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Research Article

A New Sonographic Phantom for Quality Control and Training Purposes

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Background: Evaluation of the accuracy and performance of sonography units needs tissue-mimicking phantoms. These phantoms play an important role by simulating soft tissues, obviating the need to experiment on humans or animals.

Objectives: To present a simple sonographic phantom for quality control and training purposes.

Materials and Methods: The presented phantom consists of a two-part Plexiglas box. The larger part is filled with a mixture of ethanol (9.5 ± 0.25%) in distilled water and a solution of sodium nitrite (0.1 M) to prevent rusting. The second part is filled with a combination of 3.85% by wt. % agar, and 50 g/L of powdered graphite as the background material. In this study, chrome-plated electric guitar strings, 0.52 mm in diameter, were used. Several objects were considered as tissue-equivalent material, and their images were obtained at different times. Criteria for the selection of suitable objects comprised similarity between the obtained image and the corresponding tissues in the human body, minimal shrinkage, and change in brightness level at different times. In addition to quantitative analysis obtained from image processing, a blind qualitative study was done by a radiologist.

Results: Both results of quantitative analysis using MATLAB software and independent qualitative analysis showed that the commercial rubber and agar were appropriate as solid and cystic objects, respectively. Moreover, quantitative analysis done with MATLAB on images obtained from the phantom showed that the commercial rubber and agar had a 5% and 2% change in image pixel intensity (brightness) after 2 months, respectively.

Conclusions: The presented phantom not only has lower cost and complexity, which make it suitable for educational centers, but also is capable of providing good images of cystic and solid objects for quality control and training purposes. Furthermore, it confers reliable stability for at least 2 months, as was assessed in the present study.

*Keywords:*Sonography; Quality Control; Training; Phantom

1. Background

Diagnostic use of ultrasound waves became increasingly apparent in the 1950s and in the 1960s (1). Application of ultrasound waves has been increased dramatically in the past 30 years owing to their effectiveness and safe employment (2, 3) as well as their importance in the non-invasive imaging of the human body, especially in fetal, cardiac, and abdominal studies (4). Furthermore, developments in transducer technology and real-time image processing techniques mean that ultrasound waves now account for 25% of all imaging procedures (5). In this imaging modality, routine quality control and quality assurance are necessary to ensure that scanners run under required high quality. In addition, recent advances have raised concern amongs the medical community about the safety of diagnostic ultrasound applications (3). Evaluation of the accuracy and performance of ultrasound systems usually needs tissue-mimicking (TM) phantoms (6). These materials should mimic the acoustic properties of the tissue (with regard to the speed of sound, average attenuation, etc.) and approximate the sonographic appearance of the tissue (7).

Gelatin-based phantoms using graphite as the attenuator have been developed recently. Presence of alcohol varies the longitudinal sound speed, and the concentration of graphite modulates the coefficient of attenuation (8). When using TM materials, one should keep in mind three key characteristics of the normal tissue: speed of sound, attenuation, and backscattering coefficients (9).

Implication for health policy/practice/research/medical education:
The presented phantom provides a tool for periodic calibration and checking out different parameters of sonographic units. Besides, it has the potential to be used in educational purposes.

The most common TM materials used in available phantoms are gelatin, evaporated milk, agar, urethane rubber, and Zerdine®.The manufacturers of these materials have reported sound speed of 1540 m/s (with the exception of urethane-rubber, which has a sound speed of 1460 m/s) (10) and attenuation coefficients of either 0.5 or 0.7 dB/cm/MHz. Non-flat TM materials can be further classified based on the type of their background material as gelatin-and graphite-based, agar-and graphite-based, and evaporated milk-based (11).

2. Objectives

Some studies have recommended other TM materials such as agar with suspended graphite, polyurethane foam, and magnesium silicate gels (7) or TM materials such as agar (polysaccharide), oil gel, polyvinyl alcohol gel (PVA), and polyacrylamide gel (PAA) (6). Unfortunately, the cost of phantoms is a major limiting problem for imaging centers, which is why the use of phantoms is sometimes construed as extra unnecessary work. The aim of this study was to present a new, simple, and low-cost TM sonographic phantom which might be used for training and quality control purposes.

