Numerical Simulation and Thermal Analysis of Tumor in the Human Body

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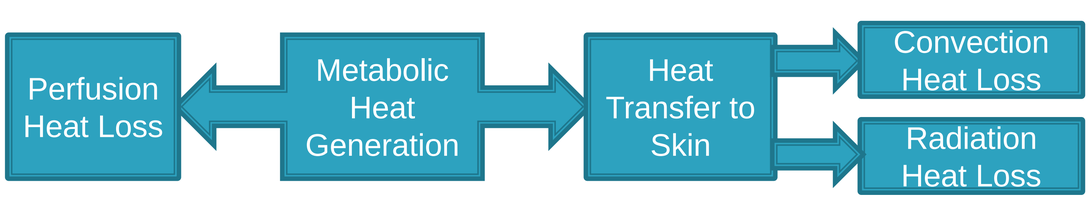
1. Introduction:

Abnormalities in local body surface temperature have been recognized as a sign of disease for centuries, much before humans knew about the cause of ailments or of pain [1]. The idea of this work is to use numerical simulation tools to predict the location, size and metabolism of tumor embedded in any outer body organ of human. Idealized thermal data of an organ, modeled either as a solid rectangle, cylinder or hemisphere respecting to its physical structure, which encompasses a hyperactive region, modeled spherical heat source, has been obtained using finite element method by solving the steady-state Pennes' bioheat equation with non-linear boundary conditions [2].



$$\rho c \frac{\partial T}{\partial t} = \nabla.(k\nabla T) + \omega_b c_b (T_a - T) + Q_m$$

where T is the unknown temperature, k is the thermal conductivity of tissue, ρheat generation rate in tissue, ω_b and c_b are the density, perfusion rate and specific heat of blood, respectively. T_a is the artier temperature and Q_m is the volumetric metabolic heat generation rate in tissue.

2. Computational Methods:

Numerical simulation using the COMSOL finite element software was performed to solve the problem stated in Section 1. Developed 3-D finite element models for the three different physical cases to study the bio-thermal properties of the tissues with tumor (hot nodule embedded in healthy organ) are shown in Fig. 1 to Fig. 3. Bio-thermo-physical parameters of the model are listed in Table 1. Mesh sensitivity analysis were performed to determine the optimum sizes in order to obtain a good resolution in the simulated patterns, and to minimize the computational time. In addition, nodes along the surface area constrained in the normal-translational direction for all three geometries. All other nodes are unconstrained in all directions. A constant temperature of 293.15 K was applied at the entire section as an initial condition.

