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3D FINITE ELEMENT ANALYSIS FOR NON-ASYMMETRY STRUCTURE ANTENNA FOR MICROWAVE ABLATION THERAPY

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Abstract. This paper presents analysis of non-asymmetry antenna configuration for microwave ablation at 2450 MHz using three-dimensional finite element analyses. Treatment of hepatic cancer often requires removal or destruction. Using coaxial-slot antenna is opened slot at one-side of antenna. We study the characteristics of various slot size and various power for non-asymmetry structure antenna to observe temperature distributions and SAR. The results illustrate that the coaxial-slot non-asymmetry structure antenna can be used in microwave ablation for destruction of the cancer cell in the area closed to the very fragile tissue or blood vessel.

Keywords: microwave ablation, finite element analysis, hepatic ablation, etc.

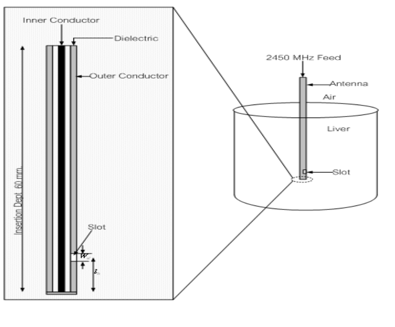
1. Introduction

In hyperthermic oncology, cancer is treated by applying localized heating to the tumor tissue, often in combination with chemotherapy or radiotherapy. Some of the challenges associated with the selective heating of deep-seated tumors without damaging surrounding tissue are, control of heating power and spatial distribution and design and placement of temperature sensors. Among possible heating techniques, RF and microwave heating have attracted much attention from clinical researchers. Microwave coagulation therapy is one such techniques where a thin microwave antenna is inserted into the tumor. The microwave heats up the tumor, producing a coagulation region where temperature above 50°C is reached and the cancer cells are effectively destroyed.In recent years, various types of medical applications of microwaves have been widely investigated. L. Hamada al. [1] performed an experiment using dipole antenna at 915 MHz, with varying insertion depths, and compared the results with conventional antenna. In 1996 [2] presented new dipole antenna called "Cap-choke antenna" which was used in an experiment at a frequency of 2.45 GHz [3] and 915 GHz [4]. Hurter et al [5] used computer simulation [6] to investigate a new antenna design called "tri-axial chocked dipole antenna" and discovered that it has higher SAR values than dipole antenna and helps reduce the effect of insertion depth .Saito et al [7]. [8] used two coaxial-fed slot coaxial antenna for microwave ablation at 2.45 GHz which resulted in larger lesion sizes than using one coaxial antenna. In this paper, we investigated the coaxial-slot non-asymmetry structure antenna by varying the slots size and varying power. We perform the analyses using 3D finite element modeling. For comparison of the results, we determine the SAR and temperature distributions in tissue generated by the antennas with different slot size.

2. structure of non-asymmetry antenna

TABLE 1
DIMENSIONS AND RELATIVES PERMITTIVITIES
OF THE COAXIAL-SLOT ANTENNA

Inner conductor [mm.]	1.02
Diameter of dielectric [mm.]	3.02
Diameter of outer conductor [mm.]	3.53
Length from the tip to the center of the slot [mm.]	20
Insertion depth [mm.]	50



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Length of antenna [mm.]	60
Width of the slot [mm.]	2
Length of slot [mm.]	2, 4, 6, 8

Fig. 1. Antenna Structure

Fig. 1 and Table 1 we show the configuration and parameters of coaxial-slot non-asymmetry structure antenna used in this study. This structure is the same as [7], [8].

3. Finite Element analysis

The finite element method (FEM) involves dividing a complex geometry into small elements for a system of partial differential equation, evaluated at nodes or edges.

