A Survey of Medical Imaging Techniques Used for Breast Cancer Detection

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Abstract-In this survey paper, we explore different medical imaging techniques used in the diagnosis of breast cancer. We compare their effectiveness, advantages, and disadvantages for detecting early-stage breast cancer. We mainly focuse on X-ray mammography, ultrasound, and magnetic resonance imaging (MRI), as they are the primary imaging modalities used in the clinic for the diagnosis of breast cancer.

***Keywords*--X-ray Mammography, Ultrasound Imaging, Magnetic Resonance Imaging (MRI), Breast Cancer**

I. INTRODUCTION

According to the American cancer society, breast cancer is the second highest cause of mortality among women in USA [1]. In 2013, over 232,000 women will be newly diagnosed with breast cancer, and more than 39,000 women will die from this disease [1]. Breast cancer death rates generally increase with age. 95% of new cases and 97% of breast cancer deaths occur in women 40 years of age and older [2].

X-ray mammography was originally the only accepted imaging modality for detecting breast cancer [3]. However, this method is not reliable for imaging patients with dense breasts. Furthermore, it exposes patients to ionizing radiations. In recent years, new imaging techniques have been used to complement X-ray mammography and overcome some of its limitations and disadvantages. Nowadays, X-Ray mammography, ultrasound, and magnetic resonance imaging (MRI) are imaging modalities routinely used to screen for breast cancer.

The American cancer society recommends that patient with a family history of breast cancer or who are more vulnerable to the disease due to other factors be screened annually beginning age 40, or 10 years before the age of diagnosis of a first-degree relative [1]. When screening high risk women, the overall detection rate of mammography is 36% and the combined detection rate of mammography and MRI is 92.7% [4].

Detecting breast cancer in high risk women using mammography and ultrasound id 52%, compared with 92.7% of combined mammography and MRI [4]. Therefore, the combined effectiveness for detecting breast cancer with mammography, ultrasound, and MRI is much higher than that of only one of these imaging techniques. When breast cancer is diagnosed, an ultrasound or MRI guided biopsy can confirm the cancer. In many cases, ultrasound-guided biopsy is preferred because of its lower cost, relative ease, and higher degree of patient comfort. Several treatment options are available after the diagnosis of breast cancer. The most common treatment is breast mastectomy, which removes cancerous tissues and prevents cancer from spreading. Even after breast mastectomy, breast cancer may recur and still be a cause of death.

In this paper, we describe the advantages and disadvantages of X-ray mammography, ultrasound, and MRI. We also compare their performances using several metrics, including cost, safety, and ability in detecting microcalcifications, which are the first sign of breast cancer.

II. X-RAY MAMMOGRAPHY

X-ray Mammography is the most widely used medical imaging modality for early detection of breast cancer. This method mammography uses X-ray radiation in the frequency range of 30 petahertz to 30 exahertz (3×10^{16} Hz to 3×10^{19} Hz). The method produces an image that is a projection of the entire breast (3D to 2D). The spatial resolution of the mammogram image is approximately 20 lines pairs/mm. This method can detect approximately 78% of invasive breast cancer [4] and its sensitivity is as high as 98% in women over 50 years old with fatty breasts [4].

One of the major limitations of X-ray mammography is its low sensitivity in dense breasts. Mammograms of dense breast tissue common in younger women are difficult to interpret. Dense breasts are more likely to develop breast cancer and the sensitivity of mammography in these dense breasts can be low as 30%-48% [3]. Another disadvantage of X-ray mammography is the exposure of patients to the X-ray ionizing radiation, which may induce cancerous cells. In addition, the mammography screening process is sometime uncomfortable because the breast has to be compressed between flat surfaces to improve image quality.

Digital mammography has shown better results for screening of women with dense breast and it is more sensitive for women with dense parenchyma and premenopausal women as well as for those women who are under 50 [8]. However, digital mammography does not eliminate the fact that small, noncalcified breast cancers can be obscured by dense parenchyma. Among almost 50,000 women who participated in the Digital Mammographic Imaging Screening Trial (DMIST) in 2008, the overall sensitivity of screening mammography was only 55% [8]. With the errors, approximately half of the cancers are visible in retrospect due to the lack of recognition of the suspicious nature of the lesion and by using double reading one can improve detection by 7% to 15% [9]. Physicians experience also plays an important role for detecting breast cancer in the early stage. Due to wrong interpretations sometimes breast cancer cannot be detected. Despite improvements and technological modifications done regarding mammography, still now at least 10% of breast cancers remain occult mostly for dense parenchyma [10]. For this reason ultrasound imaging and magnetic resonance imaging have been used for further confirmation of breast cancer when screening a patient adjunct to mammography. For wider excisions and even mastectomies improved identification of disease extent is necessary.

