Latest Advances in Quality Control for Ultrasonic Pulse Echo Imagers

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Introduction

The current quality measurement for ultrasound pulse echo imagers is based on AIUM: "Quality Assurance Worksheet for a Fiber/Cylinder Type Phantom". The initiative of AIUM and IEC to measure the lesion detectability did not find the attention that appropriately reflects the importance of this quality parameter. Although the clinical importance of the lesion detectability is recognized, the adequate tools for measuring lesion detectability were not made commercially available.

The new trends in 3D imaging and complex 2D beam forming (matrix technology) require a reliable and fast determination of the quality parameters and quality assurance in the clinical practice. The necessities of defining "Expiration parameters" for transducers appear as another urgent requirement.

Existing test procedures in practice

Most hospitals, clinics and service organisations use multipurpose phantoms like Type 539 (ATS) or RMI403GS (Gammex). This measurement is performed according to the protocol or guidelines described in the AIUM Quality Assurance Manual.

In the "Quality Assurance Worksheet for Fiber/ Cylinder Type Phantom" the following items are listed:

a) Machine, Phantom and Transducer Description
b) Transducer Inspection
c) General Cleanliness
d) Hard Copy Imaging
e) Machine Settings
f) Tissue-Mimicking Phantom Measurements
- -Maximum Depth of Visualisation
- -Image Uniformity
- -Vertical (Axial) Distance Measurement Accuracy
- -Horizontal (Lateral) Distance Measurement Accuracy
- -Axial Resolution
- -Lateral Resolution

In order to fully express the quality parameters as far as possible quantitatively, the "RamSoft" software was used.

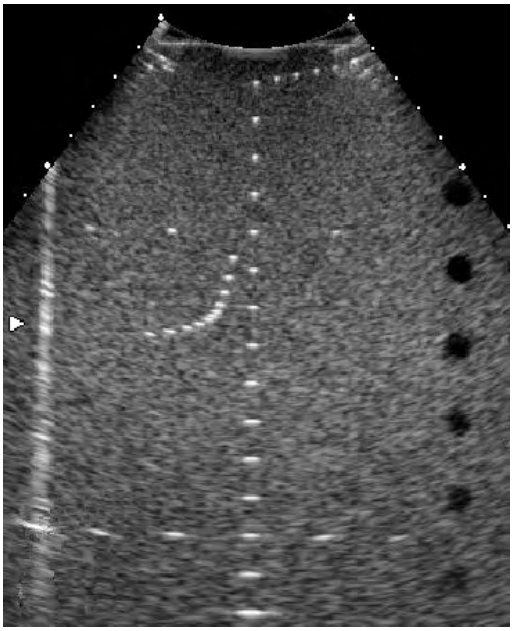

Fig.1 B-Image of "Type 539" phantom

The application of RamSoft software improved the accuracy of geometrical imaging and resolution parameters evaluation. It is impossible to measure or to estimate the clinically most important quality parameter – the **detectability** of **lesions** just by using Fiber/Cylinder Phantoms. Unfortunately only the Fiber-Cylinder Phantoms are mostly used in clinics, hospitals and companies, which produce ultrasound diagnostic equipment. Most measurement protocols based on AIUM and IEC Standards

do not take in account the necessity of measuring the **lesion detectability.**

AIUM and IEC initiative to measure detectability of lesions

Already the early AIUM Standard [1] describes the "Phantoms for Measuring Detectability of Anechoic Masses". The spherical anechoic masses embedded in tissue mimicking material, called also "spherical voids phantom", appear later in AIUM Quality Assurance Manual [3] as "Focal Lesion Phantom". In the "Quality Assurance Worksheet for a Focal Lesion Type Phantom" the additional item appears as:

- **Resolution -Lesion Detectability**

The introduction of this quality parameter is justified by the following – citation [3]:

"Determination of the low–echo focal lesion resolution is an important parameter determination because many diagnostically significant objects are characterized in part, if not entirely, because of their reduced echogenicity relative to that of their surroundings.

Examples of such objects are cysts, some benign tumors such as fibroadenomas, and some malignant tumors. Accurate delineation of object boundaries is particularly important in many situations such as die detection of malignant tumor masses. Such boundaries are better delineated by scanners with higher overall resolution (including axial, lateral, and elevational resolution). The ability of a scanner to detect smaller low echo spherical lesions in the phantom indicates higher overall scanner resolution, which correlates with a better boundary delineation for larger in-vivo lesions.