3. Materials and Methods

3.1. Phantom Design

The phantom consists of a cubic box (23 × 10.5 × 19 cm) made of Plexiglas. It is divided into two parts with internal Plexiglas frames for quality control and training purposes. The phantom has a sound speed of 2657 m/s, attenuation coefficient of 5.3 dB/cm/MHz, and density of 1180 kg/cm^3. Figure 1 depicts the box and its frames.

3.2. Background Material

The larger part of the phantom, which relates to quality control, is made of a uniform low-dispersion medium (12). Accordingly, a mixture of water and alcohol (9.5 ± 0.25% ethanol in distilled water) is used. The speed of sound in the mixture at a temperature of 20 ± 0.75°C with accuracy of ± 0.1% is 1540 ± 1.5 m/s, so the mixture is suitable for a range of clinical measurements. A solution of 0.1 M of sodium nitrite was used to prevent the wires from rusting (13). The second part of the phantom, designed for educational purposes, can detect solid and cystic structures. In this section, the velocity, dispersion, and attenuation of sound should be similar to those of the tissue; consequently, a combination of graphite and agar (3.85% by wt. % agar for rigidity and 50 g/L of powdered graphite to produce an attenuation coefficient of about 0.5 dB/cm/MHz) (11) was utilized as the background material (Figure 2).

3.3. Selection of Wire

A good target should provide appropriate contrast in the background material. Our targets consisted of wires, the important parameters of which are their diameter, density, strength, flexibility, and ability to create images with high resolution. Wire density should be carefully selected so that the wires can be easily detected in the

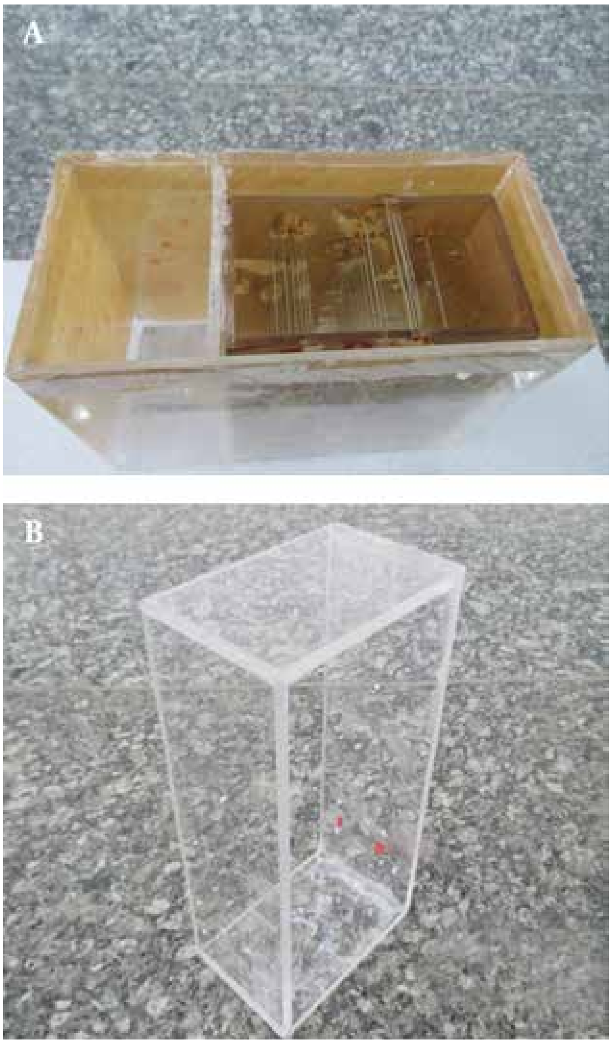

Figure 1. A: First Frame Is Embedded inside the Box. B: Second Frame before Placement inside the Box

Figure 2. Tissue Samples Made from a Mixture of Agar and Graphite

image. Moreover, the wires must not create shadows. Mechanically, the wires should be tight and flexible to prevent rupture. In this study, chrome-plated electric guitar strings, 0.52 mm in diameter, were employed.

