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Original

Thorax thermographic simulator for breast pathologies

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Abstract

New diagnostic techniques for breast cancer detection have been developed and improved, in order to increase patient life expectancy. These techniques were emphasized in early detection of tumors with smaller dimensions, providing a better prognosis. Along with these new methods, it is necessary to propose training devices or tools to support health professionals to use them and rely on them. Our purpose is to develop a device to support thermographic analyses for early breast pathology detection. A programmable thorax was developed with the aim of simulating hyperthermic characteristics of breast pathologies in a defined area. Temperature distributions of breast tissue with a cancerous lesion were mathematically modeled using Pennes's equation, and a thermo-visual control system was built within the physical model in order to simulate a local thermal pattern of a patient's thermal image with infiltrating ductal carcinoma. Our results showed a good approximation of simulated thermal patterns to real images from a patient. In consequence we archived to obtain a thorax simulator device as first step in training health professionals in thermography techniques and to impulse the use of this method for early detection of breast pathologies.

Keywords: Breast pathologies; Thermography; Simulation; Thermal; Pattern; Training device

1. Introduction

Breast cancer is an important concern worldwide because of its high incidence. It is a common type of cancer both in developed and developing countries. This type of cancer represents 25% of women's cancer globally. The 2030 projection, according to Panamerican Health Organization, estimates more than 596,000 new cases and more than 142,100 mortal cases in the region, especially Latin America and the Caribbean (Acharya, Ng, Tan, & Sree, 2012). The options of treatment had lead health professionals to search tools for the detection of cancer in the early stages. Mammography is one of the most widely used techniques because it has good results in general population; however, it has important limitations in sensitivity and specificity, for example, limited diagnosis of women with dense breasts, especially young women. (Ng, Acharya, Keith, & Lockwood, 2007).

For this reason, new diagnostic techniques for breast cancer detection have been developed and improved, in order to increase patient life expectancy. These techniques focus on early detection of tumors with smaller dimensions providing a better prognosis; one of them is the infrared thermography (thermal imaging) that is a procedure used to record body thermal patterns using an infrared (IR) camera. The color segmentation of infrared thermal images is used for detecting a tumor's region by different temperature patterns associated with angiogenesis, inflammation, and blood supply increase (Acharya et al., 2012; Arora et al., 2008; EtehadTavakol, Sadri, & Ng, 2010).

Also, it is feasible to obtain delimited patterns with common data related to pathologies because temperature distribution in the body is influenced by many biological and physiological complex factors (Kateb, Yamamoto, Yu, Grundfest, & Gruen, 2009). Recent studies recognized that infrared thermography increases the possibility of early breast cancer detection and

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analyzed the technique performance using strict indoor controlled environmental circumstances (Etehadtavakol & Ng, 2013; Ng, 2009). The temperature of breast has been also previously analyzed with multiple sensors in the breast obtaining discrete data in three conditions, normal, benign and cancer as a static system. That analysis concluded that it is possible to obtain reliable data for a diagnosis, but a deeper analysis on dynamic systems is needed (Ng et al., 2007).

Thermography is less uncomfortable for the patients because it does not imply direct contact, radiation or compression. It is useful for women of all ages and different conditions like pregnancy, breastfeeding, implants, dense or fibrocystic breasts, and pre or post menopause. Even if women are under a hormonal replacement treatment could be candidates to use thermography for pathology detection (Ng & Sudharsan, 2001b; Ng, 2009). In past decades, thermography had many disadvantages compared with X-ray and mammography, such as thermographic cameras with low resolution, problems finding the dimensional origin of the lesion, or lack of training in the use of specialized equipment. Then it was not possible to use thermography to early pathology detection, alongside with the fact that it is a functional study (unlike anatomical studies such as ultrasound and mammography). Nevertheless, nowadays, using strict standardized protocols to interpret thermal patterns, proper infrared trained personnel have achieved reliable results (Acharya et al., 2012; Etehadtavakol & Ng, 2013; EtehadTavakol et al., 2010; EtehadTavakol, Chandran, Ng, & Kafieh, 2013; Ng et al., 2007; Ng, 2009). Thermography has an average sensitivity and specificity of 90%, as documented in literature (Ng, 2009).

