Received: December 22, 2018. Revised: May 17, 2019. Accepted: June 11, 2019. Published: June 21, 2019.

Assessment of an anthropomorphic ultrasound breast phantom

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***Abstract*— The objective of this investigation was to evaluate the acoustical properties of agar-based (polysaccharide gel) anthropomorphic breast phantom for use in diagnostic ultrasonography. The agar breast phantom was included tissue mimicking (TM) non adipose glandular tissue and tissue mimicking (TM) fat. The agar phantom was fabricated using a range of temperatures of 15 ^{o}C to 35^{o}C with different composition of anise oil. The sound speed and acoustic impedance of the agar phantom were determined. The result of sound speed of agar phantom was observed to increase within the range of 1407 ms^{-1} to 1624 ms^{-1} with the increase the temperature of phantom from 15^{o}C to 35^{o}C. In addition, the sound speed for different concentration of anise oil was increased in the range of 1519 ms^{-1} to 1562 ms^{-1} when the concentration of anise oil decreases. The acoustic impedance of agar phantom was decreased by increasing the percentage of anise oil. These results indicate that the agar material phantom is suitable for using in ultrasound imaging applications.**

***Keywords*— Ultrasound; Breast phantom; Agar; sound speed**

I. INTRODUCTION

Ultrasound imaging is a form of medical imaging which involves the use of high frequency sound waves to produce dynamic visual images of organs, tissues or blood flow inside the body [1]. Ultrasound possesses unique characteristics that are advantageous in comparison to other competing modalities such as X-ray computed tomography (CT), radionuclide emission tomography, and magnetic resonance imaging (MRI). Ultrasound is a form of non-ionizing radiation and is considered safe to the best of present knowledge. It produces images in real time, unattainable at the present time by any other methods. This kind of medical imaging has a resolution in the millimeter range for the frequencies being clinically used today, which may be improved if the frequency is increased. It also can yield blood flow information by applying the Doppler principle [2].

The ideal ultrasound imaging phantom should have same acoustical properties as those of human tissues, such as: speed of sound, attenuation coefficient, acoustic impedance and backscatter coefficients [3][4][5]. At present, commercially available phantoms are not fit for this purpose, due to the acoustical properties of the Tissue Mimicking Materials (TMMs) used in their production [6]. In general, the acoustical properties of ideal phantom were not satisfactorily achievable with commercially available phantoms. In addition, commercially available phantoms are all similar in design, consisting in general of nylon filaments and tissue mimicking cylindrical objects (representing anechoic and contrast structures) embedded in a homogeneous tissue mimicking background material.

Agar-based phantoms have been used in magnetic-resonance imaging (MRI) and ultrasound imaging for decades, and they were adopted in optical tissue phantoms in many laboratories in the mid 1990's. Agar allows inclusion of organic molecules and cellular-based constituents, while providing a semisolid object that can have a variety of shapes [7]. A phantom made of agar gel has been widely used because its acoustic characteristics can be easily controlled in the manufacturing process. However, hydrophilic organic material such as agar has disadvantages in that bacteria propagate in them and thus their acoustic characteristics change with time [8][9]10].

The preparation of agar into any desired shape usually is simple and fast. Handling and preparation are harmless. In addition, it can be stable for quite a few weeks by storing under water at about 4 □C [11].

The breast phantoms are used in order to provide a common and reproducible way for breast ultrasound interpretation in medicine and medical physics [10]. Breast phantoms are an important tool for performance testing and optimization of medical ultrasound systems as well as a training tool to teach ultrasound guided interventional procedures like biopsy, fine needle aspirations [5]. This study presents the characterization of acoustic properties of agar, and the assessment of the results as possible tissue-mimicking materials. The acoustic properties of agar phantom, including the sound speed, acoustic impedance were evaluated. The objective was to establish long-term stable and easy-to-handle breast phantoms for acoustical measurements.

II. EXPERIMENTAL PROCEDURE

A. *Fabrication of anthropomorphic breast phantom*

An agar was selected as the basis for fabricating the breast phantom. Additional components were selected that are easily mixed into the mixture and finally produced the desired ultrasound breast phantom. The additional selected material constituents of 2-isoprpyl alcohol, anise oil, tartrazine and distilled water, these components were consumer products, user- gently and recycle materials. The constituent materials of distilled water, 2-isoprpyl alcohol and agar were mixed by Magnetic stir bar in appropriate proportion in order to fabricate tissue mimicking material (TMM). The mixture was mixed for 20 min at room temperature of 22±1 °C. Subsequently, the mixture was heated using hot plate with continued stirring to dissolve all agar fiber and uniformity solution, when the temperature of mixture exceeded 90 ºC the beaker was removed from the hot plate and allowed to cool down at room temperature. The tartrazine was added to mixture when the temperature cooled down to 50 ºC. The mixture was poured into appropriate molds of breast shape, where curing for 24 h. Following release from the appropriate mould, the phantom parts were finished and leveled to the desired dimensions.

