A new Imaging Science Phantom for Performance Evaluation of Ultrasonic Imaging Systems

Daniel Phillips, Kevin J. Parker

Department of Electrical Engineering and Rochester Center for Biomedical Ultrasound
University of Rochester
Rochester, NY 14627

Abstract - We have developed a phantom manufactured with thin film techniques that enables precise placement of sub-resolvable "digital scatterers" on an acoustically transparent supporting medium within the scan plane of an ultrasound system. This technique permits formation of sophisticated test targets commonly used in imaging science. These phantoms can reveal the combined influence of all the stages in the imaging chain, as well as demonstrate imaging phenomenon that are difficult or not feasible to evaluate with conventional ultrasound phantoms. Use of half-tone mask techniques permit the specification of placement, pattern and statistical distribution of these "digital scatterers" necessary to produce images with definable gray scale characteristics. We have also been able to produce controlled stimulus sources for Doppler and color flow Doppler evaluation.

INTRODUCTION

The image produced and displayed by an ultrasound scanner is the result of many complex stages and operations. In current generation systems, beamforming and adaptive focusing are applied to phased array transducers; received scan lines are non-linearly amplified, detected and interpolated to a cartesian image space in digital scan converters; and other temporal and spatial filtering (including non-linear processing) may be applied as post-processing steps which finally culminate in the displayed image. As health care costs come under increasing scrutiny, the topic of quality assurance for medical imaging has received increased attention. At the same time, an award-winning paper by Hill et.al. entitled "What might echography learn from Image Science" has recently pointed how far removed diagnostic ultrasound imaging assessments are from conventional imaging science methodologies [1]. Therefore, a need exists for an ultrasound phantom that is useful for quality assurance and conventional imaging science assessments of the entire imaging chain.

It is desirable to have the means for a rapid assessment of the modulation transfer function (MTF), spatial aliasing, and other characteristics of ultrasound imaging scanners by having available test "targets" based on patterns which include lines, circular rosettes, the MTF "chirp" and others which are widely used in quality and performance assessments. [2, 3, 4, 5] However, currently available phantoms, due to their conventional construction techniques, are unable to produce the detailed, high resolution patterns that permit accurate evaluation of these criteria. The requirements for constructing such targets for ultrasound imaging include precise distribution of scatterers on a surface (or in a volume) with control over the local concentration and distribution of scatterers. This approach is described in the next section.

A THIN FILM PHANTOM WITH A DIGITAL SCATTERING DISTRIBUTION

Thin film propagation

The basic premise of this phantom is the implementation of a flat substrate with a spatial test pattern of "digital scatterers" produced via an appropriate thin film deposition technique. The thin film is then oriented co-planar to the scanning plane of the ultrasonic imaging system to be evaluated. Since conventional two-dimensional (2D) ultrasound imaging systems realistically interrogate a three-dimensional (3D) volume due to the actual thickness of the ultrasound beam, the acoustic inhomogeneities presented by the deposited pattern will actually produce reflected waves that will be detected and processed by the ultrasound scanner. (Figure 1)

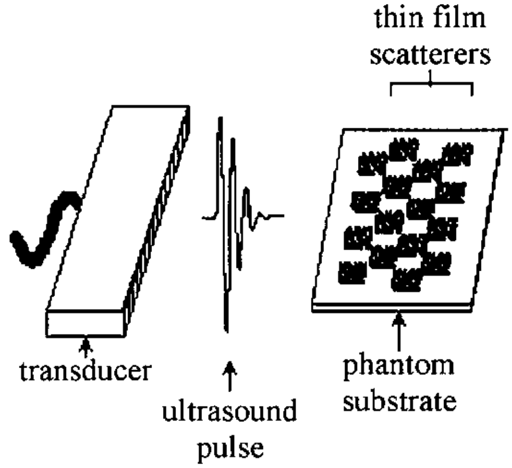

Figure 1 - Thin film phantom concept

In essence, this technique allows a very controlled volume distribution of scatterers, albeit of minimal thickness. In this manner, the volume distribution of the scatterers is tightly controlled in two ways: in the 2D scanning plane,

0-7803-2940-6/95/$4.00 © 1995 IEEE

the scatterers are limited by the resolution of the deposited pattern; in the thickness direction of the interrogating beam, the scatterers are limited by the plane of the phantom substrate and the thickness of the deposited pattern.

