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BREAST SKIN HEATING PARAMETRIC ANALYSIS AND ITS EFFECTS IN CARCINOGENIC INCLUSIONS

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Abstract. *This work proposes to study the way in which the penetration of a heating applied on a breast skin surface, aiming show the influence of tumor thermal behavior in infrared thermography analyzes. COMSOL MULTIPHYSICS was used for computational simulations, of a 2D anatomical breast model, whith properties from skin, fat, lymph node, milk lobule and milk duct. Analyses were developed considering how occurs the heat propagation on the breast tissues, in regions with most inclusions presence, as a ductal carcinoma* $in\ situ$ *and invasive, and also Lobular carcinoma invasive. The behavior of a constant and periodic heating was analyzed and compared, considering several time intervals. Results indicate that a periodic heating offers greater thermal comfort during thermographic exams, because the surface termperatures are lower than the constant heating. Increases in the time of skin heating increases its thermal penetration region, improving deep tumor detection capability.*

Keywords: *breast cancer, skin heating, heat transfer, thermography, numerical simulation.*

1. INTRODUCTION

In the United States, three types of cancers account for half of the cases diagnosed among women, these are: breast, lung & bronchus and Colon & rectum. Breast cancer represent 30 % of all diagnostics of cancers in women, which corresponds to 268.600 diagnostics and 66.020 death (Siegel *et al.*, 2019). Development of early diagnostic techniques prevents high deaths among women, in 2018 were avoided between 45.3 and 58.3 % of the deaths caused by breast cancer, due to the development of mammography and auxiliary techniques of treatment and diagnosis in 2018 were avoided between 45 and 53 of the deaths caused by breast cancer (Hendrick *et al.*, 2019).

Mammography, ressonance imaging and ultrasound are the most commonly used techniques for early breast cancer diagnosis and yet have limitations. Mammography, the main breast cancer screening technique, has high rates of false-negative or false-positive results, and is inefficient for women with dense breasts (especially younger women), among other limitations (Boyd *et al.*, 2007).

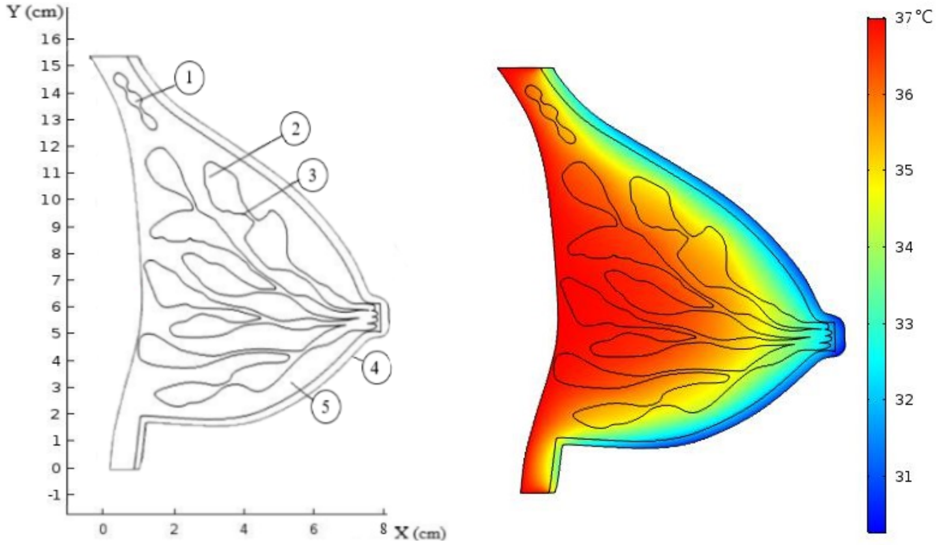
Currently, research has been developing some techniques to improve the exams such as the use of infrared thermography. The International Academy of Clinical Thermology states that thermography has the ability to detect signs of cancer at a very early stage, but alone it is not able to detect the location of the tumor, so it can only contribute to the tumor detection of another examination, such as mammography (IACT, 2018).

Some studies resort to changes in the breast contour conditions examined, for example, by applying cooling or heating to the skin, in order to optimize the results obtained by thermographic exams (Cheng and Herman, 2014). Dutta and Kundu (2018) developed an analytical study of heat propagation in biological tissues for constant and variable heat flux at the surface of the skin correlated with the treatment of hyperthermia. In this study mentioned the heat fluxes were analyzed: constante, sinusoidal and cosine, and its impaired tissues close to the skin, it can be concluded that when the heat flux is periodic the superficial results are better for the location of inclusions in the breast skin.

