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SIMULATION OF MICROWAVE INDUCED THERMO-ACOUSTICAL IMAGING TECHNIQUE FOR CANCER DETECTION

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ABSTRACT

Microwave-induced thermal acoustic imaging (MITAI) is a promising early breast cancer detection technique, in which image construction is based on thermo acoustics signals generated by the illumination of microwave pulses in tissue. In this work we have performed a microwave induced thermal acoustic signal generation simulation study using Comsol Multiphysics. A biological tissue model irradiated with pulsed microwave source from a waveguide is simulated and studied. We have evaluated the deposition of heat in the biological tissue irradiated by electromagnetic fields and the corresponding pressure variation in tissue due to temperature variations. It is then studied for different power levels to find out the minimum power required to generate the thermo-acoustic signal using 2.45 GHz microwave source.

Keywords: MITAI, breast cancer, microwaves, medical imaging, EM waves.

INTRODUCTION

Breast cancer is the second most common cancer in the world and, by far, the most frequent cancer among women [1]. Though mammography techniques have improved, the rates of false positive and false negative have also in-creased [2]. Breast cancer can be detected by imaging techniques using X-ray mammography. But X-ray mammography is found to be inefficient in early stages of cancer detection, because in X-ray mammography the cancerous tissues are distinguished based on their density and this density variation is of no significance when compared to breast tissues.

In Microwave imaging rather than relying on density based interactions, dielectric based interactions are employed for early detection of breast cancer [3]. Biological tissues have high imaging contrast due to the wide range of microwave absorption coefficients like relative permittivity and conductivity [4]. As microwaves have long wavelength, the spatial resolution is usually poor for pure microwave imaging of biological tissues. Ultrasound is another option, which offers a high spatial resolution. But image contrast is poor due to very small variation in acoustical properties of non-tumorous and tumorous tissues since both being soft tissues [5].

Microwave-induced thermal acoustic imaging (MITAI) combines the advantages of microwave stimulation and ultrasound imaging [4]. In MITAI, a short-pulsed micro-wave source is used to irradiate the tissue. The relatively long wavelength of the microwave (2.45 cm at 2.45 GHz) in tissues serves to illuminate the tissue homogeneously.

The biological tissues both non-malignant and malignant, is irradiated by microwave. This biological tissue undergoes expansion due to heat generated by microwave absorption and, contraction due to cooling in off time of pulse thus producing pressure variation in the tissue. It launches a thermo-elastic pressure wave from tissue, which propagates away from the absorbing tissue in all directions. A wide-band ultrasonic transducer can then be employed to acquire the thermo acoustic signals due to a thermo elastic expansion.

Microwave absorption mainly depends on dielectric property of the material and shows a large variation between non-cancerous and cancerous tissues [6]. Therefore a variation is expected from the thermo acoustic waves generated from non-cancerous and cancerous tissues due to micro-wave irradiation. In this work, we have used Comsol Multiphysics to study the thermo acoustic emission from non-cancerous and cancerous tissues.

Kurger and team developed a thermo acoustic CT with 434 MHz [7]. They used 25-kW microwave generator and sup-plied 1.0-msec duration pulses of radio frequency energy to excite the tissue. Minghua Xu proposed another system in which the microwave pulses transmitted from a 3 GHz microwave generator have pulse energy of 10 mJ and a pulse width of 0.5 us [8]. Liming Nie developed a system with 1.2 GHz and demonstrated the feasibility of foreign body detection using MITAI [9]. Wei Gong used 2.45 GHz microwave generator with pulse energy of 2.5 mJ and duration of 0.5μs [10]. These researchers use high power microwave and costly circuits; in this paper we have studied the feasibility of low cost and low power microwave source to generate pressure variations with low temperature variation. In [6, 11] presented simulation works with FDTD tools in which performed the microwave-induced thermal acoustic simulation in two steps. The first step determines the specific absorption rate (SAR) by using the electromagnetic field stimulated. The second step finds the acoustic wave simulation, which uses the specific absorption rate distribution from the previous step as the acoustic pressure source through the thermal expansion coefficient.

In this paper FEM based Comsol multiphysics is used to study the simulation. Due to multiphysics capability in Comsol electromagnetic heating and thermal expansion in biological model is done in a single step and, studied the pressure variation obtained in the tumorous and non-tumorous tissue with electromagnetic heating.

