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Role Of Shear Wave Elastography In The Diagnosis Of Small Malignant Breast Lesions

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Abstract
Background: *Breast cancer incidence is increasing, and conventional imaging is limited, particularly in dense breasts and indeterminate lesions, necessitating the use of advanced techniques like elastography for improved diagnostic accuracy.*
Aim: *To examine the performance of 2D Shear Wave Elastography (SWE) combined with BI-RADS classification of greyscale ultrasound images in the characterization of small breast lesions.*
Patients and methods: *This research was a prospective analysis that involved 91 women with 100 lesions of breast, who had been referred to the radio-diagnosis departments at Baheya Institute and National Cancer Institute in the intervals from January 2022 to December 2024.*
Results: *The US-BI-RADS alone showed good diagnostic performance (sensitivity 83.3%, specificity 95.5%, accuracy 89.47%, $\kappa = 0.805$, $p < 0.001$). When combined with qualitative SWE, diagnostic accuracy improved (sensitivity 95%, specificity 91.1%, accuracy 92.7%, $\kappa = 0.849$). The combined analysis of both conventional US-BIRADS and quantitative SWE (lesion elasticity) had a sensitivity of 98.3%, specificity of 92.2%, positive predictive value of 89.39%, negative predictive value of 98.8% and accuracy of 95.25% in distinguishing malignant from benign breast lesions. The combined approach allowed for more accurate lesion classification, including downgrading 12 benign cases and upgrading 9 suspicious ones, some of which were confirmed malignancies (e.g., tubular and mucinous carcinoma).*
Conclusion: *SWE enhances breast lesion identification when combined with B-mode ultrasound, but accuracy may be influenced by lesion location, necessitating careful use and further guideline development.*

Key words: *Shear Wave Elastography, BI-RADS, Breast Cancer, Small Breast Lesions.*

INTRODUCTION

The prevalence of cancer of the breast has risen significantly recently **(1)**. A palpable breast mass is a common feature of several cancerous and benign illnesses. Imaging assessment is essential in nearly all patients to identify and detect further lesions that may lack distinctive physical findings. Mammography is extensively utilized for breast cancer screening, although its application is limited in cases with dense breast tissue **(2)**.
Certain breast masses may lack definitive cancerous characteristics on ultrasound, although they don't meet the criteria for lesions of benign, classified as BI-RADS group 4a (low suspicion of malignancy). The advised approach for such masses is biopsy, despite the positive predictive value (PPV) of BI-RADS group 4a masses being under six percent. Incorporating stiffness data into ultrasound findings, elastography may reduce false positive results in this group and enhance the ultrasound specificity **(3)**.
SWE was shown enhanced specificity for solid breast masses, as the stiffness or elasticity of breast tumors is often greater than that of benign masses **(4)**.
Strain US elastography necessitates manual compression or little natural motion to evaluate the stiffness of the targeted tissue, rendering it operator-dependent and occasionally yielding conflicting findings. Moreover, the lack of quantification of tissue stiffness constrains its applicability in clinical practice. Conversely, SWE quantifies tissue stiffness by measuring shear wave velocity (SWV) or shear wave modules, rendering it potentially more independent of the operator **(1)**.

Shear wave elastography operates by remotely triggering mechanical vibrations by acoustic radiation force released by a focused US beam. The displacement at the focus releases a shear wave that transmits data on the local viscoelastic characteristics of the tissue, hence facilitating a quantitative evaluation of elasticity values. Utilizing these diverse variables, SWE has demonstrated superior accuracy in distinguishing between malignant and benign solid tumors of the breast (5).

Recent studies indicate that shear wave elastography is effective in distinguishing benign from cancerous complex masses of the breast, and the combination of shear wave elastography with US may decrease needless biopsies (6). Mao et al. (7) conducted a comprehensive score evaluation that revealed SWE possesses good diagnostic accuracy in differentiating cancerous from benign lesions of the breast. The combination of shear wave elastography and traditional ultrasound has the greatest discriminative capability for malignancy identification, indicating that SWE holds potential for incorporation into standard imaging protocols. This research aimed to examine the efficacy of 2D-SWE in conjunction with BI-RADS categorization of greyscale US images for identifying tiny cancerous breast lesions (≤ 2 cm).

PATIENTS AND METHODS

The research was a prospective analysis involving 91 women's cases with 100 breast lesions, referred to the radiodiagnosis departments at Baheya Institute and the National Cancer Institute from January 2022 to December 2024.

