ELECTROMAGNETIC BIOLOGY AND MEDICINE

http://informahealthcare.com/ebm
ISSN: 1536-8378 (print), 1536-8386 (electronic)

Electromagn Biol Med, Early Online: 1–5
 DOI: 10.3109/15368378.2013.869753

informa healthcare

ORIGINAL ARTICLE

Applicator modeling for electromagnetic thermotherapy of cervix cancer

Behrooz Rezaeealam

Department of Electrical Engineering, Lorestan University, Khorramabad, Iran

Abstract

This report proposes an induction heating coil design that can be used for producing strong magnetic fields around ferromagnetic implants located in the cervix of uterus. The effect of coil design on the uniformity and extent of heat generation ability is inspected. Also, a numerical model of the applicator is developed that includes the ferromagnetic implants, and is coupled to the bioheat transfer model of the body tissue. Then, the ability of the proposed applicator for electromagnetic thermotherapy is investigated.

Keywords

Cervix tumor, electromagnetic hyperthermia, excitation coil,

History

Received 14 May 2013
Accepted 29 September 2013
Published online 21 January 2014

Introduction

Hyperthermia is a procedure for treatment of cancerous tumor by raising its temperature and there is a spectrum of ways of local intracorporal heat generation using focused microwave radiation, capacitive or inductive coupling of RF fields, implanted electrodes, focused ultrasound, or lasers. It is noteworthy that in each technique, a suitable applicator must radiate energy into the targeted medium, for instance, Johnson (1986) has described an inductive applicator based on dielectric loaded waveguide, which covers the frequency range 22 to 900 MHz. Also, a modified Fletcher-Suit brachytherapy applicator has been employed for synergic treatments by radiotherapy and microwave hyperthermia in patients with cervix cancer (D'bicki et al., 2006).

One of the hyperthermia therapies is high-frequency induction heating type by using nano-mgnetic materials and magnetic implants. A tumor with injected magnetic materials is heated by hysteresis loss and eddy-current loss under high frequency magnetic fields with a few hundred kHz. The hyperthermia using ferromagnetic implants has been reported in several studies for local warming of body tissues (Cetas et al., 1984; Satoh et al., 1990). Also, as an alternative therapy, magnetic particle (MP) hyperthermia is a method where MPs are deposited in tumor tissue with subsequent heating by means of an external alternating magnetic field (Kumar and Muhammad, 2011). Although magnetic nanoparticles represent very promising systems due to their multifunctional capabilities, however, bulk metallic implants have recently been shown to display higher efficiency rates than iron oxide nanoparticles (Zuchini et al., 2011). For example, it has been shown by Du et al. (2006) that nanosized As_2O_3/Fe_3O_4 complex has a significant therapeutic effect on cultured human cervical cancer cells and xenograft cervical cancers combined with magnetic fluid hyperthermia by inducing apoptosis and inhibiting growth of tumor cells.

Traditional devices used to generate the magnetic fields are Helmholtz and simple solenoid coils. Solenoids are often the preferred choice for many applications because they efficiently generate high peak-amplitude fields, with limited stray fields extending outside the coil. Solenoid coils have been employed as suitable applicators for RF hyperthermia (Ellinger et al., 1989), tissue ablation (McCann and Sherar, 2006), and magnetic fluid hyperthermia (Bordelon et al., 2012; Stauffer et al., 1994). For example, the modified air-core solenoid designed by Bordelon et al. (2012) is to improve the field homogeneity within the coil in which the sample is inserted.

In this work, a pen-type applicator is proposed for electromagnetic hyperthermia of cervix cancer, which is composed of a solenoid coil wound on MnZn ferrite core. In order to examine the performance of the proposed applicator, a numerical model is developed that includes the ferromagnetic implants and the bioheat transfer model of the body tissue. Heat generation within magnetic nanoparticles is counteracted by heat depletion into surrounding tissue due to blood perfusion and heat conduction. In general, this needs the consideration of the so-called bioheat equation (Kotte et al., 1996).

Applicator configuration and principle of operation

As shown in Figure 1, the proposed applicator is to be employed for electromagnetic hyperthermia of cervix cancer. Figure 2 shows the schematic illustration of the applicator that

Address correspondence to Behrooz Rezaeealam, Department of Electrical Engineering, Lorestan University, Khorramabad, P.O. Box 465, Iran. E-mail: rezaeealam@gmail.com

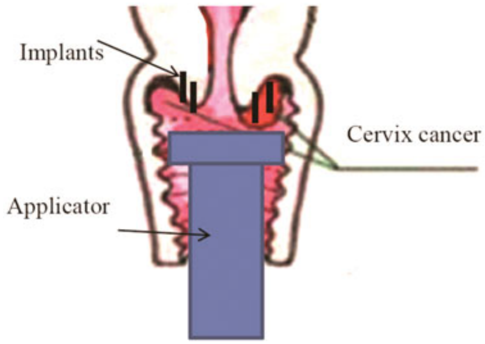

Figure 1. Applicator for electromagnetic thermotherapy of cervix cancer.

