Design and characterization of a non-homogeneous elastosonographic breast phantom using PVA-C gel

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Purpose

The principle of elastosonography (ES) is that tissue compression produces strain within the tissue and that the strain is smaller in harder tissue than in softer tissue. Therefore, by measuring the tissue strain induced by compression, it is possible estimate tissue hardness, which may be useful in diagnosing breast cancer [1]. The mechanical properties of tissues are generally correlated with pathological changes: some cancerous lesions are characterized by an increased stiffness.

Despite the recent studies from both the imaging [2] and computational point of view [3], there is a lack of realistic breast phantoms for testing and benchmarking procedures. To date, phantoms are mainly based on *homogenous materials*, consequently the comparison of the results with real cases can be difficult.

Tissue-mimicking materials (TMM) are indispensable for the assessment of ES. There is a need to find materials that can mimic different tissue properties over a wide range of material properties and show similar dispersive behavior.

The aim of the current work is to investigate the use of poly(vinyl alcohol) cryogel (PVA-C) as a tissue mimics material for breast elastosonography to enhance the ES.

Methods and Materials

PVA-C was chosen for the phantom design for its biological tissue-mimicking properties [4]. The stiffness properties of PVA-C can be manipulated by processing the solution through a number of freeze/thaw cycles or varying the PVA concentration. First, different PVA-C were obtained, then mechanical tests were performed and finally different phantoms were created by changing tissue composition in terms of layers dispositions and dimensions.

**PVA-C preparation**

Commercial PVA powder (99% hydrolysed poly(vinyl alcohol) powder, Sigma-Aldrich) was used to make our PVA liquids. To mimic both soft and hard tissue three types of cryogels have been prepared (% weight of PVA): 5% (PVA-C$_5$), 10% (PVA-C$_{10}$), 15% (PVA-C$_{15}$). The PVA powder was mixed with de-ionised water and maintained in autoclave for 40 minutes (1 atm, 121 °C) in order to achieve complete dissolution.

PVA-C preparation were induced by physical crosslinking of PVA solution due to crystallite formation. This physical cross-linked material exhibit higher mechanical
strength than PVA gels cross-linked by chemical techniques because mechanical load can be distributed along the crystallites of the three-dimensional structures.

Gelation of PVA samples were induced by one freezing-thawing cycle at -80 °C for 18 h.

**Phantom design**

The breast phantom was made by alternating layers of PVA-C in order to mimics glandular, fatty and fibro-glandular layers.

For hard lesions, ellipsoidal inclusions of Poly(methyl methacrylate) (PMMA) were used.

**Mechanical tests**

In order to characterize this material in terms of its mechanical uniaxial tensile tests were performed on each PVA-C samples. Tests were performed in displacement control in a quasi-static condition on a testing machine (custom design, custom scripting Matlab and Python), Figure 1.

![Fig. 1: Example of set-up apparatus with markers on a sample for the stress-strain measurements.](image)

**References:** - Pisa/IT

Samples were tested after 24 h from the freezing cycle. For each PVA-C three sample were analyzed and tested. The stress-strain curves were obtained and the initial tangential Young’s moduli \( E_0 \) were calculated as the slopes of the stress-strain curves in the range of 0-10%.
Results

Mechanical test: The obtained $E_0$ moduli are reported in Figure 2.

\[
\begin{array}{|c|c|c|}
\hline
& \text{PVA-C}_{15} & \text{PVA-C}_{10} & \text{PVA-C}_{5} \\
\hline
E_0 (kPa) & 58 \pm 7 & 30 \pm 12 & 18 \pm 8 \\
\text{TMM} & \text{fibrous/glandular} & \text{glandular} & \text{fat/adipose} \\
\hline
\end{array}
\]

Fig. 2: Initial tangential moduli

References: - Pisa/IT

By comparing the $E_0$ values with those of the breast tissue, PVA-C$_{15}$ is correlated with fibrous/glandular, the PVA-C$_{10}$ with glandular and PVA-C$_{5}$ with fatty tissue.

Our results are in good agreement with data reported in [5] for glandular and fatty tissue. For the fibrous material, our data cover only a part of the published Young's moduli values.

It is worth to notice that for this type of material the $E$ values range from 3.55 ut to 139 kPa, [3].

Phantom: A schematic draw of the breast phantom is reported in Figure 3 (a) where an hard inclusion with minor axis equal to 4 mm and major axis equal to 7 mm is in a fibro-glandular layer.

In Figure 3 an example of quasi-static US imaging and ES exams on our phantom is reported (the white dash lines in the B-mode image represent the phantom layers for clarification).
**Fig. 3:** Schematic representation of the phantom (a); B-mode image of hard inclusion encapsulated in a fibrous/glandular background (b), ES example (c).

**References:** - Pisa/IT

**Conclusion**

The PVA-C is characterize by a non homogeneous elastic material properties due to the peculiarities of its making process (freezing/thawing cycle). To obtain strain maps from tissue we have used, the Q-elastography, which is based on the compression of tissue by the probe, tracing a sinusoid shaped curve. This software is characterized by the impossibility to check in real time the if the compression is correct ) off-line evaluation:

- operators must have trained
- need of realistic phantoms.

This breast phantom can serve as valuable intermediary between simple homogeneous phantom and real breast.

Tissue-mimicking phantoms can be essential in elastosonography for the purpose of training the operator and for the validation of computational models.

**Personal Information**

**References**


