# EFSUMB Course Book, 2nd Edition

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## Ultrasound probe quality assurance by the clinical user

**Bálint Botz**[1]

1University of Pécs, Medical School, Department of Medical Imaging, Pécs, Hungary

**Corresponding author**

Bálint Botz MD, PhD

University of Pécs, Medical School, Department of Medical Imaging, Pécs, Hungary

H-7624 Pécs, Ifjúság útja 12.

botz.balint@pte.hu

## The importance and rationale of user-driven quality assurance in clinical ultrasound

Ultrasound devices are delicate and complex machines, with many elements sensitive to physical damage, and prone to be influenced by even subtle manufacturing defects. Thus both inherent defects (e.g. those introduced during assembly) or acquired damage (those sustained during their use) have a potential to induce errors that significantly reduce the performance of the device, and thus deteriorate the diagnostic quality. According to one study more than one in three probes surveyed had demonstrated significant damage during visual inspection, and 13% had damage that warranted immediate replacement (1). Other authors have found 39.8% of tested probes faulty during their survey (2). These concerning data highlight the considerable risk to patients, the inadequacy of quality assurance, as well as the suboptimal level of awareness among ultrasound practitioners.

Unfortunately knowledge of the various forms of ultrasound probe defects is generally limited even among medical imaging professionals, as this is rarely considered part of the curriculum, and is also not an integral part of most textbooks. However, a user familiar with these errors can identify most of the clinically significant ultrasound probe defects, and do this without the need for material investment into special tools. This chapter provides an overview of ultrasound probe defects that can be encountered and diagnosed in the daily practice, even in a low resource setting. The aim is to make users able to identify the most common forms of these defects, which makes an early recognition of probe faults possible. This in turn makes it possible to request further testing with specialized equipment, and consider potential solutions (repair or replacement). As an important caveat these methods are not a substitute for diagnostic assessment done with designated tools (electronic testing equipment and tissue mimicking phantoms etc.), but should ideally serve as an “early warning system” where users can raise the red flag and request early intervention and further assessment by medical physics professionals. It has been shown that a thorough visual assessment technique has excellent detection sensitivity even compared to electronic probe testing, and thus can serve as the foundation for the daily or weekly quality assessment done by the user (3).

It has been proven that the majority of ultrasound probe defects can “fly under the radar” for extended periods if a targeted search strategy is not employed. This is partially due to the ever increasing amount of post-processing applied, which can mask early warning signs of probe faults (4). Fortunately, it has been also shown that regular observational assessment of ultrasound probes by users can identify the majority (more than 90%) of the clinically significant probe defects.

As many probe defects can also be inherent failures of the device (i.e. manufacturing issues) thorough assessment of newly acquired equipment in the setting of formal acceptance testing is also recommended (1). Concerning data have been provided by a recent study on acceptance testing where 13.7% of new probes have demonstrated significant image quality reductions during visual inspection (5).

## Examination technique

Ultrasound probe defects arise due to the hardware failure of the ultrasound equipment. They result in focal or global image quality degradation, and in severe cases may even cause complete signal loss. Test phantoms or electronic testing equipment are very sensitive and specific in this regard; however their availability is generally limited. Furthermore they have to be tailored to the type of probe undergoing investigation (e.g. linear, curvilinear, phased array etc.). Significant probe defects result in the appearance of characteristic image artifacts, which can and should be distinguished from those resulting from physical phenomena encountered during scanning (6). In theory probe defects influencing image quality should be identified during examinations, but it has been shown that in real world situations most of these errors lurk insidiously for extended periods, evading early detection. Clinical ultrasound images are due to their nature constantly changing and inhomogeneous, and its precisely their inhomogeneity that carries most of the diagnostic information. In such an environment subtle, stationary artifacts that could herald equipment damage are not easy to detect, especially as the user is already focusing on a different task (scanning and evaluating the patient). To accentuate and recognize artifacts caused by probe damage we need a more homogeneous backdrop, and the in-air reverberation artifact is a readily available candidate for this role. It has been shown that implementation of regular visual inspection of the probes and their in-air reverberation pattern has been is a prudent approach to detect a substantial majority of such probe faults (1).

## Visual inspection of probe integrity

Each investigation should begin with careful assessment of the probe itself. Visually apparent damage (cracks of the housing, scratches of the particularly vulnerable lens surface, wheel marks on the cable e.g.) indicate that potentially significant damage has been sustained.

**Important Note 1** **If the probe integrity is potentially compromised, gel or water ingress might be possible. Such probes need to be immediately taken out of service, and further electrical safety tests need to be carried out by trained professionals (4).**

Significant physical damage may even warrant immediate removal of the probe without further testing (Figure 1). The lack of visually apparent damage however does not rule out the presence of probe faults per se. Even if external damage such as cracks do not influence the image quality at the moment, they can pose a serious infection control issue, by making proper cleaning of the probe impossible (1). Furthermore, if they remain unattended external damages can progress, and ultrasound gel leaking into the internal elements of the probe can induce further deterioration. Thus, early intervention and repair of probes with visible damage is of key importance.

**Tip 1** **External structural probe fault on its own represents a serious cross-contamination risk for patients, and, poses a risk of further structural damage.**

**Figure 1** **A full thickness tear of the probe lens means that gel can penetrate even down to the piezoelectric elements of the transducer. Also, this probe cannot be properly cleaned between examinations. Thus, it had to be disconnected**

**immediately. Subsequent re-lensing of the probe was successful, at a fraction of the cost of the new probe.**

This should be followed by switching on the probe in question. The reverberation pattern in-air is usually apparent as several parallel running bright lines in the near-field. If necessary, adjustment of B-mode gain and depth can better accentuate these streaks. The lines should be normally parallel running, and homogeneous. Decreased or increased brightness, or non-parallel running lines likely represent equipment failure.

**Remember 1** **The below detailed technique applies to linear and curvilinear array probes in particular. Due to their unique beam production, assessment of phased array probes is more difficult, and requires a different approach. This will be briefly discussed at the end of the chapter.**

**The normal reverberation pattern**

The investigation should continue with the probe staying switched on, and the image un-freezed. For this part we should select a preset which represents a typical area of use for the selected transducer (e.g. abdominal preset for a curvilinear array probe, or thyroid preset for a linear array probe). The in-air reverberation pattern should be in the focus of our investigation. As we have mentioned, these are the distinct, parallel running bright artifacts appearing in the near field of the image (Figures 2-5). Their number, brightness, and sharpness is dependent on the type of the probe, the manufacturer, the preset, and various further user-influenced parameters (B-gain, tissue harmonic imaging, line density etc.). Thus familiarity with the normal in-air reverberation pattern of your probes substantially facilitates your judgment.