The type of breast cancer is determined by the type of cell where the tumor spreads. The most common types of breast cancer are ductal carcinoma $in\ situ$, invasive ductal carcinoma and invasive lobular carcinoma Li *et al.* (2005). The primary goal of this work was to perform a comparative analysis on the propagation of heat applied to the breast skin, when using a constant and a periodic heating. Analyzes were performed on the total time of skin heating application. Heat propagation regions analyzed was chosen to verify that thermal penetration is sufficient to achieve inclusion in the breast, in cases the inclusion is in the ductal carcinoma $in\ situ$, invasive ductal carcinoma and invasive lobular carcinoma.

2. MATERIALS AND METHODS

Breast model used in the simulations represents a real breast anatomy, where was used the properties of the tissues presented in the Figure 1a: 1. Lymph node, 2. Milk lobule, 3. Milk Duct, 4. Skin and 5. Fat. Figure 1b shows the thermal profile of simulated breast at steady state that was used as a reference to be related to transient analyzes.



(a) (b)

Figure 1: Breast model used in the simulation, (a) tissue distribution and (b) thermal breast profile on steady state.

Table 1 shows the values of the properties of each tissue used in the computational simulations. The heat convection coefficient was 10 $\text{Wm}^{-2}\text{K}^{-1}$, the blood temperature was 37 °C and the ambient temperature was 22 °C.

Table 1: Thermophisical properties of the tissues. (Zhou and Herman (2018) and Figueiredo *et al.* (2019).)

Properties	Tissue		
	Skin, Fat	Lymph node, duct and lobule	Tumor
Thermal conductivity, k ($\text{Wm}^{-1}\text{K}^{-1}$)	0.21	0.52	0.62
Blood perfusion, ω_b (s^{-1})	0.00022	0.00052	0.01600
Density, ρ (kgm^{-3})	1000	1000	1000
Specific heat, c ($\text{Jkg}^{-1}\text{K}^{-1}$)	4186	4186	4186
Volumetric heat generation, Q_m (Wm^{-3})	420	420	5000

Figure 2 presents the mesh used in the simulations in the software COMSOL, which has 19,735 triangular elements in its domain. The softwar uses the Finite Element Methodology to solve the problems, when in bioheat problems the resolutions are made by Eq 1, proposed by Pennes (1948).

$$k\nabla^2 T + w_b \rho_b c_b (T_b - T) + Q = \rho c \frac{\partial T}{\partial t} \tag{1}$$

where the properties k, c, w e ρ represent the thermal conductivity, specific heat, blood perfusion and density of breast tissue. b represent when the properties are of the blood. Q and T represents the metabolic heat generation rate and the temperature, of the tissue.

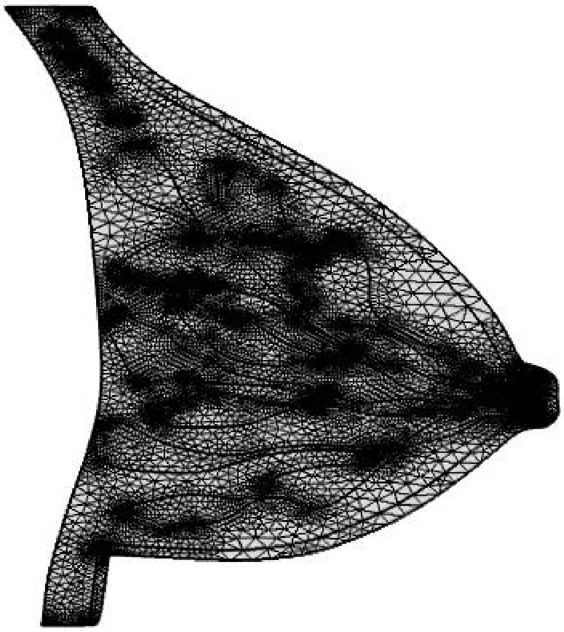


Figure 2: Mesh used in computational simulations.

A next step the skin heating of the breast are presented, in the case of the constant rate, Figure 3a and a periodic heat rate, Figure 3b. In this work, such divergent heating conditions were explored in order to identify the potential of using a thermal recovery period during skin heating application, which would be the heat wave intervals in which the breast is not being heated.