3.4. Quality Control Test Parameters

For quality control testing, a standard set of parameters based on Gammex-RMI phantom (model 403GS TM) and CIRS phantom (model 40 TM) was considered (12). Table 1 shows the characteristics of these phantoms, Table 2 illustrates the characteristics of the solid and cystic objects, Figure 3 depicts a schema of the wire scaffold in the phantom, and Figure 3b demonstrates a sonographic view of it.

Table 1. Phantom Characteristics Based on Gammex-RMI (Model 403GS TM) and CIRS (Model 40 TM) Phantoms

Parameters	Characteristics
Dead Zone	
Number of Wires	4
Depth Range, mm	1-10
Vertical Spacing, mm	3
Horizontal	
Number of Groups	2
Depth of Each Group, cm	3 and 9
Numbers of Wires	4 and 7
Horizontal Spacing, mm	10 and 20
Vertical	
Number of Wires	15
Depth Range, cm	1-16
Vertical Spacing, mm	10
Lateral Resolution	
Number of Groups	3
Depth of Each Group, cm	2.5, 6 , 10
Number of Wires	6
Horizontal Spacing, mm	5, 4, 3, 2, 1
Axial Resolution	
Number of Groups	3
Depth, cm	3, 8, 14
Number of Wires per Group	4
Axial Separation Between Wires, mm	2, 1, 0.5

Table 2. Size and Position of the Solid and Cystic Objects in the Phantom

Object	Specification
Solid	
Number of Solids	4
Diameter, cm	4, 6, 8, 10
Depth, cm	3, 5, 7, 9
Cyst	
Number of Cysts	4
Diameter, cm	4 , 6, 8, 10
Depth, cm	3, 5, 7, 9

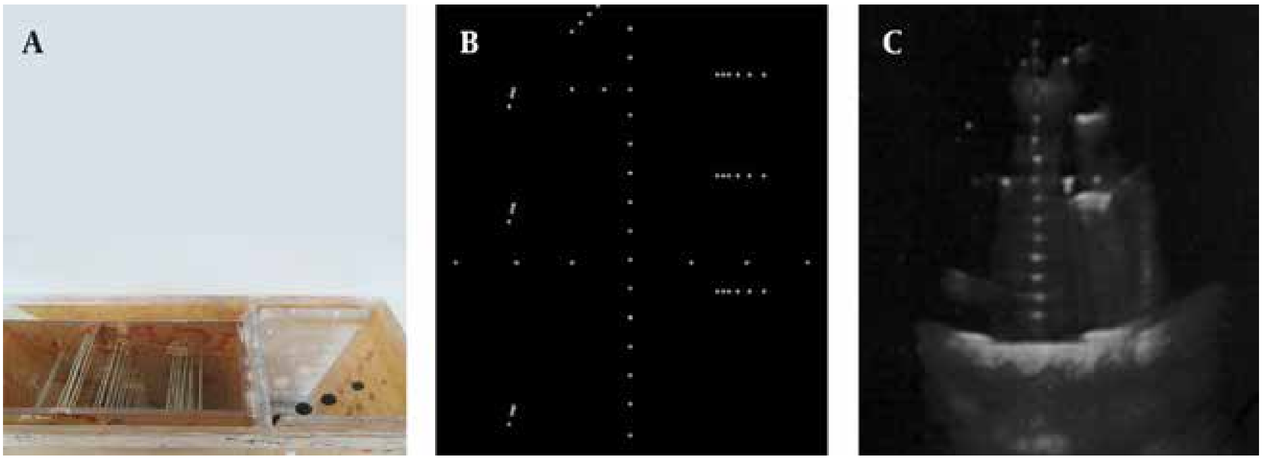

Figure 3. A: Upper View of the Phantom. B: Schematic Side View and C: Sonographic View of the Constructed Phantom

3.5. Transducer and Imaging Device Specifications

For imaging the phantom, the Sonix OP ultrasound system (Ultrasonic, British Columbia, Canada) with a C5-2/60 convex transducer (2-5 MHz, 5-30 cm depth range) and an L14-5/38 linear transducer (5-14 MHz, 2-9 cm depth range) was used. All the obtained images were gray-scale images, in which pixel intensity for each gray-level (contrast) was extracted in MATLAB and is presented in Tables 3 and 4 and as intensity.

