Performance Analysis of Breast Cancer Imaging Techniques

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Abstract— **Breast cancer is considered as the most common cancer type and the second leading cause of death in women around the world. It happens when cells in the breast begin growing out of proportion and results in malignant tumor that spreads throughout the body. Women over the age of 50 years are the most commonly affected by breast cancer. There are one million cases and nearly 600,000 deaths occurring worldwide annually. The early detection of breast cancer can help to save thousands of lives each year. It is carried out by using one of several established imaging techniques such as CBE, mammography, Breast Ultrasound, CT-scan, PET, MRI, EIT and breast thermography. More efforts have been made to improve the accuracy and efficiency of breast cancer diagnosis using these different imaging techniques. The objective of this paper is to provide and discuss the capabilities of the various breast imaging modalities. As several screening tools are developed, this paper helps to learn more about the risks and benefits of each screening test.**

Keywords- Breast cancer; imaging techniques; mammography; thermography;

I. INTRODUCTION

Breast Cancer is one of the most common diseases among women worldwide which can lead to death [1] [2]. There are about 10% of women facing breast cancer in their lives. In Canada, approximately 25,700 Canadian women will be diagnosed with breast cancer during 2016 [3]. This is equivalent to 130.1 cases per 100,000 women. Breast cancer continues to be the most commonly diagnosed cancer and representing 26 % of all newly diagnosed cancers in Canadian women. The risk of being diagnosed with breast cancer increases with age. It is estimated that 83% of new breast cancer cases occurred among Canadian women over the age of 50 in 2016 as shown in Table 1 from [3]

Statistics have shown that there are a five-year survival rate of 87%, meaning that 87 percent of women diagnosed with breast cancer 5 years ago are living as shown in figure 1. The early detection, fast diagnosis and treatment of breast cancer can help more women, of all ages, to live longer after a breast cancer diagnosis. So, the early detection of breast cancer is considered necessary and vital to save the patient's life [4] [5]. The highest degree of specificity and sensitivity is required in breast cancer diagnosis because the false positive result may cause surgical removal of the breast.

TABLE I
ESTIMATED NEW BREAST CANCER CASES DIAGNOSED IN CANADIAN WOMEN BY AGE GROUP IN 2016 [3].

Age Group	# of new cases	% of new cases
0-19	5	0.02%
20-29	140	0.54%
30-39	1,050	4.09%
40-49	3,300	12.84%
50-59	6,200	24.13%
60-69	6,900	26.85%
70-79	4,900	19.07%
80+	3,200	12.45%
Total	25,695	100.00%

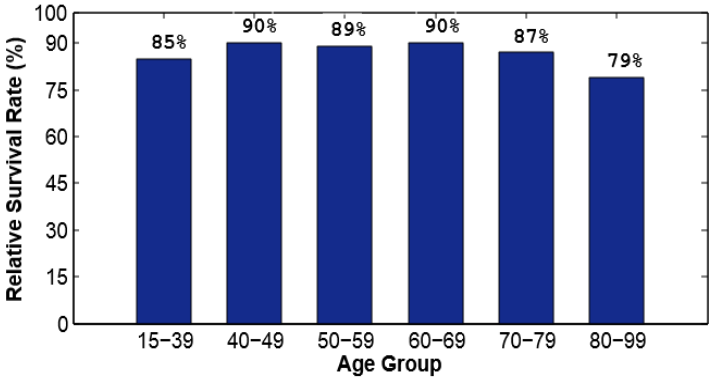

Figure1. *Five year relative survival ratios for female breast cancer by age group [3].*

The breast cancer can also occur in men as it is composed of identical tissues in both men and women. There are about 1% of men prone to breast cancer, but both men and women have the same statistical survival rates [6][7][8].

