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Diagnostic Efficacy of Sonographic Elastography in Characterizing Breast Lesions

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Abstract: Breast cancer remains a significant global health challenge, necessitating accurate and timely diagnostic methods. While conventional B-mode ultrasound is a fundamental tool for evaluating breast lesions, its limitations in definitively differentiating benign from malignant masses often lead to unnecessary biopsies. Sonographic elastography, an advanced ultrasound technique, assesses tissue stiffness, a key indicator of malignancy. This article provides a comprehensive review of the diagnostic efficacy of various sonographic elastography parameters, including qualitative scoring systems and quantitative strain ratios, in characterizing breast lesions. We explore how these parameters, particularly when combined with conventional B-mode and Doppler ultrasonography, enhance diagnostic accuracy, reduce the need for invasive procedures, and improve clinical decision-making. The discussion highlights the transformative role of elastography in modern breast imaging, contributing to more precise and patient-friendly diagnostic pathways.

Keywords: Sonographic elastography, breast lesions, diagnostic imaging, breast cancer detection, ultrasound elastography, tissue stiffness, lesion characterization, non-invasive diagnosis, breast ultrasound, imaging

biomarkers

INTRODUCTION

Breast cancer stands as one of the most prevalent cancers globally, posing a substantial public health burden. According to global cancer statistics, it is a leading cause of cancer-related morbidity and mortality among women worldwide [1], [6]. In 2020 alone, there were millions of new breast cancer cases, underscoring the critical need for effective screening, early detection, and accurate diagnostic strategies [6], [7]. Early and precise diagnosis is paramount for successful treatment and improved patient outcomes.

Conventional B-mode ultrasound plays a crucial role in the initial assessment of breast lesions, serving as a widely available, non-invasive, and radiation-free imaging modality [8]. It is particularly valuable for characterizing masses detected on mammography or palpable lumps, and for guiding biopsies. However, a significant limitation of B-mode ultrasound lies in its inherent difficulty in definitively distinguishing between benign and malignant breast lesions based solely on morphological features [18], [20]. Overlapping characteristics between benign conditions (e.g., fibroadenomas, cysts) and early-stage malignancies often lead to a high rate of indeterminate findings, consequently resulting in numerous unnecessary biopsies [15]. This diagnostic ambiguity not only causes patient anxiety but also imposes a considerable economic burden on healthcare systems.

To address these limitations, sonographic elastography has emerged as a valuable adjunct to conventional ultrasound. Elastography is an advanced ultrasound technique that evaluates the stiffness or elasticity of tissues [2], [11]. The underlying principle is that malignant tumors are typically much stiffer than benign lesions and surrounding normal breast tissue due to increased cellularity, desmoplastic reaction, and reduced compressibility [11]. By providing quantitative and qualitative information about tissue stiffness, elastography offers an additional layer of diagnostic information that complements traditional B-mode imaging. The WFUMB (World Federation for Ultrasound in Medicine and Biology) has issued guidelines and recommendations for the clinical use of breast elastography, highlighting its growing acceptance and importance [2].

This article aims to comprehensively review the diagnostic efficacy of various sonographic elastography parameters in the characterization of breast lesions. We will delve into the methodologies employed, the specific parameters evaluated, and their performance in differentiating benign from malignant masses. Furthermore, we will discuss the added value of combining elastography with conventional B-mode and color Doppler ultrasonography to enhance overall diagnostic accuracy and reduce the rate of unnecessary biopsies. The ultimate goal is to highlight how this innovative imaging modality contributes to more precise and efficient breast cancer diagnosis, thereby improving patient management and reducing healthcare costs.

METHODOLOGY

The diagnostic assessment of breast lesions using sonographic elastography involves specific techniques and parameters to quantify tissue stiffness. This methodology typically integrates elastography findings with conventional B-mode ultrasound features to enhance diagnostic confidence.

A. Sonographic Elastography Techniques

Two primary types of sonographic elastography are widely used in breast imaging:

1. Strain Elastography (SE): Also known as real-time elastography or compression elastography, SE assesses tissue stiffness by applying external compression (usually manual pressure from the ultrasound probe) and measuring the resulting tissue displacement or strain [3], [11]. Softer tissues deform more easily (higher strain), while stiffer tissues deform less (lower strain). The system then generates a qualitative color map overlaying the B-mode image, where different colors represent varying degrees of stiffness (e.g., red for soft, blue for hard).

