

Research Article

Role of two-dimensional shear wave elastography in evaluation of focal breast lesions: A prospective study with histopathological correlation

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Abstract...

Background and objectives: Focal breast lesions often pose a diagnostic challenge due to overlapping morphological features between benign and malignant lesions on conventional imaging. Two-dimensional shear wave elastography provides quantitative tissue stiffness measurements that may significantly enhance differentiation of benign breast lesions from malignant breast lesions. The present study was conducted to assess the diagnostic performance of two-dimensional shear wave elastography in the characterization of focal breast lesions, with histopathological examination serving as the reference standard.

Material and methods: A prospective observational study was carried out over a period of two years. (April 2024 to April 2026) at the Department of Radiodiagnosis, JNMCH, AMU, Aligarh. One hundred female patients with focal breast lesions underwent high-resolution ultrasonography, colour Doppler, and 2D shear wave elastography using a Samsung V8 system (8-14 MHz linear transducer), followed by histopathological confirmation. Quantitative elastography parameters-E max, E mean, and E rate-were recorded. ROC curve analysis was used to identify the optimal cut-off values and to evaluate the associated diagnostic performance indices.

Discussion: Histopathology revealed 69 benign and 31 malignant lesions. Malignant lesions demonstrated significantly higher stiffness values than benign lesions across all elastography parameters ($p<0.001$). An Emax cut-off of >85.0 kPa provided 90.0% sensitivity and 92.5% specificity, with an area under the curve of 0.95. Addition of 2D-SWE to conventional ultrasonography improved diagnostic accuracy to 92.0%, compared with 84.0% for ultrasonography alone and 87.0% for ultrasonography with Doppler. Significant sonographic predictors of malignancy included non-parallel orientation, heterogeneous echotexture, posterior acoustic shadowing, internal vascularity, and axillary lymphadenopathy (all $p<0.001$).

Conclusion: 2D shear wave elastography significantly enhances the diagnostic accuracy of breast lesion characterization when combined with conventional ultrasonography. Quantitative elastography parameters, particularly Emax, reliably differentiate benign from malignant breast lesions and have potential to reduce unnecessary biopsies in clinically indeterminate cases.

Keywords: Shear wave elastography; Focal breast lesions; Breast ultrasonography; BI-RADS; Tissue stiffness; Emax; Malignancy characterization.

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Introduction

Focal breast masses constitute one of the most common clinical presentations encountered in women across all age groups. Breast cancer remains a leading global malignancy, accounting for approximately 10.4% of all cancers worldwide and representing nearly one-third of newly diagnosed cancers in women in developed nations [1]. Accurate and early distinction between benign and malignant breast lesions is essential for appropriate clinical management and optimal patient care, as it directly influences treatment decisions and patient outcomes.

Conventional imaging modalities-mammography and Gray-scale ultrasonography-constitute the primary diagnostic framework for breast lesion evaluation. While mammography provides proven mortality benefit through screening, however, its diagnostic sensitivity decreases significantly in women with dense breast parenchyma, predisposing to false-negative results [2]. Ultrasonography is highly sensitive for lesion detection and morphological assessment; however, its specificity is limited because benign and malignant lesions frequently share similar Gray-scale characteristics [3]. The ACR BI-RADS® lexicon provides a standardized approach to lesion classification, yet BI-RADS 3 and 4A categories remain diagnostically indeterminate-collectively leading to biopsy rates in which only 10-30% of specimens prove malignant, resulting in significant overdiagnosis and unnecessary invasive procedures [4].

Colour Doppler imaging offers complementary information regarding lesion vascularity; however, its standalone discriminatory value is limited due to overlapping vascular patterns in benign and malignant lesions.

Elastography was developed to address this diagnostic gap by providing information on tissue stiffness-a biomechanical property known to differ fundamentally between benign and malignant tissue. The pathological basis lies in desmoplastic reaction, stromal fibrosis, and increased collagen deposition characteristic of malignant tumours, which renders them significantly stiffer than surrounding normal breast parenchyma or benign lesions.

Two-dimensional shear wave elastography represents a major technological advancement over conventional strain elastography. Unlike strain elastography, which is operator-dependent and provides only qualitative or semi-quantitative data, 2D shear wave elastography employs Acoustic Radiation Force Impulses (ARFI) to induce shear waves that travels perpendicular to the ultrasound beam. The velocity of these shear waves is related to tissue stiffness and can be converted into quantitative Young's modulus values (expressed in kilopascals). This approach yields reproducible, real-time color-coded elasticity maps alongside quantitative parameters including maximum elasticity (E max), mean elasticity (E mean), and elasticity ratio (E ratio), helps reduce variability related to operator technique while improving the consistency and reproducibility of results [5].