In this paper, our focus is on breast cancer diagnosis techniques which use breast images obtained by various techniques for analysis and detection. Now, many imaging techniques are available to the breast radiologist to help in diagnosis the breast cancer as early as possible. Recently there are new improvements in these imaging techniques which

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show great promise for the future. These imaging techniques include Clinical Breast Examination (CBE), mammography, breast ultrasound, computed tomography (CT), positron emission tomography (PET), magnetic resonance imaging (MRI), Electrical Impedance Tomography (EIT) and breast thermography [9] [10]. Breast thermography is a new recent technique which is a relatively new screening method based on temperature a tumor may produce, and helping in early detection of breast cancer [11] [12] [13]. These imaging techniques examine the abnormalities indicating the presence of cancer and also declare host of other breast conditions. There are some of these imaging techniques used for screening objectives, some others for diagnostic objectives, and a few others used as adjunctive tools. For an effective screening method, it must have some important features like accuracy, high sensitivity and acceptable specificity, easy to use, using comfort tool during the test, and low cost.

The main objective of this paper is to provide a detailed discussion of the capabilities of each of these imaging techniques, which are presented in the following sections. It will also demonstrate the advantages and risks of each of these imaging techniques.

II. SCREENING TECHNIQUES FOR BREAST CANCER

This section introduces a brief review and comparison between the different screening techniques applied for estimating breast abnormalities.

A. Clinical Breast Examination (CBE)

A clinical breast exam (CBE) is a manual physical exam, which done by the physicians. A trained health care provider may detect changes in both breasts of a patient, such as lumps and other abnormalities like nipple discharge, inverted nipple that are difficult to detect by self-examination [14]. The physician will visually check breasts of patients while they are sitting up and physically examine their breasts while they are reclining.

The studies found that the well performed CBE detects at least 50% of asymptomatic cancers [15]. CBE does not be recommended for breast cancer screening by the American Cancer Society. However, the National Comprehensive Cancer Network says that when women start CBE at age 25 and continue after they begin 50 years having mammograms. The CBE has a sensitivity of 21%, while the sensitivity of mammography is 64.3%, but both together have a sensitivity of 81% for breast cancer diagnosis [16] [17]. So, it can be used as an adjunctive tool with mammography imaging method.

B. Mammography

Mammography is the primary examination for screening breast cancer. It is considered as the gold standard and the most common imaging modality used for early detection of breast cancer [18]. It uses low dose amplitude X-rays to observe if there are any alarming tissues in the breast [19]. Each breast is compressed using two parallel plates instrument as shown in Figure 2. Then a beam of x-ray breaks the breast and creates a projected image on a film. There are no dyes to be injected or swallowed in mammography. The abnormal tissues and cancerous masses appear brighter [19] [20] in the mammogram as shown in figure 3.

