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Anthropomorphic Ultrasound Elastography Phantoms – Characterization of Silicone Materials to Build Breast Elastography Phantoms*

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Abstract— **In this paper a mechanical characterization of low cost and simply available materials to build efficient anthropomorphic ultrasound elastography phantoms is described. The class of silicone materials was selected because of their deformability, durability and the possibility of reproducing specific tissue properties and shapes. Innovative formulations of silicone mixtures with echogenic and/or softening additives were tested. The proposed models have good acoustic properties and tactile feedback; moreover they are durable and do not require special storage since they do not dehydrate or decompose over time.**

I. Introduction

Elastosonography (ES), which was first proposed during the 90s for an early diagnosis of breast cancer, is an ultrasound (US) based imaging technique allowing the evaluation of elastic properties of tissues under external compression [1].
Tissue-mimicking phantoms are commonly used in therapeutic US for dosimetry [2], visualization and measurement of ultrasound-induced cavitation damage [3], training purposes but also to validate virtual ES models [4].

Some breast phantoms are already commercially available for training purposes but they cannot be used to characterize ES devices or validate software models because no information regarding the mechanical properties of their constitutive materials is provided. On the other hand, phantoms for ES machine quality certification are quite expensive.

In [5] we investigated the mechanical properties of some low cost and simply available materials to build ES breast phantoms. In particular, Polyvinyl alcohol (PVA) hydrogels and four different types of room-temperature vulcanizing (RTV) silicones were selected as potential candidates for the development of ES breast phantoms, since they are commonly used for the manufacturing of US phantoms [6].

In this work we focus only on silicone materials due to their high durability and their easier fabrication procedure. Starting from previous results we improved mechanical and acoustical properties adding specific additives to the standard commercial formulation. Moreover we selected the most suitable materials to build ES breast anthropomorphic phantoms with different type of pathologic inclusions.

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II. Materials and Method

A. Samples preparation and formulation definition

Three types of room-temperature vulcanizing (RTV) silicones were selected: Dragon Skin® 10 Medium (DSM), Dragon Skin® FxPro (DSF) ad Ecoflex® 0010 (ECO) all from Smooth On Inc.

Samples 12.5±0.5 mm in thickness and 29.0±0.5 mm in diameter were prepared according to the ASTM D395-03.

Slacker®, a commercial additive, was added in different amount (0-10-20-30% in volume) to the silicone mixtures to improve their mechanical properties in terms of Young Modulus (E). This component is commonly used to achieve flesh-like consistence in silicone phantoms, and in this work was selected to adjust Young's modulus values according to literature values. [4, 7]

As for the acoustic properties, a Polyacrylimide Gel (PAAG) based formulation was added (0-10-20-30% in volume) to the silicone mixtures. The PAAG is the basic ingredient of most ultrasound coupling media and in this work it was selected to improve the echogenicity of silicone mixtures in order to mimic the acoustic properties of health tissue.

Finally, considering intermediate results, both additives were added to the ECO samples in an equal amount of 10% in volume.

All the samples were obtained by mixing the base and curing agent in the standard ratio and by adding the selected additive percentage. Vacuum degassing cycles were performed to remove trapped air; all the silicones' components were cooled to slow down the curing speed and reduce mixture viscosity in order to facilitate air removal.

Three samples were made for each different formulation; each set was made from the same mixture to minimize inter-samples variability.

B. Mechanical testing and echogenicity assessment

Mechanical compression tests, in displacement control, were performed leading samples to a deformation of up to 30% of their original thickness. The samples were compressed at three different strain rates: 1.6, 2.5 and 5 %/s. Collected data were analyzed and a stress-strain curve was plotted for each sample, finally the elastic modulus was calculated as the slope of the initial linear part of the curve.

The echogenicity of each material was qualitatively assessed through US examination, testing their US transmission capability in water using MylabONE portable US imaging device from Esaote.

C. Anthropomorphic phantom fabrication

Fig.1 shows the CAD project of the moulds, manufactured with a rapid prototyping machine (Dimension Elite 3D Printer [8]) and used for the anthropomorphic breast phantom fabrication. A first mould was designed to achieve the breast shape and a different one to fabricate lesions (spherical, with two different diameters). A specific type of lesion, the malignant infiltrating ductal carcinoma, were instead hand-made (without a mould) to reproduce their typical speculated and not defined shape [9].

The fabrication procedure consists of a three steps process:

1. To pour inside the mould an initial layer of healthy tissue-mimicking material;

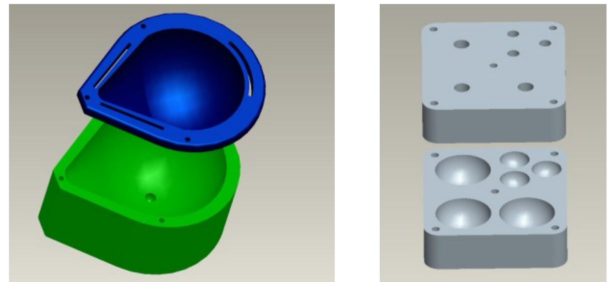
2. To fabricate the lesions with the proper material and to place them on the previously cured layer;

3. To pour a final layer of healthy tissue-mimicking material.

III. RESULTS

A. Mechanical Results

Among all the tested specimens, four formulations were selected according to their mechanical and acoustical properties.



