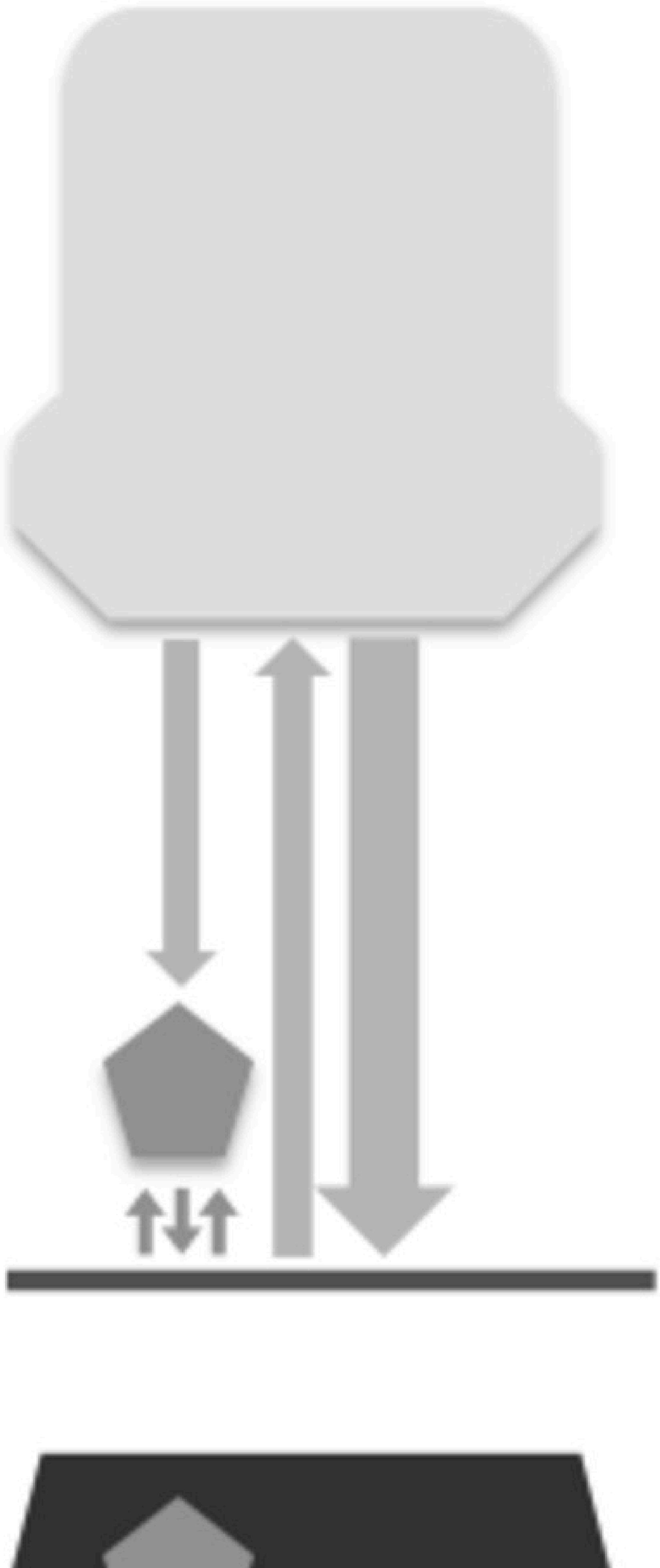

Fig. 16: Diagram of the mirror artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

Fig. 18: Diagram of the speed displacement artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

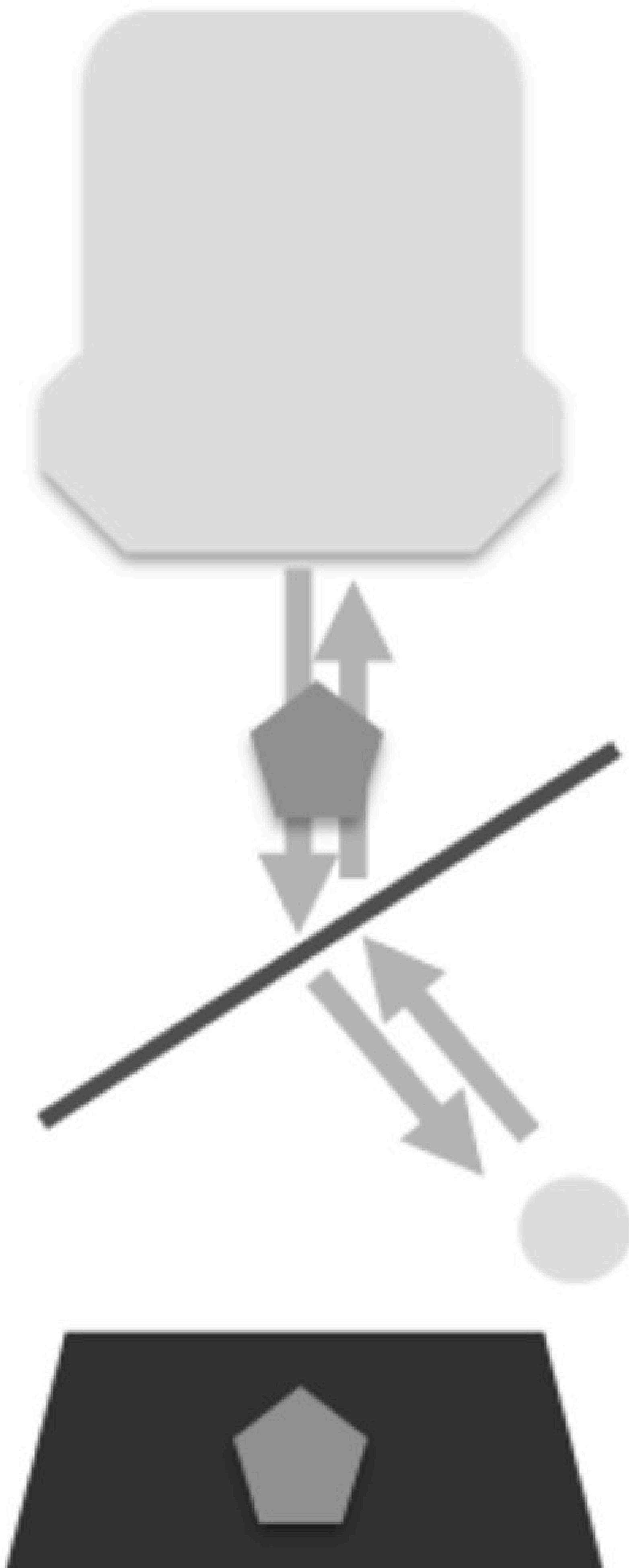

Fig. 20: Diagram of the refraction artifact. Adapted from: Feldman MK et al. US artifacts. Radiographics. 2009

Conclusion

It is important for any radiologist to be able to recognize US artifacts and know how to use them as a diagnostic advantage, or eliminate/minimize them to improve image quality and diagnostic accuracy.

Personal information

References

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