3.1 Bioheat Equation

The bioheat equation below was employed to analyze heat generated from electric energy [9]. We solved the bioheat equation to obtain the thermal distribution in hepatic cancer tissue.

$$\rho C \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T) = \rho_b C_b \omega_b (T_b - T) + Q_{met} + Q_{ex} \quad (1)$$

where

ρ = Density [kg/m^3]
C = Specific heat [$J/kg.K$]
k = Thermal conductivity [$W/m.K$]
J = Current density [A/m^2]
E = Electric field intensity [V/m]
T_{b1} = Temperature of the blood [$°C$]
ρ_{b1} = The blood density [kg/m^3]
C_{b1} = Specific heat of the blood [$J/kg.K$]
ω_{b1} = blood perfusion [$1/s$]
h_{b1} = The convective heat transfer coefficient accounting for blood perfusion in the model
Q_{met} = The energy generated by the metabolic processes [W/m^3]

Since Q_{met} is negligible, we excluded it from our FE models. We also omitted h_{b1} from our preliminary studies.

3.2 SAR Distribution

In order to evaluate the heating ability of the antenna, SAR distribution is widely used. The SAR shows the heat generated by the electric field in the tissue given by

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

where

σ = conductivity of tissue [S/m]
ρ = Density of tissue [kg/m^3]
E = Electric field [V/m]

In this study, we calculate SAR distributions for all cases and compare the results to determine the potential heating patterns of the antennas. The thermal and electrical properties used are from [9]. We can link the volume of SAR to this following heat equation (3) below

$$\rho C \frac{\partial T}{\partial t} + \nabla .(-k \nabla T) = \rho_b C_b \omega_b (T_b - T) + \rho .SAR \qquad (3)$$

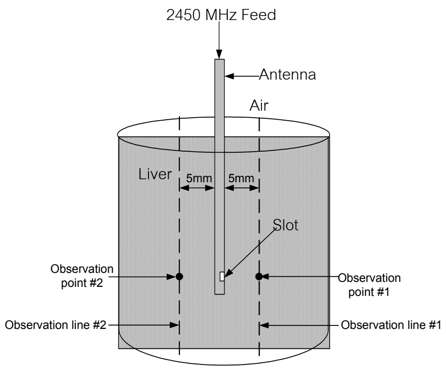
4. Experimental

In this paper, we performed computer simulation using the finite element method. We selected Comsol 3.5a (Comsol Inc., Burlington, MA), to solve our thermal-electrical problems. In process of Finite element method, we used a nonuniform mesh and an three dimension model in this study on the 64 bit Sun Fire 240 operating system (2 processor with Ram 8 GB). The simulation consists of 2 modules:

1) Rf Module
2) Heat Transfer (Bioheat Equation)

It creates the antenna and other components by Solid Work version 2010 emitting in the form of IGS to Comsol Multi-physic Version 3.3a in order that the boundary is put together with other invariants used for simulating the work by requiring that record shall be made every second for 300 seconds. The detail of the parameter of simulation is as follows:

Parameter for simulating the density of tissue = 1050 [kg/m^3], specific heat of Liver = 3700 [$J/kg.K$], density of blood = 1000 [kg/m^3], specific heat of blood = 3639 [$J/kg.K$], blood perfusion rate = $3.6\text{x}10^{-3}$ [$m^3/kg.s$], thermal conductivity of liver = 0.56 [S/m], parameter of electrical properties ε_{liver}(Relative permittivity) = 43.03, δ_{liver}(Electrical Conductivity) [S/m] = 1.69, $\varepsilon_{dielectric}$ = 2.03, $\varepsilon_{insulator}$ = 2.6.



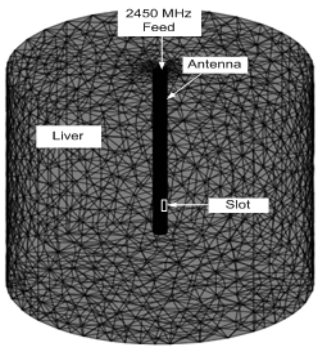


Fig. 2(a). Observation line at 5 mm. and Observation point (b). FEM Model

The Fig. 2(a) shows triangular element with irregular tetrahedra. The number of elements used for simulation is 131,765 approximately, the number of degree of freedom is 947,089 and memory for running is 1,262 MByte approximately.