Inclusion criteria: cases with palpable breast or axillary tail lesions at physical investigation and those with breast mass lesions detected by traditional ultrasound or mammograms measuring about or less than 2 cm were included. The lesions were either complex or solid/cystic in nature.

Exclusion criteria: Breast lesions exhibiting inadequate shear wave quality characteristics, lesions where the region of interest (ROI) could not be accurately positioned due to internal calcifications or external interference from the chest wall or skin; and images demonstrating artefactual stiffness resulting from excessive probe pressure or instability during scanning have been excluded. Moreover, lesions above two centimeters, simple cystic breast lesions, cases with insufficient data, and those lacking pathological test findings or who were lost to monitoring were removed as well.

METHODS

The utilized equipment involved GE Logiq E9 ultrasound machines. The cases underwent examination as detailed below: Conventional B-mode ultrasound and SWE exams have been conducted with the same ultrasound scanner utilizing a 6-15L probe, with the case positioned supine. The standard US images for each breast lesion have been acquired. Two-dimensional shear wave elastography has been conducted in a plane displaying the longest diameter of the mass of the breast, with the transducer placed softly to avoid artefactual stiffness, utilizing ample contact gel for many seconds to permit stabilization of the SWE picture. A color-coded map illustrating tissue elasticity, denoted by Young's modulus in kilopascals (kPa), has been acquired and overlaid on the real-time greyscale ultrasound picture, utilizing a standard color scale from zero (dark blue; soft) to 180 kPa (red; hard). Analysis of traditional ultrasound images: The features of traditional ultrasound pictures of breast lesions have been examined per the American College of Radiology (ACR) US Lexicon and categorized according to the ACR BI-RADS evaluation classifications. This study classified BI-RADS categories two and three as benign, but categories four and five were considered cancerous. Analysis of SWE images: For qualitative analysis, the ROI of the shear wave elastography color map has been modified to adequately encompass the mass and adjacent breast tissue while excluding the chest wall and skin. This research evaluated shear wave elastography color overlay patterns utilizing the 4-color overlay pattern presented by Tozaki & Fukuma (8) as follows: Pattern 1: The color around the lesion exhibited no distinction between the lesion's edge or its inside (coded uniformly blue). Pattern 2: A distinction was seen between the coloration surrounding the lesion and the lesion's perimeter or interior, extending beyond the lesion and continuing vertically in cords on the cutaneous or thoracic wall side (an artifact peculiar to shear wave elastography). Pattern 3: A confined chromatic region was seen near the periphery of the lesion. Pattern

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4: Heterogeneous colored regions have been observed within the lesion's interior. Lesions exhibiting SWE color overlay patterns one and two were considered probably benign (assumed SWE BI-RADS II and III), but those with patterns three and four were considered indicative of malignancy (assumed SWE BI-RADS IV and V). The supplementary diagnostic utility of qualitative SWE (color overlay patterns) in distinguishing cancerous from benign breast masses, in conjunction with standard US-BIRADS, was examined across all cases. In the research, a positive outcome from either was classified as cancerous.

quantitative analyses, customized presets of SWE quantitative elasticity parameters (lesion maximum elasticity) have been measured in all patients. Quantitative elasticity has been assessed on each shear wave elastography picture with the system's quantification instrument, termed the "Q-Box," which delineated a 2×2 millimeter area of interest (ROI) situated over the most rigid portion of the mass or adjacent tissue on the image of the SWE. The system computed the maximum, minimum, and average stiffness values in kPa inside the ROI. The red hue indicated rigid tissue, whereas the blue tint denoted soft tissue on shear wave elastography. Among the quantitative SWE lesion characteristics, E-max was chosen because of the utilization of 2-millimeter-diameter ROIs for evaluating the elasticity value. Moreover, E-max exhibited superior sensitivity in identifying the focal stiff regions among heterogeneous breast masses. The influence of ROI size on E-max values was minimal (9). The supplementary diagnostic utility of quantitative shear wave elastography (maximal lesion elasticity in kPa) compared to traditional US-BIRADS in differentiating cancerous from benign masses of the breast across all cases was examined. In the research, a positive outcome was classified as cancerous. Histopathological correlation: The histopathological outcomes from ultrasound-guided core-needle biopsy, and surgical excision acted as the reference standard for worrisome lesions of breast. The stability during monitoring for a period of 1 to 2 years was established as the standard reference for typical lesions of benign.

