Journal of Medical Ultrasonics (2019) 46:317–324
https://doi.org/10.1007/s10396-019-00938-2

REVIEW ARTICLE

Range-ambiguity artifact in abdominal ultrasound

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Received: 6 December 2018 / Accepted: 19 February 2019 / Published online: 19 March 2019

Abstract
Range-ambiguity artifacts (RAAs) are an erroneous mapping of returning echoes into a composite picture. The purpose of this review was to illustrate the mechanism of RAAs and to present the diagnostic problems caused by RAAs. RAA features differ slightly from organ to organ. At the level of the urinary bladder, RAAs take the form of a cloud-like, ill-demarcated, immobile, echogenic area, and the depth of the echogenic area differs depending on the pulse repetition frequency (PRF). This form is referred to as "static RAA" in this review. There are two key ultrasound characteristics of RAAs at the level of the liver: (a) the depth of RAAs change according to the PRF, and (b) RAAs move in accordance with the cardiac cycle. This form is referred to as "mobile RAA" in this review. At the level of the gallbladder, RAAs take the form of fine echogenic lines in the gallbladder. This phenomenon is actually a combination of two phenomena: a ring-down artifact and RAA. This form is referred to as "complex RAA (searchlight phenomenon)" in this review. The easiest way to reduce RAAs is to change the image depth. Sufficient knowledge of RAAs can prevent misdiagnosis of erroneously displayed returning echoes as real pathologic changes.

Keywords Ultrasound · Range-ambiguity artifact · Urinary bladder · Liver · Gallbladder

Introduction

Although known for a long time [1–4], range-ambiguity artifacts (RAAs) have recently drawn increased attention from physicians specializing in abdominal ultrasound (US) [5, 6]. It is mainly because they become more obvious when using recent high-end US equipment [4]. In fact, most operators encounter RAAs with everyday abdominal B-mode US, but they sometimes possess insufficient knowledge of RAAs and feel diagnostic confusion with real structures, because compared with other US artifacts, such as refraction artifact [7–10], posterior echo enhancement [11, 12], acoustic shadowing [13], mirror image [14, 15], double image artifact [16–18], reverberation artifact [19–21], and ring-down artifact [22], there is a marked paucity of data on RAAs in the English literature [5, 6]. In this review, we attempt to clarify the mechanism and characteristic B-mode pattern of RAAs. We also enumerate some important points for differentiating RAAs from real structures.

Mechanism of RAAs

An artifact is any structure appearing in a US image that is not present in actual tissue. Of a wide range of US artifacts, RAAs have been very seldom described in the literature [6]. Understanding the process by which US images are composed in US equipment is important to understanding RAAs, like the other above-mentioned well-known US artifacts [2, 3, 6–22].

The composition of US images is based on the following assumptions: (1) the US beam passes along a straight-line path from the transducer to the object and back to the transducer along this line, (2) the US beam is infinitely narrow, and (3) all received echoes come from the most recently transmitted pulse. RAAs are thought to be produced in some

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situations where assumption cannot be properly adapted [3]. The explanation of the emission–reception of a pulse forms the basis of understanding of RAAs. The pulse repetition frequency (PRF) is the number of US pulses emitted per second. The pulse repetition period is the time between the beginning of a pulse emission and the beginning of the next one (Fig. 1). It indicates that when a pulse is emitted from the transducer, the transducer is silent for a period of time to receive returning echoes; a second pulse is then emitted, and the transducer is again silent to detect returning echoes. This series of emission–reception continues for a certain period. It indicates that PRF must decrease inevitably if the maximal depth of visualization increases, assuming that the number of lines of sight is the same, because the sound propagation velocity in soft tissues of the human body is assumed to be 1540 m/s [23]. This trade-off limitation inevitably causes the following phenomenon: the structures beyond the scanning range appear in the US image because at high PRFs the echoes from deep structures detected by the first pulse arrive at the transducer after the second pulse has been emitted, and as a result the echoes coming from deep structures are misinterpreted as having originated from the second pulse and are improperly placed near the transducer in the US image (Fig. 1). This ambiguity in depth placement is generally referred to as a "range-ambiguity artifact (RAA)."

