Electric Field Distribution of Malignant Breast Tissue under Needle Electrode Configuration

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***Abstract*- Breast cancer is the second leading disease causing death in women. The most recent data tells that breast cancer accounts for 28% to 38% of all cancers in women in big cities like Mumbai, Delhi, Chennai, etc. in India and it is also becoming an issue worldwide with 400,000+ deaths an year. This indicates that the current standard of cure is not adequate and we need additional/alternate therapies. Electrochemotherapy, which is the process by which external electrical pulses are applied to facilitate the transport of chemo drugs in to cells, is gaining momentum as an alternative treatment for chemorefractory and inoperable cancers. This paper deals with the electric field distribution study of breast tissue with ductal carcinoma model using MAXWELL 3D Simulator. The results indicate that the electric field distribution is in general homogeneous and the malignant tissue has different electric field intensity compared to the normal tissue for a given condition, depending upon with or without fat and skin.**

I. INTRODUCTION

Cancer is the uncontrolled growth of abnormal cells in the body. Cancer originating in the breast, most commonly in the milk duct or lobule of the human breast, is termed breast cancer [1]. The breast is mainly composed of three types of tissues: breast fat (or adipose tissue), glandular tissue and connective tissue (fibrous strands called Cooper's ligament) [2]. Mainly, there are two most common types of cancer: In situ (or non-invasive) and Invasive. In situ cancers are those in which cancer cells remain within the basement membrane of the lobules and the draining lactiferous duct. Invasive cancers are those in which there is dissemination of cancer cells outside the basement membrane of the ducts and lobules into the surrounding adjacent normal tissue. The most frequently occur breast cancer are Ductal Carcinoma In Situ (DCIS), Lobular Carcinoma In Situ (LCIS), Invasive Ductal Carcinoma (IDC), Invasive Lobular Carcinoma (ILC) [3]. Ductal Carcinoma in Situ (DCIS) is a type of cancer in which cancerous cells are inside some of the ducts, but have not spread to other regions of the breast or body. Lobular Carcinoma in Situ (LCIS) is not a type of cancer per se, but in presence of this disease there are high chances of developing cancer. LCIS is characterized by changes in the cells within the breast lobes. Invasive Ductal Carcinoma (IDC) is the most common type of breast cancer (70 to 80% of breast cancer cases), and occurs in the cells that line the ducts of the breasts. Invasive Lobular Carcinoma (ILC) represents about 10% of breast cancer cases and occurs in the cells that line the lobules of the breast [3].

Common methods of treating cancer are surgery, chemotherapy, radiation therapy, immunotherapy, and monoclonal antibody therapy. These conventional therapies have major side effects and are expensive. In addition, there is a woman dying every 13 minutes in US and one in every 45 seconds (400,000+ deaths) worldwide, each year. Hence alternative treatments are urgently needed and electroporation is a promising concept which introduces electrical pulses in chemotherapy [4-7]. Electroporation is the physical process of inducing transient permeability of biological membranes by short pulses of electric fields [7].

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 [4-7].

Needle electrode are used for the sub-cutaneous tumor. This paper aims at developing a simple model of the human breast duct tissue and analyzing the electric field distribution of ductal carcinoma under eight needle electrode configuration [4-7].

II. MODELLING

A. *Software*

The ductal carcinoma is modeled by Finite Element Method using the package ANSOFT 13, Ansoft Corporation [8]. The electrical stress and electric field distribution can be found with the negligible percentage of error by increasing the number of iterative meshes. The field distribution is analyzed by selecting proper boundary conditions [9, 10].

B. *Model*

Fig .1 shows the representations of two of the most common types of breast tumor: in situ and invasive [3]. This was modeled in our work as shown in Fig. 2, for analyzing the electric field distribution under needle electrode configuration. Systematic approach was adapted. The dimension of the model is shown in Table I and the electrical parameters are also shown in Table II [11]. Eight needle electrode are deeply inserted in to the tumor. A high voltage 480V is applied to the left electrode and right electrode is grounded.

First the normal and malignant breast was modeled with tissue only, using the electrical parameters assigned as given in the Table II, without fat and skin. Then layers of fat and skin was added and the field distributions were evaluated.

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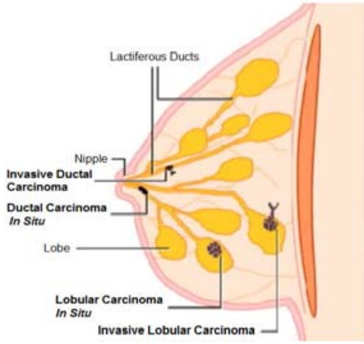

Fig. 1. Breast tumor: in situ and invasive [3].

