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NUMERICAL ANALYSIS OF HEAT TRANSFER IN A BREAST CONSIDERING TWO CANCER TYPES

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Abstract. *The aim of this work is to perform a numerical evaluation of thermal behavior of two breast cancer types: ductal carcinoma in situ and invasive ductal carcinoma. Analysis is developed considering a two-dimensional geometry that characterizes the anatomy of a breast. The thermal behavior is obtained using numerical solution of bioheat equation, i.e., Pennes's equation, solved by commercial COMSOL software. Temperature profiles of healthy and compromised breast are compared in specific tumor regions and on skin surface. The results indicate that the greatest temperature variation occurs in invasive ductal carcinoma case. These results can significantly help in the development of new diagnosis techniques using thermal images obtained by infrared thermography.*

Keywords: *breast cancer, tumor, thermal behavior, numerical simulations, thermography.*

1. INTRODUCTION

Cancer is a group of more than 100 diseases, which have in common the cells disordered growth that invade tissues and organs, and can spread to others body regions. If, these cells divide rapidly, they tend to form malignant tumors (cancerous cells). On the other hand, a benign tumor means a localized mass of cells that multiply slowly and resemble their original tissue, rarely constituting a life threat (NIH, 2017). The malignant tumor developed in the breast, as a consequence of genetic changes in some breast cells, is called breast cancer, which normally occurs in the breast ducts and lobes (CANCER, 2017).

According to the World Health Organization, breast cancer is the leading cancer affecting women in the world. Early diagnosis is the best way to reduce the risk of death from this type of cancer since prevention involves several environmental and behavioral aspects that are difficult to control (WHO, 2017).

The diagnosis of breast cancer can only be established, in deed, by means of a suspicious tissue biopsy after the analysis of a pathologist. It is observed, however, that the biopsy occurs only after the detection of some suspicious alteration citep BCW which in turn can be obtained through physical or imaging examinations (mammography, radiography, tomography, ultrasound, resonance magnetic, thermography, among others) (MD, 2005).

Thermography is a non-invasive technique that uses an infrared camera to obtain images of the breast surface. Because cancer cells grow and multiply at a greater rate than normal cells, blood flow and metabolism in the affected regions are greater. As blood flow and metabolism increase, the temperature in that region increases. This increased heat is then diffused through the tissue until its effect could be verified at the superficial region of the breast, thus allowing its detection by thermography.

In recent years, the breast cancer diagnosis using skin surface temperature (thermography) has been considered by the medical community as good an adjuvant method. It means, thermography can be used but only together with other established method such as tomography, magnetic resonance imaging (MRI) or mammography (CANCER.ORG, 2017).

In this work, a numerical model was developed to analyze the heat transfer in mammary tissue for two breast cancers types using commercial COMSOL software. This study aims to present the thermal behavior of the main breast cancer types, showing the temperature changes caused by tumors internally and in the breast skin surface, to encourage research about thermography ability for the early breast cancer diagnosis.

2. FUNDAMENTALS

2.1 Breast anatomy

Figure 1 shows the anatomy of a breast, which is basically composed of three tissues types: glandular, fibrous and adipose tissues. The mammary glands consist of a series of ducts and secretory lobules. Each lobule consists of many alveoli drained by a single lactiferous duct. The fibrous (muscle) tissue has the function of supporting the internal structures. The adipose (fat) tissue, besides to coat the entire milk gland, fills the spaces between the acini, ducts, and fibrous tissues, contributing significantly to the shape, volume, and contour of the breasts (FOUNDATION'S, 2017).

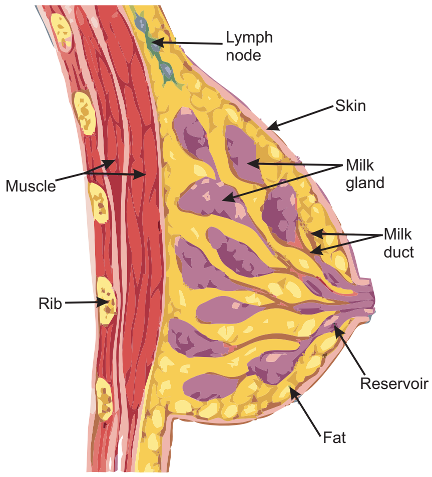


Figure 1: Anatomy of a breast (Swierzewski, 2017).

