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COMPARISON OF SINGLE SLOT AND DOUBLE SLOT ANTENNA FOR THE TREATMENT OF HEPATOCELLULAR CARCINOMA

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Abstract

Microwave Ablation (MWA) is the most recent therapy developed in the field of tumor ablation. MWA offers effective treatment of deep-seated and non resectable liver tumors. There are ambiguities, however, concerning the relative contributions of specific and indirect thermal effects. Many advantages of microwave ablation over the other ablative therapies in the field of Hepatocellular Carcinoma (HCC) have driven researchers to develop innovative interstitial microwave antennas. A comparison between coaxial double slot antenna and single slot antenna for microwave ablation therapy is discussed in this research paper. Two dimensional Finite Element Method (FEM) is used to simulate measure and compare the results of both the antennas. The paper represents the comparisons regarding different heating characteristics, temperature distribution pattern and finite element meshing analyses at frequency of 2.45GHz and at a power of 10 Watt.

Keywords- Microwave Ablation (MWA), Finite Element Method (FEM), Slot Antenna, Hepatocellular Carcinoma (HCC).

1. Introduction

Hepatocellular carcinoma accounts for most liver cancers in the world. It is the third most common cause of death from cancer [1]. Options for the treatment include surgical resection, chemotherapy, radiation therapy, liver transplantation and thermal ablation techniques [2] [3]. But all these treatment measures prove to be ineffective as this tumor can reoccur in the patients [4]. Ablative treatments are started to become viable alternative methods to treat patients who cannot be treated through surgery, hepatic resection or any other means as there is high surgical risk, or unfavourable tumor location [5]. Ablation refers to the method of selectively killing a well defined target tissue by the application of heat based (radiofrequency ablation &microwave ablation), cold (cryotherapy), chemicals (precautaneous ethanol injection), or laser hyperthermia techniques directly to a tumor causing cell death. These ablation methods are performed in either open-hepatic operations or minimally invasive precautaneous operations [6] [7].It allows very flexible technique including percutaneous laproscopic and open surgerical access [8]. Microwave frequency of the range 2.45GHz are introduced in the body tissue with the help interstitial antenna. MW antenna generates frictional heat from electromagnetic radiations which produces the agitation in polar water molecules causing them to rapidly change their orientation (as a result of increased kinetic energy) and rise their temperature. This induces cellular death due to coagulation necrosis (heat) at temperatures above 60°C [9] [10]. The short wavelength options of MW as compared to other ablation procedures, directs and focuses the energy into tissues by direct radiation from a small antenna [11]. Most microwave ablation antenna designs are straight and needle-like [12]. Moreover the active heating zone and power coupling efficiency of an antenna is determined by its geometry. Many researchers are doing effort to develop less invasive interstitial antennas for microwave ablation for treating the liver tumor. These antennas are capable of producing highly localized patterns of electromagnetic power deposition in tissue . If the antenna input impedance is not matched to the feed line, too much of applied power is reflected from the antenna and hence not deposited on the tissue. This results in power reflection and energy dissipation within the transmission antenna. Coaxial-based microwave antennas are extremely important for ablation application because of their low cost and small dimensions.

In this paper temperature distribution pattern, heating characteristics and finite element meshing of coaxial double slot as well as single slot antenna has been analyzed and compared at frequency of 2.45GHz and at a power of 10 Watt. Thermal models were simulated by using the heat transfer modelling feature in FEMLAB. COMSOL Multiphysics version 4.2 has been used as primary computer simulation tools.

2. Methods and Models

A Numerical Methods

Finite Element Method (FEM) is a numerical technique can be formulated as functional minimization. It involves dividing a complex geometry into small elements for a system of partial differential equation, evaluated at nodes or edges. The method centred around the formulation of solutions to the fundamental electromagnetic equations collectively referred to as Maxwell's equations. In order to develop accurate models of the ablation process the knowledge of tissue electromagnetic properties like permittivity and conductivity and appropriate initial and boundary conditions are must. The commercial FEM package, COMSOL Multiphysics has been used to simulate the performance of the double slot antenna. When EM waves propagate though the biological materials, the temperature profile in tissue during ablation is obtained by solving a Penne's bioheat equation [13].

$$\rho C\, \partial T/\partial t = k\nabla^2 T - \rho\rho_b C_b F(T-T_b) + \rho SAR$$

where T is the temperature (°C), t is the time (s), ρ is the tissue density (kg/m^3), c is the specific heat capacity (J/kg K), k is the thermal conductivity (W/m K), ρ_b is the density of the blood (kg/m^3), C_b is the specific heat capacity of the blood (J/kg K), T_b is the temperature of the blood (C), and F is the blood flow rate (m /kg s). Biological effects depend on the field in the tissues, i.e. on the specific absorption rate SAR (W/m^3), defined as power deposited in a unit mass of tissue. The SAR can be expressed as the power dissipation rate normalized by material density [14]. It can be shown that:

$$SAR = \sigma/\rho\, E^2 \quad W/kg$$

Where σ is the conductivity of the tissue (S/m), ρ is the density of the tissue (kg/m), and E is the electric field (rms) (V/m) [15].

