Breast Tissue Phantoms to Assist Compression Study for Cancer Detection using Microwave Radiometry

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Abstract— **Microwave radiometry is a passive imaging modality proposed for breast cancer detection without the need for ionizing radiation. Detection of breast tumor using radiometry is challenging as the intensity of thermal radiation received by the antenna is influenced by tumor stage, location, physiological conditions and the imaging setup. The controllable parameters for setting up a good imaging modality for early detection of breast cancer are ambient temperature (T_a), convection cooling of tissue surface (h), and tissue compression (c). Amongst these parameters tissue compression plays an important role since reducing the breast thickness increases visibility. In this work, fabrication of hydrogel breast tissue phantoms with varying concentrations of polyvinyl alcohol (PVAL) is carried out to mimic breast fat and glandular tissue properties for compression study. The phantoms were subjected to compression to investigate the mechanical properties for varying PVAL concentrations. A 3D numerical model was developed for phantom tissue compression simulations. Simulated tissue compression results were compared with phantom measurements for model validation.**

Keywords: breast cancer, radiometry, compression, hydrogel phantom.

I. Introduction

Contrast in physiological and functional behavior of cancerous tissues compared to benign tissues in the microwave frequency spectrum has led to interest in microwave imaging of breast cancer [1]. Despite a low cost and safe imaging modality, microwave imaging has not gained momentum due to the challenges associated with repeatability and specificity. Several microwave imaging techniques have been proposed for breast cancer detection [1]. Amongst these microwave radiometry is a passive imaging modality that relies on the change in the metabolic activity of cancerous tissue compared to its benign counterpart [2]. In our earlier work, we established that the following controllable factors influence early detection of cancer using microwave radiometry [3]: i) ambient temperature, T_a ii) tissue surface cooling provided by convective coefficient, h and, iii) uniaxial tissue compression, c. Amongst the primary controllable factors (T_a, h, c), breast tissue compression, c was demonstrated to play an important role in cancer detection.

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It is well known that breast compression during mammography improves image quality and enables visualization of small and deep seated lesions by reducing breast thickness [4]. The purpose of this work is to fabricate phantoms with elastic property equivalent to breast tissues and validate tissue compression simulations with phantom measurements. Section II presents materials and methodology adopted for phantom fabrication and testing and compression model design and validation. Section III presents phantom measurements and comparison with literature data for fatty and glandular breast tissues and, numerical model validation with experimental compression data. Section IV concludes this work.

II. Methodology

A. Phantom preparation for compression study

Phantoms with mechanical properties of breast tissue were fabricated by freeze and thaw of polyvinyl alcohol (PVAL) in ethanol and water mixture [5]. Commercial grade PVAL with average degree of polymerization of 1,700 was used for phantom fabrication. Homogeneous PVAL solutions with 6%, 8% and 10% PVAL concentration by weight was prepared by dissolving it in a mixture of deionized water and ethanol. Water to ethanol ratio of 50:50 by weight was used for phantom fabrication as listed in Table I. The phantom mixture in a round bottom flask was elevated to 90°C using a heating mantle and was stirred continuously for a homogeneous solution. The setup was fitted with a condenser to avoid evaporation of ethanol. The homogeneous PVAL solution was poured in cylindrical glass containers for freeze thaw cycles. In Price et al [5], the phantom was stored in a freezer at -13°C for 12 hours and later stored in 1:1 mixture of water and ethanol. Phantoms prepared following this procedure were soft at the beginning. However, the stiffness increased with storage life thus repeatability in phantom elastic property was an issue. To avoid variations in phantom elastic property, freeze thaw cycle reported in [6] for a hydrogel phantom was adopted in this study. All PVAL phantoms were subjected to 4 freeze and thaw cycles with 12 hours freezing at -20°C and thawing at room temperature. This yielded phantoms with repeatable elastic property. Two cylindrical samples with 45mm diameter and 40mm height each were fabricated for 6, 8 and 10% PVAL Concentration. The phantom dimensions were chosen as per the American Society for Testing and Materials (ASTM) standard for cylindrical samples

TABLE 1: Phantom compositions for 100 gm of PVAL solution.

SI No.	PVAL (g)	Ethanol (mL)	Deionized water (mL)
1	6	60.83	48
2	8	58.30	46
3	10	57.00	45

B. Characterisation of phantom elastic property

Elastic property of breast tissue phantoms were characterized using an universal testing machine (UTM) (M/s BiSS, India). Each sample was subjected to uni-axial compression as shown in Fig. 1. During compression cycle, sample was compressed at a rate of 5mm/min until 50N applied force. After maximum compression, the sample was held at compressed state for one min and then it was slowly released as the compression plate was brought to its original position. Each sample underwent three compression cycles.