Similarity, TM fat was fabricated by mixing distilled water, 2-isoprpyl alcohol and agar in beaker. The mixture was heated with continues stirring until it exceeds temperature of 90 °C, thereafter, the mixture was removed and allowed to cool down at room temperature. At the same time, anise oil was heated and with surfactant was added to the solution. The mixture was poured into the appropriate moulds and cured for 24 hr. Upon the TM fat released from appropriate mould and implanted into the (TMM) as shown in the Fig. 1.

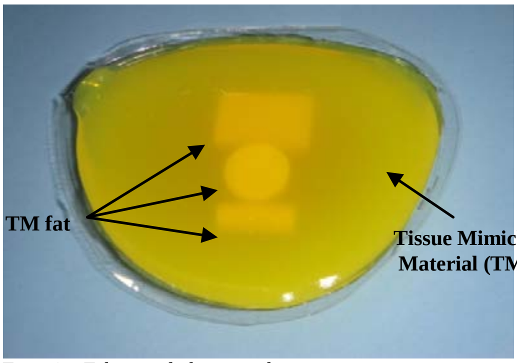

Fig. 1. Fabricated breast phantom in supine position contained tissue mimicking material (TMM) and TM fat.

B. Density measurment

The TMM was initially weighed using digital scale and put into the measuring cylinder with the known amount of water. A change in the volume of water is equal to the volume of the TMM. The measurements were repeated three times to give the reliability of the results. Thereby, the density of TM samples was calculated by dividing the average of sample mass (kg) to the average of sample volume (m^3).

The density of TM fat was calculated using knowledge of the density of the pure agar gel (1068 Kg/m^3), oil droplets (950 Kg/m^3) and surfactant (975 Kg/m^3) using the following Equation (1) suggested by Madsen et al. [12].

$$\text{Density of TM fat} = [(D_a \times w_a) + (D_o \times w_o) + (D_s \times w_s)] \qquad (1)$$

where D_a : Density of agar gel.
w_a : weight fraction of agar gel.
D_o : Density of oil droplets.
w_o : weight fraction of oil droplets.
D_s : Density of surfacetant.
w_s : weight fraction of surfacetant.

C. Sound speed measurment

The speed of sound can be described as the phase of sound waves in the medium to be studied, and is also known as the sonic speed or velocity of sound (AIUM Technical Standards Committee 1995). This particular parameter is fundamental to the characterization of images acquired by ultrasound [13].

The speed of sound in the materials was measured by using a portable ultrasonic flaw detector (KrautKramer USM-25). In order to gain accurate data, the equipment was first calibrated .The calibration block with 25.0 mm thickness and 5920 ms^{-1} sound speed was used to calibrate the instrument.

The probe of ultrasound flaw detector was positioned on the phantom sample in order to ensure good contact between the probe and sample, ultrasonic gel smeared at the interfaces. The required display range in function group BASE was set somehow that two calibration echoes selected could be displayed on the screen. The second calibration echo was located on the right edge of the screen. The distances of two calibration echoes were entered in S-REF1 and S-REF2. The gate of device was positioned on the first calibration echo and it was recorded. The gate was moved to record the second calibration echo. The measured sound speed in the sample could be obtained from material velocity (MTLVEL).

D. Acoustic impedance

Acoustic impedance is a characteristic of a material which is a measure of how ultrasound traverses that tissue. It is related to its density and elastic properties. The relationship is such that the impedance, Z, is the product of the velocity, V, and the material density, ρ , which can be expressed as (2):

$$Z=\rho V \qquad (2)$$

E. Acquisition of ultrasound image

An Ultrasound (US) Scanner Machine (Ultrasound diagnostic System, model: CMS600C-2) was used to obtain the ultrasound image of the fabricated breast phantom sample. The frequency range that is used for breast scanning is 5-10 MHz [7]. Thus for this experiment, 5 MHz frequency was used.

The probe was selected depending on the surface of the phantom. The linear probe can be used for top surface of phantom and curved probe for the sides of phantom. The probe is acoustically coupled to the sample using gel as a couplet between the transducer and the sample. The sectional gains with different penetrating depths are adjustable through the sectional TGC (Time Gain Control), with the combination of total gain and sectional gain adjusted; the best illuminating image is acquired.

III. RESULTS AND DISCUSSION

A. Deansity measurement

The density of the pure agar gel, anis oil and surfactant was calculated simply by dividing the sample mass (kg) with the sample volume (m^3). The density of TM fat was calculated using the Equation 1. Table 1 shows the calculated density of the experimental samples with different percentage of anise oil.

TABLE 1. Measured densities of samples with different percentage of anise oil.