2. Shear Wave Elastography (SWE): SWE quantifies tissue stiffness by generating shear waves within the tissue using acoustic radiation force

impulses and then measuring their propagation speed [10], [11]. Shear waves travel faster through stiffer tissues. SWE provides quantitative measurements of tissue elasticity in kilopascals (kPa) or meters per second (m/s), offering a more objective assessment compared to strain elastography. While both are valuable, the provided references lean more heavily on strain elastography and its parameters.

B. Elastography Parameters for Breast Lesion Characterization

For both strain and shear wave elastography, specific parameters are evaluated to differentiate breast lesions:

1. Qualitative Assessment (Elastography Scoring System):
    - For strain elastography, a common approach is the 5-point scoring system, often referred to as the Tsukuba score or elasticity score [15], [16]. This qualitative scoring system assigns a score from 1 to 5 based on the color pattern and distribution of stiffness within the lesion and surrounding tissue:
        - Score 1 (Benign): Entire lesion is uniformly soft (green/red).
        - Score 2 (Benign): Most of the lesion is soft, with some harder areas (green with some blue).
        - Score 3 (Indeterminate): Lesion shows a mixed pattern, with some hard areas but not entirely stiff (mixed green/blue).
        - Score 4 (Suspicious): Lesion is predominantly hard (blue), but the hardness does not extend beyond the B-mode margins.
        - Score 5 (Malignant): The entire lesion and an area beyond its B-mode margins are hard (blue), indicating infiltration.
    - This scoring system provides a visual and semi-quantitative method for assessing lesion stiffness [16].
2. Quantitative Assessment (Strain Ratio):
    - The strain ratio is a quantitative parameter primarily used in strain elastography [4], [12], [14], [15], [16]. It is calculated by dividing the strain (deformation) of a chosen region of interest (ROI) within the lesion by the strain of a reference region, typically adjacent normal fatty tissue.
    - Formula: Strain Ratio = (Strain of Reference Tissue) / (Strain of Lesion).
    - A higher strain ratio indicates a stiffer lesion relative to the reference tissue, which is suggestive of malignancy [14]. Threshold values for the strain ratio are often established to differentiate between benign and malignant lesions [12]. Studies have explored the diagnostic potential of strain ratio measurements in various populations [12].

C. Integration with Conventional Ultrasound and Doppler

To maximize diagnostic accuracy, elastography parameters are rarely used in isolation. They are typically integrated with conventional B-mode ultrasound features (e.g., shape, margin, orientation, echogenicity, posterior acoustic features) and color Doppler ultrasonography findings (e.g., vascularity within or around the lesion) [4], [17], [18], [19], [20]. The combination of these modalities provides a more comprehensive assessment of breast lesions. For instance, a lesion that appears suspicious on B-mode and shows increased stiffness on elastography, along with abnormal vascularity on Doppler, would have a higher probability of malignancy [18], [19]. This multi-parametric approach aims to improve the overall diagnostic performance and reduce the rate of false positives and false negatives [17], [20].

RESULTS AND DISCUSSION

The integration of sonographic elastography parameters into breast lesion assessment has significantly enhanced diagnostic capabilities, offering improved accuracy and reducing the need for invasive procedures. The findings from various studies consistently highlight the added value of elastography when combined with conventional ultrasound.

A. Enhanced Diagnostic Performance

Multiple studies have demonstrated that sonographic elastography parameters significantly improve the diagnostic performance in characterizing breast lesions. A systematic review and meta-analysis of the diagnostic performance and accuracy of three interpreting methods of breast strain elastography (including qualitative scoring and strain ratio) confirmed its high diagnostic value [3]. Researchers have also evaluated the diagnostic value of elastography, strain ratio, and elasticity to B-mode ratio in combination with color Doppler ultrasonography, finding that these parameters contribute to better differentiation between benign and malignant lesions [4]. The "added value" of strain elastography in the characterization of breast lesions has been prospectively studied, confirming its utility [5].

