Comparison of the Accuracy of Thermography and Mammography in the Detection of Breast Cancer

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Keywords

Breast cancer · Infrared · Mammography · Neoplasm · Thermography

Summary

Background: Benefits and harms of screening mammography have been disputed in recent years. This fact, along with the limitations of mammography as well as its unavailability in all our medical centers, tempted us to evaluate the accuracy of thermography in detecting breast abnormalities. **Patients and Methods:** All patients who were candidates for breast biopsy were examined by both mammography and thermography before tissue sampling in a referral center between January 2013 and January 2014. We defined sensitivities and specificities, and positive predictive values (PPVs) and negative predictive values (NPVs), of the 2 modalities in comparison with histologic results as the gold standard. **Results:** 132 patients were included. The median age of all patients was 49.5 ± 10.3 years (range 24–75 years). The sensitivity, specificity, PPV, NPV, and accuracy for mammography were 80.5%, 73.3%, 85.4%, 66.0%, and 76.9%, respectively, whereas for thermography the figures were 81.6%, 57.8%, 78.9%, 61.9%, and 69.7%, respectively. **Conclusion:** Our study confirms that, at the present time, thermography cannot substitute for mammography for the early diagnosis of breast cancer.

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Introduction

Nowadays mammography is used as the gold standard for breast cancer screening and diagnosis; this modality can demonstrate masses or microcalcifications in the earliest stages of the disease. Nevertheless, mammography has a low sensitivity in young women and in dense breasts [1]; also, its facility requires high-quality, expensive equipment and entails high costs [2].

A non-invasive means of breast imaging, thermography was reported by Lawson in 1957 as a new tool in the investigation of breast lesions [3]. This entity was considered rather extensively in the 1970s and 1980s [4], and was approved by the US Food and Drug Administration (FDA) as an adjunctive tool for the diagnosis of breast cancer, but not as a useful screening or diagnostic tool for breast malignancy, due to its low sensitivity and specificity [5, 6]. However, since advanced digital equipment and recent advancements in technology and image processing methods have led to superior detection of heat waves, the current study focuses again on the subject, in order to investigate the potentially improved detection of breast pathology by digital thermographs. Considering these facts, we conducted a study to determine the sensitivity and specificity of thermography, in comparison with mammography, in differentiating benign and malignant disease in breast lesions undergoing biopsy and histological review.

Methods

This prospective study was undertaken in the breast clinic of the Cancer Institute of Tehran, Iran, between January 2013 and January 2014 among women attending the clinic with any breast-related complaint or just for opportunistic screening. Inclusion criteria consisted of any clinical, mammographic, or ultrasonographic finding in need of tissue histological exam. Exclu-

sion criteria consisted of age under 35 years for cases harboring benign-appearing lesions, because mammography was not necessary in these cases. The study was approved by the ethics committee of the Cancer Institute of Tehran on September 2012.

Table 1. The Marseille risk assessment system for breast thermography results

TH1	no unusual features, normal breast tissue
TH2	area(s) of increase in heat, responsive to cold challenge
TH3	area(s) of atypical increase in heat, unresponsive to cold challenge
TH4	area(s) of abnormal increase in heat, unresponsive to cold challenge
TH5	area(s) of severely abnormal increase in heat, unresponsive to cold challenge

Table 2. Patient and tumor characteristics

Variable	n (%)
Menopausal status	
Premenopause	52 (39.4)
Perimenopause	9 (6.8)
Postmenopause	57 (43.2)
Hysterectomized	6 (4.5)
Family history of breast cancer	
Positive	61 (46.2)
Negative	71 (53.8)
History of breast cancer	
Positive	4 (3)
Negative	128 (97)
Tumor side	
Right breast	57 (43.2)
Left breast	75 (56.8)
Tumor size	
< 2cm	27 (20.5)
2–5 cm	51 (38.6)
> 5 cm	1 (0.8)
Unknown	53 (40.2) ^a
Tumor pathology	
Benign	45 (34.1)
Malignant	87 (65.9)
Mammographically suspicious sign	
Spiculated mass	52 (59.7)
Microcalcification	23 (26.4)
Paranchymal distortion	12 (13.7)

^aOperated elsewhere, so exact pathologic size not available.

Table 3. Number of benign and malignant histologies for each score in mammography and thermography

Pathology	Mammography						Total
	B0	B1	B2	B3	B4	B5	
Malignant	10 (41.7%)	1 (25%)	1 (12.5%)	6 (40%)	43 (79.6%)	26 (96.3%)	85
Benign	14 (58.3%)	3 (75%)	7 (87.5%)	9 (64.3%)	11 (20.4%)	1 (3.7%)	45
Pathology	Thermography						Total
	TH1	TH2	TH3	TH4	TH5		
Malignant	6 (40%)	10 (37%)	30 (76.9%)	30 (88.2%)	11 (64.7%)		87
Benign	9 (60%)	17 (63%)	9 (23.1%)	4 (11.8%)	6 (35.3%)		45

B0 = Inconclusive, B1 = normal, B2 = benign, B3 = probably benign, B4 = suspicious, B5 = highly suspicious, TH1–2 negative, TH3–5 = positive.