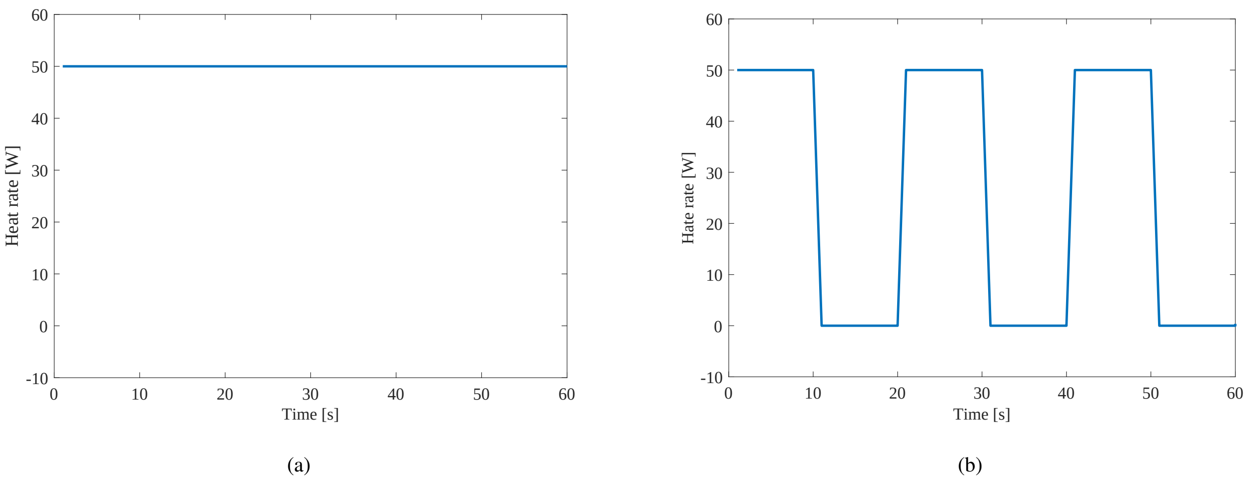
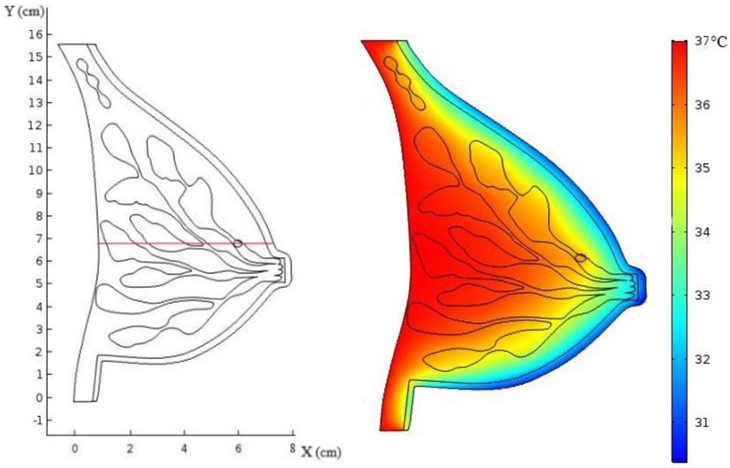


Figure 3: Heat rate used to skin heating, (a) constant and (b) periodic.

3. RESULTS AND DISCUSSIONS

Figueiredo *et al.* (2019) studied two main regios for the occurrence of Ductal carcinoma $in\ situ$. In this work, one of these casos was evaluated, where the tumor is centered in the coordinates x = 5.7 cm and y = 6.8 cm, with diameter of 3 mm. The cut line on breast was constructed to cross the center of the tumor and allow analysis of the temperature variation caused by the skin heating in the tumor region, this was called thermal penetration, as shown in Figure 4a. Figure 4b shows the thermal behavior of the breast with the Ductal carcinoma $in\ situ$ on steady state.



(a) (b)

Figure 4: Breast model used in the simulation of Ductal carcinoma *in situ*, (a) analyzed cutting region and (b) breast thermal profile.

Figure 5 shows the temperature profile in the case of steady state and after the application of a constante heating (50 W) on skin with different duration times. These temperatures are on the chosen cutting region and shown in Fig. 4a. One can observe that the temperatures near the skin increase with the increase of the total time of duration of the heating, what was expected.

