Focusing Techniques in Breast Cancer Treatment Using Non-invasive Microwave Hyperthermia

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***Abstract*— Different techniques for non-invasive microwave hyperthermia for breast cancer treatment are discussed. Although microwave hyperthermia was presented as a promising tool for cancer treatment, its clinical application is still far from maturity due to the drawbacks of current approaches. Hence, the main proposed techniques are explained in this paper to highlight the advantages as well as limitations of current approaches. A comparison on the system design and focusing techniques for localized heating tumor is then presented. To that end, several possible techniques to improve the focusing of microwave hyperthermia for breast cancer treatment are proposed.**

Keywords—Breast cancer; microwave hyperthermia; thermal therapy.

I. Introduction

Hyperthermia is cancer treatment wherein elevated temperature causes direct cytotoxicity or increases sensitivity of cancerous cell to other therapies, for example radiation therapy and chemotherapy [1]. The goal of hyperthermia for cancer treatment, including breast cancer, is to elevate the temperature to above 42°C at the tumor location for a sufficient period of time while maintaining a normal temperature in other areas.

Over the past decade, studying non-invasive microwave hyperthermia for breast cancer treatment has drawn tremendous interests from researchers worldwide. Previous studies have shown that microwave hyperthermia is a promising non-invasive treatment for breast cancer [3]-[8]. However, one of the persisting challenges of cancer hyperthermia is the requirement to focus the microwave power at the target while preventing auxiliary foci in surrounding tissues. Many studies are dedicated to investigate different techniques for focusing microwave hyperthermia for non-invasive treatment of the breast. These studies present interesting results of focusing microwave power for breast cancer treatment; however, there are several drawbacks that need to be solved.

In this paper, various techniques for non-invasive microwave hyperthermia treatment for breast cancer are examined. Their advantages, limitations as well as suggestions for possible improvements of the focusing technique of microwave hyperthermia are discussed.

II. Techniques for Non-invasive Microwave Hyperthermia Treatment

In designing noninvasive microwave hyperthermia system, the general approach is to utilize antenna arrays to transmit microwave signals that are constructively combined at the desired location and destructively added elsewhere. Generally the temperature profile in the breast phantom is governed by Pennes bio-heat equation [2]:

$$C_p(r)\rho(r)\frac{\partial T(r)}{\partial t} = \nabla.\left(K(r)\nabla T(r)\right) + A_0(r) + Q(r) - B(r)(T(r) - T_B)\ \ (Wm^{-3}) \quad (1)$$

where $C_p, \rho, K, A_0, B, T_B$,Q are: specific heat, density, thermal conductivity, metabolic heat generation, capillary blood perfusion coefficient, blood temperature and power dissipated per unit volume, respectively.

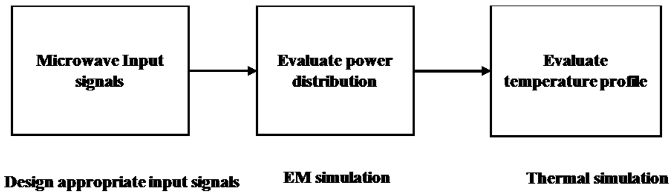


Fig. 1 Evaluation steps for non-invasive microwave hyperthermia.

Hence, to determine the temperature distribution in breast phantom, the power dissipated per unit volume (Q) produced by EM wave is first calculated while the thermal calculation is followed to estimate the temperature profile produced by Q. A general diagram of the procedure for the computational techniques used in breast hyperthermia is shown in Fig. 1. Following this procedure, tremendous efforts have been spent on studying non-invasive microwave hyperthermia for breast cancer treatment. Up to date, the published studies on controlled environment have shown promising results on localized heating tumor for cancer hyperthermia treatment. Although these studies may use different techniques to maximize delivering microwave power to target location, they can be divided into two main groups based on their propagation models.