2.2 Breast cancer

Breast cancer consists of a malignant tumor that develops from the breast cells. The breast cancer type is generally determined by the origin of the growth of cancer cells, which is almost always in the lobules or ducts. In rare cases, breast cancer can start in other tissues, such as adipose and fibrous tissues (NIH, 2017).

Breast cancer can be in situ, with no risk of invasion and metastasis, with a cure rate of approximately 100%. Invasive tumors (when invade the cells basement membrane) can be cured, if early diagnosed. The most common breast cancer types are ductal carcinoma in situ (DCIS), invasive ductal carcinoma (IDC), lobular carcinoma in situ (LCIS), and invasive lobular carcinoma (ILC) (SOCIETY, 2017). In this work, only the healthy breast, DCIS and IDC were studied.

2.2.1 Ductal Carcinoma In Situ

Figure 2 illustrate the ductal carcinoma in situ (DCIS), that is a non-invasive breast cancer. In DCIS, the cells do not spread through the ducts into the adjacent breast tissue. DCIS represents 20% of new breast cancer cases. Almost all women at this disease stage can be cured.

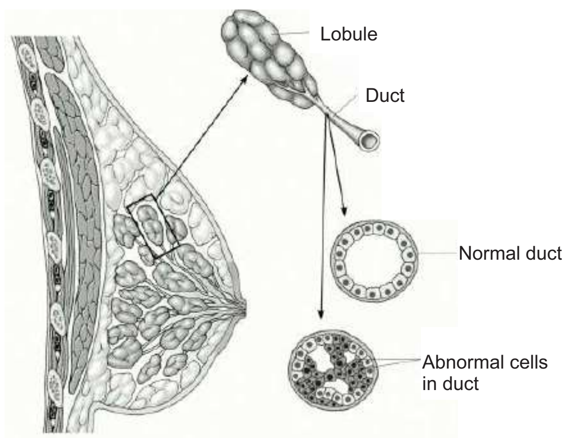


Figure 2: Ductal carcinoma in situ (DCIS) (Society, 2017).

2.2.2 Invasive ductal carcinoma

Invasive ductal carcinoma (IDC) is the most common breast cancer type. IDC starts in the breast milk duct, ruptures the duct wall, and grows into the breast adipose tissues. IDC corresponds to 80% of invasive breast cancers.

2.3 Bioheat Equation

Heat transfer in living organisms can be characterized using Eq. (1), known as Pennes's equation (Pennes, 1948).

$$\nabla(k.\nabla T) + Q_p + Q_m + Q_e = \rho c \frac{\partial T}{\partial t} \tag{1}$$

where Q_p is the heat source due to blood perfusion, Q_m is the volumetric metabolic heat generation, and Q_e is related to an external heat source.

The heat source due to blood perfusion (Q_p) is characterized by convective heat transfer effected by the blood through the capillary vascularization present in living tissue, which is proportional to the temperature difference between arterial blood entering the tissue and venous blood exiting the tissue (Charny, 1992). This term is given by

$$Q_p = w\rho_s c_s (T_a - T) \tag{2}$$

where w is blood flow rate, ρ_s is the blood specific weight, c_s is the blood specific heat, T_a is the arterial blood temperature, and T is the tissue temperature.

3. RESULTS AND DISCUSSION

The heat transfer in biological tissue is analyzed using commercial COMSOL software. The two-dimensional breast anatomy, shown in Fig. 1, was recreated in CAD as shown in Fig. (3) for computer simulations in steady-state. Figure (3b) shows the boundary conditions of the studied model. Dirichlet and Robin boundary conditions were considered in this thermal problem. Dirichlet boundary condition specify the temperature value on internal surface line (rib) as T_c = 37 °C (body internal temperature). Robin boundary condition defines the external surface line (skin surface) exposed to convective medium, with convective heat transfer coefficient is equal to h = 10 W/mK and ambient temperature of T_∞ = 25 °C.