In a clinical setting, RAAs are obvious, especially in organs or pathologies with homogeneous echo-texture or cystic structures, because RAAs may be buried in the background in structures with complex or echogenic structures. As a result, we very frequently encounter RAAs in the urinary bladder (Fig. 2) or ascites. In this situation, RAAs are usually imaged as an immobile "cloud-like" echogenic area in the anechoic background. This is the classical RAA [1, 2], which shows two key characteristics: (a) the shape of this echogenic area closely resembles the structure located behind it, and (b) the depth of the echogenic area changes according to the PRF. Thus, changing the PRF is the most useful way to eliminate RAAs at the level of the urinary bladder or ascites. This immobile RAA can be referred to as "static RAA." The liver is also an organ where RAAs are recognized very clearly. Faint moving echoes in large hepatic cysts are the most representative example of RAAs (Fig. 3). These echoes appear especially when the heart is located distal to the hepatic cyst, and they move according to cardiac motion. Naganuma et al. emphasized two key US characteristics of RAAs at the level of the liver: (a) the depth of the RAA changes according to the PRF, and (b) the RAA moves in accordance with the cardiac cycle [4]. This mobile RAA can be referred to as "mobile RAA." Understanding these two characteristic patterns prevents us from misinterpreting RAAs as a real structure at the level of the liver (Fig. 4). However, at the level of the gallbladder, the problem becomes more complex. The gallbladder is a large cystic area in the right upper abdomen, and it can produce RAAs. A structure located at a large depth causes static RAAs in the gallbladder, as is the case with hepatic cysts. However, RAAs take the shape of fine echogenic lines in the gallbladder (Fig. 5). This phenomenon, referred to as the "searchlight phenomenon" [5], is actually a combination of two phenomena: a ring-down artifact and RAA (Fig. 6). The echogenic line in the gallbladder is a ring-down artifact from duodenal gas. However, a ring-down artifact should generally appear behind the gas. A ring-down artifact is an echogenic line posteriorly extending continuously downward. This continuity is important when thinking about the searchlight phenomenon as the arrival of the echo signals continues even after the next pulse is emitted so that an echogenic line appears along the same line of sight in the gallbladder and the duodenum. The combination of two artifacts occurs, similar to this process, exclusively at the level of the gallbladder. This can be referred to as a "complex RAA." Understanding the continuity of an echogenic line and ring-down artifact can prevent us from misinterpreting this RAA as a real structure at the level of the gallbladder.

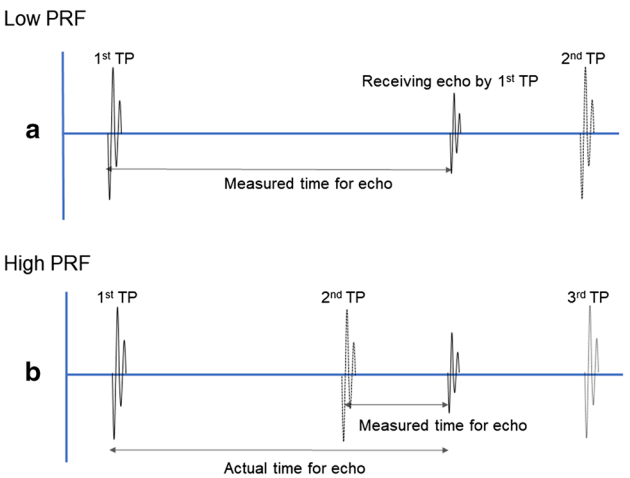

Fig. 1 Schematic drawing of emission–reception of a pulse. **a** When the PRF is low, the returning echo from the deep object is received during the first pulse's receiving period and displayed at the correct location. **b** When the PRF is high, the echo from the deep object is received during the second pulse's receiving period and erroneously displayed at a closer location. *TP* transmitted pulse

Clinical implications of RAAs

As mentioned above, in a clinical setting, RAAs appear most frequently at the level of the urinary bladder, liver, and gallbladder. Here, we show some representative RAA images in these organs and discuss the differentiative points between RAAs and real structures.

