

Parametric analysis on the influences of tumor position and size in breast temperature profile

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Abstract— The main objective of this work is the development of a software written in the MATLAB language to aid parametric analysis. It can manage a mesh generator software (GAMBIT) together with a commercial Computational Fluid Dynamics software (FLUENT), following a correct sequence of task and optimizing the file storage in the memory. To simulate the breast geometry it was used a female mannequin as a human phantom. The breast geometry was taken by a coordinate measuring machine (CMM) to obtain the geometrical points over the breast. The commercial software FLUENT was used to calculate temperature profiles of the referred geometry. The finite volume method was used to solve the Bio Heat Transfer Equation (BHTE). Some results for a supposed spherical tumor are shown. Finally some preliminary numerical results were compared with the measured the temperature through the thermographic images of the phantom. In this phantom the heat generate by a breast tumor was simulated by a little electrical lamp.

Keywords: *thermography, breast cancer, numerical simulation, parametric analysis, coordinates measuring machine.*

I. INTRODUCTION

Despite of the fact that the breast cancer is a disease which has an easy diagnosis, it is the second cause of women death in Brazil. This fact occurs because women are still afraid of searching for medical help and do it only when the cancer is in an advanced stage. Due it, brazilian health agencies have made some efforts to alert the people about the importance of the breast self examination, the clinical examination and the mammograms, that is seen as the most efficient way to achieve the earlier diagnose of breast diseases [1].

Thermography uses the infrared radiation emitted by an object or a body. When it is applied together with other traditional examination tools, it can increase the detection of tumors in 14% [2]. The work against breast diseases includes the prevention campaigns, the drugs development and the improvement of the equipments. The big target of these campaigns is the women that have no information about breast disorders or those who

because of their taboos do not search medical help. Some studies showed that small tumors (i.e. diameter less than 1cm) can be easily cured. Moreover, it has the advantages of no emission of ionizing radiation and any physical contact with the patient.

The present work does a parametric study about the influence of the tumor position and of the tumor size in a breast temperature profile. In order to do this, it was necessary to obtain the real breast geometry. In this work, the breast geometry was taken from a female mannequin used as a human phantom. For that, the mesh generator software (GAMBIT) and a coordinate measuring machine (CMM) were used. To perform the parametric analysis, to manage the functions of the used software of fluid dynamics (Fluent) and to generate meshes for the GAMBIT software, a software (called PARAMETRICA) was developed in the MATLAB platform. The objective of these analyses is to identify the influences of the depth and of the size of a tumor in the breast infrared images. In this study all the simulated tumors were of spherical format.

II. METHODOLOGY

To obtain the real breast geometry the mannequin was attached to a coordinate measuring machine CMM (MITUTOYO, CRYSTA547 model). By a computational processing named "scanpak", the point coordinates of the breast were measured. The CMM has its calibration certification emitted by a lab of the Brazilian Calibration Network.

Fig. 1 shows the phantom attached to the workstation. Metal brackets and plastic glue was used for fasten it. By this way the mannequin becomes static and no movement can interfere in the coordinate acquisitions. The origin of the axis was set over the nipple of the reconstructed breast. The acquisition room had a constant temperature of 20°C. The phantom had to be acclimated to the room temperature for about one hour to avoid some errors in the process due to its natural dilatation. The breast geometry was obtained from points over longitudinal lines that swept the whole breast, all of them passing through the nipple. Those points of the breast base were taken with a contour line.

All the acquired points were read by the GAMBIT to build a three-dimensional non-structured mesh of the breast. The computational simulation was processed by the FLUENT to calculate the temperature distribution of the breast. The computational tool "PARAMETRICA" was developed in order to execute the automatic study of the influence of the tumor position and of the tumor size in all the performed simulations.

Fig. 2 shows the process of interaction with the GAMBIT during the mesh generation. The next step is to insert the tumor information inside the mesh. The tumor was a single sphere with known size and position. This work is interested in tumors that are located inside the breast but outside of the thoracic wall.



Figure 1. The phantom attached at the CMM workstation.

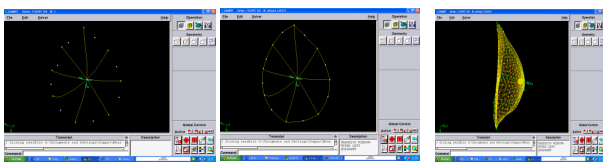


Figure 2. a) Sequence of the point acquisition, b) the building of a contour line, c) the mesh generation.

The simulations were performed for several tumor sizes and positions. For any simulation one new directory is created named with the "patient name", the "tumor position (x, y, z)" and the "radius of the tumor (r)", as can be seen in the "Fig. 3".

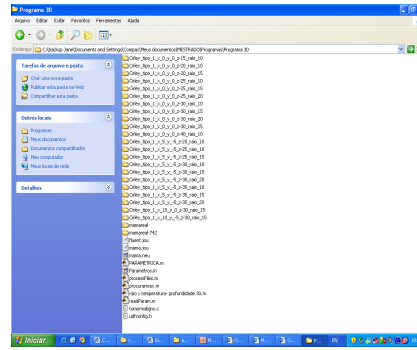


Figure 3. Directories created for the several simulations.