STATISTICAL ANALYSIS:

The gathered information was encoded, processed, and analyzed utilizing the SPSS software (Version 21) for Windows. Descriptive statistics have been determined involving means, medians, standard deviations, ranges, and percentages. Independent ANOVA tests have been conducted for continuous variables to compare the means of normally distributed data, with a p-value of less than 0.05 deemed statistically significant. Analytical statistics included the use of the ANOVA test to assess the statistical significance of variances in parametric variables between more than two research group means. The chi-square test has been utilized to examine the association among 2 qualitative variables. ROC curve analysis has been utilized to study the cutoff values of different study parameters for the diagnosis of malignancy.

RESULTS

Table (1): Distribution of Patients' Characteristics and Tumor Types in All Lesions

	All lesions N =100
Age (years) **Mean ±SD** **Range**	 46 ±12.63 23-75
Size of lesion (mm) **Mean ±SD** **Range**	 15.318 ±4.05 5.5-20
Distance from skin (mm) **Mean ±SD** **Range**	 7.75 ±3.55 2-19
Type of tumor	

Benign	60 (60%)
Malignant	40 (40%)

This prospective study initially evaluated 91 patients with 100 breast lesions.
The table shows that the mean age was 46 ± 12.63 years, varying from 23 to 75 years.
The mean lesion size was 15.318 ± 4.05 mm, with a range from 5.5 to 20 millimeters.
The mean distance from the skin was 7.75 ± 3.55 millimeters, ranging from 2 to 19 mm. In the current study, 60 breast lesions (60.0%) were benign, while 40 lesions (40.0%) were malignant (Table 1).

Table (2): Correlation between conventional US- BIRADS and final diagnosis with statistical analysis in distinguishing of malignant and benign lesions of breast based on traditional US- BIRADS

		Final Diagnosis				**Total**
		Malignant		**Benign**		
		Count	%	**Count**	%	
US- BIRADS	**Malignant**	34	85%	2	3.3%	36 (36%)
	Benign	6	15%	58	96.6%	64 (64%)
Total		40	100%	60	100%	100 (100%)
Kappa		**0.805**				
p-value		**< 0.001**				
Sensitivity		83.3%				
Specificity		95.5%				
True Positive (TP)		34				
True Negative (TN)		58				
False Positive (FP)		2				
False Negative (FN)		6				
Positive Predictive Value		92.6%				
Negative Predictive Value		89.5%				
Accuracy		89.4%				

The US-BIRADS test demonstrates strong diagnostic capabilities, with a good balance of sensitivity and specificity. Its sensitivity is 83.3% and its specificity is 95.5% and accuracy was 89.47%. With a Kappa value of 0.805 and statistical significance (p-value < 0.001), the outcomes are statistically significant (Table 2).

Table (3): Correlation between Combined US-BIRADS + Qualitative SWE and final diagnosis with statistical analysis in distinguishing between malignant and benign breast lesions

		Final Diagnosis				**Total**
		Malignant		Benign		
		Count	%	**Count**	%	
Combined US + Qualitative SWE	**Malignant**	38	95%	5	8.3%	43 (43%)
	Benign	2	5%	55	91.6%	57 (57%)
Total		40	100%	60	100%	100
Kappa		**0.849**				
p-value		**<0.001**				
Sensitivity		95%				
Specificity		91.1%				
True Positive (TP)		38				

True Negative (TN)	55
False Positive (FP)	5
False Negative (FN)	2
Positive Predictive Value	87.7%
Negative Predictive Value	96.5%
Accuracy	92.7%

The combined US-BIRADS + Qualitative SWE test demonstrates excellent diagnostic performance in distinguishing among lesions of cancerous and benign breasts, with a sensitivity of 95% and a specificity of 91.1%, PPV of 87.7%, and NPV of 96.5%. Accuracy was 92.7%, with a Kappa value of 0.849 (p-value of below 0.001); the outcomes are statistically significant (Table 3).

