Electric Field distribution study of Brain tumors for various Electrode Geometries

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Abstract—**Brain tumor has been one of the major leading diseases, causing deaths majorly in children under 20 and in males between 20-29 years old. Several drugs and methods have been developed for treating these tumors, finally leading either to major side effects or deaths of patients. Hence alternate techniques are urgently needed and electroporation is a promising technique capable of curing brain tumors, with a very less damage to the patient. This study investigated the various possible electrode configurations that are being and can be used for the electroporation technique. In this study, a 2D model of brain slice with tumor is constructed and simulated using the industry standard FEM software, COMSOL. Using this FEM software, the electric field distribution due various electrode shapes, voltages and material properties are studied. A critical field strength of about 1200 V/cm, has been set as the upper threshold value for the electric field simulated for the model. Based on this threshold value, the electrode voltage had been set up for each electrode geometry and the electric field distribution is studied. The results indicate that though the plate electrodes are capable of providing higher magnitude electric fields near white matter and dura matter. Needle and micro needle electrodes are observed to be showing much better electric field distribution inside tumor with a negligible damage to the other parts of brain. These results are useful for transferring this technique to clinical practice.**

I. INTRODUCTION

Due to its location and delicacy, it is very difficult to both diagnose and treat brain tumors. In addition, there are also over 120 types of brain tumors, hence identifying the effective therapy is challenging after all these years of research [1]. Brain tumor has been one of the major leading diseases, causing deaths majorly in children under 20 and in males between 20-29 years old [2, 3]. Unlike other tumors, these tumors are located in one of the most delicate parts of our body, which makes it very difficult to identify and handle. The standard treatments, consisting of maximal surgical resection, radiotherapy and chemotherapy, however, have not yet significantly improved the prognosis of patients with brain tumors. Furthermore, even with discovery and development of promising anticancer drugs in vitro in the last few decades, it has also not demonstrated any huge impact on disease in clinical trials. Adding to the inefficiency of the drugs, there will be huge side effects [4] on the body because of the poor drug delivery. Only about 2 percent of the intake drugs are said to be reaching the desired area. Hence, there is a critical need for alternate, physical therapies and electrical pulse-mediated drug delivery, known as electroporation appears to be a promising technique for the treatment of brain tumors.

Electroporation is the application of high intensity, short duration pulses to open up pores that allow external drugs that are typically impermeable thorough the lipid bilayers of the plasma membranes of human cells. When used for chemo drug uptake, it is known as electrochemotherapy (ECT) whose success has been evidenced by various clinical trials [5-7]. Appropriate electric field intensity and its distribution is critical for effective drug uptake, as, if the field intensity is lower, the pores won't open-up and if the electric field intensity is higher, there will be cell death. The electric field distribution also depends on the electrode configurations. This necessitates the study of electric field distribution for various needle geometries.

II. SIMULATION

A. Software

In order to determine the electric field generated inside the tumor and other layers of brain, a two-dimensional finite element model was implemented in the COMSOL software package (Comsol Multiphysics, V.4.3b; Stockholm, Sweden). Electrostatics (es) module of AC/DC physics in COMSOL is used to compute electric field while varying geometry, voltage and some other parameters. The electrical boundary condition along the tissue in contact with the energized electrode was ϕ=V0 (electrode voltage) and ϕ= 0 at the ground electrode. The boundaries where the analyzed domain was not in contact with an electrode were treated as electrically isolative. Generated results are exported to obtain the average and maximum electric field values to resemble the electrode stimulation during electroporation on brain tumors.

Comsol solves a series of equations for solving the given problem. The governing equations that COMSOL uses to compute electric field (E) are given as follows:

$$\nabla . D = \rho V \qquad ------ \quad (1)$$

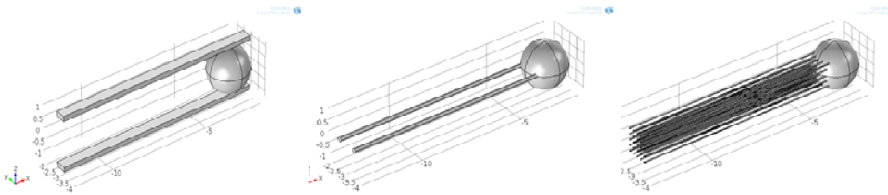
$$D = \varepsilon_0 \varepsilon_r \mathrm{E} \qquad ------ \quad (2)$$

$$E = -\nabla V \qquad ------ \quad (3)$$

Where, D being electric displacement,
ρ is the electrical charge density,
ε_0 is the permittivity of the free space
ε_r is the relative permittivity of the medium

B. Electrode configurations

Different electrode configurations namely parallel plate electrodes, needle electrodes and micro needle array as shown in Fig. 1 are used in this work. The dimensions of these electrodes are specified in the Table 1 along with the voltage applied to them.