Also, detectability of a low-echo focal lesion is related to detectability of a higher echo focal lesion. Thus, low-echo focal lesion detectability has some relation to the ability of the scanner to outline the boundary of higher echo objects as well as low-echo objects.

The target object for measuring a low-echo focal lesion resolution is a spherical volume, simulating a focal lesion, with a reduced echogenicity relative to its surroundings. For a given depth and echogenicity relative to the surroundings, there will be a minimum diameter of the spherical volume such that its presence can be detected in the image.

Note: All three aspects of resolution, viz. axial, lateral, and elevational are involved in this detectability. Because of the variety of focusing properties of scan equipment, the minimum size (diameter) of the detectable volume will depend on the depth of the volume-or the distance from die transducer to the spherical volume. For a given size volume, the result will be a zone of depths over which detectability occurs.

Photography and processing should always reproduce image features clearly in the hard copy image. An image of a material with uniform ultrasonic properties is best for careful analysis; however, images of a section of an adequately uniform patient's organ could be used for qualitative analysis ".

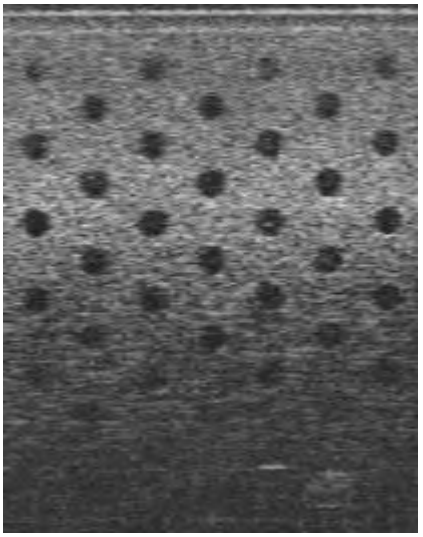

Fig 2. B-image of Gammex RMI408LE phantom.

IEC document TC 87 [4] describes the measurement with spherical masses as: "Objective procedure for determining imaging zones rely upon spherical lesion phantoms that have masses of the given backscatter contrast and size positioned in known locations in a plane"

The document continues: "Images of a phantom containing spherical targets of a given backscatter contrast and diameter are **digitised**." It is noticed that: "Care is required **to align** the scanning plane with the plane containing the centers of the spherical targets".

One of the first commercially available phantoms for determination of low-echo focal lesion resolution is the Gammex RMI408LE.

Fig. 2 shows the B-image of this phantom taken with a 7.5MHz linear array.

GE (General Electric) published "Voxel image processing" with "Active Matrix Array". Fig. 3 shows the advantage of matrix technology. Low-echo focal lesions (voids?) appear visible in long focal range compared to a conventional transducer.

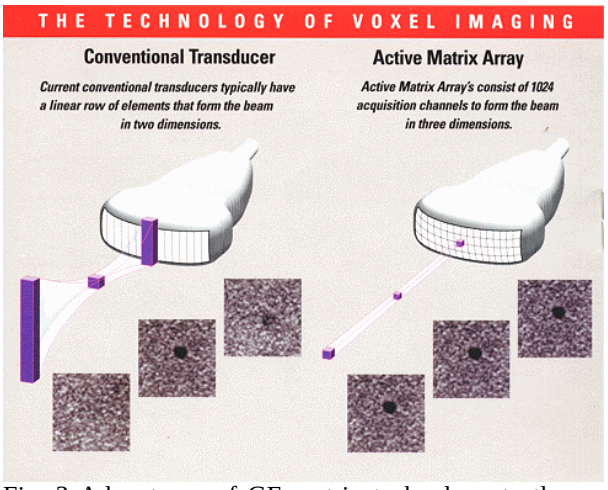

Fig. 3 Advantages of GE matrix technology to the conventional transducer.

Problems with Low-Echo Focal Lesion Resolution (LEFLR) measurement

The main problem of LEFLR measurement (also known as contrast resolution) is the availability of phantoms that fulfil the conditions for quantitative determination of the contrast resolution. The focal lesion echogenicity should be, in relation to the surrounding **expressed in dB** and should be **frequency independent**. The production of artificial lesions with a constant dB distance to the surrounding in a large frequency range is still a matter of research.