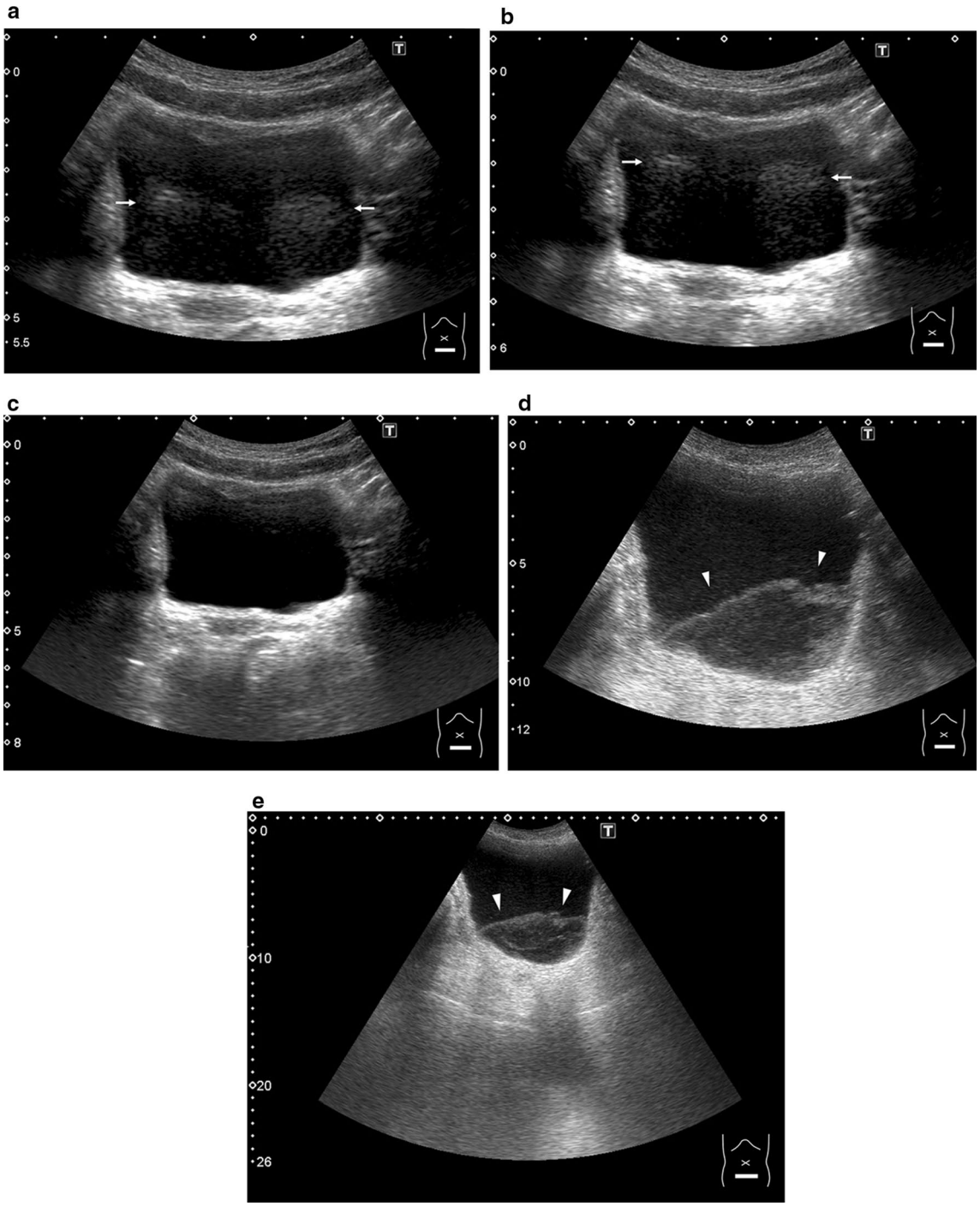

Fig. 2 RAA in the urinary bladder. A cloud-like collection of fine echoes (RAA) (arrows) is seen in the lumen (**a**). It changes location (**b**) and finally disappears (**c**) according to the changes in PRF (**a** 13 kHz, **b** 12 kHz, **c** 10 kHz) due to extension of image depth, compared with a debris echo, which does not change location despite the change in PRF (**d** 6.4 kHz, **e** 2.9 kHz) (**d**, **e**)

1. Urinary bladder abnormalities that we should differentiate from RAAs

   The differentiation includes especially debris echoes (Fig. 2d, e) and US findings suggestive of infected urine [3, 24]. Unlike a debris echo, the RAA changes and finally disappears according to the PRF (Fig. 2a–c).
2. Hepatic abnormalities that we should differentiate from RAAs