3.6. Velocity Measurement in Alcohol and Water Solution

In Figure 3a, the actual distance considered between the vertical wires in the phantom is 1 cm. The corresponding distances in the ultrasonic images (Figure 3b) were obtained via MATLAB software (Version 7.14, MathWorks, USA) using Image Processing Toolbox.

3.7. Selection of Appropriate Solid and Cyst Test Objects

3.7.1. Quantitative Evaluation of Objects

Several objects were considered as tissue-equivalent material, and their images were obtained at different times. Criteria for the selection of suitable objects was similarity between the obtained image and the corresponding tissue in the human body (brightness and shadow) in addition to minimal shrinkage and change in brightness level at different times (just after the construction of the object and after 2 months). Size and position of these objects were based on standard phantoms [Gammex-RMI (model 403GS TM) and CIRS (model 40 TM)]. To increase the reproducibility, each sample was repeated three times. The obtained results are presented as mean (SD). The results of object assessment are presented in Tables 2 and 3.

3.7.2. Qualitative Evaluation of Objects

In addition to quantitative analysis obtained from image processing, a blind qualitative study was done by a radiologist. The results will be presented in due course.

4. Results

4.1. Velocity Measurement in Alcohol and Water Solution

The measured distance in the image using MATLAB software was equal to 0.995 cm. Consequently, the relative error in the distance and velocity measurement was about 0.5%.

4.2. Quantitative Evaluation of Objects

According to the results of image processing, commercial rubber underwent less change than did the other objects over time. Thus, in this project, commercial rubber was employed as the solid object. Agar exhibited a similar behavior and was, therefore, used as the cystic material (Tables 3 and 4).

4.3. Qualitative Evaluation of Objects

According to the radiologist, commercial rubber was appropriate qualitatively as a solid object; this observation chimes in with the above-mentioned quantitative analysis. For the cystic object, agar was appropriate owing to its similarity in image to an actual cyst in the human body (Figures 4 and 5).

Table 3. Comparison of the Different Solid Objects Tested in the Construction of the Phantom[a]

Parameter	Intensity (Pixel Intensity)		Size, mm		Relative Intensity (Normalized to Background)		Percentage Change (Within 2 Mo)
	Immediately	After 2 Mo	Immediately	After 2 Mo	Immediately	After 2 Mo	
Flowering Dough							
Brightness Level	211.33 (1.53)	166.66 (1.53)	7.16 (0.05)	8.15 (0.05)	0.85 (0.01)	0.68 (0.01)	20
Shadow Level	164.67 (3.51)	141 (1)			0.67 (0.01)	0.57 (0.01)	14.92
Commercial Rubber							
Brightness Level	171 (3)	162 (2)	7.99 (0.07)	8.39 (0.04)	0.70 (0.01)	0.66 (0.01)	5.71
Shadow Level	112 (2)	147.33 (1.53)			0.46 (0.01)	0.60 (0.01)	27.66
Radiotherapy Bolus							
Brightness Level	139.67 (3.51)	178.66 (1.53)	10.01 (0.11)	8.69 (0.07)	0.57 (0.01)	0.73 (0.01)	28.07
Shadow Level	137 (2)	167 (2)			0.56 (0.01)	0.68 (0.01)	21.43
Artificial Pearls							
Brightness Level	151 (1)	119.67 (1.53)	9.10 (0.03)	9.48 (0.06)	0.62 (0.01)	0.49 (0.01)	20.97
Shadow Level	113 (1)	86 (1)			0.46 (0.02)	0.35 (0.02)	23.91

[a] Data are presented as mean ± SD.