A. Two-dimenional (2D) computational techniques

To assess the ability of focusing EM energy for effective microwave hyperthermia treatment of breast cancer, authors in [3] apply time-reversal and robust Capon beamforming technique. The employed techniques are used to shape the transmitted signals temporally and spatially. The study is performed on 2D simple breast phantom and circular array constructed from point sources. The results of the proposed approach show better focusing ability compared to existing methods and can provide necessary temperature gradient for microwave hyperthermia. However, this study is conducted based on simple propagation models.

An improvement in propagation models is presented in [4]. A study of the performance of ultra-wideband (UWB) and narrow-band (NB) microwave hyperthermia based on transmitting beamforming was investigated theoretically [4]. This study examines the difference between UWB and NB focusing hyperthermia treatment. It performed 2D simulations to determine power distribution and temperature profile throughout the 2D realistic numerical breast phantom. That proposed approach uses space-time beamforming to determine input signals for the antenna array so that the energy deposited at a given location is maximized while the energy is minimized in the remainder of the breast region. The study showed interesting results of selective heating at the tumor position. Moreover, it is concluded that UWB focusing produces more effective hyperthermia treatment compared to NB focusing.

Also performing in 2D environment, the recent study in [5] has introduced an optimization technique to focus the microwave power inside the breast phantom. The approach exploits the Green function for solving the bio-heat equation and uses the optimal constrained power focusing method to design the antenna array. The proposed technique successfully achieves globally optimal solution for array excitation signals. Thus, selective heating at the target location while avoiding hot spots elsewhere in the phantom are accomplished.

Although those presented studies are conducted by using different techniques, they are performed on 2D breast phantom while the microwave power is delivered by ideal antenna array that constructed by point sources. Hence, while the proposed techniques show interesting results and useful knowledge of focusing microwave hyperthermia for breast cancer treatment, they are not practical due to the use of oversimplified propagation models.

B. Three-dimensional (3D) techniques

The drawbacks of 2D computational techniques for non-invasive microwave hyperthermia are alleviated by performing 3D computational techniques. To overcome the breast model limitation, a numerical study using three-dimensional model was conducted [6]. Several breast models were used to study the sensitivity and robustness of noninvasive transmit beamforming for hyperthermia treatment. In comparison with previous studies, this study is an extension of [4] by using 3D patient-specific propagation models illuminated by an antenna array. The performance of transit beamforming for patients with widely varying breast tissues' density is investigated. Moreover, this approach is also used to study the effect of narrow band and wide band frequency on the focusing of microwave power for hyperthermia. The study illustrates the potential of non-invasive microwave hyperthermia treatment via beamforming with assumed knowledge of the breast phantoms. Contrary to [4], it is concluded that the use of NB frequency is slightly better than WB focusing. Although the study uses a realistic breast model, it is conducted using ideal sources for antennas.

The impractical source for focusing microwave power has drawn researchers' attention recently [7], [8], [9]. In the most recent effort, instead of using point source, a circular array of antennas was placed around a realistic breast model [8]. This work presents a preclinical hyperthermia system for targeted treatment of breast cancer using image-based time-reversal focusing technique. This study proposes a system in which 2D antenna array was used to transmit microwave power to realistic breast phantom. Time-reversal techniques were employed to find a solution of the excitation signal for focusing at target location. The study was confirmed by experiments. The simulated and experimental results of the preclinical system show the potential to improve non-invasive focusing microwave heating for thermal therapy.

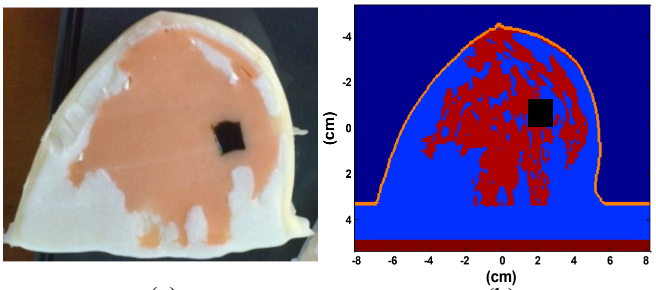
III. Possible Improvements for Successful Clinical Applications

Although there has been enormous effort to investigate focusing microwave hyperthermia for breast cancer treatment, clinical tests have yet to be performed. Despite the interesting and promising results, previous studies have not overcome the engineering issues for focusing microwave hyperthermia. One of the causes of limitations is the used propagation model. As can be noticed, most studies were performed in either simple 2D breast phantom and/or ideal sources. By ignoring the radiation properties of actual antenna, these studies might produce inaccurate results when applied to practical situations.