In order to avoid acoustical enhancement or ultrasound shadows, the material inside the lesions must have the same attenuation as the surrounding. It can be realized by using very fine powder as scatterers inside of the lesions. The **danger of conglomeration** of such fine powder in gel is probably a huge problem. Fig.2 shows the inside of lesions discrete echoes or distributed specularity. Precise analysis of phantom lesion ehogenicity shows the large differences between particular lesions.

The required alignment of the scan plane (B-scan) with the plane containing the centers of the spherical targets [4] is a tedious work to achieve. If the small spherical lesions, from 1-2mm in diameter, are not precisely hit in the center, then this will result in a large measurement error in contrast resolution.

Low-echo focal lesions are not suitable targets for the detection of transducer side and grating lobes. The side lobes are visible as tiny echoes and can only be only be registered quantitatively using **anechoic masses** or **voids** [1].

If the voids are not completely echo free, an ambiguity will exist between echoes from scatterers in inside the void and the echoes caused by existing side lobes. It cannot be differentiated, if the echoes appear inside of the voids as side lobes or appear because of non-perfect voids.

Advances in Low-Echo Focal Lesion Resolution measurement

The first step to improve LEFRL measurement is made by the implementation of **echo free masses** (voids) in order to **determine** the influence of **transducer grating or side lobes** in lesion detectability **quantitatively**.

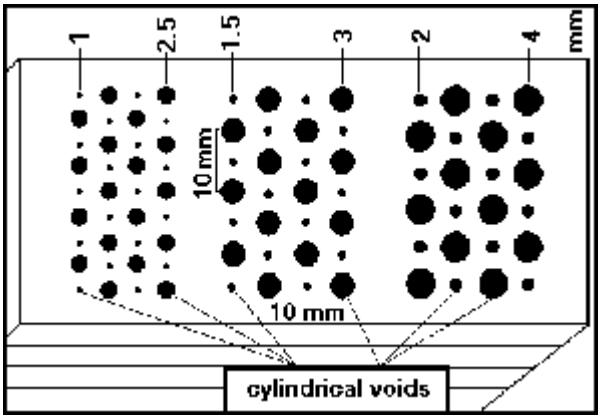

Fig. 4 - Arrangement of the voids in special phantom visible in C-images.

In order to resolve the problem of voids with very low echogenicity, a special phantom structure design was necessary. The phantom was conceptually designed with horizontal slices 5mm high. Void free highly attenuating slices alternate with very low attenuation slices, which contain vertical void-cylinders with diameters from 1-4mm (Fig.4).

The voids in the low attenuating material do not produce acoustical "enhancement" or "shadows". The attenuation average is pre-

dominantly due to the highly attenuating slices. The voids are filled with a gas free liquid end the echogenicity is more than >60 dB below the echo level from the surrounding material.

The problem of: "care required **to align** the scanning plane with the plane containing the centers of the spherical targets" is solved using:

- **3D Image acquisition**
- **Cylindrical voids of 5mm height** with axes parallel to sound propagation.

Because of this, the problem of coplanar alignment is solved. By using the 3D-acquisition the coplanar adjustment of the B-scans are no longer necessary. Cylindrical voids allow the adjustment in the C-plane within a tolerance of ±2.5mm without noticeable influence on the void contrast resolution.

The 3D image acquisition was the first step to a reliable and robust automated LEFLR measurement. The next images (Fig. 5 – 8) show the results of the automated phantom 3D-image analysis.

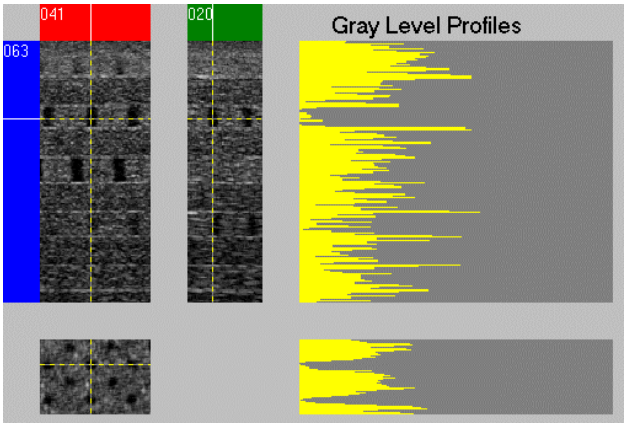

Fig. 5 - Result of the analysis for GE matrix technology transducer shows dynamic presentation of 3D-ROI with Gray Level Profiles.