Comsol simulation was initiated by combining the electromagnetic and thermo-elastic and thermo-acoustic formulations and by using models of human tissues. The analyses show that the minuscule but a rise in temperature as a result of the absorption of pulsed microwave energy. It creates a thermo-elastic expansion of tissue matter, which then launches an acoustic wave of pressure.

THEORY AND SIMULATION TOOL

The thermo heating function $H(r,t)$ due to temperature T at a given location [4], can be stated as

$$\rho C_p \frac{\partial}{\partial t} T(r,t) = H(r,t) \ldots\ldots\ldots (1)$$

where ρ is the density, C_p is the specific heat, $\frac{\partial}{\partial t} T(r,t)$ is the rise in temperature due to irradiated microwave energy.

Consider *u* as the vector-valued displacement, then biological sample certainly reacts to changes in pressure by acceleration then:

$$\rho \frac{\partial^2}{\partial t^2} u(r,t) = -\nabla p(r,t) \ldots\ldots\ldots (2)$$

The biological sample contracts due to cooling and expands based on changes in temperature:

$$\nabla \cdot u(r,t) = \frac{p(r,t)}{\rho c^2} + \beta T(r,T) \ldots\ldots\ldots (3)$$

β is a thermo expansion coefficient, p(r, t) is the thermo acoustic pressure at position r and time t.

Combining (1)-(3) the pressure p(r , t) produced by the heat source H(r, t) obeys the following equation

$$\nabla^2 p(r,t) - \frac{1}{c^2} \frac{\partial^2}{\partial t^2} p(r,t) = \frac{\beta}{C_p} \frac{\partial}{\partial t} H(r,t) \ldots\ldots\ldots (4)$$

The solution based on Green's function

$$p(r,t) = \frac{\beta}{4\pi C_p} \iiint \frac{d^3 r'}{|r - r'|} \left. \frac{\partial H(r', t')}{\partial t'} \right|_{t' = t - (|r - r'|/c)} \ldots\ldots\ldots (5)$$

Human breast tissue and microwave waveguide models are created in Comsol Multiphysics. Electromagnetic waves frequency domain physics, heat transfer in solids and structural mechanics physics are used for simulation. Tissue model kept inside the waveguide and microwave energy is induced into it. The temperature and pressure variation in human breast tissue model are then studied.

DESCRIPTION OF MODEL

We have created microwave oven waveguide geometry in Comsol Multiphysics. The TE_{10} mode waveguide is fully made up of Copper material, which operates in the frequency of 2.45GHz. The waveguide with dimension 78 x 50 x 18 mm is perfect electric conductor on all sides. Electromagnetic waves in frequency domain, heat transfer in solid and solid mechanics are the physics added into model builder. In thermal stress multiphysics electromagnetic heat source is coupled with heat transfer in solids and heat transfer in solid is coupled with solid mechanics. Material properties variation is studied so shape of sample is not considered to make 2D geometry in Comsol. Human breast tissue model is kept inside the waveguide for heating with microwave energy from port. Tumor is kept inside the breast tissue. Figure-1 shows the electric field magnitude at fatty breast tissue and tumor inside the waveguide exited with 700 W microwave powers.

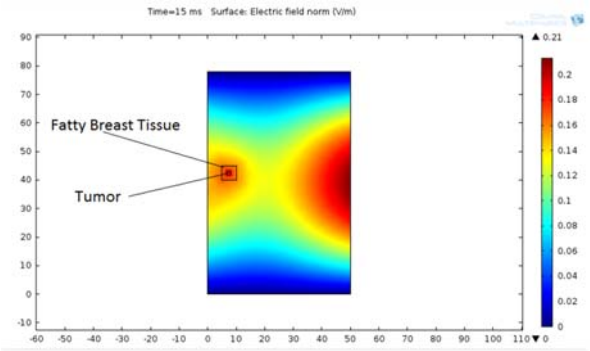

Figure-1. Fatty breast tissue and tumor inside waveguide with 700 W microwave power.

In electromagnetic waves frequency domain physics the excitation source for microwave power in port P_{in} is provided with piecewise function pw1(t[1/s]) in W. In piecewise function with name pw1 intervals are given to produce pulsed microwave excitation. Dielectric properties values of human tissues from literatures are used for simulation as shown in Table-1.

Table-1. Measured dielectric properties of ex vivo female breast. [6].

Tissues	**Dielectric properties**	
	Permittivity (F/m)	**Conductivity** (S/m)
Fatty breast tissue	9	0.4
Tumor	50	4

Table-2. Acoustic and thermal parameter for tissues [6, 12, 13].