Table (4): Correlation between combined US + Quantitative SWE (mass stiffness/ kPa) and final diagnosis with statistical indices for the combined analysis of both traditional US-BIRADS & quantitative Shear Wave Elastography (mass stiffness/kPa)

		Final Diagnosis				Total
		Malignant		Benign		
		Count	%	Count	%	
Combined US + Quantitative SWE	Malignant	39	97.5%	3	5%	42 (42%)
	Benign	1	2.5%	57	95 %	58 (58%)
Total		40	100%	60	100%	100
Kappa		0.891				
p-value		<0.001				
Sensitivity		98.3%				
Specificity		92.2%				
True Positive (TP)		39				
True Negative (TN)		57				
False Positive (FP)		3				
False Negative (FN)		1				
Positive Predictive Value		89.39%				
Negative Predictive Value		98.8%				
Accuracy		95.25%				

In the current work, 42 lesions were reported on combined analysis of both traditional US-BIRADS and quantitative shear wave elastography analysis as malignant lesions, with 39 true positive and 3 false positive lesions. Also, 58 lesions had been reported as benign cases; out of them, 57 cases proved to be true benign lesions (true negative) and 1 was a false negative. The combined US+ quantitative SWE resulted in downgrading 7 cases from BIRADS 3 by US down to BIRADS 2, which all proved to be of benign etiology, and downgrading 5 cases from BIRADS 4 by US to BIRADS 3, which proved to be fibroadenomas by histopathology. It also resulted in upgrading 9 cases from BIRADS 3 by US to BIRADS 4; one of them proved to be tubular carcinoma, 1 case was pathologically proven mucinous carcinoma, and 5 cases were pathologically proven complex fibroadenomas, as well as 2 cases that proved to be sclerosing fibroadenoma (Table 4).

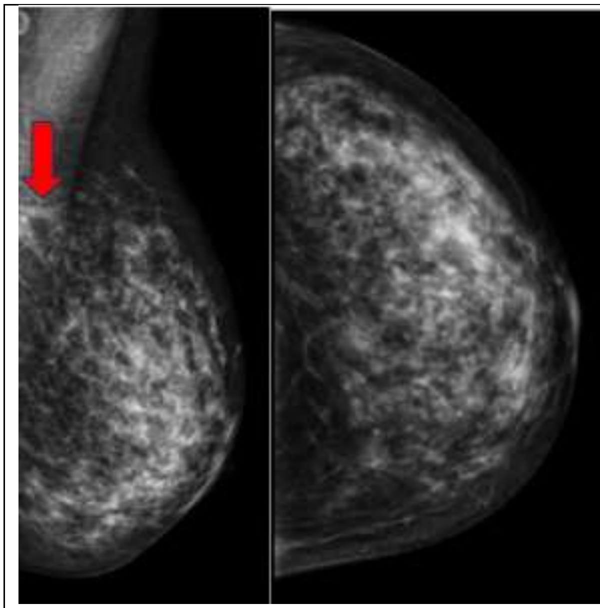
CASES PRESENTATION

Case (1):

A 46-year-old woman existed with a left breast lump.

Figure (1 – a & b): Left MLO & CC mammographic views illustrating left axillary tail asymmetry (**red arrow**). **Lunite AI** revealed an increased suspicion probability of the lesion (48%).
Figure (1–c): A Greyscale ultrasound image of the left breast revealed a rather defined hypoechoic mass lesion with a surrounding echogenic halo, measuring about 9x12 mm. The lesion was classified as BIRADS 4.
Figure (1–d): Shear wave elastography illustrating
Shear wave elastography color overlay pattern 4: The lesion presents varied colored areas within its interior.
The maximal stiffness of the lesion = 157.6 kPa.
Stiffness ratio = 9.85.
Figure (1-e): DCE-MRI subtraction image of both breasts showing left axillary tail; an irregular, spiculated, homogeneously enhancing mass lesion is seen measuring 17x22 mm. It shows restricted diffusion associated with segmental non-mass enhancement seen extending anteriorly, reaching the nipple, and occupying an area measuring about 9x3 cm.

Final diagnosis: IDC grade II.

