COMPUTER MODELING OF A HYBRID RF/US PHASED ARRAY SYSTEM FOR HYPERTHERMIA CANCER TREATMENTS IN THE INTACT BREAST

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1. INTRODUCTION

Among women living in the United States, breast cancer is the most common malignancy diagnosed and the second leading cause of death from cancer [1]. Better therapies are clearly needed for breast cancer, which motivates the development of new adjuvant hyperthermia treatments. External heating devices appropriate for deep hyperthermia in the intact breast include ultrasound phased arrays [2] and radio-frequency (RF) electromagnetic phased arrays [3]. Ultrasound (US) is an appropriate local modality for heating small targets in the breast (up to about 2cm diameter [4]), whereas heat generated by RF electromagnetic devices is delivered regionally across a much larger area. Ultrasound phased arrays have been evaluated for ablation of fibroadenomas in the breast [2], and RF phased arrays have been developed previously for deep hyperthermia in the pelvis [3] and in the extremities [5], respectively.

When these two modalities are combined, significantly improved temperature distributions are observed in simulated hyperthermia treatments of locally advanced breast cancer (LABC). Power distributions are simulated for a hybrid applicator consisting of a planar square US phased array and an RF phased array, and temperature responses are evaluated for hyperthermia treatments in the intact breast.

2. METHODS

2.1 Applicator and patient model

A 16.2cm wide and 16.2cm high 2D 1MHz US phased array is placed on one side of a water tank that defines the patient interface. This US phased array consists of 5329 circular sources, where each source has a diameter of one wavelength with λ/2 spacing between adjacent elements. The RF phased array, which operates at 140 MHz, consists of four end-loaded dipole antennas mounted on a Lexan water tank. The thickness of the lexan tank is about 0.5 cm. To facilitate coupling of US and RF into the patient model, the tank is filled with deionized water.

The 3D patient model, including breast, tumor, chest wall, heart, and lung structures, are extracted from MR or CT images. The contours that define these structures are manually extracted from patient images with a Matab based program and reconstructed in the finite element modeling software package HFSS (Ansoft Corp. Pittsburgh, PA).

2.2 Fast Near Field method US pressure computations

The pressure field generated by a single source is calculated with the Fast Near field Method (FNM) [4]. The mode scanning technique [6] generates 2 or 4 focal spots while canceling the fields in some planes to reduce unwanted heat accumulated between the array and the tumor region. In order to reduce intervening tissue heating, focal spots are placed at the distal half of the tumor. The power deposition from each focal pattern is computed and multiplied by a weighting factor.

2.3 E field simulation and optimization

An edge based 3D finite element (FE) model calculates the electric (E) field distribution inside the breast and tumor region. The permittivity and conductivity values for human tissue are from Joines [6]. The FE mesh is truncated with a radiation boundary condition. The mesh node spacing is adapted such that the electric field is densely sampled near material interfaces. The E-field, based on Maxwell's equations, is computed for each antenna with the finite element (FE) method using the commercial software HFSS.

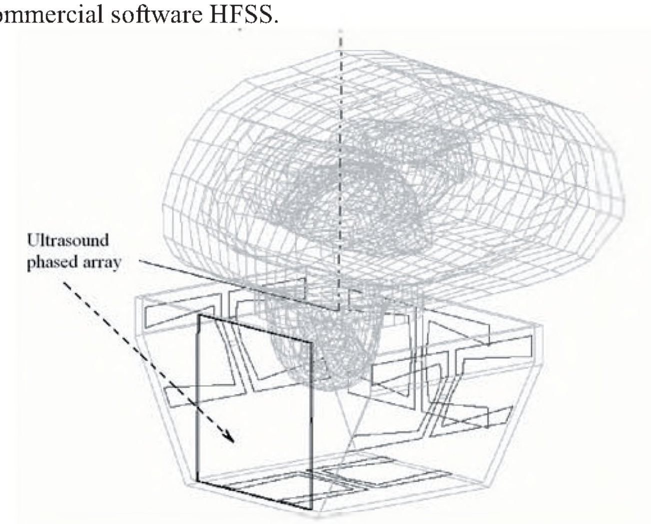

Fig 1: Hybrid applicator model and patient model.

2.4 Temperature calculation and optimization

The total specific absorption rate (SAR) is the sum of the SAR from the E-field and the SAR produced by the pressure field. The temperature increase is calculated from the SAR using a finite difference formulation of the linear bio-heat transfer equation (BHTE). To obtain a more uniform temperature distribution inside the tumor, a Powell search algorithm determines the optimal relative weighting of the RF- and US-induced powers.

3. RESULTS

Based on the computed E-field and pressure fields, the SAR and temperature values are evaluated in a 16cm× 16cm × 10cm volume that contains the breast and surrounding water. The fields produced by the RF and US arrays are calculated separately and then the SAR values are combined for temperature calculations. All fields are computed in 3D. Temperatures are demonstrated for individual and combined modalities in the central portion of the tumor, namely the xz plane with y = 5mm. Fig. 2 shows the temperature distribution produced by the RF phased array in this sample plane. The input power for each antenna is the same, and the phases of the four RF antennas channels are 70°, -63°, 113°, 0°. The US array likewise targets a spherical region located at (-2.5, 1.7, -3)(cm) with 15 focal spots distributed in the back portion of the tumor. The temperature produced by the US array in the same plane as Fig. 2 is shown in Fig. 3.