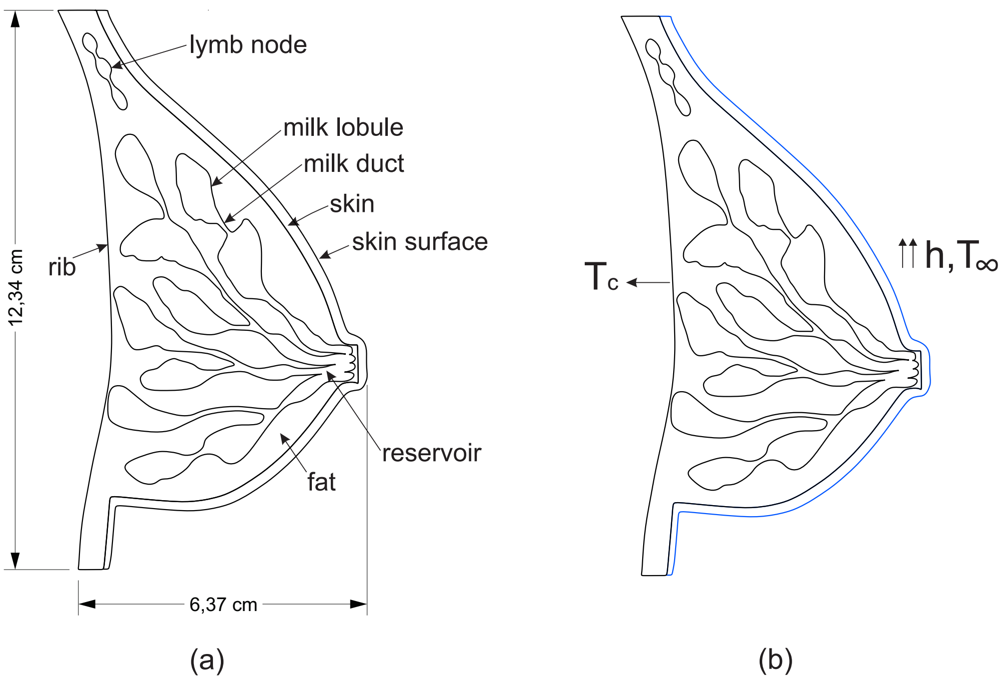


Figure 3: Breast anatomy model: (a) breast composition and dimensions, (b) boundary conditions.

Table 1 lists the thermal and biological properties used to solving bioheat transfer problem in COMSOL. The physical models are discretised into finite element models. Mesh is composed by 21527 triangular elements, the minimum element quality is 0.3167 mm and the maximum element aspect ratio is 1.666×10^{-5}.

Table 1: Tissues thermal and biological properties (J.P.Agnelli *et al.*, 2010; Hossain and Mohammadi, 2016)

Properties	Symbols	Value and unit	Tissue types
Thermal conductivity	k	0.21 W/mK	Skin, Fat
		0.52 W/mK	Milk duct, Milk gland, Lymph node
		0.62 W/mK	Tumor
Blood perfusion	w	2.2×10^{-4} $1/s$	Skin, Fat
		5.2×10^{-4} $1/s$	Milk duct, Milk gland, Lymph node
		1.6×10^{-2} $1/s$	Tumor
Specific mass	ρ	1000 kg/m^3	Everywhere
Specific heat	c	4186 J/kgK	Everywhere
Volumetric metabolic heat generation	Q_m	420 W/m^3	Skin, Fat, Milk duct, Milk gland, Lymph node
		3×10^5 W/m^3	Tumor

The analysis consists in obtaining the thermal behavior (COMSOL) of three different breast conditions:

- Case 1 - Healthy (without tumor)
- Case 2 - With ductal carcinoma *in situ*
- Case 3 - With invasive ductal carcinoma

Figure4 shows the temperature distribution in a healthy breast (without tumor). The temperature profile ranging from the maximum internal temperature of 37 °Cto the surface temperature of the skin (exposed to a convective medium) of 31.56 °Cis observed in this figure.