By applying actual antenna element to build the preclinical microwave hyperthermia system, the work in [8] solves the problem of impractical sources. However, that study faces engineering and clinical issue as 2D array of antenna was used. That 2D configuration limits the localized heating to tumor at the middle plane of the array. Thus, the treatment of tumor away from that plane cannot be accomplished.

For a practical microwave hyperthermia, a realistic environment has to be carefully considered; that includes using accurate thermos-dielectric breast model and realistic antenna array configurations. Since the localized heating tumor is controlled by the excitation signals (phases and amplitudes), accurate focusing microwave hyperthermia requires optimal input signals. Therefore, effective global optimization techniques need to be extensively investigated.

In recent efforts in that direction, a realistic thermo-dielectric breast phantom has been developed [10]. The phantom emulates the real thermal and dielectric properties of breast tissues. It was developed using a mixture of low-cost and stable materials. A photo of the developed very dense breast phantom is shown in Fig. 2. Moreover, a realistic simulation environment that includes a detailed fatty breast model and antenna array has been built in CST Microwave Studio environment. The breast model was derived from MRI data taken from a real patient in the prone position whereas the antennas are circularly distributed around the breast phantom [7], [9]. A screenshot of the developed simulation environment, which includes an array of corrugated tapered slot antennas [11], is shown in Fig. 3. Furthermore, Fig. 4 shows the output of the thermal simulation after 10 s in which the high temperature can be seen at the location of the glands due to their high permittivity compared with the fat layers.



(a) (b)

Fig. 2 Developed realistic thermo-electric breast phantom: (a) Fabricated; (b) breast data.

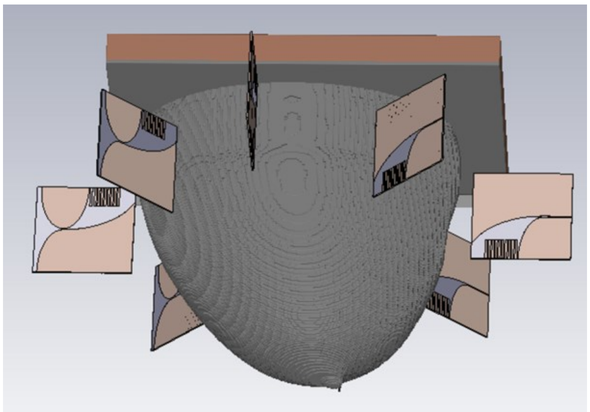


Fig. 3 Realistic simulation setup in CST.

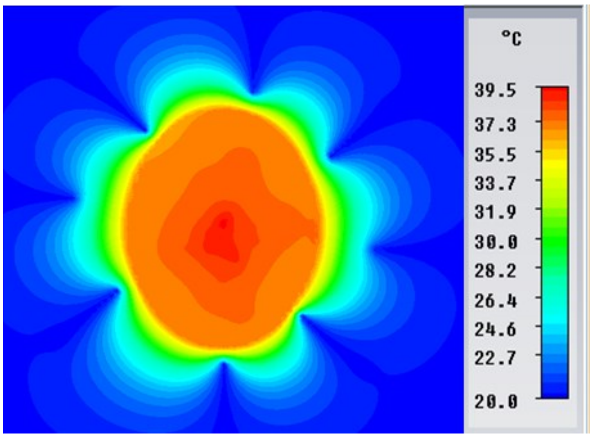


Fig. 4 Temperature distribution inside breast phantom.

IV. Conclusion

A review of current microwave hyperthermia for breast cancer treatment has been reported. Recent techniques for focusing microwave hyperthermia, their advantages and limitations are discussed. Furthermore, suggestions that could improve the focusing techniques for future clinical application are also presented.

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