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Kill Cancer Tumour Cells Using Radio-frequency Ablation

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Abstract - Radiofrequency ablation is the most commonly used percutaneous ablation technique and well-documented in the literature on focal therapies. It has become the image-guided ablation method of choice because of its efficacy, safety, and ease of use. Radiofrequency ablation has shown promise in treating selected solid tumors, particularly those involving the liver, kidneys, lungs, and the musculoskeletal system. It is a minimally invasive technique often used in inoperable patients with other comorbidities. Radiofrequency ablation requires a minimal hospital stay or can be performed on an outpatient basis. The trocar design in this paper has smaller size of electrodes and does not affect the health tissue nearby the electrode. This is achieved because of the electrode shapes which cure volume of 12 mm.

Key Words: **RF Ablation, FEM, Liver, Trocar, Blood Vessel, 2D, 3D.**

1. INTRODUCTION

In last decade, there has been a rapid advancement in the utilization of percutaneous, image-guided tumor ablation methods. Radiofrequency (RF) ablation has become the method of choice because of its safety and efficacy. Image-guided RF ablation is minimally invasive and usually appropriate for inoperable patients with other comorbidities. It requires a minimal hospital stay or can be performed on an outpatient basis. This paper present a heating device to get a significant temperature by inserting a four armed electric rod and electric current is passed through it. Equations for the electric field for this technique shows in the Electric Potential section and which is coupled to the bio-heat equation which are used to analyze the temperature variation in the tissue. The heat source generating from the electric field is also called as resistive heating or Joule heating. The COMSOL Multi-physics model provides the RF heating energy with DC currents. Temperature above 45°C to 50°C is the least significant temperature required to start the killing of the tumor tissue [3]. The treatment needs a local heat source, which physicians create by inserting a small electric rod [4]. Liver tissue boiling and charring act as electrical insulators and limit the effect of RFA through increased resistance. The important liver tissue properties for RFA are electrical and thermal conductivity [4]. Radio-frequency ablation is also reasonable by the heat-sink effect, a process that occurs when thermal energy is scatters from the target wound due to blood flow in the blood vessels adjacent to it [5]. Consequently, the shape and size of the ablation zone may be unpredictable and the efficiency of RFA may be restricted as multiple sessions are necessary for complete tumour eradication [6]. In order to attain larger necrosis volumes, numerous innovative electrode modifications are applied such as expandable electrodes or internally cooled electrodes as well as multiple electrodes. The result is ablation zones of lesions up to 2-5 mm. A margin of 0.5-1.0 mm of healthy liver tissue is mandatory to be ablated in order to secure treatment of the peripheral tumour, including any microscopic extension beyond the radio graphically visible margins [7]. The proposed rod is made of a trocar (the main rod) attached to the four electrode arms as shown in figure 1[8]. The trocar is made up of electrically insulated steel except near the electrode arms as named called rod tip. An electric field in the tissue is created by the electric current provided in the rod. Around the rod electric field generated by joule's heating have maximum value and decrease when calculated far from the electric rod.

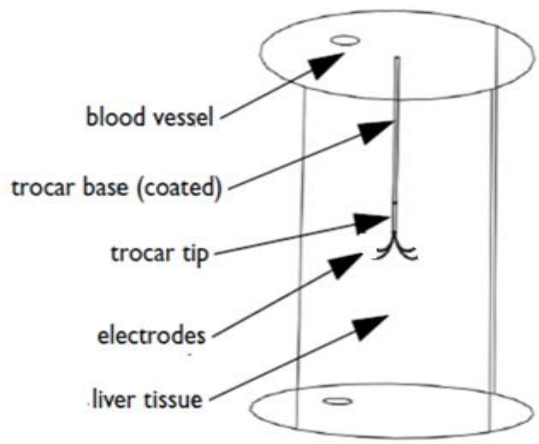

Figure 1: Cylindrical Liver Design [8].

