INTERNATIONAL JOURNAL OF RESEARCH IN COMPUTER APPLICATIONS AND ROBOTICS
ISSN 2320-7345

MICROWAVE ABLATION THERAPY FOR THE TREATMENT OF HEPATOCELLULAR CARCINOMA USING DOUBLE SLOT INTERSTITIAL ANTENNA

Simran Kaur[1], Surita Maini[2]
[1]*Faculty of Electrical Engineering ,DAV Institute of Engineering & Technology,Jalandhar, Punjab, India*
[2]*Sant Longowal Institute of Engineering & Technology, Longowal, Punjab, India*
E-mail: psmaan@hotmail.com

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 new coaxial double slot antenna for microwave ablation therapy has been proposed in this research paper. The paper represents 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), Double 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]. 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. If the antenna input impedence is not matched to the feed line, too much of applied power is reflected from the antenna and hence not deposited on the tissue. In this paper temperature distribution pattern, heating characteristics and finite element meshing of coaxial double slot antenna has been analyzed at frequency of 2.45GHz and at a power of 10 Watt. Thermal model was simulated by using the heat transfer modeling feature in FEMLAB. The model is 2D axial-symmetric geometry structure and is solved by PDE (Partial differential equation) solver after applying the appropriate boundary/domain parameter settings. COMSOL Multiphysics version 4.2 has been used as primary computer simulation tools. In section II the numerical method and model design of coaxial double slot antenna is described. In section III temperature distribution, heating characteristics and SAR been investigated using FEM.

2. Methods and Models

2.1 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 .

$$\rho C\, \partial T/\partial t = k\nabla^2 T - \rho\rho_b C_b F(T-T_b) + \rho SAR \qquad (1)$$

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 .It can be shown that:

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

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].

2.2 Antenna design

The interstitial antenna consists of a microcoaxial 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:

$$\lambda_{eff} = c/f\sqrt{\varepsilon_r} \qquad (3)$$

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. 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.

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]

Figure1. Coaxial Antenna

This antenna shown in figure 1 is 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, surface temperature distributions a finite element mesh has been generated. In this study, the FEM is used to analyze the transient problems. Fig 2. shows the axisymmetric finite element mesh, generated by FEMLAB using the free mesh parameters with the maximum element size 3 mm, in order to achieve a best compromise between computational accuracy and optimized dimensionality of the model (table III). A dense mesh generated near the vicinity of tip of antenna is observed, where the temperature is high and having variable distribution.

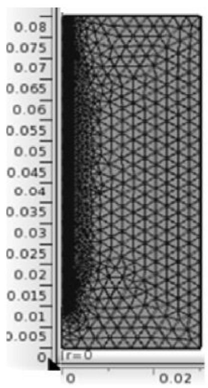

Figure 2.

Table 3. The properties of mesh

Maximum element size	3[mm]
Minimum element size	2.4E-5
Resolution of curvature	0.3
Maximum element growth rate	1.3

There are 26 edges and 5864 triangular elements in the model. Figures 3 and 4 shows the simulated results of surface temperature distribution and resistive heating in the liver tissue with 2D modeling, in a longitudinal plane. It is clear that the temperature field follows the heat source distribution quite well and is nearly ellipsoidal distribution around the slot and its highest values in the vicinity of the antenna and decreases with the distance which corresponds to the microwave power absorbed. In addition, temperature distribution increases with increasing time. This is because the microwave power absorbed within the liver tissue attenuates, owing to energy absorption, and after that the absorbed energy is converted into thermal energy, which increases the liver temperature upto 101°C near the slot. The heat lesion is strong near the antenna, which leads to high temperatures, while far from the antenna, the heat lesion is weaker and the blood manages to keep the tissue at normal body temperature of about 37 °C. The figure3 shows the resulting steady state temperature distribution in the liver tissue for an input microwave power of 10 W.

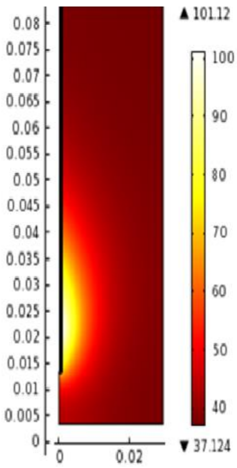

Figure 3 Surface temperature (deg C)

The surface temperature distribution figure 4 makes it clear that the thermal lesion produced by coaxial slot antenna is of tear-drop shape. The lesion produced depend upon the power supplied to the antennas, when the input power is increased, lesions produced will be large. The Peak SAR 3.060 kW/kg is obtained at the insertion depth of approximately 62.5 mm close to the upper slot position of the antenna.

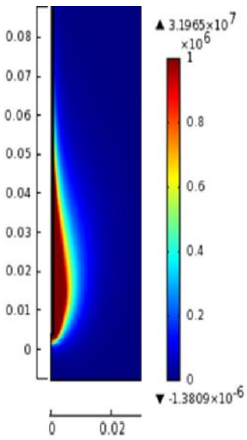

Figure 4 Surface: total power dissipation density(W/m^3)

Vol.2 Issue.1, Pg.: 56-61
January 2014

Reflection coefficient and power drop

We can also perform the boundary and volume integrations for the field variables for the calculation of the values of power being delivered, reflected, deposited and leaked.