Tissues	**ρ** (Kg/m^2)	**Cp** (J/(°C-Kg))	**YM** (Pa)	**β** (W/mK)
Fatty breast tissue	1020	3550	20E+03	0.217
Tumor	1041	3510	90E+03	0.545

RESULTS

The variation in temperature and pressure at different points in biological sample is taken for the study. We obtained various temperatures and pressure graphs at points inside the tumor, inside the fatty breast tissue and also at intersect of the tumor and fatty breast tissue. Figure-2 shows the points where we measure the different pressure and the variation in the temperature.

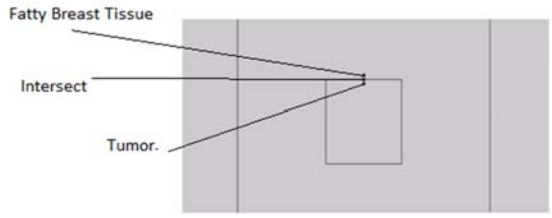

Figure-2. Points at which we obtained point graphs for Temperature variation and Pressure.

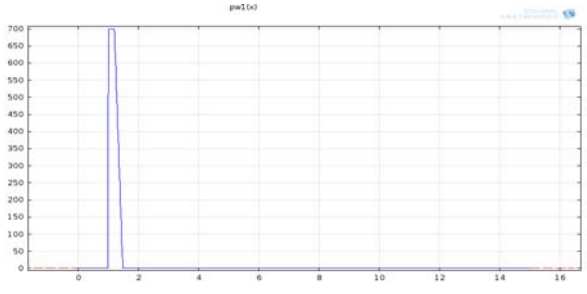

Figure-3. Excitation pulse of 700 W 200 us plot used for simulation with piecewise function.

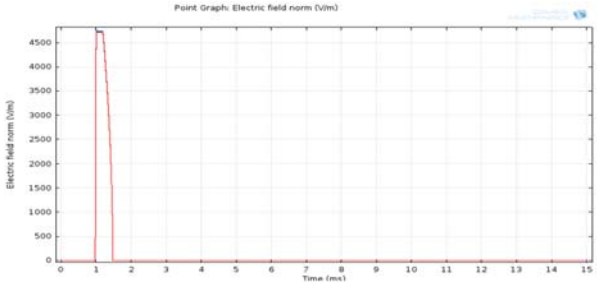

Figure-4. Electric field amplitude for 700 W 200 us excitation pulse.

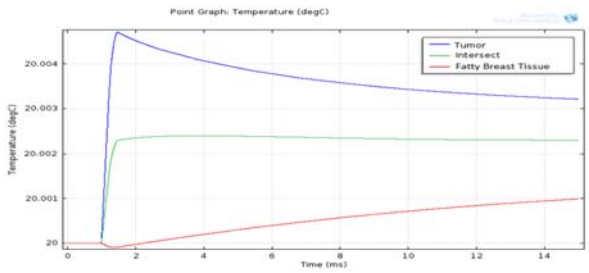

Figure-5. Temperature variation at different points with 700W 200 us pulse.

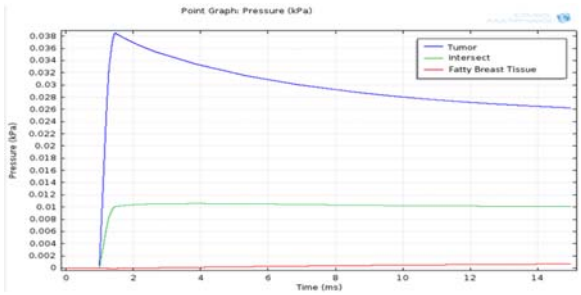

Figure-6. Pressure variation at different points with 700W 200 us pulse.

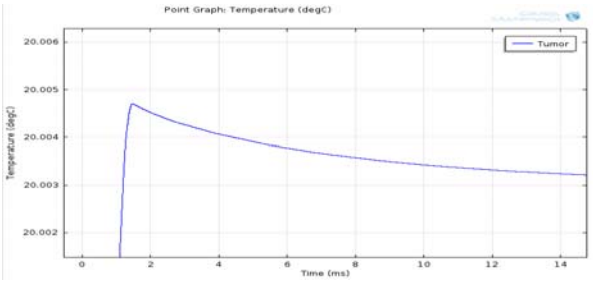

Figure-7. ΔT for 10 ms time is 0.0015°C for tumor with 700 W 200 us excitation pulse.