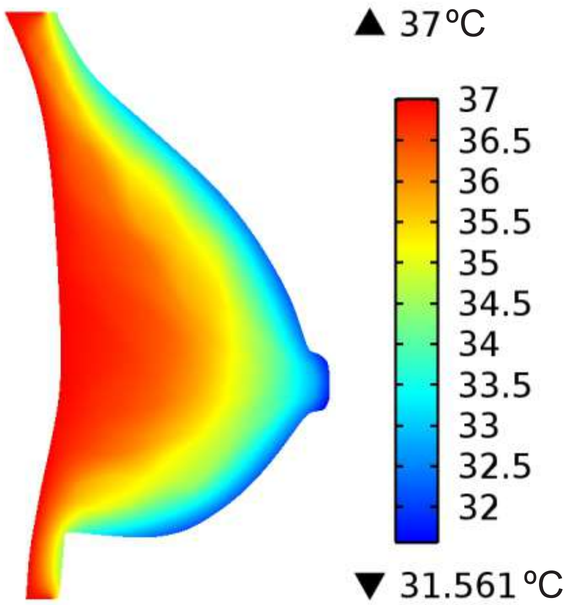
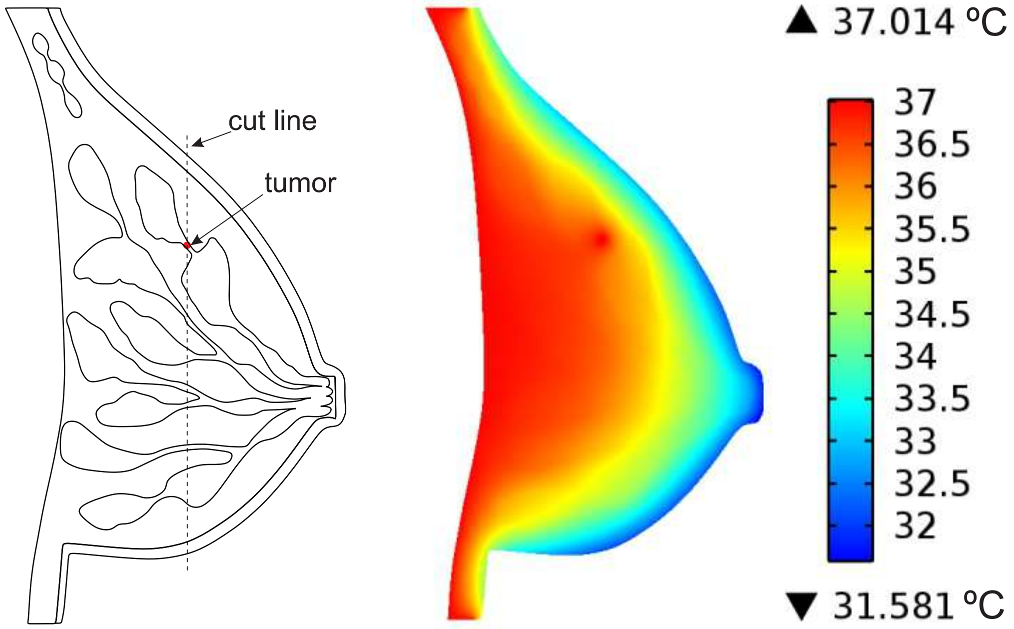


Figure 4: Thermal behavio of a healthy breast.