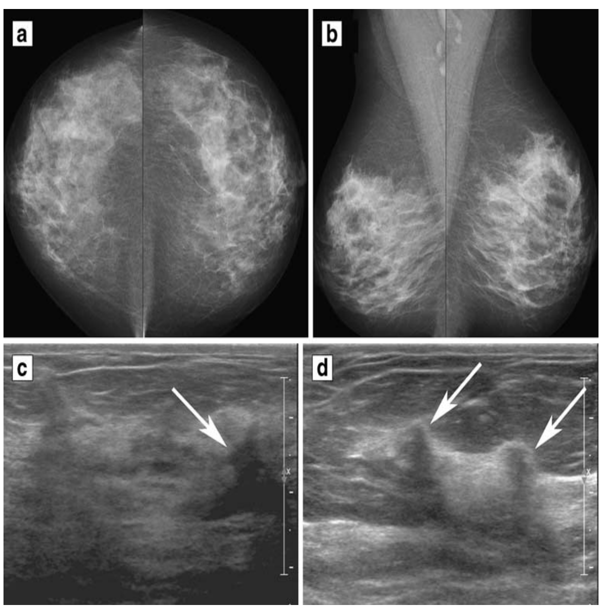

Fig.1. (a) Craniocaudal digital mammogram image of a 54 year old woman. (b) Mediolateral oblique digital mammogram image of the same patient. (c) Arrows shows a 7 mm grade I, stage 1, and invasive ductal carcinoma in situ on right breast. (d) Arrows shows a 10mm (d), grade I, stage 1, invasive ductal carcinoma in situ on left breast [5].

III. ULTRASOUND IMAGING

With ultrasound imaging, breasts are irradiated with sound waves through a probe containing an array of transducers. The frequency of sound waves is of 2-20 MHz, which is much lower than the frequency range of X-ray, and, thus is safer. Ultrasound imaging systems produce images of single plane. These systems provide images in real time with a frame rate of approximately 25 frames per second. Because of advances in transducers and ultrasound technology, current ultrasound imaging systems can detect breast cancers as small as 3 mm [4]. Recent studies [12] suggest a predictive value of almost 98% for detecting invasive lobular carcinoma when both mammography and ultrasound imaging are used for screening. In another recent study [13], 88% of invasive lobular carcinomas, that were identified mammographically, were also detected with ultrasound imaging. Other studies showed that additional cancers were detected with ultrasound screening of women who had already been screened mammographycally. Results of a recent study show that with an increase in breast density [4], the detection rate of breast cancer also increases with the use of ultrasound screening.

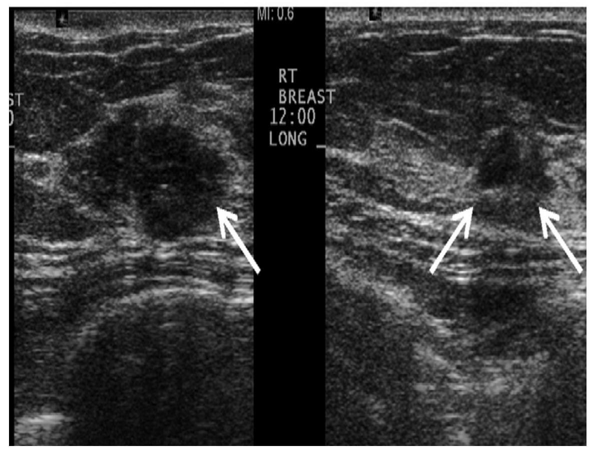

Fig.2. Longitudinal grayscale ultrasound images show two irregular hypoechoic masses (arrows), measuring 1.5 cm and 0.6 cm at the 10- and 12-o'clock positions respectively in the right breast. Ultrasound-guided core needle biopsies revealed intermediate grade ductal carcinoma in situ at both sites [4].