In Fig 2(b), the distance from the antenna is 5 mm. The Observation Line 1 on the side of slot opening. On the side opposite to the slot opening, the distance of the observation line is 5mm. to observe the SAR volume and the temperature at each level. The Observation Line 1 shows the change of the temperature at the slot opening.

5. Result

The result of the simulation in this article shows the result of the simulation by the 3 dimension finite element.

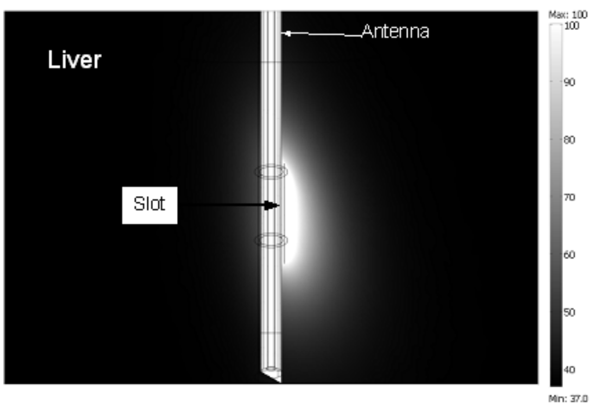
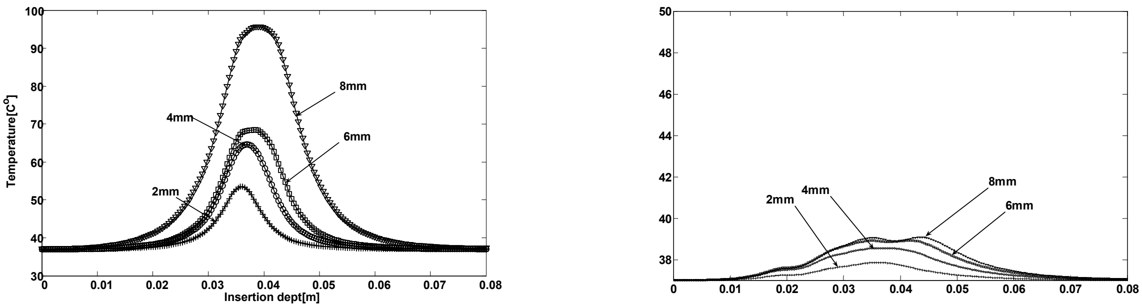


Fig. 3. Distribution of Temperature at the Liver Tissue

In Fig. 3 shows the distribution of the liver tissue whose maximum width is 0.356 mm. and the maximum length is 4.123 mm.

The Fig. 3 and the graph in the Fig. 4 show the temperature at various levels of the tissue. The Fig. 3 shows that the temperature at the slot is higher than at other areas. The Fig. 4(a) shows the temperature at various levels of depth. The temperature at the depth of 0.03 – 0.04 meter is higher than at other levels of depth of the antenna since it is the level of the antenna slot and the longer slot will cause higher temperature.



(a) (b)

Fig. 4 A graph showing the distribution of the temperature at the liver tissue with various levels of depth of the Observation Line No. 1(a) and No.2(b) at the distance of 5 mm. from the antenna;

The Fig. 4(b) shows the temperature at various depths. At the Observation Line No. 2 at the opposite side of the slot opening, the temperature is very low, whereas the temperature at the depth of the slot is slightly higher than at other levels. The difference between the antenna with the largest slot and that with the smallest slot is 4°C, which is very low.