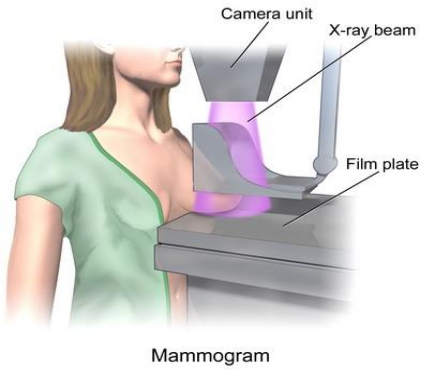

Figure 2. *Mammogram instrument*

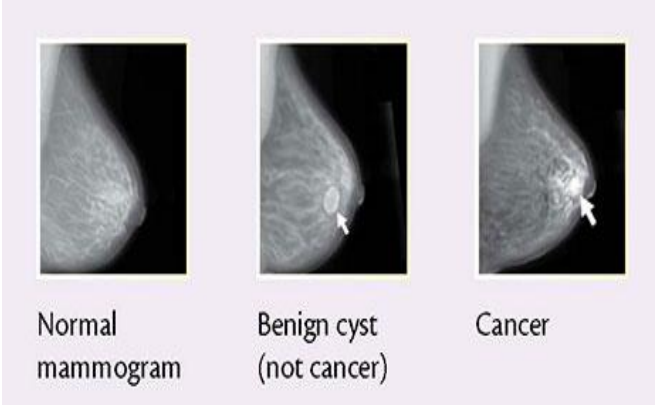

Figure 3. *Example for breast cases in mammography*

A true-positive rate of mammography is ranged from 83% to 95% and a false-positive rate from 0.7% to 6.5%, which is considered as the most frequent harm of mammography [21] [22]. The breast density has a great effect on the sensitivity and specificity of mammography [23]. The range of sensitivity values is from 62.9% in extremely dense-breasted women to 87% in extremely fatty-breasted women, while specificity values ranged from 89.1% to 96.9%, respectively. Although mammography is a cost effective tool and a more powerful technique for detection of breast cancer, it has some inherent limitations and risks which are difficult to overcome [23] [24]. The limited dynamic range and contrast characteristics are the most important limitations that face mammography. It is also not well suited for women with dense breasts as both dense breast tissue, and cancer tissues appear bright. Hence, it will be difficult to distinguish between the dense tissue and cancerous tissue. The Radiation exposure is considered as one of the risk

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factors of mammography as there is a risk of causing radiation induced breast cancer tissues.

The rupture risk is another risk factor of the mammography screening tool. It uses around 42 pounds of pressure, and this would be a sufficient amount of force to rupture the encapsulation and potentially release malignant tissues into the bloodstream. Finally, there are a lot of studies detect that mammogram is less effective for women less than 50 years old [24] [25]. So, newer technologies may be more adequate than mammography, and much research focuses on obtaining better systems for breast cancer detection.

C. Breast Ultrasound

Breast ultrasound, also known as sonomammography, is another medical imaging technique for breast cancer. In this technique, ultrasound transducer sends high frequency waves through the breast tissues and then collects the reflected waves to display a 2D image of the breast as shown in figure 4. The ultrasound tests on the breast are most often done with a handheld ultrasound device, so the quality of the output image can vary greatly depending on the skill and experience of the radiologist performing the test [26].

There are some advantages of using breast ultrasound like its safety, ease of use, and real-time imaging capability. However, some studies show that breast ultrasound is not a good breast cancer screening tool to be used alone and has many false negative and false positive results [26]. It should be used as an adjunctive tool to mammography in the evaluating of breast abnormalities. As known, the mammography alone is not effective for detection of cancer in dense breasted women. The diagnosis of breast cancer using mammography with an automated whole breast ultrasound (AWBU) will be more effective for women with dense breasts [27] [28].

There are other limitations that face the ultrasound screening technique like that the low sensitivity of this technique when uses it in detecting impalpable tumors. The captured images should be labeled by the radiologist in regard to location in the breast and orientation. Any little change in the beam orientation may miss a part of the breast or image it twice, So, the breast ultrasound is an operator dependent method [29].

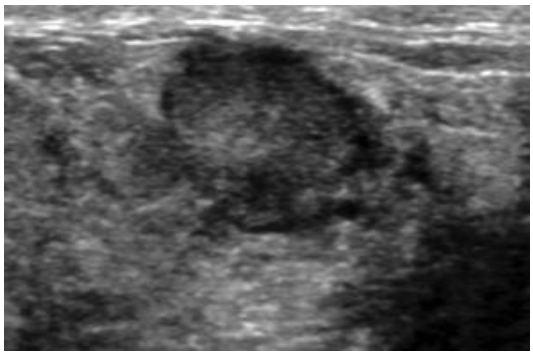

Figure 4. *Breast imaging using Breast Ultrasound.*

D. Computed Tomography (CT)

Computed Tomography, or CT scan, is a medical screening method that uses X-ray projections taken from different angles to capture 2D breast images. The patient lie on a moving table during a CT scan and enter through a doughnut-shaped machine which takes X-rays of the body from many different angles as shown in figure 5. Then these X-rays are put together using a computer to create a detailed image of the inside of the breast. Figure 6 shows an example of breast cancer patient. The patient must have a contrast solution (dye) before the scan injected into arm through an intravenous line[30]. Recently, 3D images are built by using different algorithms which provide information on anatomical issues like the location of lesions. These CT images allow doctors to get very precise 3D views of the breast, which help in breast cancer diagnosis [31].