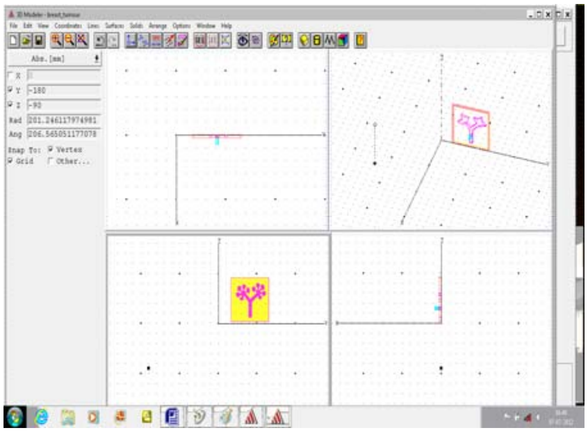

Fig. 2. ANSYS model of a ductal carcinoma.

TABLE I
DIMENSION OF THE HUMAN BREAST CELL

	Length (mm)	Breadth (mm)	Radius (mm)	Thickness (mm)
Electrode	25	-	1	-
Fat	-	-	20	30
Skin	-	-	22	30
Lobule	-	-	3.2	30
Duct	10	5.67	-	30

Table II
ELECTRICAL PARAMETER OF THE HUMAN BREAST CELL [11]

Tissue type	Parameters	
	Relative permittivity	Conductivity (S/m)
Normal tissue	52	2.2
Cancerous tissue	260	10.34
Fat	15	0.2
Skin	33.5	0.7
Stainless steel	1	$1.1e^6$

III. RESULTS AND ANALYSIS

Figs. 3a and 3b show the electric field distributions of the ductal carcinoma for the malignant and normal tissues respectively. The eight needle electrode is inserted into the duct as illustrated in these. The electric field is homogenous in and around the electrode/tumor area. The intensity of the electric field in the tumor tissue is about 329V/cm and it is about 287V/cm, in the normal tissue portion. In the adjacent areas, the electric field is high near the electrode and it is reduces towards the tissue.

It is observed that the electric field magnitude of ductal carcinoma is 11.5 % higher than that of the normal tissue. This compares fairly with those obtained for the lobular model where the electric field intensity of the malignant tissue was higher than normal tissue by about 5% (Fig. 4a and b [12]). The magnitudes varied when the fat and skin were introduced to represent a more realistic scenario (Figs. 5 and 6).

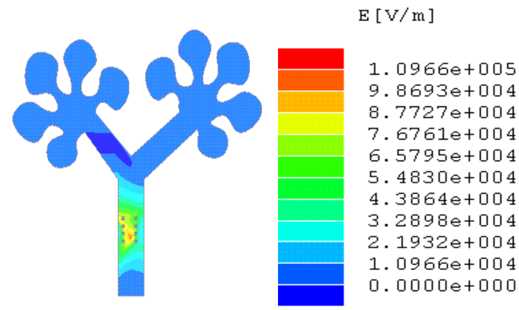

Fig. 3a. Electric field distribution of ductal carcinoma.

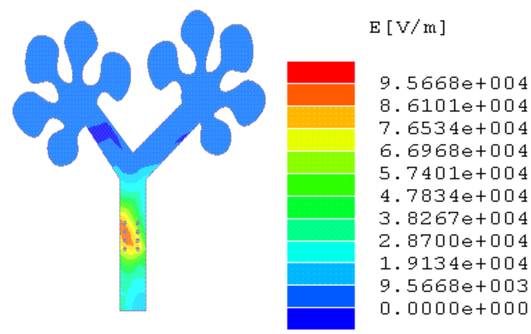

Fig. 3b. Electric field distribution of normal tissue.

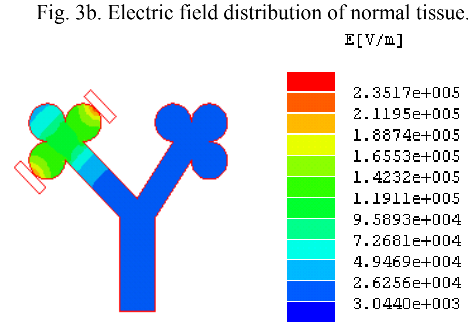

Fig. 4a. Electric field distribution of malignant tissue.

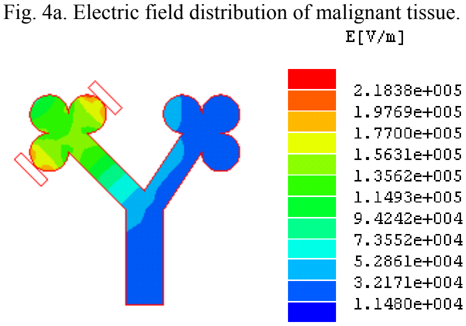

Fig. 4b. Electric field distribution of normal tissue.

From Fig. 5a and b, the electric field intensities of the malignant and the normal breast tissue with fat were about 323V/cm and about 1125V/cm respectively. This shows a decrease of about 3.5x in the malignant part compared to the normal part. This correlates well with similar values obtained in [11]. This could also be due to the change in the properties of the malignant tissue compared to the normal tissue, especially the lipid layer with its changed moisture and ion contents.