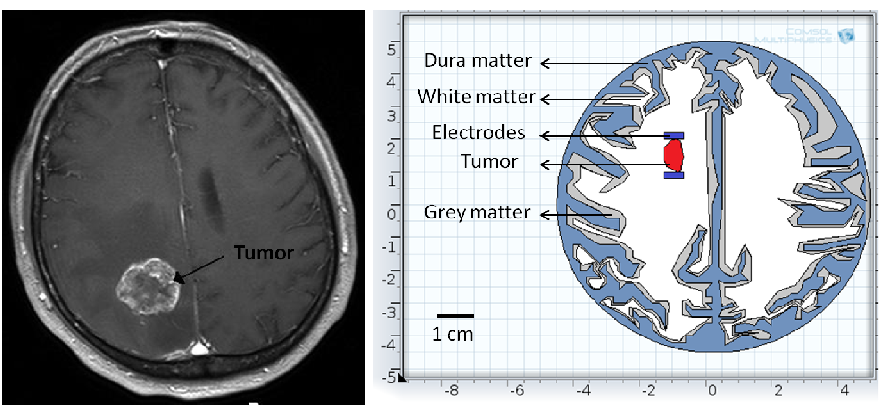


(a) (b) (c)

Fig. 1. Various electrodes used to the tumor-(a) plate electrodes, (b) Needle electrodes and (c) Micro needles.

A. Model

A two-dimention model consisting of the human brain, tumor tissue and electrodes was developed to study electric field distribution. Fig. 2a shows a brain tumor configuration [8]. This is modeled as shown in Fig. 2b. Here, the upper electrode (positive) and the lower electrode (ground) are used to apply voltages. A maximum critical electric field of 1200-1300 V/cm is taken as a control parameter, using which, the voltage applied is limited. The various models studied include the brain tumor with (a) parallel plate electrodes (Fig. 2b.), (b) needle electrodes and (c) micro needle array electrodes. The dimensions of model components are listed in Table 1 and parameters in Table 2 [9].



(a) (b)

Fig. 2. a) A tumor present inside the human brain [8], b) Its Model created for simulation.

TABLE 1: DIMENSIONS OF THE GEOMETRY USED

Model Component	LengthxBreadth (cmxcm)	Diameter (cm)	Applied Voltage (V)
Parallel plate electrode (with 1 cm distance between them)	0.5x0.2	-	500
Needle electrode (with 0.25 cm distance between them)	-	0.1	200
Micro Needle electrode array (with 1 mm distance between them)		0.025	15
Tumor	1x0.5 (arbitrary)	-	-

TABLE 2: PROPERTIES OF THE MATERIALS USED INSIDE THE GEOMETRY [9]

Material	Relative permittivity, ε_r
Tumor	260
Dura matter	1.54×10^3
Grey matter	4.23×10^4
White matter	2.09×10^4
Electrodes	1

III. RESULTS AND DISCUSSION

A. Using Plate electrodes

Figs. 3a-d show the electric field distribution inside the tumor, the white matter, the grey matter, and the dura matter, respectively. For an applied voltage of 500V across an electrode gap of 1cm, the uniform electric field intensity will be 500V/cm. However, in this case, using plate electrodes, a maximum e-field value of 1213.7 V/cm is obtained. Maximum Electric fields of 1213.7 and 964.35 V/cm are obtained for white and dura matter respectively. This high field outside the tumor region is undesirable, as they may lead to some other side effects. As by using plate type electrodes, this type of phenomena is unavoidable, it is suggested to use needle electrodes.

B. Using Needle electrodes

By using needle electrodes, the intensification of the electric field inside other areas excluding tumor have minimized drastically. The voltage and electric field plot of the tumor is shown in Fig. 4. The voltage applied to the needle electrodes has been reduced to 200 V because of the shape and the reduced distance between electrodes.