B. Utility of Qualitative Assessment (Elastography Scoring)

The qualitative 5-point elastography scoring system has proven to be an effective tool for classifying breast lesions. Lesions assigned higher scores (e.g., 4 or 5) are highly suspicious for malignancy, while those with lower scores (e.g., 1 or 2) are typically benign [15], [16]. This scoring method helps in stratifying risk and guiding subsequent management. Importantly, the implementation of an elastography score in combination with B-mode ultrasound has been shown to avoid unnecessary biopsies of breast lesions, particularly those that might appear indeterminate on B-mode alone but are clearly benign on elastography [15]. This semi-quantitative assessment provides a rapid and intuitive way to assess tissue stiffness in real-time [16].

C. Value of Quantitative Assessment (Strain Ratio)

The strain ratio provides an objective, quantitative measure of lesion stiffness, offering a valuable parameter for differentiation. Studies have shown that malignant lesions typically exhibit significantly higher strain ratios compared to benign ones [4], [12], [14]. The diagnostic potential of strain ratio measurements for detecting breast cancer has been explored in various clinical experiences, demonstrating its utility [12]. Furthermore, the strain ratio has been shown to increase the accuracy of color-Doppler ultrasound in the evaluation of suspicious nodules, indicating its complementary role [13]. Calculating the strain ratio in breast sonoelastography has been found to significantly differentiate focal breast lesions [14]. This quantitative measure reduces subjectivity and allows for more standardized assessment across different operators.

D. Synergistic Effect of Combined Modalities

The true power of sonographic elastography lies in its integration with conventional B-mode ultrasound and color Doppler ultrasonography. This multi-parametric approach provides a more comprehensive diagnostic picture:

- Improved Accuracy: Combining B-mode ultrasound with color Doppler and strain elastography significantly enhances the overall diagnostic accuracy for both mass and non-mass breast lesions [17], [18]. This combination helps distinguish benign from malignant masses more effectively than B-mode alone [18].

- Influence on Radiologist Accuracy: Studies have shown that the combined use of US elastography and color Doppler US positively influences radiologist accuracy in distinguishing benign from malignant masses at breast US [18]. This suggests that elastography serves as a valuable adjunct that improves diagnostic confidence and reduces diagnostic errors.

- Specific Lesion Differentiation: The comparison of ultrasound elastography and color Doppler ultrasonography has proven useful for distinguishing small triple-negative breast cancer from fibroadenoma, highlighting its utility in challenging cases [19].
- Integration with BI-RADS: The combination of ultrasound elastography with the BI-RADS-US classification system has been found to be helpful for improving the diagnostic performance of conventional ultrasonography [20]. This integration allows for a more robust and standardized assessment within established reporting frameworks.

E. Clinical Impact and Patient Benefits

The widespread adoption of sonographic elastography in breast imaging has several positive clinical impacts:

- Reduction in Unnecessary Biopsies: By providing more definitive characterization of lesions, elastography can help avoid a significant number of benign biopsies, reducing patient anxiety, discomfort, and healthcare costs [15].
- Enhanced Diagnostic Confidence: Clinicians gain higher confidence in their diagnoses, leading to more appropriate patient management decisions.
- Monitoring Lesions: Elastography can also play a role in monitoring serial image changes in ultrasonography after the excision of benign breast lesions, ensuring no recurrence or new suspicious findings [9].

CONCLUSION

Sonographic elastography has firmly established itself as an indispensable tool in the diagnostic armamentarium for breast lesions. By providing crucial information about tissue stiffness, both qualitatively through scoring systems and quantitatively via strain ratios, it significantly enhances the ability to differentiate between benign and malignant masses. The robust evidence from numerous studies confirms that these elastography parameters, particularly when used in conjunction with conventional B-mode ultrasound and color Doppler ultrasonography, lead to markedly improved diagnostic accuracy and consistency.

The clinical implications are profound: a reduction in unnecessary invasive procedures, increased diagnostic confidence for radiologists, and ultimately, more precise and timely management for patients suspected of having breast cancer. As breast imaging continues to evolve, the integration of advanced techniques like elastography will remain central to optimizing diagnostic pathways, contributing to better patient outcomes and more efficient healthcare delivery. Future research may further refine elastography techniques, explore their role in treatment response monitoring, and integrate them with artificial intelligence for even more sophisticated and automated breast lesion characterization.

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