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MATHEMATICAL MODELING OF TUMOR ABLATION ON 2D PANCREATIC GEOMETRY USING MICROWAVE THERAPY

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Abstract

Cancer is a disease characterized by uncontrolled, uncoordinated and undesirable cell division. Unlike normal cells, cancer cells continue to grow and divide for their whole lives, replicating into more and more harmful cells. Different treatments are used to treat the cancer cells. Microwave therapy focused to control spatial and temporal distribution and follows the basic principal of blood flow and heat transfer. With the help of bio heat equation and TM waves, a 2D mathematical model of Pancreas is developed by designing a double slot antenna. This antenna is then placed in 2D geometry of pancreas with the help of COMSOL Multiphysics software. This model helps us to treat the cancer cells while protecting the healthy tissues at the same time.

1. Introduction

Mathematical modeling is very helpful in the biological field to understand the bio-medical phenomenon. It provides vast information in experimental and clinical settings. At present many mathematical models related to the cancer treatment has been introduced (Deisboeck *et al*., 2009). The pancreas is the essential organ of the human body and is located behind the stomach. It is the part of the digestive system that secretes specific enzymes in the intestine. The structure of the pancreas has consisted of two main parts; endocrine and exocrine (Peng *et al.*, 2016).

Exocrine pancreas secretes digestive enzymes in the duodenum. The pancreas is composed of 95% of the endocrine part. The endocrine pancreas produces insulin, glucagon, somatostatin and pancreatic polypeptide in the bloodstream. It usually comprises 1-2% of pancreatic mass.

Cancer is defined as the uncontrollable cell division; form lumps or mass of tissues called a tumor. A tumor can grow and interfere with other organs of the body, release hormones that can afterward alter body function. It is considered a highly fatal disease. pancreatic usually diagnosis at the advanced/later stage. It is difficult to diagnose pancreatic cancer at an earlier stage, because of its most common symptoms like abdomen pain, Vomiting, back pain, weight loss and many others. Many people died annually due to pancreatic cancer throughout the world. (Longnecker, 2014). Despite of medical advancement, little progress has been made to reduce its effects and mortality rate. The causes and basis of pancreatic cancer are incompletely understood (Trefna & Fhager, A., 2005)..

Cancer treatment includes Hyperthermia that involves heating of cancerous body cells. It damages the cell membrane because of heating, results in the destruction of cancer cells. Hyperthermia is an effective cancer treatment, in which the uncontrollable growth of cells i-e cancerous cells are exposed to increased temperature for a long period of time. Hyperthermia like chemotherapy destroys cancerous cells without any additional long-term side effects. In this process, the temperature is raised from 40 to 44°C for at most one hour to achieve tumor cell death. (Baronzio, 2014).

In local hyperthermia, several methods are used to deliver the energy to heat the tumor which includes ultrasound, microwave and radio frequency (Kim *et al*., 2007). One of the best techniques is interstitial hyperthermia. In this technique, a tumor is heated through ferromagnetic rods, high-frequency needle (375 KHz) or probe. With the help of ultrasound, the probe is properly connected to the heat source and is correctly inserted into the tumor. Radiofrequency ablation (RFA) is one kind of interstitial hyperthermia. (Kim *et al*., 2011; Li *et al.*, 2007).

Tumor ablation is a useful technique to destroy the tumor when surgery is not a good option for a patient. For the cancer treatment by tumor ablation, probe or needle is inserted into the tumor tissue of the patient through the skin. While through CT scanning or ultrasound, a probe or needle is guided into place in the tumor (Brace, 2009).

One or more microwave antennas can be used to treat the tumor, depending on the tumor size and location in the body. When the antenna is turned on, body tissues having a high concentration of water and blood content get exposed to significant amounts microwave energy leads to tissue heating. In this process, microwave energy is transformed into heat energy (Wust, 2002). Microwave heat generations are like rubbing your hands together to produce warming sensation. Microwave energy passes through the tissue causing vibration of water molecules. Due to the heating, friction between water molecules is generated. By concentrating and focusing the microwave energy, it is possible to destroy the selected tumor organ while protecting healthy tissues at the same time (Haemmerich, 2010).

For pancreatic cancer treatment, high energy radio waves are used. By inserting a needle or probe into the tumor through probe tip high-frequency waves passes to heat up the tumor tissues and destroy the tumor (Rubio, *et al.*, 2011).

Microwave energy ablation, a widely used method, is transferred through antennas. Antennas are linked by their ability to transfer energy from a source to a load. Many designs have been proposed for microwave heating. Needle-like geometry is the most common design used in antennas to ablate tumor (Acikgoz, 2015; Bertram *et al.*2006,). Several antennas have been used by the researcher to achieve the goals including monopole, dipole, triaxial antenna, coaxial antenna, lope antenna and a helical antenna. Coaxial antennas are widely used by many researchers to ablate tumor due to the simple structure and design. A developed chocked version of these antennas produces localized power deposition in tissues for treating deep and hepatic tumor.