Scattering

Acoustic scattering is basically due to differences in the acoustic impedances of the insonated material. The three acoustic impedances of interest in this case are those of the propagating media, the phantom substrate and the material deposited on the substrate that forms the thin film pattern used for evaluation. This phantom is intended for evaluation of medical ultrasound scanners, where the propagating media is normally assumed to have an acoustic impedance close to that of tissue and an attenuation of 0.3 to 1.0 $dB \bullet cm^{-1} \bullet MHz^{-1}$ as suggested by the AIUM guidelines. [6] We are not interested in visualizing the substrate upon which the pattern is deposited, so it has an acoustic impedance relatively close to that of the propagating medium. Finally, as we are concerned with imaging the deposited thin film pattern, the material forming the pattern requires a detectably different acoustic impedance than either the supporting substrate or the propagating medium.

Precise deposition of "digital" scatterers

Since we are interested in precise control of the scattering pattern produced in the 2D scanning plane, the scattering material concentration, size and spacing in the thickness dimension should be pre-determined and reproducibly manufactured. This is facilitated by the use of thin film deposition techniques, [7, 8] which provide a known and even thickness of material along with a substrate of known and constant dimensions. The material used to deposit the patterns is of a uniform consistency. If the number of scatterers per unit volume can be specified and precisely controlled, the scattering strength can be controlled. Thus, the deposited pattern can be considered to be "digital" in nature, i.e., the plane of the substrate will consist of areas, at a given resolution, that either scatter with specified characteristics or will not scatter at all. This is an advantage in terms of presenting a consistent/uniform test target for evaluation. It also opens the door to the use of established half-tone techniques for purposes of providing the scattering analogue of the visual gray scale. (See Figure 2)

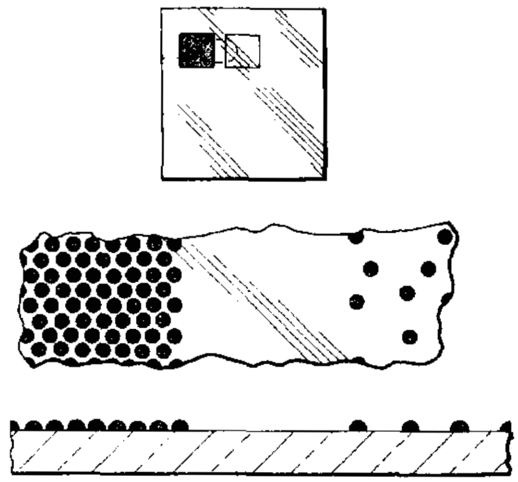

Figure 2 - Detail of thin film target

In the foregoing discussion, it is assumed that the ability to specify the number and location of "digital scatterers" is on a scale much finer than that of a wavelength produced by the ultrasound imaging system being evaluated. For a diagnostic scanner with a 5 MHz transducer in soft tissue, one wavelength corresponds to approximately 300 μm. Conventional semiconductor techniques are easily capable of producing 1 μm features and even a common 300 dpi (dots per inch) laser printer using 10 μm toner particles is capable of producing 84.67 μm "dots" or features, sub-resolvable in terms of the wavelength of the interrogating ultrasound beam. [8] Therefore, it is possible to use 300 dpi laser printing to produce sufficiently high resolution scattering patterns for the purposes of ultrasonic imaging system evaluation.

Randomized patterns

Given the discrete and sub-resolvable (in terms of the ultrasonic wavelength) nature of the scatterer characteristics of the thin film phantom technique, it is possible to modulate the measured scattering strength of an area of the phantom using digital half-tone techniques. Unstructured, or randomized scatterer positions are preferred in cases where a broadband response is required. This is because regularized, periodic scattering profiles will produce frequency dependent changes in the speckle pattern. [9] An image obtained from this type of pattern is shown in Figure 3. The vertical bars are generated by the "Blue Noise Mask", a digital halftone screen that produces unstructured patterns with carefully controlled power spectra. [10, 11] A greater number of "minority" scattering sites per unit area will produce a greater echogenicity.