The contrast analysis (Fig.6) shows the contrast resolution depth dependency for cylindrical voids of 2.5mm diameter. (Matrix technology GE-Logiq700 transducer)

The useful range (focal zone) as shown, reaches from 0.5 to 5cm. The void detection limit is set empirically at the signal to noise level S/N=2.5 [5].

Compared to a conventional transducer (Fig.8) with approximately the same nominal frequency, bandwidth and aperture the focal zone with the transducer (Fig.7) is unusually stretched but not as ideal as shown in Fig. 3.

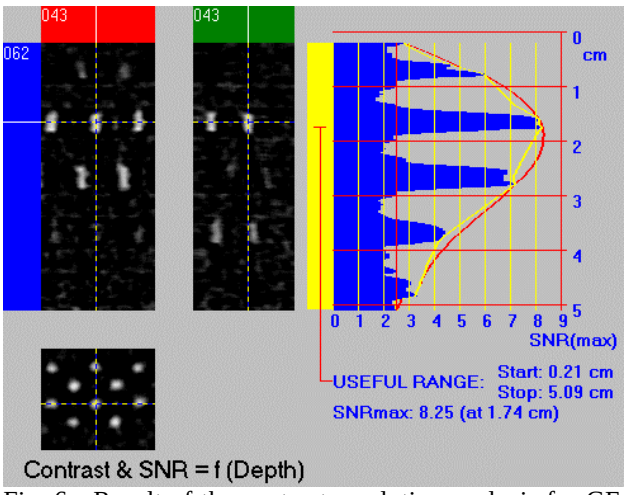

Fig. 6 - Result of the contrast resolution analysis for GE matrix technology transducer.

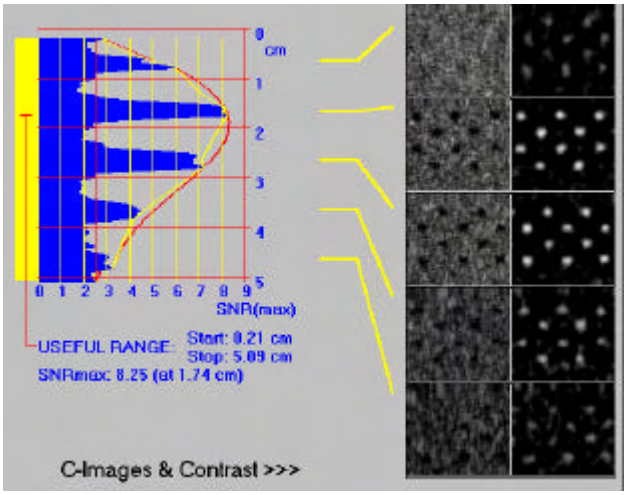

Fig 7. Contrast, C-images and 2D-contrast function for different depths for matrix technology transducer.

Progress in quality assurance

The contrast resolution measurement using echo free masses or voids is also indispensable for the estimation of the "**Expiration parameters**" for transducer arrays.

The inside of any transducer array are polarized narrow side piezo-ceramic array elements. In matrix technology the array elements are subdivided into small rectangles. In normal transducer operation, the piezo-ceramic elements are fired using high voltage transmitting pulses. These pulses slowly depolarize the piezo-ceramics step by step. This magnitude of this effect is not the same for all elements. Some random depolarization takes place and

irregularly changes the sensitivity of the ceramic elements. As the polarization changes very little with each transmitted pulse, the depolarization appears like continuous process. After some time this irregular depolarization results in a generation of **grating and side lobes** and an overall **reduction of the transducer sensitivity**.

