Quality Features Definitions for Ultrasound Scanners

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Introduction

The development of the ultrasound diagnostic equipment has been accompanied by a permanent concern for the quality features of this type of instrument. Already for early products of ultrasound imaging the first quality parameters, such as geometry checkout and somewhat later the axial and lateral resolution, were defined. The introduction of the gray scale imaging demanded an update of definitions for existing quality parameters. It was insufficient to estimate the quality parameter with simple nylon threads stretched in a water bath. The necessity of anthropomorphic phantom was urgent concern. The production of tissue mimicking materials began 20 years ago (May 1978). Unfortunately the tissue mimicking materials alone did not solve the problem of the quality parameters and quality control. The definition of new quality parameter began with the embedding of new targets in tissue mimicking material.

With digital ultrasound data acquisition (AIUM Standard 1995) advanced methods are being introduced into quality control. The principle of assessment of the B-images quality by pure visual control may be essentially improved. The redefinition of quality parameters using new digital measurement methods thus results as necessary task.

Tissue mimicking materials

The introduction of tissue equivalent phantoms opened the question in how far the phantoms are really equivalent to the living tissue. From a practical point of view, only globally acoustically homogeneous materials with defined attenuation, backscattering, speed of sound and frequency dependent backscattering f^1 (similar to liver) are suitable as tissue equivalent. Most of the parameters are temperature dependent and must be declared with their tolerances at a specific temperature. Although the tissue equivalent material acoustically mimic the liver tissue, the larger part of inhomogeneous tissues, such as abdominal wall and breast, show very different properties compared to liver. It is a legitimate question, why to use tissue equivalent at all, if we have such big differences in tissues? A detailed study of propagation of ultrasound in living tissue reveals the following:

1. most of the examined tissues are globally homogeneous and
2. an estimate of image quality in inhomogeneous medium is possible if only

the image quality in homogeneous medium is known.
The image quality in breast is indirectly measurable using a phantom with homogeneous material posterior to the breast. The comparison of the

resolution in direct scan of the phantom to the results when placed behind the breast allows to estimate signal deterioration in the breast. This means that the first step in quality control therefore is a precise knowledge of quality parameters measured in homogeneous medium. In an abdominal wall similar phase aberrations and reverberations are observed as in breast.

Phantom targets

The measurement of quality parameters using tissue mimicking phantoms without suitable targets is difficult task. Therefore most of the phantoms are supplied with adequate targets. The targets used are:

1. LINE TARGETS as thin rod, such as stainless steel, or any material that does not have resonance scattering in the frequency range used for measurement.
2. PLANE TARGETS using acrylic, stainless steel or other reflectors.
3. TUBES, anechoic or hyperechoic
4. CONICAL objects with different backscatter contrast and background phantom material.
5. SPHERICAL objects, e.g. voids or providing a backscatter contrast with respect to the background phantom material.
6. CYLINDRICAL objects, e.g. voids.

There are no targets with "wrong" properties, however not all targets are suitable for interpretation of ultrasound instruments quality by observing the phantom image or by automated phantom image processing. Unfortunately, some types of target are greatly misleading in the interpretation of measurement results and this must be especially accentuated.

The line targets are most suitable objects for the measurement of scanner image geometry. In some phantoms however the line targets are used for measuring the axial and lateral resolution. Unfortunately the definition of axial resolution - "The minimum separation between two equally reflecting point targets along the direction of sound travel, such that each can be separately distinguished on the display (AIUM)" - is not precise enough to give any reliable assessment of resolution in tissue and is object of many manipulations of quality data. The ultrasound image of point targets suffers from interferences and this is the reason for inaccurate interpretations! Unlucky the same situation exists for azimuthal and elevational resolution which are similarly defined.

The depth of penetration is likewise unprecisely defined as: The maximum distance from transducer into the medium along the beam axis at which echoes can be detected. In this definition nothing is said about the properties of the medium or instrument adjustments.

The IEC document TC87 (1999) has improved the definition from "depth of penetration" to "maximum depth of visualization" with "echo detection at a satisfactory level above noise"!? It is still questionable how valuable measurement results following these definitions are for user of ultrasound instruments in clinical practice.

The drawbacks of discrete targets was recognized and new volume targets appeared embedded in tissue mimicking materials: i.e. TUBES and CONICAL objects with different BACKSCATTER CONTRAST with respect to the background material. Tubes with different diameters were placed inside a homogeneous medium. The orientation was chosen perpendicular to the scan-plane. This resulted in simple location of the measurement object, but neglected the influence of slice thickness of the scan plane, i.e. the elevation resolution of the scanner.

The orientation of the conical targets is such, that the area of the intersection of the scanning plane and the target can be varied, simulating targets of different size (IEC). This property of "different size" and thus inherently not being able to a-priory define the geometry scanned provided an additional problem with respect to discriminating between the resolution in axial and azimuthal direction and the primary contrast properties. As for tube structures, using conical objects the contrast is not influenced by elevational resolution. The main problem for this type of quality evaluation can be identified as a "definition conflict" because it is not clear, if the contrast is due to spatial resolution or if it is influenced only by backscattering difference or if it result from both phenomena (contrast-detail detectability). If it is accepted, that contrast is a result of both phenomena then conical targets provide misleading information due to the lack of information on the dimensions of the scanned object at the point of intersection. Additionally influence from the elevational resolution or slice thickness is not reflected in the measured values. This was probably the reason for the AIUM standard commission not to include conical targets in the AIUM standard. In IEC standard however conical targets are accepted as equivalent to spherical targets. There a not any notice in IEC standard concerningthis "definition conflict" and the resulting misleading properties of conical targets.

