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Image Enhancement by Microwave Double Irradiation for Early Diagnosis of Breast Carcinoma

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Abstract: Cancer is the uncontrolled growth of abnormal cells; if not detected and treated at the early stage cancer would become fatal. Early detection of the disease increases the survival rate. Though there are several diagnostic methods, each method is having its own merits and demerits. In this study, a method of obtaining an active thermo gram by irradiating the patient's breast twice using a microwave source of 2450 MHz and allowing them to cool naturally after every radiation is proposed. Results of the experiments conducted using phantom models show the temperature difference between the cancerous and normal breast tissues is increased by the first irradiation considerably; the second irradiation further elevated the temperature difference between the normal and breast tissues. Results obtained show that double irradiation technique produces a temperature difference of about 6°C between the normal and cancerous breast tissues for a cancer tumor which produces a temperature difference of 1°C between normal and cancerous tissues by passive radiation. Hence, there is a marked intensity variation between the normal and cancerous tissues of the breast in thermogram which makes the early diagnosis of breast carcinoma possible. A thermogram of normal breast is taken as a base line image to simulate the images that would be produced by the proposed method; MATLAB7.1 is used for simulating 38, 41 and 43.75°C thermal images. Thermal images for 37, 38, 39 and 43.75°C were taken using Thermal image (FLIR system-Model FLIR i5-Sweden).

Key words: Breast carcinoma, double irradiation, early diagnosis, image enhancement, MATLAB 7.1, microwave, thermal imaging

INTRODUCTION

Cancer is the uncontrolled division of abnormal cells which result in an in orderly cell growth (Human Biology, 2010). It is reported by Indian Health news that the incidence of breast cancer in India is on the raise that one in 22 women in India is likely to suffer from breast cancer during her life time One in eight women (Medindia on Mobile, 2006) is affected by this dangerous disease in America (BreastCancer. Org, 2011). Breast cancer remains the second leading cause of cancer induced deaths despite the advances taken place in treatment methods (Kennady *et al*., 2009). Stage -0 and stage-I cancers have a survival rate of 100%. At stage-IIA it is 92% which is 81% at stage- IIB. When tumor grows to stage-IIIA, survival rate declines to 67% and it is 52% at stage III -B. At the fourth or final stage it is reduced to 20% (American Cancer Society, 2011). The cancer growth is classified into different stages based on the size of the tumor and its nature.

Stage-0 cancer is non invasive and stage- I cancer is invasive and is about 2 cm in size. When cancer grows into 2 to 5 cm tumor, it is known as II -A type cancer; II -B type cancer is one at which the tumor may be of a size less than 2 cm but few auxiliary lymph nodes are affected. When tumor is of a size greater than 5 cm and more lymph nodes are affected, it is called III -A type cancer. III -B type cancer is not characterized by its size but by the invasion it makes through the breast skin. Most advanced form of cancer is the fourth or final stage cancer, at which the cancer cells have moved far away from the breast and the other organs of the body have also been affected. (Fiset, 2007). Presently clinical examination and X-ray mammography are used for detecting breast cancer. Clinical examination suffers a sensitivity rate of 65%. X-ray mammography is inexpensive and reliable (Keyserlingk *et al*., 2002) but the patient is exposed to ionizing radiation and the test is uncomfortable to the patient for the breast is compressed (Pragati *et al*., 2010). If the breasts are dense or with implants, it is very difficult to obtain adequate images. Hence thermogram can be used as a tool for breast cancer detection (Foster, 1998). Using thermo gram is a simple, safe and comfortable method for breast cancer detection; since breast is not

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compressed in this, it can be used conveniently for young women or whom mammography is not very effective (Keyserlingk *et al*., 1997). Thermographic imaging of breast is a non contact, non invasive technique and can be easily used outside hospitals (Gutierrez-Delgado *et al*., 2009).

MATERIALS AND METHODS

A method is proposed in this study to obtain an active thermogram to detect early breast carcinoma. In the Proposed method, a microwave source of 2450 MHz is used to irradiate the breast twice. The period of irradiation is chosen in such a way that the normal breast tissue temperature would not go beyond 42°C for protein denature takes place at 42°C (Mark *et al*., 2004; Buzug *et al*., 2006). The breasts are given the first irradiation using 2450 MHz microwave source for a set time period as mentioned above. At the end of the first irradiation, the source is switched off and the breasts are allowed to cool back to 37°C by thermoregulatory action; 37°C is the core body temperature and it is taken as the breast temperature here. When the breasts come back to 37°C, the second irradiation is given to them for the same pre-set time period as given in the case of first irradiation. At the end of this period, once again the breasts are allowed to cool back to 37°C by thermoregulatory action of the human body. When breasts attain 37°C they are imaged using a thermal imager. The thermo gram can be analyzed to find out if there is any sign of early cancerous growth. By this method, the temperature difference between the normal and the cancerous breast tissues is enhanced much and this leads to early diagnosis of breast cancer with increased specificity.