**Figure 2** **In-air reverberation of a convex probe using the default settings (7).**

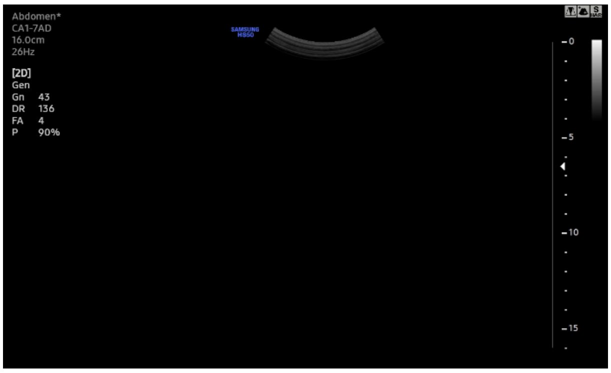


**Figure 3** **After adjustment of depth and gain (7).**

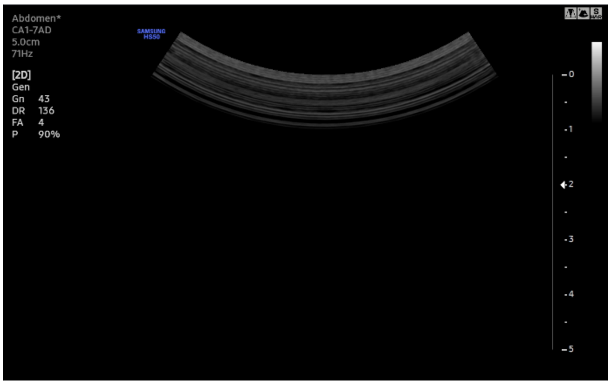


**Figure 4** **In-air reverberation of a linear array probe (7).**

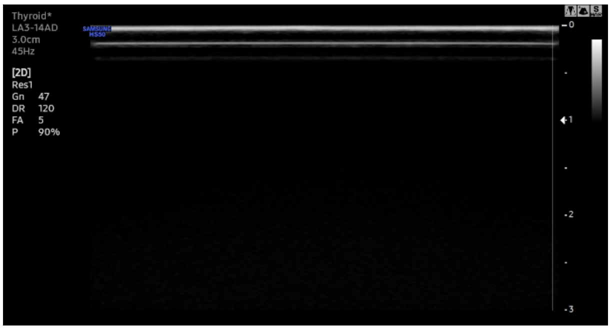
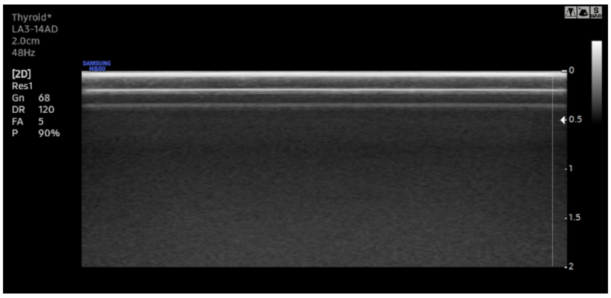


**Figure 5 Optimized image (7).**



**Tip 2 Store representative examples of the normal in-air reverberation pattern of your probes as part of the first checkup of newly acquired equipment. This will help during future monitoring and can serve as the baseline to compare with.**

After choosing an appropriate preset the user should reduce the depth in order to increase the size of the reverberation artifacts on the image (be careful not to clip out the edge of the image however). Adjust the B-gain until their visibility is optimal (not too bright but not too dark either), and reduce the amount of noise to the minimum (typically noise disappears last from the far-field). If there is excessive noise then subject the probe to further noise testing (see later).

Use a single focus and position it in the near-field (typically the most superficial focus position results in the best depiction of reverberation lines). Time gain compensation (TGC) sliders are typically best positioned centrally. It is also important to also check the reverberations using the fundamental frequencies with post-processing and tissue harmonic imaging in particular being switched off, as this can also sometimes “blur” the reverberation lines. It is very important to switch off acoustic compounding, beam steering, and the virtual convex/trapezoid option which is available on most linear array probes (4,5). The optimized image should be stored in the Picture Archiving and Communication System (PACS) with all the above mentioned parameter adjustments indicated, to facilitate further comparisons.

Next, we will discuss artifacts that can distort these lines, and thus indicate of hardware damage to your ultrasound device.

**Tip 3 Make sure to assess the probes using a preset that represents their typical area of use. Adjustment of the above mentioned scanning parameters improves the visualization of the in-air reverberation pattern, and thereby increases sensitivity for probe faults.**

**Advanced Tip 1 Storing the individualized and optimized "test" preset of each probe will make future monitoring considerably easier and saves time.**

**Noise assessment**

The aim of this test is to observe the B-gain at which noise completely disappears from the image, and document the gain level. For this purpose a typically used preset is selected, and depth is increased so that the far-field becomes visible. The gain is then increased to the maximum and then gradually reduced until image noise is eliminated even from the deeper regions [Figures 6-8].

**Figure 6 At maximum B-gain considerable image noise can be seen.**

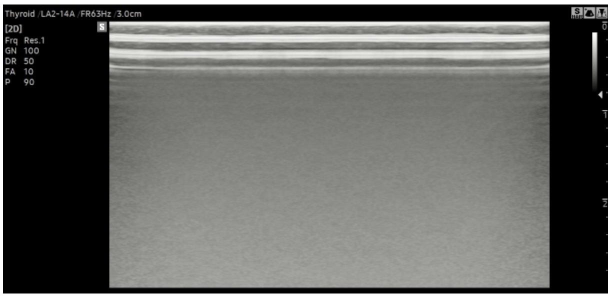

Thyroid /LA2-14A /FR63Hz /3.0cm
[2D]
Frq Res.1
GN 100
DR 50
FA 10
P 90

**Figure 7 As the gain is reduced noise becomes more subtle and predominantly present in the far-field.**

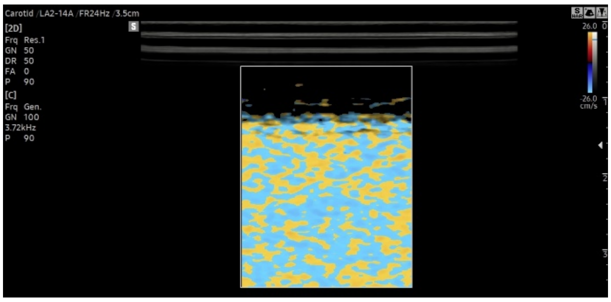
Thyroid /LA2-14A /FR63Hz /3.0cm
[2D]
Frq Res.1
GN 57
DR 50
FA 10
P 90

