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Three Dimensional Finite-Element Analysis For Hepatic Tumor Ablation

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***Abstract*— Cancer is a major health disease observed in many people. This paper offers methodology for the treatment of hepatic malevolence to find the temperature of the tissue spreading during the process of hepatic ablation. We use the finite-element method (FEM) as the mathematical modeling. The thermal-electrical 3D FEM prototype consisting of alarge blood vessel, a hepatic tissue, and four-tine probe, located at altered locations. Duration of 8minutes and controlled temperature of 50° C are used in the simulation of FEM based analyses. The highest value of the tissue temperature observed next to electrode A, during this process the distance from blood vessel and electrode is 5 mm. similarly if distance is 1mm then hot spot observed nearer to the electrode but opposite side. In the 2-D model temperature is non-uniformly distributed because of the diverged blood vessel. The tumor may be regenerated near areas which are under dosed next to the blood vessel.**

***Index Terms*— Bio-heat equation, finite-element method, hepatic ablation, malignancies.**

I. INTRODUCTION

Liver is a place where the cancerous cells develop. Abnormal growth of the tissues in the body is called Primary growth and metastatic malignancies. Medical field uses surgery for the treatment of the cancer. Many patients not suggested for the surgical resection due to certain condition such as tumor size, position of the tumor [1]. Hence recently many researchers and scientists are developing the invasive techniques. The one technique for removing cancer affected tumors from healthy, not affected tissue is by heating. The cancer cells are removed by heating the tissues to a very high temperature.

The Electric Currents interface uses the electric field equations and this model uses bio-heat equation has been explained in [2]. This models the temperature field equations in the tissue. The resultant heat source from the electric field is also called as Joule heating or resistive heating. This method of medical procedure removes the tumorous tissue by heating it above 45 °C to 50 °C.A heat source is used by the physicians. This process involves the insertion of the micro sized electric probe has explained in [3]. The probe is made of a trocar (the main rod) and four electrode armsas shown in Figure 1. The trocar is modeled such that it is electrically insulated except near the electrode arms. An electric current through the probe creates an electric field in the tissue has been explained in [3]. The electric field is strongest in the immediate vicinity of the probe and creates resistive heating, which dominates around the probe's electrode arms because of the strong

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electric field.
The model analyses the body tissue with a cylinder structure. The assumed boundary temperature is 37°C. The tumor and tissue both has same thermal properties. The model shows the probe along the cylinder's center line such that its electrodes span the region where the tumor is located. A large blood vessel is also present in the simulation process. Current electric probe designs are simple, using probe tip temperature, impedance as control parameters. Thermal heating of tissues depends on factors such as ablation duration, mode of ablation (temperature controlled), hepatic material properties, tumor location, and the ablation probe geometry. The factors such as inefficient probe design, overheating, or placement of tissues contribute to imperfect destruction of tumor affected cells.

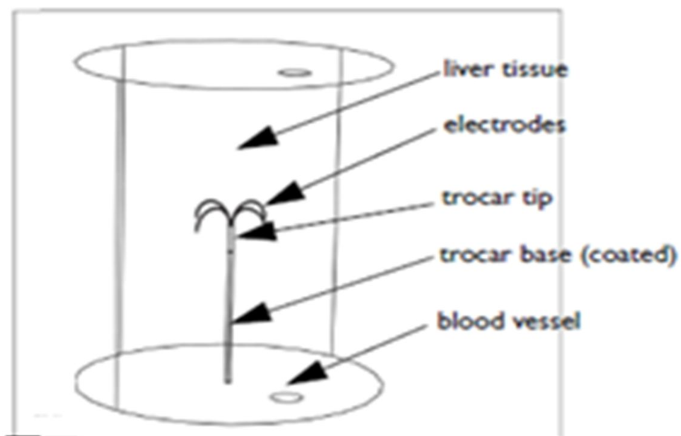

Figure1. The model geometry consists of electric probe which is four armed, which is present nearer to the lager blood vessel.

II. METHODOLOGY

In this paper, the designing of hepatic ablation model uses the FEM methodology. FEM basically modeled to analyze the electric field, rate of specific absorption, and the temperature distribution.FEM models of electric probes to understand how current flows from probe to surrounding liver tissue. Figure 1 shows the geometry of the probe modeled.