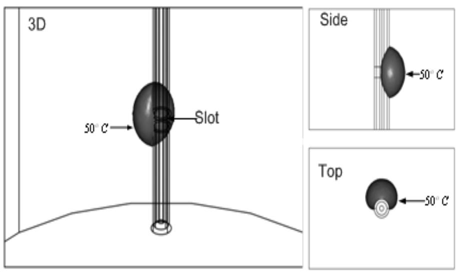
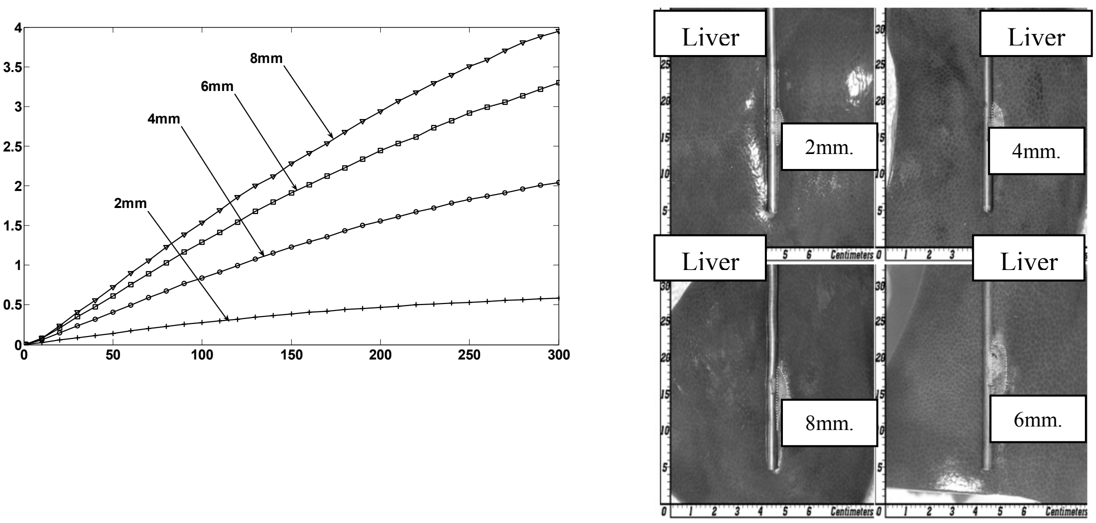


Fig. 5. 3D Temperature Distribution in Liver Tissue

This Fig. 5 shows 3-dimension image of the cancer cell destruction at 50°C and over. The destruction starts at this level of the temperature. 50-watt power is supplied to the slot coaxial non-asymmetry antenna with 2mm. slot at 60 seconds. The volume is 0.172707 cm3. The simulation time is 946.25 seconds and the used memory unit is 1823 MB.



(a) (b)

Fig. 6. (a) Changes in the volume of the cancer cell destruction at 50°C and over; (b) *Ex* Vivo Experiments and Results

This Fig. 10 shows the changes in volume of the cancer cell destruction in the tissue at 50°C and over from the beginning to 300 seconds with the record made every 10 second. The graph shows time of the changes in the volume in the horizontal line and the volume (cm^3) in the vertical line. The 50 watt power is consistently supplied to the antenna with 2mm, 4mm, 6mm and 8mm-width slot.

The change in the volume of the antenna with 8mm.-width slot is higher than that with smaller slot. At the point of 300 seconds, the volume of the antenna with 8mm slot is 8 times higher than the antenna with 2 mm. slot. According to the simulation with changes in the slot size, it is found that the antenna with larger coaxial non-asymmetric slot provides with higher volume of destruction at 50°C than the antenna with smaller slot.

6. conclusions

The antennas to be presented are the slot coaxial non-asymmetry whose remarkable characteristic is to cause one-sided heat when the slot is opened. The maximum temperature and the SAR is caused on the one-sided slot. When the length of the slot is changed, the temperature is also changed and the volume of the cancer cell destruction is also higher with no change in power supplied to the antenna. When the power supplied to the antenna is increased, the temperature is also increased. The slot coaxial non-symmetry structure antenna can be used in MCT system which is for destruction of the cancer cell in the area closed to the very fragile tissue.

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