**Figure 8 Virtually all image noise is eliminated at the noise threshold.**

Thyroid /LA2-14A /FR63Hz /3.0cm
[2D]
Frq Res.1
GN 50
DR 50
FA 10
P 90

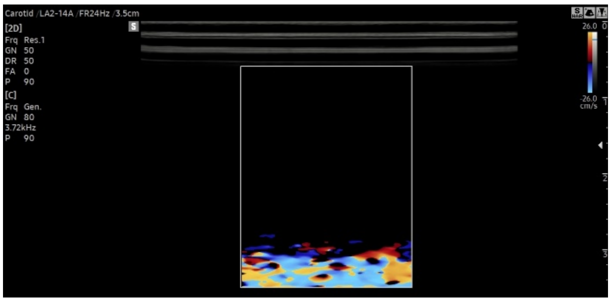
Noise testing can be done with pulsed wave (PW) Doppler, with the sampling gate positioned in the center of the image, and also for colour Doppler (colour box positioned in the center of the deeper part of the image). Again record the gain levels at which noise disappears from the image (4). Excessive noise present at even low gain levels warrants further equipment testing by professionals (Figures 9-14).

**Figure 9 At maximum gain the entire colour box is filled with spurious noise signal.**



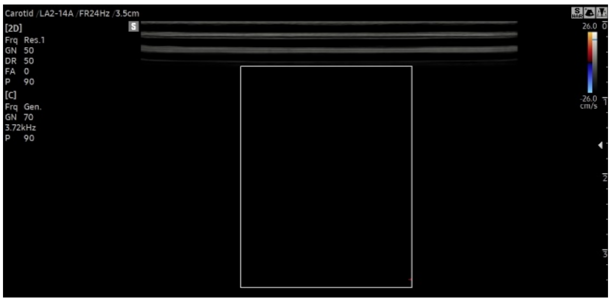
Carotid /LA2-14A /FR24Hz /3.5cm
[2D]
Frq Res.1
GN 50
DR 50
FA 0
P 90
[C]
Frq Gen.
GN 100
3.72kHz
P 90

**Figure 10 As the gain is reduced noise persists in the deeper regions.**



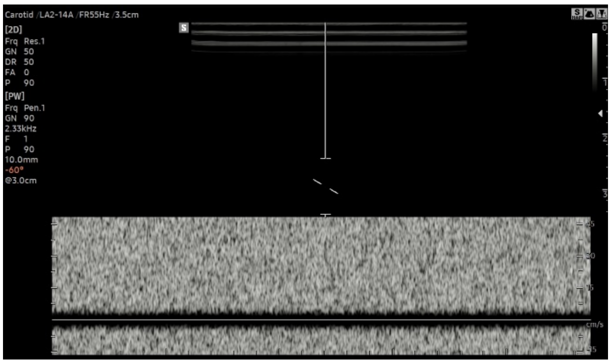
Carotid /LA2-14A /FR24Hz /3.5cm
[2D]
Frq Res.1
GN 50
DR 50
FA 0
P 90
[C]
Frq Gen.
GN 80
3.72kHz
P 90

**Figure 11 At the noise threshold virtually all noise is eliminated.**



Carotid /LA2-14A /FR24Hz /3.5cm
[2D]
Frq Res.1
GN 50
DR 50
FA 0
P 90
[C]
Frq Gen.
GN 70
3.72kHz
P 90

**Figure 12 PW Doppler at maximum gain shows considerable noise. Note the sampling gate positioned in the center of the image, and in the far-field.**



Carotid /LA2-14A /FR55Hz /3.5cm
[2D]
Frq Res.1
GN 50
DR 50
FA 0
P 90
[PW]
Frq Pen.1
GN 90
2.33kHz
F 1
P 90
10.0mm
-60°
@3.0cm

**Figure 13 Signal is considerably reduced as the gain is decreased.**

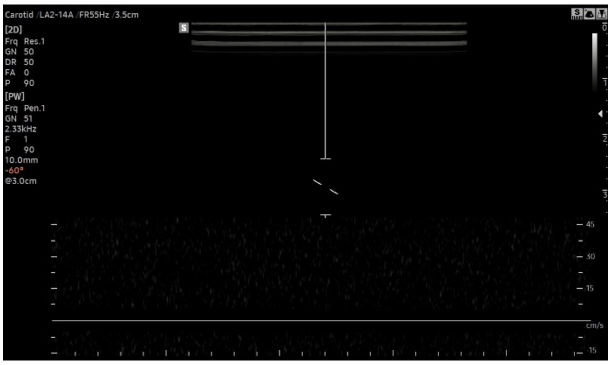
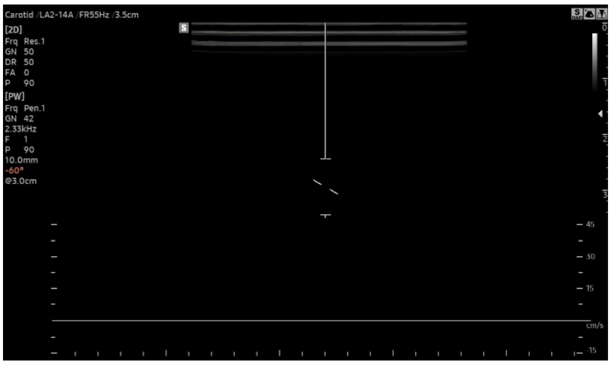


**Figure 14 At the noise threshold virtually all noise is eliminated.**



## The most common forms of probe defects and their appearance

Below we will discuss the major forms of probe defects. Note that these often occur in combination with each other. Furthermore some forms such as internal delamination often show gradual progression with time. Also, some forms of damage such as cable injuries are prone to mimic other types of probe defects. The point is however not to make a forensic level diagnosis of the underlying problem, but to identify red flags that require further assessment with more sophisticated methods, or necessitate probe replacement or repair with high certainty.