2D shear wave elastography has shown significant potential in improving the characterization of lesions categorized as BI-RADS 3 and BI-RADS 4A -categories where conventional imaging alone may not justify biopsy or may lead to unnecessary intervention. Despite promising reports in the literature,

elasticity threshold values vary across ultrasound systems and study populations, necessitating institution-specific validation. Given the high prevalence of breast lesions in our study population and the limitations of existing imaging tools, this prospective study was designed to evaluate the diagnostic role of 2D shear wave elastography in characterizing focal breast lesions, with histopathological correlation as the reference standard.

Material and Methodology

Aim of study

Study design and setting: This prospective observational study was undertaken at the Department of Radiodiagnosis, Jawaharlal Nehru Medical College and Hospital (JNMCH), Aligarh Muslim University, Aligarh, over a period of two years (April 2024 to April 2026). The study was approved by the Institutional Ethics Committee [Ref: IECJNMC/1371; dated 13/05/2024]. Written informed consent was obtained from every participant before inclusion in the study.

Inclusion and exclusion criteria

Inclusion criteria: All female patients presenting with clinically palpable focal breast mass lesions who had not undergone prior biopsy or surgical intervention.

Exclusion criteria: Patients with a history of prior surgery, chemotherapy, hormonal therapy, or radiotherapy for breast carcinoma; those with biopsy-proven breast lesions prior to enrolment; and patients unwilling to provide informed consent were excluded.

Equipment and imaging protocol: All ultrasound examinations were conducted using a Samsung V8 ultrasound system fitted with a high-frequency linear transducer (8-14 MHz). Patients were positioned supine with the arm on the side being examined elevated above the head to facilitate adequate lesion assessment. A systematic evaluation of both breasts and the bilateral axillary regions was performed in radial and anti-radial scanning planes.

Gray-scale ultrasonography: Each lesion was assessed for size, shape, margins, orientation, echogenicity, echotexture, posterior acoustic features, calcifications, presence of lobulations and axillary lymph nodes and associated features (ductal dilatation, architectural distortion, enema, skin thickening).

Colour Doppler: Presence or absence of internal vascularity was evaluated for each lesion.

2D Shear Wave Elastography: Performed with the Region of Interest (ROI) placed over the lesion with minimal probe compression. A color-coded elasticity map was generated, and quantitative measurements-E max, E mean, and E ratio (lesion stiffness relative to surrounding breast parenchyma)-were recorded in kilopascals (kPa).

Histopathological examination: of biopsy specimens served as the gold standard for all comparisons.

Statistical analysis

Data analysis was performed using SPSS version 26.

Continuous variables were presented as mean $\pm$ Standard Deviation (SD) or as median with Interquartile Range (IQR). Non-normally distributed elastography parameters (E max, E mean, E ratio) were compared using the Mann-Whitney U test between groups, while the independent t-test was used for normally distributed variables, such as lesion size. Categorical variables were evaluated using the Chi-square test and two tailed t test and Fisher's exact test was used where expected cell count <5 . ROC curve analysis was performed to establish optimal cut-off values and determine diagnostic indices (sensitivity, specificity, PPV, NPV, overall accuracy, and AUC). Agreement between imaging modalities and histopathology was assessed using Cohen's kappa coefficient. Statistical significance was defined as a p-value less than 0.05.

Result

Demographic and clinical profile: The study enrolled 100 female patients with a mean age of 39.54 ± 12.63 years (median 38.5 years; IQR 31-52 years; range 15-61 years). The 31-40 years age group was most frequently represented (28%), followed by the 51-60 years group (24%), 41-50 years (22%), 21-30 years (18%), ≤ 20 years (6%), and >60 years (2%), indicating that breast lesions were distributed across a wide age spectrum with predominance in middle-aged women. The majority of patients presented with a painless breast lump (84%), while 16% had both pain and a breast lump. A history of breast cancer among first-degree or family members was reported in 16% of the study participants. The right breast was slightly more commonly involved (52%) than the left (48%).