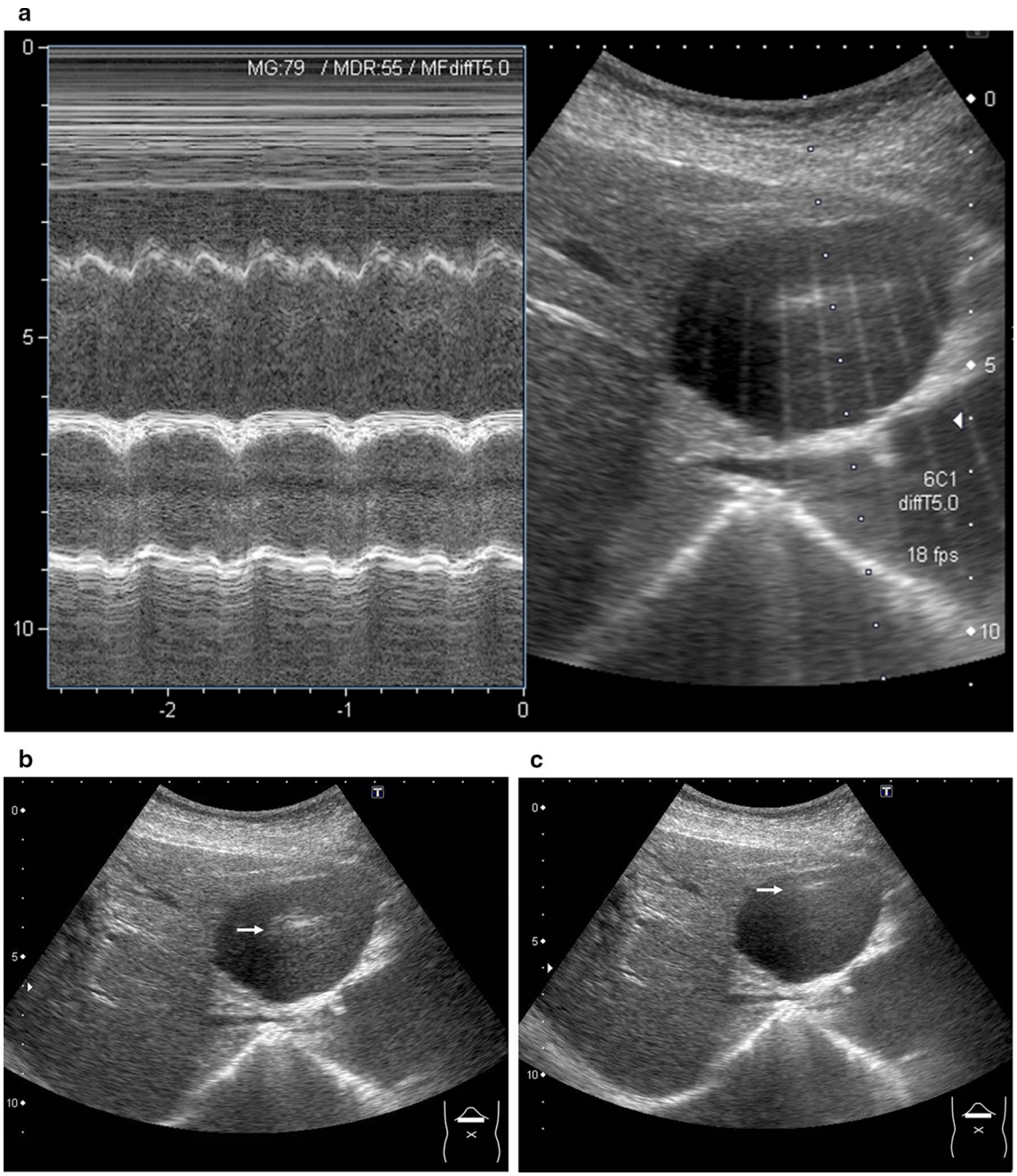

Fig. 3 RAA in a large hepatic cyst. **a** RAA shows a cardiac movement (shown by M-mode). **b**, **c** This mobile RAA also changes location according to the PRF (**b** 7.0 kHz, **c** 6.4 kHz). Arrows: RAA

The differentiation includes two important situations where RAAs pose some diagnostic dilemmas: (a) echogenic mass lesions and (b) complicated cystic lesions.

(a) Differentiation from echogenic mass lesions

The differential diagnosis includes all kinds of echogenic mass lesions, either benign or malignant, including hepatocellular carcinoma, metastasis, adenoma, and hemangioma [25]. RAAs differ generally from echogenic mass lesions in that RAAs take the form of a very ill-defined, finely echogenic area (Fig. 7). RAAs closely mimic irregular fatty liver in some cases.

