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Evaluation of Breast Thermography Images According to Ultrasound Reports and Temperature Patterns

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ABSTRACT

Background: Breast cancer is one of the most common types of cancer among women, and researchers have been trying to examine it by various methods for several years. Different imaging methods have different precisions and accuracies, so choosing an appropriate imaging method, particularly for women with dense breast tissue, is very important. Since vascular structures and consequently regional temperatures are different between cancerous and non-cancerous tissues, thermography imaging is able to diagnose cancer earlier than other methods.

Methods: In this research, vascular pattern and symmetry are checked in thermography images. Also, a special protocol was tested on 113 subjects, who were classified into 2 groups. Ultrasound reports were used for evaluation. Since some of the ultrasound images were suspicious, biopsy reports were used as more accurate criteria for assessment.

Results: The results of this study showed the usefulness of the protocol applied and the benefits of thermography as an inexpensive, painless, and radiation-free imaging technique appropriate for all ages.

Conclusion: Final evaluations in this study showed that thermography is not only an inexpensive, painless, and radiation-free imaging technique that is appropriate for all ages, but also, if it is conducted according to the mentioned protocol, it would yield good results.

INTRODUCTION

The most common type of cancer in women is breast cancer[1,2], which is the deadliest kind of cancer among them worldwide. Until now, there are no powerful strategies for stopping breast cancer, because the source of the disease is not clear.[3,4] Early diagnosis significantly increases survival rates and reduces the need for invasive treatments. Mammography, the gold standard for breast cancer screening, has limitations, particularly for women with dense breast tissue, with false-negative rates reaching 30%. Sonography complements mammography, but it has limitations. Thermography, a non-invasive and radiation-free imaging method, detects abnormalities through metabolic heat patterns, offering potential advantages for screening dense breast tissue. This study evaluates breast thermography images in comparison with ultrasound reports to determine their diagnostic effectiveness.

Almost 12.5% of women (1 out of 8) are diagnosed with breast cancer annually, 2.5% of whom (1 out of 39) die.[5] Recent advances in cancer treatment have increased the survival probability. Since 2003, the mortality rate of breast cancer has decreased by approximately 1% per year, due to advances in diagnosis and treatment.[6] Early diagnosis of breast cancer not only increases survival probability, but also mitigates the need for surgeries and systematic invasive treatments such as

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chemotherapy and radiotherapy. Different methods are used for early diagnosis of breast cancer, and the most common one is mammography, which is the gold standard of diagnosis.[7]

Mammography detects the lumps inside the breast tissue, which may indicate the existence of tumors. This method is based on X-rays that can stimulate some cells. Although mammography is the most commonly used imaging examination for the screening of breast cancer, the false negative rates of this method can reach 30%.[8] Furthermore, mammography has less sensitivity and weaker performance in women with denser breast tissue (women with larger fibroglandular-to-fat tissue ratio). Due to the fact that the glandular tissue ratio is larger in younger women and the fat ratio increases with age, additional screening with various modalities is recommended.[9]

One of the methods used in patients with dense breast tissue is sonography.[10] This method is usually used for checking the most suspicious breast areas, which are revealed during breast examination. Also, it can distinguish cysts (nontumorigenic sacs with blood) from solid lumps, guide aspiration biopsy, and preoperative localization even in dense breast tissue. Ultrasonography alone is not suitable as a screening method for breast cancer[11] and in some dense cases, biopsy is recommended.

One of the other imaging techniques for screening of breast cancer is thermography, which is an emerging method. Infrared thermography detects abnormal tissues based on their metabolism, which causes greater angiogenesis, producing more thermal energy than normal tissues. Advances in thermography have turned it into a powerful screening tool for breast cancer, which requires less advanced technical operator training relative to other screening methods. Thermography is advised to be used as an aid for breast cancer diagnosis, based on the Food and Drug Administration (FDA) approval in 1982.[12]

In this article, a protocol for thermography imaging is suggested. Then, sonography and mammography images are taken from patients just after thermography images (on the same day, within a few minutes). After temperature pattern analysis, the results of thermography images are evaluated and compared to ultrasound and mammography reports. The primary objective is to evaluate the diagnostic accuracy of breast thermography compared to ultrasound, considering the significant cost difference between thermography cameras and ultrasound machines. This evaluation aims to explore the feasibility of using thermography for initial breast cancer screening in underprivileged areas lacking access to ultrasound devices.

