

Targeted Radiation Dipole Antenna using 3D Numerical Simulation in Microwave Ablation

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Abstract: Microwave ablation technology is being utilised in several medical applications for ablation therapy and other applications. Microwave energy generates fast and high temperatures sufficient and capable to produce coagulation necrosis. Theoretical models by numerical simulation of microwave ablation is a distinct step in the implementation of system design, as well as in the results analysis before the ablation procedure. Furthermore, these models play a role in design the microwave antennas. Classic microwave ablation antenna around its radiating section applies electromagnetic field in tumors without worry about near neural structures. This paper presents the temperature distributions of targeted radiation dipole antenna model with active and non-active sides for microwave ablation at 2.45GHz at different powers and ablation times. Temperature maps and SAR distributions around the radiating section show in two sides.

1 INTRODUCTION

Thermal ablation technology is an alternative to surgical resection for destruction of several types of tumors. Thermal ablations could be using many energy sources, including laser, high intensity focused ultrasound, radiofrequency and microwave. While radiofrequency has been the most applied in clinical thermal ablation, microwave ablation has several advantages including, faster heating of large tumors, less susceptibility to heat-sink effect and no ground pads requirement.

Efficiency of minimally invasive percutaneous thermal microwave ablation (MWA) has been proved in treating several types of tumor including the liver, lung, kidney (Kuang et al. 2007; Wolf et al. 2008; Castle, Salas, and Leveillee 2011) and recently bone (Kastler et al. 2013; Kastler et al. 2014). The phenomenon of denaturation is induced by tissue temperature rising above 50°C which causes coagulation and cells death in a matter of minutes (Brace 2009).

Several coaxial-based antenna have been designed for microwave ablation including the slot antenna (Ito et al. 2004), dipole antenna (Hurter, Reinbold, and Lorenz 1991), monopole antenna (Labonte et al. 1996), cap-choke antenna (Lin and

Wang 1996), floating sleeve antenna (Yang et al. 2006), triaxial antenna (Brace et al. 2007), and minimally invasive antenna (Cavagnaro et al. 2011).

Clinical application and several microwave ablation devices have been reviewed in (Lubner et al. 2010). Microwave energy at 915MHz or 2.45GHz induces a phenomenon known as dielectric hysteresis to create heat generation (rotation of water, proteins and other polar molecules in tissues).

Computational simulation using commercial software (HFSS or COMSOL..) have been used to predict the electromagnetic fields from the antenna, temperature profile in tissue, and to integrate electromagnetic and thermal solutions for understanding how the ablation zones form (Chiang, Wang, and Brace 2013).

Some tumors may be located in proximity of neural noble structures which may be damaged by the ablation process (nerves, vessels, biliary ducts...). Therefore, in this paper, we design and simulate a coaxial antenna with directive radiation by varying the directive windows angle during the ablation. The analyses were performed by 3D finite element modelling. In order to compare the results in terms of power and application time, we have used a tissue temperature distribution model. The targeted radiation in MWA has been presented in (Thaiwat et al. 2011) for slot antenna in different open angles

without however discussing lesion radius in the active and non active side.

2 ANTENNA GEOMETRY

2.1 Structure

The goal was to design a coaxial antenna to realize direction ablation on one side of antenna and prevent it on the other side. The configuration and dimensions of antenna geometry are presented in Fig.1 and Table 1. To design our model, we chose the coaxial dipole antenna model presented by yang (Yang et al. 2006) without the sleeve as initial antenna. We also were partly inspired by the work presented in ("DIRECTIVE WINDOW ABLATION ANTENNA WITH DIELECTRIC LOADING - Patent - Europe PubMed Central" 2014). We have inserted our antenna in a catheter with a dielectric window at different lengths and angles opening. i.e. 8mm length and 300° angle. Our original idea was to block the microwave energy by a metal catheter in order to guide the wave to the desired directional window for targeted tumoral ablating purposes.

We designed this model using Comsol 4.3 computer simulation for temperature distribution around the antenna tip on two opposite sides (active window side and non active side).

The model supposes that antenna is inserted in a homogeneous liver block with diameter 50mm and length 60mm. The dielectric insulator between inner and outer conductors is Teflon with relative permittivity equal to 2.03, and the dielectric window is Ceramic with relative permittivity equal to 10 as depicted in Fig. 2.

The parameters of material for the antenna and liver are shown in Table 2. The liver parameters are chosen in the static state without thermal effects on the dielectric properties of tissue. All dielectric properties value were taken from literatures published static values.

2.2 Materials and Equations

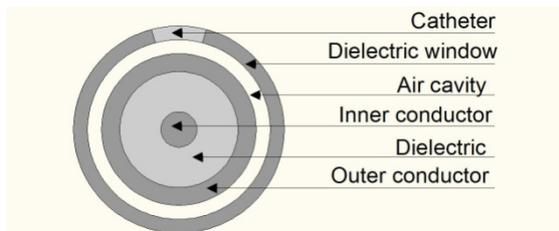


Figure 1: Antenna top section with layers.