(b) Differentiation from complicated cystic lesions

The differential diagnosis includes complicated cysts (hemorrhagic, infectious), liver abscess, and liver metastasis

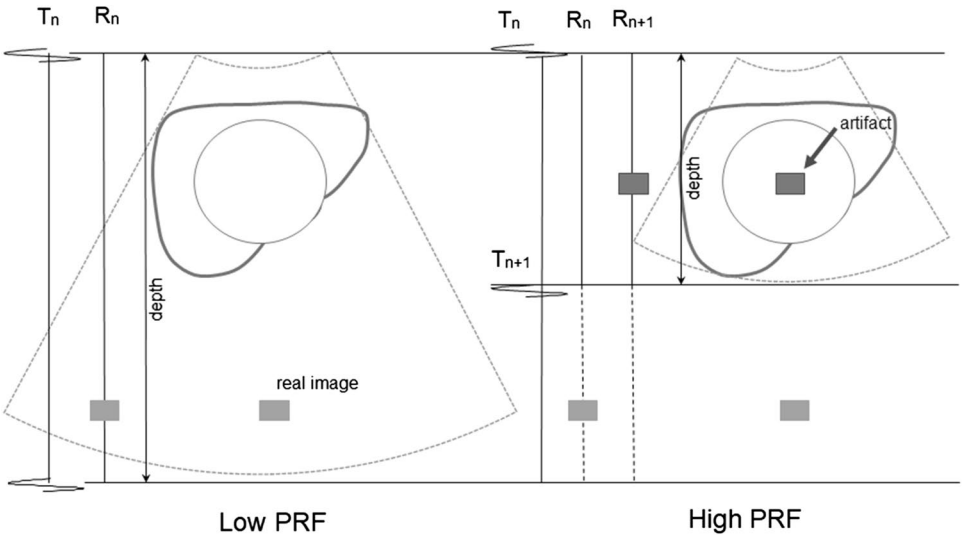

Fig. 4 Schematic drawing of the mechanism of RAAs in the liver. (Left) when the PRF is low, the returning echo from the heart is received during the first pulse's receiving period and displayed at the correct location. (Right) when the PRF is high, the echo from the heart is received during the second pulse's receiving period and displayed closer to the transducer because the returning echo is erroneously assumed to belong to the second pulse. *Tn* first transmitted pulse, *Tn + 1* second transmitted pulse, *Rn* first pulse's receiving period, *Rn + 1* second pulse's receiving period