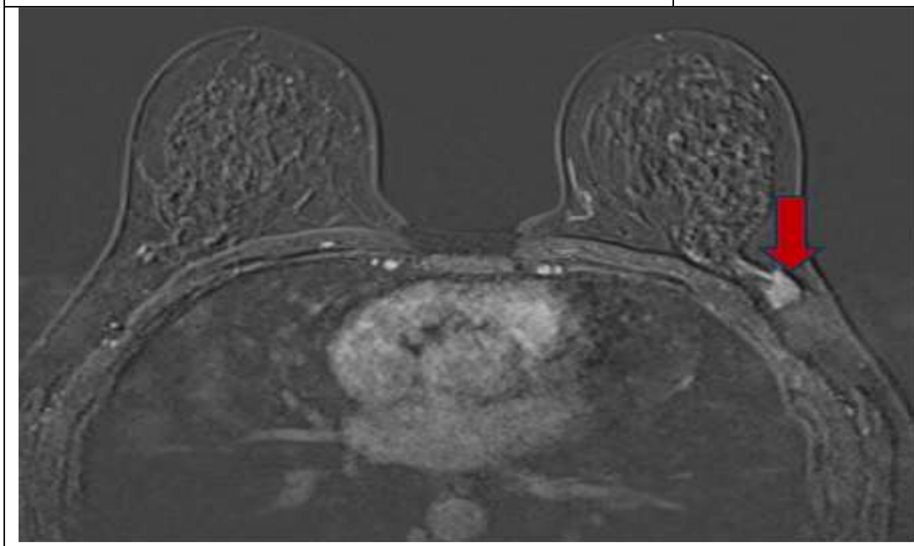


(1a)

(1b)

(1c)

(1d)



(1d)

Figure (1)

Case (2):

A sixty-year-old woman came for screening.

Figure (2–a & b): Right CC & MLO mammographic views illustrating right UOQ spiculated small dense lesion **(red arrow)**. **Lunite AI** revealed an increased suspicion probability of the lesion (91%).

Figure (2–c): A Greyscale ultrasound image of the right breast revealed an ill-defined hypoechoic mass lesion with a surrounding echogenic halo, measuring about 12x10 millimeters. The lesion was classified as BIRADS 4.

Figure (2–d): Shear wave elastography illustrating

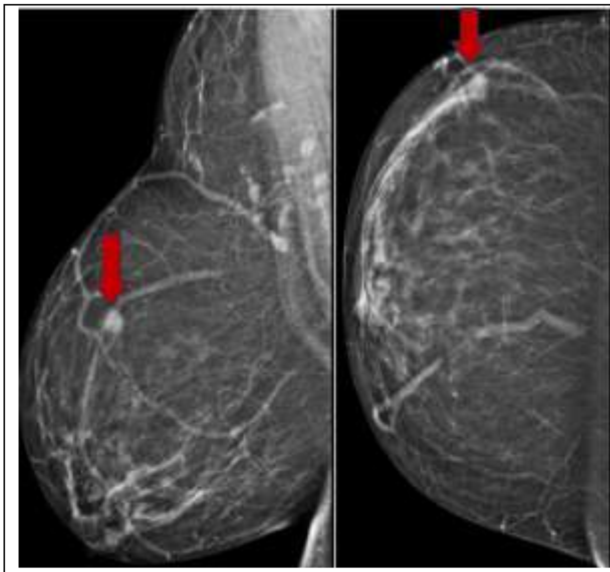
Shear wave elastography color overlay pattern 4: The lesion presents varied colored areas within its interior.

The maximal stiffness of the lesion = 148 kPa.

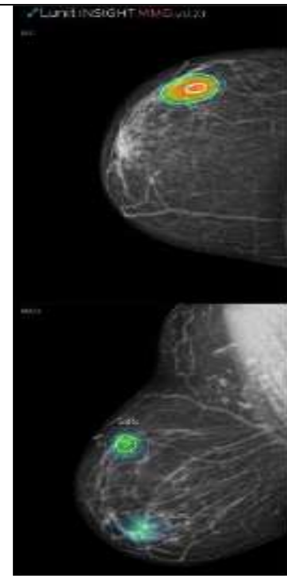
Stiffness ratio = 10

Figure (2–e): CEDM revealed a right breast UOQ, irregular, spiculated, heterogeneously enhancing mass lesion measuring 14 x 11 mm.

