Analysis of Cancerous Tissue Temperature in the Breast During Hyperthermia

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ABSTRACT: *In this paper, the breast cyst diagnosis based on the surface temperature profile is proposed. The temperature profiles of normal breasts and breasts with cyst have been investigated. Heat transfer inside the breast is modeled by the Penne's bio-heat equationand solved by the finite element method using COMSOL Multiphysics software. A two dimensional (2-D) cross-section of the breast is modeled by a semicircle, whereas the cyst is modeled by a small circle. The temperature distribution on the breast surface for the normal breast and the breast with a cyst of various sizes were determined. The results show the difference in the surface temperature profiles of the normal breast and of the breast with a cyst of different sizes.*

KEYWORDS –*breast tissue, finite element method, hyperthermia*

I. INTRODUCTION

As wireless technology becomes more popular, effects of electromagnetic (EM) waves radiated from these devices become a serious problem in the public mind. Breast is the most vulnerable organs to EM waves, thus breast cancer has become one of the most serious health problems in every society [1]. Early detection is very important for successful treatment.

Over the last decade, the number of EM exposure surveys on the female breast cancer at microwave frequencies has dramatically ascended. Two dimensional (2D) analysis of the breast exposed to microwave energy is studied in 2007 by Lazebnik et al. [2] and three dimensional (3D) breast analysis is conducted by Santorelli et al. in 2011 [3]. Santorelli has introduced the energy levels using finite difference time domain (FDTD) analysis into the microwave energy exposed human breast exposure levels when the antenna is positioned in specific locations at several frequencies. Helix type applicators are used by Vojackova et al. in 2014 to determine SAR and temperature characters at 2.45 GHz in SEMCAD X software program with a sphere breast and tumor models [4]. 3D distribution of pattern of specific absorption rate (SAR), and temperature of multilayered model of the cancerous breast is analyzed when it is exposed to EM wave phenomenon at 2.45 GHz [5]. The distribution of SAR pattern, the standing wave ratio (SWR), the tissue hazard and the tissue temperature are analyzed during the exposure of the antennas operating at 2.45 GHz with varying diameters [6]. In addition, FDTD numerical simulations of radio frequency (RF) safety evaluation for the breast tissue are analyzed using a female anatomical model at 64 and 128 MHz exposures [7]. They all concluded that the increase in SAR is not sufficient to demonstrate a critical heating risk in tissue.

While treating the cancer, the main aim is to annihilate the cancerous tissue using heat without hurting the healthy tissues nearby. Several imaging methods such as thermography, microwave tomography, ultra-wideband radar, narrow and wide-band microwave techniques, and other time-domain techniques have been reported recently [8-15]. High intensity focused ultrasound is a newly developed treatment method for breast cancer. Zhang et al. [16] analyzed the temperature rise distribution in the human breast during this treatment using FDTD numerical method. They used the breast model of MRI images of 4 different patients. A new breast cancer detection method combining the thermography and high-frequency excitation techniques is represented in 2017 by Rahmatinia et al. [17]. They have estimated the location and size of a malignant tissue by the variation of the temperature on the breast surface.

In parallel, realistic breast phantoms and different antenna configurations have also improved in the literature. The fabrication of homogeneous and heterogeneous phantom models is discussed for microwave imaging applications to simulate the human breast's dielectric properties [18]. A realistic 3D microwave breast model of different shape, size and tissue density is studied in 2015 [19]. In addition, EM exposure sources models have been studied too. Contrast of circular and planar antenna for breast cancer is investigated in 2014 using microwave imaging with 2D FDTD models of the breast [20]. It is concluded that circular configuration is shown to be more robust to natural variations in dielectric heterogeneity in the breast. The performance of the wide slot antenna and the patch antenna is studied in 2013 by Sam et al. in detection of breast cancer in terms of radiation patterns, return loss, bandwidth and SAR values in between 2GHz to 10 GHz frequencies. They concluded that in ultra-wide band frequency range wide slot antenna has excellent performance [14].