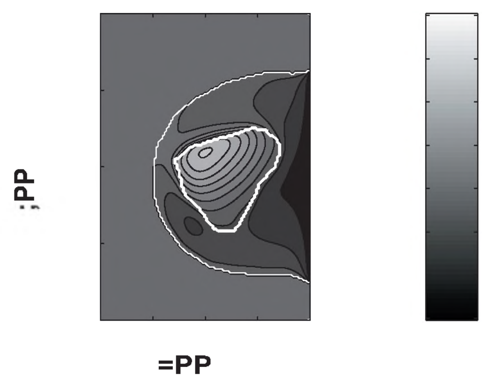

Fig 2: The temperature distribution obtained with RF alone.

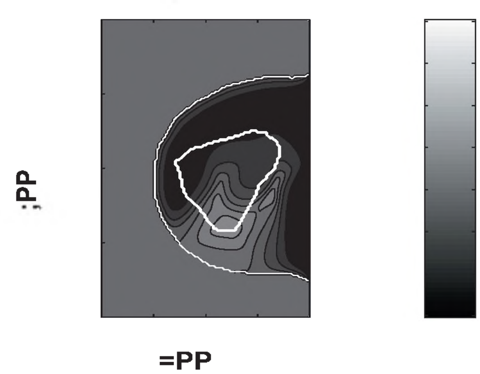

Fig 3: The temperature distribution obtained with US alone.

The total SAR of the hybrid RF/US phased array is the sum of the SAR computed from E field and the pressure field. The temperature calculated from the total hybrid SAR is shown in Fig. 4.

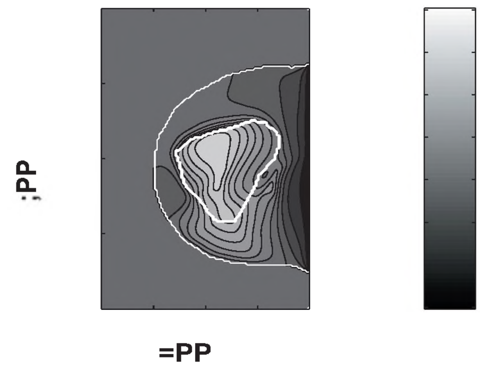

Fig 4: Temperature distribution obtained with the RF/US hybrid approach.

4. DISCUSSION

In the Fig. 4, the RF and US components heat separate portions of the tumor. As shown in Figs. 2-4, the hybrid method achieves a better temperature distribution inside the tumor than either modality applied alone. The hybrid method achieves this result because of the overlapping power contribution of the RF and US in the tumor, and problems with hot spots are therefore reduced.

REFERENCES

[1] R. T. Greenlee, T. Murray, S. Bolden, and P. A. Wingo, (2000) "Cancer statistics, 2000," CA-Cancer J. Clin., vol. 50, no. 1, pp. 7–33.
[2] K. Hynynen, O. Pomeroy, D. N. Smith, P. E. Huber, N. J. McDannold, J. Kettenbach, J. Baum, S. Singer, and F. A. Jolesz,(2001) "Mr imaging-guided focused ultrasound surgery of fibroadenomas in the breast: A feasibility study," Radiology, vol. 219, no. 1, pp. 176–185.
[3] P. Wust, J. Nadobny, R. Felix, P. Deuflhard, A. Louis, and W. John, (1991) "Strategies for optimized application of annular-phased-array systems in clinical hyperthermia," Int. J. Hypertherm., vol. 7, no. 1, pp. 157–173.
[4] M. Malinen, T. Huttunen, K. Hynynen, and J. P. Kaipio, (2004) "Simulation study for thermal dose optimization in ultrasound surgery of the breast," Med. Phys., vol. 31, no. 5, pp. 1296–1307.
[5] Y. Zhang, W. T. Joines, R. L. Jirtle, and T. V. Samulski, (1993) "Theoretical and measured electric field distributions within an annular phased array: Consideration of source antennas," IEEE Trans. Biomed. Eng., vol. 40, no. 8, pp. 780–787.
[6] W. T. Joines, Y. Zhang, C. X. Li, et al.(1994) "The measured electrical properties of normal and malignant human tissues from 50 to 900 MHz" Medical. Phys, 21 (4).
[7] R. J. McGough *et.al*,(2004) An efficient grid sectoring method for calculations of the nearfield pressure generated by a circular piston. *Journal of Acoustic Society of America,* 115(5).
[8] R. J. McGough, H. Wang, E. S. Ebbini and C. A. Cain, (1994) Mode scanning: heating pattern synthesis with ultrasound phased arrays, *International Journal of Hyperthermia*, 10(3).

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