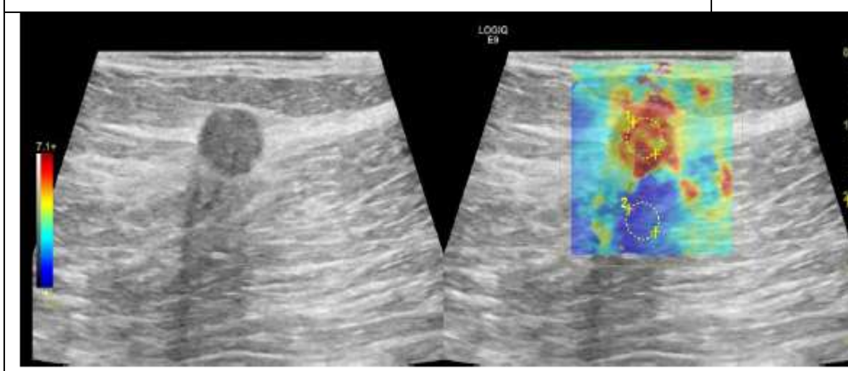
Final diagnosis: IDC grade II



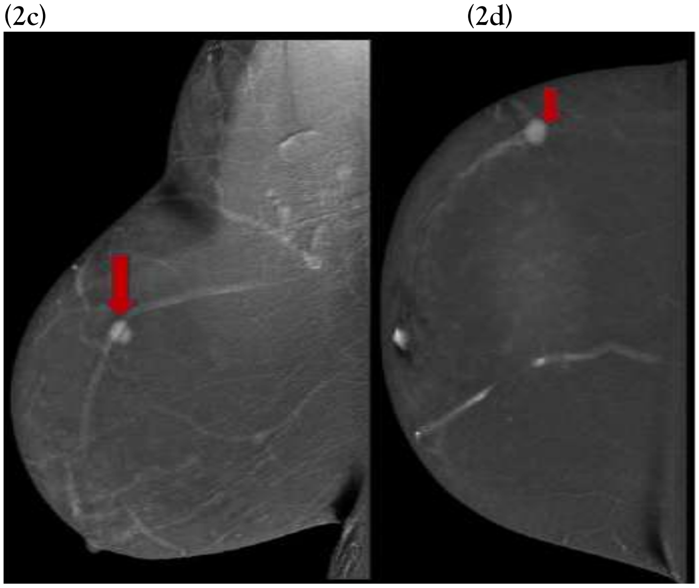
(2a)



(2b)



(2c) (2d)



(2e)

Figure (2)

Case (3):

A 29-year-old woman existed with a left axillary tail lump.

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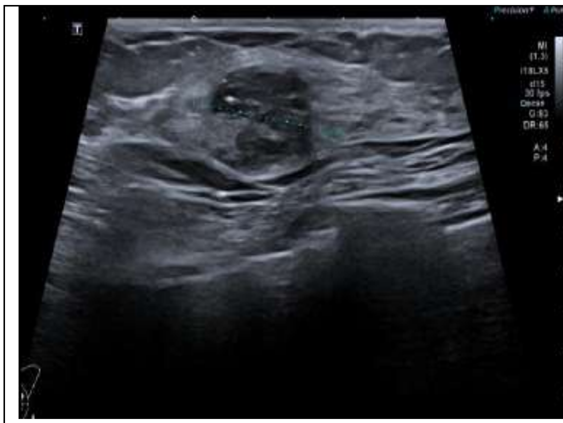
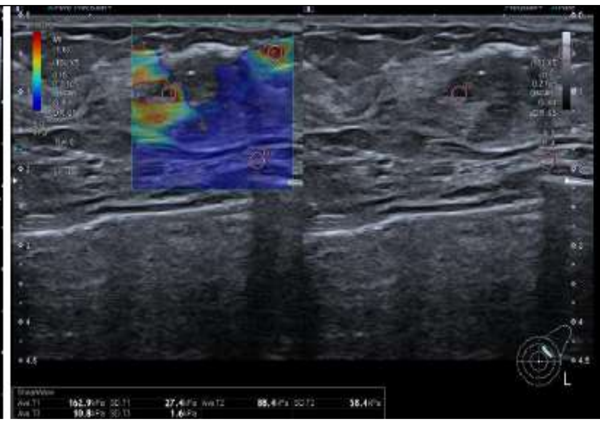
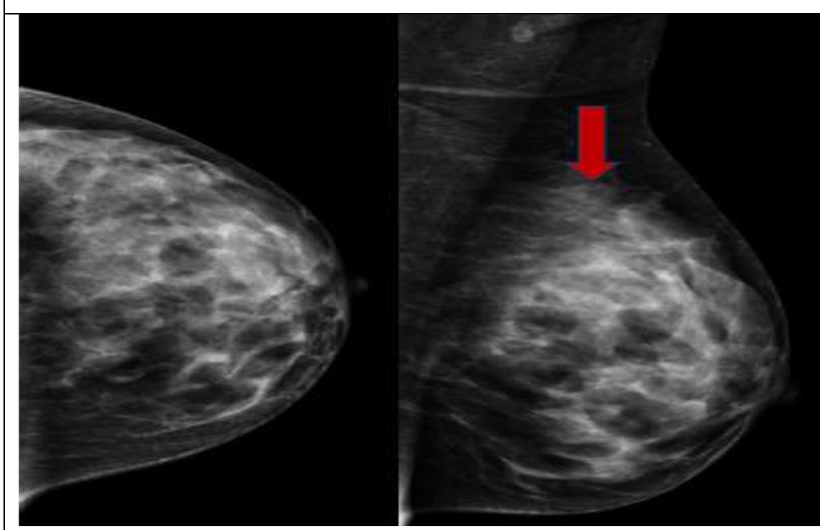
Figure (3–a): A Greyscale ultrasound image of the left breast revealed a left axillary tail rather defined hypoechoic heterogeneous mass lesion, measuring about 18x20 mm. The lesion was classified as BIRADS 3.
Figure (3–b): Shear wave elastography showing
SWE color overlay pattern 3: A localized colored area exists at the margin of the lesion.
The maximal stiffness of the lesion = 162 kPa.
Stiffness ratio = 10.3.
Figure (3-c): Left CC & MLO mammographic views showing left axillary tail obscured iso-dense lesion.
Figure 3—d DCE-MRI subtraction image of the left breast showing the left axillary tail, lobulated, faint heterogeneous enhancing mass lesion measuring 18x20 mm. It shows restricted diffusion (red arrow).
Final diagnosis: IDC grade III (triple negative).