2. MODEL DISCRIPTION

The Bioheat physics, the Electric Currents physics, multiphysics feature and Electromagnetic Heat Source to apply a transient analysis is used in the model. Kelvin (K) is the predefined temperature unit in COMSOL Multiphysics. The model designed uses the Celsius temperature unit, which is convenient for the bioheat equation. The model approximates the liver tissue with a large cylinder and having its temperature constant at 37 °C for the entire procedure. The tumor is to be found near the center of the liver and has the same thermal properties as the nearby tissue. The proposed model locates the rod along the cylinder's center line such that its electrodes distance the region where the tumor is located. The geometry also includes a large blood vane.

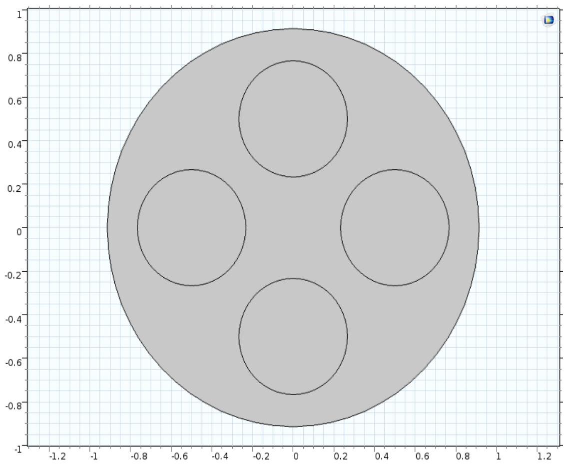

Figure 2: Basic Geometry of trocar tip.

The rod is made of a trocar attached with four electrode arms. The main rod has a radius of 1 mm and the four electrode arms has a radius of 0.25 mm. Blood vain has a radius of 5mm can see in figure 2.

Table 1: Material Properties.

Electrode Properties (Titanium Alloy)	
Electrical Conductivity	6.7e8 (S/m)
Thermal Conductivity	18 (W/m.K)
Trocar Tip Properties (Conducting Steel)	
Electrical Conductivity	4e6 (S/m)
Thermal Conductivity	71 (W/m.K)
Trocar Properties (Insulating Steel)	
Electrical Conductivity	1e-5 (S/m)
Thermal Conductivity	0.026 (W/m.K)

Material properties are described in the table 1. Four electrodes are made up of titanium alloy which is good electrical conductor, trocar tip is made up of conducting steel which is good thermal conductor and trocar main rod made up of insulating trocar.

The electrodes arms are reveled in figure 3to increase the effect of heating or we can say to produce thermal heating in larger radius. The torous tip is of 10 mm height and complete rod is of 70 mm long.

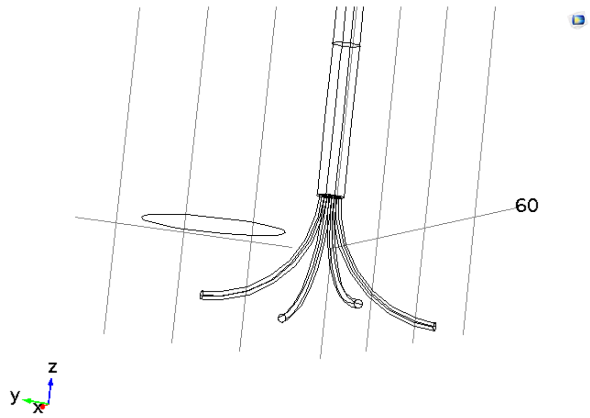

Figure 3: Revolvery Rods.

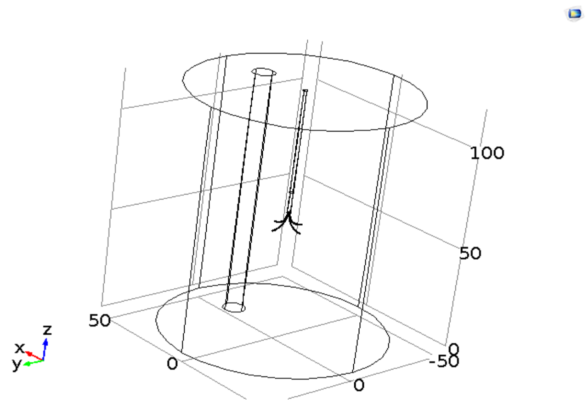

Figure 4: Complete Geometry.