In [32], it is proved that CT perfusion is considered as an effective tool to examine enlarged axillary lymph nodes in breast cancer patients. One of limitations of CT scan is that the low contrast of CT images. However, the visualization of tumors is enhanced by using the iodine contrast injection. Another limitation is that the diagnosis with CT can be used only after appreciable size taken by the formation of cancer. Generally, if the breast cancer is in an early-stage, CT scans wouldn't be needed.

Recently, researchers have been checking if breast CT scans could be more effective screening tool than traditional mammography. Through the CT scan, the human body is exposed to large amounts of X-rays. This total amount of radiation is the same as in a traditional mammogram [31].

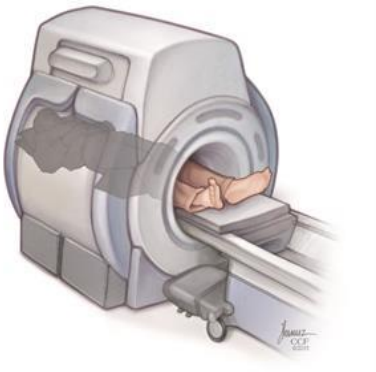

Figure 5. *CT-scan machine*

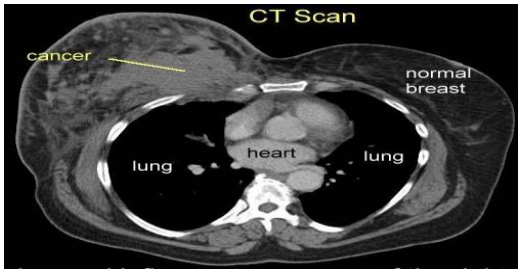

Figure 6. *Breast cancer patient using a CT scan.*

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E. Positron Emission Tomography (PET)

The physicians can be provided with information about how tissues and organs are functioning by using the Positron Emission Tomography (PET) technique. It is a nuclear imaging technique that produces 3-D images of the examined part of the human body. This type of breast cancer tests is done by using a form of radioactive sugar. A Glucose, which is a form of sugar and contains a radioactive atom, is injected into the bloodstream. The sugar travels through the body. The cancer cells absorb large amounts of the radioactive sugar compared to the normal cells, as they grow rapidly. After about an hour, a picture of areas of radioactivity in the body is created by using a special camera [33].

The output images of PET scan have distinct contrast between cancerous and normal cells as shown in figure 7. One of the most important limitations of PET scan is the poor resolution of output images. It's also very expensive. Moreover, PET scans are used in patients known to have breast cancer to see if the cancer has spread. It has a limited ability to detect small tumors [33].

There is a hybrid technique combining PET and CT scans. This technique is useful for staging potential metastatic cancers. It has the combined advantages of both CT and PET as tumor location is better get by CT scan and PET indicates a malignant tumor or cancer cells based on glucose uptake [34].

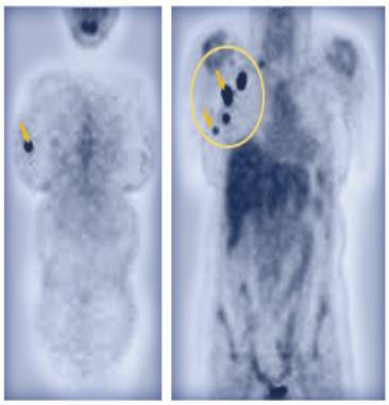

Figure 7. *Scan breast by PET scan*

F. Magnetic Resonance Imaging (MRI)

Magnetic Resonance Imaging (MRI) is a medical screening tool that uses radio waves and strong magnetic fields for breast imaging. It creates detailed images of organs and tissues of breast cancer patient. By using this method, the physician can evaluate the extent of breast cancer and the response to chemotherapy before surgery. This technique is done by injecting the bloodstream of breast cancer patient by contrast enhancing dye-like material and then observes the way in which the material is taken up and drains out by the tumor [35]. The examined patient by MRI should be put in a magnetic field. Then, a radio frequency wave is applied to create high contrast images of the breast. An example of patient uses MRI scan for diagnosis in figure 8. Figure 9 shows a breast image using the MRI scan method [35] [36].

