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Simultaneous estimation of size, radial and angular locations of a malignant tumor in a 3-D human breast – A numerical study

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ABSTRACT

This article reports a numerical study pertaining to simultaneous estimation of size, radial location and angular location of a malignant tumor in a 3-D human breast. The breast skin surface temperature profile is specific to a tumor of specific size and location. The temperature profiles are always the Gaussian one, though their peak magnitudes and areas differ according to the size and location of the tumor. The temperature profiles are obtained by solving the Pennes bioheat equation using the finite element method based solver COMSOL 4.3a. With temperature profiles known, simultaneous estimation of size, radial location and angular location of the tumor is done using the curve fitting method. Effect of measurement errors is also included in the study. Estimations are accurate, and since in the inverse analysis, the curve fitting method does not require solution of the governing bioheat equation, the estimation is very fast.

1. Introduction

Breast cancer has been the second most common cancer in the world for several decades, with highest mortality rate in women. Presently, every 1 out of 4 women carry the risk of having the breast cancer (GLOBOCAN, 2012), out of which, 6% are of age below 45 (American Cancer Society, 2014). Unregulated lifestyles, consumption of contaminated food, alcohol and tobacco products along with certain genetic factors are the main causes of this disease. The increasing number of cases of cancer over the years is a real cause of worry for everyone.

The rate of survival and cure of any patient is decided by the stage of cancer at which it is detected. An early and accurate detection of a cancer help the physicians to better plan the treatment procedure specific to the patient. Modern X-ray based mammographic technique is the most widely used method of diagnosis for the breast cancer. In addition to any other established techniques in 1982, the US Food and Drug Administration approved thermography as one of the techniques for detection of the breast cancer (Mittal and Scott, 2007). Thermography uses infrared image of the skin surface to detect any variation in the temperature profile of the breast (Mitra and Balaji, 2010).

Thermal modeling of a living tissue is a complicated process. In the year 1948, Pennes proposed the first mathematical bioheat model, which is known as Pennes bioheat equation (PBHE) (Pennes, 1948; Wissler; 1998). It is the first mathematical model that successfully described the thermal behavior of a living tissue having blood perfusion and metabolic heat generation rate. Since then, many bioheat models have been proposed by researchers (Charny, 1992), and it has been found that despite its simplified mathematical approach, PBHE holds good for many cases like cancer diagnosis and treatment (Huang et al., 1994, Zhang, 2008; Okajima et al., 2009; Osorio et al., 2009; Gupta et al., 2010; Liu, 2011; Shiha et al., 2014). In the simultaneous estimation of the location and the size of the tumor in the human breast, the present work also utilizes the PBHE.

Human body is a thermal system, and with any malignancy in any portion of the body, thermo-physical and optical properties of the malignant tissue changes. In other words, the thermal signals from the malignant tissue carry the signatures of the malignancy. From the knowledge of the thermal signals, such as temperature distribution, through inverse analysis, the nature of malignancies could be ascertained. To ascertain the malignancy in a human brain and breast, in Das et al., (2013), the present group of authors considered the 1-D tissue, and the PBHE as the governing bioheat transfer equation. With the simulated temperature profiles inside the tissue domain, the direct search method combined with the finite volume method was utilized in the inverse analysis to estimate the size and location a malignant tumor. In Das et al., 2013, the geometry was not only 1-D, but the invasive measurement of temperature was another limitation.

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Nomenclature

A	amplitude of temperature profile, °C
c_p	specific heat of the tissue, J/kg K
c_{pb}	specific heat of the blood, J/kg K
k	thermal conductivity, W/m K
Q_m	metabolic heat generation, W/m^3
Q_s	distributed volumetric heat source due to spatial heating, W/m^3
r	radius, cm
r_b	radius of breast, cm
r_t	radius of tumor, cm
r_T	radial location of tumor, cm
t	time, s
T	temperature, °C
T_a	temperature of the artery, °C
T_e	local heat source temperature, °C
$\bar{x}_c$	center of Gaussian profile, cm

Greek symbols

η_b	blood perfusion rate, m^{3}s/m^3
ρ	density, kg/m^3
ρ_b	density of blood, kg/m^3
θ, ϕ	angular position of tumor, degree or radian

To estimate the unknown attributes of a breast tumor non-invasively, in another work (Das and Mishra, 2013), the authors considered the skin surface temperature of a 2-D rectangular domain of the breast tissue, and used the genetic algorithm (GA) to optimize estimate the location and size of the tissue. Estimation using the breast skin surface temperature, though is convincing, however, in the estimation of parameters, the use of the GA was very time consuming. With skin surface temperature known, in the subsequent work Das and Mishra (2014) proposed a curve fitting method (CFM) to estimate the size and location of a tumor in a 2-D rectangular breast tissue. Compared to the GA, the CFM was exceedingly fast.

