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Breast Ultrasound Imaging Phantom to Mimic Malign Lesion Characteristics

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Abstract

Ultrasound (US) phantoms are used to simulate the main acoustic properties of human soft tissues and are usually applied in guided biopsy training and equipment calibration. In this work it is presented an ultrasound phantom that mimics breast lesions with irregular edge, which is a typical feature related to malignancy. The phantom matrix was made of a mixture of water, agar, glycerine and graphite and PVC powders and the lesions were of silicon and polyacrylamide. The mimicking properties were US attenuation, propagation speed and density. The images obtained were visually compatible to malignant and benign lesions and are meant to be used as references for evaluation of segmentation algorithms for image processing.

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1. Introduction

Ultrasound (US) phantoms are testing objects that simulate the basic human soft tissue properties related to US wave propagation. In image diagnostic area, breast phantoms are an important tool for performance testing and optimization of medical ultrasound systems as well as for medical training purposes [1]. Nevertheless, commercial phantoms present basically regular-shaped homogeneous targets imitating benign solid or liquid lesions.

The construction of phantoms for US in medical images evaluation is based on properties of mimicking materials that should present the basic acoustic parameters of biological tissue as (*i*) sound propagation speed, (*ii*) attenuation coefficient (absorption and scattering) and (*iii*) acoustic impedance [2].

Due to the individual anatomical variations of breast, such as size, shape and tissue composition, phantoms are usually designed to represent only some typical characteristics, for example, the glandular and adipose tissues, cysts and lesions in different shapes and sizes [3].

Some studies report the construction of phantoms for breast mammography (X-ray) [4,5,6], but for evaluation of US images, there are only a few in literature. Among the most recent ones is the work of Madsen *et al*. [7].

The aim of this work is to develop a phantom for ultrasound that simulates breast lesions with irregular contours of different geometries, sizes and orientations, as well as values of density, US speed and attenuation of breast tissue.

2. Material and Methods

The experimental strategy adopted consisted of four steps: (i) preparation of tissue-mimicking matrix to obtain similar values to glandular tissue properties, (ii) lesions designing and fabrication, (iii) final assembly of the phantom (tissue-mimicking matrix with lesions included), and (iv) image acquisition in different scanning plans.

2.1. Preparation of mammary gland tissue mimicking

The first step was to mixture the distilled water with agar, glycerine, PVC and graphite powder at room temperature. Both powders were used to promote wave scattering and to tune thermophysical properties.

The agar is useful to give a gelatine-like consistence to the phantom matrix, as well as increasing the fusion temperature from 38ºC (gelatine) to 78ºC (mixture), which minimizes the loss of water during the manufacturing process [8].

Glycerine is added to the agar (3%) to obtain US speed values of 1540 m/s at 24.5 ± 0.1ºC [2], which is the average value for human soft tissue. An important advantage is that glycerine (fusing point 17.9ºC and boiling point 290ºC) is less volatile than isopropilic alcohol that could be also used to tune the US speed.

The mixture stayed in vacuum for about the 30 minutes, to extract the air bubbles, thus ensuring that when an image is produced, the wave scattering is caused only by graphite and PVC powders.

2.2. Design and Fabrication of Breast Lesions

Breast lesions were made of polyacrylamide or silicon in four different shapes (cylindrical; spiculated; large circle and small circle), with maximum diameter ranging from 5 to 30 mm, as shown in fig.1, and implanted randomly into the glandular tissue-mimicking phantom.

2.2.1. Construction of Silicon Lesions

For the preparation of the silicon material (GEO RTV615), two constituents were used: The component A which contains the platinum catalyst and component B (hardener), the cure agent to form the silicon network. The components are mixed in the proportion 9:1 (A:B).

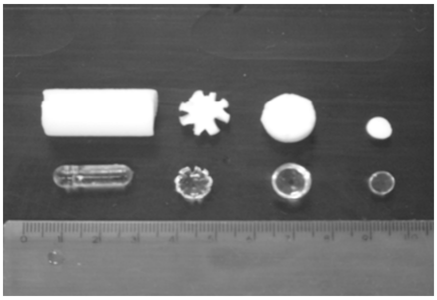

Fig.1 Shape of the polyacrylamide (I) and silicon (II) simulated lesions: (a) cylindrical; (b) spiculated; (c) large circle (disk); (d) small circle (disk). These shapes are commonly found in real lesions.