First, a breast exam was performed for all patients by 1 of 2 breast surgeons in the clinic, and then all included cases underwent both mammography and thermography after obtaining informed consent. The mammography apparatus in this study was a Hologic fully digital direct mammography system. Digital mammography images were interpreted by 2 expert radiologists blinded to the thermography results; they were assigned numbers from B1 to B5 according to the Breast Imaging Report and Data System (BI-RADS) of the American College of Radiology staging system. Breast thermography was done by a trained certified medical thermographer, using a medical thermography system (FMG-MED IR; Fanavarzan Madoon Ghermez Company, Tehran, Iran), which was a non-cooled microbolometer with a focal plane array detector. The image matrix size was 640 × 480, the pixel size 25 × 25 μm, with a response wavelength of 8–12 μm and a temperature resolution of 0.08 °C. Images were viewed with dedicated software with manual brightness and contrast adjustment and were displayed with either a gray palette scale or a preset color palette. Digital infrared thermal imaging (DITI) was carried out at 21 °C room temperature with the patient disrobed from the waist up (fig. 1). The overall timing for each thermography scan was 20 min including an ice test. In order to perform the ice test, the hands of the patients were placed in ice and cold water for 45–60 s after the first round of thermography (after taking the first 5 thermal images). Then, the next 5 thermal images were taken. The ice test could enhance the sensitivity and specificity of the thermography results because of the small temperature changes before and after ice immersion, which may modify the thermography levels (TH, see below) and show details of the suspicious lesions as hyperthermic areas. This test is more important in the dense breast.

Results of breast thermography were categorized by the Marseille system, a risk assessment system demonstrated in table 1. This analytic method provides for a TH1–TH5 scale as a summary based on specific, objective, and quantitative thermal features, and differential levels of infrared energy. Further assessment and screening are recommended when images are classified from TH3 to TH5.

Subsequent to breast imaging, tissue sampling was performed in all participants via core needle biopsy or surgery. Histologic results were considered as the gold standard test. We defined the sensitivities and specificities of mammography and thermography, and of thermography after applying the ice test,

Fig. 1. Digital infrared thermal imaging (DITI) scan in a 48-year-old woman with infiltrating ductal carcinoma in the upper outer quadrant of the left breast.

in comparison with the gold standard. We also defined a test package, consisting of hybridization of the 2 tests (mammography and thermography); this package was also compared with the gold standard test. Besides, we used Cohen's kappa coefficient to calculate the agreement between the mammography and thermography (with and without ice test) interpretations, and between each of the two tests as well as the hybrid test and the histologic results.

Results

Overall, 132 patients were included in the study. The median age of all patients was 49.5 ± 10.3 years (range 24–75 years). The personal and family history of cancer, menopausal status, side and size of tumors, and histologic result are demonstrated in table 2. The final pathologic result consisted of 45 benign lesions and 87 malignant ones, including 79 cases of invasive ductal carcinoma and 8 cases of invasive lobular carcinoma.

The numbers of histologically benign and malignant cases in each class of mammography (BI-RADS) and thermography (TH) as well as thermography after applying the ice test are demonstrated in table 3. We divided the mammography and thermography results into 2 broader categories as given below:

Table 4. Numbers of positive and negative results in mammography, thermography, and package in histology groups

	Histology	
	Malignant	Benign
Mammography		
+ (B4,5)	70	12
– (B1–3)	17	33
Thermography		
+ (TH3–5)	71	19
– (TH1,2)	16	26
Thermography + ice test		
+ (TH3–5)	77	25
– (TH1,2)	6	18
Imaging package ^a		
B4,5 and TH3–5	84	25
B1–3 and TH1,2	3	20

^aCombination of mammography and thermography.

Mammography: B0 = inconclusive, B1–3 = negative, B4–6 = positive

Thermography: TH1–2 = negative, TH3–5 = positive

Category BI-RADS 0 (B0) needs additional viewing or additional imaging like ultrasonography for further evaluation. We consider only B0 cases if the last BI-RADS assessment was defined by an additional mammographic view.

The numbers of the results in each group and the hybrid imaging package in patients with benign and malignant tumors are demonstrated in table 4. The sensitivities and specificities of the 2 imaging modalities alone and in combination are shown in table 5. The accuracy of thermography was obviously lower than that of mammography (69.7% vs. 76.9%). The sensitivity of the combined imaging package was higher than that of each imaging (96.2% vs. 80.5% and 81.6%), but the specificity and accuracy became lower.

In order to evaluate the agreement coefficient of different imaging modalities in differentiating benign from malignant masses, we obtained Cohen's kappa values, as demonstrated in table 6. This value was 0.52 for mammography (p-value 0.000) and was 0.209 for thermography (p-value 0.005), which means that mammography was more powerful than thermography for the differentiation of benign and malignant lesions.

Discussion

It is anticipated that the increased metabolic rate and new angiogenesis in tumors cause some increase in temperature of the area, which could be detected by thermography [7]. In addition, rising nitric oxide levels produced by proliferating malignant cells result in local vasodilation, which subsequently leads to heat emission from that spot [8].