The motivation of this study is to employ mobile phone signals to detect the tumor in a breast. This study aims to measure the effects of cell phone signals on human breast. Temperature increases and SAR levels are taken into consideration and they are compared to the limits determined by authorities such as ICNIRP [21]. It may also simplifies the detection of the tumor area due to EM properties (permittivity, and etc.), as the characteristics of cancerous area are significantly different from healthy regions. For this purpose, the finite element method (FEM) is selected for solving partial differential equations (PDE) related to EM wave equations and bio-heat equation. Input values such as tumor size, tumor location, the distance of the antenna to the breast are varied to determine the SAR and temperature elevation.

II. THEORETİCAL BACKGROUND

When the human tissue is exposed to RF sources, the measure of absorbed energy is called SAR [14, 15] and it is calculated using

$$\mathrm{SAR} = \sigma \frac{E^2}{\rho} \quad (1)$$

where E is rms value of the electric field inside the human body, ρ is the mass density of the tissue (kg/m3) and σ is the conductivity (S/m). The penetration depth of the EM energy should be 1 cm or more in order to SAR becomes meaningful. The FEM method is used for calculating SAR in the spherical model and the patch antenna is located next to the breast as the mobile phone excitation source.

When the human head is exposed to EM fields, blood flow and metabolic range parameters should be taken into consideration. The relation between EM fields and heat transfer can be calculated by Pennes Bioheat equation:

$$c\frac{\partial T}{\partial t} = \nabla.(k\nabla T) + \rho Q_{met} + \rho(SAR) - B(T - T_{blood}) \quad (2)$$

where the ρ [kg/m^3] is the material density, c [J/(kg°C)] is the specific heat capacity, k [W/(m°C)] is the thermal conductivity, Q_{met} [W/kg] is the metabolic heat generation rate, B [W/m^3°C] is the blood perfusion coefficient, ω [L/(s*kg)] is the blood perfusion rate, and T_{blood} is blood temperature.

III. SİMULATİON RESULTS

As it is seen from Fig. 1, the breast tissue covered by air is modeled as half circle with 9 cm. radius and is attached to 20 cm height and 18 cm width rectangular which is defined as patient body, and the cancerous tissue is modeled as a full circle with 2 cm radius. An arrow shows the direction of 2.45 GHz wave which leaves from top port to lower port passing through the air. The FEM model which is used in the simulations is depicted in Fig. 2.

The objective is to achieve 42 – 43 ^{0}C at cancer cell while minimizing the increased temperature in other region of the breast. First simulation is conducted with the fixed power input of top port with varying curing time. The result in Fig. 3 shows that curing time 75 – 115 s is optimal for 300 W input port power.

Secondly, fixed energy associated with the input port power and curing time is defined as 30000 W.s. Six different combinations of the same total energy have been simulated and the results are shown in Fig. 4. The result indicates that with the same total energy, the temperature remains constant ignoring the combination of power input.

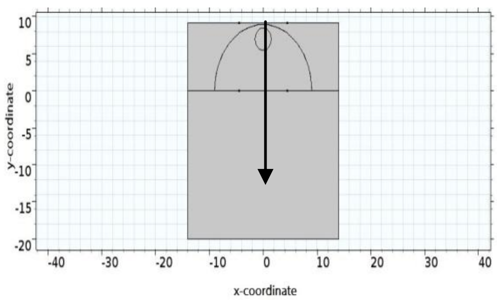

Figure 1. Model of the process.

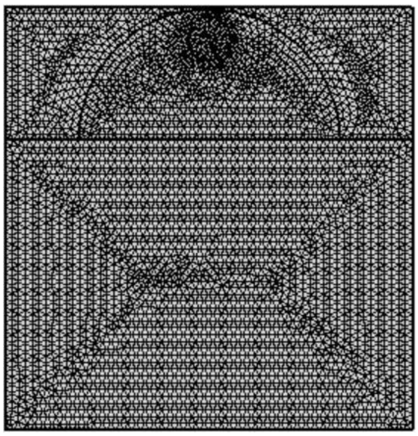

Figure 2. FEM model of the process.