C. Using Micro Needle Array electrodes

A micro needle array of electrodes has been created, where the consecutive column of electrodes will be applied with voltage. The spacing between the electrodes is maintained at 1 mm, with a voltage of 15 V. Though the average electric field is decreased to 150 V/cm, a maximum electric field of about 1340.7 V/cm is obtained at the tip of the electrodes.

The maximum electric fields inside the tumor, white, grey and dura matter are plotted for different electrode geometries as shown in Fig. 6. It can be seen that except plate electrodes, there is no electric field intensification inside white, grey and dura matter. White and Dura matter are more susceptible to get affected because of the plate electrode geometry.

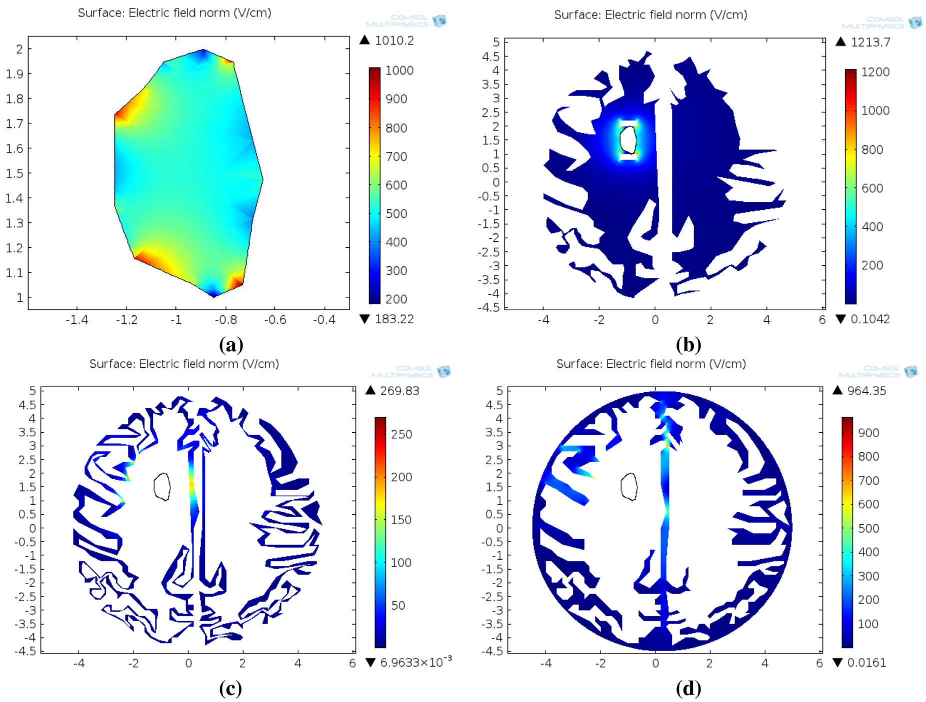


Fig. 3. Electric Field distribution inside (a) tumor, (b) white matter, (c) grey matter and (d) dura matter plotted separately for plate electrodes configuration.

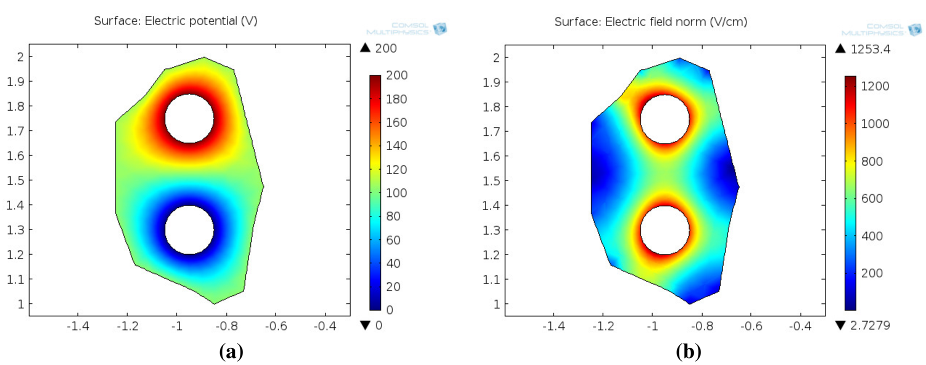
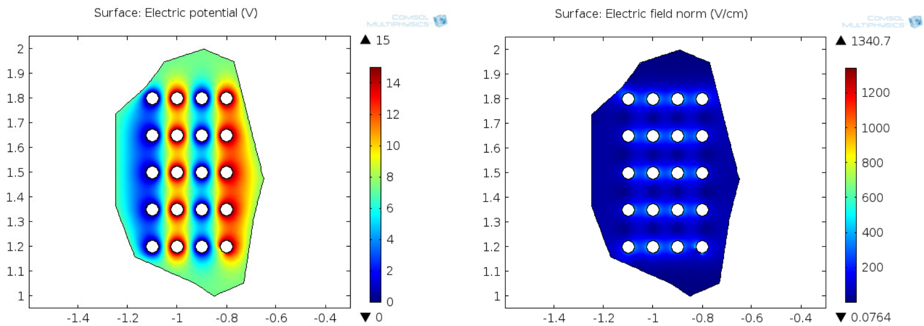


