Development of fabrication method for a phantom emulating breast tumor tissue for percutaneous antenna coupling measurements in microwave thermotherapy.

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Abstract — **Breast cancer is one of the most common diseases and has high mortality among Mexican women. Thermic therapies are one of the most promising techniques these days. Microwave ablation transmits electromagnetic energy inducing a focalized temperature increment to achieve tumor necrosis in a minimally invasive way. One of the main limitations in the development of thermotherapy percutaneous applicators is the measurement of certain parameters in biological tissue. The proposed solution is the fabrication of a phantom that emulates the dielectric properties (permittivity and conductivity) of breast tumor tissue in order to make coupling measurements of the applicator in an experimental setting. A methodology for the fabrication and measurement of a breast tumor phantom was developed, achieving, with low error, the imitation of dielectric properties of the breast tumor tissue reported in the literature. The use of low-cost materials and the simplicity of the methodology allow reproducibility of the phantom for experimentation in the fields of diagnostic and treatment of breast cancer through RF in the microwave range.**

Keywords — **Phantom, thermotherapy, diagnostic, ablation, applicators, microwaves, cancer, breast.**

I. Introduction

Breast cancer is the second most common type of cancer worldwide and the most frequent among women with an estimate of 1.67 million new cases diagnosed in 2012 (equivalent to 25% of all type of cancer) [1].

Thermal therapies are used as an alternative therapies in the treatment of different types of cancer. Depending the temperature range, the thermal therapy can be divided in thermal ablation, hyperthermia, diathermia or cryotherapy [2]. When the target tissue exceeds temperatures above 50°C for a few minutes ablation is obtained [3], above 60°C a state of protein coagulation is induced, which cause cell death almost instantaneously [4]. Microwave ablation therapy is a promising technology for the treatment of certain types of cancer tumors [5], an applicator is fed with RF energy in the microwave rage, normally at frequencies of 915 MHz or 2.45 GHz, this energy is irradiated in the target tissue where it is absorbed, causing heating of the tissue via dielectric hysteresis [6].

The development of applicators for microwave ablation therapy is one of the most studied fields. The antenna performance are strictly linked to the antenna design [7]. The applicator coupling with the medium is determined by the standing wave ratio (SWR), if the SWR value is low, the coupling of the antenna is better and the power delivered to the target tissue is higher. Moreover, the absorbed power distribution is more concentrated around the active part of the antenna assuring the focalized heating of the target tissue preventing the damage to healthy tissue [8], as well as a spherical ablation zone [7].

A normal breast is mainly composed of glandular and adipose tissue, but breast cancer cells have higher water content than the surrounding tissue, therefore, during microwave ablation therapy the cancer cells heats more rapidly than the healthy tissue [9]. Reference [10] shows that the microwave-frequency dielectric-properties contrast between breast tumor and normal adipose dominated breast tissue range up to 10:1 contrast. However, the clinical experience using microwave ablation therapy in breast cancer [11] and the development of percutaneous applicators for breast cancer ablation are limited.

A method for the fabrication of a phantom emulating dielectric properties was developed. The dielectric properties were taken from the values reported by [10].

II. Methodology

A. Phantom Material Production

Agarose (UltraPure™ Agarose, Invitrogen) was used as elastic matrix for the phantom, agarose has been used as tissue mimicking material (TMM) substrate before [12] to give the phantom the mechanical strength necessary to conduct the percutaneous antenna coupling measurements.

To simulate the dielectric properties of the breast tumor tissue different liquid materials were used in order to approximate the values reported. Employing bidistilled degassed water as the base substance, ethanol (Ethanol, J.T. Baker) was added to reduce the permittivity while the addition of sodium chloride (106404, Merck) increase the conductivity of the phantom.

A protocol and recipe for the fabrication of 270 mL of the phantom is presented in the Appendix.