A. Heat Transfer

Heat transfer means that the mechanism by which electric current induces tissue injury is the conversion of electric energy into heat. The circuit includes the current generator, the joining wire to the distal electrodes, liver (the abdomen may contain the other tissues), a surface dispersive electrode, and the connecting wires to the generator that will complete the electric circuit. The bio-heat equation holds good for heat transfer in the tissue is given in equation (1).

$$\delta_{ts}\rho C(\frac{\partial T}{/\partial t}) + \nabla.(-k\nabla T)=\rho_b C_b \omega_b (T_b-T) +Q_{met}+Q_{ext} \ldots\ldots (1)$$

Where δ_{ts} is a time-scaling coefficient
ρ is the tissue density (kg/m3)
C is the tissue's specific heat (J/(kg·K))
and*k* is its thermal conductivity (W/(m·K))
On the right side of the equality, ρ_b gives the blood's density (kg/m3)
C_b is the blood's specific heat (J/ (kg·K))
ω_b is its perfusion rate (1/s)
T_b is the arterial blood temperature (K)
whileQ_{met} and Q_{ext} are the heat sources from metabolism and spatial heating, respectively (W/m3).

In this model, the bio-heat equation also models heat transfer in various parts of the probe with the appropriate values for the specific heat, C(J/ (kg·K)), and thermal conductivity, k(W/ (m·K)). For these parts, all terms on the right-hand side are zero.
In addition to the heat transfer equation this model provides a calculation of the tissue damage integral. This will give an idea about the degree of tissue injury α during the process, based on the Arrhenius equation:

$$\frac{da}{dt}=Ae^{\frac{-dE}{RT}} \quad \ldots\ldots\ldots. (2)$$

B. Material Properties

The materials used to design the model and their property for solving bio-heat equation is mentioned in the following table.

TABLE 1:MATERIAL ELECTRICAL AND THERMAL PROPERTIES USED IN THE FINITE ELEMENT METHOD

MATERIALS	**PROPERTIES**			
	Electrical conductivity (s/m)	Heat capacity at constant pressure(J/(kg·K))	Thermal conductivity (W/(m·K))	Density (kg/m³)
Liver tissue	0.33	3600	0.512	1060
Blood vessel	0.667	4180	0.543	1000
Electrode	1e8	840	18	6450
Trocar	4e6	132	71	21500
Trocar Base	1e-5	1045	0.026	70

C. Software

We use COMSOL MULTIPHYSICS version 5.0 to preprocess our FEM model. The geometric model is created by using COMSOL.It is used to assigns material properties. We can also model the geometry using COMSOL. COMSOL helps in testing of various geometrical and physical characteristics the design.the flexible nature of the COMSOL environment facilitates further analyses the geometry.

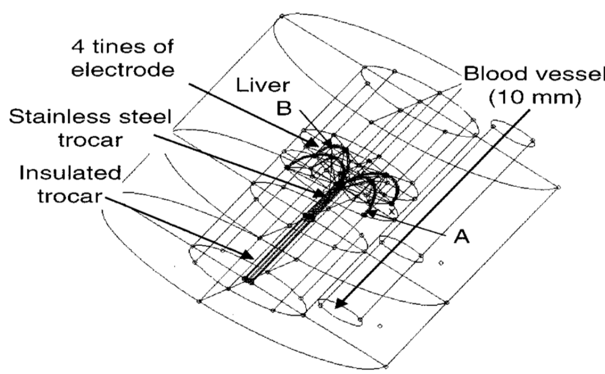

Figure2. FEM Model For Hepatic Ablation .Probe Is Fully Arranged In The Liver And A Single 10-Mm Blood Vessel Is Located 5 Mm To The Right Of 'A' Electrode

III. RESULTS

A. Temperature distribution after 60 seconds

The cross-sectional temperature distribution after 1 min, 90°C ablation in uniform hepatic tissue is shown in figure 3(a). The symmetric temperature distribution is observed between the two sides of the probe. The places for the highest temperatures, or the "hot spots" were adjacent to electrodes.