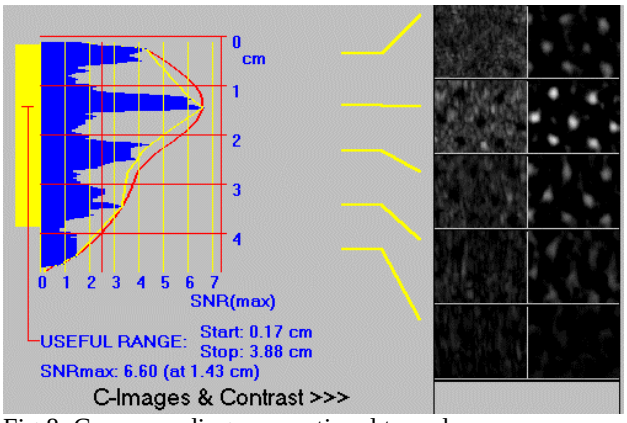

Fig 8. Corresponding conventional transducer

The process of depolarization takes roughly 8-15 years if the transducer is daily in use. The human adaptation to such a creeping process of contrast reduction is a serious risk and is generally known. The spatial transducer resolution does not change essentially with the ceramic depolarization. Only the contrast resolution (LEFLR) changes substantially. This however leads to a **serious inferiority in the lesion detectability**.

The shown void contrast analysis allows to detect even small contrast changes. It is a problem to show what can happen with a transducer's contrast in a period of 5, 10 or 15 years.

There is the question how to "prepare" a new and perfect transducer and "simulate" the "aging" process. There is fortunately a pretty simple way to "change the transducer" and to show what can happen through the depolarization process. We only need to **stick several layers of adhesive tape** onto the transducer active surface. The tape simulates the sensitivity reduction of the transducer and at the same time the inhomogeneous tape randomly reduces the single ceramic elements sensitivity. This generates grating and side lobes and in consequence the contrast reduction.

The transducer performance thus changed by tape layers or by normal aging process, can only be detected by using anechoic masses. As already mentioned – it cannot be measured with artificial low-echo focal lesions.

The analysis result of the "unprepared" linear array transducer as a contrast-depth function, C-images and C-contrast images are shown in Fig.9.

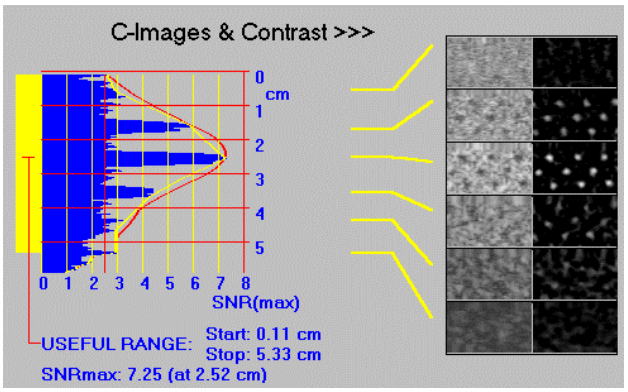

Fig. 9 - Contrast-depth function with G-images and G-contrast images of "unprepared" linear array.

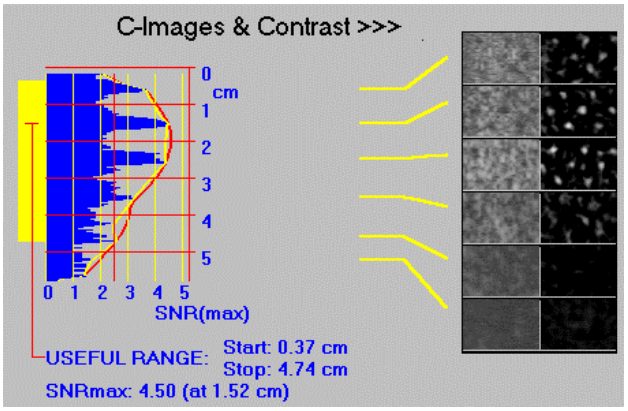

Fig.10 - Contrast-depth function with G-images and G-contrast images of the linear array with 3 layers of the adhesive tape.

The analysis of the same linear array, however this time using 3 layers of adhesive tape (Fig.10) shows reduced contrast and a changed focus. In the near field there inherently are plenty of side lobes and the additional side lobes change the contrast only negligibly. In the focal depth where side lobes are normally insignificant, the new side lobes caused by the tape, obviously have a strong influence on the contrast.

The "artificial transducer aging" is also visible in the G-images of the phantom voids. The visual contrast assessment without com-

puter analysis is not precise enough to decide if the transducer has to be replaced. On the basis of such a measurement the transducer "Expiration parameters" must be first defined.

Image quality and inhomogeneous media

Image quality determination using phantoms does not include the image deterioration caused by phase aberration, multiple scattering, and reverberations or in general, by image deteriorations in an inhomogeneous tissue. An inhomogeneous tissue influences the generation of additional side lobes and echoes, which do not correspond to the position of the reflectors in living tissue.