TABLE I
PHANTOM FABRICATION RECIPE

Ingredients	%(w/v)	Italic
Ethanol	25.92 (v/v)	
Sodium chloride	1.85	
Agarose	1.11	

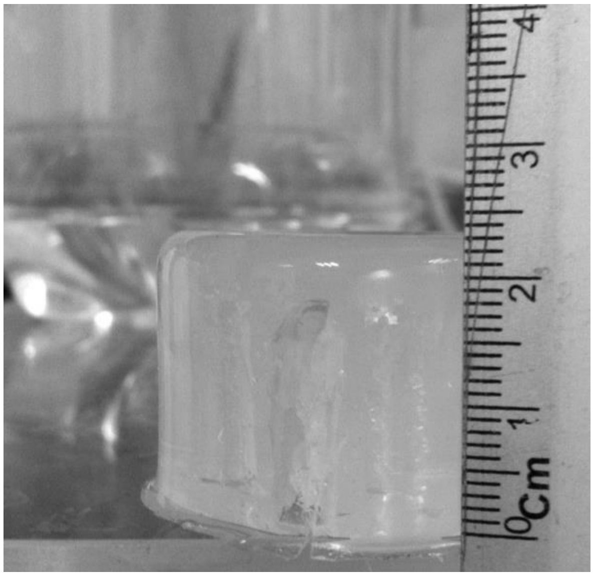

Fig. 1. Agarose based breast tumor phantom.

B. Measurement of Dielectric Properties.

The dielectric constant is equivalent to the complex relative permittivity, as it is described by (1).

$$K = \varepsilon'_r - j\varepsilon''_r \quad (1)$$

The real part is a measure of the amount of energy stored in the material from an external field. The imaginary part is called loss factor, and is related to the conductivity by (2).

$$\varepsilon''_r = \frac{\sigma}{2\pi f \varepsilon_0} \quad (2)$$

The term ε_0 is the permittivity of free space and f the frequency at which the measure was taken. The complex relative permittivity was measured using a slim form dielectric probe (85071B, Agilent Technologies) connected to a network analyzer (E5071B, Agilent Technologies). The probe was inserted into the phantom at 5 different depths ranging from 8 to 12 mm, the position of the measurements were also distinct in order to evaluate the heterogeneity of the TMM. All measures were taken at a constant temperature of 25°C using a temperature-regulated water bath, the complex permittivity was taken with and without the container (beaker) showing no significant differences in the outcomes.

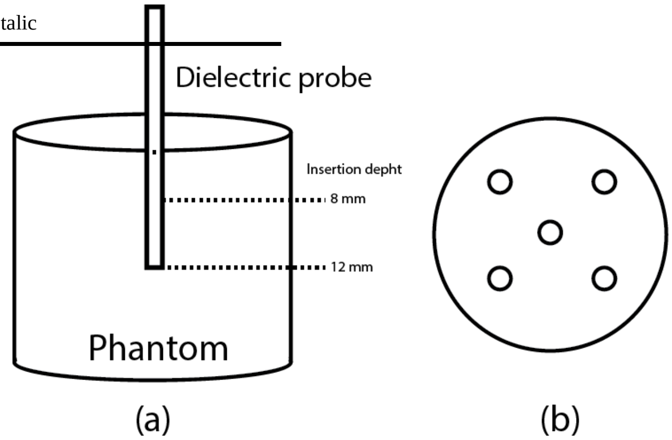

Fig. 2. (a) Insertion depth and (b) radial position of the dielectric probe used to take complex relative permittivity measures.

The network analyzer measures the medium response to RF energy, the system was set up to transmit a linear swept-frequency signal from 2 to 3.5 GHz with steps of 0.01 GHz trough the slim probe into the material under test. The functional frequency of the microwave ablation therapy applicators is 2.45 GHz.

III. RESULTS

A. Complex relative permittivity.

A total of 6 phantoms were fabricated by different persons using the method describe in the appendix. The complex relative permittivity was obtained for each sample. The real part (ε'_r) is a ratio of the permittivity (ε) of the material to the permittivity of free space (ε_0), so it is dimensionless. The relative permittivity for breast tumor tissue was retrieved from [10], the data was interpolated to calculate the value at 2.45GHz, obtaining a relative permittivity of 58.57.

The electrical conductivity is a measure of how easily electrical current can flow through a material and is measured in Siemens per meter [S/m]. Electrical conductivity is related to the imaginary part of the complex relative permittivity by (2), following the same procedure the electrical conductivity for breast tumor tissue calculated from [10] at 2.45 GHz was 3.8.

Fig. 3 shows the relative permittivity and electrical conductivity of breast tumor tissue in a range from 2 to 3.5 GHz from [10] compared to the relative permittivity and electrical conductivity of the TM phantom measured at 25°C.