METHODS

Breast cancer

Breast cancer can occur in any part of the breast. The most common types of breast cancer are ductal and lobular breast cancers whose origin is ductal epithelium and glandular, respectively.[13] Although lumps can be found anywhere in the tissue, cancer mostly spreads in the upper-outer quadrant and retro areolar region of the breast (Figure 1).

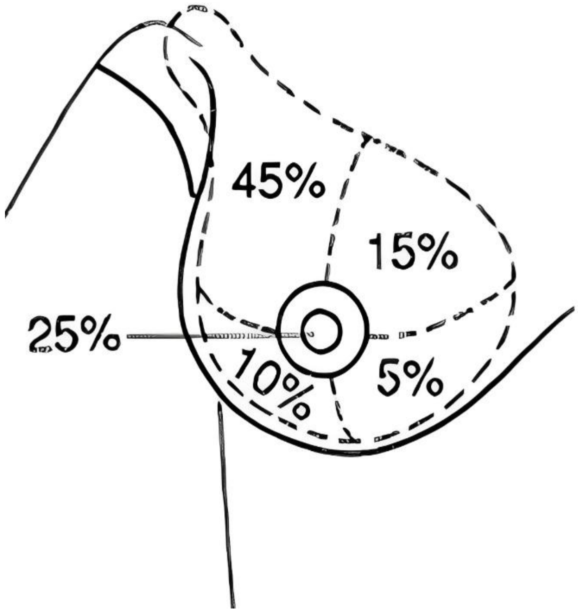

Figure 1. Abundance Percentage of Cancer in the 4 Quadrants of the Breast and Around the Areola

According to shape, margin, density, size, and position, breast lumps and lesions are classified as benign or malignant, which depends on their influence on peripheral tissues, the existence of calcification, skin thickness, skin elongation or depression, changes in nipple shape or color, and the existence of discharge. If fibrosis threads stretch radially from the central lump to the periphery, the malignant disorder is said to be "acerose". Generally, the bigger the central tumor, the longer the peripheral spread scars. If the lump margins have small convexities and concavities, the lump is said to be micro-lobulated. Lumps with irregular shapes are more likely to be cancerous. These are the clinical diagnostic factors of breast cancer.[14]

The exact cause of cancer is not known yet. However, researchers believe that the probability of breast cancer occurring in women is almost 100 times higher than in men, which is due to high levels of estrogen and progesterone hormones. Aging increases cancer risk as well. In the published statistics, about 77% of breast cancer cases have been found in people over 50 years old. High-risk women are those who have at least one immediate or extended family member with breast cancer or ovarian cancer, especially before the age of 50 or before menopause, or has had the mutated genes of *BRCA1* and *BRCA2*.[15] Furthermore, when someone undergoes cancer treatment, the risk of tumors occurring in that breast and the other breast increases. Other factors such as dense breast tissue, menstruation before the age of 12, menopause after the age of 55, and having one's first pregnancy after the age of 30, obesity, hormone therapy, alcohol and tobacco consumption, and exposure to ionizing radiation also affect the risk of cancer.