The phase aberration is correctable but there are not many imagers, which are able to perform this. The degree of artefacts, which cannot be corrected as for example reverberations occurring on tissue inhomogeneities, must be properly assessed in order to avoid the image misinterpretations.

Revision needed for current quality assurance practice

Unfortunately the current practice with "Quality Assurance" and ultrasound imagers' assessment of quality parameter with "Fiber/Cylinder Type Phantom" is not sufficient to determine the changes of clinically very important quality parameters. The lesion detectability – as shown – is determinable only on one type of phantom target. These targets have to be echo free masses. All other target types may be useful but none of them shows what happens in the complete gray scale dynamic range.

The echo free masses have a unique phantom target feature with a transducer aging measurement possibility. Transducer aging is clinically the most important quality assurance subject in order to guarantee the continuous diagnostic decision quality.

Conclusion

The quality control and quality assurance based on existing standards is not sufficient for the essentially important quality parameters of pulse echo imagers. The precise measurement of contrast reduction as a consequence of grating and side lobes is an indispensable step in the quality assurance. For such measurements the phantoms with anechoic masses are extraordinarily important.

For the clinical practice it is necessary to define the minimal allowed contrast in focus (or working range) for each transducer and each application. If the transducer falls below the minimal allowed contrast it must either be declared unfit for the application and taken out of service, or must be refurbished. All other causes of image deterioration such as electronic noise or any other electronic failure should be avoided in order to assure the correct imager quality judgment, for in the end-effect the described procedure gives an overall system quality measurement. It does not discern between the different sources of the aberration.

The Fig. 11 shows the defective phantom also as a possible source of error for the imager quality judgment. The given example shows the defect in 1.7cm depth, caused probable by scatterer agglomeration. The defect appears in all visible masses in this depth because the diagram shows SNR maxims for this depth.

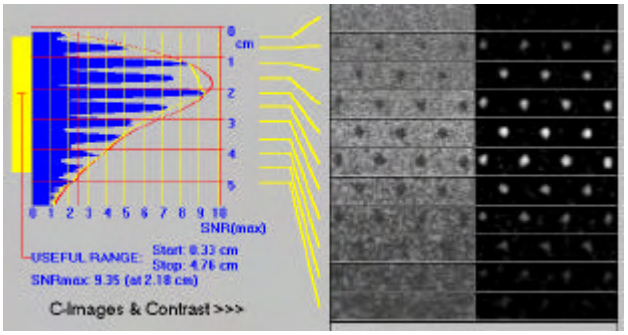

Fig. 11 - RMI408LE defective phantom in 1.7cm depth.

Appendix

Contrast resolution of ultrasound B-images is expressed as S/N or SNR (Signal to Noise Ratio) for a given focal lesion.

If the signal standard deviation and mean of noise inside the void (σ_2, μ_2) is equal the standard deviation and mean of the void surrounding (σ_1, μ_1), then the spatial contrast resolution is zero. Otherwise the contrast resolution for a certain void is [4]:

$$SNR = (\mu_1 - \mu_2) / \sqrt{(\sigma_1^2 + \sigma_2^2)/2}$$

The limit for the void detectability is taken by the empirical value SNR = 2.5. The range given

with values SNR ≥ 2.5 is the resolution zone, focal range or "useful range"[5].

The determination of the SNR strongly depends upon the lesion shape. If the lesion or void does not have a circular cross section in the C-image as it is shown in IEC document (Figure 6, Ref. [4]), then one of the lateral directions is preferred, as it is in the case with conical (or equivalent cylindrical) targets. Such targets are not suitable for a quantitative approach. The transducer contrast resolution comparison with different slice thickness and equal azimuthal and elevational resolution on conical targets may appear equal. The explanation that in this case an equal contrast resolution exists would be a severe misinterpretation.

The low-echo focal lesion detectability strongly depends upon the dimensional lesion extension. Exception is the lesions axial extension because the axial resolution of a transducer is always in order of a magnitude better than both lateral resolutions.

Because no adequate phantoms are currently available the direct lesion detectability measurement is not possible. In fact, the detectability of voids (equivalent to cysts) is always better than the detectability of equal lesion size. This means that the void detectability is the detectability threshold for any lesion of equal size with low echogenicity.

References

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