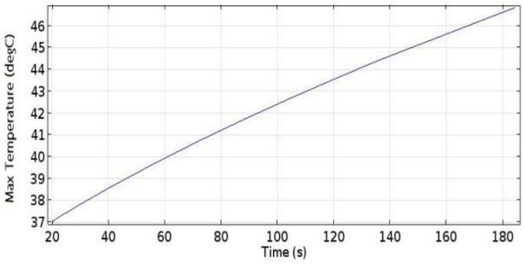

Figure 1. Max temperature on cancer cell with 300 W input port power

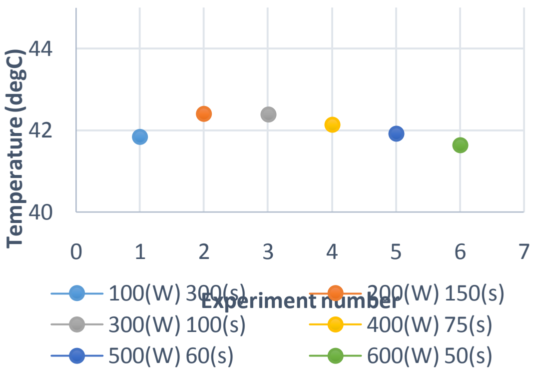

Figure 2. Temperature variations at fixed energy levels.

Healthy breast and malignant tumor tissues are different in the dielectric properties. The unhealthy part of the breast contains higher levels of water, which leads to higher conductivity values. This result in obtaining high SAR values and temperature increase in tumor tissue compared to healthy areas. Table 1 depicts the simulated values of conductivity and permittivity for normal tissue and tumor area as the previous studies [22].

Table 1. The properties of normal tissue and tumor tissue

	Conductivity (S/m)	Permittivity
Normal tissue	4	9
Tumor	9	50

The simulations have been conducted for a radius of 5 mm, 7.5 mm, 10 mm, 12.5 mm, and 15 mm cancerous tissue where the distance between the breast and the antenna is fixed to 2.5 cm and the breast radius is 5 cm.

In Fig. 5 it is seen that as tumor size increases, the effect of radiation on human breast also increases, and therefore malignant area becomes more distinguishable from healthy area.

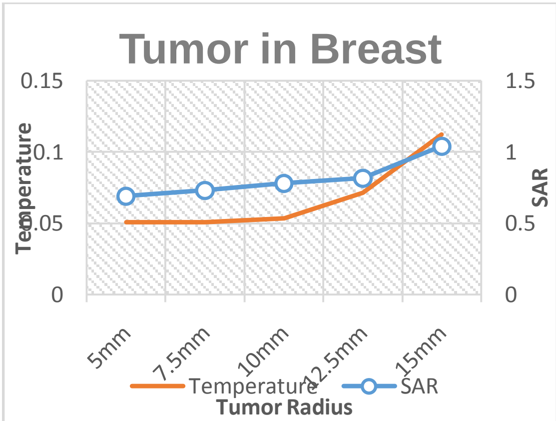

Figure 5. SAR and temperature incease on tumor area in human breast for various tumor sizes.

IV. Conclusion

This paper presents the 2D model of the human breast to determine the tissue temperature where it is irradiated by a source of electromagnetic field at 2.45 GHz in hyperthermia. Maxwell's equation for a model of tumor cells in breast and Pennes' bioheat equation used for coupling tissues are solved using the finite element analysis method in COMSOL software programme.

It is obviously seen from the simulations that tumor regions are heated to 42-43 ^{0}C to their optimum degrees after 75 s of exposure duration. When the energy is fixed to 30000 W.s, it is observed that the distribution of the temperature remain the same on the tumor cell of the breast.

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