Electric Field Distribution of Human Breast Tissue

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***Abstract*- Breast cancer is the one of the most leading diseases and cause of death in the world. 21% of females diagnosed with breast cancer in 2009 did not survive. Hence, cancer therapy requires a new and novel approach to treat them. Over the last two decades, electroporation, which is the process by which external electrical pulses are applied to facilitate the transport of drugs into cells, is gaining momentum as an alternative treatment for cancers. Electric field distribution and magnitude is a dominant parameter in electroporation. This paper presents the electric field distribution in normal and cancerous breast tissues and the effects of electrode positions and additional layers of fat and skin. Using Maxwell SV, a two dimensional model of the human breast tissue is created and analyzed. Size of tissue is estimated based on the average size of breast and electrical parameters such as permittivity and conductivity are set for normal and cancerous tissues from available literature. From the Finite Element Analysis of the mode, electric field distribution is obtained and field strength is compared for different cases. Cancerous tissues have higher permittivities and conductivities compared to normal tissues. Analyses of electric field distributions show that they have reduced field strength thereby signifying greater susceptibility to external influence using electrical pulses. These results will help improve electroporation and pulse mediated drug delivery techniques for cancers that are not receptive to conventional therapies.**

I. INTRODUCTION

Cancer is a group of diseases in which cells are aggressive, invasive and metastatic. Cancer originating in the breast, most commonly in the milk duct or lobule of the human breast, is termed breast cancer. Common methods of treating cancer are surgery, chemotherapy, radiation therapy, immunotherapy, and monoclonal antibody therapy [1]. These conventional therapies have major side effects and are expensive. Hence alternative treatments are sought and electroporation is a promising concept which introduces electrical pulses in chemotherapy. It has been established that electrochemotherapy is an efficient, safe, inexpensive once-only treatment that can be offered to cancer patients with tumors of a variety of different histologies [2].

Electroporation is the physical process of inducing transient permeability of biological membranes by short pulses of electric fields [3]. The resulting high field strength in the membrane can lead to the formation of areas of increased permeability, often called pores, which allow transmembrane transport of molecules. Factors that effect electroporation are, electric field strength, pulse length, shape of electrical pulse, polarity, number of pulses, interval between pulses, size of target cells, thermal conditions during and after the pulse, as well as other internal and external factors. Electric field in the tissue is generated by a potential difference (voltage) between electrodes surrounding, or adjacent to, the tissue [4].

The electrical characteristics of the cytoplasm and membrane of cells, such as the conductivity and permittivity govern the response due to electroporation in addition to the voltage applied [5]. This paper aims at developing a simple model of the human breast tissue and analyzing the electric field distribution of normal and cancerous tissue.

II. SIMULATION

A. Software

Maxwell Student Version (SV), Version 3.1.04, freely available software by Ansoft Corporation is used to create model and run simulations [6].

B. Model

A two dimensional electrostatic model is created to represent the duct and lobules of a human breast tissue. Fig. 1 shows the actual arrangements [1] and Fig. 2 shows the model developed in this study. Parallel plate electrodes are placed on either side of a lobule and a voltage of 1300 V/cm [2] is applied to electrode 1; electrode 2 is grounded.

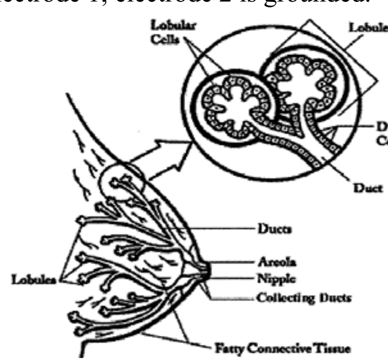

Fig. 1. Human breast showing duct and lobules [1].

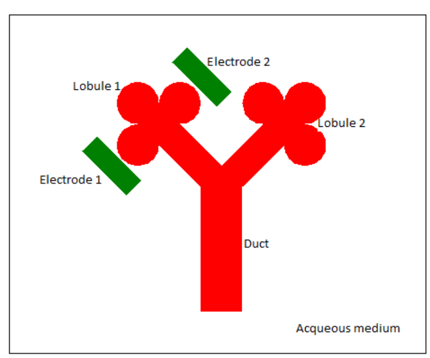

Fig. 2. 2D model of human breast tissue in Maxwell SV.