(3a) **(3b)**



(3c)

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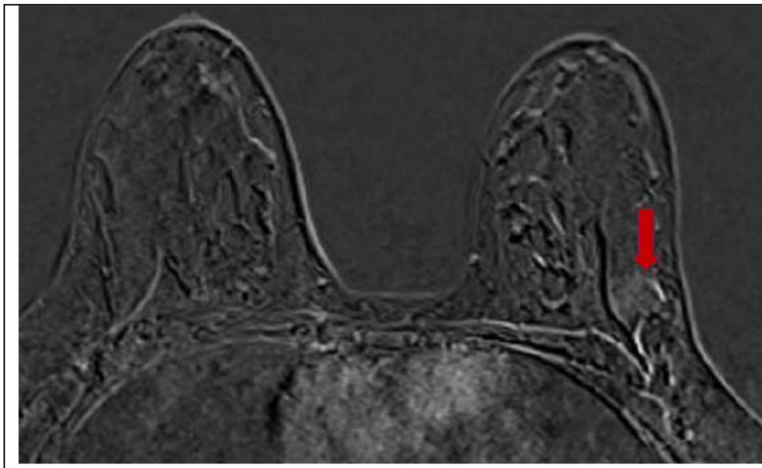

(3d)

Figure (3)

DISCUSSION

Recently, there has been a significant rise in the frequency of cancer of the breast. Mammography was utilized extensively in cancer of breast screening; however, it has limited sensitivity in people with dense breast tissue, which lowers its ability to detect breast cancer **(9).**

As a result, ultrasonography (US) has emerged as a crucial additive to mammography. In addition to traditional US, ultrasonography elastography seeks to recognize stiffness of tissue to differentiate cancerous from benign breast tumors **(10).**

This prospective study initially evaluated 91 patients with 100 breast lesions.

The table shows that the mean age was 46 ± 12.63 years, varying from 23 to 75 years.

The mean lesion size was 15.318 ± 4.05 millimeters, with a range from 5.5 to 20 millimeters.

The mean distance from the skin was 7.75 ± 3.55 mm, ranging from 2 to 19 mm. In the current study, 60 breast lesions (60.0%) were benign, while 40 lesions (40.0%) were malignant.

In our research, we 1st assessed the features of traditional ultrasound images of the involved lesions of the breast, in line with the ACR Ultrasound Lexicon, & categorized them in line with the ACR BI-RADS evaluation classifications.

For distinguishing malignant and benign lesions of the breast, traditional US-BIRADS showed specificity: 95.5%; PPV: 92.6%; sensitivity: 83.3%; NPV: 89.5%; and accuracy: 89.4%.

Comparable outcomes have been encountered in the work of **Zheng et al. (9),** who illustrated conventional US-BIRADS had a PPV of 73.68%, a diagnostic specificity of eighty percent, a diagnostic sensitivity of 93.33%, an NPV of 95.23%, and a diagnostic accuracy of eighty-five percent.