In a more recent study [4], women with heterogeneously dense and extremely dense parenchyma who had negative mammograms were found to have bilateral breast cancers when screened with ultrasound. Overall, ultrasound screening of mammographically negative dense breasts contributed to an additional cancer detection rate of 20% in asymptomatic women, compared with mammography alone, while maintaining a very low surgical biopsy rate (0.9%) [14]. The contribution was substantially greater for younger women than for older ones in the proportion of cancers detected (an additional 41.3% for under 50 years relative to an additional 13.5% over 50 years) [15]. These findings suggest that routine ultrasound screening in asymptomatic women might provide the greatest relative cancer detection yield if applied to women under 50 years of age with dense breasts [4].

Although ultrasound screening is very helpful in detecting breast cancer, in some cases it has a higher false positive rate. In addition, ultrasound imaging is highly operator-dependent, requiring real-time adjustments of gain, focal zones, dynamic range, pressure, patient positioning, and, most importantly, recognition of abnormalities. Therefore, ultimately, if ultrasound imaging is to be used as a supplemental screening tool, the current model of physician-performed scanning using hand-held transducers will likely need to be changed [12].

Automated ultrasound imaging allows for reproducible image quality and consistency, and removes user variability [16]. However, there are limitations to using this technique because the resolution of the images obtained by most automated scanners is sometimes limited [16]. Furthermore, there is a learning curve with automated ultrasound imaging, as physicians need to gain familiarity with interpreting the data sets. As vendors continue to improve image quality, automated breast ultrasound is likely to become a helpful tool for breast cancer screening [17].

Older technology enabled only differentiation of "cyst" versus "solid," whereas the higher-frequency transducers available today provide greater shape and margin definition, internal characteristics, and vascular patterns of solid masses such that better differentiation of benign and malignant is possible. Hence, further recommendations for biopsy or follow-up can be more confidently made.

Ultrasound also provides the best guidance method for biopsy of suspicious lesions in terms of cost, ease, and patient comfort. Use of ultrasound imaging can obviate the need for more costly stereotactic and MRI-guided procedures. As discussed previously, there are efforts being made to supplement mammography with other imaging tests in some women. Although those women at greater risk can be candidates for undergoing MRI, the majority, at low or intermediate risk, do not qualify. For these women, primarily those with dense tissue, screening with ultrasound imaging is suggested for early detection of breast cancer.

IV. MAGNETIC RESONANCCE IMAGING

Magnetic resonance imaging (MRI) is valuable tool for local staging before breast cancer surgery. Small invasive cancers and ductal carcinoma in situ can be detected using breast MRI due to remarkable advances in temporal resolution and spatial resolution [18]. For high-risk women, when supplemental screening is planned, MRI is performed in lieu of ultrasound imaging. The American cancer society has updated its breast cancer imaging guidelines and now advocates breast MRI for certain groups of high-risk women [22]. MRI imaging uses a large magnet of 3-5 Tesla and RF coils to produce 3D images of the breast. The signals received are processed to produce the images. Compared to other imaging techniques, MRI is relatively expensive and requires an intravenous injection of gadolinium, which causes the development of nephrogenic systemic fibrosis in a small group of patients with impaired renal function [23]. Therefore, a patient with a history of renal disease may not be able to undergo breast MRI. Because this method uses large magnets it cannot be performed for breast cancer detection in patients who have pacemakers or any metal implants [24]. MRI imaging techniques are time-consuming and produce blurred images. Misinterpreted MRI images require that patients undergo the same imaging process several times. Although MRI may save patients from unnecessary surgery, there is a concern that findings on MRI may prompt unnecessary excess tissue removal or in some cases unnecessary mastectomy.