There are some advantages of using MRI as a screening tool for the diagnosis of breast cancer. First, it is non-ionizing and it can be used in women with dense breasts. Second, it helps to evaluate if the cancer has spread to the chest wall. Third, it can also help the women who have undergone lumpectomy to check for recurrence of cancer [37]. Finally, it is highly sensitive to small abnormalities and the specificity can be limited.

The limitations of MRI are that it is expensive, requires injection of a contrast agent for functional imaging. It is a time consuming procedure (30 min. to 60 min.) as it requires long scan times compared to mammography. [37] [38].

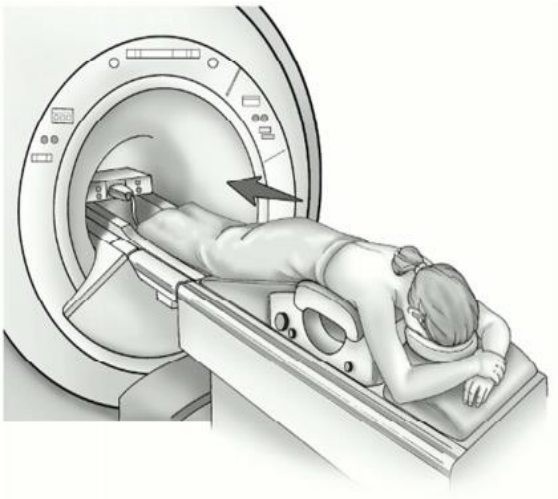

Figure 8. *Breast MRI device*

Figure 9. *Scan breast by MRI scan.*

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G. Electrical Impedance Tomography (EIT)

Electrical impedance tomography (EIT) is a screening technique which is electrical impedence based imaging technique. As known in electronics, the tissues of human body present impedance to the electric current passing through the body. Some studies show that the cancerous breast tissues have lower impedance when compared to normal tissues. EIT produces 2D or 3D images [39]. These images are produced due to a large number of impedance values which are captured by setting electrodes around the surface of the breast in a circular way. Then, a small amount of alternating currents will be passed through some or all of the electrodes. It will then be repeated for a number of various electrode configurations. Finally, a 2D tomogram will be resulted due to the image reconstruction algorithms [40] [41]. Figure 10 presents the physical configuration of the EIT method.

This imaging technique has some advantages like that it is low cost technique, does not use radiation, the equipment used in EIT process is much smaller, and does not require breast compression [41] [42]. But it also has some limitations such as the low Signal-to-Noise ratio of this test and low resolution of the output images.

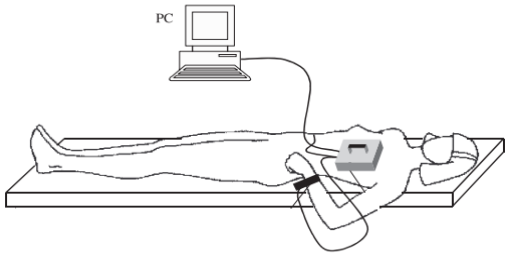

Figure 10. *Physical configuration of the EIT system.*

H. Breast Thermography

Breast Thermography is a powerful imaging technique for breast cancer detection. This technique provides physiological information not only the anatomical features of woman breast. It is used to detect the thermal infrared (IR) radiation emitted from human skin of the breasts. It uses a special kind of infrared cameras to obtain an image which records the surface temperature distribution of the breasts [17]. The concept of breast thermography as a diagnostic tool for cancer detection depends on the fact that the high metabolic rate of cancerous and precancerous tissues resulting in neoangeogenesis, supplying nutrients to the tumor. As a result, the abnormal tissue temperature is higher compared to normal breast tissue temperature [43]. As breast thermography focuses on physiological investigation, thermography is considered as the unique screening technique for early detection of breast cancer, i.e. before tumor takes its physical shape. Thermography is able to detect breast abnormalities up to 10 years before a cancer is found [19][44].

