

● *Part I: Science and Technology*

QUALITY ASSURANCE FOR GREY-SCALE IMAGING

ERNEST L. MADSEN

Medical Physics Department, University of Wisconsin, Madison, WI, USA

NEED FOR DEFINITIVE QUALITY ASSURANCE STANDARDS

In 1992, the American College of Radiology (ACR) recommended a specific phantom and image analysis procedure for (x-ray) mammography (American College of Radiology 1992). This event removed uncertainty in the USA regarding quality assurance (QA) in mammography. Although the phantom and analysis procedure are probably not ideal, existence of definitive recommendations has resulted in essentially 100% practice of regular QA in the clinic.

The most urgent need for ultrasound (US) QA is that there exist specific recommendations from national and/or international organizations corresponding to the ACR mammography case. At the time of this writing, there continue to be a broad range of commercial phantom types available for use in US QA. Though suggested procedures for quality assurance have been published (AIUM 1995; American College of Radiology 1999), clinical facilities have not yet been given definitive guidance by authoritative organizations regarding a specific phantom or small set of phantoms that are adequate for routine QA testing. Thus, clinical personnel charged with QA are usually in a quandary regarding which phantoms to purchase and use, without confidence that those phantoms will not be rendered obsolete by future authoritative recommendations.

PHYSICAL COMPLEXITY OF ULTRASOUND IMAGING

A major reason that specific recommendations do not yet exist is that the physics involved in the formation of the US image is much more complicated than that in radiographic imaging. Radiography involves attenuation

and scattering due to the photoelectric effect and Compton scattering by tissues with well-defined chemical composition. Grids greatly reduce the contribution of scattered photons to the image. Thus, the image results from attenuation integrated along beam lines to form a projection-type image. Adding to the simplicity, the breast is compressed between parallel plates, so that the total thickness is constant. The simplicity of mammography physics makes adequate mimicking of tissues and relevant structures relatively straightforward. An example of the higher degree of complexity of US imaging is the fact that the slice profile in US is usually a strong function of depth, but in mammography there is no corresponding variable because the latter is a projection image. Another example is the fact that the US receiver must accept whatever echoes return to it from each pulse emitted; thus, distortions can have occurred, resulting from extensive refraction and diffraction of the pulse and echoes.

The tissue parameters influencing US images are numerous. Included are attenuation coefficients, propagation speeds, the geometry and extent of local speed and density variations, and the nonlinearity parameter, B/A .

PHANTOM NEEDS MORE SOPHISTICATED FOR ULTRASOUND THAN FOR MAMMOGRAPHY

Due to the complexities of US imaging, US QA phantoms cannot be simple, and the production cost for an adequate US QA phantom will be much more than for the simple ACR mammography phantom. Following is an attempt to present aspects of US imaging that deserve to be addressed in QA phantoms, followed by components to be included in one or two phantoms required for adequate routine QA. Items are listed approximately in order of importance. The items marked with asterisks are depth-dependent and, thus, should be determined at various depths: 1. depth of visualization (sensitivity); 2. axial and lateral distance measurement accuracy; 3. im-

Address correspondence to: Dr. E. L. Madsen, Department of Medical Physics, University of Wisconsin-Madison Medical School, 1530 Medical Sciences Center, 1300 University Avenue, Madison, WI 53706-1532 USA.

age uniformity; 4.* low contrast resolution; 5.* 3-D resolution with equal weight for axial, lateral and elevational components; 6. axial resolution; 7.* lateral resolution; 8. dynamic range; and 9. effect of beam distortion due to the abdominal wall on parameters 2, 3, 5, 7 and 8. For items 1–4 and 6 and 7, methods of measurement are well established and are (or can be) provided for in commercial phantoms.

Depth of visualization refers to the maximum depth at which echoes can be distinguished from image noise related to electronic amplification. An alternative definition is the maximum depth at which a structure such as a simulated blood vessel can be discerned.

Distance measurement accuracy seems adequately to be addressed with inclusion of parallel reflecting fibers accurately positioned relative to one another.

Image uniformity refers to the extent to which local mean grey level can be made independent of position in the image by adjustment of TGC when the tissue-mimicking material has uniform ultrasonic properties (including backscatter coefficient) throughout the volume imaged.

