AGC. Res., 58 (1s) 121-127, 2014
ISSN : 0002-1857

Heat Generation Ability of Ferromagnetic Implants in Hyperthermia

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Article History:
Received 13th, April, 2014
Accepted 22th, June, 2014

Keywords:
Electromagnetic hyperthermia, Finite element methods.

ABSTRACT

In this paper, proposed implants in literature are compared in terms of the ability to heat generation in electromagnetic thermotherapy. To destroy the tumor cells, their temperature must rise above 42.5^{o}C. The magnitude of the temperature rise depends strongly on the thermal conductivity of the tissue that has not been considered in most studies. For this reason, liver tissue is modeled using bioheat transfer equation that is coupled to the electromagnetic equations and electrical circuits by employing Multiphysics finite element package COMSOL, in order to create the numerical model of the system.

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. Recently, researchers are looking to employ electromagnetic thermotherapy as a treatment with no major side effects in comparison with various established treatments, such as surgical resection, radiation therapy and chemotherapy.

The hyperthermia using ferromagnetic implants has been reported in several studies for local warming of body tissues [1,2]. 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 [3]. 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 [4]. Roughly, particles with big sizes can show the ferromagnetic behavior while the smaller particle displays the superparamagnetic characteristic. Therefore, the heat generation mechanisums are totally different.

Radiofrequency ablation (RFA) is regarded as a powerful and effective technique by which an ac current (usually 460-500kHz) is conducted by the RFA probe to flow through the tissue such that the local temperature can be raised rapidly and efficiently (about 90-110^{o}C) to cause thermal ablation. However, the cost of the RFA probe is relatively high and it must overcome the blood coagulation issue because the blood clots may act as highly resistive objects that reduce the desired heating effect [5]. Meanwhile, RFA is not suitable for coagulate the main blood vessels in an organ since there is a heat-sink effect.

Alternatively, microwave ablation is relatively expensive and difficult to be applied for bloodless resection of tissues, since the area affected by the microwave ablation is limited to only about 2 cm away from the microwave probe [6].

The main advantage of hyperthermia using ferromagnetic implants is heating repeatedly the target tissue at lower temperature zone than that for RFA therapy in order to maintain safe temperatures in the surrounding healthy tissues [7]. In literature, several types of implants for hyperthermia have been proposed such as materials with low curie temperature [8,9], ferromagnetic core on which a coil is wound and connected to a chip capacitor [10] and also stainless steel needles [11,7]. The selection criterion of implants is their heat generation ability; however, the effectiveness of all types of implants has not been tested in vitro or in vivo experiment. In [12], implant of magnesium ferrite has been proposed that under an alternating magnetic field can achieve a temperature beyond 60^{o}C for the first time.

Irreversible cell injury occurs when cells are heated to 46^{o}C for 60 minutes and with increasing temperatures the time necessary to induce cell death is shortened and at 60-100^{o}C cell death is immediate and irreversible.

In this work, a numerical model is developed as shown in Fig. 1, that can be used to evaluate the temperature rise in the tissue when exposed to high frequency magnetic field, and also a comparative study of heat generation for different configurations of implants is done.