Numerical electromagnetic and heat stimulation are used to predict the antenna design and heating pattern. A mathematical model of double slot antenna was designed by using a finite element method and Finite difference time domain (Ahmed.*et al*., 2014).

2. Methodology

In order to develop the model, it was needed to develop finite differential equation suitable to the model of Pancreatic tumor. 2D model of pancreas and double slot Microwave antenna was constructed for the heating Purpose. The results would be verified accordingly.

2.1.Model Description-Basic Biological Model

COMSOL Multiphysics software was used which consist of different modules including Earth science module, heat transfer module, AC/DC module and others. To draw the model of microwave cancer therapy, two basic models were needed i-e heat transfer model and the RF model in 2 dimensional (Deisboeck *et al.,* 2011). Furthermore, the bio heat equation was also used and in combination with plane harmonic waves in RF model. Moreover, the constants were set for more refine results (Cristini *et al.,* 2009). The values of constants are provided in the Table 1.

Table 1: Constants in Bio Heat equation

Name	Expression	Expression
k_Pancreas	0.56[W/(kg*K)]	Thermal conductivity, Pancreas
rho_blood	1e3[kg/m^3]	Density, blood
C_blood	3639[J/(kg*K)]	Specific heat, blood
omega_blood	3.6e-3[1/s]	Blood perfusion rate
T_blood	37[degree]	Blood temperature
P_in	1.23e9	Input microwave power
nu	2.45[GHz]	Microwave frequency
eps_diel	2.03	Relative permittivity, dielectric
eps_cat	2.6	Relative permittivity, catheter
eps_Pancreas	0.1	Relative permittivity, Pancreas
Sig_Pancreas	1.5[S/m]	Electric conductivity

2.2.Subdomain Settings of Bio Heat Equations

Six different subdomains were made i.e. the domain of pancreas around the antenna, two catheters, two slots and a shield covering around the catheters and slots. The basic subdomains were set of Bioheat equation and choose the domain around the antenna and enter the values by using following formula:

$$\nabla.\,(K\nabla T) = \rho_b C_b\ \omega_b(T_b\text{-}T) + Q_{\ met} + Q_{\ ext}$$

3. Result And Discussion

The model develops here is made on COMSOL Multiphysics. Different Concentrations of heat are given to the tumor to control the damage of the tumor tissues. The temperature is kept high in the center region, its concentration starts decreasing as we move away from the antenna. Our ability to control the heating power enables to heat the malignant tissues and minimize the damage of healthy tissues. The following Figure 1 shows the placement of the double slot microwave antenna in Pancreas in their respective sub domain. It shows steady state temperature distribution in tissues at the power of 10 W. The temperature is higher near the slots and reaches about 100.546 near the boundaries of the pancreas Domain.

The Figure 2 shows the image of heat around the antenna. The electric field is very strong around the antenna which is necessary for interstitial heating. The antenna is covered in catheter made up of PTFE.

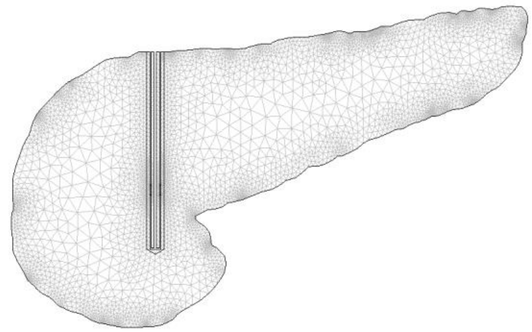

Figure 1: Mesh Image of Pancreatic Cancer Treatment

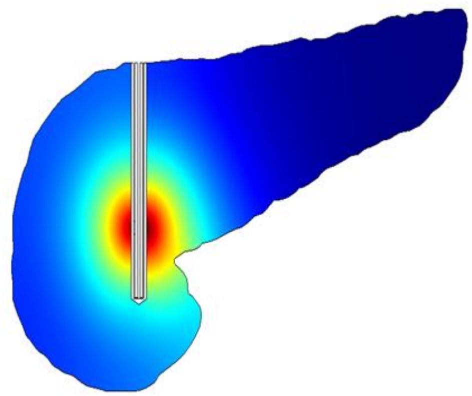

Figure 2: Temperature Distribution image

4. Conclusion and Suggestions

In this research work, we make a 2D mathematical model of microwave cancer therapy of pancreatic cancer. We follow that principal of flow of blood, mass and heat transport. We placed the Microwave multi slot antenna in tumor considering the exact geometry of pancreas. This model helps us to place antenna anywhere in liver in 2D where the microwave heats the tumor tissues and minimally damage the healthy tissues. We combined the bio heat equation with In-Plane TM waves and give the power of 10 W to antenna. The temperature near the antenna is high as compared to the other areas of the organ. The results show that we properly control the spatial and temporal distribution and the solution converge.

The present model can be further extended to 3D, we can make the temperature sensor in 3D. Also, it is possible to draw geometry of antenna in 3Ds. It will help the doctor to place antenna exactly in the tumor tissues. The heating will be more accurate if we able to find the center of irregular shape tumor and place the antenna there.

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