Percentage of anise oil (%)	**Percentage of agar gel (%)**	**Percentage of anise oil (%)**	**Percentage of surfactant (%)**	**Density (kg/m^3)**
0.00	100.00	0.00	0.00	1068.00
18.00	72.91	18.00	9.09	1038.31
36.00	54.91	36.00	9.09	1017.07
45.00	45.91	45.00	9.09	1005.45
55.00	36.91	54.00	9.09	995.83
70.00	18.91	72.00	9.09	974.59

From Table 1, it was found that sample with no anise oil has the highest density difference of 6.8% from target density of 1000 kg/m^3 compared with 3.8%, 1.7%, 0.5%, -0.4% and -2.5% density difference for samples with percentage of anise oil of 36%, 45%, 55% and 70%, respectively. Consideration must be taken that all samples were fabricated at the same of room temperature of 22±1 ^oC.

B. Sound speed measurment

B.1 Temperature variations

The range of the sound velocity in various materials represents their ultrasonic characteristics. Fig. 2 shows the sound of speed as a function of a temperature. It was found that the sound speed in agar breast phantom increased with temperature and the rate of increasing trend line over the data was approximately constant.

The relationship between the sound speed and temperature of the material can be used to find the suitable material that can mimic soft tissue at specific temperature such as human body temperature. Overall, the results obtained indicate that the increase in the average values of the sound speed in the range of 15- 35 ^oC is about 15.4 %. Hence, the rate of increase of the sound speed for each 1 ^oC drift is 0.77 %. In comparison with AIUM experiments object with a mixture of water, alcohol and algae inhibitor showed a rate of sound speed variation less than 1.00% when the temperature is varied by 5 ^oC [12].

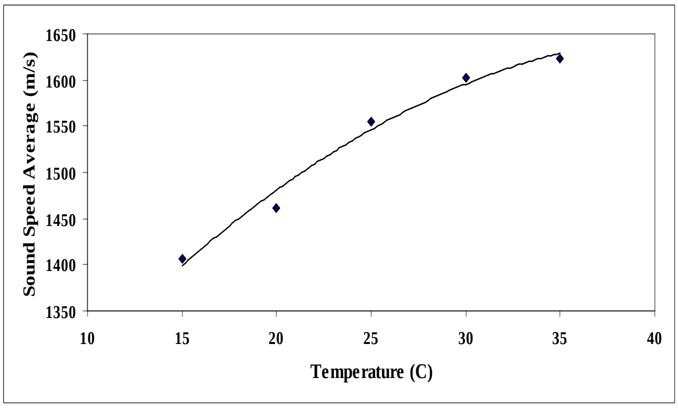

Fig. 2. Sound speed average (m/s) as a function of temperature (□C).

B.2 Percentage of anise oil

The phantoms are made to mimic the human body tissue. Therefore, finding the correct concentration of material is a vital factor to fabricate the phantom. Samples with different anise oil concentration were produced to determine the effect of anise oil on the sound speed. Fig. 3 shows the sound of speed as a function of an anise oil concentration. It was found that the speed of sound increased across the range of 1519 ms^{-1} to 1562 ms^{-1} with increasing concentration of anise oil. It is due to this fact that the higher anise oil contents in the material causes the lesser density.

The trend line in the Fig. 3 is polynomial and fallows a decreasing trend with increasing percentage of the anise oil. A reduction in speed of sound with increasing anise oil concentration was observed. Consequently, when the anise oil is mixed with the material including tissue mimicking and targets, it would reduce the overall sound speed of the resulting materials.

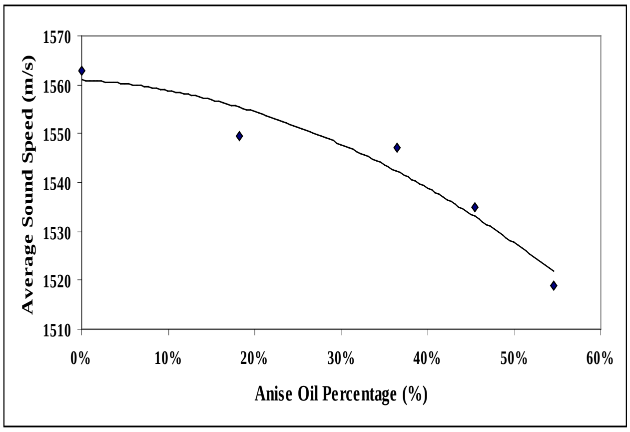

Fig. 3. Sound speed average (m/s) as a function of anise oil percentage (%).

