Electro-Biomechanical Breast Phantom for Hybrid Breast Imaging

B. Henin and A.M. Abbosh
School of Information Technology and Electrical Engineering, University of Queensland.
Brisbane, Australia

W. Al Abdulla
Australian Institute for Bioengineering and Nanotechnology, University of Queensland.
Brisbane, Australia.

***Abstract*— The fabrication of an electro-biomechanical breast phantom for testing microwave-mechanical hybrid systems designed for breast imaging is presented. The presented breast phantom is designed to emulate both the electrical and mechanical properties of the human breast tissues. A material that has electrical and mechanical properties equal to those of the soft human breast tissues is manufactured using simple low-cost substances. The measured electrical and mechanical properties of the phantom are in good agreement with the properties of the real breast tissues. The presented phantom is vital for validating strain imaging techniques that relies on the contrast in both of the dielectric and mechanical properties between the healthy and cancerous breast tissues.**

Keywords- Breast phantom, microwave imaging, strain imaging.

I. INTRODUCTION

Breast cancer is the most common non-skin malignancy which causes death for women. Over the past several decades, there has been a growing interest in developing and testing microwave imaging techniques for breast cancer detection [1-8]. Microwave imaging involves the propagation of very low levels of microwave energy through the breast tissue. Normal breast tissue is largely transparent to microwave radiation, while malignant tissues, containing more water and blood, cause strong backscattering. This scattered signal can be picked by an antenna array and analyzed using a suitable processing algorithm to create a microwave image of the breast showing any abnormality.

The physical basis for the microwave techniques is tissue-dependent microwave scattering and absorption in the breast due to the contrast in the dielectric properties between the malignant and normal tissues. When the dielectric contrast becomes small, the accuracy of microwave imaging systems deteriorates rapidly. As a result, microwave techniques have limitations in differentiating between tumors and fibro-glandulars due to the small dielectric contrast between them.

Recent researches showed that tumors in the breast are stiffer with higher elasticity modulus compared with the healthy tissues. Using this fact along with the contrast in the electrical properties between healthy and malignant tissues, new imaging modalities that rely on the contrast in the electrical or mechanical properties between healthy and malignant tissues have been investigated [9-11].

For breast imaging using both dielectric and biomechanical properties, there is a need for the development of different phantoms to test the validity of those techniques before moving to test them on human beings. The electrical properties (dielectric constant and conductivity), and the mechanical properties (elasticity and Young's modulus) of those phantoms should closely emulate the properties of human tissues. This condition on the fabricated phantoms is needed so that they can emulate correctly the interactions of the electromagnetic waves with the biological tissues at the microwave frequency range.

In this paper, a new realistic breast phantom that can be used to test different microwave breast imaging systems before moving to test them on human beings is presented. This paper presents a simple fabrication procedure to emulate both electrical and mechanical property of the healthy tissues of the breast and the tumor. The measurements done using a suitable dielectric probe and modulus machine indicate that the developed phantom correctly emulates human breast tissues. This phantom opens the door wide to build a realistic test platform to validate the recently proposed hybrid imaging techniques.

II. PROCEDURE OF FABRICATION

Low-cost materials (gelatin, water, grape seed oil, propylene glycol and commercial dishwashing liquid) are the main components used to fabricate the phantom. To create the materials that represent the breast tissues, the following steps are followed:

(1) Mix 10 g propylene glycol and 200 mL of water in a beaker and heat it gradually to 90°C. Add 20 g of gelatin slowly with stirring in this stage.

(2) Remove the beaker from the heater once the mixture become transparent with no air bubbles on the surface of the beaker. Keep the mixture until it cools to 50 ◦C.

(3) Heat 200 mL of grape seed oil to 50°C and add it to the mixture in step 2. In this stage 11 mL of commercial dishwashing liquid (Trix, by ChemWatch, Australia) is added as a surfactant to form oil emulsion. Stir the mixture with a spoon until most oil droplets are less than about 0.2 mm. The emulsion should become uniform and—for larger percentages oil—nearly white.

(4) At this stage, the volume percent oil is 50%. In order to increase it up to 80%, add about 100 ml of 50◦C oil and stir continuously until the emulsion has again become uniform. (Do not add any more surfactant.)

(5) Keep adding extra 100 ml of 50◦C oil with continuously stirring until the emulsion has again become uniform and until you get to the right percentage.

The dielectric probe HP85070 is used to measure the electrical properties of the developed mixture. All the samples are measured at room temperature (~24°C) after a suitable calibration of the vector network analyzer and the probe using the three terminating standards: open, short and distilled water. For the developed mixture, three measurements are taken at different positions and the average value is taken as the final result.