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Dimensions and electrical parameters such as conductivity and permittivity vary for normal and cancerous tissues [7] and are listed in Tables I and II.

TABLE I
DIMENSIONS OF TISSUE(S) AND ELECTRODES

	Dimension (mm)		
	Length	Breadth	Radius
Duct	12	4	
Ductile	5.6	2	
Lobule			4.24
Electrode	4	1	

TABLE II
ELECTRICAL PARAMETERS OF TISSUES

Tissue Type	Parameters	
	Rel. Permittivity	Conductivity (/ohm.m)
Normal Tissue	52	2.2
Cancer Tissue	260	10.34
Fat	15	0.2
Skin	33.5	0.7

III. RESULTS AND ANALYSIS

A. *Normal versus Malignant tissue*

Fig. 3 shows the electric field distribution of normal tissue. The electric field is higher near the electrodes and reduces towards the centre of the lobule at which electrodes are placed (lobule 1). Electric field is much lower in lobule 2. Comparison with malignant tissue electric field distribution (Fig. 4) indicates that the cancer tissue has an electric field distribution different from that of normal tissue illustrating the difference between the tissue characteristics.

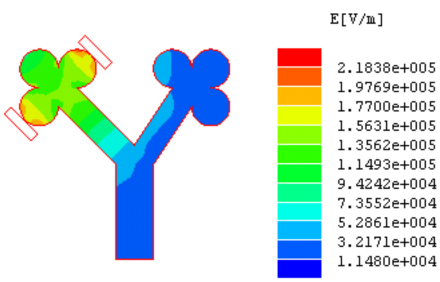

Fig. 3. Electric field distribution of normal tissue.

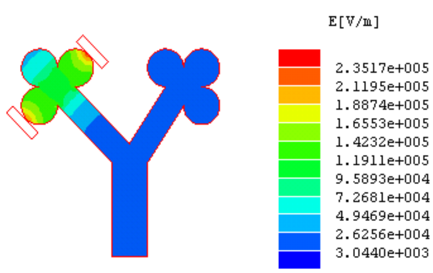

Fig. 4. Electric field distribution of malignant tissue

B. *Effect of fat and skin layers*

In order to simulate conditions close to reality, fat (20 mm) and skin (2mm) layers are introduced in the model. Fig. 5 and Fig. 6 show the electric field distributions of normal and cancer tissue with the layers included. It is evident that electric field is lower in case of cancer tissue than normal tissue with layers included.

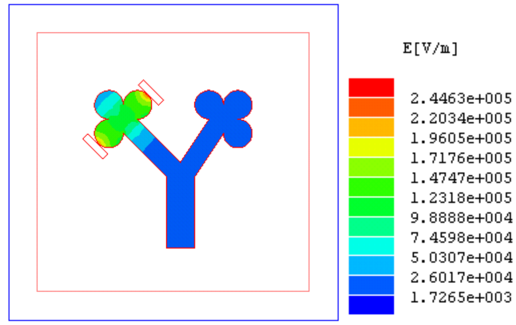

Fig. 5. Electric field distribution of normal tissue with fat and skin layers.

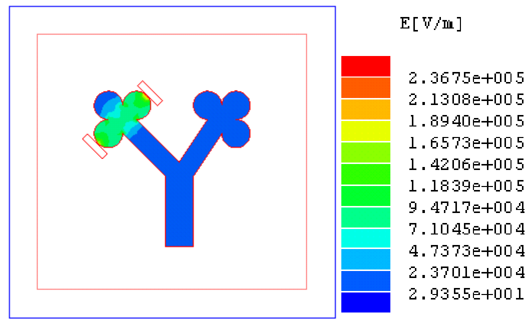

Fig. 6. Electric field distribution of malignant tissue with fat and skin layers.