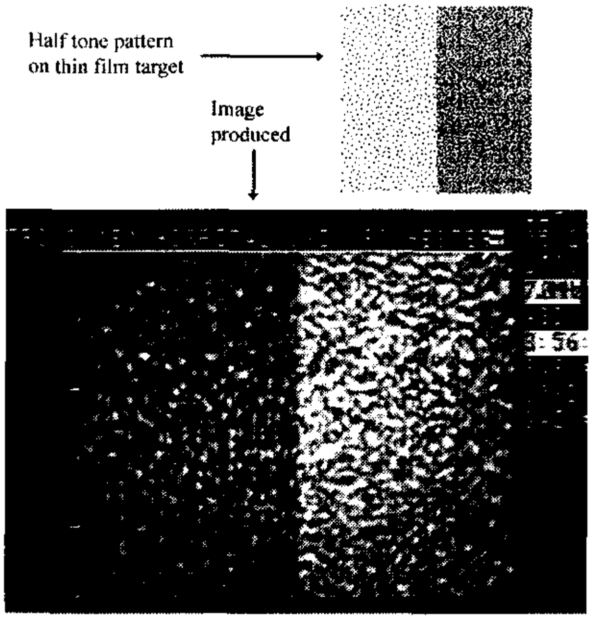

Figure 3 - Example of thin film half-tone pattern and resultant image

An alternative to varying scattering number per unit area would be to vary either the thickness, density or speed of sound of the deposited scattering material in relation to the its position, analogous to continuous tone printing technology.

Implementation

It is necessary to use a thin, stable, nominally rigid substrate with an acoustic impedance relatively similar to physiological saline. As mentioned above, the scattering material must have an acoustic impedance relatively dissimilar from physiological saline while at the same time exhibiting good stability when immersed in a saline solution (or other appropriate propagating medium) and have the capacity to be deposited in a uniform film, in terms of both material properties and thickness.

RESULTS AND DISCUSSION

Initial electrostatic transparency results

Due to ready availability, low cost and well developed computer interface for pattern transfer via laser printing, initial phantoms were generated utilizing 300 and 600 dpi laser printers. Some of the patterns were first printed on common 20 lb copier paper and then transferred to Kodak Ektaprint Transparency Material (Cat 151 4793) using a Kodak Ektaprint Model 225 Copier-Duplicator system (Kodak, Rochester, NY). Some of the patterns were printed directly on to the Transparency material with a DEClaser 1152 300 dpi laser printer (Digital Equipment Corp, Boston, MA).

Pieces of transparency material approximately 7.6 cm. x 12.7 cm with patterns ranging from 3.8 cm^2 to 6.4 cm x 7.6 cm in size were placed in a u-shaped acrylic frame that provided rigid support of the phantom as it was imaged. The blank copier transparency material had a nominal measured thickness of 132 µm and that of the transparency with pattern 142 µm, providing a 10 µm thick pattern film. The edges of the transparency parallel to the face of the transducer were abraded with emery cloth or cut at random angles in an effort to minimize the specular reflections and possible reverberation artifacts from those surfaces.

Water bath experiments

The transparency and the acrylic frame were placed in a 17.8 x 12.7 x 30.5 cm (H x W x L, inner dimensions) plexiglas tank filled with de-gassed tap water at room temperature. The frame was arranged so that the transparency would lie in the scanning plane of the imaging transducer. Either a Quantum QAD-1 (Quantum, Issaquah, WA presently Siemens, Seattle, WA) scanning system with a 7.5 MHz linear array transducer or an Acuson 128/XP10 (Acuson, Mt.View, CA) imaging system with a 7 MHz linear array transducer was used to image the phantom. The transducer was placed in direct contact with the water surface and held in alignment with the phantom by a common laboratory ring-stand and test-tube clamp. In an attempt to avoid initial ring down artifacts and edge effects from the transparency material, the pattern was positioned away from the leading edge of the transparency material and the leading edge of the transparency material was placed in close proximity to the transducer face. Once a suitable image was obtained (using a "flat" time/gain compensation), it was either captured and stored in TIF file format on a 386DX based PC compatible computer equipped with an Imaging Technology PCVisionplus (Imaging Technology, Woburn, MA) video acquisition board and the JAVA video analysis software package (Jandel Scientific, Corte Madera, CA) utilizing the video output from the QAD-1 rear panel or, in the case of the Acuson 128/XP10, recorded to VHS video tape and then captured by the same computer system.