Fig. 4. (a) Voltage distribution and (b) Electric field inside tumor with energized needle electrodes.



(a) **(b)**

Fig. 5. (a) Voltage distribution and (b) Electric field inside tumor with energized micro needle electrodes.

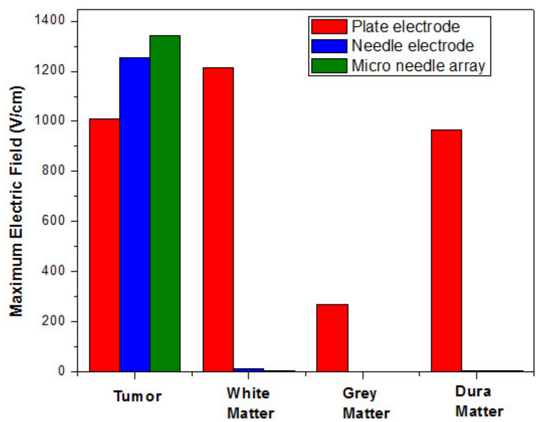


Fig. 6. Comparison of the maximum Electric field inside tumor, white, grey and dura matter for different electrode configurations.

D. By varying permittivity of the tumor

As the permittivity of the tumor got increased, there is a slight decrease in average e-field value inside tumor. The slope of this decrement is high for the needle electrode, then plate and at the last micro needle electrode configuration (Fig. 7).

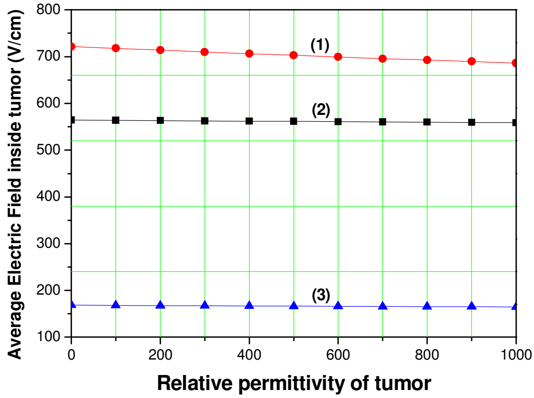


Fig. 7. Average electric field inside tumor vs relative permittivity of the tumor for (1) needle electrode, (2) plate electrode and (3) micro needle array electrodes. .

IV. CONCLUSION

1. In case of parallel plate electrode configuration, electric field is not only getting intensified inside tumor, but also in white matter and dura matter (Fig. 3).

2. In needle and micro needle configuration, the above problem is resolved and the entire e-field is confined only to the tumor (Figs. 4, 5, and 6).

3. As the size of the electrodes decreases, the critical electric field value for the given applied voltage, exceeds is increasing. Hence there is a limitation on the voltage to be applied in case of micro needle electrodes.

4. So as per the limitation 500 V for plate, 200 V for needle and 15 V for micro needle are adjusted. Though the critical e-field values are same, the average e-field value inside tumor got reduced with size of electrodes (Fig. 6).

5. As the permittivity of the tumor got increased, there is a slight decrease in average e-field value inside tumor. The slope of this decrement is high for the needle electrode, then plate and at the last micro needle electrode configuration (Fig. 7).

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