The complete Geometry is shown in figure 4 with blood vain designed model.

3. RESULTS

There are mainly three parameters which are studied in this paper are electric potential, temperature and cancer cell die.

ELECTRIC POTENTIAL

The governing equation for the Electric Currents interface is

$$-\nabla.(\sigma \nabla V - J^e) = Q_j \quad (1)$$

Where V is the potential (V), σ the electrical conductivity (S/m), **J**e an externally generated current density (A/m2), *Qj*the current source (A/m3). In this model both **J**e and *Qj*are zero. The governing equation therefore simplifies into:

$$-\nabla.(\sigma \nabla V) = 0 \quad (2)$$

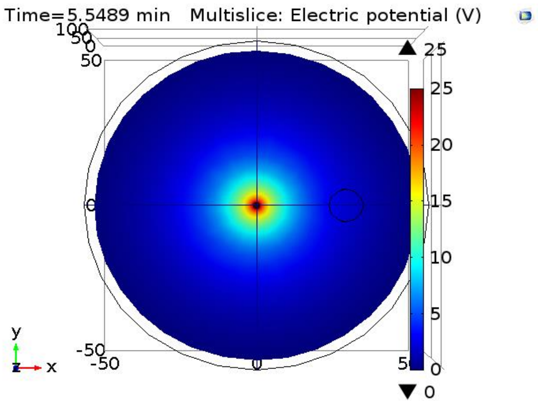

Figure 5: Electric Potential in 2D.

The cross like shape at the center of the figure 5shows the four electrode of trocar red color has the maximum voltage, blue color has zero potential. Figure 6 shows the applied electric potential the electrodes has the maximum potential of 25V. As we go away from the electrode, the electrode potential decreases.

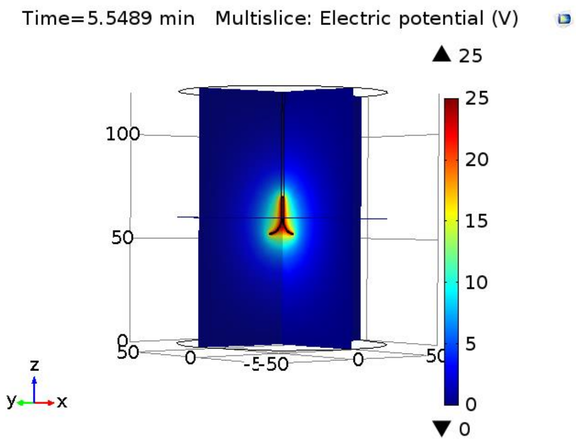

Figure 6: Electric Potential 3D.

- **TEMPERATURE**

The heat transfer in electrode and trocar tip is given by equation below.

$$\delta_{ts}\rho C\frac{\partial T}{\partial t}+\nabla.(-k\nabla T) = \rho_b C_b \omega_b (T_b - T) + Q_{met} + Q_{ext} \quad (3)$$

Here it is a time-scaling coefficient; ρ is the tissue density (kg/m^3); *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, ρb gives the blood's density (kg/m^3); *C*b is the blood's specific heat (J/(kg·K)); ωb is its perfusion rate (1/s); *T*b is the arterial blood temperature (K); while *Q*met and *Q*ext are the heat sources from metabolism and spatial heating, respectively (W/m^3).The bioheat 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. The figure 7 shows how the temperature increases with time in the tissue around the electrode. The slice plot illustrates the temperature field 60 seconds after starting the procedure. The maximum temperate achieved in 60 sec is 101 ^{0}C, which is shown at the edges of electrode tip and the trocar tip shown by yellow color.