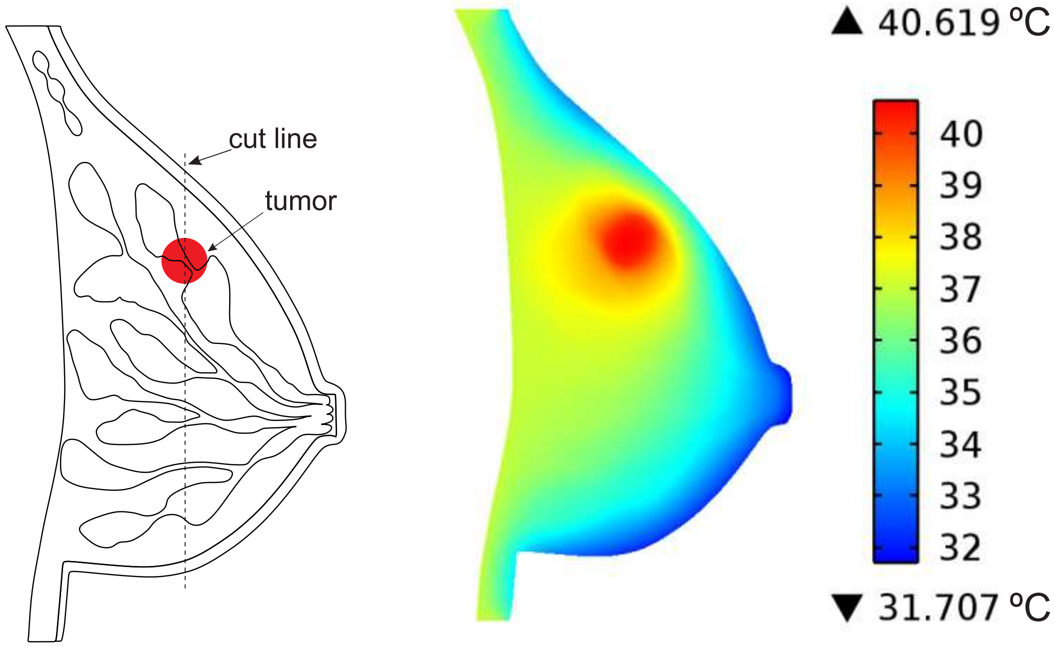
Figure 5 a shows the numerical model used in the breast with ductal carcinoma in situ. The tumor with a diameter of 2 mm is located inside the milk duct. A cut line can be seen in Fig. 5. This line is created for the comparison between the temperature profiles of the healthy breast and the breast with the DCIS tumor (Fig. 4). Figure 5 b presents this comparison. It is noted that because the tumor has a small size, only a small change in the distribution of temperature near the tumor is noticed.



(a) (b)

Figure 5: Ductal carcinoma in situ: (a) numerical model with tumor, (b) behavior thermal

Fig.6a shows the model used in the breast with invasive ductal carcinoma. However, in this case, the diameter of the tumor is equal to 10 mm and breaks the duct wall and invades the adipose tissue and the lobe. Again, the cut line used for the comparison of the profiles is observed. Figure 6b presents this comparison. In this case, a large increase in temperature is observed in the region near the tumor.



(a) (b)

Figure 6: Invasive ductal carcinoma: (a) numerical model with tumor, (b) behavior thermal

Figure 7 shows the comparison (cut lines) between breast temperature with (IDC and DCIS) and without tumor. The maximum temperatures in the region of the center of the tumor are 40.61 °Cand 37.01 °C, respectively, for the IDC and DCC , while in the same region without tumor is 35.50 °C. As expected, it is observed that the most aggressive tumor

(IDC) presents the region with the highest temperature.