2.2.2. Construction of Polyacrylamide Lesions

The polyacrylamide is a polymer, which has been used in phantoms designing because it has nearly the same behaviour in thermal and acoustic fields of biological tissues. Its development requires a more complex preparation than for physical hydrogels as gelatine and agar. When the chemical reactions are completed, it becomes a more stable and easier-to-handle material. Measurements of the acoustic properties were made by applying the substitution method in pulse-transmission configuration. The phantom is immersed in a tank with distilled water (at 25ºC) in between a pair of plane circular transducers of 1-MHz central frequency (fig. 2). An SR-9000 (Matec) pulse generator excites one of the transducers. The US pulse crosses the phantom and is received by the other transducer, and then it is sampled at 2 Gs/s in a digital oscilloscope (2024B TDS, Tektronix) and saved in a microcomputer. The phantom is then removed and a new US pulse is acquired, this time travelling through water only (the transducers are kept at the same original distance). By comparing the propagation times and spectral amplitude of the echoes with and without the phantom, it can be estimated the US speed and attenuation of the phantom (details in [9]). The effects of non-linear propagation were not considered because the pressure amplitude and travelling distance are small enough to assume a linear behaviour.

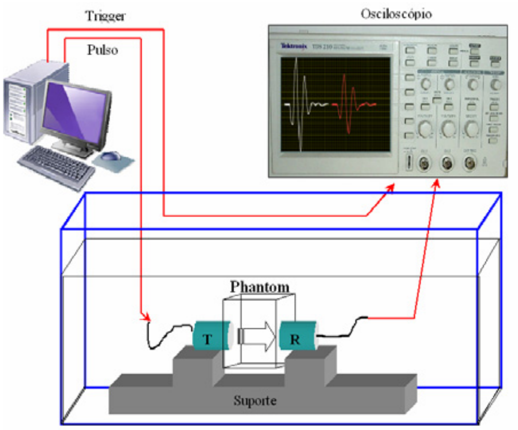

Fig.2 Experimental assembly used in the acquisition of signals for the acoustic properties estimation of the phantom, based on the substitution method. Transducer T sends a US pulse that travels through the phantom and is received by transducer R. Then the phantom is removed and another pulse is captured. Both pulses are used to obtain US speed and attenuation.

2.3. Acquisition and Evaluation of the Images

The phantom images were acquired by a qualified ultrasonographer that performs US breast scanning routinely at the Gaffrée & Guinle Universitary Hospital (Rio de Janeiro, Brazil) with a commercial equipment dedicated to breast scanning (Image Point M2410A U.S. System - Hewlett Packard), with a transducer operating at a central frequency of 10 MHz, as shown in Fig.3. The images were then scanned (Scanjet 3800, Hewlett Packard), with a resolution of 200 dpi.

Fig.3 Experimental assembly used in the phantom images acquisition. US equipment routinely used for breast scanning. In the figure the transducer (traced arrow) is touching the phantom surface. The image is collected in a hardcopy that is scanned later.

3. Results

The values of density (ρ), propagation speed (V), attenuation (α) and acoustic impedance (Z) of the glandular tissue and the lesions mimicking materials are shown in Table 1.

The lesion images of the phantoms are shown in Figure 4. In the first row are the polyacrylamide lesions, in the second are the silicon lesions and in the last one, are images of real breast lesions so that similarities can be compared in each case.

4. Discussion and Conclusion

With respect to the values obtained for the phantom acoustic properties, the speed of sound for mammary glandular tissue (1544 m / s) was very close (less than 2% of difference) to that obtained by Madsen et al. (1519 m / s) [1]. The US speed found for the silicon lesions is about 30% smaller than the average standard value accepted for biological tissues (1540 m/s) and although giving good ultrasonic images, the estimation of their sizes by electronic callipers (commonly used in standard commercial US equipment) would have this 30% of overestimation, therefore they are adequate only to be used as qualitative lesion mimicking objects. On the other side, the US speed values obtained for the polyacrylamide lesions are inside the window accepted for biological tissue US speed variation (less than 2% of difference), therefore, they are good candidates for quantitative lesion mimicking.