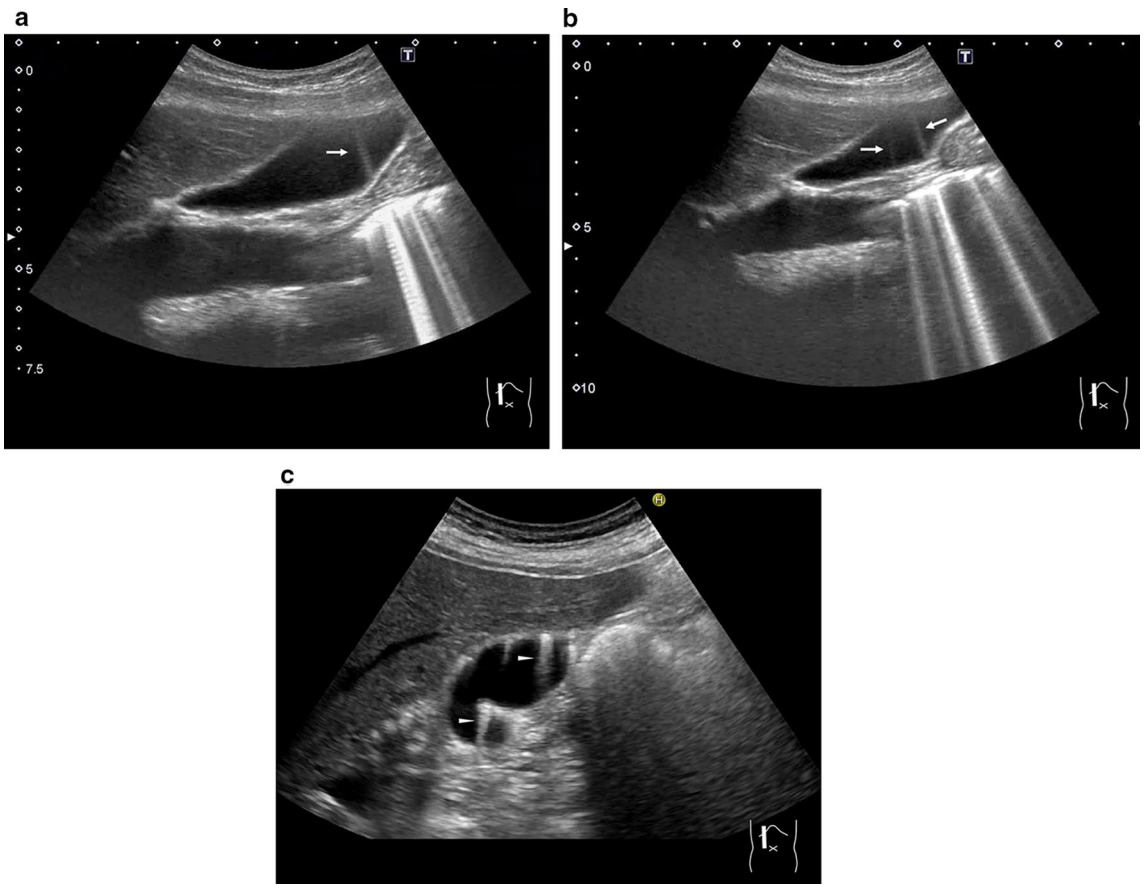

Fig. 5 RAA (fine echogenic lines) in the gallbladder. They appear anteriorly to the ring-down artifacts from duodenal gas. This phenomenon continues to appear regardless of the PRF (**a** 10 kHz, **b** 7.6 kHz). RAA: arrows. Comparison with a comet-tail artifact (arrow heads) in **c**

with massive necrosis [25]. Of these pathologies, intracystic debris echoes (important US sign suggestive of intracystic hemorrhagic or cyst infection) closely mimic RAAs [26]. However, RAAs differ from intracystic debris echoes in that RAAs take the form of a collection of fine echoes flying in the cyst (Fig. 3b) and changing according to the PRF (Fig. 3c); on the other hand, intracystic debris echoes take

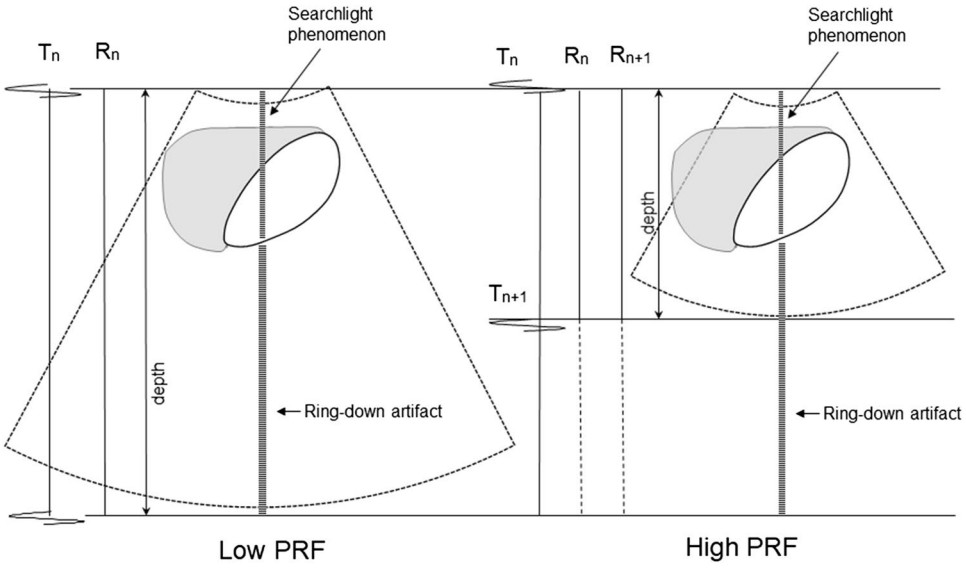

Fig. 6 Schematic drawing of the mechanism of this RAA (searchlight phenomenon) in the gallbladder. (Left) ring-down artifact appearing behind duodenal gas. Fine echogenic lines are seen in the gallbladder because this phenomenon is actually an RAA of a ring-down artifact from duodenal gas. (Right) the searchlight phenomenon does not exhibit a change in location according to the PRF. *Tn* first transmitted pulse, *Tn + 1* second transmitted pulse, *Rn* first pulse's receiving period, *Rn + 1* second pulse's receiving period

