A review of thermography as promising non-invasive detection modality for breast tumor

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Abstract

From the last 1.5 decades of complying with the strict standardized thermogram interpretation protocols by proper infrared trained personnel as documented in literature, breast thermography has achieved an average sensitivity and specificity of 90%. An abnormal thermogram is reported as the significant biological risk marker for the existence of or continues development of breast tumor. This review paper further discusses the performance and environmental requirements in characterizing thermography as being used for breast tumor screening under strict indoor controlled environmental conditions. The essential elements on performance requirements include display temperature color scale, display temperature resolution, emissivity setting, screening temperature range, workable target plane, response time and selection of critical parameters such as uniformity, minimum detectable temperature difference, detector pixels and drift between auto-adjustment. The paper however does not preclude users from potential errors and misinterpretations of the data derived from thermal imagers.
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1. Introduction

Thermography is a non-invasive, non-contact skin surface temperature screening method that is economic, quick and does not inflict any pain on the patient. It is a relatively straightforward imaging approach that detects the variation of temperature on the human skin surface. Thermography is widely used in the medical arena [5,7,9,12,14,16,17,21,32,35,47–52,55–59,63,68, 70,71,73,76,80,85]. These include the detection of breast cancer, which is the refocus of many biomedical researches in recent years [1]. The earliest breast thermogram was reported by Lawson [37–40]. He observed that the venous blood draining the cancer site is often warmer than its arterial supply. However, these measurements have never been confirmed by others and the findings might thus have been questionable. Thermograms alone however will not be sufficient for the medical practitioner

to make a diagnosis. Analytical tools such as bio-statistical methods and artificial neural network are recommended to be incorporated to analyze the thermogram objectively [30,48,52, 55–57,60,87]. Notice that these approaches may improve the interpretation of thermal images which may lead to a higher diagnostic accuracy of infrared thermography, but these methods for analysis are not more objective than any other highly accurate and precise measurement. With the rising use of thermal imaging, there is a need to have regulations and standards to provide accurate and consistent results. The standards are mainly based on the physics of radiation and thermoregulation of the body.

Like in many other developed countries, breast cancer is the main cancer afflicting women in Singapore today. Every day, 3 women are diagnosed with breast cancer here and every week 5 women die in this part of the world from malign breast disease. But breast cancer is a highly treatable disease, with 97% chance of survival if discovered early. Application of thermography in suspected malign breast disease holds great promise in detecting early cancer [35]. Gros and Gautherie [22] reported a large scale study comprising 85,000 patients screened. Cul-

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mination of the data resulted in a 90% sensitivity and 88% specificity for thermography [22,41,74] when compared with clinical mammogram examination. In brief, a quick review of 15 large scale studies from 1967 to 1998, breast thermography revealed an average sensitivity and specificity of 90% [31,61, 64,82,83]. The researchers summarized the study by stating that "the findings clearly support that early identification of women at high risk of breast cancer based on the objective thermal assessment of breast health results in a dramatic survival benefit" [6,18,29].

Keyserlingk et al. [35] observed that the tumor diameter missed in thermogram was 12.8 mm and that in a mammogram was 16.6 mm. They conducted a study using a retrospective case-control design to investigate the potential adjuvant benefit that could be gained from infrared imaging in a multi-modality diagnostic setting. This study was classified as a level-four evidence because interpretation of both the index test and the comparators were not blinded, and it is unclear what information was available to those interpreting the reference standard. However, the authors themselves have been aware of the restrictions of their study and have expressed the need for further investigations in a controlled, prospective manner. Keyserlingk et al. [35] reported that the sensitivity for the detection of ductal carcinoma by clinical examination alone was 61%, by mammography alone was 66%, and by infrared (IR) imaging alone was 83%. When suspicious and equivocal mammograms were combined the sensitivity increased to 85%. A sensitivity of 95% was obtained when suspicious and equivocal mammograms were combined with abnormal IR images. However, when clinical examination, mammography, and IR images were combined, a sensitivity of 98% was achieved [35]. Both IR imaging and mammography technologies are of the complimentary nature. Neither used alone is sufficient, but when combined, each may counteract the deficiencies of the other. It also seems evident that a multimodal approach would serve the screening best for other diseases such as orthostatic disease in children [75] or imaging of Raynaud's phenomenon [46], respectively. A combination of clinical examination, mammography and IR imaging may provide the greatest potential for breast conservation and survival. Thermography may have the potential to detect breast cancer 10 years earlier [19,35] than the traditionally golden method—mammography. However, due to inconsistencies in diagnosis from breast thermograms, it has not been commonly used and is not regarded as a reliable adjunct tool to mammography in Singapore currently. This review paper aims to achieve a high level of consistency in the use of breast thermography by providing some pointers to its performance evaluation.

The main components recommended to characterize thermal imaging as a potential complimentary tool for breast cancer detection include:

- Thermal radiation theory.
- Preparation of patient.
- Examination environment.
- Standardization of thermal imager system.
- Image capture protocol.
- Image analysis protocol.
- Reporting, archiving and storing.

2. Thermal radiation theory

2.1. Planck radiation law

Any object whose temperature is above absolute zero Kelvin emits radiation at a rate and with a distribution of wavelengths. This wavelength distribution is dependent on the temperature of the object and its spectral emissivity, $\varepsilon(\lambda)$. The spectral emissivity, which may also be considered as the radiation efficiency at a given wavelength, is in turn characterized by the radiation emission efficiency based on whether the body is a blackbody, grey body or selective radiators. The blackbody is an ideal body. It is a perfect absorber that absorbs all incident radiation and is conversely a perfect radiator. This implies that a blackbody absorbs and emits energy of the maximum theoretically possible at a given temperature. Within a given wavelength:

- $\varepsilon = 1$ for blackbody.
- $\varepsilon = $ constant < 1 for grey body.
- $0 \leqslant \varepsilon \leqslant 1$ for selective radiator.

The radiative power (or energy) and its wavelength distribution is given by Planck radiation law [10]:

$$W(\lambda, T) = \frac{2\pi hc^2}{\lambda^4}\left[\exp\left(\frac{hc}{\lambda kT}\right) - 1\right]^{-1} \text{W cm}^{-2}\,\mu\text{m}^{-1} \quad (1)$$

or in number of photons emitted:

$$P(\lambda, T) = \frac{2\pi hc}{\lambda^4}\left[\exp\left(\frac{hc}{\lambda kT}\right) - 1\right]^{-1}$$

$$\text{photons s}^{-1}\,\text{cm}^{-2}\,\mu\text{m}^{-1} \quad (2)$$

where:

h (Planck's constant) $= 6.6256 \times 10^{-34}$ J s.
c (velocity of light in vacuum) $= 2.9979 \times 10^8$ ms^{-1}.
k (Boltzmann's constant) $= 1.38054 \times 10^{-23}$ W s K^{-1}.
$\lambda = $ wavelength μm.
$T = $ temperature K.

Human skin emits IR radiation mainly in the range of 2–20 μm wavelength and with an average peak at 9–10 μm [6]. With the application of Plank's equation and Wien's law, it is found that approximately 90% of the emitted IR radiation in humans is in the longer wavelengths (6–14 μm).

2.2. Heat transport mechanism of skin and physiology of thermal signatures

The skin is the largest organ in the human body and helps to maintain the core body temperature within a narrow range by modifying heat transfer processes from the body and to the environment and vice versa (thermoregulation). Heat transport to, within and from the skin utilize all three mechanisms of

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