It is necessary that the heating of the skin propagate in the tissues of the breast to the point of reaching the region of the tumor, so that the heating causes alterations in the thermal response of the tumor. To make this observation, a point was constructed which represents the location where the temperature profile after skin heating is 99 % of the steady state temperature profile, from this point it is considered that the heating does not cause temperature variation, points are represented by green diamonds in the graphs.

In this study, the ductal carcinoma *in situ* is located in x = 5.7 cm, for this situation can be observed: the skin heating lasting 1 min is not enough to reach the tumor; the skin heating lasting 5 min reaches the tumor, but does not cause major changes in temperature relative to the steady state; finally, the skin heatinh lasting 10 min causes greater temperature variations in the region of inclusion.

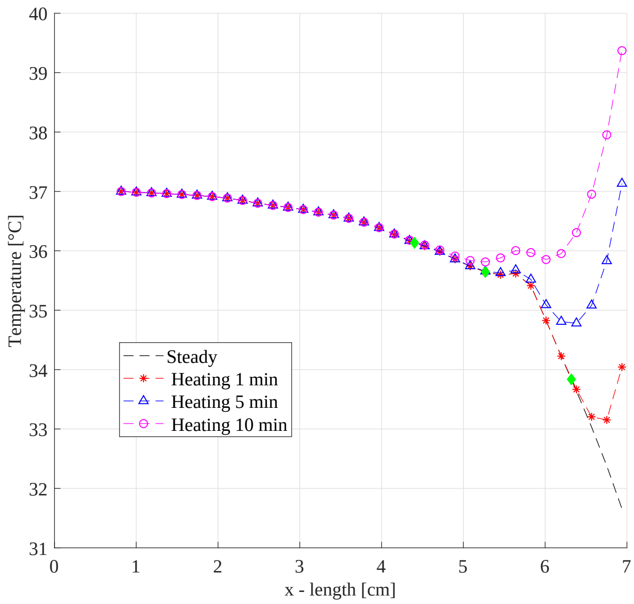


Figure 5: Temperature profile on the cut line of the breast with Ductal carcinoma *in situ* when applied to constant skin heating.

Figure 6 shows the temperature profile on the cut line shown above, when heating applied with the periodic heat rate.

The increase in total application time causes higher temperatures on the surface of the skin, in the same way that it was observed for heating with constant heat rate. However, it can be observed that the periodic heating reaches the same thermal penetrations of the constant heating, and the surface temperatures lower by 3 °C. This effect provides greater comfort in the performance of thermographic exams, justifying the use of periodic heat rate.

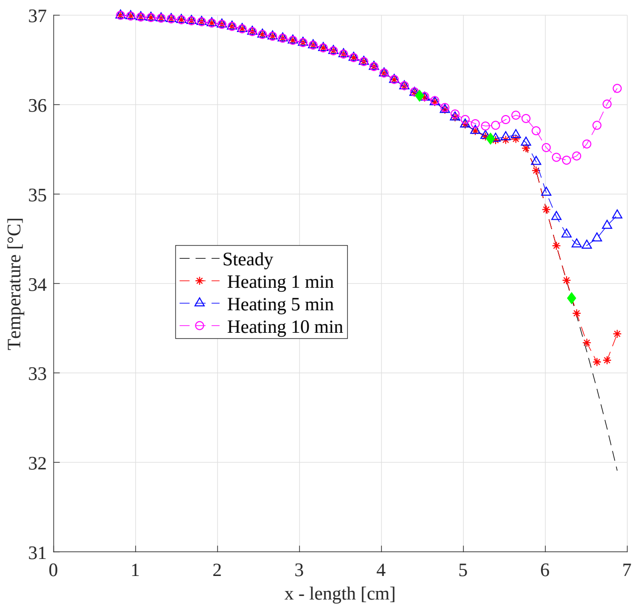
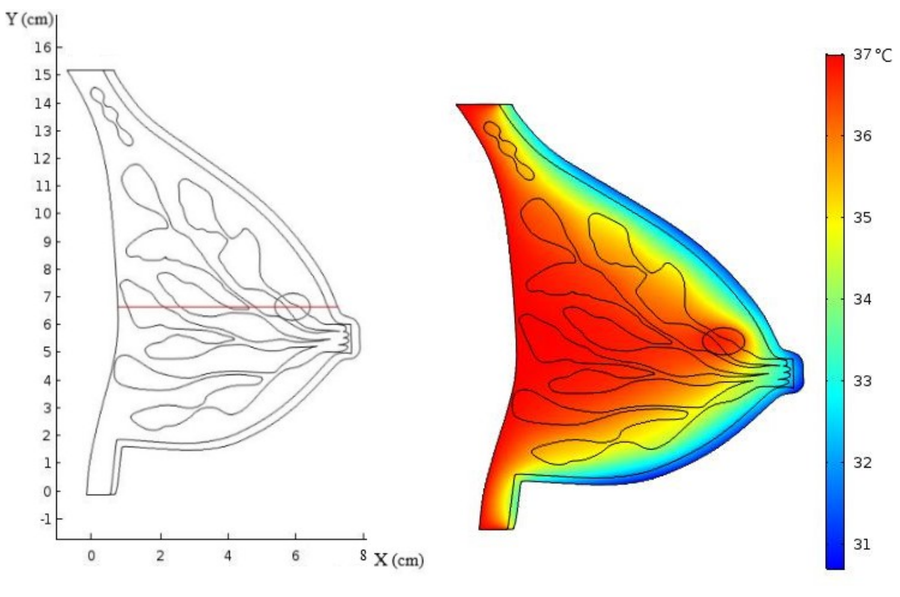