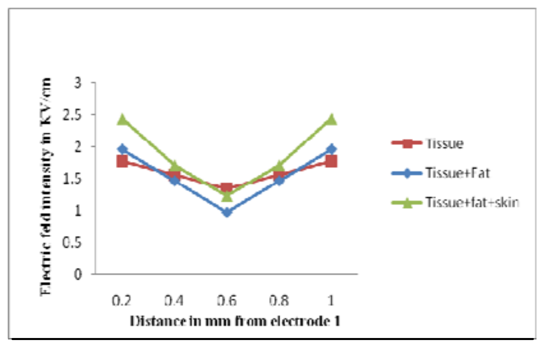

Fig. 7a. Electric field intensity of normal tissue with fat and skin layers.

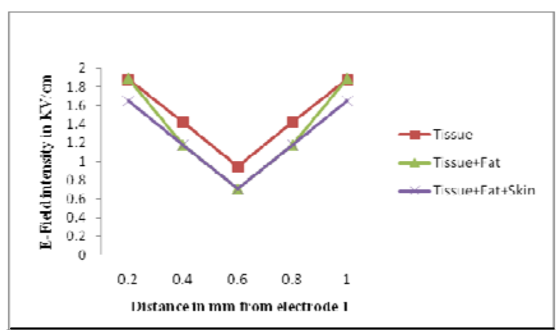

Fig. 7b. Electric field intensity of cancer tissue with fat and skin layers.

The electric field intensity is highest near electrodes and reduces with distance from the electrode. However, the values of electric field intensity do not vary too much with the introduction of layers. Fig. 7 shows that the trend remains the same and values of field intensity vary only within a small range.

C. Effect of voltage type (DC versus AC)

For the same value of voltage (1300 V/cm), simulations were run for DC and AC types. As shown in Fig. 8, AC conduction yielded much lower electric field than DC. The plot is drawn to compare the field intensity at the centre of the breast lobule.

There is a minimum decrease of 22% (3) and a maximum reduction of 117% (1) in the electric field intensities of AC over DC.

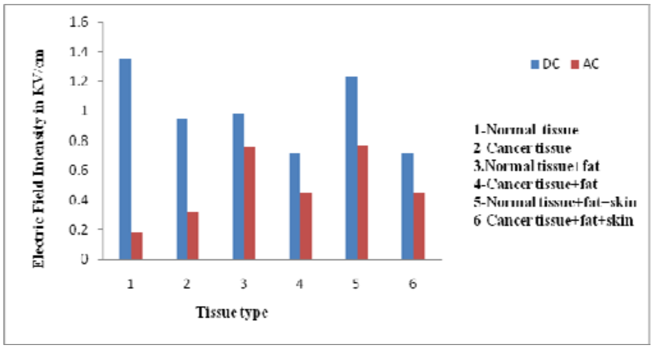

Fig. 8. Comparison of DC versus AC for various tissue types.

D. Effect of Electrode Position

Figs. 9 and 10 show the model and electric field magnitudes for internal and external electrodes. The internal electrode is 24 times smaller than the external electrode and yet has a much higher field magnitude. This clearly shows the importance of inserting an electrode inside. The voltages applied were the same – 1300 V/cm and even with a much smaller electrode, the field values are higher and symmetric when applied directly to the breast lobes. External electrodes yielded lower electric field intensities and were asymmetrical.

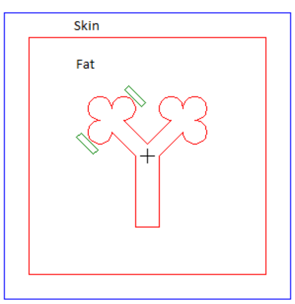

Fig. 9a. Internal Electrode

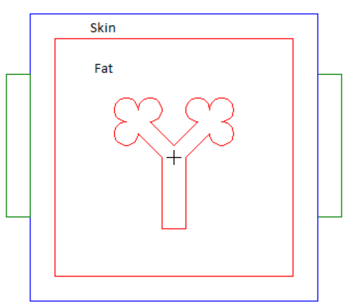

Fig. 9b. External Electrode

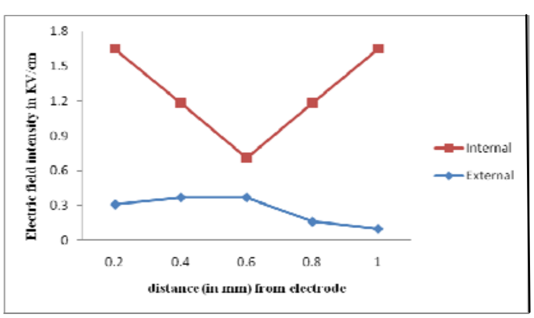

Fig. 10a. Internal versus External electrode (DC)