Table 4. Comparison of the Different Cystic Objects Tested in the Construction of the Phantom

Parameter	Intensity (Pixel Intensity)		Size, mm		Relative Intensity (Normalized to Background)		Percentage Change (Within 2 Mo)
	Immediately	After 2 Mo	Immediately	After 2 Mo	Immediately	After 2 Mo	
Silicon							
Brightness Level	175 (2)	183 (2)	13.1 (0.1)	11.30 (0.02)	0.45 (0.02)	0.47 (0.02)	4.44
Shadow Level	124.66 (1.53)	180 (2)			0.32 (0.03)	0.46 (0.03)	43.75
Agar							
Brightness Level	161 (1)	158 (2)	9.72 (0.08)	9.17 (0.21)	0.41 (0.03)	0.41 (0.03)	~0
Shadow Level	387 (3.61)	398 (2)			0.99 (0.03)	1.05 (0.06)	6.1

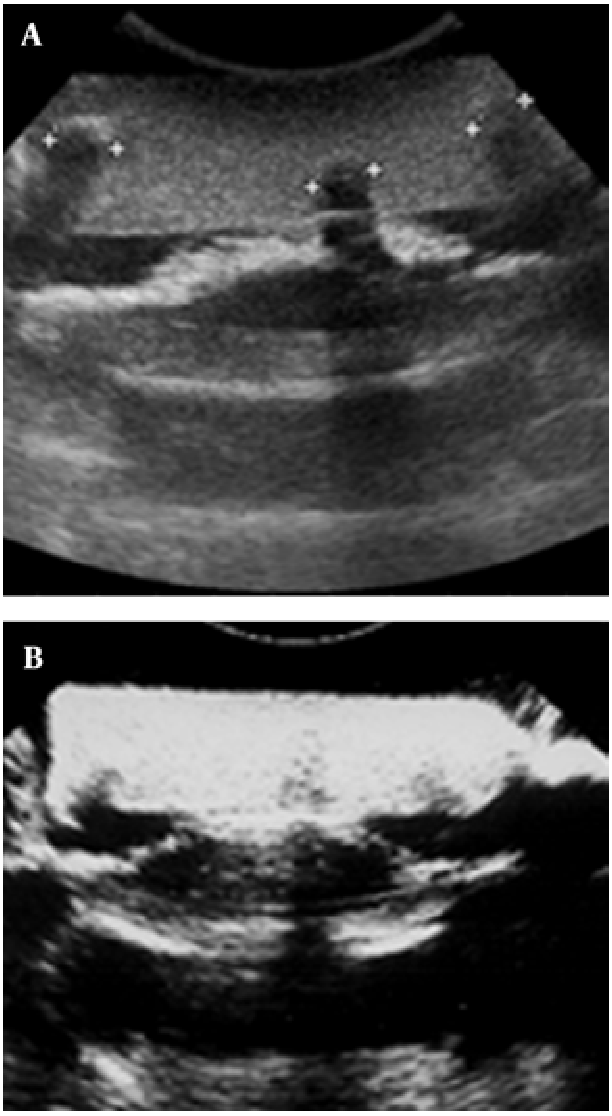

Figure 4. Solid Samples A: Respectively, from Left to Right: Flowering Dough, Rubber, and Radiotherapy Bolus. B: Same Object after 2 Months

5. Discussion

Quality control has a crucial role in all imaging and therapeutic centers and should, thus, be run periodically. Ultrasound phantoms are generally of two types: test objects and TM phantoms. The main purpose of TM phantoms is to approximate the sonographic appearance of tissues such as cysts and solid masses, which mimic the acoustic properties of the tissue (with regard to the speed of sound, average attenuation, etc.) (7). Phantoms have been used for the characterization and calibration of ultrasound imaging systems by simulating soft tissues without the need to experiment on humans or animals (14, 15). The optimal way to estimate the resolution capability of ultrasound scanners is to estimate axial and lateral resolutions individually using fibers or wires which are perpendicular to the beam axis (16).