Thermography

Because of metabolic activities, all body organs emit heat. Some of the emitted heat reaches the skin surface with a particular pattern or map. The temperature emitted from the body is an exponential function of the skin temperature, hence, asymmetrical heat distribution in hot or cold spots can be a symptom of a disorder. The human body emits infrared (IR) rays with a wavelength in the range of 2 to 20 micrometers. Human body temperature on the skin surface depends on metabolic activities, blood, and the temperature of the environment.[16] Any abnormality in tissue, such as tumors, changes the natural skin temperature due to the tumor's metabolic activity. Cell growth increases blood circulation by opening up existing blood vessels, inactive vessels, and new vessels to supply nutrition to cells. Therefore, an abnormal increase in skin-surface temperature can indicate disorders such as breast swelling, benign tumors, fibrocystic breast disease, or cancer.[17]

Protocol

In this study, patients who visited Chamran Clinic in Mashhad for an ultrasound over a 6-month period were included. Only patients who adhered to all pre-thermography conditions were selected.

Infrared imaging must be carried out in a controlled environment because of the physiological nature of the human body. Changes in the ambient environment (uncontrolled room), clothes, etc., can result in an unrealistic temperature in the person's body. To have a standard imaging, considering the following regulations is crucial:

To appropriately prepare the patients for imaging, they should be guided to avoid using alcohol, caffeine, and nicotine, exposing themselves to sunlight, applying beauty products, lotions, antiperspirants, deodorants, exercising, bathing, shaving breast or armpit hair, breast stimulation[18], and drinking liquids or eating food before the test. On the day of the test, before starting imaging, the patient is asked to keep belongings such as necklaces or earrings at home or put them away from herself, gather her hair into a hat, and take off the clothing that covers her trunk. Then, they sit on a chair for 15 minutes, while their arms have no contact with the body. This causes their body temperature to stabilize. Images are taken in 5 directions: front, 45°, and 90° rotation to both left and right.

During the test, room temperature must be kept between 18 and 23 °C,[19] and it must be dark.[20] This guarantees that the patient will not tremble or perspire. The room must be free of any kind of heating or cooling source. Furthermore, either the floor must be carpeted or the patient must wear shoes. The wall behind the patient must be covered with a cloth so there will be no reflection.

It should be mentioned that the patients who did not follow the recording regulations were removed from this study.

Image analysis

In this study, a forward-looking infrared (FLIR) camera (FLIR_T62101) was used. In the images taken, the least value corresponds to black, which indicates the coldest point, and the highest value corresponds to white which indicates the hottest point. To analyze the images better, a color spectrum was assigned to them. This color scale starts with blue and includes cyan, yellow, green, orange, and red shades.[21] Figure 2 shows the color spectrum and its application to patient images.

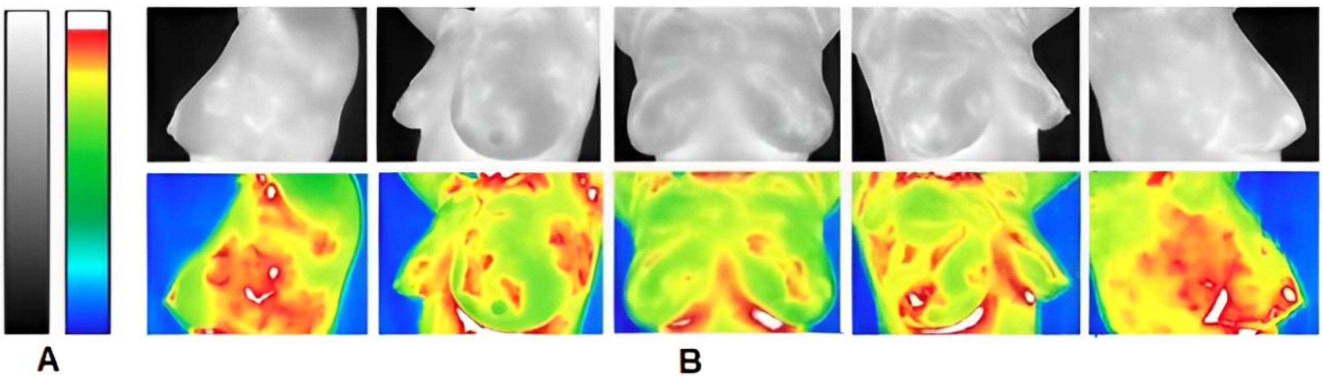

Figure 2. Color Spectrum and Mapping of Colors to Breast Surface Images: A, color spectrum. B, colorizing grayscale images in different directions.