Mechanical test were carried out at room temperature using Instron model 5543 universal testing machine with a capacity of 50 N load cells. Modulus results were obtained with the compression mode of crosshead speeds of 1 mm per minutes. Modulus for cubic dimensional samples was measured for strain up to 20%. The modulus results are the rate for five replicates of each sample.

III. RESULTS AND DISCUSSION

For human breast tissues, while the contrast in the electrical properties is not high in all cases, the contrast in the mechanical properties (Young's modulus) is always high. Thus, the detection's success is higher if the contrast in the mechanical and electrical properties is utilized. The biomechanical imaging approach is based on the fact that tissues compression produces displacement within the tissues. This displacement, or deformation, is smaller in harder tissues (tumour) than in softer tissues. Table 1 shows both the electrical and mechanical properties of breast tissues as well as tumors.

Table. 1 Electrical and Mechanical properties of breast tissues.

Material	*Relative Permittivity*	*Young's modulus (kPa)*
Fatty Tissue	4.2	3.25
Gland	20	3.25
Skin	34.3	10
Tumor	43.7	42.5

Different electrical proprieties of the fabricated artificial tissues can be realized using mixtures with different percentage of the grape seed oil [12]. For example, if 0% oil is used, the dielectric constant of the mixture will be about 70, which is close to pure water dielectric constant. When 50% oil is used, the dielectric constant of the mixture will be about 40. Finally, when 80% oil is used the dielectric constant of the mixture will be about 5. Two samples with 50% and 80% oil concentration were fabricated and tested using the dielectric probe HP85070 in the frequency range from 1 to 4 GHz.

The mechanical properties of the fabricated material in section II was tested using Instron machine. The modulus results are the rate for five replicates of the sample. Figure 1 shows the compressive stress in MPa relative to a compressive strain up to 20%. Table 2 summarizes the Modulus, the maximum compressive strain and the compressive stress at maximum compressive strain for the five specimens. The average Modulus for this sample is 3 kPa. The Modulus of this sample is suitable to represent the mechanical properties of fatty tissue and gland.

In order to increase the Modulus of the sample, we have to increase the gelatin concentration in the mixture. The fabricated material in section II used 10 gm/100ml water. Figure 2 shows the compressive stress in MPa relative to a compressive strain up to 20% for a new sample with gelatin concentration of 17 gm/100ml water. Table 3 summarizes the Modulus, the maximum compressive strain and the compressive stress at maximum compressive strain for the five specimens. The average Modulus for this sample is 40 kPa. The Modulus of this sample is suitable to represent the mechanical properties of tumor.

Figure 3 shows the fabricated breast phantom. Firstly, a special sample was prepared for the tumor with the right electrical and mechanical properties. Then, a breast phantom is prepared using the procedure in section II with 80% oil concentration. Finally, the tumor is implanted inside the breast phantom.

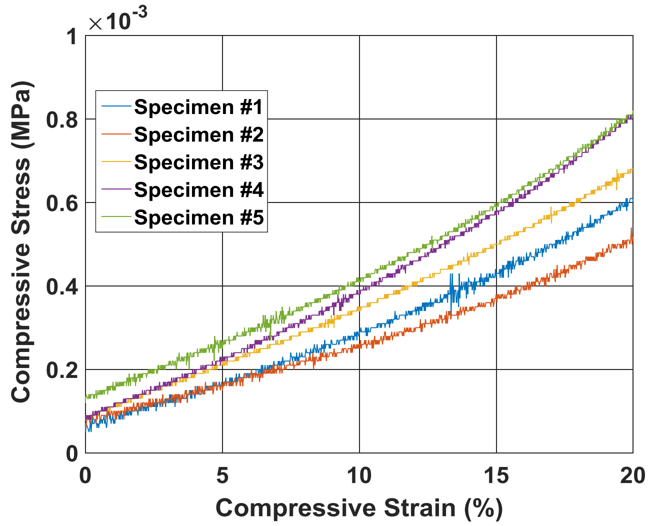

Fig. 1 Strain – Stress relation for 10gm/100ml gelatin concentration.

Table. 2 Mechanical properties for 10gm/100ml gelatin concentration.