III. RESULTS

Bi-dimensional and tri-dimensional simulations were done. The thermophysical properties used are close to those of a real breast. Some hypotheses were adopted: the heat transferred inside the breast is through the conduction mode; the blood temperature is considered to be at 37 °C; the breast tissue was considered to be the glandular one, because the data of the adipose tissue were not found.

The boundaries and the initial conditions were: the breast surface exchanged heat with the external environment at 23.8 °C through the convection mechanism; the thoracic temperature wall was 37° C; the breast initial temperature was 37° C.

The thermophysical properties are showed in Table 1.

The convection transfer heat coefficient in the exam room is [7]:

$$h = 13.5 \text{ W/m}^2\text{°C}$$

One of the results that were obtained is shown in the Fig. 4, where it is possible to check the reduction of the temperature in a fixed position when the tumor radius is reduced. For example in the position (0mm, 0mm, -30mm) the fall is 6.99% in the temperature value when we do compare the 17 mm tumor radius with the 5mm radius one.

In the Fig. 5 it is shown another result of the simulations performed by the PARAMERICA. We can see the disappearance of the tumor image when its size is reduced. In the "Fig. 5 (a)" the nodule have 20mm radius with the maximum temperature equal to 34.6 °C. In the "Fig.5 (b)" it is observed the nodule image with it has 15 mm radius. The image is not so clear and has its maximum temperature equal to 32.7°C. In the case of a 10mm radius we can observe that the nodule image is almost invisible and the temperature maximum is 31.7 °C.

TABLE I. THERMOPHYSICAL PROPERTIES

TISSUE	k (W/m°C) (a)	ρ (kg/m³) (a)	c (J/kg°C) (b)	ω (s ⁻¹)	Q _m (W/m ³) (a)
Normal -(Glandular)	0.480	1080	3000	0.00018 (d)	450
Malignant Tumor	0.480	1080	3500	0.009 (c)	5790
Fibroadenoma	0.480	1080	3500	0.00183 (c)	65400
Blood	---	1060	4200 (a)	---	

a. (a) Ng EY. et al., 2001; (b) Ekstrand et al., 2005; (c) Furman-Haran et al., 2005; (d) Gupta, 2002.

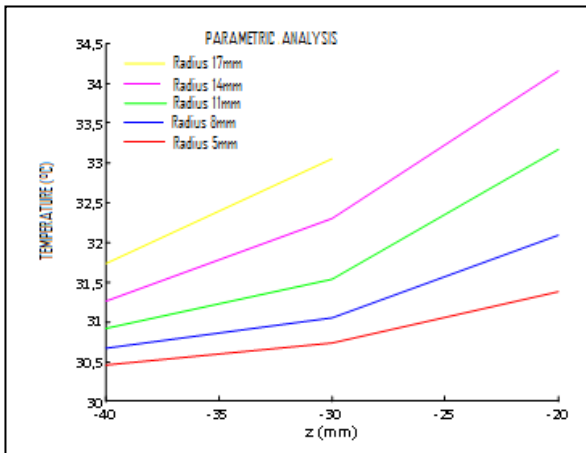


Figure 4. Temperature profile versus deep of tumor with different radius.

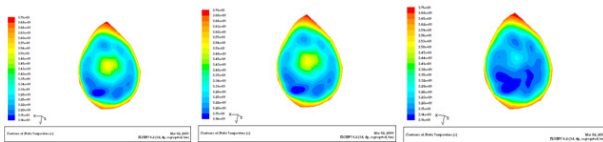


Figure 5. Breast profiles of front (a) Case 1 (b) Case2 (c) Case3.

A preliminary comparison was performed among the temperatures which were obtained by the PARAMETRICA and the temperatures of the real phantom thermogram. An incandescent 7 W lamp was inserted inside the right breast of the phantom that was filled with rubber silicone. This lamp simulates the tumor heat generation for the computational simulation. The volumetric generation heat rate of the lamp used for the calculation was 1.65×10^7 W/m³. The breast was filled with silicone rubber and the inner part of the lamp was considered filled with air. The tungsten was the material used in the filament. The thermophysical properties considered are presented in Table 2.

The lamp was inserted into the silicone during the drying process, enabling the control of the approximate coordinates x, y and z. For the correct measurement of the temperature by the infrared camera it was necessary to obtain an approximated value of the emissivity of the phantom. Because we do not know the exact emissivity of the used material, initially, we adopted the value of 0.92. This is the value used for the porcelain (Özsisik, 1990, in: [8]).

TABLE II. THERMOPHYSICAL PROPERTIES OF MATERIALS

MATERIAL	$k(W/m^{\circ}C)$	$\rho(kg/m^3)$	$c(J/kg^{\circ}C)$
Silicone Rubber	0.21	970	65.68
Air	0.0242	1006.43	1.225
Tungsten	174	19250	132

The surface temperature of the mannequin was measured by calibrated thermocouple (OMEGA HH84), Thus with the emissivity adjusted on the camera the value of 0.93 was obtained, which was very close to the initially used value.