Metabolic heat directly relates to cancer growth rate. Gautherie[4] pointed out that in rapidly-growing tumors, perfusion and the amount of metabolic heat production are more than in the normal state. After that, other researchers said that the density of small blood vessels is related to metastasis.[22] It has been stated that the tumor malignancy stage can be estimated from the measurement of tumor metabolic activity, which is extracted from the superficial temperature.[23] In addition, symmetry is an important parameter in diagnosis because breast structure and density are usually symmetrical. Breast asymmetry usually happens when the right and left breasts are different in size, shape, and temperature pattern. In some articles, breast asymmetry has been linked to hormonal changes and breast cancer risk. Similarly, breast ptosis variations have been related to age, body mass index, breast volume, history of smoking, pregnancy, and weight loss.[24]

In this study, temperature and symmetry are considered as 2 important detection criteria alongside each other because when images are approximately symmetrical, small asymmetries can indicate a suspicious region. Using asymmetry analysis to detect lumps in breast cancer is a fundamental principle in breast cancer studies.[25]

RESULTS

In this test, 113 patients with an average age of 37.4 were examined. The age range of participants was between 17 and 58 years. To evaluate the thermography images, the ultrasound sonography reports, which were recorded on the same day, and in some cases, biopsy results, were used. The data showed that 44 cases had Breast Imaging Reporting and Data System (BIRADS) 3 or higher, and 69 cases had BIRADS 1 and 2. This classification was due to the distribution of patients who were referred to the clinic. The number of patients with BIRADS 4 or 5 was too small to allow for meaningful classification into 2 distinct groups. Additionally, follow-up was recommended for all patients with BIRADS 3, justifying their inclusion in the higher-risk category. The average height, weight, and age of these cases were evaluated according to Table 1. It can be seen that the proportion of cases with dense breasts that had American College of Radiology (ACR) density categories (d and c) was expectedly larger than the proportion of patients with ACR (a and b) (Figure 3). ACR represents the American College of Radiology, which classifies breast density into 4 categories.

The color spectrum of the images is very important because the color in each region is directly related to its temperature and indicates cellular and tissue activity levels in that region.

Table 1. Demographic Characteristics of Participants in the 2 BIRADS Groups

BIRADS	Number	Age	Weight	Height
BIRADS ≥3	44	39.1±10.5	65.81±14.4	163.19±5.9
BIRADS <3	69	36.34±10.2	68.20±12.6	162.73±5.5

Data are presented as mean ± standard deviation. BIRADS, Breast Imaging Reporting and Data System.