### Axial banding and dropout

Axial banding represents a focal loss of continuity in the reverberation lines. It is usually apparent and readily distinguishable in the near-field, and it may slightly broaden with the depth increasing (Figures 15-17). It may influence all or only the deeper reverberation lines. Dropout represents a complete malfunction of piezo elements in the affected area and it is the most common cause of axial banding. It usually represents a serious injury of the probe (dropped probe or puncture injury). Further characterization of axial banding and suspected dropout can be conducted using the paperclip test (described in detail later).

**Figure 15 Dropout represents a focal gap in the reverberation artifact (8).**

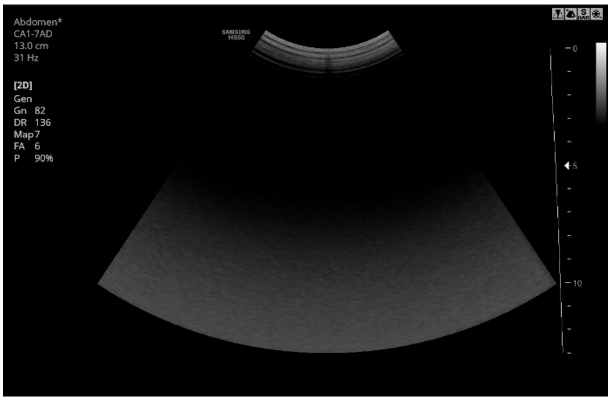


**Figure 16 Optimized image of the defect (8).**

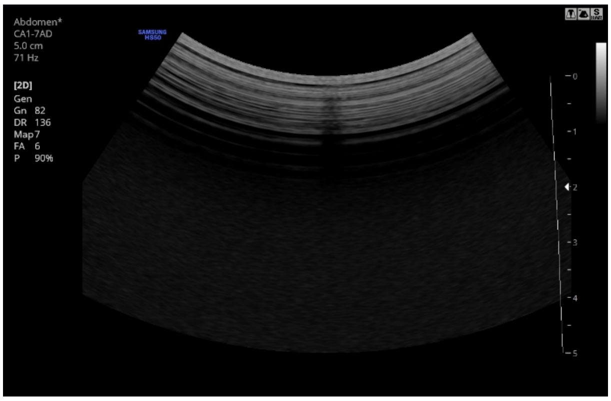
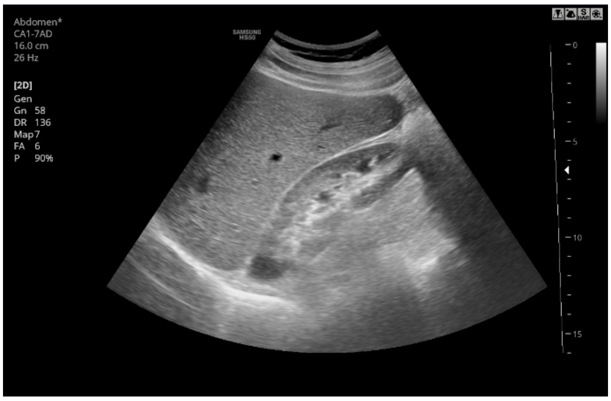


**Figure 17** **The artifact was almost inapparent during scanning. Further assessment revealed a tiny puncture injury of the probe, most likely inflicted during a fine needle aspiration biopsy earlier (8).**



If the dropout is acquired, the lens surface should be scrutinized to look for a visible damage (e.g. puncture entry point). In rare cases it can be inherent, which represents a serious manufacturing defect.

**Tip 4** **One or more focal axial dark bands in the reverberation lines are most likely to be dropouts.**

It has been proven that dropout can influence spectral or colour Doppler measurements (typically causing a decrease of the measured velocities) (9). It is advised not to place a Doppler beam in the area affected by dropout in any case. If this is not feasible i.e. the dropout is large or centrally located, then probe repair or replacement need to be considered.

**Tip 5** **Dropouts not only degrade image quality; they also reduce the reliability of Doppler measurements.**

## Delamination

Delamination is a typically more subtle, and also more common form of probe defects. In this cases the reverberation lines are focally disrupted, but not entirely absent (Figures 18-20).

**Figure 18 Subtle, focal inhomogeneity of the reverberation lines on the left, but no defect (10).**

**Figure 19 The irregularity is better appreciated on the magnified image, and can be confirmed as delamination (10).**

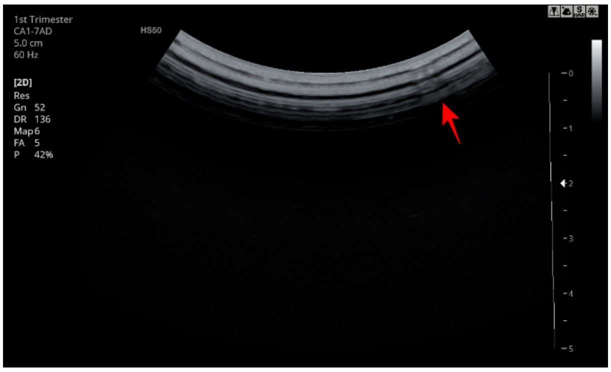
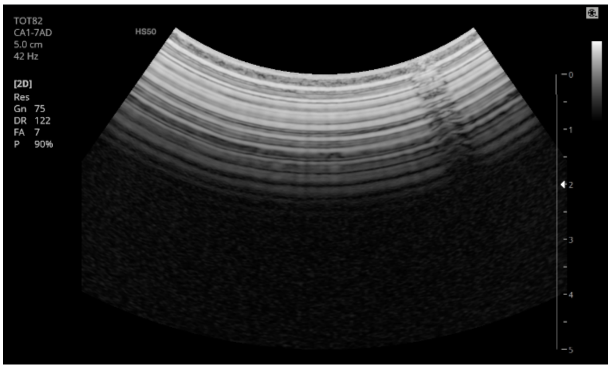


**Figure 20** **Further optimization can substantially facilitate assessment (image courtesy of Dr. András Tóth)**



The underlying cause could be again either blunt or penetrating trauma to the probe, or manufacturing issue. A dropped probe is particularly likely to show this kind of artifact. The etiology of delamination is most commonly due to focal separation of the internal layers of the probe, or weakness of piezo elements. Delamination can remain stable or progress gradually into complete dropout as layer separation progresses. Most studies have found it to be the most common form of probe faults.

**Tip 6** **Delamination can be discrete, and its mild forms are hard to be distinguished from the minimal unavoidable irregularity of the reverberation lines. It has a potential to progress, and therefore new probes should be particularly scrutinized for delamination.**

## Lens nonuniformity

A distorted orientation, waviness, or uneven distance between the reverberation lines indicates lens nonuniformity (Figures 21-22).