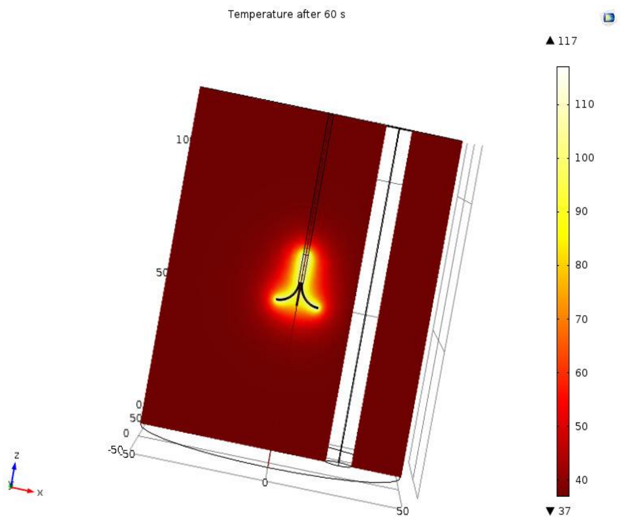

Figure 7: Temperature Effect.

The temperature at the tip of one of the electrode arms is shown in figure 8. The temperature rises quickly until it reaches a steady-state temperature of about 105 °C, That can be achieved in less than in one half a minute and it becomes constant 110^{0}C in 3 minutes.

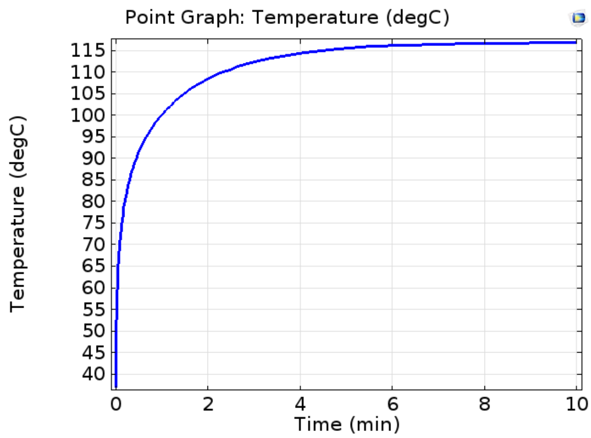

Figure 8: Temperature Vs Time.

- **CANCER CELLS DIE**

It is also interesting to visualize the region where cancer cells die, that is, where the temperature has reached at least

50 °C. You can visualize this area with an area for that temperature in figure 9 shows one after 10 minutes.

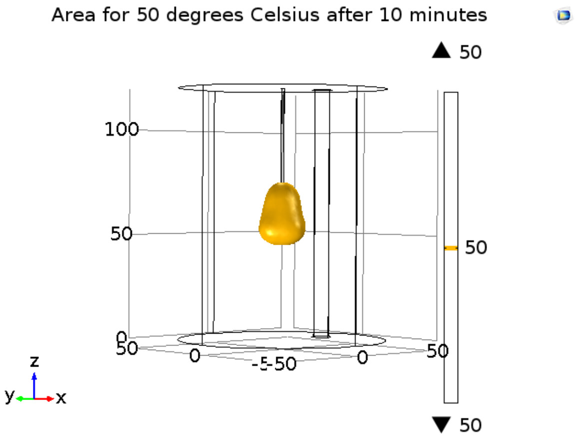

Figure 9: Died Cancer Cell.

Figure 10 visualize the fraction of necrotic tissue after the process is completed.