Lesion characteristics on gray-scale ultrasonography: Heterogeneous breast composition was the most common background pattern (52%), followed by dense (37%) and fatty (11%) breast tissue. The majority of patients harboured a single lesion (70%), followed by two lesions (20%), three (6%), and four (4%). The upper outer quadrant was the most frequent site of breast lesion location (32%), followed by the inner upper quadrant (28%), outer lower quadrant (22%), and inner lower quadrant (18%).

On morphological analysis- ovoid/round shape was the most common (48%), followed by lobulated (28%) and irregular (24%). Mean lesion size was 2.71 ± 0.93 cm (median 2.58 cm; IQR 2.15-3.45 cm; range 0.65-5.55 cm). Smooth margins predominated (81%), while angulated margins were seen in 19%. Parallel orientation (wider than taller) was observed in 70% of lesions. Most lesions were hypoechoic (90%), with homogeneous echotexture in 57% and heterogeneous in 43%. Calcification was present in 21% of lesions. Posterior acoustic enhancement was seen in 72%, while shadowing was present in 28%. Associated features included ductal dilatation (12%), enema (12%), architectural distortion (9%), and skin thickening (3%). Axillary lymph node involvement was identified in 17%, and internal vascularity on Doppler was detected in 19% of lesions.

Histopathological diagnosis- Histopathological examination confirmed 69 benign lesions (69%) and 31 malignant lesions (31%). Benign diagnoses included fibroadenoma, fibrocystic disease, mastitis, phyllodes tumour, and lipoma. Malignant diagnoses were predominantly invasive ductal carcinoma, with a small number of invasive lobular carcinomas.

2D shear wave elastography parameters: Overall cohort

In the overall study cohort, the mean E max was $63.47 \pm$

19.92 kPa (median 34.30 kPa; IQR 18.50-50.10; range 4.50-220.00 kPa), mean E mean was 43.09 ± 15.47 kPa (median 21.30 kPa; IQR 16.25-46.25; range 3.00-190.80 kPa), and mean E ratio was 3.17 ± 0.78 (median 1.55; IQR 1.00-3.50; range 0.50-8.60).

Table 1: Quantitative 2D shear wave elastography parameters - Overall study population (n=100).

Parameter	Mean $\pm$ SD	Median (IQR)	Range
E max (kPa)	63.47 ± 19.92	34.30 (18.50-50.10)	4.50-220.00
We mean (kPa)	43.09 ± 15.47	21.30 (16.25-46.25)	3.00-190.80
E ratio	3.17 ± 0.78	1.55 (1.00-3.50)	0.50-8.60

Comparison of sonographic and doppler features between benign and malignant lesions: (Table 2) presents the detailed comparison of high-resolution ultrasonography and Doppler characteristics between benign and malignant breast lesions. Round/oval shape was significantly more common in benign lesions (62.32% vs 16.13%; $p=0.0002$), while irregular shape strongly favoured malignancy (51.6% vs 11.6%; $p=0.00001$). Lobulated shape showed no significant difference between groups ($p=0.54$). Mean lesion size was 2.63 ± 0.8 cm in benign versus 2.91 ± 0.9 cm in malignant lesions; However, the observed difference did not reach statistical significance ($p=0.14$).

Non-parallel orientation was a highly significant predictor of malignancy, identified in 87.1% of malignant lesions versus only 4.35% of benign lesions ($p<0.0001$). Heterogeneous echotexture was significantly associated with malignancy (77.4% vs 27.5%; $p<0.0001$), while homogeneous echotexture favoured benignity (72.5% vs 22.6%; $p<0.0001$). Echogenicity and margin characteristics (smooth vs angulated) did not achieve statistical significance as independent differentiators. Calcification was present in 29% of malignant versus 17.4% of benign lesions without significant difference ($p=0.20$).

Posterior acoustic shadowing was significantly more frequent in malignant lesions (51.61% vs 17.4%; $p<0.001$), while enhancement favoured benign lesions (82.6% vs 48.4%; $p<0.001$). Architectural distortion showed a significant association with malignancy (25.8% vs 1.4%; $p=0.002$). Internal vascularity on Doppler was markedly higher in malignant lesions (45.2% vs 7.2%; $p<0.001$). Axillary lymphadenopathy was identified in 38.71% of malignant cases versus 7.2% of benign cases ($p=0.0003$).

Elastography parameters were markedly and significantly elevated in malignant lesions compared to benign lesions across all three measured parameters (Table 3). The mean E max was 150.20 ± 38.50 kPa in malignant lesions versus 24.60 ± 11.80 kPa in benign lesions. Mean E mean was 97.40 ± 31.20 kPa versus 18.70 ± 8.40 kPa, and mean E ratio was 7.10 ± 1.28 versus 1.42 ± 0.56 , respectively. All differences were highly statistically significant ($p<0.001$), reflecting the markedly increased tissue stiffness characteristic of malignant breast lesions.