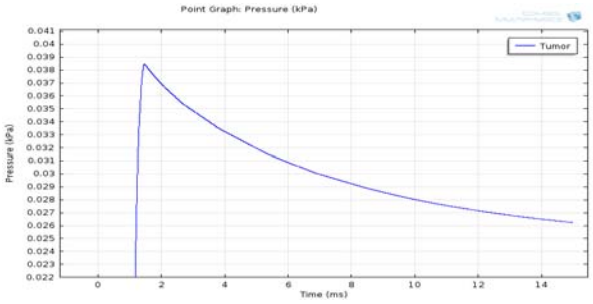

Figure-8. ΔP for 10 ms time is 0.0105KPa for tumor with 700 W 200 us.

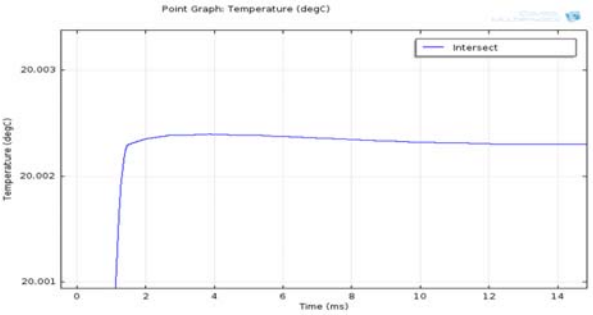

Figure-9. ΔT for 10 ms time is 0.000015°C for Tumor-Fatty Breast Tissue intersects with 700 W 1ms pulse.

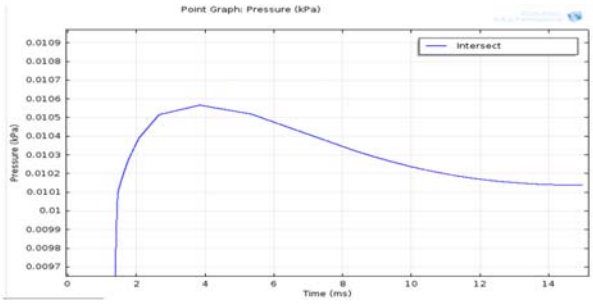

Figure-10. ΔP for 10 ms time is 0.0004 KPa for Tumor-Fatty Breast Tissue intersects with 700 W 1ms pulse.

DISCUSSIONS

In TE_{10} waveguide excitation pulse of 700 W 200 us (Figure-3) was used to produce absolute electric field maximum of 5000 V/m (Figure-4). Both non-malignant and malignant tissues absorb this microwave energy. Due to absorption of microwave energy the temperature is increased in both tissues as shown in Figure-5. Temperature rise in tumor is more because of high dielectric properties (conductivity 4 S/m and permittivity 50 F/m) than fatty breast tissue which has low dielectric properties values (conductivity.4 S/m and permittivity 9 F/m). Tumor cools faster than fatty breast tissue. Tumor undergoes more expansion due to this heating and increase in pressure due to this heat than breast tissue as shown Figure-6. The temperature rise of the tumorous tissue is greater than non-tumorous fatty breast tissue and this in turn produces an increase in pressure at tumorous than non-tumorous fatty breast tissue. Increase in pressure at fatty breast tissue is much less compared to tumor and tumor - fatty breast tissues intersect points. 700 W 200 us microwave pulse energy is irradiated at biological sample then the difference in temperature (ΔT) at tumor after 10 ms cooling is 0.0015 °C (ΔT in Figure-7) which creates a pressure difference (ΔP) of 0.0105 KPa (ΔP in Figure-8) and tumor - fatty breast tissue intersect point ΔP is about 0.0004 KPa (Figure-10) with ΔT0.000015°C (Figure-9). Pressure and temperature variations with different power levels are shown in Table-3.

Table-3. Pressure and Temperature variations with different power levels.

Power Watt	Tumor ΔP KPa	Intersect ΔP KPa	Tumor ΔT °C	Intersect ΔT °C
700	0.0105	0.000015	0.0015	0.000015
2500	0.033	0.0012	0.005	0.00005
7000	0.13	0.009	0.016	0.0012
10000	0.16	0.007	0.0171	0.0015
25000	0.45	0.01	0.065	0.004

CONCLUSIONS

Simulation results show that with small temperature variation in tumor produce several Kilo Pascal of pressure variations. Such minuscule values are far beyond causing tissue damage. This pressure variation will produce acoustic signal, which can be detected with array of transducers and used for construction of image. The results thus obtained from this model shows that the MITAI is a powerful tool for the determination of cancer in inhomogeneous tissues.

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