Low-contrast resolution testing requires presence of large objects at low contrast values (*e.g.*, -1 , -2 , -3 and -4 dB). Objects should exist at various depths. Beam shape should not play a role in detectability of these objects; thus, their dimensions should be 2 cm or greater. For example, cylindrical objects 2 cm in diameter and 5-cm long, with their axes perpendicular to the image slice, are adequate. The greater length than diameter accounts for the possibility of large slice thicknesses.

3-D resolution is a critical parameter. Most clinical US imaging involves scattering from objects that have arbitrary orientations relative to the image slice. It is argued here that quality of depiction of such objects means that the three conventional resolutions (*viz.*, axial, lateral and elevational) play roles of nearly equal weight; therefore, a means of resolution testing incorporating all three with equal weight (3-D resolution) is needed. To aid in the argument, consider a “thought” example with a straight row, or line, of microscopic diffuse scatterers oriented at 45° to the axial, lateral and elevational “directions.” The ideal depiction in the image is a point. If axial and lateral resolutions remain perfect (0 mm) and the elevational resolution (length) increases to s , then the point becomes a line of length s on the image oriented at 45° to the direction of propagation. If the axial and elevational resolutions are perfect and the lateral increases to s , the point becomes a line of length s perpendicular to the direction of propagation. Finally, if the lateral and elevational resolutions are perfect and the axial resolution increases to s , the point becomes a line of length s parallel to the direction of propagation.

A sphere is an object with no preferred orientation

and, therefore, is well suited for resolution tests where the objects or surfaces to be depicted in the US image have no preferred orientation. Thus, it is reasonable that the smaller the sphere that can be resolved (detected), the more accurate will be the depiction of the intersection of the plane of symmetry of the image slice with clinical structures such as a spiculated tumor. Commercial phantoms exist with regular arrays of very low-echo coplanar spheres extending from the scanning window to depths far beyond that at which the spheres are likely to be detectable in the speckle background. The diameter of the spheres in one array is 2 mm and in the other array is 4 mm. In use, the scan slice is centered on an array of equal diameter spheres and the proximal and distal depth limits of detectability are determined by operator inspection of the image.

Axial and lateral resolutions can be determined in the usual ways, by determining the minimum distance separating parallel fibers so that they are barely resolved. Alternatively, the -6 -dB axial and lateral widths of the image of a single fiber might be determined.

Items 1–7 can be included in a single general-purpose phantom. Determination of dynamic range will likely require a second phantom containing specular reflectors with reflection coefficients spanning a 100- to 120-dB range. A low-cost phantom with this large range can be produced, containing 2-cm diameter cylinders with axes parallel to the scanning window.

The general-purpose phantom mentioned above could be made with opposing scanning windows, one window having a simulated abdominal wall providing realistic beam distortions.

NEED FOR AUTOMATION

Modern scanners are very stable, and significant changes in image quality are not likely for, perhaps, years. However, scanners can deteriorate at any time, to the detriment of the patient. If deterioration is subtle and develops continuously over weeks or months, it can go unnoticed until serious shortcomings in quality exist. Thus, routine periodic QA is necessary, but it is reasonable that QA for a representative scanner configuration need not be carried out more than once every 6 months. (A “scanner configuration” is defined to include scanner and scan head make, model and serial numbers, depth of field, focus, frequency choice, etc.) However, it is common for a hospital to have a dozen different scanners, each scanner outfitted with at least four scan heads. If only one representative field of view, focus, frequency, etc. is tested for each scanner and scan head combination, there will be 60 to be done 2 times per year, or a total of 120 per year.

The large number of scanner configurations needing

biannual QA testing can by itself be discouraging to clinical personnel charged with carrying out QA because of the real or perceived large time commitment. Thus, automation methods need to be available to ease the burden of phantom image analysis. Such automated analysis is being pursued at various sites. Computation of image contrast-to-noise ratios for large low-contrast targets is straightforward, by building on available software, such as NIH Image; the operator need only designate $1\text{ cm} \times 1\text{ cm}$ sample areas in targets and adjacent background. Software for automated computation of de-

tectability depth ranges for spherical low echo targets will soon be available commercially.

REFERENCES

- American College of Radiology. ACR mammography accreditation program. Reston, VA: American College of Radiology, 1992.
- American College of Radiology. ACR standard for diagnostic medical physics performance monitoring of real time B-mode ultrasound equipment. Reston, VA: American College of Radiology, 1999.
- AIUM. Quality assurance manual for gray-scale ultrasound scanners (stage 2). Laurel, MD: American Institute of Ultrasound in Medicine, 1995.