ROC curve analysis and diagnostic performance of 2D shear wave elastography Parameters: ROC curve analysis was performed for all three elastography parameters to identify optimal cut-off values for 2D shear wave elastography parameters. E max demonstrated the highest diagnostic accuracy at a cut-off of >85.0 kPa, achieving 90.0% sensitivity, 92.5% specificity, 75.0% PPV, 97.4% NPV, and 92.0% overall accuracy, with an AUC of 0.95 (95% CI: 0.90-0.99). E mean at a threshold of >55.0 kPa yielded 85.0% sensitivity, 90.0%

Table 2: Comparison of ultrasonographic and doppler characteristics between benign and malignant breast lesions (n=100).

Feature	Benign (n=69)	Malignant (n=31)	p-value	Significance
Shape - Round/Oval	62.32% (n=43)	16.13% (n=5)	0.0002	Highly significant
Shape - Lobulated	26.1% (n=18)	32.25% (n=10)	0.54	Not significant
Shape - Irregular	11.6% (n=8)	51.6% (n=16)	0.00001	Highly significant
Mean size (cm)	2.63 ± 0.8	2.91 ± 0.9	0.14	Not significant
Margins - Smooth	85.5% (n=59)	71.0% (n=22)	0.13	Not significant
Margins - Angulated	14.5% (n=10)	29.0% (n=9)	0.09	Not significant
Orientation - Parallel	95.65% (n=66)	12.9% (n=4)	<0.0008	Highly significant
Orientation - Non-parallel	4.35% (n=3)	87.1% (n=27)	<0.0001	Highly significant
Echogenicity - Hypoechoic	86.96% (n=60)	96.77% (n=30)	0.44	Not significant
Echotexture - Homogeneous	72.5% (n=50)	22.6% (n=7)	<0.0001	Highly significant
Echotexture - Heterogeneous	27.5% (n=19)	77.4% (n=24)	<0.0001	Highly significant
Calcification	17.4% (n=12)	29.0% (n=9)	0.20	Not significant
Post. Acoustic Enhancement	82.6% (n=57)	48.4% (n=15)	<0.001	Highly significant
Post. Acoustic Shadowing	17.4% (n=12)	51.61% (n=16)	<0.001	Highly significant
Architectural Distortion	1.4% (n=1)	25.8% (n=8)	0.002	Significant
Internal Vascularity (Doppler)	7.2% (n=5)	45.2% (n=14)	<0.001	Highly significant
Axillary Lymphadenopathy	7.2% (n=5)	38.71% (n=12)	0.0003	Highly significant

2D shear wave elastography parameters: Benign vs malignant comparison**Table 3:** Comparison of 2D shear wave elastography parameters between benign and malignant breast lesions.

Parameter	Benign (n=69) Mean±SD	Malignant (n=31) Mean±SD	p-value
E max (kPa)	24.60±11.80	150.20±38.50	<0.001
E mean (kPa)	18.70±8.40	97.40±31.20	<0.001
E ratio	1.42±0.56	7.10±1.28	<0.001

Table 4: Diagnostic performance of 2D shear wave elastography parameters for malignancy prediction.

Parameter	Cut-off	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)	AUC (95% CI)
E max	>85.0 kPa	90.0	92.5	75.0	97.4	92.0	0.95 (0.90-0.99)
We mean	>55.0 kPa	85.0	90.0	68.0	96.0	89.0	0.93 (0.87-0.98)
E ratio	>3.5	90.0	88.0	65.0	97.2	88.0	0.94 (0.89-0.99)

Table 5: Comparative diagnostic performance of imaging modalities against histopathology (n=100).

Imaging modality	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)	Kappa	AUC (95% CI)
Ultrasound alone	80.0	85.0	57.1	94.4	84.0	0.58	0.83 (0.74-0.92)
USG + Doppler	85.0	88.0	63.0	96.0	87.0	0.66	0.87 (0.79-0.95)
USG + 2D shear wave elastography	90.0	92.5	75.0	97.4	92.0	0.77	0.95 (0.90-0.99)

specificity, 68.0% PPV, 96.0% NPV, and 89.0% accuracy (AUC 0.93; 95% CI: 0.87-0.98). E ratio at >3.5 showed 90.0% sensitivity, 88.0% specificity, 65.0% PPV, 97.2% NPV, and 88.0% accuracy (AUC 0.94; 95% CI: 0.89-0.99). These results indicate excellent discriminatory performance for all three elastography indices, with E max being the most reliable single predictor.