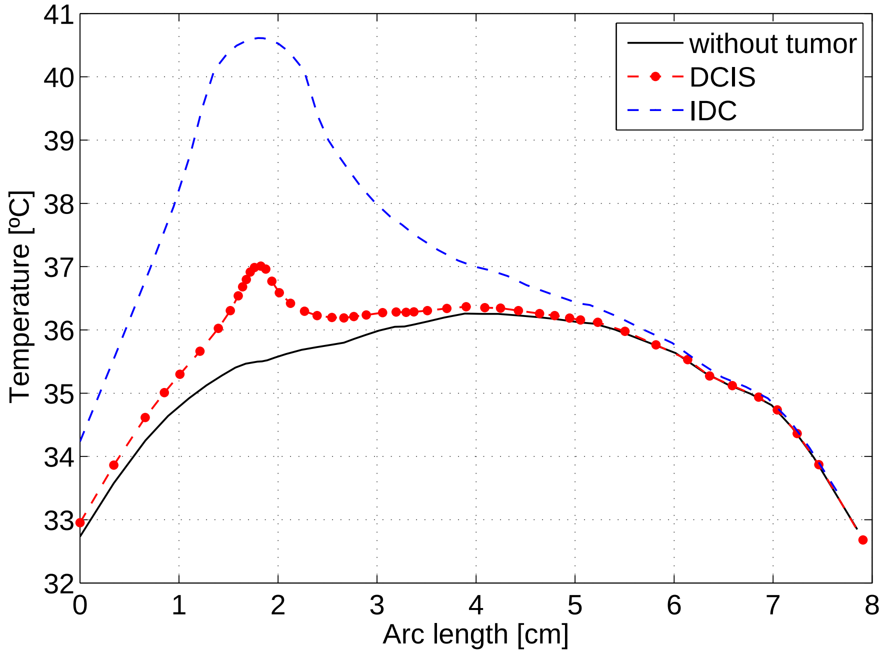


Figure 7: Comparison between the temperatures of the breast without tumor, with DCIS, and with IDC (cut lines).

Fig. 8 presents the temperature perfil on skin surface for all studied breasts cases. The highest temperature increase was observed in the breast with IDC. Besides the fact that this tumour hat largest diameter it is the closest to the skin surface.

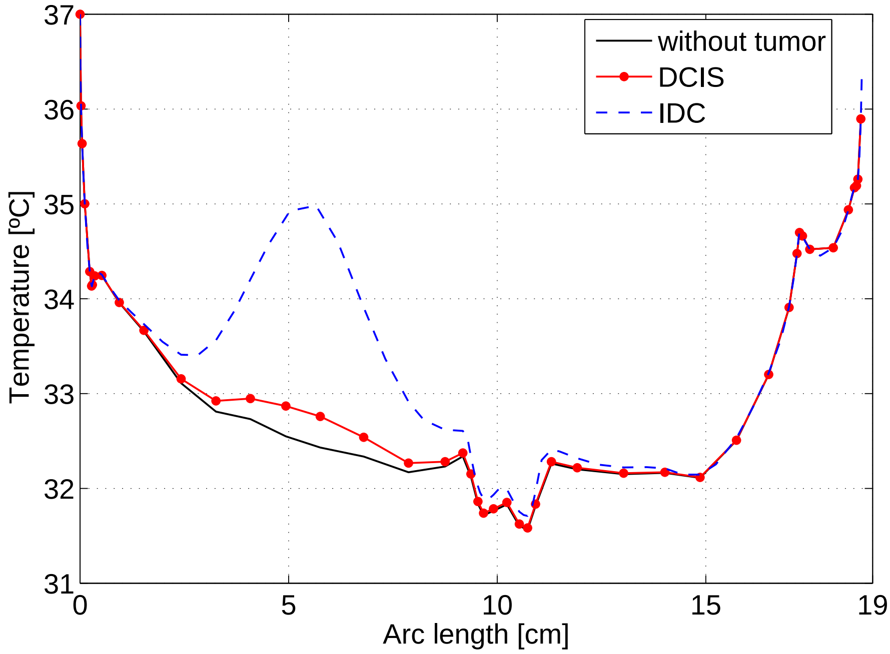


Figure 8: Comparison between the temperatures in skin surface of all studied breasts cases.

4. CONCLUSION

The thermal behavior of a breast with and without tumor was analyzed. Breast temperature profiles were presented for three different cases (with and without tumor). It was observed that the thermal field in the breast is altered mainly by the presence of invasive tumor. The thermal effect of these tumors was also determined on the surface of the breast. It was observed, in this case, that the temperature of the skin of the breast is significantly altered by the different types of tumors. This information can contribute to the increase in the specificity of the thermography technique as a diagnostic examination.

5. ACKNOWLEDGEMENTS

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