To simplify the design, all the conductors material of the antenna were modelled using perfect electric conductor (PEF) boundary conditions. The microwave energy was chosen at 2.45GHz and between power range 0-70W, with ablation duration 900 seconds.

We performed the simulation using the Finite Element Method (FEM) Comsol 4.3 to solve our Electromagnetic-Thermal problems. The mesh was non uniform. A three dimension model was chosen on platform Intel(R) Core(TM)2 Duo CPU P8400 @ 2.26 GHz with RAM 4 GB.

The bioheat equation is represented in (1):

$$\rho C \frac{\partial T}{\partial t} + \nabla \cdot (-K \nabla T) = h_b (T_b - T) + Q_m + Q_{ext} \quad (1)$$

ρ Density of liver (kg/m^3), C Heat capacity of liver (J/kgK), K Thermal conductivity (W/mK), T Temperature ($^{\circ}\text{C}$), T_b Temperature of blood ($^{\circ}\text{C}$), h_b The convective heat transfer coefficient, Q_m Energy from metabolic processes (W/m^3), Q_{ext} External heat source (W/m^3) (2).

Since Q_m is negligible, we excluded it from our FE models. We also omitted T_b from our preliminary studies. The Specific Absorption Rate SAR [W/kg] in tissue is calculated as a function of position as follows (3):

$$Q_{ext} = \sigma E^2 [\text{W}/\text{m}^3] \quad (1)$$

$$\text{SAR} = \sigma E^2 / 2\rho [\text{W}/\text{kg}] \quad (2)$$

E Electric field (V/m), σ Conductivity of liver (s/m).

Table 1: Radius of antenna layers.

Layer	Radius(mm)
Inner Conductor	0.256
Dielectric	0.84
Outer Conductor	1.1
Air Cavity	1.3
Catheter	1.5

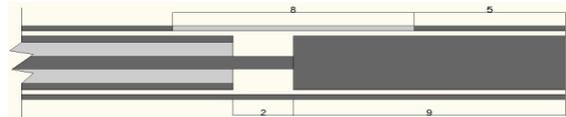


Figure 2: Antenna side section in a liver block.

3 SIMULATION RESULTS

3D Temperature distributions are shown in Fig.3 from active side section at different powers and after

different application times we chose the temperature level equal to 100°C.

The simulated lesion size is defined as the area within the 50°C contour line, which corresponds to actual ablation size. The Fig. 4 presents the temperature distributions on active and opposite non active sides of antenna tip at different powers after 900s and including contour 50°C. We can see non-spherical lesion form around the antenna. These lesions are in proportion with the power and application time increase.

The temperature changes from active side and opposite non active side at 10mm from antenna axis at 0,300,600,900s and for powers 50, 60, 70W are shown in Fig. 5. We see higher temperature level at window side than the other side and the radius increasing of lesion with the long duration of ablation.

Table 2: Parameters of tissues.

Properties	Values
ρ (density of liver)	1060(kg/m ³)
C_p (Heat capacity of liver)	3600(J/kgk)
K(Thermal conductivity of liver)	0.56(W/mK)
ρ_b (density of Blood)	1000(kg/m ³)
C_b (Heat capacity of liver)	3639(J/kgk)
σ_{liver} (Conductivity of liver)	1.69(S/m)
ϵ_{liver} (Permittivity of liver)	43.3
$\epsilon_{dielectric}$ (Permittivity of dielectric)	2.03

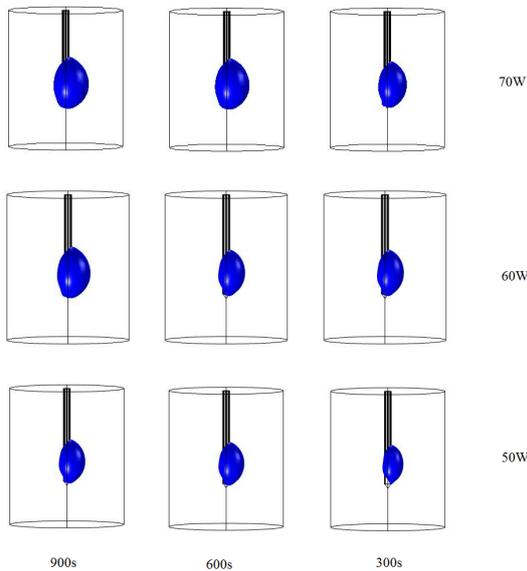


Figure 3: three dimensions Temperature distributions from top to down 70,60,50w and from left to right 900,600,300s.