Figure 1: Universal compression testing machine with one of the phantoms positioned between the compression plates.

All measurements were performed at room temperature and stress-strain relationship of the phantom was obtained. Phantom Young's modulus (E) and Poisson's ratio (ν) were calculated using,

$$E = \frac{F/A}{\delta l/l} \quad (1)$$

$$\nu = \textit{lateral strain /axial strain} \quad (2)$$

In equations (1)-(2), E is Young's Modulus in kPa, F is applied force in N, A is original cross sectional area of the sample to which the force is applied in mm^2, δl is change in sample height in mm, l is the original height in mm. The Poisson ratio, v is dimensionless quantity that represents the degree to which a material expands laterally as it is strained (compressed) axially.

C. Numerical model for compression study

A 3D computation model was developed in COMSOL Multiphysics® [7], a finite element method (FEM) based simulation software to mimic phantom compression experiments and to validate the numerical model for tissue deformation studies. Figure 2 shows the 3D model developed to simulate phantom compression in the structural mechanics module of COMSOL. The model geometry incorporates two horizontal plates between which the sample was placed for uniaxial compression.

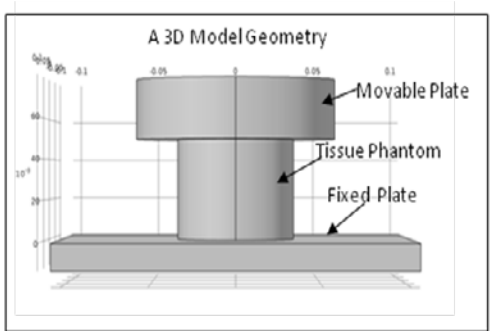

Figure 2: 3D Model geometry mimicking phantom compression experiment. Top plate is movable and the bottom plate is fixed.

In numerical simulations, the cylindrical tissue phantom of height 40mm and diameter 45mm placed in between the two plates was compressed for varying load specified in steps of 5 Newton until 30% compression. The governing equation solved for phantom compression assuming it to be a linear elastic isotropic material is given by,

$$-\nabla \bullet \sigma = Fv \quad (3)$$

where σ is stress, F is applied force and v is Poisson's ratio. The plate at the bottom was fixed at zero displacement and the top plate in contact with the phantom was modeled as a rigid Aluminium slab. At the interface between top plate and phantom, a non-penetration condition was enforced. Force was applied to the phantom top surface through the top plate. As the load varied, phantom mechanical properties, E and v were varied in the simulations using Young's modulus (E) and Poisson's ratio (v) obtained from phantom compression measurements. Simulated phantom displacements were compared with phantom measurements to validate the numerical model for breast tissue compression study.

III. Results and Discussion

A. Phantom measurements

Figure 3 shows the hydrogel breast phantoms fabricated for 6, 8 and 10 % PVAL concentration by weight. Figure 4 shows phantom stress versus strain measured from compression experiments. Figure 4 indicates an almost linear stress-strain relationship for all phantoms till 30% uni-axial compression. Further, it indicates that the linearity varies with PVAL concentration. Stress-strain measurements of breast tissue samples reported in [8] are also plotted in Figure 4 for comparison. It can be observed that the 6% PVAL phantom mimics fatty breast tissue [8]. As PVAL concentration is increased, phantom elastic property shifts towards glandular breast tissue. Phantom elastic property calculated from the stress strain measurements are listed in Table 2. Measurements in Table 2 indicate increase in Young's modulus with increase in PVAL concentration and Poisson's ratio close to literature data for biological tissues. This suggests that tissue phantoms with varying elastic property can be fabricated by choosing appropriate PVAL concentration to mimic breast tissue with varying fat and glandular tissue composition.

TABLE 2: Phantom elastic property for varying PVAL concentrations

PVAL % by wt.	E at 15% strain (kPa)	E at 30% strain (kPa)	Poisson's ratio
6% S3	13	19	0.47
S4	13	17	0.47
8% S1	37	46	0.49
S2	39	45	0.50
10% S5	53	68	0.45
S6	49	68	0.44

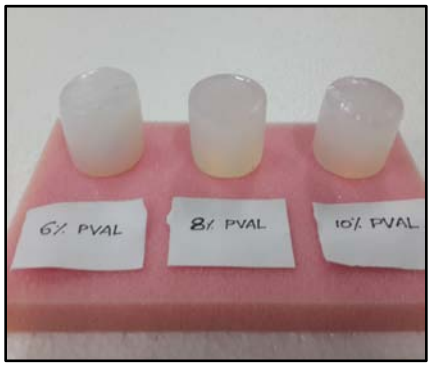

Figure 3: Phantoms with varying PVAL concentration fabricated for elastic property characterization.