Breast thermography imaging technique must be performed in a controlled environment. The temperature and humidity of the imaging room must be controlled and maintained between 18 and 23°C. Then after preparing the patient, the breast thermal images must be captured and obtained using an IR camera which is used to convert IR radiation emitted from the skin surface of the breast into electrical impulses that are represented in RGB colored image on a monitor then go through software to be analyzed [45][46]. Figure 11 represents the breast thermography procedure. An example of the captured breast thermal image is shown in Figure 12.

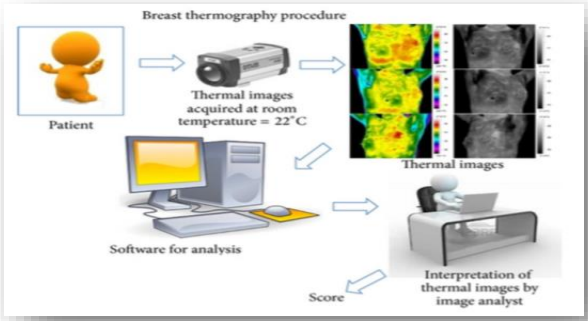

Figure 11. *Breast Thermography Procedure*

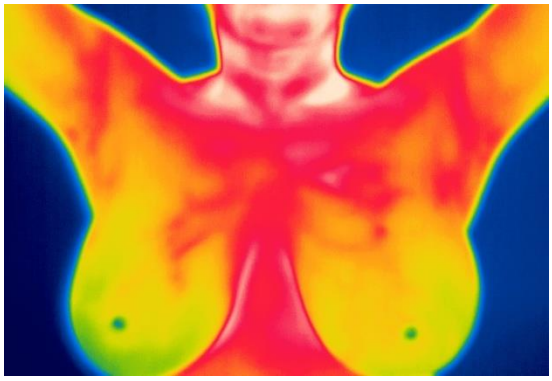

Figure 12. *Breast Thermal Image*

Breast thermography has some important advantages over other traditional methods and leading to be unique in several aspects as:

- Its ability to test dense breast tissues in young women, even children and men is possible [11].
- Noninvasive method; No need for ionizing carcinogenic radiation, high pressure, and compression of breast so no rupture risk here [11] [43] [44].

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- Harmless, fast method, and helps in early detection of breast cancer [17].
- Effective in all age groups.
- High resolution of output breast images[17].

However, it has also some of the limitations like operator dependent, environment dependent, not descriptive and requires a special kind of the IR camera. Nowadays, breast thermography is widely used for the fast and accurate detection of breast cancer. It is considered as a promising screening tool because its ability to detect breast cancer at least ten years in advance. However, both analysis and interpretation of thermal images depend on analysts [47] [48].

III. PARAMETERS AND RISK FACTORS OF SCREENING TECHNIQUES

The selection of the most suitable screening technique for a person who needs to be screened depends on some important parameters and risk factors. The most common parameters include the gender and age of the patient who should be screened, the output image quality, cost, accuracy, sensitivity and specificity. The sensitivity and specificity are the most important parameters for the screening method to detect the breast cancer. Sensitivity refers to the screening test's ability to correctly detect patients who do have the breast cancer (i.e, true positive results). Specificity relates to the screening test's ability to correctly detect patients without a breast cancer [49]. Then, the overall accuracy is determined according to the sensitivity and specificity values.

However, not all of them are helpful but most of breast screening tests have risk factors such as:

- Harms that can be caused by some screening techniques:

The degree of pain and discomfort of the selected screening technique is considered one of the most important harms. In some screening techniques, the patient must exposure to radiation which can also cause harms. However, there are screening techniques that can cause rupture risk due to the using of large amount of pressure [24] [25].