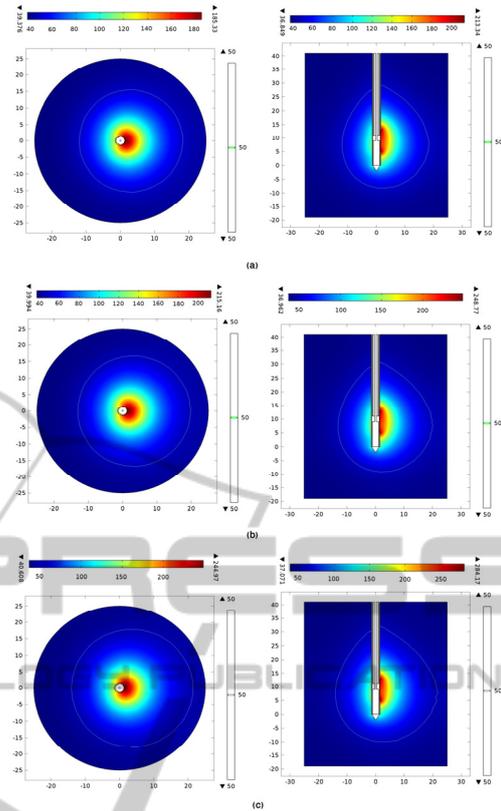


Figure 4: Temperature distribution (a) 50W,(b) 60W,(c) 70W for 900s, 2 views.

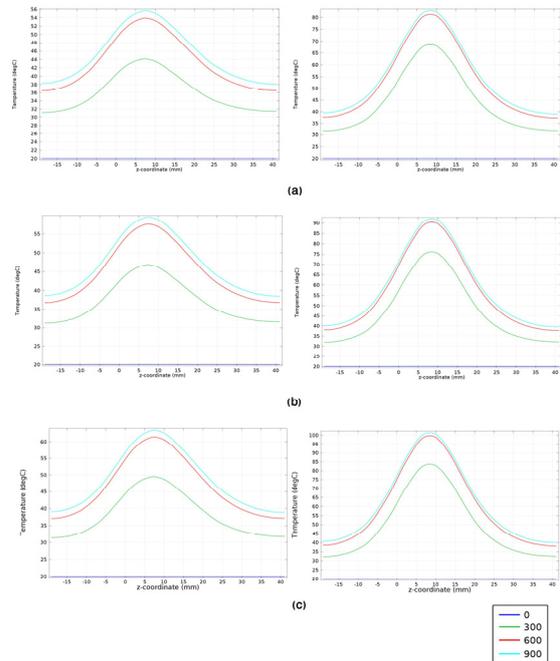


Figure 5: Temperature value left, non active side right active side (a)50W,(b)60W,(c)70W and ablation times (300,600,900s).

The temperature value increases with power increases, and we see higher temperature peaks on the active side comparing to the non active side.

Fig. 6 shows the SAR values along the longitudinal direction for the non active side (green) and active side (blue) of antenna in the lesion regions. SAR values indicate there are differences between the two sides and these values are constrained.

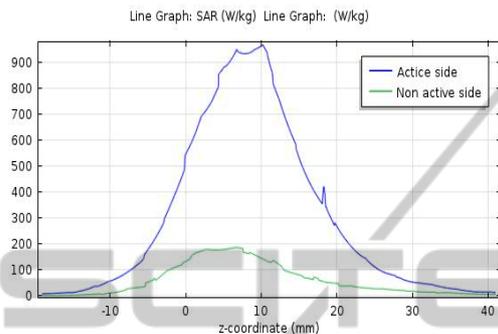


Figure 6: SAR values non active side (green) , active side (blue).

4 DISCUSSION AND CONCLUSIONS

In this study we designed a novel dipole antenna inserted in an asymmetric metallic catheter with a dielectric window. We tested the simulation of this MW ablation antenna achieving a directional ablation in liver model by using a 3D Finite Elements Method (FEM) which analyses the temperature distribution. We chose a dipole antenna because with 3mm diameter allowing high power delivery and large lesion size. A metal catheter was chosen for two goals: First to guide the generated electromagnetic waves to the dielectric window, Second: to obtain an air cavity through which water may be circulated for cooling purpose and to prevent backward heating.

Increasing power application times from 600 to 900s did not significantly contribute to temperature induced changes, nor did it affect lesion radius on both active and non active side.

The antenna we elaborated can selectively ablate tissue on the active side. The lesion size on active side can be controlled by increasing power and ablation duration until 600s.

The disadvantage of our antenna is the relatively large diameter 3mm, however still compatible for percutaneous bone or laparoscopic microwave ablation.

In this work dipole antenna model radiates a directive electromagnetic field, the goal is to achieve a selective ablation while avoiding damaging the healthy tissue structures near targeted tumour. According to temperature values and SAR distributions levels between active side and non active-side show promising results in targeted ablation.

These simulation results are considered as a first step before implementation of our device. May be more computational modeling and experimental searches are needed to understand the dielectric and thermal tissue properties, as well as to increase the lesion size.

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