Human breast is in fact a 3-D one. In the present study, therefore, consideration is given to a 3-D human breast. With the skin surface temperature of the 3-D breast known numerically, the presence of the tumor, and its attributes like size, radial location and angular location are simultaneously estimated. The skin surface temperature profile of the tumor infused 3-D breast is calculated by solving the PBHE. The finite element method (FEM) based solver COMSOL 4.3a is used to solve the PBHE. Irrespective of the size and location of the tumor in the breast, skin surface temperature profiles are found to be Gaussian. However,

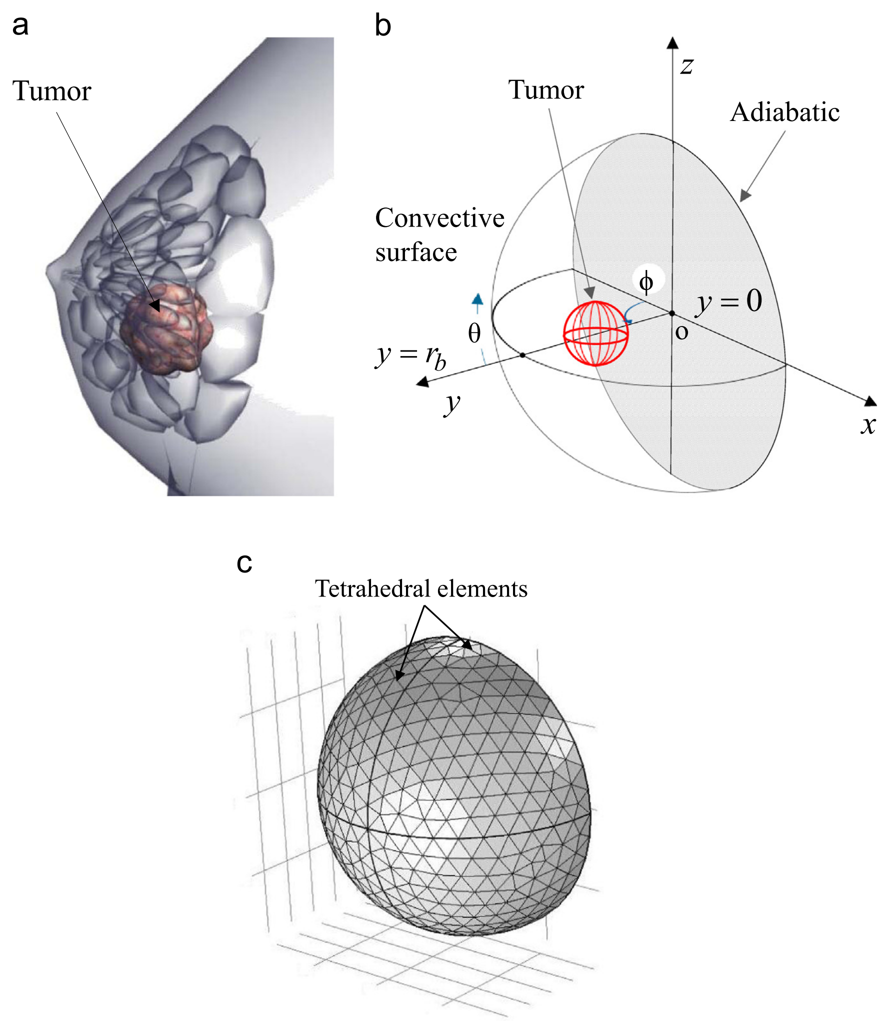

Fig. 1. Schematic of (a) human breast affected by a malignant tumor and (b) 3-D model of tissue-tumor system and (c) finite element tetrahedral grid used for analysis.