**Figure 21 Striking irregularity of the reverberation lines is seen on the image.**

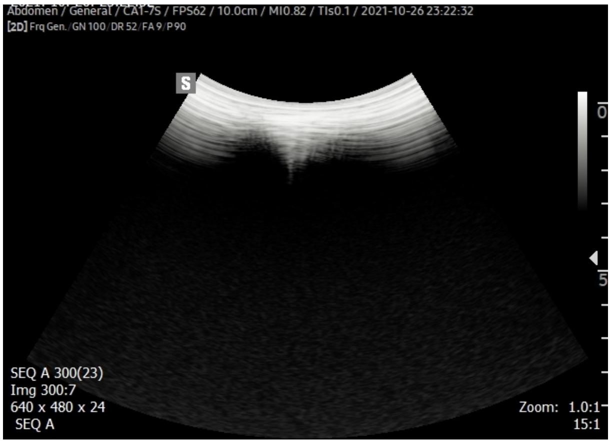
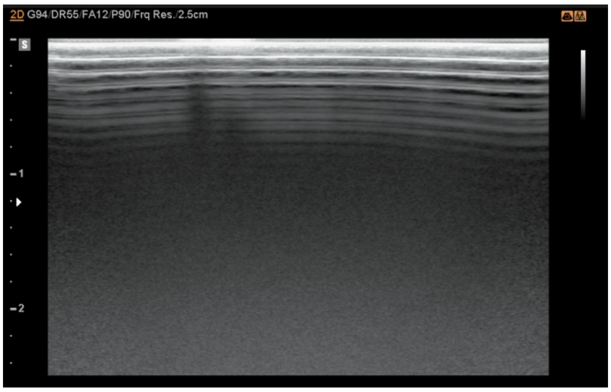


**Figure 22 Peculiar "waviness" of the reverberation lines on a linear array transducer, another example of nonuniformity (accompanied by discrete axial banding).**



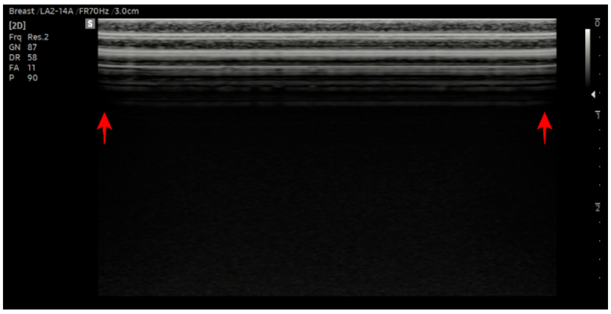
The most common cause is the uneven thickness of the lens material due to either material fatigue, uneven wear, or improper lens repair. It is less likely to be caused by accidents. The distortion can influence the image quality to a varying degree, and further testing of the affected probe with dedicated tools is warranted.

**Tip 7 Nonuniformity signals a lens irregularity, and can result in significant image distortion.**

## Lens wear

A symmetric weakening of the reverberation lines along the peripheries of the image is likely the sign that the probe is aging, to some extent it can be even normal (Figure 23).

**Figure 23** **Bilateral, subtle, and symmetric weakening of the deepest reverberation lines in particular can be a normal phenomenon, or if novel can be a sign of lens wear.**



If there is no asymmetry, the artifact is subtle, and the probe has been in use for extended periods of time (typically years) then lens wear is the most likely culprit. It usually remains discrete; progression is also very slow. Lens wear alone only indicates that the probe is past its prime, and getting closer to the end of its lifespan.

**Tip 8** **Lens wear is typically a sign of an aging probe and is usually mild. It is important to differentiate it from more sinister forms of image artifacts.**

## Cable damage

We should begin this subsection with a caveat: cable damage is a great mimicker and can simulate most of the aforementioned artifacts. The point is once again not to conduct a forensic level analysis, but to raise the red flag: the probe in question is not meeting standards.

Cable damage is most often blunt (think of wheel rollover), resulting in shearing injuries of its delicate internal fibers. This can lead to crosstalk, resulting in spurious B-mode or colour Doppler signals. In more severe cases dropout-mimicking artifacts can occur. An intact cable housing is not a guarantee that the internal fibers have also retained their integrity. Thus, its particularly important to prevent cable rollover or jerking accidents as much as possible, and conduct a thorough quality check after such incidents (Figures 24-26). The aforementioned noise testing technique using B-mode and colour Doppler is particularly recommended.

**Figure 24 In-air reverberation of this visually intact probe only shows slight inhomogeneities.**

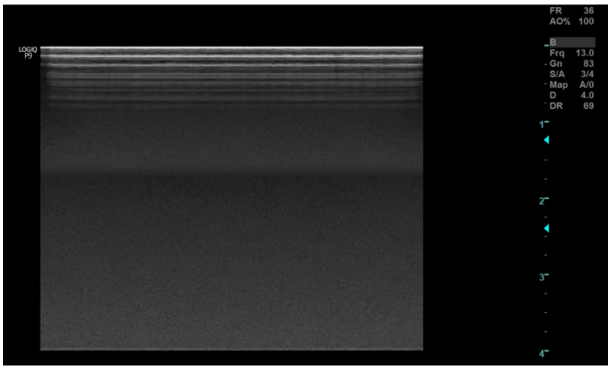


**Figure 25 After applying a layer of gel further “bar code-like” artifacts become apparent in the far-field.**

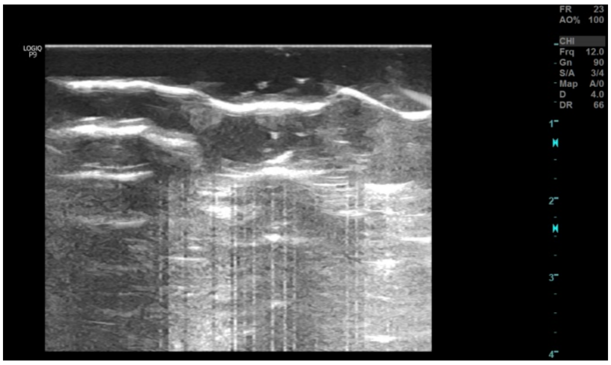
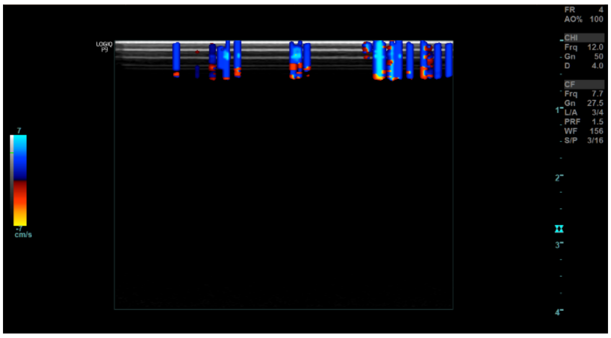