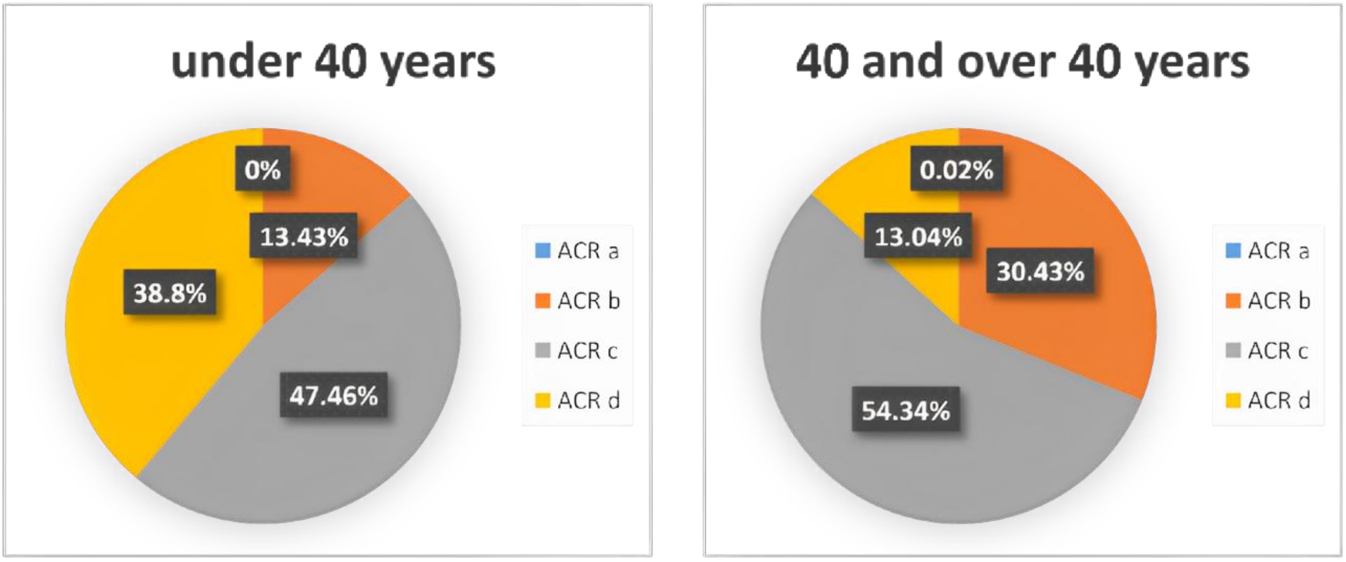

Figure 3. Comparing the Proportions of Patients with Different ACR in 2 Age Groups. ACR is divided into 4 classes: a: The breasts are almost entirely fatty. b: There are scattered areas of fibroglandular density. c: The breasts are heterogeneously dense, which may obscure small masses. d: The breasts are extremely dense, which lowers the sensitivity of mammography.[26] ACR, American College of Radiology.

In Figure 4a, the whole breast is green and completely symmetrical. Therefore, from a thermography point of view, this case is considered a healthy person. These observations were approved by the ultrasound sonography report with BIRADS 1 and without any cysts, lumps, or even texture disarrangement. Hot points (white and red) in locations such as the neck, armpits, and under breasts are due to factors such as perspiration and less susceptibility to environmental temperature, which, from a diagnostic point of view, are considered to be normal. This phenomenon was observed in most subjects.

Considering previous explanations, hot points in Figure 4b attract the thermographer's attention. Although heat is a necessary sign to detect suspicious regions, it is not enough, and point symmetry must also be considered. Regarding the image, it is seen that the hot region observed in the upper-inner quarter of the right breast is symmetrical to the upper-inner quarter position of the left breast. Therefore, since all hot points are symmetrical, the case is assumed healthy. The significance of symmetry can be seen in the decision-making of this image. The ultrasound report confirmed the analysis derived from thermography. Furthermore, hot points in breasts can sometimes be related to age. In younger women, hot points with symmetry are observed more often.

One of the important factors to keep in mind is that the lesion distance to the skin strongly affects temperature. Therefore, focal hot may not be seen in the anterior view angle but might be found in images from other angles. Hence, when analyzing these images, examining them from at least 3 to 5 angles is necessary.

It is obvious that many distributed hot points that exist in Figure 4(c) need further examination. According to the image, in the upper-outer quadrant of the right breast, close to the auxiliary 11 o'clock, a hot region is observed with a similar pattern in the right breast at the 1 o'clock position in the same region. Furthermore, there exists another hot region at the 3 o'clock position of the breast. Since no symmetry can be found for it in the right breast, it is suspicious and needs to be looked into by another method. By comparing ultrasound and thermography reports, the suspicious lesion observed in the left breast was confirmed by the radiologist, and BIRADS 4a was diagnosed in the ultrasound report. In this image, another hot region is seen in the upper quadrant of the left breast which does not possess symmetry with the right breast, but it has not been pointed out in the ultrasound sonography report.