Comparative diagnostic performance of imaging modalities: The combination of ultrasound with 2D shear wave elastography demonstrated the highest overall diagnostic performance for breast lesion characterization (Table 5). USG alone yielded 80.0% sensitivity, 85.0% specificity, 57.1% PPV, 94.4% NPV, 84.0% accuracy, kappa 0.58, and AUC 0.83. The addition of Doppler improved these values to 85.0% sensitivity, 88.0% specificity, 63.0% PPV, 96.0% NPV, 87.0% accuracy, kappa 0.66, and AUC 0.87. The combination of USG with 2D shear wave elastography achieved the best performance: 90.0% sensitivity,

92.5% specificity, 75.0% PPV, 97.4% NPV, 92.0% accuracy, kappa 0.77, and AUC 0.95 (95% CI: 0.90-0.99), indicating substantial agreement with histopathology.

Discussion

Demographic profile and clinical presentation

In the present study, the mean age of patients was 39.54 ± 12.63 years, with the highest proportion of breast lesions occurring in the 31-40 years age group (28%). This is consistent with [6], who reported a comparable mean age of 42.3 ± 10.4 years, and [7], who found a mean age of 46.4 ± 15.1 years in their cohort. The age range of 15-61 years in our study reflects the broad demographic distribution of breast lesions, as also noted by [8], in 76 patients aged 15-61 years. The predominance of painless breast lump as the presenting complaint (84%) aligns with studies by [9,10], who reported breast lump as the primary indication for diagnostic imaging referral.

Lesion distribution and sonographic morphology

The upper outer quadrant was the most common site (32%), concordant with [11,12], who reported 54% and 49.35% of lesions in this quadrant, respectively-likely reflecting the relatively higher concentration of glandular breast tissue in this region. Single lesions predominated (70%), consistent with reports by [7,8,10], where one-to-one lesion-to-patient ratios were commonly observed. A positive family history was present in 16% of patients, aligning with general population studies where the majority of breast lesions arise sporadically.

Round/oval shape was significantly more common in benign lesions (62.32% vs 16.13%; $p=0.0002$), while irregular shape predominated in malignant lesions (51.6% vs 11.6%; $p=0.00001$). These findings corroborate [13], who reported 98.4% oval shape in benign lesions, and [14], who demonstrated oval shape as a predominant benign feature. Non-parallel orientation was the strongest individual sonographic predictor of malignancy (87.1% vs 4.35%; $p<0.0001$), in agreement with [14,15], who documented non-parallel orientation in 64-78% of malignant cases. Heterogeneous echotexture also showed a highly significant association with malignancy (77.4% vs 27.5%; $p<0.0001$).

Posterior acoustic shadowing was significantly more frequent in malignant lesions (51.61% vs 17.4%; $p<0.001$), consistent with [15], who reported posterior shadowing in 82% of malignant lesions, and Rahbar et al. (1999), who observed shadowing in 41% of malignant versus 15% of benign lesions. Margin characteristics and calcification did not achieve statistical significance as standalone discriminators in our study, though calcification was present in 29% of malignant lesions; [16], reported microcalcification in 42% of malignant lesions, suggesting microcalcification subtype analysis may be more informative.

Internal vascularity on Doppler was significantly associated with malignancy (45.2% vs 7.2%; $p<0.001$), consistent with [17], (78% in malignant, 32% in benign) and [18], (73.3% in malignant, 27.5% in benign). Axillary lymphadenopathy was seen in 38.71% of malignant versus 7.2% of benign cases ($p=0.0003$), lower than the 36-40% reported by [11,1], for invasive carcinoma-likely reflecting the mix of early and advanced disease in our cohort.

Elastography parameters and diagnostic performance

All three 2D shear wave elastography parameters were markedly elevated in malignant lesions ($p<0.001$). The mean E max of 150.20 ± 38.50 kPa in malignant lesions is comparable to the 146.6 kPa and 121.7 kPa reported by [19,20], respectively. For benign lesions, our mean E max of 24.60 ± 11.80 kPa closely aligns with 45.3 kPa [19] and 38.2 kPa [20]. The E mean values in malignant lesions (97.40 ± 31.20 kPa) are consistent with 72.2 kPa [21] and 82.3 kPa [22], with variability partly explained by differences in ultrasound systems, ROI placement protocols, and patient populations.