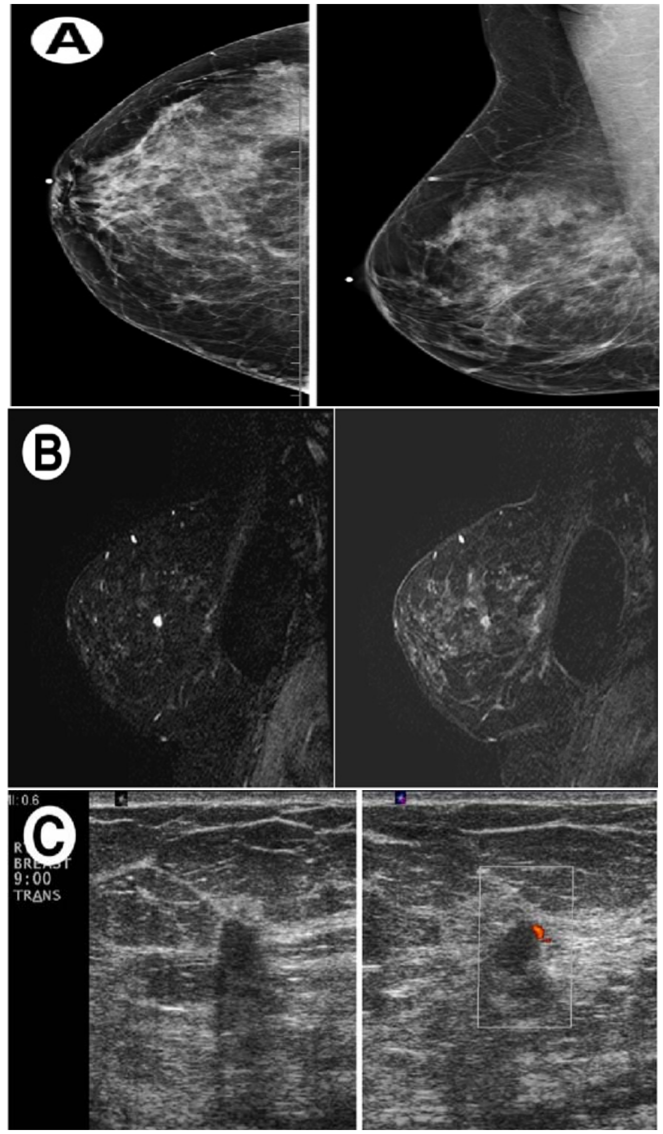

Fig.3. (A) Annual mammography screening done upon a 59-year-old woman with a strong family history of breast cancer. No suspicious mammographic findings were identified. (B) Then the patient went through MRI screening on the same day and a 8-mm suspicious mass at the 9-o'clock position was found using MRI screening. (C) Later on transverse grayscale and power Doppler ultrasound images of the right breast in the 9-o'clock region show a corresponding 7-mm irregular mass with peripheral vascularity. Then Ultrasound-guided biopsy was performed, revealing evidence of invasive ductal carcinoma [4].

When lesions are identified, using MRI can be a reliable method for biopsy or localization of breast cancer. Many breast biopsy systems are beginning to reach the market, however they are hardly ubiquitous. From all the imaging techniques that have been investigated, MRI has the highest sensitivity for detecting invasive breast carcinoma and can provide valuable information that is not appreciated on the mammogram. Breast MRI screening is very encouraging when applied to high risk groups. Below summery of comparisons between different medical imaging techniques shown inside a table:

V. CONCLUSION

In breast cancer screening, mammography still plays a major role. To detect early stage breast cancer, the individual patient's risk profile can serve as a good guideline for the entire screening process. Ultrasound can be a valuable adjunctive tool in the evaluation of lesions detected with mammography and clinical examination. MRI is recommended for women with a high risk of developing breast cancer. A combination of mammography, ultrasound, and MRI has shown to give very good results in detecting ductal carcinoma in situ and invasive cancer. Their combined use increases the likelihood of detecting breast cancer, and also reduces the rates of false detections. However, further improvements of these medical imaging techniques are needed in order to overcome current limitations and to increase their effectiveness in detecting breast cancer.

TABLE I

Comparisons between different imaging techniques for breast cancer detection

Imaging Techniques	Operating Frequency Range	Radiation Safety	Effectiveness	Patients Comfort	Cost	Time Required
Mammogram	30 Petahertz to 30 Exahertz (3×10^{16} Hz to 3×10^{19} Hz)	Ionizing radiation	Can detect tumors up to few mm Not effective for dense breast.	Uncomfortable	Low	Less than 5 min
Ultrasound	2-20 Megahertz (2×10^{6} Hz to 20×10^{6} Hz)	Non-ionizing radiation	Can detect tumors, up to few cm Effective for dense breast	Comfortable	Low	15 - 25 min
MRI	1-100 Megahertz (1×10^{6} Hz to 100×10^{6} Hz)	Non-ionizing radiation	Effective in detecting tumors up to few mm Effective for dense breast	Uncomfortable	High	45 min - 1hr

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