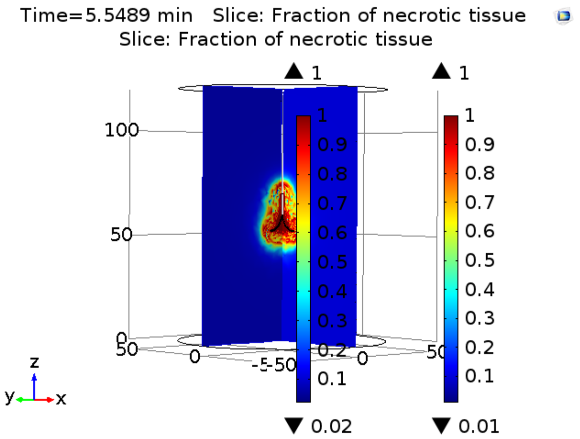

Figure 10: Necrotic Tissue.

Finally, figure 11 shows the fraction of necrotic tissue at five different points above the electrode arm i.e. 4mm in blue, 8 mm in green,12 mm in red, 16 mm in sky blue and 20mm in pink. Trocar is inserted into the centre of the tumor. We observe that necrosis happens faster next to the electrode and the trocar tip. Cancer cell die in 3 minutes till distance 4 mm from the trocar and at 8 mm distance it will be cured in 9 minutes.

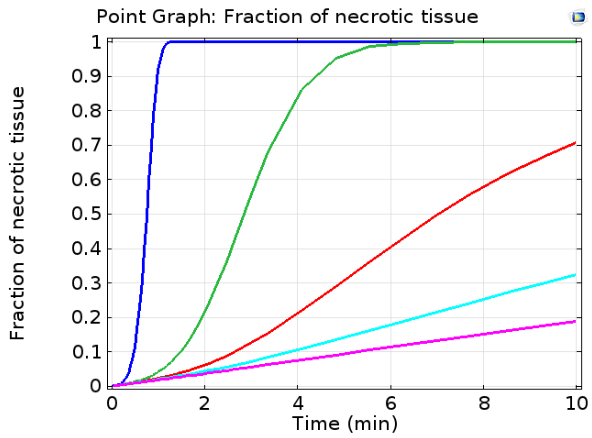

Figure 11: Necrotic Tissue at Five Different Points.

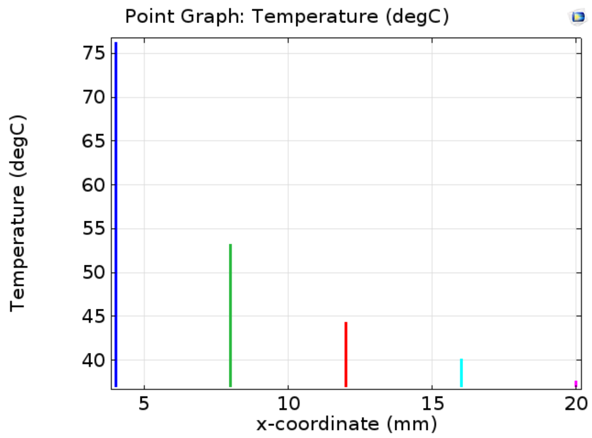

Figure 12: Temperature Vs Distance from Trocar.

Temperature required to cure tumor is to be more than 46 ^{0}C, so this temperature is achieved till 12 mm distance from the tumor after that the temperature is less than the significant temperature. It can be said that tumor of 24 mm diameter can be cured by this device within 9 minutes.

4 CONCLUSION

In RFA, an electrical current in the radio-frequency range is delivered through a needle electrode under imaging or surgical guidance, producing heat-based thermal heating. A complete electrical-thermal design is created and simulated through comsol. Temperatures range between 50 °C to 110 °C and results are obtained accurate and better to the previous results that goes maximum till 85 ^{0}C. These temperatures are observed near the electrode resulting in a small area of necrosis, with the larger portion of the final ablation zone being attributed to thermal conduction into more peripheral areas around the electrode. The time taken by the proposed geometry to reach 50^0 C in just 1 sec and can cure tumor of 8mm diameter in 2 minutes. Design does not affect the tissues nearby and also has smaller size of electrode. This is achieved because of the electrode shapes which cure volume of 12 mm.

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