- False-positive results:

Sometimes, the breast screening test results may appear to be abnormal while there is no cancer. A false-positive test result can cause despondency and is usually followed by more tests and procedures, which also have risks [25].

- False-negative results:

The false negative results mean that although there is cancer, screening test results may appear to be normal. A patient who receives a false-negative test result may postpone seeking medical care even if there are symptoms [25].

For an effective breast screening method, it must have output image with good resolution, high accuracy percentage, high sensitivity and acceptable specificity, low cost ,easy to use, using comfort tool during the test, and low percentages of false-positive and false-negative results.

In this paper, a comparison between the most common screening techniques as PET, Ultrasound, MRI, Mammography and thermography is done. This comparison depends on the parameters and the risk factors of each screening technique. Table.2 summarizes the comparison result between the most common screening technique according to the parameters and risk factors of each technique. The accuracy is calculated according to the values of sensitivity and specificity. It is an estimate because these techniques perform differently based on different types of breast cancer and on different age group.

CONCLUSION

Breast cancer is a dangerous disease which can lead to death. The survival rate of patients can be increased due to the early detection of breast cancer. Breast imaging techniques play a vital role in the detection and characterization of breast cancer. In this paper, we have discussed the abilities of the different breast imaging techniques that are currently used. The most common imaging techniques are mammography and thermography. Although mammography is said to be the gold standard, it has some limitations and risks such as breast density, discomfort due to breast compression, tumor encapsulation rupture risk and ionizing radiation exposure. Some studies suggest that it also cannot be used for women less than 50 years old. Although the mammography is a most common screening technique, it has a limited sensitivity and specificity of 67.8% and 88.2%, respectively. The accuracy of it reaches to 83%. However, modern imaging techniques are starting to focus on physiological alterations specific to tumors such as breast thermography technique. Breast thermography is a noninvasive functional imaging method, painless, passive, fast and sensitive method. It also can be used in all age groups and suitable for dense breast tissues. It faces some limitations like environment dependent, requires trained person to use the correct type of thermography cameras. The accuracy of breast thermography reaches to 96% and it has high sensitivity of 95% and acceptable specificity of 95%. This paper introduces a comparison table between the different breast screening techniques according to important parameters and risk factors. It is clear from table that thermography provides significant data for the early detection of breast cancer.

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TABLE 2
THE COMPARISON BETWEEN THE MOST COMMON BREAST SCREENING TECHNIQUES.

Screening technique	**Parameters**							**Risk Factors**		
	Gender	***Age***	***output image quality***	***Accuracy rate***	***Sensitivity [50]***	***Specificity [50]***	***Cost***	***Harms***	***False-Positive rate***	***False-negative result***
PET	Female only.	Effective for women older than 25 years old.	Poor resolution of output image.	80%	96%	99%	High cost.	-Painful due to injection of glucose into blood stream. -Radiation exposure.	1%	4%
Ultrasound	Female only.	Effective for women older than 25 years old.	Depends on the skill and experience of the person doing the exam.	75%	13-98.4%	67.8-94%	Low cost.	-Painless. -The sound waves it uses are harmless. -Radiation free.	6-12.9%	1.6-87%
MRI	Female only.	Effective for women older than 30 years old.	Good output image resolution.	79%	86-99%	21-97%	High cost.	-Painful due to injection of a contrast agent. -Discomfort due to it take longer and patient must lie in narrow tube. -No ionizing radiation.	3-79%	1-14%
Mammography	Female only.	Effective for women ages 50 and over.	Good output image Resolution.	83% for women over 50.	67.8%	88.2%	Low cost.	-Discomfort due to breast compression. -Rupture risk. -Radiation exposure.	11.8%	32.2%
Thermography	Female and male.	Effectivefor all age groups.	High resolution of output image.	87-96%	95%	95%	High cost.	- Painless. -Safe and radiation free.	5%	5%

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