The proposed method uses a novel microwave double irradiation technique. First irradiation and thermoregulatory cooling would elevate the temperature difference between the normal and cancerous breast tissues to some degrees and at this elevated level the second irradiation is given. The second irradiation and the thermoregulatory cooling would further increase the temperature difference between the normal and cancerous tissues of the breast. This difference is captured by the pickups in the thermal imager and converted into image. In the conventional thermographic method, the passive emissions from the breast are collected and converted into image. In the method proposed here, since the double irradiations given to the breast considerably increase the temperature difference between the normal and cancerous tissues of the breast, the thermal image would show more intensity variation between these tissues than the conventional passive thermogram.

In the proposed method, after every irradiation a natural cooling period is provided. During this period the breasts are allowed to cool naturally. Since the breast tissues are cooled by blood perfusion by the breast vasculature, the temperature of the breast would come to the original level from the elevated level in a span of time after the irradiation is stopped. This thermoregulatory action is missing in cancer tissues for cancer blood vessels are not under the control of brain. Due to this the cancer cells cannot dissipate the heat deposited by the external irradiation as effectively as the normal breast cells by blood perfusion. Though the normal and cancer cells would dissipate heat effectively by radiation, for cancer cells it is the major source of dissipation. Hence, cancer cells remain at a boosted and considerably higher temperature when normal breast cells come to their original temperature level. Thus, the microwave double irradiation method increases the intensity of radiation in a novel way. Since, this method increases the intensity of radiation substantially, even smaller tumors and tumors buried deeper could be imaged which otherwise would not produce enough energy to cause a thermal signature of considerable intensity variation in the breast skin.

An experiment was conducted to verify the fact that double irradiation from a microwave source and natural thermoregulatory action of the breast would enhance the temperature difference between the normal and cancerous tissues. A breast phantom was constructed of 32% water, 57% of vegetable oil and 11 of 2% agar solution for breast containing 32% water and 57% lipids (Li *et al*., 2003). Fifty millilitter breast phantom consists of 28.5 mL coconut oil, 16 mL water and 5.5 mL of 2% agar solution. The Two percent agar solution is used to mimic the tissues (Santyr *et al*., 1994). Cancer cells are of 80% water; thus a 50 mL cancer phantom was constructed of 40 mL water and 10 mL of 2% agar solution. The phantoms are taken in glass beakers and irradiated by a microwave source of 2450 MHz first. The temperature versus time of irradiation was noted down separately for each Phantom. After heating, the beaker containing the normal breast phantom was immersed and slowly moved around in a water bath of 37°C; this is to mimic the convective effect of blood flow in normal breast tissues. Time taken by the breast phantom to cool back to 37°C was noted down. Cancer phantom at 38°C was heated for a period of 5 sec, since the breast phantom took 5 sec to go to 42°C from 37°C. After heating, the cancer phantom was kept on the table and allowed to cool naturally for exactly the time taken by the breast phantom to cool back to 37°C. It was observed that the cancer phantom cooled down to 41°C in this period. After this cooling period, the cancer phantom now at 41°C was once again irradiated by the microwave source for 5 sec and its temperature went up to 49°C. The cancer phantom was allowed to cool down as explained previously; it was noted that the cancer phantom cooled down to 43.75°C.

Normal thermo gram indicates the possibility of cancerous growth when there is a temperature difference of 1.5°C between adjacent cells. Using Stefan Boltzmann's law, (O'Keefe, 2006) the total emissive power for the normal breast tissue at 37°C and the unheated cancer cells (passive radiation) at 38°C (1°C difference between cancer and normal breast cell is considered here) are calculated; the total emissive power for the cancer cell after double irradiation and natural cooling (active radiation) is also calculated. The difference is found out; only this difference is converted into contrast in brightness while imaging. Passive radiation yields a difference of 0.68 mw cm^{-2} for 1°C growth of cancer cells while microwave double irradiation for the same gives 4.72 mw cm^{-2}. Hence, this method produces much more emissive power from cancer cells than normal breast cells even at the early stage. Though the phantom model does not have the blood vessels, the convective effect of blood flow through the blood vessels of the breast has been considered. Most clinically apparent tumors (above 1 cm in diameter) have blood perfusion rates less than 1/5th of the surrounding normal tissues. Apart from this when the temperature is increased the normal blood vessels dilate and supply more blood to the tissues where as cancer tissue's blood vessels do not dilate since they are not under the thermoregulatory action of brain; hence normal breast tissues cool rapidly while cancer tissues would remain hot. Though the breast phantom used here is not having any in built vessels to study the convective effect of vasculature, it is immersed in 37°C water bath and moved around to simulate the convective effect of blood flow through the breast vasculature.