Especially the concern about elevation resolution i.e. (it means) slice thickness led the leading researchers in ultrasound quality assurance to look for new target objects. The first phantom with spherical voids was presented by Prof. Ernest L. Madsen at the Tissue Characterization Conference in Washington D.C. end of 80's as ANECHOIC MASS IMAGING ZONE with masses of particular size located in random positions in a parallelepiped. The Dr. Madsen´s proposal was vehemently attacked from industry representative as - misleading in quality control!

Only a few years later the very same phantom for measuring detectability of anechoic masses appeared in AIUM standard. Ten years later, based on exactly the same principle, RMI´s spherical masses phantoms were presented on the market, in spite of the strong criticism of industry. There is evidently more to this phantom than some would have liked to admit. The contrast detail detectability, as it had been defined, motivated to fill the spherical voids with material with different backscattering properties. This was a very difficult task because it is almost impossible to keep the frequency dependence of both the background backscattering and the spherical masses linear over a frequency range of 2 to 15 MHz. The practical realization of spherical voids with the identicalattenuation but much lower backscatter than the respective background is also a great problem. The mismatch in attenuation produces acoustic "enhancement" or "shadows".

With the introduction of small spherical void targets the problem of the "alignment" arises. Depending on target size it can be quite difficult to "hit" a spherical target precisely in its center. Even if the targets are arranged in a plane, it is quite tedious to adjust the plane of the scanner (B-plane) to the plane of targets especially if the targets are small in size (about 1mm).

Although the spherical and tubular (cylindrical) "targets" which correspond to cysts, lesions, blood vessels and milk ducts are not simple to imitate for measurement purposes, medical people are very well acquainted with this type of object and the corresponding ultrasound images. The relevance of the measured results to clinical experience consequently is much better then results obtained from discrete targets (AIUM).

Measurement automation

The multitude of definitions and the "definition conflicts" are obstacles for any automated and robust measuring method of quality parameters. A new type of measurement definition based on cystic objects and making use of the new digital ultrasound imaging and volumetric data acquisition is mandatory to succeed with this task.

One of the most critical adjustments for automated procedures is the alignment. The measurement results may not depend on the individual ability of "hitting" spherical targets in their centers! The only solution for this problem is acquisition of a phantom volumetric image and thus being sure to "hit" all targets defined by volumetric region of interest (VROI) in their "center". If the targets are small cylinders instead small spheres, there are better chances to "hit" more targets with identical cross sections: i.e. small cylindrical targets, with axis parallel to sound propagation direction, reduce the sensitivity to "alignment" in the C-plane without any disadvantages in azimuthal and elevational direction.

Independent of use of small spheres or small cylinders as targets, both could be filled with backscatterer contrast material. Unfortunately there is no way to detect the weak side lobes using targets of this kind. **It cannot be discriminate if the backscatter is generated by the internal backscatterers or by the reflection of side lobes of defected scanner by the surrounding material!** That is **reason enough** to use the targets (voids) without any internal backscatterers and to measure the global gray scale distribution using other suitable methods. Poor contrast caused by side lobes can be very evident for the defective scan heads. Sometimes the generation of side lobes is obvious. Unfortunately, there are some creeping defects, which can be only recognized as contrast reduction on the larger artificial cysts with backscattering offset to background > 60 dB.

The contrast measurement using spherical masses is defined by IEC standard recommendations and this definition is sufficient for automated contrast measurement. For other quality parameters adequate definitions must still be found. It is the question if the axial, azimuthal and elevational resolution, as defined quality parameter will necessarily coincide with the volumetric resolution given by minimum contrast (SNR=2.5) as recommended by IEC

standard. The maximum depth of visualization can be probably defined as depth, where contrast curve touch the noise level "1" for a given target size. The contrast reduction in weakly inhomogeneous tissue mostly appears as a "creeping effect". Phase aberrations in distributed inhomogenities result in a supplementary generation of side lobes. This means that side lobes caused by inhomogenities will be added to possible existing intrinsic side lobes of a scanner. Scanners with intrinsic side lobes are less suitable as breast scanners. Unfortunately the modern 1.5D and 1.75D scanner technologies produce the intrinsic side lobes by strong changes of elevational focus. Such scanners have to be carefully tested in order to avoid the misinterpretations of breast examinations.

Conclusions

Both the redefinitions and any new definitions of quality parameters will have to provide a high level of agreement between human observers and measurement results. A new type of measurement definition based on cystic objects and making use of the new digital ultrasound imaging and volumetric data acquisition is therefor mandatory. With the progress of ultrasound image analysis automation a redefinition of quality parameters will be necessary and new definitions especially in the field of tissue characterization will have to be added.

Special care must be given to observing the difference in imaging quality after passing through homogeneous or inhomogeneous medium. The side lobes, generated in any inhomogeneous medium, such as the breast, reduce the contrast and cannot be neglected in general quality assurance performance tests as they were hereto neglected by most of standard recommendations. The human observer will need a high level of awareness about the instruments quality parameters and overall system quality parameters including the specificity of the patient tissue.

The volumetric image processing provides the chance to determine and express overall system quality parameters quantitatively. Let us take this chance to improve diagnostic quality of ultrasound by assuring a constantly high level ultrasound equipment for the benefit of the patients.