B Antenna design

The interstitial antenna consists of a micro coaxial cable, to transfer microwave power into liver tissue for the treatment of liver cancer. This antenna has a diameter of 1.79 mm and is enclosed within a catheter made of polytetrafluorethylene for hygienic and guidance purposes. This antenna is composed of an inner conductor, a dielectric and an outer conductor.

Table 1. The relevant geometrical dimensions of the antenna

Diameter of the central conductor	0.29 mm
Inner diameter of the outer conductor	0.94 mm
Outer diameter of the outer conductor	1.19 mm
Diameter of catheter	1.79 mm
Slot	1mm

The slots spacing are chosen based on the effective wavelength (λeff) in tissue at frequency of 2.45 GHz, which is calculated using the following equation:

$$\lambda_{eff} = c/f\sqrt{\varepsilon_r}$$

where c is the speed of light in free space (m/s), f is the operating frequency of the microwave generator (2.45 GHz) and ε_r is the relative permittivity of tissue at the operating frequency (table II). The value of effective wavelength comes out to be 18mm.

Table 2. The properties of liver tissue

Thermal conductivity,liver [W/mK]	0.56
Specific heat,blood [J/kgK]	3639
Density,blood [kg/m3]	1060
Blood perfusion rate[1/s]	.0036
Blood temperature [degC]	37
Relative permittivity, liver	43.03
Electric conductivity, liver [S/m]	1.69
Thermal conductivity, liver [W/(m*K)]	0.56
Relative permittivity, dielectric	2.03
Relative permittivity, catheter	2.6
Input microwave power	10[W]

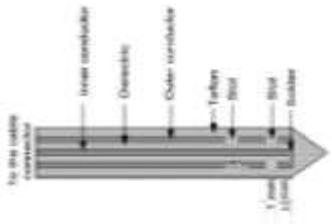

Figure 1. Coaxial slot antenna with single slot

For the double slot microwave antenna, the slot spacing length of 4.5 mm corresponds to 0.25λeff. The slot spacing length is chosen to achieve localized power deposition near the distal tip of the antenna.

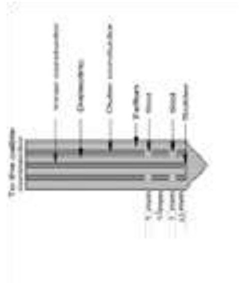

Figure 2. Coaxial Antenna with double slot

This antennae shown in figure 1& 2 are placed 2D axisymmetrically in cylindrical coordinates in the liver tissue. In the electromagnetic wave propagation analysis, a scattering boundary condition is set on that surface, which means that the boundary does not disturb the electromagnetic field distribution. The external surface of the liver tissue acts as boundary for the computational domain and insulating boundary conditions are applied on the edges of the liver domain. The model assumes that the wall of the antenna is a perfect electric conductor, and the dielectric properties of liver tissue have been determined as a function of temperature.

3. Results

After creating the geometrical models, and assigning all the material properties and boundary conditions, in the surface temperature distributions study, the FEM is used to analyze the transient problems. In case of the study of microwave double slot antenna in the treatment of liver tumor ablation the power drop comes out to be 0.58W which is lower than the single slot antenna power drop 0.65W.Thus more power is focussed and is absorbed by the tissue in case of double slot antenna. Moreover, at the frequency of 2.45GHz, the double slot antenna has a very low power reflection coefficient of -21.015, which is much lower than the single slot antenna power reflection coefficient i.e. -18.115. Thus power wastage is less in case of double slot antenna design. Figure 3 shows the combined plot for both the antennas i.e. with single slot as well as double slot.

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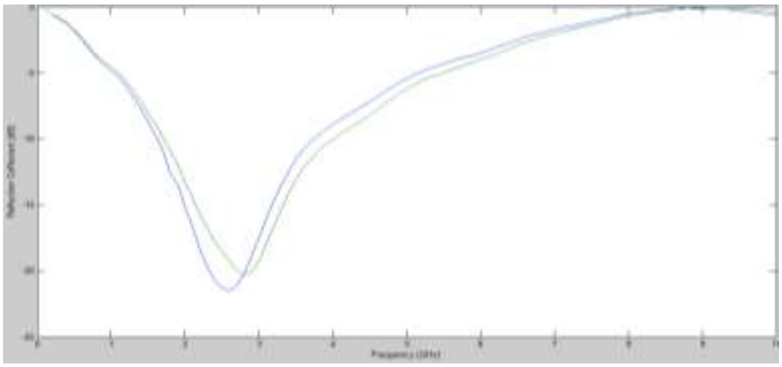

Figure 3. The combined plot for single and double slot antennas

The green color represents the response of single slot antenna and blue color represents the double slot antenna. The peak SAR value obtained for 10W of microwave power for the reference model is 3.035 kW/kg at the insertion depth of approximately 62.8mm. While in case of double slot antenna, the peak SAR value obtained is 3.060 kW/kg, which is at the insertion depth of 62.5 mm. Thus, the formation of lesion in case of double slot antenna is fast and denser at the position close to the upper slot with less insertion depth as compared to the single slot antenna (fig 4). The heat lesion is strong near the slot of antenna, which leads to high temperatures. It is found that the variation of SAR values in the liver tissue is due to the antenna type and the insertion depth.