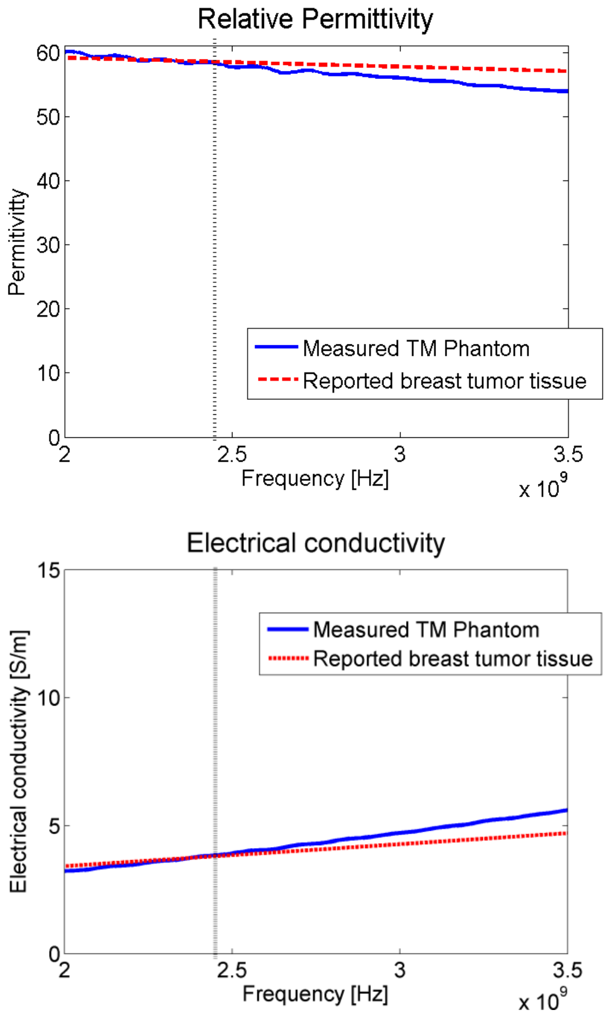

Fig. 3. Relative permittivity and electrical conductivity obtained from the measurements in the TM phantom vs reported values of breast tumor tissue.

The relative permittivity and electrical conductivity measured from the TM phantom at 2.45 GHz was 58.32 $\pm$ 0.218 and 3.846 $\pm$ 0.0352 respectively.

IV. Discussion

The development of microwave ablation therapy applicators for breast cancer has been limited, the proposed TM phantom can be used to make experimental measurements of the SWR of different antenna design due to the close approximation to the dielectric properties of breast tumor tissue. The characterization of the phantom when an electric field is applied and the thermal properties for the extended use of the phantom to ablation simulation are yet to be studied and it's a subject of work for the laboratory.

V. Conclusion

The aim of this work was to develop a tissue mimicking phantom with complex relative permittivity values as close as possible to the dielectric properties of breast tumor tissue reported by literature. The TM phantom developed has the mechanical strength and values of relative permittivity and electrical conductivity necessary to make SWR measures of a percutaneous applicator designed specifically for breast cancer therapy. Computational models of the coupling of percutaneous antennas can be validated experimentally with the TM phantom, and the use can be extended to applications that uses microwave energy at 2.45 GHz in the fields of diagnostic or therapy of breast cancer.

Appendix

This appendix describes the method for the fabrication of 270 mL of TM phantom.

1) Weigh all the ingredients listed in Table I.
2) Add ethanol (70 mL) and sodium chloride (5 g) to a beaker with 200 mL of bidistilled degassed water along with a magnetic stir bar, and mix on an electric stir plate for 30 seconds.
3) Pre-heat a hot plate to 25°C for 5 minutes.
4) Start heating the mixture in the hot plate while continuing to stir up to 75°C, when the mixture reaches 50°C add the agarose (3 g).
5) When the mixture reaches 75°C retire from the hot plate and let the mixture cool on a recipe fill of water for 3 minutes while continuing to stir, then pour the solution into the designated phantom holder.
6) The solution will be solidified after 10 minutes of the pouring.

Acknowledgment

Authors would like to thank the National Council for Science and Technology (CONACYT, Mexico) for the support received with project CONACYT-Salud 2013-I; 201590, 201256, Joint Cooperation México-Uruguay (SRE-AUCI) 2012-2013.

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