Figure 6: Temperature profile on the cut line of the breast with Ductal carcinoma *in situ* when applied to periodic skin heating.

Ductal carcinoma invasive is represented with a tumor centered on the coordinates x = 5.7 cm e y = 6.8 cm, with diameter of 10 mm. The cut line on breast was constructed to cross the center of the tumor and allow analysis of the temperature variation caused by the skin heating in the tumor region, as shown in Figure 7a. Figure 7b shows the thermal behavior of the breast with the Ductal carcinoma invasive on steady state.



(a) (b)

Figure 7: Breast model used in the simulation of Ductal carcinoma invasive, (a) analyzed cutting region and (b) breast thermal profile.

Figure 8 shows the temperature profile inthe section region shown in Fig. 7a, when heating with the periodic heat rate is applied. From this analyis it is possible to notice the temperature increase in the breast skin caused by the tumor, which is close to the surface (like Ductal carcinoma *in situ*) but has a considerable size. For this case, the heating of 5 min also causes a increase of temperature in the tumor region, but as in the previous analysis the temperature rise is more considerable when the heating is for 10 min.

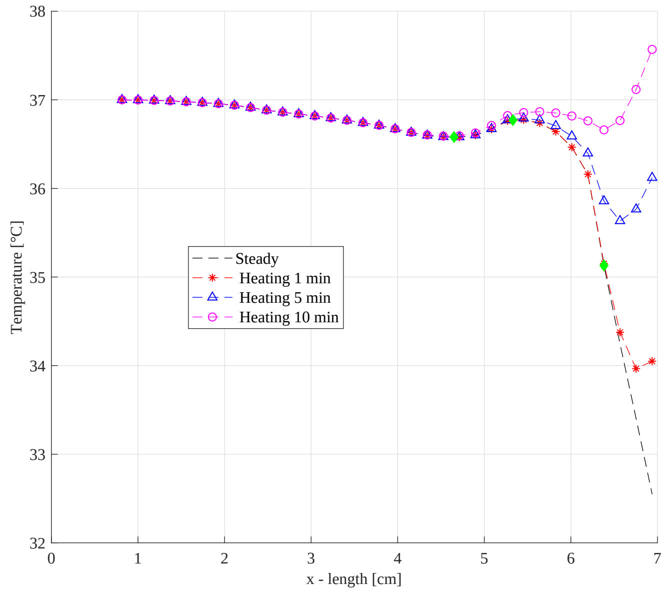
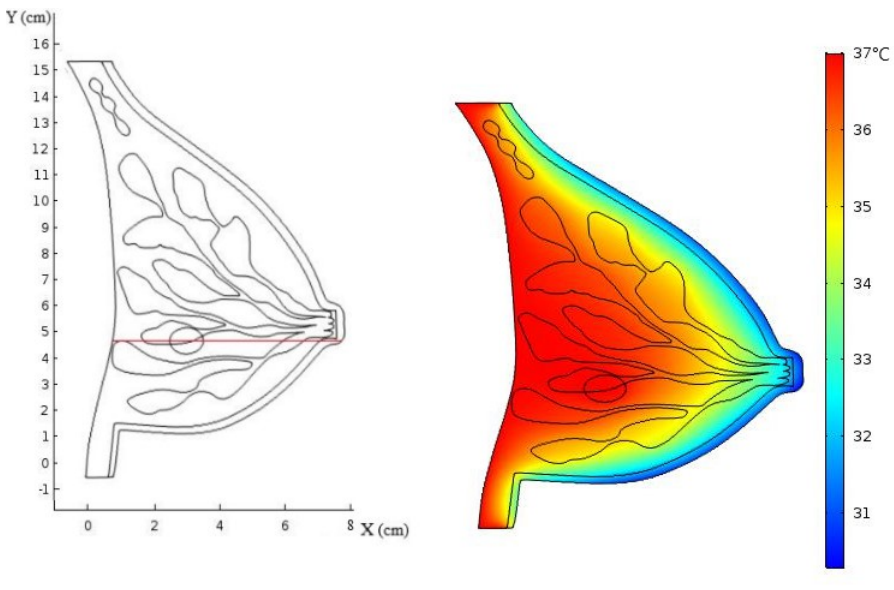