Calculation: Stefan Boltzmann states that $E = \varepsilon\sigma T^4$ where E is the total emissive power, T is the temperature in Kelvin, σ is Stefan Boltzmann's constant and is equal to 5.67×10^{-8} W m^{-2}, ε is the emissivity and is taken as 1 for the breast skin.

Passive radiation: Power emitted by normal breast cell at 37°C (310°K) is:

$$E = (5.67\times10^{-8})\,(310)^4\ W/m^2 = 5.236\times10^2\ W\ m^{-2}$$

Cancer cell at 38°C (311°K) emits 5.304×10^2 W m^{-2} power.

Active radiation: First irradiation by the microwave source and natural cooling elevates the temperature of 38°C cancer cell phantom to 41°C. Hence, thermal energy emitted by cancer phantom at 1°C cancer growth can be calculated by taking its temperature as 41°C. Power emitted by cancer cell of 1°C growth, by first irradiation using the microwave source is:

$$E = (5.67\times10^{-8})\,(314)^4\ Wm^{-2} = 5.512\times10^2 W\ m^{-2}$$

By the second irradiation from the microwave source and natural cooling, cancer cell's temperature is raised to 43.75°C from 41°C. Hence, the thermal energy emitted is,

$$E = (5.67\times10^{-8})\,(316.75)^4\ W\ m^{-2} = 5.708\times10^2\ W\ m^{-2}$$

RESULTS AND DISCUSSION

Figure 1 shows that when breast phantom is heated to 42°C (the maximum acceptable skin temperature (Kaczmarek *et al*., 2002)) from its initial value 37°C by first irradiation using a micro wave source, cancer phantom goes to 45°C from its initial temperature of 38°C. Figure 2 shows that breast phantom goes to 42°C from 37°C after the second irradiation given by the microwave source for 5 sec, where as the cancer phantom at 41°C (by the first irradiation and cooling) goes to 49°C after the second irradiation by the microwave source. Figure 3 shows that the cancer phantom after the first irradiation cools down to 41°C in 663 sec from 45°C and after the second irradiation it cools down to 43.75°C in 663 sec from 49°C which it attained after second irradiation. Since breast phantom takes 663 sec to cool back to 37°C from the

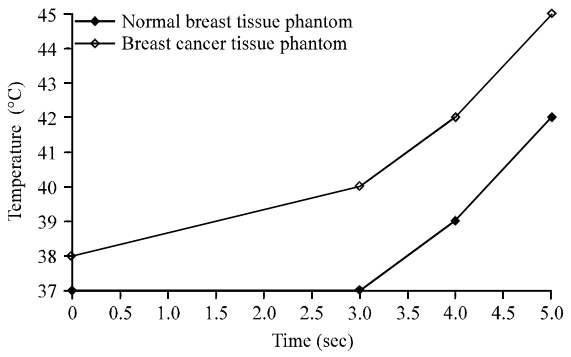

Fig. 1: Microwave heating characteristic of Phantom Models (First irradiation)

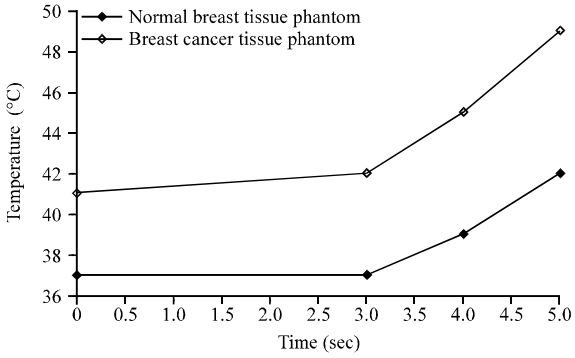

Fig. 2: Microwave heating characteristic of Phantom Models (Second irradiation)

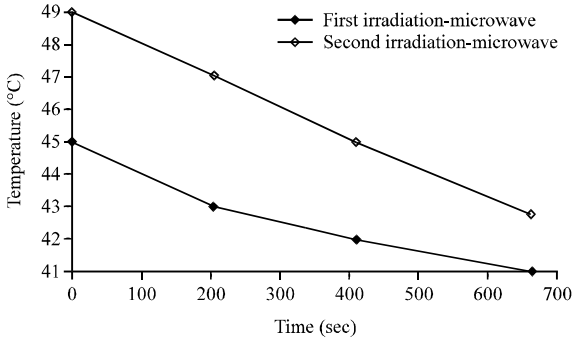

Fig. 3: Cooling characteristic of Cancer Phantom Model

microwave elevated temperature level of 42°C, the temperature of cancer phantom at this time interval is noted down to calculate the difference in power emission by the proposed microwave double irradiation method.

