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● *Review*

ULTRASOUND IMAGING TECHNOLOGIES FOR BREAST CANCER DETECTION AND MANAGEMENT: A REVIEW

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Abstract—Ultrasound imaging is a commonly used modality for breast cancer detection and diagnosis. In this review, we summarize ultrasound imaging technologies and their clinical applications for the management of breast cancer patients. The technologies include ultrasound elastography, contrast-enhanced ultrasound, 3-D ultrasound, automatic breast ultrasound and computer-aided detection of breast ultrasound. We summarize the study results seen in the literature and discuss their future directions. We also provide a review of ultrasound-guided, breast biopsy and the fusion of ultrasound with other imaging modalities, especially magnetic resonance imaging (MRI). For comparison, we also discuss the diagnostic performance of mammography, MRI, positron emission tomography and computed tomography for breast cancer diagnosis at the end of this review. New ultrasound imaging techniques, ultrasound-guided biopsy and the fusion of ultrasound with other modalities provide important tools for the management of breast patients. (E-mail: bfei@emory.edu) **© 2017 World Federation for Ultrasound in Medicine & Biology. All rights reserved.**

Key Words: **Breast cancer, Ultrasound imaging, Ultrasound-guided biopsy, Computer-aided detection, Image fusion, Three-dimensional (3D) ultrasound, Automated ultrasound, Detection and Diagnosis, Magnetic resonance imaging (MRI), Positron emission tomography (PET).**

INTRODUCTION

Breast cancer is the most frequently diagnosed cancer and the leading cause of cancer death among females worldwide (Torre et al. 2015). Among women in the United States, breast cancer has the highest incidence of all cancers and is the second most common cause of cancer death after lung cancer (Siegel et al. 2015). It is estimated that there were 252,710 new cases of (30% in all cancers) and 40,610 deaths from (14% in all cancers) breast cancer in females of the Unites States in the year 2017 (Siegel et al. 2017). A woman living in the United States has a 12.3% or a 1-in-8 lifetime risk of being diagnosed with breast cancer (DeSantis et al. 2014). Early diagnosis is important for both treatment and the prognosis. Patients with smaller primary cancers at the time of their diagnosis have a significantly higher survival rate and a significantly reduced probability of dying from their cancer (Duncan and Kerr 1976). Early detection of breast cancer and accurate assessment of lesions are the goals of various imaging modalities. As a conventional, medical imaging modality, ultrasound (US) has had a very important role in breast cancer detection, image-guided biopsy and lymph node diagnosis for many years.

We conducted the literature search within the PubMed database using the key words "Breast" and "Ultrasound" in the title field plus "Cancer" and "Ultrasound" in the Abstract/Title file for the period 1996 to 2017. We also used the Google Scholar database for an additional literature search. After reading the abstracts, we manually selected the relevant papers for this review. Each cited study had institutional review board/institutional animal care and use approval, which was part of the search criteria. In this review, we begin with an explanation of various ultrasound techniques, including ultrasound elastography, contrast-enhanced ultrasound, 3-D ultrasound, automatic breast volume scanning and computer-aided detection of breast cancer. We then provide an overview of ultrasound-guided breast biopsy and summarize ultrasound fusion with other imaging modality navigation systems. We also review the performance of various imaging modalities for breast

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lesion detection and lymph node diagnosis. Finally, we conclude with discussions and future directions.

ULTRASOUND IMAGING TECHNIQUES FOR BREAST CANCER DETECTION

Breast ultrasound imaging in the clinic

Ultrasound can assess the morphology, orientation, internal structure and margins of lesions from multiple planes with high resolution both in predominantly fatty breasts and in dense glandular structures. The general criteria for breast cancer detection with ultrasound are listed in Table 1. Among those characteristics, surrounding tissue, shape, margin contour, lesion boundary and posterior acoustic features are significant factors to consider when classifying a lesion. Ultrasound has been used to classify benign, solid lesions with a negative predictive value of 99.5% (Stavros et al. 1995). The measurement results of tumor, including the "halo," predict tumor size for invasive lobular carcinoma with high diagnostic accuracy (Skaane and Skjorten 1999). The Breast Imaging Reporting and Data System (BI-RADS) of the American College of Radiology (ACR 2015) has been widely used in most countries where breast cancer screening is implemented. BI-RADS is designed to reduce variability between radiologists when creating reports for mammography, ultrasonography or magnetic resonance imaging (MRI). The fourth version of the American Edition (2003) is completed by ultrasonography and MRI lexicons. As an extensive update of the Fourth Edition, the BI-RADS Fifth Edition (2013) made some revisions based on accumulated clinical practice. Observer variability of BI-RADS for breast ultrasound (Lee et al. 2008) indicates that inter- and intra-observer agreement with the BI-RADS Lexicon for US is satisfactory. The BI-RADS Lexicon can provide an accurate and consistent description and assessment of breast US. BI-RADS is integrated into the standard DICOM and is implemented directly on digital mammography stations and in computer-aided diagnosis (CAD) (Balleyguier et al. 2007).

Ultrasound elastography

Elasticity is a property of a substance. Deformation occurs when the body is subjected to external forces and the original shape or size is restored on removal of the external force. The slight deformation of tissue can be followed and marked by the speckle, ubiquitous and low attenuation of ultrasound images. Echo data are acquired by the high speed of ultrasound to observe tissue displacement (Bamber et al. 2013). Elastosonography has become a routine tool in ultrasonic diagnosis and measures the consistency or hardness of the tissues non-invasively to differentiate benign from malignant breast lesions.

Different categories for various elastographic techniques. Many different elastography techniques are available to measure and display elastography qualitatively or quantitatively, using the displayed modus and different forces. Commonly used techniques are strain elastography (SE), acoustic radiation force impulse (ARFI) imaging, transient elastography (TE), point shear wave elastography (pSWE) and shear wave elastography (SWE). According to the property displays, there are three types: strain or strain rate, displacement and shear wave speed. Strain elastography calculates and displays tissue strain; ARFI imaging detects and displays tissue displacement; TE and pSWE record the shear wave propagation speed (without making an image); and SWE displays images of shear wave speed (Bamber et al. 2013). There are two types of applied forces in elastography: quasi-static, for example, by probe palpation; and dynamic, for example, by a thumping, vibrating, acoustic radiation force. Quasi-static force is induced mechanically, whereas dynamic force can be induced by ultrasound. SWE is quantitative, and its applied force is a dynamic force and needs to create shear. Other methods can use dynamic power, but can also use static or quasi-static force. Ultrasound-based elastography is created by a focused US impulse that transmits ultrasound pulses at a high speed from the same transducer without compressing the skin. ARFI imaging and SWE

Table 1. Characteristics of the sonogram evaluation of breast cancer

Lexicon	Malignant tumors	Benign tumors
Shape	Irregular	Oval, round
Orientation	Vertical, taller than wide, indifferent	Parallel, wider than tall
Margin	Indistinct	Circumscribed, identifiable, thin echogenic capsule
Margin contour	Irregular, angular, spiculate	Smooth, three or fewer gentle lobulations
Echogenicity	Markedly hypo-echoic	Hyper-echoic, iso-echoic or mildly hypo-echoic
Geneity	Homogeneous	Heterogeneous
Posterior features	Shadowing	Enhancement, no changes
Calcification	Microcalcification	Absent
Surrounding tissue	Architectural distortion	Compression, no alteration
Retraction phenomena	Present	Absent

Sources. Chen et al. (2013), Gokhale (2009).