Figure 8: Temperature profile on the cut line of the breast with Ductal carcinoma invasive when applied to periodic skin heating.

Lobular carcinoma invasive is represented with a tumor centered on the coordinates x = 2.9 cm e y = 5.0 cm, with diameter of 10 mm. The cut line on breast was constructed to cross the center of the tumor and allow analysis of the temperature variation caused by the skin heating in the tumor region, as shown in Figure 9a. Figure 9b shows the thermal behavior of the breast with the Lobular carcinoma invasive on steady state.



(a) (b)

Figure 9: Breast model used in the simulation of Lobular carcinoma invasive, (a) analyzed cutting region and (b) breast thermal profile.

Figure 10 shows the temperature profile in the section region shown in Fig. 9a, when a periodic heating is applied. In thes case, the tumor stays very close to the muscular region of the breast, so breast temperatures are cofused with body temperature. As shown in the graphs of the previous cases, the 10 min thermal propagation can not reach this tumor due to its location, therefore a new simulation was performed with a heating applied for 20 min. With these results ir can be noticed that even applying a skin heating that penetrates the breast until the tumor region, it is still not able to cause changes in the tumor region when it is very close to the breast muscle base, thus having much incluence on muscle temperature.

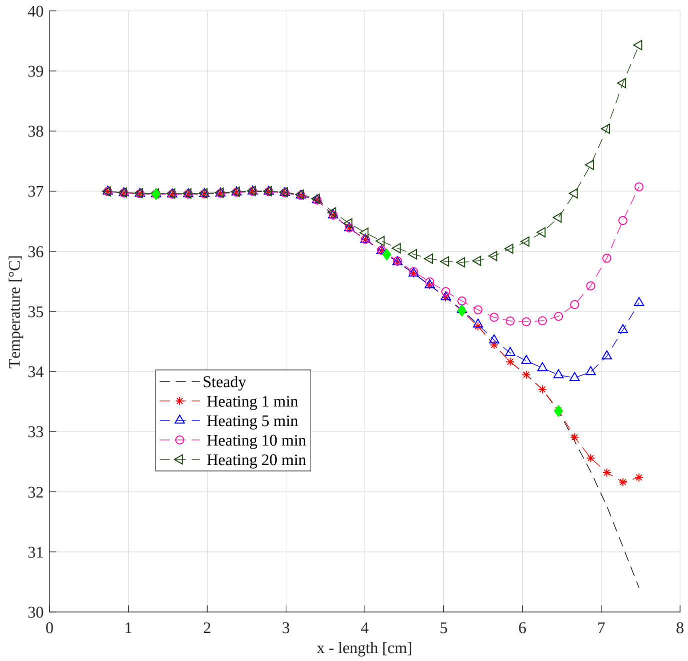


Figure 10: Temperature profile on the cut line of the breast with Lobular carcinoma invasive when applied to periodic skin heating.

4. CONCLUSION

From this work it is possible to undertastand a profile heating in pulses is more effective for skin heating than one of constante value, when you want to change the temperature of the tumor. Because the periodic skin heating can achieve the same thermal penetration as the constante, while keep a lower skin temperature, which positively implies the application of the technique in laboratory tests.

On the other side, the effect that the heat rate has on carcinogenic inclusions it was observed that in Ductal carcinoma $in\ situ$ and invasive the periodic skin heating during 10 min causes changes in the tumor region. For Lobular carcinoma invasive, it was seen that due to the close proximity of the tumor to the breast base it is not possible to cause changes in tumor temperature even with longer heating.

5. REFERENCES

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