In our research, combined analysis of traditional US-BIRADS and shear wave elastography color overlay patterns has revealed specificity of 91.1%, sensitivity of 95%, negative predictive value of 96.5%, PPV of 87.7%, and accuracy of 92.7% for distinguishing benign and cancerous lesions of the breast.

Our outcomes were comparable to **Jung et al. (11),** who stated that depending on the assumption that patterns 3 and 4 were malignant and patterns 1 and 2 were benign, the shear wave elastography analysis provided a specificity of 92.0%, a sensitivity of 100% (50/50), an NPV of 100% (46/46), a PPV of 92.5% (50/54), and an accuracy of 96.0% (96/100) for distinguishing cancerous and benign breast lesions.

Suvannarerg et al. (12) found that the SWE heterogeneous color overlay pattern (patterns 3 & 4) had a specificity of 93.24%, PPV of 87.65%, sensitivity of 73.96%, and NPV of 84.66% in the distinguishing of cancerous and benign lesions of the breast.

Based on that, the combined analysis of both traditional US-BIRADS and quantitative shear wave elastography (lesion elasticity) had a sensitivity of 98.3%, a specificity of 92.2%, a PPV of 89.39%, an NPV of 98.8%, and an accuracy of 95.25% in distinguishing malignant from benign breast lesions.

Our outcomes were comparable to those of **Ahmed (13),** who showed that the cancerous lesions illustrated a significantly greater elasticity value than lesions of benign.
In our study, the highest added diagnostic value of SWE was achieved using quantitative assessment (lesion stiffness/kPa) with an overall diagnostic accuracy of 95.25%, as compared to 92.7% achieved using qualitative shear wave elastography (color overlay patterns) in the distinguishing of cancerous and benign lesions of the breast.
That matched **Suvannarerg et al. (12),** who studied 244 breast masses regarding the added value of different qualitative and quantitative SWE parameters to conventional ultrasound. They stated that the maximum elasticity of the quantitative shear wave elastography variables had the best diagnostic performance in distinguishing cancerous and benign breast lesions.
In research done by **Choi et al. (14),** a total of 428 minor lesions of the breast (≤ 2 cm) have been involved. The diagnostic efficacy of each set has been assessed by area under the receiver operating characteristic curve (AUC) analysis. The sensitivity of B-mode ultrasound was superior to that of SWE or the combined modality (B-mode ultrasound: 97.2% against shear wave elastography: 71.1% vs. combination modality: 88.7%). Nevertheless, the specificity was much greater for shear wave elastography, or the combined modality, compared to B-mode ultrasonography (B-mode ultrasound: 17.1% versus shear wave elastography: 72.4%, combination modality: 69.6%). The accuracy and positive predictive value rise in the combined modality than B-mode US & in SWE than B-mode US.

LIMITATION

Our study on ultrasound SWE for malignant breast lesions had limitations including no assessment of observer variability, lack of consensus on SWE cut-off values, absence of guidelines for combining shear wave elastography with B-mode ultrasound, possible bias from one radiologist performing the exams, and potential selection bias due to patient referral criteria.

CONCLUSION

In conclusion, the use of SWE enhanced the diagnostic performance of B-mode ultrasound for minor (≤ two centimeters) lesions of the breast. Nonetheless, the size of the lesion on the ultrasound, its pathology, and its anatomical placement are likely to influence the shear wave elastography value, potentially leading to false outcomes. Lesions situated near the chest and skin wall or among thick tissue of the breast may yield false positive results. It is believed that the benefit of adding shear wave elastography will be greater when the shear wave elastography outcome is selectively combined with B-mode ultrasound on small lesions of the breast, preventing the patient from being misled by the shear wave elastography outcome. Additional prospective research is required to create precise recommendations for the combination of BI-RADS scores and shear wave elastography values for minor lesions of the breast.

RECOMMENDATION

Our research recommends that ultrasound SWE be used as a complementary tool alongside standard B-mode imaging, especially for solid or complex breast lesions under 2 cm. SWE can help upgrade BI-RADS 3 lesions with high stiffness for biopsy and downgrade BI-RADS 4a lesions with low stiffness to monitoring, improving diagnostic accuracy. SWE should be avoided for very superficial (<3 mm) or very deep (>4 cm) lesions. Additionally, when a malignant lesion appears soft, assessing stiffness in the surrounding tissue is important for accurate characterization.

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