General concept

General purpose use of any phantom for quality assurance purposes dictates robust construction techniques. The thin film phantom under consideration could be implemented in a number of ways to accomplish this objective. For the sake of conciseness, we will focus on a configuration incorporating a fixed mounting scheme. This implementation would consist of a pattern (or patterns) fixed in any number of the currently available tissue mimicking phantom media (e.g., hydrogel or urethane rubber) and could even be included in any one of the current solid target type (wires, inclusions, etc.) phantoms. (See Figure 4) The main difference would be an addition to the phantom of a guide (or guides) for alignment purposes and possibly ruled demarcations of lengths and/or angles for analysis purposes (e.g. to measure beam thickness or actual angle of the scan plane from a plane perpendicular to the face of the transducer).

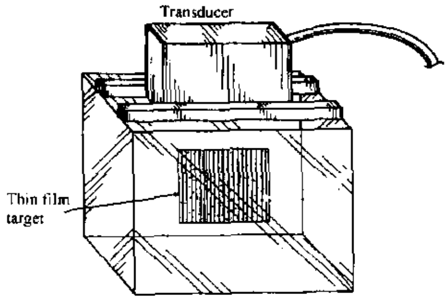

Figure 4 - Diagram of fixed pattern configuration

Potential uses

From an overall point of view, this type of phantom should enable a direct method for quantifiable, repeatable and reliable assessment of performance across all levels of an ultrasound scanner's imaging chain. In terms of the actual imaging equipment, it will allow detection and quantification of factors such as transducer mis-alignment and interrogating wave beamwidth, spatial frequency aliasing effects, dynamic focusing and focus position. It should also provide a means of determining, in a quantifiable manner, how the operator-imaging system interface including the control-display interaction and interpretation ultimately affect the acquired image.

CONCLUSION

This article describes a novel approach for constructing an ultrasound imaging phantom utilizing thin films and precise positioning of "digital" scattering patterns that allows assessment of ultrasonic scanning system characteristics in terms of established imaging science standards. For the first time, complicated test targets for assessing MTF, aliasing, anisotropy, spatial frequency resolution and other imaging science parameters can be mass produced for diagnostic ultrasound scanners. This makes possible direct and quantitative assessment of the performance characteristics of the entire imaging chain as well as facilitating quality assurance and optimization procedures for individual scanners

REFERENCES

[1] C.R. Hill et al, "What might echography learn from image science?" Ultrasound in Med. & Biol. 17(6), pp. 559-575, 1991.

[2] R.L. Lamberts, "Engineering Notes: Use of Sinusoidal Test Pattern Arrays for MTF Evaluation." Sine Patterns, Penfield, NY, 1993.

[3] K. Shiloh et al, "Characterization of high frequency focused ultrasonic transducers using modulation transfer function: Concept and experimental approach." IEE Proceedings-A, 138(4), pp. 205-212, 1991.

[4] R. Frayne et al, "A geometrically accurate vascular phantom for comparative studies of x-ray, ultrasound, and magnetic resonance vascular imaging: construction and geometrical verification." Med. Phys., 20(2), Pt. 1, pp. 415-425, 1993.

[5] J.E. Gray et al, "Multiformat video and laser cameras: History, design considerations, acceptance testing, and quality control. Report of AAPM Diagnostic X-Ray Imaging Committee Task Group No. 1." Med. Phys., 20(2), Pt. 1, pp. 427-438.

[6] AIUM, *Standard Methods for Measuring Performance of Pulse-Echo Ultrasound Imaging Equipment.* Rockville, MD: American Institute of Ultrasound in Medicine, 1991.

[7] R.V. Stuart, *Vacuum Technology, Thin Films, and Sputtering, An Introduction.* Orlando, FL: Academic Press, 1983.

[8] L.B. Shein, *Electrophotography and Development Physics.* Berlin: Springer-Verlag, 1992.

[9] T.A. Tuthill et al, "Deviations from Rayleigh Statistics in Ultrasonic Speckle." Ultrasonic Imaging, 10, pp. 81-89, 1988.

[10]T.Mitsa and K.J. Parker, "Digital halftoning technique using a blue-noise mask." J. Opt. Soc. Am. A, 9(11), pp. 1920-1929, 1992.

[11]M. Yao and K.J. Parker, "Modified approach to the construction of a blue noise mask." J. Electronic Imaging, 3(1), pp. 92-97, 1994.