The acquisition of the thermo grams of the phantom had begun when the steady state was reached after the heating was started. The tumor shape was considered to be spherical, because this is the unique geometry that is permitted by the PARAMETRICA.

During the filling of the phantom breast the x and y coordinates of the location of the lamp were obtained empirically using the strings to measure the distances between the inner walls of the breast. The lamp was modeled as a sphere of 13.1 mm radius obtained from the actual volume of the lamp. The lamp filament was modeled as a sphere of 4.7 mm radius. Later, the sizes of strings and z coordinate were obtained through a ruler.

For the calculations the boundary conditions we consider: the heat exchange between the breast surface and the environment (at 26.4 °C) occurred by convection; the thoracic region presenting 37.2 °C; the influence of convection, radiation, and evaporation effect in the used transfer heat coefficient, which is adopted as 13.5 W/m² °C [7].

Fig. 6 shows the lateral thermogram of the right breast of the phantom, where the maximum measured temperature was 53.3 °C. “Fig.7” shows the frontal image of the same breast. Its maximum temperature was 55.8 °C. We can see that exist a difference of 1.25% when we compare the results obtained from the thermogravimetric of Fig.7 with the simulation of Fig.8. This difference increases to 3.26% when the simulation is compared with Fig.6. Fig. 8 shows the maximum temperature obtained in the simulation for the phantom.

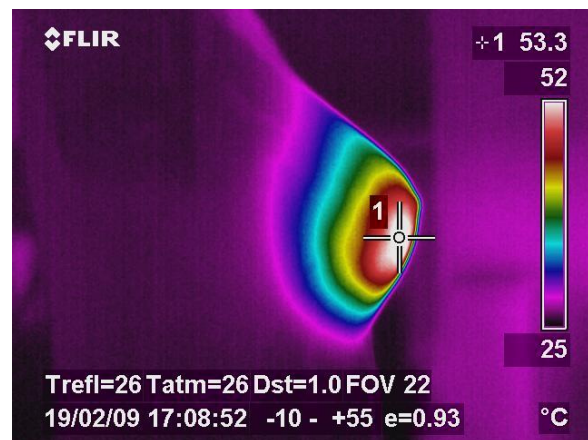


Figure 6. Thermo gram from the phantom breast (lateral view).

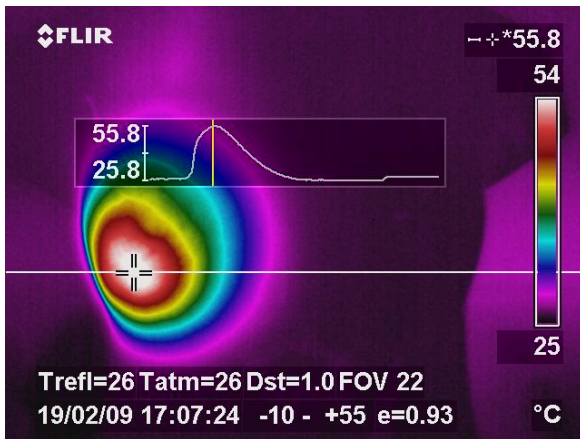


Figure 7. Thermogram from the phantom breast (frontal view).

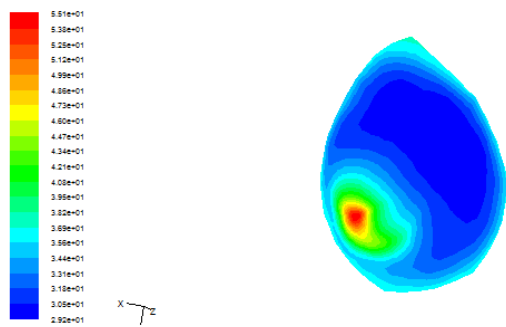


Figure 8. Calculated breast temperature distribution (frontal view).

IV. DISCUSSION

The developed computational tool PARAMETRICA has still some limitations such as the spherical shape of the tumor. It does not yet perform simulations of tumors adhered to the wall of the breast, as well. Although these facts it managed very satisfactorily the successive executions of the commercial software FLUENT and GAMBIT.

The analysis shows that there is an influence of the position and of the size of the tumor on the calculated breast temperature. If the tumor is far from the surface of the breast or when its size is diminished, its image can disappear from the surface of the breast. The opposite effect is observed if the tumor grows in size or when it approaches the surface of the breast.

Comparisons with the experiments are still incipient and show some coincidence especially in the lateral view. Improvements should be done also in order to fill properly the breast phantom with the silicone rubber, and for the correct positioning of the heat source. The shape of the lamp is closer to that of a cylinder and this form is not yet implemented in the PARAMETRICA.

V. CONCLUSIONS

Although the geometrical model used to represent the tumor in the PARAMETRICA is different from the model used in the phantom it was possible to perform a preliminary comparison between the maximum temperature obtained by the PARAMETRICA and the maximum temperatures shown in the thermograms. Better comparisons with the temperatures acquired from the infrared images need to be improved. It is desirable that we be able to compare temperatures at all the points of the images.

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