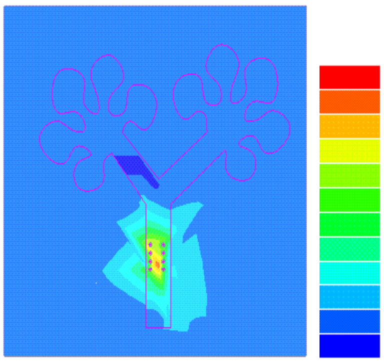

Fig. 5a. Electric field distribution of ductal carcinoma with fat.

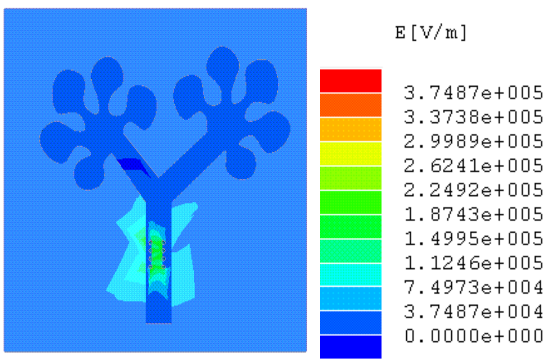

Fig. 5b. Electric field distribution of normal tissue with fat.

From Figs. 6a and b, the electric field intensity of ductal carcinoma with skin is 2.5% higher than the electric field distribution of normal tissue with skin.

In general the electrical properties of cancer cells differ from the normal cells as discussed by Haltiwanger [13]. This is caused by the lower negative charges at the surface, and changes in the pH, mineral content, ionic species, structural membrane changes, membrane potential changes, extra cellular matrix changes, and the protein changes. In addition there are changes in the genes and the sialic acid content. Cancer cells have lower potassium concentration and higher sodium and concentrations than normal cells. As a resulst of these mineral changes, energy abnormalities and membrane charge distribution abnormalities, the capacitance changes and hence the relative permittivity, leading to the changes in the electric field intensities as observed in the simulation using different magnitudes for the relative permittivity and the conductivity (or the resistivity) for malignant tissue compared to the normal tissue. These are also supported other researchers. It was reported that the electric field is decreased if the same protocol is used for tumors, deep seated with a human breast [14]. The tumor tissue had lower electric field strength compared to normal cells [15]. The capacitance or conductance of breast cancer malignancy is 50 times higher than that of normal tissues or benign lesions [15].

A clear understanding of these variables will enable to obtain the optimal parameters of voltage to be applied for a given duration for effective electrochemotherapy applications in the clinic.

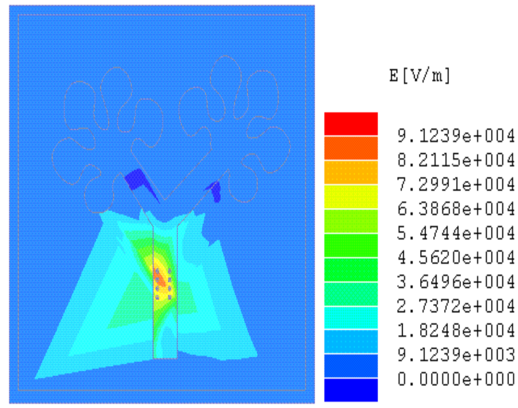

Fig.6a. Electric field distribution of ductal carcinoma with skin.

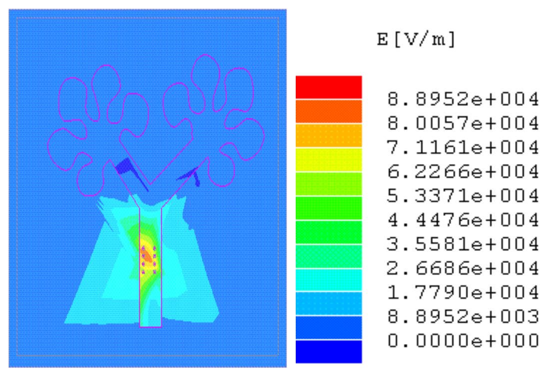

Fig. 6b. Electric field distribution of normal tissue with skin.

IV. CONCLUSION

In electrochemotherapy, electric field distribution plays an important role to inactivate the tumor. Electric field distribution in the ductal carcinoma is analyzed using MAXWELL 3D Simulator.

The Electric field distribution of ductal carcinoma with tissue only configuration is 11.5 % higher than the electric field distribution of normal tissue. The electric field at the needle electrode at the tumor has higher electric field, while comparing with elsewhere due to the sharp point. The malignant tissue with fat showed a 3.5x reduction, while that with fat and skin show only 2.5% change compared to normal tissue.

These results emphasize that cancer tissues are more susceptible to external electrical influences. These results will aid in effective electro chemotherapy, the pulse-mediated drug delivery technique for cancers that are not receptive to conventional therapies.

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