However, it is important to use the technique along with X-rays because some studies have found that small tumors in deeper regions do not have a significant isolated impact on the surface and in consequence could not be identified by thermography (Ng & Sudharsan, 2001a). Still, we believe that thermography should be most frequently used for pathology detection because thermal patterns could be easily integrated and analyzed by a computer while mammography, in general, is linked to the radiologist's interpretation and it is more probable to yield false positives or negatives (Ng & Sudharsan, 2004).

Despite this international situation, in the Mexican health system, this technique has not been recognized as an efficient pre-diagnostic tool or complementary tool. We believe that this is related with the lack of tools for training personnel properly or the difficulty to transport those tools to remote communities. For that reason, we propose the design and construction of a programmable thorax model to promote the use and confidence of health care professionals on infrared thermography, as a prediagnosis tool. This simulator device could be used in training for thermography operators. The aim is to display a simulation of normal and abnormal thermal morphologies, facilitating thermographic analyses for early breast pathology detection.

Simulations of breast tissue have already been reported for technical imaging applications. Using computational simulations of breast models, a difference of temperature distribution is highlighted, depending on the size, depth and metabolic rate of the tumor (Agyingi, Wiandt, & Maggelakis, 2015; Kennedy, Lee, & Seely, 2009; Mital & Scott, 2006; Ng et al., 2007) These breast tissue phantoms were reported using static models; also, we are proposing a dynamic physic model that could simulate the thermal pattern according to parameters of real thermal images from patients. Our model will be a phantom of a woman's thorax from ectomorph complexion with an electric actuator within hydrogel. Therefore, it is possible to simulate thermal breast pathologies by integrating a thermo-visual control system in the electric actuator, inside a medium with physical features comparable with mammary gland characteristics.

The methodology consisted in computational modeling of temperature distribution on two conditions: 1) healthy and 2) cancerous breast tissue, followed by the construction of the physical thorax model device. Later, a thermo-visual control system was added for thermal patterns simulation, then the ITAE criteria algorithm was implemented with the purpose of evaluating the control performance, and finally a simulated thermal image was compared to a patient's thermal image (with infiltrating ductal carcinoma).

2. Methods

2.1. Mathematical model of healthy and cancerous tissue

Pennes's equation was used in order to obtain a temperature distribution model from a tumor in the mammary gland (González, 2007; Lin et al., 2009; Paruch & Majchrzak, 2007; Pryor, 2011); this equation describes the distribution of the tissue temperature as a function of its blood perfusion and metabolic rate. This study used mammary tissue parameters. For tumor simulation, a heat source was added with tumor tissue parameters. The equation was solved by the Element Finite Method (EFM) in COMSOL Multiphysics 4.3 and was fixed with average parameters of mammary gland reported elsewhere (Pryor, 2011).

$$\rho C_p \frac{\partial T}{\partial t} - k\nabla^2 T = \rho_b C_b \omega_b (T_b - T) + Q_{met} \quad (1)$$

where

ρ = tissue density
C_p = heat capacity
k = thermic conductivity
T = tissue temperature
ρ_b = blood density
C_b = blood heat capacity
ω_b = blood perfusion
T_b = blood temperature
Q_{met} = metabolic rate

The simulation was based on models involving two different tumor sizes of 1 and 2 cm in diameter, both with 5 cm of depth and 3 different tumor metabolic rates of 29,000, 45,000 and 80,000 W/m^3. For the model's geometry, a hemisphere with a diameter of 18 cm was used, the average breast size used in Gautherie's study (Gautherie, 1980) (Fig. 1). The boundary condition of the system was the heat exchange by the concave part of the system, while the initial conditions were set at T = 309.5 K.

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