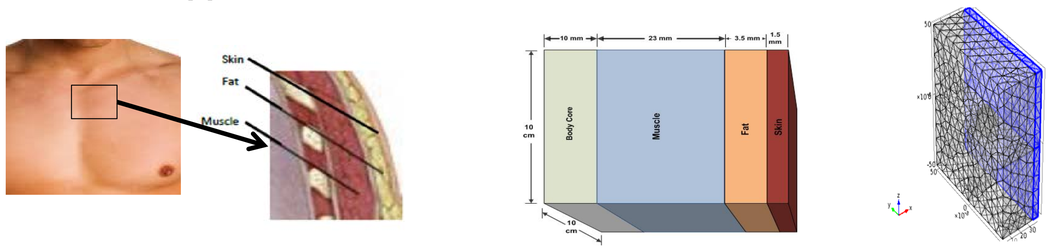


Fig. 1: Chest Model

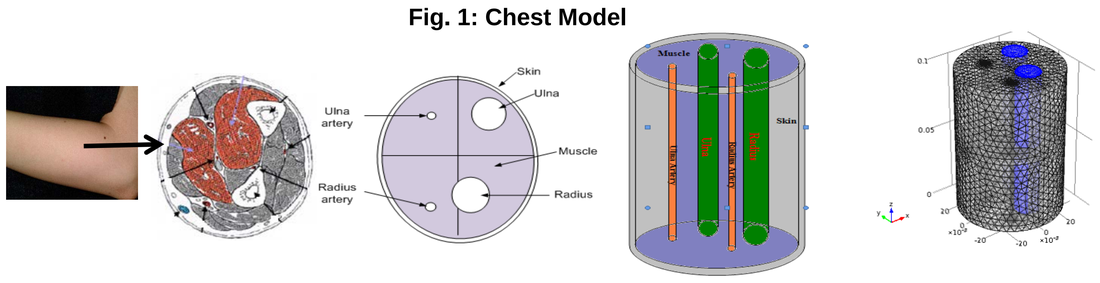


Fig. 2: Forearm Model

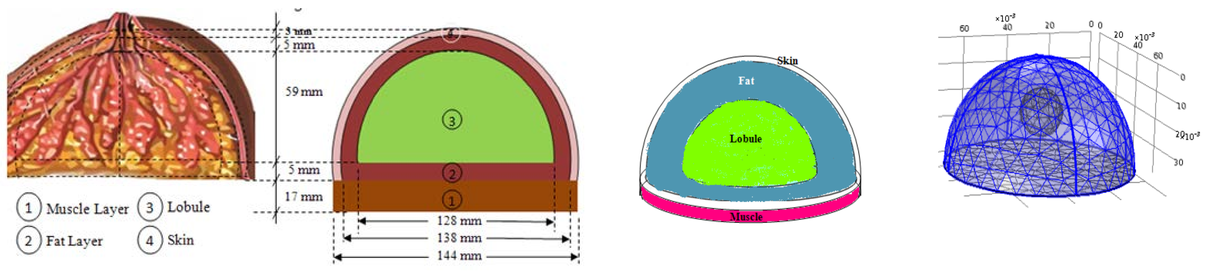


Fig. 3: Brest Model

Parameter	Value	Tissue
Thermal conductivity (W/m.K)	0.52, 0.27, 0.52-0.82	Muscle, lobule, fat, tumor
Metabolic rate (W/m^3)	420, 700, 25000-90000	Fat/skin, muscle, tumor
Perfusion rate (1/s)	0.0052, 0.0016, 0.16-0.047	Muscle, fat/skin, tumor
Heat exchange rate (W/m^{2}K)	8.77, 13.66	Ambient

Table 1: Bio-thermo-physical parameters

3. Results:

The simulated temperature patterns at skin surface and tissue interior for various tumor size (listed in Table 2) are presented in the following Fig. 4 to Fig. 6. In Fig. 4, the 1-D temperature distribution along the line parallel to the xy- plane and directly above the tumor center is presented, Fig. 2b presents its 2-D temperature evolution over the skin surface that bears the sign over which the temperature grows; and also a three level isothermal boundaries having around 0.1 C separation is shown in the isothermal contour plot in the Fig. 2b. Temperature distribution for forearm and breast model are also presented in Fig. 5 and Fig. 6, respectively.

Parameter	T -1	T-2	T-3	T-4
D [mm]	12	12	20	18
h [mm]	16	12	16	12
Q_m $[kW/m^3]$	20	50	70	80
k $[W/(m.k)]$	0.62			
ω_b [1/s]	0.0022			