C. *Acoustic impedance*

The acoustic impedance values of samples were calculated using the Equation 2. The acoustic impedance results as a function of anise oil percentage was illustrated in Fig. 4. It was found that acoustic impedance decreased by increasing the percentage of anise oil. Due to adding oil to the agar TMM reduces the sound speed and the inclusion of the oil more than 40%, prevent the TMM to be congealed. Therefore, the acoustic impedance decreased with increasing the concentration of oil in fat mimicking. The acoustic impedance has dependency on sound speed and density. As it was found that sound speed and density both decreased by increasing the oil concentration.

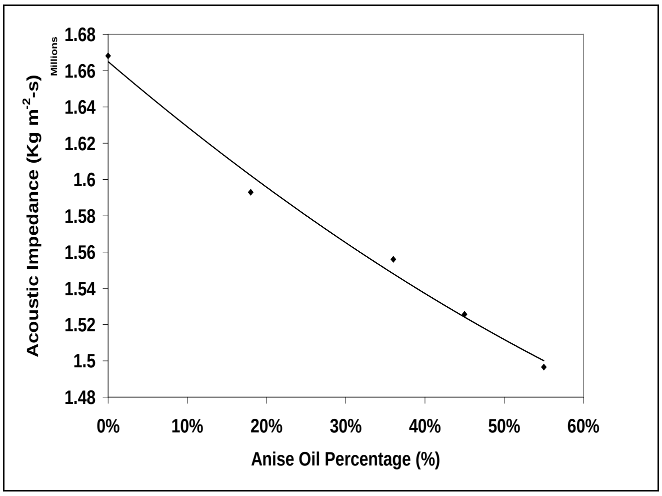

Figure 4. Acoustic impedance as a function of anise oil percentage (%).

D. *Acquired ultrasound image*

Tissue mimicking (TM) fats could be clearly observed in the ultrasound image of the breast phantom. Additionally, dimensions and shapes of the targets are easily distinguishable in the provided image as shown in Fig. 5. The ultrasound image was scanned from the lateral side of the phantom with a convex probe. The frequency that was used in acquisition of ultrasound images was 5 MHz. The external side of the phantom (interface with air) is clearly seen with white color in the bottom of the image as shown in Fig. 5. The evaluation on the ultrasonic image showed that agar material phantom material for fabricating the tissue mimicking material and tissue mimicking fat are suitable for breast phantoms in ultrasound imaging.

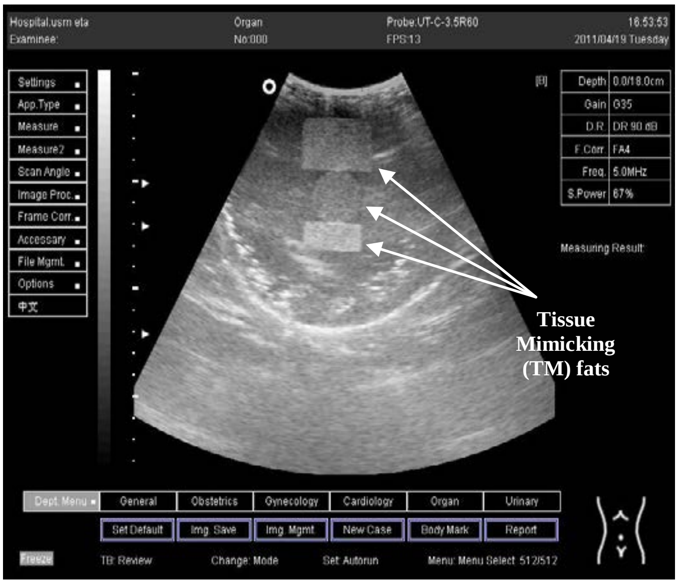

Fig. 5. Ultrasound image of fabricated phantom showing different shapes of TM fat.

IV. Conclusion

Agar was chosen as tissue mimicking for this work because agar acoustic characteristics can be easily controlled during the manufacturing process, and it can be stable for several weeks. These properties make this phantom suitable for use in the production of quality assurance phantoms and anthropomorphic breast phantoms for training purposes.

Krautkramer USM-25 with 5 MHz transducer was used to measure the sound speed in fabricated breast phantom as the frequency range that is used for breast scanning is 5-10 MHz. The effect of variation in temperature and weight composition of the materials on the properties of fabricated breast phantom was evaluated. The acoustic properties of fabricated breast phantom were in the range of human breast properties.

The analysis on acquired ultrasound images indicates that the materials used for fabrication of this phantom are suitable for ultrasound imaging applications. The actual choice of material depends on which tissue type within the body is to be simulated. The advantage of used agar material in this research was their relative ease of manufacture and the ease of controlling their acoustic properties. Furthermore, the materials used to fabricate the phantom were odorless, non toxic and could be formed in any desired shape. The fabricated agar breast phantom was non expensive with a long life span and suitable for various ultrasound applications.

Acknowledgment

We are grateful to the Universiti Sains Malaysia for the supplying materials to achieve this work.

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