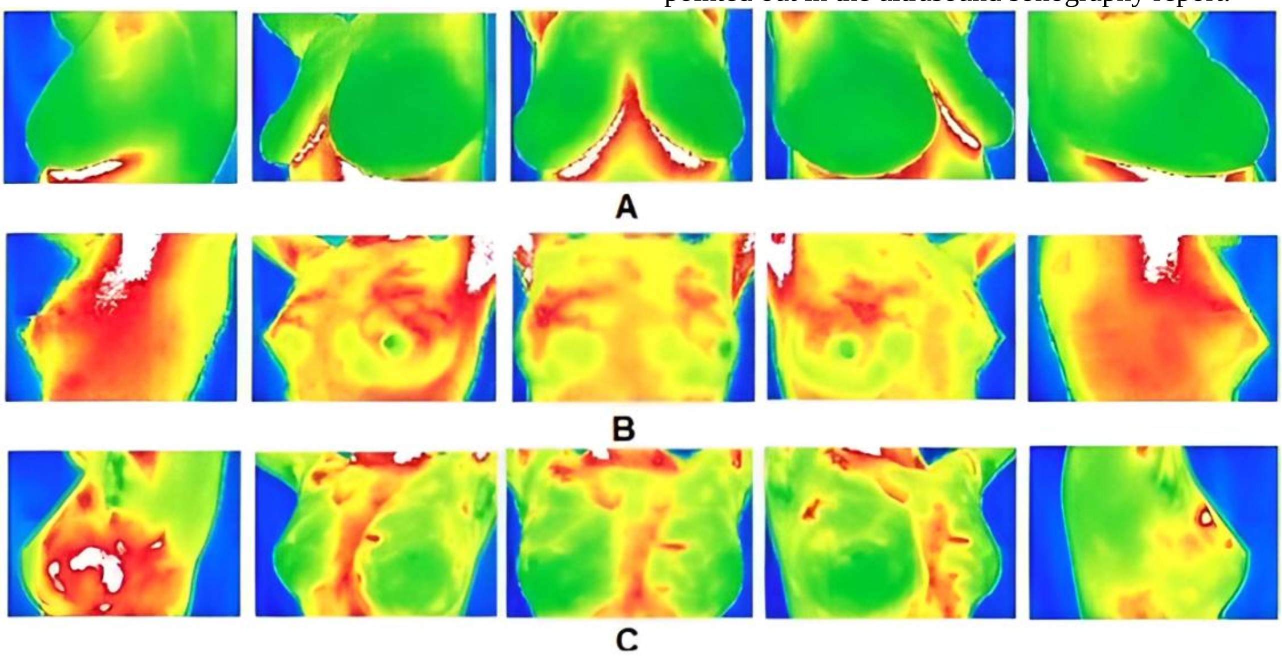

Figure 4. Representative thermographic patterns in normal and abnormal breast cases. A, normal case without any hot spot. B, normal case with symmetrical hot spots in both breasts. C, abnormal case with a significant difference in its heat pattern.

Statistical Analysis

To evaluate the diagnostic performance of breast thermography compared to ultrasound, standard diagnostic measures were calculated using the following formulas:

- Accuracy = (TP + TN) / (TP + TN + FP + FN)
- Sensitivity (recall) = TP / (TP + FN)
- Specificity = TN G/ (TN + FP)
- Positive Predictive Value (PPV) = TP / (TP + FP)
- Negative Predictive Value (NPV) = TN / (TN + FN)

Where:

- TP (true positive) are cases correctly identified as abnormal.
- TN (true negative) are cases correctly identified as normal.
- FP (false positive) are cases incorrectly identified as abnormal.
- FN (false negative) are cases incorrectly identified as normal.