Power delivered by the power source should equal the power deposited. In the present model P_{in} is 10W. So, In case of double slot antenna design with 0.25λeff distance between the slots the computed value of $P_{delivered}$ is 9.42W, with input power 10W. The power reflected value is reduced to 0.58W. Hence around 94.2% of the power supplied to the antenna is being utilised by the tissue without much wastage of power.

Computation of the antenna frequency response

As in the previous section, the antenna power reflection coefficient Γ can be calculated. The FEMLAB and MATLAB integration in the antenna frequency response provides a great advantage in the computation of power spectrum in antenna model at discrete frequencies ranging from 0.1 GHz to 10 GHz. At each discrete frequency, the dielectric properties of liver tissue are adjusted in the model to account for the frequency dependence of the dielectric properties. The values of S_{11} parameter is then accordingly arranged with the help of MATLAB plot tool in graphical form. At a frequency of 2.45GHz, the double slot antenna has a very low power reflection coefficient of -21.015. The simulated reflection coefficient is expressed logarithmically and the graph is shown in figure5.

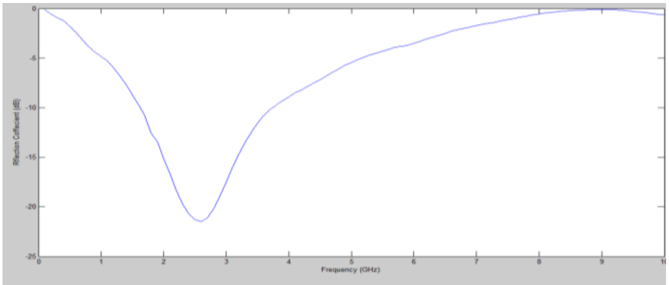

Figure 5 The simulated reflection coefficient expressed logarithmically

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. 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 and less detrimental backward heating.

REFERENCES:

[1] Llovet JM , Fuster J , Bruix J . Intention - to - treat analysis of surgical treatment for early hepatocellular carcinoma: resection versus transplantation . Hepatology 1999 ; 30 : 1434 –1440.

[2] A.P.O'Rourke,D.Haemmerich,P. prakash,M.C.Converse,D.M.Mahvi,and J. G. Webster, "Current status of liver tumor ablation devices,"Exp.Rev. Med. Devices, vol. 4, pp. 523–537, 2007.2003.

[3] Clavien PA , Petrowsky H , deOliveira ML , Graf R . Strategies forsafer liver surgery and partial liver transplantation . N Engl J Med 2007 ; 356 : 1545 – 59

[4] Krishnamurthy VN, Casillas J, Latorre L. Radiofrequency ablation of hepatic lesions: a review. Appl Radiol. 2003;32:11–26

[5] L. X. Liu, W. H. Zhang, and H. C. Jiang, "Current treatment for liver metastasesfrom colorectal cancer," *World J Gastroenterol*, vol. 9, pp. 193-200, 2003, 29 Llovet JM: Updated treatment approach to hepatocellular carcinoma, J Gastroenterol *40*: 225-235, 2005

[6] Wright AS, Sampson LA, Warner TF, Mahvi DM, Lee FT. Radiofrequency versus microwave ablation in a hepatic porcine model. Radiology 2005; 236: 132-139

[7] A. P.O'Rourke,D.Haemmerich, P. Prakash,M.C.Converse,D.M.Mahvi, and J. G. Webster, "Current status of liver tumor ablation devices," Exp.Rev. Med. Devices, vol. 4, pp. 523–537, 2007.2003.
[8] Simon CJ, Dupuy DE, Mayo-Smith WW. Microwave ablation:principles and applications.*RadioGraphics*. 2005;25:S69–S83.
[9] H. Rhim, S. N. Goldberg, G. D. Dodd, III, L. Solbiati, H. K. Lim, M. Tonolini, and O. K. Cho, "Essential techniques for successful radiofrequency thermal ablation of malignant hepatic tumors," R*adiographics*, vol. 21, pp. S17–S35, 2001 (discussion S36–S39).
[10] Swift B, Strickland A, West K, Clegg P, Cronin N, Lloyd D. The histological fea-tures of microwave coagulation therapy: an assessment of a new applicator design. Int J Exp Pathol 2003;84:17-29.
[11] Chiu HM, Mohan AS, Weily AR, Guy DJR, Ross DL. Analysis of
novel expanded tip wire (ETW) antenna for microwave ablation of
cardiac arrhythmias. *IEEE Trans Biomed Eng.* 2003;50:890–9.
[12] Wright A.S., Lee, F.T.jr., Johnson C., Mahvi D.M., "Comparison of Microwave and Radiofrequency Ablation of Hepatic Tissue in a Porcine in Vivo Model," Radiological Society of North America, Chicago, November 2001.