(a) (b)

Figure 1. Designed mould for the fabrication of the anthropomorphic phantom: (a) external mould (b) inclusions mould.

The selection was made upon the reference values of human breast tissues [7].

Table 1 shows Young's modulus of the selected formulations in comparison with literature reference values.

Notice that the elastic moduli of the different silicones do not change with the frequency of the applied displacement over the experimental range of strain rates.

The same result was obtained for the natural tissues in [7], which underlies how the tissue components of the breast behave as elastic materials (and the viscous component is negligible).

B. Acoustic properties results

US examination showed, as expected, that all the silicones without PAAG additive have a marked hypoechogenity and exhibit acoustic shadowing. For this reason they were considered good candidates to simulate breast lesions which attenuate the US signal producing a black shadow under the nodule.

More particularly, DSM+S and ECO+S could mimic benign lesions as fibroadenomas which are hypoechogenic with a well-defined posterior wall, while DSF+S could mimic malignant lesions such as infiltrating ductal carcinoma.

On the other hand the samples with the PAAG additive showed a marked increase in echogenicity, so they could be considered good candidates to mimic normal glandular tissue (Fig.2).

TABLE I. YOUNG MODULUS (KPA)

Silicone mixtures	Silicone Specimens			Breast Tissues	
	1.6[a] *(%/s)*	*2.5 (%/s)*	*5 (%/s)*	*5 (%/s)*	
ECO+ PAAG 20%	18.94±8.71	18.00±8.64	18.67±9.78	**18±7**	**Fat**
ECO+ S10%+PAAG10%	45.69±7.70	36.76±6.84	32.09±6.06	**28±14**	**Gland**
ECO+ S30%	121.92±34.82	101.69±10.88	112.10±20.73	**96±34**	**Fibrous**
DS+S30%	102.32±12.93	94.43±15.01	97.85±10.42	**106±32**	**Infiltrating Ductal**

a. According to ASTM standard

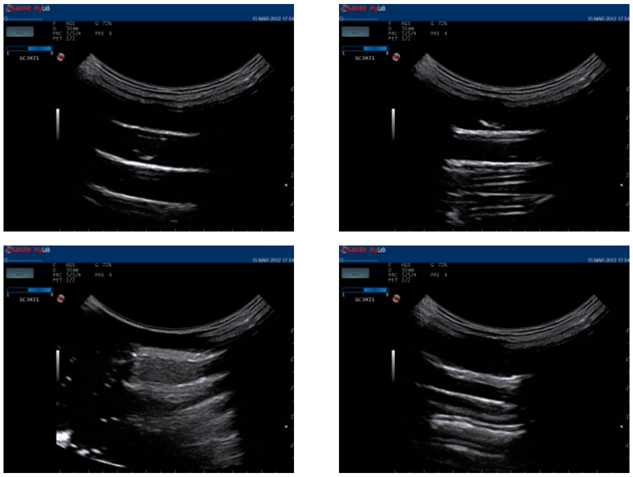


Figure 2. From top left in clockwise direction: three silicone samples without PAAG additive (ECO+S, DSM + S, DSF +S) with a hypoechoic behaviour , and a silicone sample (ECO) with PAAG additive in the formulation showing the changed behaviour.

During these preliminary qualitative tests no significant variations in echogenicity were appreciated with an increasing amount of the PAAG additive.

C. Anthropomorphic phantom fabrication

The final anthropomorphic phantom was made selecting the proper material according to mechanical and acoustic properties.

Fig. 3 shows the final phantom and a preliminary echographic test session.

IV. Conclusion

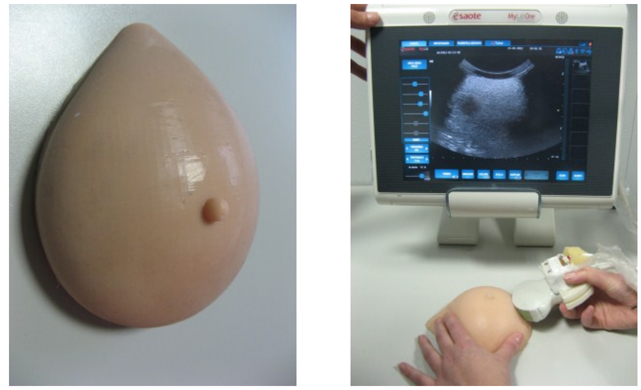
In this paper we introduce innovative RTV silicone formulations to fabricate a low-cost durable ES breast phantom.

According to mechanical and acoustic results:

- ECO+PAAG20% can mimic normal fat;
- ECO+S10%+PAAG10% can mimic glandular tissue;
- ECO+S30% can mimic fibrous tissue;
- DS+S30% can mimic invasive infiltrating ductal carcinoma.

Future work will regard the quantitative evaluation of all the silicone mixtures acoustic properties in terms of acoustic impedance (Z) to confirm or eventually steer the selected formulations.

Furthermore, a final ES assessment of the phantom will be performed in comparison with the natural tissue.



(a) (b)

Figure 3. (a) The final breast anthropomorphic phantom, (b) the phantom during an echographic test session, in the US image a malignant lesion is visible

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