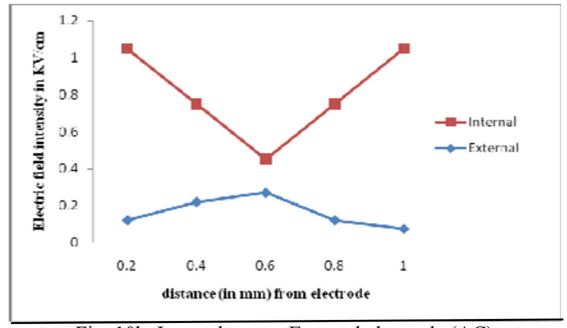

Fig. 10b. Internal versus External electrode (AC)

IV. Discussion And Conclusions

Numerical simulation for in vivo electroporation has proven to be simple and efficient tool for analysis of electrical phenomena inside biological tissues [8]. It is very useful for the explanation of experimental results and analysis of different parameters and geometries. Validated numerical simulations make possible the analysis and optimization of the shape, position and dimensions of the electrodes in electrochemotherapy for its better antitumor effectiveness. Numerical simulations can be very useful in transfer of knowledge gained in the experimental work into clinical practice.

Electroporation is an upcoming technique that proven beneficial for cancer treatment [9]. It can bring benefits to individual patients and the society. Electrochemotherapy is an attractive approach not only to treat cancer, but also to reduce the side effects of conventional chemotherapy. This would also reduce the costs of cancer treatment caused by side effects, which most often are responsible for prolonged stays in the hospitals and large consumption of other cytotoxic chemodrugs. With its possibilities in the optimization of the electrochemotherapy, numerical modeling can substantially contribute to these goals.

In order to implement this technique for treatment of breast cancer, it is important to study tissue and cell characteristics and behavior. This paper provides a simple 2 dimensional model of the human breast and gives the electrical field distributions for normal and cancer tissues. Cancerous tissues have much lower electric fields making them more susceptible to external voltages. The reduction could be due to the reason that cancer cells have altered membrane composition and permeability, due to which there are movements of minerals, such as potassium, sodium, calcium and magnesium [10]. Due to these mineral movements, membrane composition changes, energy abnormalities, and membrane charge distribution abnormalities, there is a drop in the membrane potential and its capacitance. In addition, cancer cells have different lipid and sterol content.

Introduction of fat and skin layers over the breast tissue makes the model similar to a living system. DC conduction gives higher field intensities consistently compared to ac voltages of same magnitude. It is also evident that internal electrodes are more efficient. With an electrode size several times smaller than external electrodes, the electric field intensity is much higher and symmetric as compared to those with external electrodes. Hence using internal electrodes with DC voltages to treat cancer can be explored further as a significant advancement. Similar studies have been undertaken by others [11]. Fig. 11 shows the model developed by this team. A three dimensional model of the human breast along with layers of muscle, fat and skin was created and simulated to study electric field distribution. RF waves (140 MHz) were used in their study. They found that the electric field was highest near the surface of the tumor. It can be seen that there is a similarity between the electric fields obtained by them and by us. Though the source used in both cases are different, DC and AC source in our study and RF in theirs, the electric field is found to be most near the surface of tumour. These results emphasize the fact that cancer tissues are more susceptible to external electrical influences.

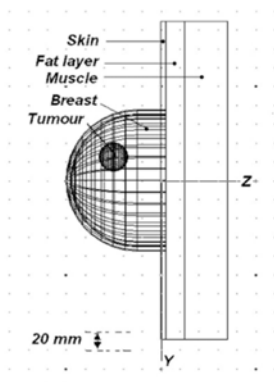

Fig. 11. Breast Tumor model used by previous researchers [11].

A more detailed model is necessary to study in-depth characteristics and behavior of breast cancer cells and tissues. Our two dimensional model can be used as the fundamental block and can be built upon further. A three dimensional model with pulse voltages for short durations can be studied to understand effects of electroporation in order to implement it as a treatment for breast cancer.

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