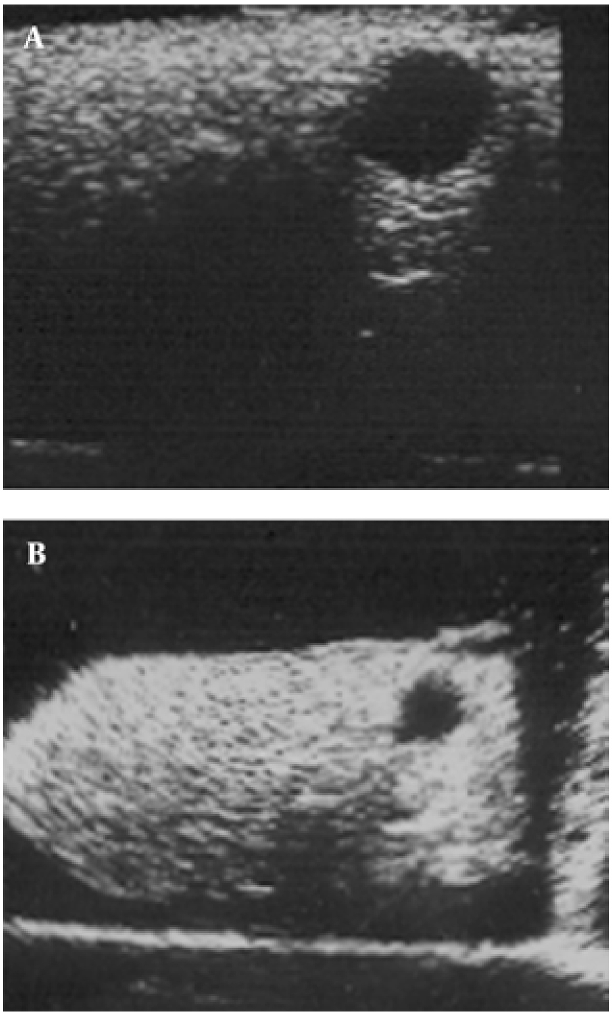

Figure 5. A: Image of Agar Cyst and B: Same Object after 2 Months

Mixture of ethanol and water is used commonly as a propagation medium in test objects for the calibration of ultrasonic imaging systems. It is widely accepted that a mixture of 9.6% ethanol by volume in distilled water yields a sound speed of 1540 m/s at 20-21°C (13). Quantitative analysis using MATLAB has shown that the relative error in distance in the phantom is about 0.5% and the corresponding error in the speed of sound is about 7.7 m/s (13). Soft tissues generally attenuate the ultrasonic beam in such a way that the attenuation coefficient is nearly proportional to frequency and the speed of propagation is about 1540 m/s. The recommended attenuation coefficient slopes for use in phantom materials range from 0.3-0.7 dB/cm/MHz (17). The attenuation coefficient for the TM material used in the phantom in the present study was 0.5 dB/cm/MHz, which is an accepted value for such a material.

Compared to multipurpose phantoms such as Zerdine® TM from CIRS Inc., condensed-milk-based gel from Gammex RMI, and urethane-rubber-based from ATS Labs, our phantom has several advantages in that not only is it easily made but also it is less expensive, less fragile, and contains fewer hazardous chemicals. It is deserving of note that we assessed the material used in the phantom design after 2 months in order to find out the stability of the phantom material with time at working room temperature. Our findings showed that after 2 months, the phantom had not undergone change and was, thus, still reliable.

Needless to say, educational centers require accessories for the training of radiology residents (5, 7, 15). The phantom presented in this study is less costly and complex than are its counterparts, which makes its use feasible for educational centers. Moreover, our phantom is capable of conferring good images of cystic and solid objects for training and quality control purposes and its metallic wire scaffold affords distance calibration as well as dead zone and resolution measurement in both axial and lateral directions.

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