Normal thermogram indicates a possibility of cancerous growth when there is a temperature difference of 1.5°C between the adjacent cells. Using Stefan Boltzmann's law the total emissive power for the normal breast tissue and the unheated cancer cells (passive radiation) at 38°C (1°C difference between cancer and normal breast cell considered here to indicate a possibility of cancerous growth) is calculated; the total emissive power for the cancer cell after double irradiation and natural cooling (active radiation) is also calculated. The difference is found out, because only this difference is converted into contrast in brightness while imaging. Passive radiation yields a difference of 0.68 mw cm^{-2} for 1°C growth of cancer cells while first irradiation by the micro wave source gives 2.76 mw cm^{-2} for 1°C cancer growth, double irradiation method produces 4.72 mw cm^{-2}. Passive radiation produces the same amount of emissive power only when the cancerous growth attains a temperature of 43.75°C (6.75°C growth). Since heat energy radiated out is directly proportional to the temperature of the radiating tissue and inversely proportional to the degree of tissue perfusion (Janicek *et al*., 2003), this method produces much more emissive power from cancer cells than normal breast cells even at an earlier stage for this method increases the temperature difference between the normal and cancerous breast tissues considerably; hence, early breast cancer detection is possible.

Though the vasculature is not considered in the phantom models, the convective effect of blood flow through the blood vessels of the breast has been considered. Most clinically apparent tumors (above 1 cm diameter) have blood perfusion rates less than 1/5th of the surrounding normal tissue (Short and Turner, 1980). Apart from this when the temperature is increased the normal blood vessels dilate and supply more blood to the cells where as cancer vessels would not dilate since they are not under thermoregulatory action of brain; though the breast phantom used here does not have inbuilt blood vessels to study the connective impact of vasculature, it is immersed in 37°C water bath and moved around to simulate the connective effect of blood flow though the breast vasculature.

The most used imaging methods for breast cancer detection are ultrasonography, MRI, thermography, X-ray mammography. Though ultrasonography is a low cost technique, it has relatively low specificity (Palacio, 2010). The sensitivity of MRI is very high as 98% but MRI is more expansive than mammography and ultrasonography; it suffers from significant false positive rate, moderately low specificity. The major limitations are that it is not available in all the places, claustrophobia and longer imaging time. The use of gadolinium based contrast agent to enhance MRI or MRA scans, leads to the development of nephrogenic system fibrosis or Nephrogenic Fibrosing Dermopathy (NFD). The diabilating NSF/NFD disease may even become fatal (Dongola, 2009). Though the mammographic imaging is the gold standard diagnostic test for breast cancer detection, it has the overall sensitivity of about 75% only (Haigh, 2007). Mammogram misses out 20 to 40% cancers during initial screening since interpreting the mammogram is a very difficult task. It also produces a very significant number of false positives and the specificity ranges from 88 to 98% (Saunders and Samei, 2006). The sensitivity (the ability to detect positive cases) of the thermo graphic method is about 98% and the specificity (the ability to detect only the positive cases) is 89 to 90%. The specificity declines to 85% for early stage cancers (Harris *et al*., 1966).

Since the method proposed in this study is also a thermographic method, higher sensitivity and specificity are the major strengths of this method. The false positives produced by the conventional method are due to commonly observed temperature difference of 2°C and rarely observed temperature difference of 3.5°C between contra lateral breasts not suffering from cancer. But a temperature difference of 1.5°C between contra lateral breasts is taken as an indication of a possible cancer growth in thermogram. The facts being this, a thermal signature produced by a difference of 1.5°C between breasts (whether or due to cancer) would be taken as a positive sign in conventional thermogram and at the early stage, so produced false positives would be more in conventional thermogram. The method proposed in this paper produces considerably higher temperature difference by cancerous growth (5.75°C difference for 1°C cancer growth) than the temperature difference produced by the other pathological conditions of the breasts. The positive cases can be identified correctly and this increases the specificity of early stage cancer detection.