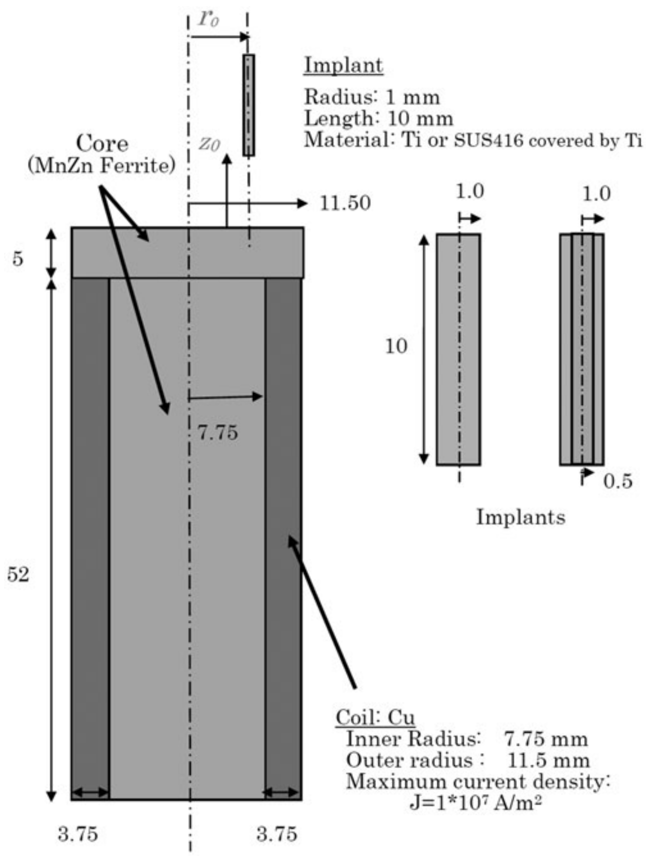

Figure 2. Schematic illustration of the applicator and implants.

consists of a solenoid coil and a MnZn ferrite core. The ferrite core covers the front end of the solenoid coil, and is called pen-type applicator. This feature causes a more homogeneous magnetic field around the cervix tissue that is often required in biomedical applications to reduce inconsistent power deposition in the tissue. Also, Figure 2 shows two kinds of implants that are inserted into the cervix tumor to be heated as the thermoseeds. The implants are made of Titanium and Stainless (SUS416) coated by Titanium, respectively (Naohara et al., 2011).

Magnetic properties for MnZn ferrite are nonlinear with maximum relative permeability of 1600 and saturation flux density of 0.45 T. We employ Multiphysics finite element package (COMSOL) to perform finite element analysis of the

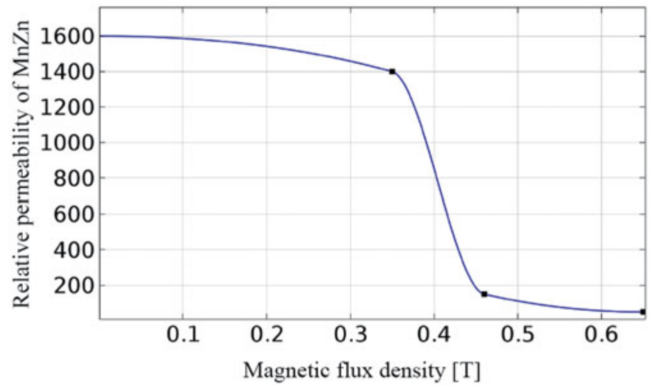

Figure 3. Relative permeability of MnZn core versus magnetic flux density.

applicator. Figure 3 depicts the relative permeability of MnZn core versus magnetic flux density, which is needed for modeling the magnetic core using COMSOL software. It is noteworthy that MnZn ferrites exhibit higher permeability and magnetic saturation level than the ones of NiZn ferrites and are suitable up to 3 MHz.

Figure 4 depicts the magnetic flux density distribution in the z–x cross section through the applicator, corresponding to the coil current density of $J = 10^7\,\mathrm{A/m^2}$ at the frequency of 400 kHz. It can be seen that the ferrite core is magnetically saturated. Now, the corresponding power dissipation in the implants is calculated. Figures 5 and 6 show the heating capacities of Ti and Ti-coated SUS implants, respectively. It is observed that Ti-coated SUS produces much higher heat than the one of Ti implant and the results demonstrate the necessity of the magnetic core to improve the heat generation. In general, the results show the good heating capacity of the overall system. Furthermore, it is observed that the power dissipation drops sharply as the distance of implants from applicator increases in the z direction, while the power dissipation remains almost flat in the x direction. This characteristic is due to the pen-type ferrite core of the applicator.

Bioheat model and simulation results

In this section, a simplified numerical model of the electromagnetic hyperthermia is developed by coupling the electromagnetic and the bioheat transfer equations, and then the performance of the applicator is examined.

The bioheat equation governs heat transfer in the tissue to determine the time-varying temperature distribution T that is caused by induced eddy currents:

$$\rho C_{pt}\frac{\partial T}{\partial t} - \nabla \cdot k_{eff}\nabla T = Q \qquad (1)$$

where $\rho = 1050$ is the mass density ($\mathrm{kg\,m^{-3}}$) of the tissue, $C_{pt} = 4000$ is the specific heat ($\mathrm{J\,kg^{-1}\,{}^{o}C^{-1}}$), $k_{eff} = 1.8$ is an effective thermal conductivity ($\mathrm{W\,m^{-1}\,{}^{o}C^{-1}}$) which takes into account the blood flow through the smaller vessels (Creeze and Lagendijk, 1990), and Q is the power density ($\mathrm{W\,m^{-3}}$) dissipated by the induced eddy currents in the tissue or the ferromagnetic implant. We neglect the heat generated by metabolic processes since it is small compared with Q.