**Figure 26** **With colour Doppler spurious, alternating band-like signals can be seen in the near field. This could be accentuated by gently bending a certain point of the cable. Suspected blunt cable damage.**



**Tip 9** **Cable damage is a great mimicker. Suspect it if there was a documented cable injury and multiple, peculiar B-mode or colour Doppler artifacts appeared.**

In some cases even gentle bending of the previously damaged cable can accentuate cable damage-related B-mode or colour Doppler artifacts, though it is not inevitable. It should be emphasized that no testing should be conducted if the cable housing integrity is broken, in order to prevent further, potentially fatal injury to personnel (see the important notice below).

**Important note 2** **If the cable or probe insulation is compromised there is a risk of potentially lethal electric shock to the personnel or patient! Testing by the user in this case is prohibited. The damaged device should be switched off, and disconnected from the electric grid following the institutional and national protocols, and the relevant emergency shutdown procedure protocol issued by the manufacturer. The responsible personnel should also be notified immediately.**

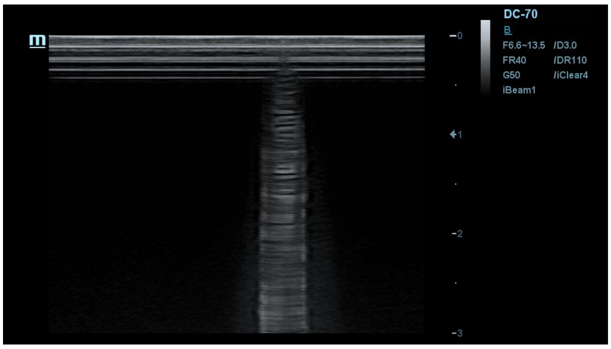
## Probe connector or port faults

If the above mentioned artifacts are encountered we also have to rule out a faulty probe connector or port as the cause of the issue before reaching a premature conclusion. For this purpose the probe must be switched off, disconnected from the original connector. Check the connector elements for abrasions, corrosions, or misaligned pins. Notify the responsible personnel in case of visible damage. If no visible injury is seen continue by moving the probe to a different port, and test the in-air reverberation pattern again in the same manner. If the artifact is no longer visible a faulty probe connector or port is the most likely cause, whereas if the issue persists then probe or cable fault can be considered more likely (1,4).

## Further assessment: the paperclip test

The paperclip test has been proposed as another low resource, simple test for probe assessment. During the test a paperclip is translated along the long axis of the lens surface maintaining a perpendicular orientation to the axis of the image. Applying a thin layer of gel or water can make the test easier particularly if the lens material is hard. The goal is to observe the focal reverberation artifacts arising in the near-field as the paperclip is gently moved along (Figure 27).

**Figure 27 A paper clip test is being conducted (for the cine loop recording see the reference) (11).**



Focal inhomogeneities and subtle weakening of the reverberation artifacts may indicate piezo-element weakness or malfunction. Changes in its orientation highlight image distortion (Figures 28-29)

**Figure 28 Paperclip test of the curvilinear array probe with nonuniformity (see Figure 12 as well). In the unaffected area the artifact maintains a perpendicular orientation to the probe surface as shown by the dashed red line.**

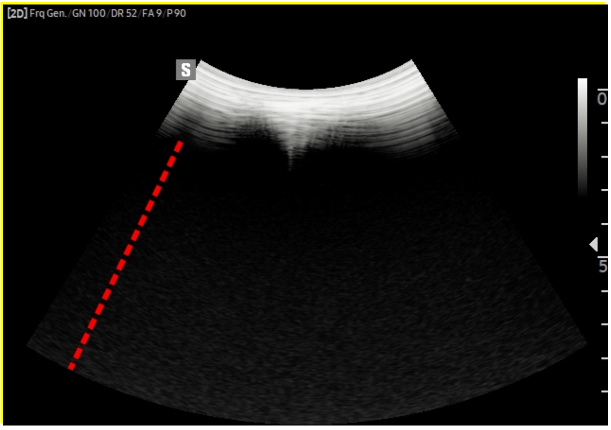
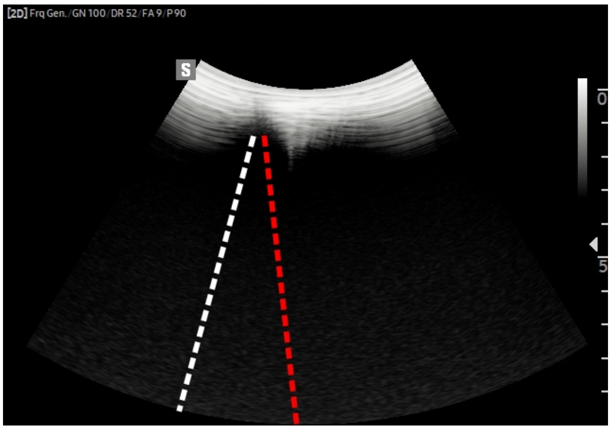


**Figure 29 In the affected area the orientation of the artifact shows angular deviation from the expected 90 degrees, indicating image distortion. The expected normal direction is indicated by the white dashed line (Courtesy of Dr. Ákos Járay).**



Unfortunately the test is highly subjective (even minimal, transient loss of contact can cause a "pseudo-dropout"), furthermore there is risk of causing further damage to the transducer lens. It has been however proposed as a good second line investigation technique for assessing the severity of dropouts. If the visually apparent dropout coincides with marked reduction of the brightness of paperclip reverberation artifacts then presence of dead piezo elements is likely (1,5).

**Tip 10** **Depending on lens material a minuscule amount of water can help the visualization of the reverberation caused by paperclip, and also reduces the chance of probe injury during testing. Double check focal inhomogeneities as transient poor contact can mimic dropout.**

## The specificities of phased array and 4D probes, and those with complicated geometry

All the aforementioned probe defects and their appearance, as well as the conventional paperclip test apply to two of the most common probe geometries: curvilinear and linear array probes. Phased array probes have received less attention in this regard, and their quality testing without testing equipment is far more challenging. The reason is the unique alignment of the phased array transducer, where the entire aperture is used for all beams, and all beams are by default steered (5). Thus, a small defect will be averaged out over the entire field of view, focal error such as dropout and delamination will therefore remain invisible early on. Due to the unique probe geometry and small lens surface the near-field is also extremely narrow, which results in the absence of distinguishable reverberation lines (Figures 30-31).