Table 2: Various tumor size

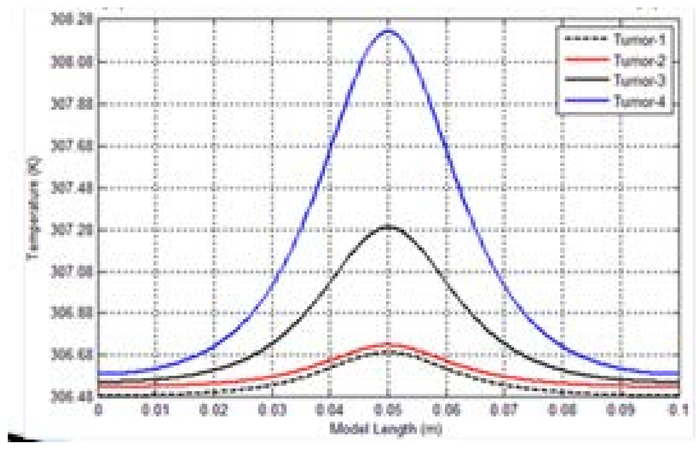


Fig. 4a: Temperature distribution

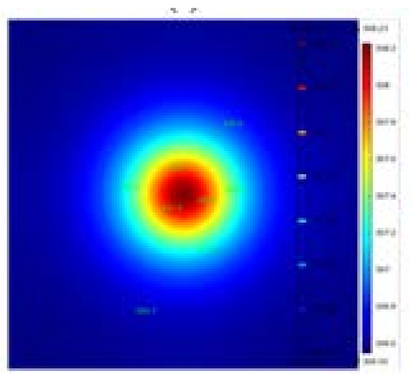


Fig. 4b: Isothermal Temperature distribution

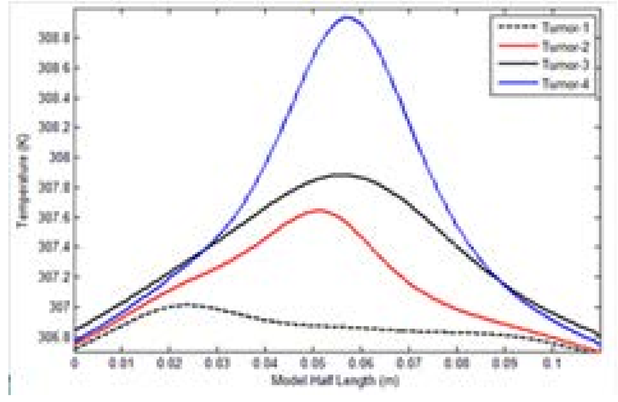


Fig. 5a: Internal temperature distribution

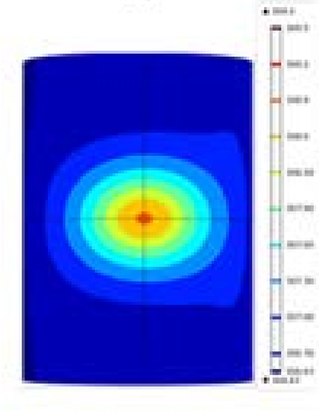


Fig. 5b: Isothermal Temperature distribution

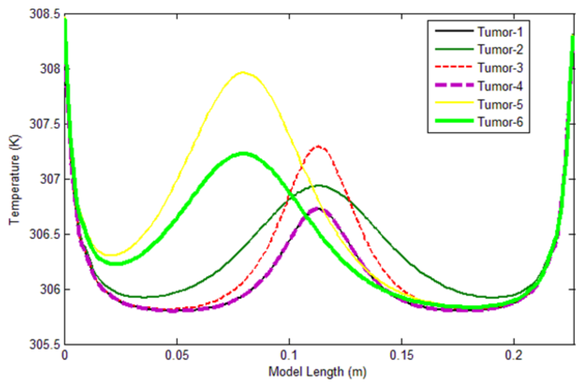


Fig. 6a: Internal temperature distribution

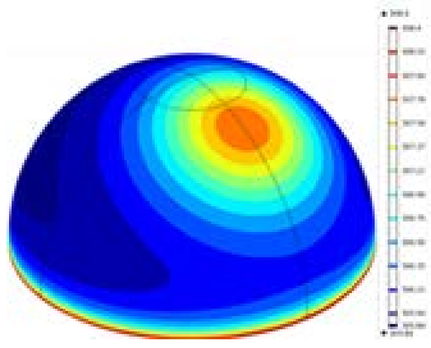


Fig. 6b: Isothermal Temperature distribution

4. Conclusions:

A methodology was developed for the estimation of thermophysical or geometrical parameters of tumor region using the temperature profile on the skin surface. The problem was solved using COMSOL finite element software for physical model of tissues with different geometry. According to the results, the methodology can help to locate tumor region on any external body part which could be useful and important to study tumor evolution after a treatment procedure.

References:

[1] J. Chato, Measuement of thermal properties of biological materials, in: A Shitzer, RC. Eberhart (Eds.), in: Heat transfer in Medicine and biology, vol. 1, Plenum Press, NY, 1985, pp. 167-173.

[2] Kai YUE, Xinxin ZHANG, and Fan YU, 2004. An Analytic Solution of One-dimensional Steady-state Pennes' Bioheat Transfer Equation in Cylindrical Coordinates. Journal of Thermal Science, Vol. 13, Issue 3, pp. 255-258.