Analysis of Cancerous Tissue Temperature in the Breast During Hyperthermia

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***Abstract*— In this paper, the computational modeling of the 2D human breast in hyperthermia treatment at 2.45 GHz is studied. The mathematical tool used in this study for investigating the distribution of generated heat is the COMSOL software where the breast is modeled by Pennes' bioheat equation. The model simulation is conducted to investigate the effects of exposure time and power inputs on the cancerous tissue temperature field. The results show that this method can cure the breast cancer patient without damaging the breast tissue.**

Keywords*— *Breast cancer, Hyperthermia, COMSOL Multiphysics, Electromagnetic wave, Bioheat transfer

I. INTRODUCTION

Cancer is an illness when cell division is uncontrollable. Cancer cells are growing and dividing and after they get into the blood or lymph system they can spread to other parts. Breast cancer is the major type of cancer in women [1-4]. Although chemotherapy is the most effective method to cure cancer, there is not a hundred percent success rate. An alternative method to suggest is hyperthermia. The hyperthermia is not used as the main method but it is considered as support method to chemotherapy to increase the success rate [5-7].

There are three curing plans for hyperthermia which is suggested in [8-9]. First one is stimulating body immune by heating the whole body to 38 – 40 ^{0}C, secondly, stimulating cancer cells by heating cancer cells to 42 – 43 ^{0}C and thirdly, using high temperature at 60 – 90 ^{0}C to kill the cells in the very specific region. This paper follows the second procedure.

Hyperthermia, using electromagnetic (EM) wave as heat source has three famous frequency band which are radio frequency, microwave and ultrasound frequency. Each has its own advantages and disadvantages due to its characteristic.

Microwave heat source can be used at 2.45 GHz in Industrial, Scientific and Medical radio (ISM) band. In this study, COMSOL Multiphysics is used to solve finite element method under Pennes' bioheat equation in this simulation.

II. METHODOLOGY

A. Pennes' bioheat equation

Pennes' bioheat equation describes heat transfer inside biological tissues. The equation is

$$pc\frac{\partial T}{\partial t} = \nabla \cdot (k \cdot \nabla T) - h_b c_b \omega (T - T_b) + Q_m + Q_{ext}. \quad (1)$$

where T is the temperature at any point inside the tissue, ρ is the tissue density, and c is the specific heat capacity of the tissue. The first term on the right-hand side describes the conduction heat transfer, where k is the thermal conductivity of the tissue. The second term represents the heat transfer by the convection and blood perfusion, where h_b is the heat convection coefficient of the blood, c_b is the specific heat capacity of the blood and T_b is the blood temperature which is typically equal to 37 ^{0}C. The term Q_m is the metabolic heat and Q_{ext} is the heat generated by an external source. For the simulation of the breast temperature profile in this work, Q_{ext} becomes zero because there is no external heat source. The boundary heat transfer condition between breast tissue and air is defined by

$$-k\nabla T = h(T - T_e). \quad (2)$$

where h is a heat transfer coefficient which is equal to 5 (W/m^2·K).

In this work, COMSOL's bioheat module employs the Pennes' bioheat equation and uses the Finite Element Method (FEM) to find the solution of the bioheat equation.

B. Modeling

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.

III. Results and Discussion

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.

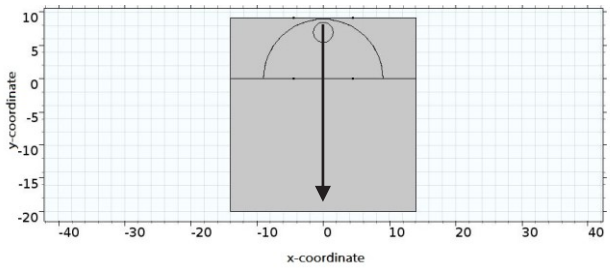

Fig. 1. Model of the process.

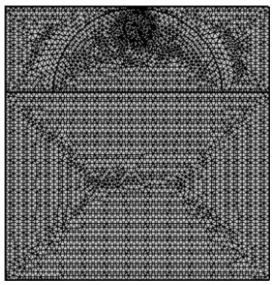

Fig. 2. FEM model of the process.

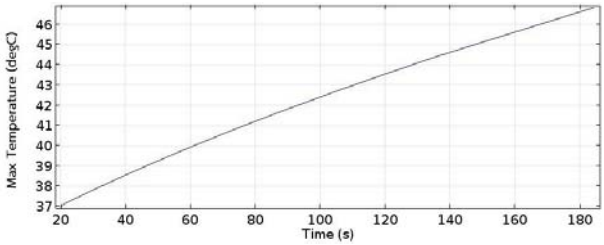

Fig. 1. Max temperature on cancer cell with 300 W input port power.

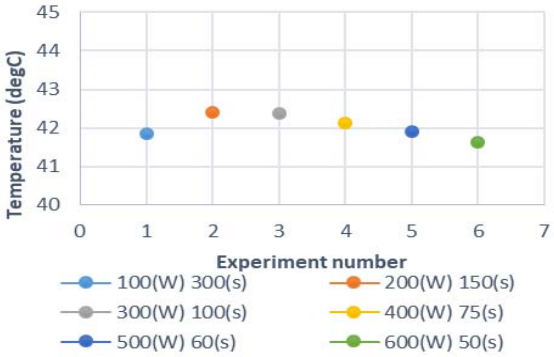

Fig. 2. Temperature variations at fixed energy levels.

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.

V. Reference

[1] "Breast Cancer", American Cancer Society, 2014. https://www.cancer.org/content/dam/cancer-org/research/cancer-facts-and-statistics/annual-cancer-facts-and-figures/2017/cancer-facts-and-figures-2017.pdf (Access Time: 30.04.2017)

[2] "Non-cancerous Breast Conditions", American Cancer Society, 2014. https://old.cancer.org/acs/groups/cid/documents/webcontent/003180-pdf.pdf (Access Time: 30.04.2017)

[3] "Guidelines for Management of Breast Cancer", EMRO Technical Publications Series, World Health Organization, 2006.

[4] Haakensen V. D., "Biology of the normal breast: Relation to mammographic density and risk of breast cancer", Department of Genetics Institute for Cancer Research Oslo University Hospital.

[5] P.M. Van den Berg, A. T. de Hoop, and N. Praagman, "A computational model of the electromagnetic heating of biological tissue with application to hyperthermic cancer therapy," IEEE Trans. J. Biomed. Eng. vol. bme-30, no. 12, pp. 797-805, 1983.

[6] I. Merunka, O. Fiser, L. Vojackova, J. Vrba, and D. Vrba, "Array of balanced antipodal vivaldi antennas used for microwave hyperthermia treatment of neck cancer," 24th Int. Conf. Radioelektronika, Bratislava, Slovak University of Technology, 2014.

[7] L. Wu, J. Cheng, W. Liu, and X. Chen, "Numerical analysis of electromagnetically induced heating and bioheat transfer for magnetic fluid hyperthermia," IEEE Transl. Magn., vol. 51, No.2, pp. 4600204, 2015.

[8] Petch Nantivatana, "A Study of Heat Distribution for Microwave Ablation using Finite Element," Department of Electrical Engineering Sripatum University, Bangkok, 2010.

[9] "Hyperthermia in Cancer Treatment," Blog post. *National Cancer Institue*. N.p., 31 Aug. 2011.. https://www.cancer.gov/ (Access Time: 28.04.2017)