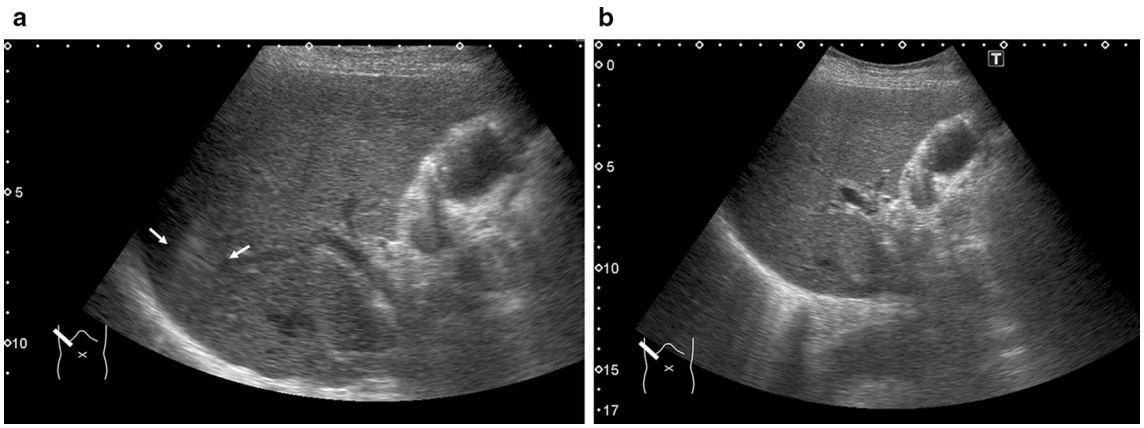

Fig. 7 RAA mimicking an echogenic mass in the liver. US shows an ill-demarcated echogenic area (arrows) in the liver. It becomes progressively more indistinct when changing the depth of view field (**a** 6.4 kHz, **b** 4.5 kHz)

the form of a collection of fine echoes lying in the bottom of the cyst and not changing according to the PRF.

In both cases [(a) and (b)], changing the PRF or, more simply, changing the image depth is the most effective way to differentiate RAAs from real pathologies.

3. Gallbladder abnormalities that we should differentiate from RAAs

The gallbladder is an oval-shaped, thin-walled sac containing a small amount of anechoic bile. This simple structure permits a detailed observation of the whole gallbladder. RAAs mimic the comet-tail artifact, usually associated with gallbladder adenomyomatosis [19–21, 27]. However, RAAs do not decrease in intensity in the depth of view field, unlike the come-tail artifact (Fig. 5c). Unlike the comet-tail artifact, when an RAA (in this case, the searchlight phenomenon) appears, duodenal gas is present dorsally in the same line of sight. Furthermore, the searchlight phenomenon appears only when duodenal gas is accompanied by the ring-down artifact (Fig. 5). The important points of differentiation consist of (a) a decrease (comet-tail artifact) or increase (searchlight phenomenon) in intensity in the image depth and (b) duodenal gas present dorsally to the echogenic line in the line of sight (searchlight phenomenon) [5].

When examining the gallbladder with US, sufficient knowledge of RAAs (searchlight phenomenon) can prevent us from making a hazardous US misdiagnosis.

How to reduce RAAs

There are two ways: (a) change the image depth and (b) change the PRF itself. In all US machines, the PRF changes in proportion to the image depth; thus, when changing the image depth, the PRF changes automatically at the same time. Thus, the easiest way to reduce RAAs is to change the image depth. However, recently, to eliminate or at least reduce RAAs, an effective system has been introduced by many US equipment manufacturers [4]. As mentioned above, PRF is the number of US pulses emitted per second. The pulse repetition period is the time between the beginning of a pulse emission and the beginning of the next one. If this period is elongated (e.g., twice the usual period), the possibility of misinterpretation of the echoes captured by the first pulse as being originated from the second pulse decreases (Fig. 8). This system is theoretically rational and considered to contribute to a decrease in diagnostic confusion between RAAs and real structures [4]. However, this system is not included in all US machines. Extended use of this system will easily reduce the occurrence of RAAs without changing the depth in the near future.

We must emphasize again the relationship between RAAs and PRF. In other words, RAAs do not change according to other factors such as focus, gain, and dynamic range.

The use of compound scanning is not so effective. The beam-former electronics are programmed to emit and receive US beams that are steered from different angles. Then, after acquiring all data, the overlapping frames are combined to form a compound image by using frame-averaging methods. By averaging many frames from different angles, inconstant artifacts are suppressed and constant signals from real structures remain [28]. This suggests that RAAs cannot be reduced using a compound scanning system because RAAs are not an inconstant artifact (all kinds of RAAs), and a