Concerning the attenuation at 1 MHz, we observed similar behaviour for glandular tissue as for the silicon lesions to reference values (Table 2); nevertheless the value for the polyacrylamide lesion is still around 20% smaller than literature values. A complementary work is necessary to find a more suitable recipe.

The values of density are compatible with literature in all three mimicking subjects [1]. However, due its lower US speed, the value of acoustic impedance of the silicon lesions is not adequate for biological tissue simulation.

The significant difference in acoustic impedance between the glandular tissue and the silicone lesion causes the image effect known as acoustic shadow illustrated in Figure 4g. Although more frequent in malignant lesions, this phenomenon can also occur in benign lesions [12].

Although acoustic parameters obtained for glandular tissue material are similar to those described in the literature, the visual appearance of this is still not adequate, requiring the inclusion of structures that mimic the anatomy of a breast, such as ducts, fatty tissue and lymphonodes.

For the images of the polyacrylamide lesions, their shape and dimensions were equal to the real objects for all practical purposes. For the images of the silicon lesions, as commented before, they appear bigger in the vertical direction due to its lower US speed. Anyway it is possible to see that images on fig. 4e and 4f presented a similar shape of the real objects. However, the images for circular lesions have a rather different shape, probably due to the scanning plane of the silicon disks during the image acquisition.

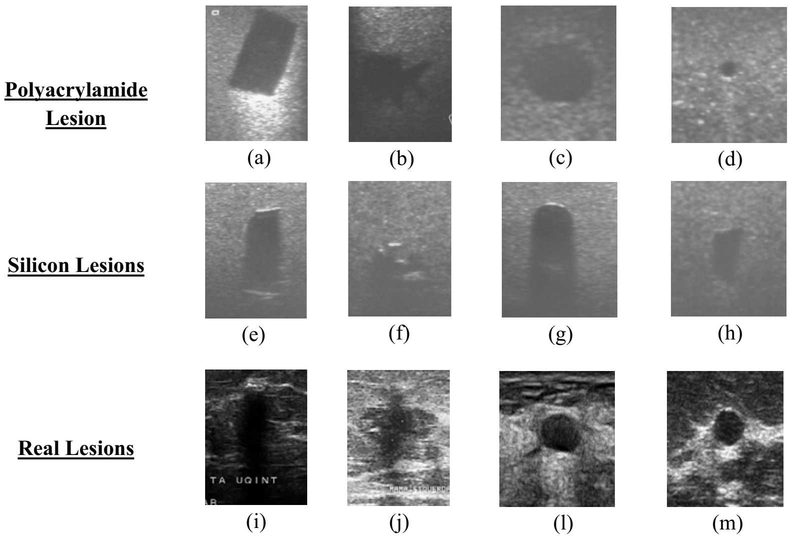

Fig.4 In the first row one can see the images of the polyacrylamide lesions and in the second row, the silicon lesions (cylindrical, speculated, large circle and small circle, respectively). Images of real lesions are presented in the third row.

Table 1. Values of acoustic parameters for the breast phantom materials obtained with 1-MHz plane circular transducers.

	ρ [kg/m^3]	V [m/s]	α [dB/cm]	Z [gm/cm^{-2}/s^{-1}]
Glandular Tissue matrix	1.11	1544	0.83	1706
Silicon Lesion	1.06	1069	1.43	1133
Polyacrylamide Lesion	1.04	1567	0.95	1629

In conclusion, a first version of a phantom able to mimic the appearance of ultrasound irregular breast lesion in routine ultrasound exams has been developed. Based on the visual evaluation and the measured US properties, the images contour obtained from polyacrylamide lesions were more consistent with the real ones if compared to those obtained with silicone objects. Regarding lesion textures, both lesion materials presented the appearance the real cystic lesions.

In the next steps we intend to improve the phantom so as to mimic the texture of nodules and also ducts and lymphonodes.

The phantom is intended to generate an image database of lesions that can be used to develop Computed - Aided Diagnosis System (CAD), in special to be applied in the segmentation phase, once the lesions size and contours are known and can be used as gold standard for algorithm evaluation.

Table 2. Acoustic parameters for glandular breast tissue and simulated lesions at 1 MHz [1].

	ρ [kg/m^3]	V [m/s]	α [dB/cm]	Z [gm/cm^{-2}/s^{-1}]
Glandular Tissue	0.99	1519	0.80	1500
Lesion	1.08	1564	1.18	1690

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