Specimen #	*Maximum Compressive strain (mm/mm)*	*Compressive stress at Maximum Compressive strain (MPa)*	*Modulus (Secant–Cursor) (MPa)*
1	0.20086	0.00061	0.00280
2	0.20091	0.00051	0.00216
3	0.20046	0.00068	0.00290
4	0.20022	0.00081	0.00363
5	0.20030	0.00081	0.00343

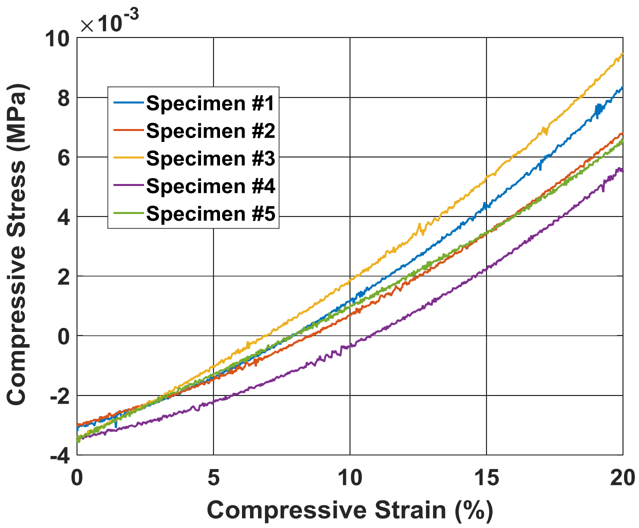

Fig. 2 Strain – Stress relation for 17gm/100ml gelatin concentration.

Table. 3 Mechanical properties for 17gm/100ml gelatin concentration.

Specimen #	*Maximum Compressive strain (mm/mm)*	*Compressive stress at Maximum Compressive strain (MPa)*	*Modulus (Secant–Cursor) (MPa)*
1	0.20095	0.00841	0.04236
2	0.20123	0.00688	0.03422
3	0.20164	0.00965	0.05282
4	0.20164	0.00579	0.03137
5	0.20048	0.00655	0.04441

(a)

(b)

Fig. 3 Fabricated breast phantom with (a) flat surface and (b) hemispherical surface

REFERENCES

[1] E.C. Fear P.M. Meaney and M.A. Stuchly, "Microwave for breast cancer detection" *IEEE potentials*, pp12-18, 2003.

[2] E. J. Bond, X. Li, S. C. Hagness, and B. D. Van Veen, "Microwave imaging via space-time beamforming for early detection of breast cancer," *IEEE Trans. Antennas Propag*., vol. 51, no. 8,pp. 1690–1705, 2003.

[3] X. Li, S. K. Davis, S. C. Hagness, D. W. van der Weide, and B. D. Van Veen, "Microwave imaging via space-time beamforming: Experimental investigation of tumor detection in multilayer breast phantoms," *IEEE Trans. Microw. Theory Tech.*, vol. 52, no. 8, pp. 1856–1865, Aug. 2004.

[4] A. Abbosh, M. Bialkowski, and S. Crozier, "A simple model for electromagnetic scattering due to breast tumour," *IEEE Antennas Prop. Symp.*, San Diego, USA, 2008.

[5] A. Abbosh, M. Bialkowski, and S. Crozier, "Investigations into optimum characteristics for the coupling medium in UWB breast cancer imaging systems," *IEEE Int Symp Antennas Prop,* pp.1-4, July 2008

[6] A. Abbosh, Y. Abbosh, and A. Yahya, "Modeling and imaging of breast using the combined effect of microwave and acoustic pulses," *Asia-Pacific Microwave Conference Proceedings (APMC)*, pp.1790-1793, 5-8 Dec. 2011

[7] A. Yahya, Y. Abbosh, and A. Abbosh, "Microwave imaging method employing wavelet transform and neural networks for breast cancer detection," *Asia-Pacific Microwave Conference Proceedings (APMC),* pp.1418-1421, 5-8 Dec. 2011

[8] A. Bakar, D. Ireland, A. Abbosh, and Y. Wang, "Experimental assessment of microwave diagnostic tool for ultra-wideband breast cancer detection," *Progress in Electromagnetics Research M*, vol. 23, pp.109-121, 2012.

[9] A. Abbosh, and S. Crozier, "Strain imaging of the breast by compression microwave imaging," *IEEE Antennas Wireless Prop. Lett.*, vol. 9, pp. 1229-1232, 2010.

[10] V. Rajagopal, P. Nielsen, M. Nash, "Modeling breast biomechanics for multi-modal image analysis - successes and challenges," *Wiley Interdiscip. Reviews: Sys Bio Med 2* , pp. 293-304, 2010.

[11] B. Henin, and A. Abbosh, "Microwave imaging of breast using combination of biomechanical and electrical properties ," *Cairo international Biomedical Engineering Conference (CIBEC), 2012* , pp. 183-186. 20-22 Dec. 2012.

[12] M. Lazebnik, E. L. Madsen, G. R. Frank, and S. C. Hagness. "Tissue-mimicking phantom materials for narrowband and ultrawideband microwave applications." *Physics in medicine and biology,* vol. 50, no. 18 (2005)