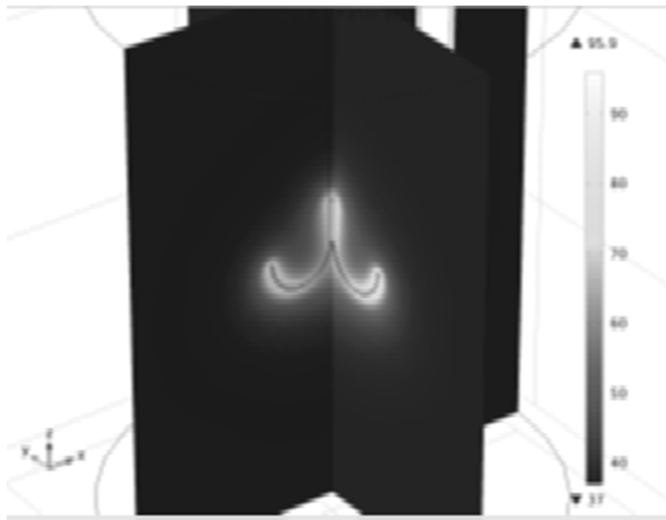

Figure 3(A). Temperature Field At 60 Seconds

B. Fraction of necrotic tissues after 8min at 50°C

The temperature distribution of the 2-D bifurcated blood vessel after 8 min, 90° C, and hepatic ablation are shown inFigure. 3(b). The temperature distribution in this model was highly non-uniform. The location of the hot spot was next to the tip of electrode. As earlier discussed, the location of the hot spot is highly dependent on the distance between electrode and vessel. Since this is a 2-D model, the temperatures in areas underneath the electrodes were likely underestimated. However, it is evident from the Fig. 3(b) that hepatic ablation under a complex vascular system has a potential to cause incomplete destruction of tumor cells.

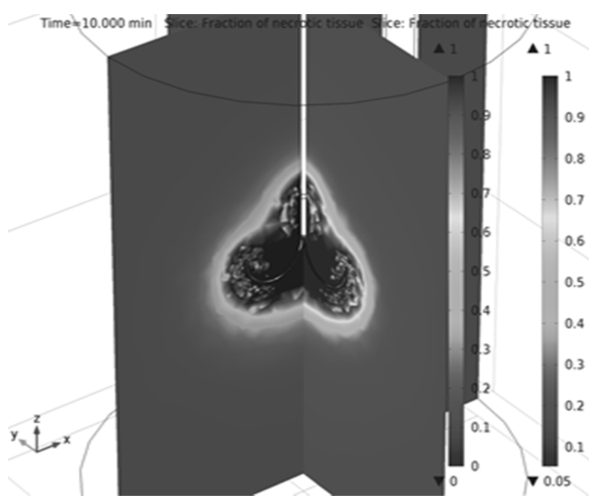

Figure.3(b). Temperature field at 60 seconds

C. Point Graph of Fraction Becrotic Tissue

Finally, Figure 3(c) shows the fraction of necrotic tissue at three different points above the electrode arm. Here we may observe that necrosis occurs faster next to the electrode and the trocar tip. Blue line indicates higher rate of tumor cells in the liver. Green line indicates more than 10% of tumor cells are destroyed in the liver. Red line indicates low rate of tumor cells after 8_min. Ablation at 50 degree Celsius.

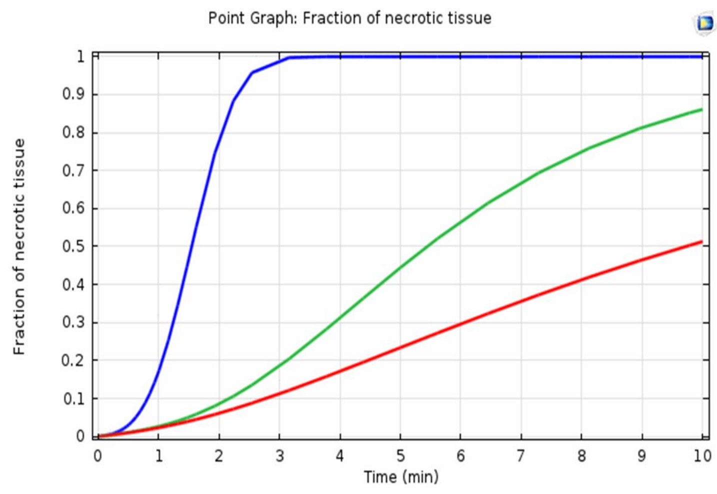

Figure 3(c). Fraction of necrotic tissues at three points above the electrode arm

IV. CONCLUSION

Modeling and simulation of the hepatic tumor ablation is analyzed by traditional four-tine electric probe. The little amount of loss is due to heating of the affected tissue, which is nearer to the large blood vessel. The blood vessels has a very high Electrical conductivity, this is due to joule effect. Here the blood vessel is a heat sink and temperature scatters with the neighbor tissue. The temperature of 50°C and duration of 8 min are used for simulation. The highest value of the tissue temperature observed next to electrode A, during this process the distance from blood vessel and electrode is 5 mm. similarly if distance is 1mm then hot spot observed nearer to the electrode but opposite side. It's a non-invasive method of treating the liver cancer.

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