**Figure 30 Default in-air reverberation artifact of a phased array probe (12).**

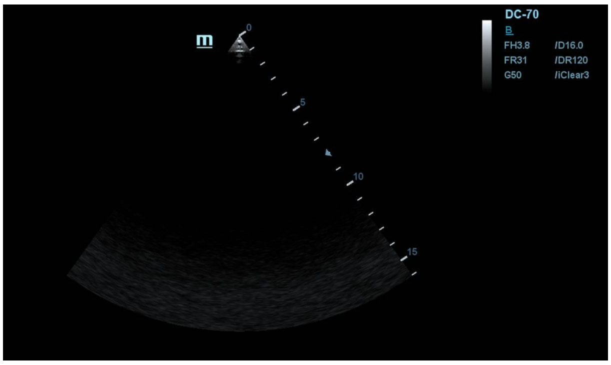
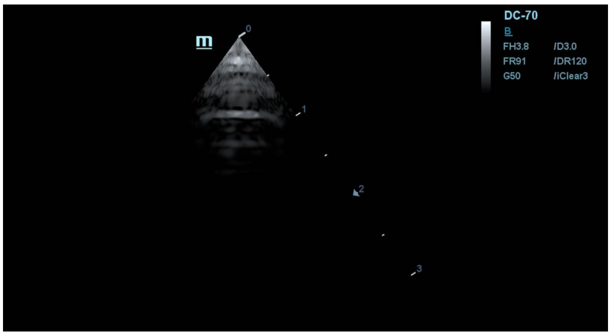


**Figure 31 Even after adjustments the near-field is still extremely narrow, with no clearly defined, parallel running reverberation lines (12).**



The modified paperclip test has been proposed as a relatively simple test of phased array probes, in this case rather than B-mode the probe is switched to M-mode. An at least medium depth (approximately 10 cm or more) should be set to ensure that the entire probe aperture is in operation. The focus is positioned in the mid- or far-field of the image, and the M-mode sampling line to the center of the image. Thereafter the paperclip is translated along the probe surface as described earlier. Defective piezo elements will be represented as dark axial bands on the M-mode image, similarly to the B-mode dropouts of curvilinear or linear array probes we have discussed earlier (1).

**Tip 11 Dropouts of phased array probes can be uncovered using the modified paperclip test.**

There is limited experience with the user-driven quality assurance testing of highly specialized probes with complicated geometry, such as most endocavitary, endoluminal, and endovascular probes. While some of the aforementioned principles can be theoretically applied, real-world evidence of it is currently minimal. For 4D probes in particular visual inspection techniques are considered insensitive and therefore unsuitable. Quality assurance of such probes is best conducted using dedicated testing equipment following the recommendations of the manufacturer (1).

**Tip 12 4D probes can mask even significant probe faults during visual assessment. Such probes require dedicated testing equipment for quality assurance.**

## Preventing probe damage

As we have seen the majority of clinically significant probe defects arise due to serious blunt or penetrating injury to the probe or its cable. While accidents are to some extent unavoidable, some good working practices can reduce the frequency of serious incidents, and thereby increase the longevity of your equipment (Figure 31).

**Figure 32 A substantial number of equipment damages can be prevented by a safe practice. A cable trailing on the ground is one of the most common and easily avoidable source of probe damage.**

First of all you need to consider the throughput of your scanner and its environment. It has been proven that probes used outside imaging departments have a higher incidence of significant probe faults (1). An ultrasound device which is stationary, used only during normal working hours, and in an outpatient setting where no invasive procedures are performed is e.g. in a relatively low-risk environment. In contrast a device which is in constant use in a high-pressure environment such as a busy emergency room or ward and is moved around a lot for urgent and sometimes invasive procedures is a textbook example of a high-risk situation regarding probe damage. Nonetheless even in the latter case you can at least reduce the chance of serious damage by following a safe technique. First of all the probes should always be stored securely in their designated holders on the device while not in use, Secondly gel should be preferentially applied directly on the examined body region rather than onto the probe to reduce the chance of gel bottle-induced injury. The cables should never trail on the ground. Especially a heavy, high-end ultrasound device can crush the probe cables under its own wheels. The chair of the user can also crush the cables. Risk of cable rollover can be further reduced if the brake of the device is by default engaged. The secured position of the cables must be confirmed before the scanner is moved.

**Tip 13** **The probe stays in its holder (when not in use), the gel is applied onto the patient, and the cables never trail on the ground – these simple techniques go a long way in reducing equipment damage.**

The patient bed can also crush or jerk the cables if moved around carelessly. Anticipate this by maintaining a safety distance between the patient bed and the device before the bed is moved. The patients should be asked to remove body jewelry which can scratch the soft transducer lens. Puncture injuries during invasive procedures are unintentional and their complete prevention is unachievable. Here the focus should be on their immediate reporting and the assessment of the damaged probe. If the puncture is relatively superficial and reported early on there is a fair chance that the probe can be repaired. If the damage is ignored, then gel fluid slowly penetrating into the internal structure of the probe can cause further, potentially irreparable damage.

**Tip 14** **Carry out a thorough inspection as soon as possible if a probe has sustained blunt or sharp injury, even if there is no visible external damage.**

## Establishing a user-driven monitoring system

Prevention and early detection form the foundation of a user-driven ultrasound quality assurance program. Education of all ultrasound users about the probe defects and their appearance should be encouraged. Maintaining a regularly updated and accessible document (e.g. a shared spreadsheet document) that includes all devices and their probes helps tracking potential quality assurance issues and the decisions (Table 1).