Studies conducted in the past were not entirely in favor of this theory; in 1975, the American College of Radiology and the American Thermographic Society defined thermography as only 'a complementary diagnostic tool that may be useful in evaluation of breast disease when it is combined with both physical examination

Table 5. Diagnostic value indices of mammography, thermography, and the imaging package

	Sensitivity, %	Specificity, %	PPV, %	NPV, %	Accuracy, %
Mammography	80.5	73.3	85.4	66.0	76.9
Thermography	81.6	57.8	78.9	61.9	69.7
Thermography + ice test	92.8	41.9	75.5	75	67.35
Imaging package ^a	96.2	44.4	77.1	87.0	70.5

PPV = Positive predictive value, NPV = negative predictive value.

^aCombination of mammography and thermography.

Table 6. Agreement between diagnostic modalities according to Cohen's kappa values

	Mammography (p), agreement	Histology (p), agreement
Mammography	–	0.52 (< 0.001), moderate
Thermography	0.22 (0.009), weak	0.40 (< 0.001), moderate
Thermography + ice test	0.388 (< 0.001), moderate	–
Imaging package	–	0.47 (< 0.001), moderate

under the supervision of a qualified physician, and mammography by a trained radiologist' [9]. In 1976, Moskowitz et al. [6] detected a low rate of true positives for early-stage breast cancer in thermograms interpreted by expert specialists, and concluded that this modality is probably not suitable for cancer screening. In more recent years, animal models have shown an early detection of breast malignancy by thermography before any mammographic change [10–12].

The present prospective study, performed on 132 women undergoing thermography and mammography before biopsy, showed a low sensitivity (47.1%) for thermography compared to mammography (80.5%) when only TH4–5 were considered as positive. In one of the earliest studies carried out by Gautherie and Gros in 1980 [13], patients with a thermogram stage 4 or 5 had a 90% chance of being affected by cancer at the time of study, while 38% of the TH3 cases (suspicious but not conclusive) developed cancer within 1–4 years of follow-up. Similarly, in a recent review by Lahiri et al. [14], an abnormal pattern in infrared images could identify a high risk for breast cancer development in the future. In our study, by considering stage TH3 as positive, and by using the ice test in the majority of patients, the sensitivity of thermography became higher (81.6% and 92.8%).

Similar studies in the literature have shown more favorable results. In a multicentric study by Parisky et al. [15], 769 patients were imaged using a DITI prior to breast biopsy; a total of 875 biopsies were performed and the sensitivity of DITI was 97%, with a specificity of 14%.

In the study by Aora et al. [7], DITI identified 58 of 60 malignancies, with 97% sensitivity and 44% specificity, and 82% negative predictive value (NPV). In another work, Wishart et al. [16] used 4 different ways for interpreting the scans and found DITI to be effective in women under 50 years with a high sensitivity (78%) and specificity (75%), by exerting an expert manual review. They concluded that reduced vascularity in breasts of older women, especially over 70 years of age, may account for the poor result of thermography in this group of patients.

Yao et al. [17] found that the sensitivity and specificity of infrared thermography was superior to that of mammography and ultrasonography in lesion less than 2 cm in diameter, and that mammography had a better diagnostic accuracy only in lesion larger than 2 cm in diameter. In a study on chemically induced rat mam-

mary tumors, the maximal tumor temperature and the thermal amplitude determined by thermography were significantly correlated with the tumor volume [18]. Other studies on breast cancer cases had shown a direct correlation between infrared thermography stage and tumor size, grade, and vascularity, as well as lymph node involvement [19, 20]. In another study by Zore et al. [21], the tumor size had no influence on the increased temperature. The increased temperature in that study was more dependent on immunohistochemistry phenotypes of the tumor than on other clinically and histopathologically prognostic factors.

The results of a literature review regarding the effectiveness of DITI in an imaging program are controversial [22–24]. A systematic search of 7 biomedical databases by Vreugdenburg et al. [23] during March 2011 found a wide variation in sensitivity (0.25–0.97) and specificity (0.12–0.85) of DITI and concluded that there is insufficient evidence to recommend the use of thermography for breast cancer screening. As well, a review by Sajadi et al. [24] did not show any acceptable diagnostic value for DITI in comparison with other diagnostic modalities.

In the current study, the accuracy of DITI was lower than that of mammography (69.7% vs. 76.9%), but the study has some limitations: The sample size is small, and all mass or mass-like densities were examined. In addition, cases fairly inadequate for DITI, such as elderly or morbid obese women, advanced stages of cancer, and large breast sizes, were included in the study.

We believe that DITI is a non-invasive, inexpensive and accessible imaging modality in our country, but its real role in clinical practice could only be evaluated through a large multicenter trial that would estimate the accuracy of digital thermography in breast cancer screening. At present, our suggestion is to perform thermography as a complementary test to a breast clinical exam. In conclusion, it seems that, despite technical advances in thermography, it cannot substitute for mammography at the present time; this modality can only be proposed as a complementary tool in breast cancer diagnosis.

Disclosure Statement

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