DISCUSSION

Due to the significance of vascular structure and regional temperature in thermography images, if images are accompanied by a standard and high-level protocol, desirable results with acceptable precision and accuracy can be acquired. One of the limitations of this study was the absence of patient follow-up. Future studies are recommended to include follow-up to provide more comprehensive and long-term insights into the effectiveness of breast thermography in cancer detection.

In this study, a new imaging protocol was used, which appeared to improve the distinction between normal and abnormal cases. The 113 images used in this study were first gray and then converted to color images with a spectrum of white (hottest points) to blue (coldest points). The breasts were examined by evaluating symmetry and regional temperature. The goal of this study was to find a suitable method for primary screening and to consider the advantages of thermography over other methods. The special prominence of this study is in juxtaposing thermography images with clinical information collected from the patients, and matching them with the consecutively-conducted ultrasound sonography and, in some cases, biopsy results.

The results of this study show that the percentage of people with distinct ACR is different. With the proposed protocol, diagnosis accuracy in different ages with different ACR is acceptable, especially in people with dense breasts, as shown in Table 2.

The final evaluations in this study show that the IR imaging technique may be suitable for various age groups, as it is inexpensive, painless, and radiation-free. Table 2 shows the overall assessment of this study, which confirms the value of conducting thermography with an appropriate protocol as a screening method.

The results of this study, showing an 86.72% diagnostic agreement between thermography and ultrasound, are consistent with previous studies. For instance, Kandlikar *et al.*[13] highlighted the potential of thermography in detecting early-stage breast cancer due to its sensitivity to metabolic changes. Similarly, Gonzalez-Hernandez *et al.*[2] reported promising results for thermography in screening dense breast tissues where mammography performance is limited. However, compared to studies like Salim Al Husaini *et al.*[12], which achieved higher sensitivity through the integration of thermography with artificial intelligence (AI)-based analysis, this study solely relied on temperature pattern analysis, which may explain the slightly lower sensitivity. In addition to the mentioned results, the data demonstrate that the number of cases with BIRADS 3 or higher in their left breasts was significantly more than in the right ones, ie, 61.38% and 38.62%, respectively.

Table 2. Accuracy, PPV, NPV, and Sensitivity of different ACRs.

ACR	Accuracy	PPV	NPV	Sensitivity
ACR a	100%	NAN	100%	NAN
ACR b	78.26%	60%	83.33%	50%
ACR c	89.83%	92.3%	93.54%	92.3%
ACR d	81.25%	71.42%	88.88%	83.33%
Total	86.72%	82.22%	89.7%	84.09%

ACR, American College of Radiology; NPV, negative predictive value; PPV, positive predictive value.

CONCLUSION

The noticeable advantages of thermography and its promising results in recent studies encouraged us to investigate this method. Breast thermography showed an 86.72% diagnostic agreement with ultrasound, highlighting its potential as a complementary, non-invasive, and cost-effective imaging tool for breast cancer screening, particularly in underprivileged areas. Although the exact temperature of hot points is really important, decision making in thermography images relies on the symmetry of the temperature pattern, which can indicate underlying abnormalities.

Because mammography has some limitations, especially for women under 40, due to dense breast tissue, this technique is not suggested for screening in early stages. Sonography was chosen as a reference method for evaluating thermography due to its widespread use across all age groups. Moreover, the consistency of thermography and ultrasound results further supports its reliability in preliminary breast cancer screening. This study was solely focused on comparing thermography and ultrasound findings for initial screening purposes and was not designed for definitive cancer diagnosis. Although some follow-up information was obtained through patient phone calls, comprehensive biopsy data were not systematically collected. Future studies should incorporate structured follow-up and biopsy-confirmed diagnoses to assess the diagnostic performance of thermography more accurately.

ETHICAL CONSIDERATIONS

The protocol adopted in this research was in full accordance with the Declaration of Helsinki and was approved by the Ethics Committee of the Department of Biomedical Engineering at Islamic Azad University of Mashhad. Furthermore, the purpose of the research was clearly explained to all participants, and written informed consent was obtained from each of them.

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CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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None.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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