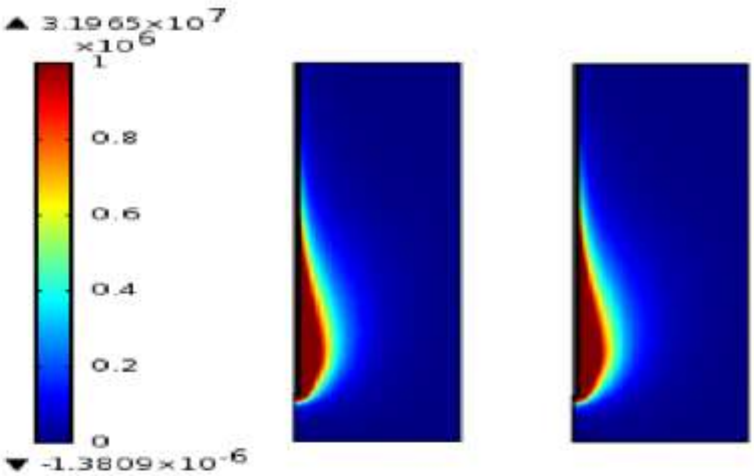

Figure 4 . Thermal lesion in case of single slot and double slot antenna

Moreover in case of temperature distribution the single slot antenna allows the rise in temperature up to 100°C near the antenna tip. But, in case of double slot antenna highest temperature near the tip of the antenna is 101°C (fig 5). Thus in discussing the parameter variation of the reference model and that of the developed double slot model of antenna we come across various positive advantages of this antenna.

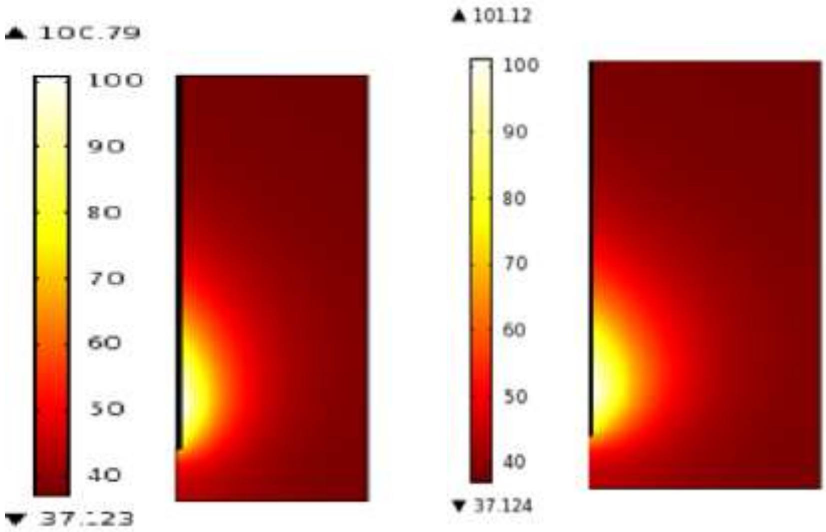

Figure 5 Temperature distribution in single slot and double slot antenna

4. Conclusion:

This work presents an analysis of electromagnetic wave propagation with coupled to heat transfer for liver MWA using double slot microwave antenna, with the objectives to approach the appropriate applicator for a given treatment area. In this work double slot antenna for Interstitial MWA in liver is evaluated in order to compare its effects on the microwave power absorbed, SAR distribution and temperature distribution in the liver tissue with respect to single slot antenna. It is found that the microwave power absorbed, SAR distribution and temperature distribution in the liver tissue is strongly dependent on the number and position of slot. The results clearly demonstrate that in double slot antenna, localized heat lesion near the tip can be produced. It has excellent reflection coefficient of the order of -21.01 dB approximately. In reference to backward heating the work successfully demonstrates that the coaxial double slot antenna does not have undesirable long tails which affects the healthy tissue. Moreover, they are accounted for providing rational and reasonable sized lesion with respect to impedance matching with low power loss of the microwave applicator to the surroundings. It is found that, the shape and size of the destructed area can be varied by adjusting the configuration and antenna design, resulting in no damage to the surrounding tissues. The surface temperature distribution and calculations using FEM can play an important role in clinic planning of heat treatments using microwave interstitial antennas. and less detrimental backward heating. This work presents an analysis of electromagnetic wave propagation with coupled to heat transfer for liver MWA using double slot microwave antenna, with the objectives to approach the appropriate applicator for a given treatment area.

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