**Table 1 An example of a shared spreadsheet for registering and tracking scanner and probe damage and other quality problems.**

| Location | Type of US scanner | Scanner damage | Transducer type | Transducer damage |
|---|---|---|---|---|
| E.g. outpatient examination room 1 | The type of the device, name of the manufacturer, year of manufacture. | Any injury to the device, casing, cable holders, keypad, monitor etc. Add more rows as needed. | The type of transducers, add a new row for each probe. Note if the probe has been previously repaired. | Probe or cable injury, image artifacts concerning for probe fault. Indicate the date of detection, and the name of the user who detected it. Final decision (follow-up, repair, replacement etc.) should also be indicated. |

It is also prudent to 1) implement acceptance testing i.e. investigate all newly acquired equipment before use, 2) schedule regular follow-up tests which can uncover early signs of transducer quality issues. Exact timing of such tests should be tailored to the setting in which the device is used. An at least quarterly test of all probes is recommended as the minimum (13). It has been shown that even among probes that have passed their most recent annual testing almost one third demonstrate faults, indicating that annual testing alone is insufficient (14,15). More detailed guidelines and recommendations have also been published about the proper timing for a variety of application areas, based on which equipment tests of varying levels can be scheduled (4,16,17). As we discussed earlier more frequent testing might be sensible for a probe which is utilized in a high-risk environment. It is also beneficial to designate local experts who can oversee retesting, and confirm suspicions of probe damage. At this point it has to be also emphasized that probe testing is only a part of overall ultrasound quality assurance, which should incorporate testing display adjustments and integrity, scanner housing and air intakes, as well as regular electric safety testing (conducted by the responsible personnel according to the applicable local guidelines). The details of these further test go beyond the scope of this chapter. The particular importance of probe testing is however underlined by their vulnerability, as it has been shown that almost 90% of ultrasound equipment failures involve the transducers (13).

The frequent quality assurance testing inevitably constitutes excess workload for the responsible personnel, but its importance is underlined by the alarmingly high rate of probe faults. Quality assurance should be encouraged by integrating and scheduling it into the workflow. There are also promising early results indicating that at least part of the quality assurance testing can be in the future automated with dedicated image analysis software (18–20).

As a final remark it has to be stressed once again that quality tests conducted by the user without specialized equipment are not a substitute of electronic or tissue mimicking phantom testing conducted by specialists. It is a complementary technique similarly to the way e.g. point of care ultrasound (POCUS) relates to a scheduled ultrasound exam on a stationary high-end scanner. Perhaps the most important point is however to nurture a culture of transparency, where users are not afraid to report accidents that might have resulted in equipment damage. A professional, non-judgmental approach, and a focus on the solution rather than the problem is of key importance in this regard.

## Conclusion

In this chapter we have discussed the various forms of ultrasound probe defects, their appearance, and the technique for identifying them in our practice using simple observational techniques available to all users.  POCUS has gained considerable momentum in the recent years in medicine. In a similar vein point of care ultrasound quality assurance can be proposed as a way to make an early diagnosis of the problems that can deteriorate diagnostic performance possible. We have seen that this is doable without any sort of expensive or complicated apparatus, and thus can be integrated into even the most low-resource and financially deprived settings. All clinical ultrasound practices should strive to make their personnel an integral part of their quality assurance program. It is also crucial to understand that ideally user-driven testing is not a substitute of complex and quantitative testing done by device experts, but can enhance its yield by pinpointing which probes need to undergo more comprehensive further testing. We have to also realize that in some low income regions, this point of care testing might be the only kind of quality assurance that can be realistically conducted. In summary all ultrasound practitioners, and most importantly their patients can benefit for introducing user-driven quality assurance programs.

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## Multiple choice questions

**MCQ 1 Visible cracks of the probe casing can result in the following detrimental effect?**

a) Risk of cross-contamination for patients
b) Further progression rendering the damage irreparable
c) Further deterioration by exposing the inner components to gel or water
d) Increasing the risk of damage for the exposed piezo elements
e) <u>All the above listed options are true</u>

**MCQ 2 In which situation would you recommend the assessment of the in-air reverberation pattern?**

a) Newly acquired probe
b) Probe returned after repair
c) Probe that has been accidentally dropped
d) The trailing cable of the probe has been ran over by the patient bed wheels (no visually apparent external damage)
e) <u>All of the above situations</u>

**MCQ 3 Axial banding of the in-air reverberation pattern accompanied by a focally reduced intensity of the paperclip test reverberation artifact most likely represents:**

a) Delamination
b) Spurious artifact of no significance
c) Lens wear
d) Lens nonuniformity
e) <u>Dropout</u>

**MCQ 4 A linear array probe used for carotid Doppler imaging shows a prominent central dropout during quality assessment. What do you recommend?**

a) No immediate action needs to be taken
b) Further testing must be done with electronic probe tester in the near future, until then the probe can remain in use
c) Use a narrower colour box
d) Add 10% to the measured velocities to correct the effect of the dropout
e) As central dropouts inevitably influence the reliability of both PW and colour Doppler measurements the probe has to be taken out of service

**MCQ 5 Blunt injury of the probe most commonly produces the following fault:**

a) Dropout due to dead piezo elements
b) Probe connector damage
c) Nonuniformity caused by uneven lens thickness
d) Delamination due to internal structural separation
e) Spurious colour Doppler signal due to crosstalk between cable fibers

**MCQ 6 Puncture injury to the lens surface is particularly likely to produce the following fault:**

a) Dropout due to dead piezo elements
b) Nonuniformity caused by uneven lens thickness
c) Delamination due to internal structural separation
d) Probe connector damage
e) Spurious colour Doppler signal due to crosstalk between cable fibers

**MCQ 7 Blunt crush injury to the probe cable is particularly likely to produce the following fault:**

a) Dropout due to dead piezo elements
b) Nonuniformity caused by uneven lens thickness
c) Probe connector damage
d) Delamination due to internal structural separation
e) Spurious B-mode or colour Doppler signal due to cable fiber damage

**MCQ 8 Uneven wear or incorrect repair of the transducer lens can lead to the following fault:**

a) Dropout due to dead piezo elements
b) Nonuniformity caused by uneven lens thickness
c) Delamination due to internal structural separation
d) Probe connector damage
e) Spurious colour Doppler signal due to crosstalk between cable fibers

**MCQ 9 During in-air reverberation assessment axial banding is revealed, and the paperclip test also supports dropout. What is the next step to be taken?**

a) Send the probe for repair without further assessment
b) Request electronic testing
c) Scan a volunteer to check how disturbing the artifact is during use
d) Switch off and disconnect the probe, assess both the port and the probe connector for the presence of injury, corrosion, or dirt buildup
e) Check if there are accompanying Doppler artifacts

**MCQ 10 The paperclip test is typically conducted in B-mode, except in case of the following probe:**

a) Linear array
b) Curvilinear array
c) Phased array
d) 4D probe
e) “Hockey stick” probe

**MCQ 11 Which probe type can not be reliably assessed using visual techniques?**

a) Linear array
b) Curvilinear array
c) Phased array
d) Microconvex probe
e) 4D probe of any geometry