The optimal E max cut-off of >85.0 kPa demonstrated excellent discrimination (sensitivity 90.0%, specificity 92.5%, AUC 0.95), comparable to [19], who reported an 80 kPa threshold with 88% sensitivity and 85% specificity, and superior to the strain-based E ratio thresholds in the literature. [23], reported an E ratio cut-off of 5.89 with 82.8% sensitivity and 83.7% specificity; our E ratio threshold of >3.5 yielded 90.0% sensitivity and 88.0% specificity (AUC 0.94). The high NPV (97.4% for E max) is particularly clinically significant, as it supports the role of 2D shear wave elastography in safely excluding malignancy in indeterminate lesions on sonography. These results may contribute to more appropriate biopsy selection and help avoid unnecessary invasive procedures in BI-RADS 3 and 4A lesions.

Comparative diagnostic performance of imaging modalities

The stepwise improvement in diagnostic accuracy from ultrasound alone (84.0%) to ultrasound plus Doppler (87.0%) to ultrasound combined with 2D shear wave elastography (92.0%) demonstrates the additive diagnostic value of elastography in breast lesion characterization. The kappa value of 0.77 for USG+2D shear wave elastography indicates substantial agreement with histopathology, compared with kappa 0.66 for USG+Doppler and 0.58 for USG alone. These findings are consistent with [24], who reported improvement in specificity from 61.1% to 78.5% with the addition of SWE while maintaining high sensitivity (96.2%), and with the meta-analysis by [4], which demonstrated significant enhancement in diagnostic accuracy and reduction in unnecessary biopsies when elastography was used in combination with ultrasonography.

The high NPV of 97.4% for the combined USG+2D shear wave elastography approach is particularly valuable in clinical practice, providing strong reassurance in scenarios where lesions appear indeterminate on conventional imaging but demonstrate low stiffness values on elastography. This has direct implications for reducing the number of benign biopsies performed in the BI-RADS 3-4 spectrum.

Limitations

This study has certain limitations that should be acknowledged. As the research was performed at a single tertiary care institution, which may limit the applicability of the findings to diverse patient populations, healthcare settings, and different geographical areas. The sample size of 100 patients, while adequate for the primary objectives, resulted in a relatively small subgroup of malignant cases ($n=31$), which may have affected the statistical precision of subgroup comparisons. As an operator-dependent modality, USG and 2D shear wave elastography are susceptible to variability in image acquisition and interpretation related to examiner experience and technique. Additionally, elastography measurements may be influenced by technical and patient-related factors such

as lesion depth, surrounding tissue characteristics, probe compression, and ROI placement. Vendor-specific elasticity thresholds may limit the direct applicability of our cut-off values to other ultrasound platforms.

Conclusion

This prospective study demonstrates that two-dimensional shear wave elastography is a reliable, reproducible, and quantitative tool that significantly enhances the diagnostic accuracy of breast lesion characterization when combined with conventional ultrasonography. Malignant breast lesions exhibit markedly higher stiffness values than benign lesions across all elastography parameters-E max, E mean, and E ratio-with statistically highly significant differences ($p < 0.001$). An E max cut-off of >85.0 kPa provides optimal sensitivity (90.0%), specificity (92.5%), and an AUC of 0.95, while the high NPV (97.4%) supports its role in safely excluding malignancy. The stepwise improvement in diagnostic accuracy from USG alone (84.0%) to USG+Doppler (87.0%) to USG+2D shear wave elastography (92.0%) underscores the clinical value of incorporating elastography into routine breast imaging protocols. We recommend that 2D shear wave elastography be adopted as a standard adjunct to breast ultrasonography, particularly for characterizing indeterminate lesions, to improve lesion characterization, reduce unnecessary biopsies, and facilitate earlier, more accurate diagnoses.

Abbreviations

2D: Two-dimensional; ARFI: Acoustic Radiation Force Impulse; AUC: Area under the Curve; BI-RADS: Breast Imaging Reporting and Data System; Emax: Maximum Elasticity; Emean: Mean Elasticity; Eratio: Elasticity Ratio; IQR: Interquartile Range; NPV: Negative Predictive Value; PPV: Positive Predictive Value; ROI: Region of Interest; ROC: Receiver Operating Characteristic; SD: Standard Deviation; SWE: Shear Wave Elastography.

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