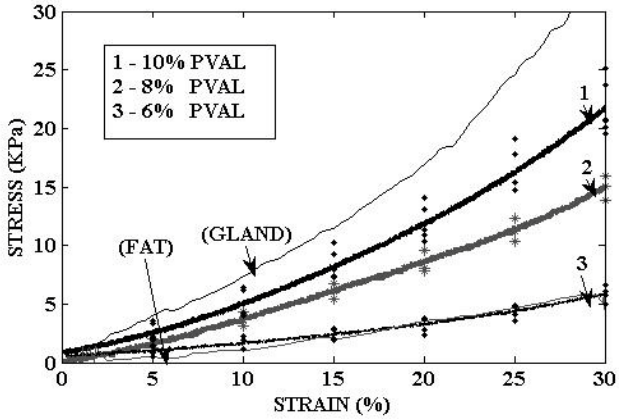

Figure 4: Stress versus strain measured for phantoms with varying PVAL concentrations. Literature data for fatty and glandular breast tissues are indicated for comparison [8]. Sample average is indicated as solid line and individual sample measurements are indicated as scatter plot.

B. Simulation results

Figure 5 shows the simulation results for 8% PVAL phantom subjected to 15N load. The displacement for the 8% PVAL phantom is observed to be 11.5mm. Figure 6 shows the displacement versus force curve generated for varying loads simulated for 8% PVAL phantom. Simulations were carried out for the elastic property calculated from the phantom average measurements. Phantom measurements for the applied load are indicated as scatter plot in Figure 6 for comparison. It should be noted that phantom displacement calculated by the numerical model is within the range measured for phantom compression experiments. This indicates that the linear elastic model used in this study for phantom tissue deformation yields acceptable results.

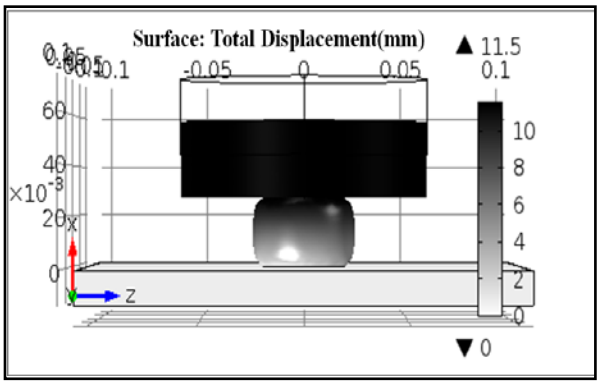

Figure 5:Simulated compression for 8% PVAL phantom and 15 N load.

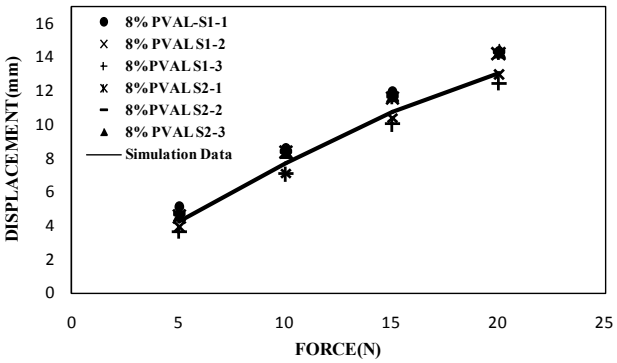

Figure 6: Comparison of simulated displacement with phantom measurements for varying load . S1 and S2 are 8% PVAL samples with S1_i and S2_i representing i^{th} repetition of compression.

IV. Conclusion

PVAL phantoms were fabricated for breast tissue compression study. Freezing and thawing of PVAL based hydrogels yielded stable phantoms with repeatable elastic property measurements. Elastic property measurements of the phantoms agreed very well with literature data. Tissue deformation estimated by the 3D numerical model based on measured phantom elastic property was in very good agreement with measured displacement for varying load. Preliminary results of tissue compression simulations based on phantom measurements will be investigated further for a heterogeneous breast tissue with lesions.

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