Image formation: A thermogram of normal breast is taken as a base line image to simulate the images that would be produced by the proposed method.

A Region Of Interest (ROI) is taken from the normal breast thermogram. The R component matrix of the ROI is found; from this matrix the mean pixel value for 37°C is found since the normal body temperature is 37°C. From this the mean pixel value for 1°C is found and from that 38, 41 and 43.75°C mean pixel values are calculated. The calculated values are used to simulate the thermal images of 37, 38, 41 and 43.75°C cancer growths using MATLAB 7.1. Figure 4 shows the simulated images.

Thermal images for 37, 38, 39 and 43.75°C were taken using a thermal imager (FLIR SYSTEMS- Model FLIR i5-SWEDEN). The operating temperature range of the system is (0 to 250°C); 36 to 48°C range is locked for taking the images; 36°C corresponds to blue color at the left and 48°C corresponds to the bright yellow color at the right of the color bar which is displayed at the bottom of the image slides. It is seen that 37°C (normal breast tissue temperature) and 38°C (1°C cancer growth) are not differentiated much in the color images; the color difference between 37 and 39°C is much visible to naked eye. But 2°C temperature difference between contra lateral breasts is common in normal cases and up to a temperature difference of 3.5°C is also occasionally found, hence the color difference produced by 37°C and 38°C may or may not be due to cancerous growth. Since Microwave double irradiation method produces 6.75°C temperature difference for 1°C cancer growth, the bright color of the thermogram taken at 43.75°C (6.75°C difference) would indicate that there is a strong possibility of cancer in the breast at the early stage.

Thermal images taken using FILR i5 thermal imager: Thermogram of agar models at 37, 38, 41 and 43.75°C were taken by FLIR i5 model thermal imaging camera; Fig. 5 shows the color images .These images clearly show the enhanced color intensity variation for 1°C cancer growth by the proposed method.

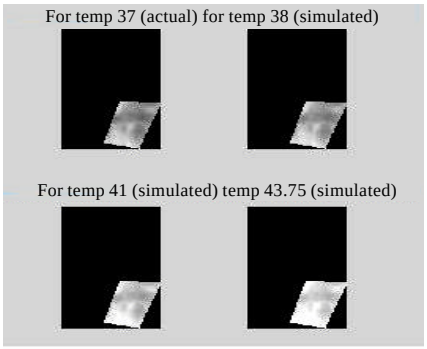

Fig. 4: Simulated images

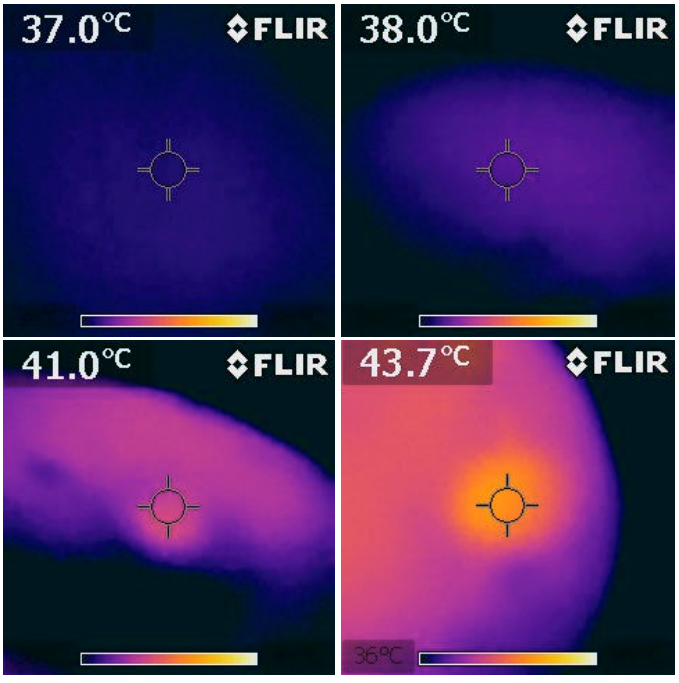

Fig. 5: Thermal images- color images

CONCLUSION

The method of heating the breast twice by microwave source of 2450 MHz and natural thermoregulatory cooling following every microwave irradiation, before taking the thermogram is proposed. The experimental results show that the temperature of the cancer cells would be increased considerably by the proposed microwave double irradiation and thermoregulatory cooling method; hence the temperature difference between normal and cancerous breast tissues is also increased considerably resulting in enhanced image intensity variation between the tumor and the surrounding area which leads to the early diagnosis of breast carcinoma.

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