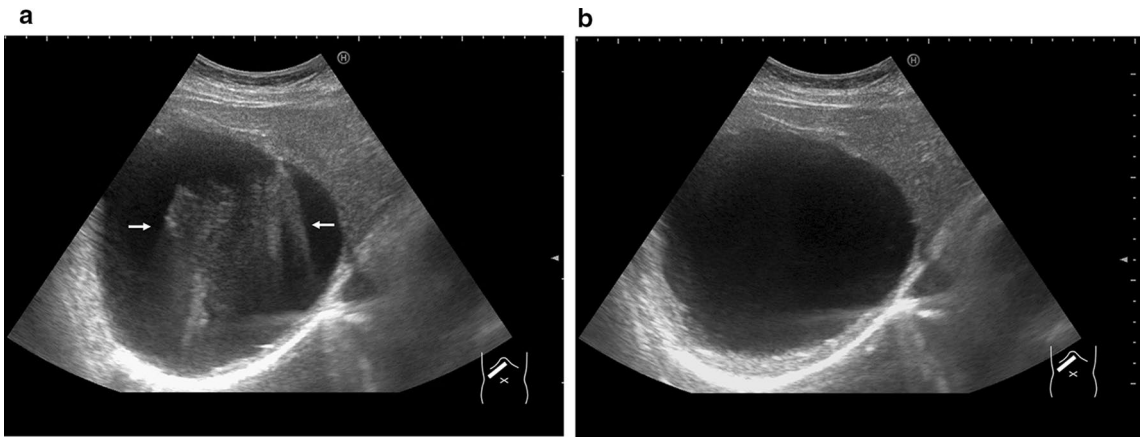

Fig. 8 RAA reduction system and RAA. **a** Hepatic US image at a high PRF. Arrows: RAA. **b** Hepatic US image at a low PRF (half of **a**). Changing the PRF (without changing the depth of view field) contributes largely to reducing RAAs

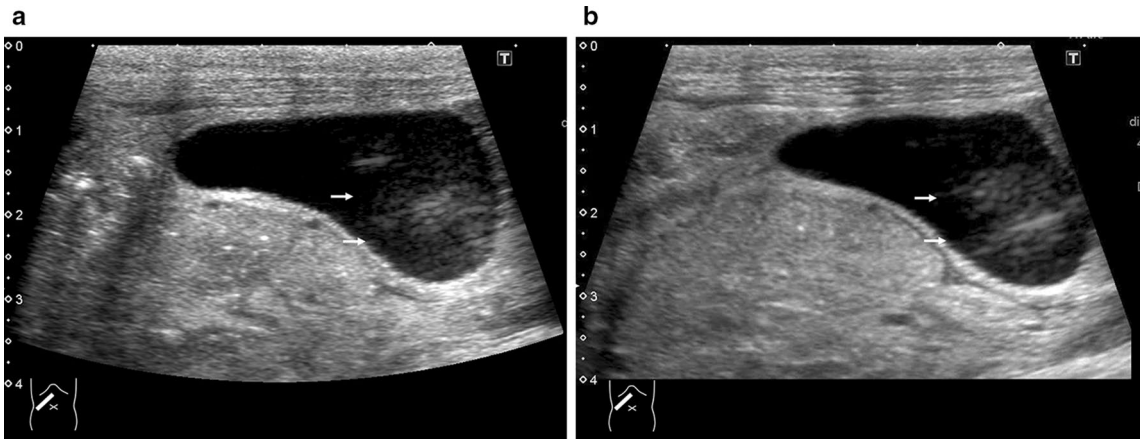

Fig. 9 Compound scanning and RAA. Comparison of RAAs in ascites on noncompound scanning (**a**) and on compound scanning (**b**). Compound scanning does not contribute to decreasing RAAs. Arrows: RAA

frame-averaging system causes the potential for image blurring if the echoes move rapidly (in the case of mobile RAAs). Thus, RAAs cannot be erased as clearly as we might expect with this system (Fig. 9). In addition to the afore-mentioned reduction system, the simplest way to reduce RAAs in a clinical setting is to change the depth of view field, which is useful in the case of static and dynamic RAAs in the urinary bladder and liver. However, at the level of gallbladder, the simplest way to confirm RAAs (searchlight phenomenon) is to observe the gallbladder for a long time, because the artifact appears and disappears according to duodenal movement. Finally, we must emphasize again that at present, the easiest way to reduce RAAs is to change the image depth, because PRF and depth change simultaneously.

Conclusion

In this review, we have described the mechanism of formation of RAAs and their characteristic US pattern. Observation of these echoes at different PRFs is the simplest and most effective key technique for recognizing RAAs. Sufficient knowledge of RAAs can prevent the misdiagnosis of erroneously displayed returning echoes as real structures.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest.

Ethical statements All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964 and later versions.

Informed consent Informed consent was obtained from all patients for being included in the study.

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