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ORIGINAL ARTICLE

Microwaves for breast cancer treatments

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Abstract Hyperthermia is potentially an effective method for the treatment of cancer, especially breast cancer tumors. One of the most attractive attributes of hyperthermia is the possibility of providing therapeutic benefit noninvasively, minimizing side effects. To be effective, a hyperthermia treatment must selectively heat the cancerous tissue, elevating the temperature in the tumor without exposing healthy tissue to excessive temperature elevations. In this paper, a suggested simple model of Annular Phased Array (APA) using eight half wavelength linear dipoles is presented. New software (COMSOL MULTIPHYSICS) is used to calculate the temperature distribution inside a model of a three layered breast (skin, breast tissue, and tumor). In addition, the effect of changing the amplitude and phases of the array elements on the temperature distributions and the conditions on the values of the phases are demonstrated in order to achieve the objective of hyperthermia for breast tumor treatment.

1. Introduction

Breast cancer is a 'multi-factorial' disease, a term describing a condition that is believed to have resulted from the interaction of genetic factors, with environmental factor, or factors. Available techniques for treating breast cancer often introduce strong side effects. The most common treatment is surgical treatment such as mastectomy, a radical approach which comes down to removing the entire breast, or lumpectomy, where only part of the breast is removed. Ablative therapies such as radiation therapy and chemotherapy that cause cellular damage are also common. In the thermal treatment of cancer, the tissue temperature is raised in order to kill the malignant tissue. The thermal treatment of cancer has a lot of potential, since it can offer a noninvasive treatment with low side effects. Therefore, further development of this approach deserves attention [1].

In oncology, the term 'hyperthermia' refers to the treatment of malignant diseases by administering heat in various ways [2]. The objective of hyperthermia treatment of cancer is to raise the temperature in the tumor volume above 42–43 °C for a sufficient period of time while preserving normal physiological temperatures (well below 42 °C) in the surrounding tissue. One of the persisting challenges in achieving this objective with noninvasive electromagnetic (EM) hyperthermia treatment is focusing EM power in the cancerous tissue while avoiding the introduction of auxiliary foci in normal tissue.

In the microwave frequency range, energy is coupled into tissues through waveguides or antennas (applicators) that emit microwaves. The shorter wavelengths of microwaves, as compared to RF, provide the capability to direct and focus the energy into tissues by direct radiation from a small applicator [2].

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The challenge in focused microwave ablation is to avoid heating the healthy tissue while heating the tumor. The relatively high conductivity of tumor tissue increases the local heating potential, and thus high temperature gradients can be obtained. However, healthy glandular tissue and skin tissue also possess a high conductivity, which implies that secondary (unwanted) hot spots may appear there. Hot spots in the healthy tissue result in undesired side effects such as extra pain, burns and blisters. Also, these hot spots deteriorate the system efficiency. Several techniques that focus EM energy at a tumor have been developed in the past. A more flexible approach for focusing EM energy is the use of a phased array system. The resulting power distribution can be steered by adjusting the amplitude and phase of each array element. This type of applicator has already been used in EM systems and at RF. It is shown that a phased array can be used to adaptively steer nulls at pre-assigned areas of the target body, while heating the part that contains the tumor. However, thermal ablation is not possible at these frequencies since the focal spot includes a large part of the body [2–7].

The problem of radiation of EM waves by an antenna in a given environment is essentially that of solving Maxwell's equations subject to the boundary conditions introduced by both the radiating antenna and its environment. Techniques to solve radiation problems can be divided into two broad classes: frequency domain and time domain. In the past, frequency domain techniques have been widely used to analyze antenna radiation. Also, a time domain method, the finite-difference time-domain (FDTD), is applied to model and predict antenna radiation. In this technique the physical space is split into elementary elements that must be smaller than both the shortest wavelength of interest and the smallest details of the geometry of the objects to be placed within the part of space of interest [8].

The perfectly matched layer, PML, is a new technique developed for the simulation of free space with FDTD method. For solving interaction problems with the finite-difference method, various techniques have been used in the past to absorb the outgoing waves, such as the matched layer [9], which consisted of surrounding the computational domain with an absorbing medium whose impedance matches that of free space, or the one-way approximation of the wave equation [10–13]. To obtain satisfactory solutions, it is well known that these absorbing boundaries must be set at some distance from the scattering structure with the result that most of the computational domain is a surrounding vacuum.

The EM phased array has the potential to overcome many of the difficulties associated with noninvasive hyperthermia, and is more effective if the driving amplitudes and phases of the array are carefully selected. A variety of approaches have been suggested to determine the optimal driving signals of phased arrays for hyperthermia. Perhaps the simplest approach is the phase-conjugate focusing scheme, in which the driving signals are chosen so that the EM radiation from each radiator interferes constructively at the desired focal spot. A major drawback of this approach is that it makes no provision for the reduction of hot spots. A more flexible approach to selecting optimal phased-array driving signals is to maximize the power deposition at the tumor site over the surrounding healthy tissues site. It has been shown that this approach can indeed focus a phased array in the presence of EM inhomogeneities without inducing hot spots [14–16].

Table 1 Electrical and thermal properties of skin, breast, and tumor at 6 GHz [21,22].

Tissue	Density (kg/m^3)	Relative permittivity	Thermal conductivity (W/m K)	Electric conductivity (S/m)
Skin	1200	39	0.5	1.1
Breast	1020	4.49	0.37	0.59
Tumor	1000	50	0.5	4

Table 2 The dipoles parameters.

Parameter	Value
Wavelength (λ)	5 cm
Arm length ($\lambda/2$)	2.5 cm
Radius of the dipole	0.125 cm
Gap size	0.5 mm

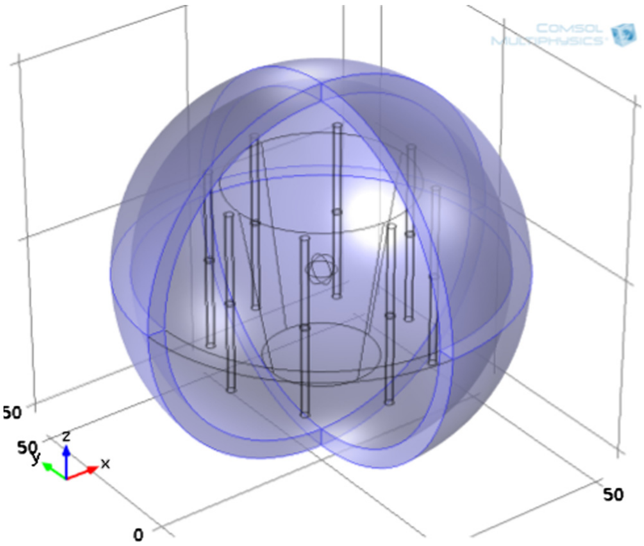

Figure 1 The developed breast model with the applied PML in COMSOL.

Numerous investigations have been conducted over the past several decades to explore and evaluate methods of focusing EM energy using arrays that transmit amplitude- and phase-adjusted narrowband (NB) signals. In contrast, until very recently, less attention has been given to the possibility of using multiple-frequency or ultra-wideband (UWB) signals.

The use of a multi-antenna array offers the opportunity for transmitting signals that constructively interfere at a desired location and, thus, provide selective heating. Constructive interference is obtained with NB (single-frequency) focusing methods [17], by adjusting the amplitude and phase of a sinusoidal signal in each antenna channel to compensate for the expected radial spreading and time delay incurred when the signal propagates from the antenna to the target focal point. In [18], the UWB approach uses a space–time beam-former