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DIAGNOSTIC ACCURACY OF SPECTRAL DOPPLER ULTRASOUND IN DETECTING SOLID BREAST LESION MALIGNANCY TAKING HISTOPATHOLOGY AS A GOLD STANDARD

Original Research

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ABSTRACT

Background: Breast cancer remains the most prevalent malignancy among women globally and a major contributor to cancer-related mortality. In Pakistan, the burden of breast cancer continues to rise, with late-stage diagnosis being a common challenge. Early and accurate identification of malignancy in breast lesions is critical for improving outcomes. Spectral Doppler ultrasonography, a non-invasive modality, offers valuable insight into vascular patterns of breast masses and may enhance diagnostic accuracy when used alongside B-mode ultrasound.

Objective: To determine the diagnostic accuracy of spectral Doppler ultrasound in detecting malignancy in solid breast lesions, using histopathology as the gold standard.

Methods: This prospective observational study was conducted at the Radiology Department of Al-Razi Institute, Lahore. A total of 190 female patients aged 18–60 years, presenting with breast lesions categorized as BI-RADS III, IV, or V, were enrolled. After obtaining informed consent, each participant underwent spectral Doppler ultrasonography, followed by an ultrasound-guided core biopsy using an 18-gauge Trucut needle. Histopathological analysis was performed on formalin-preserved cores by a fellowship-trained consultant histopathologist. Diagnostic parameters, including sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall diagnostic accuracy, were calculated by comparing Doppler findings with histopathology.

Results: Spectral Doppler ultrasonography identified malignancy in 86 cases (45.3%), while histopathology confirmed 90 cases (47.4%). The modality demonstrated 83.9% sensitivity, 95.5% specificity, 88.7% PPV, 93.4% NPV, and an overall diagnostic accuracy of 92.1%. Age-stratified and BI-RADS subgroup analyses further supported the high diagnostic value of Doppler imaging.

Conclusion: Spectral Doppler ultrasound is a reliable, accessible, and non-invasive diagnostic tool for differentiating benign from malignant solid breast lesions, offering high diagnostic accuracy when histopathology is unavailable or delayed.

Keywords: Breast Neoplasms, Diagnostic Imaging, Doppler Ultrasonography, Histopathology, Predictive Value of Tests, Sensitivity and Specificity, Ultrasound Imaging.

INTRODUCTION

Breast cancer remains the most frequently diagnosed malignancy among women worldwide and continues to represent a significant cause of cancer-related mortality (1). In Pakistan, breast cancer ranks as the third most common malignancy in women, following Kaposi's sarcoma and cervical cancer (2). Alarming epidemiological trends reveal a steady rise in incidence over the decades—from 11 per 100,000 in 1961 to 31 per 100,000 by 2006—underscoring a nearly threefold increase in burden (3). Disturbingly, the disease in Pakistan is often diagnosed at an advanced stage, typically stage II or III, and in relatively younger women. This late-stage presentation is strongly associated with a more aggressive disease course and poor prognosis, reflected by a five-year survival rate of only 39% (4). The underlying reasons behind such delayed presentations are multifactorial and not yet fully elucidated. However, proposed contributors include genetic susceptibility, lack of awareness, cultural hesitance in seeking timely medical care, limited accessibility to oncology services, and a generally lower life expectancy (5). This scenario accentuates the urgent need for improved diagnostic modalities that can facilitate early detection and accurate characterization of breast lesions, particularly in low-resource and high-burden settings.

One such promising tool is Doppler ultrasonography, grounded in the concept of tumor angiogenesis—a pivotal mechanism first described by Folkman in 1971 as essential for tumor growth and survival (6). Neoplastic tissue often creates a hypoxic microenvironment due to insufficient perfusion by existing vasculature, which in turn stimulates the formation of new blood vessels, or neoangiogenesis, to meet its heightened metabolic demands (7). Doppler ultrasound, particularly when combining color and spectral modalities, allows real-time visualization and hemodynamic assessment of this pathological vascularization (8). Malignant tumors frequently demonstrate low-resistance arterial waveforms, central vascular patterns, and increased vascular density—features that may assist in distinguishing them from benign entities. Despite the advantages, spectral Doppler is not routinely incorporated into standard breast ultrasound protocols in many clinical settings. This is particularly paradoxical given that ultrasonography remains a non-invasive, radiation-free, and accessible imaging technique, which plays an especially crucial role in populations where mammography may be limited, such as younger women, pregnant patients, or those with dense breast tissue (9,10). In such contexts, sonography is not only invaluable for lesion detection and characterization but also for guiding interventions like biopsies (11).

Recent perspectives suggest that integrating spectral Doppler analysis into routine breast imaging could enhance diagnostic precision, reduce unnecessary biopsies, and contribute to more personalized therapeutic strategies, particularly if validated through further clinical studies (12). Given the growing burden of breast cancer in resource-constrained regions and the critical need for improved diagnostic strategies, this study aims to assess the diagnostic potential of Doppler ultrasonography in distinguishing benign from malignant breast lesions, thereby offering a cost-effective adjunct to existing imaging modalities.

METHODS

Following approval from the Institutional Ethical Review Board of Al-Razi Institute, Lahore, this prospective observational study was conducted in the Department of Radiology. A total of 190 female patients meeting the inclusion criteria were consecutively recruited. Informed written consent was obtained from all participants after they were briefed about the study's objectives, potential benefits, and the procedures involved. Participants were women presenting with breast lesions clinically or sonographically categorized as BI-RADS III, IV, or V, suggestive of possible malignancy. Exclusion criteria included previously confirmed malignancies, ongoing treatment for breast cancer, prior breast biopsies, pregnancy, patients undergoing hormone replacement therapy, predominantly cystic lesions, and ulcerated or advanced-stage breast lesions. Additionally, women with high body mass index (BMI), which could compromise image resolution, were excluded due to the known limitations of ultrasonography in this subgroup. Demographic data and relevant clinical history were recorded for each participant using a structured proforma. All patients underwent spectral Doppler ultrasonography of the breast using a LOGIQ P6 3D ultrasound machine. The examination was supervised and performed by a consultant radiologist with three years of post-fellowship experience in breast imaging. According to the operational definition adopted in the study, a lesion was classified as malignant on Doppler if it demonstrated a resistive index (RI) of ≤0.68. For illustrative reference, lesions exhibiting low vascular

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resistance with an RI of 0.4 were considered more suspicious for malignancy (Figure 1), whereas those showing high resistance with an RI of 0.7 were interpreted as likely benign (Figure 2).

All lesions were subjected to ultrasound-guided biopsy using an 18-gauge Trucut needle, and three core samples were obtained per lesion and preserved in formalin for histopathological evaluation. A fellowship-trained consultant histopathologist with three years of post-fellowship experience reviewed all the specimens. Histological criteria for malignancy included architectural distortion with micropapillary formations, cribriform patterns, and preservation of ductal basement membrane integrity. The findings from spectral Doppler imaging and histopathological diagnosis were meticulously recorded by the principal researcher using a predefined proforma (Annexure-I). Data were entered and analyzed using SPSS software version 17.0. Descriptive statistics, including means and standard deviations, were calculated for continuous variables such as patient age and duration of symptoms. Frequencies and percentages were computed for categorical variables, including age groupings and BI-RADS classifications. Diagnostic performance of spectral Doppler ultrasound was assessed in comparison to histopathology as the gold standard using a 2×2 contingency table. Sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and overall diagnostic accuracy were calculated accordingly.

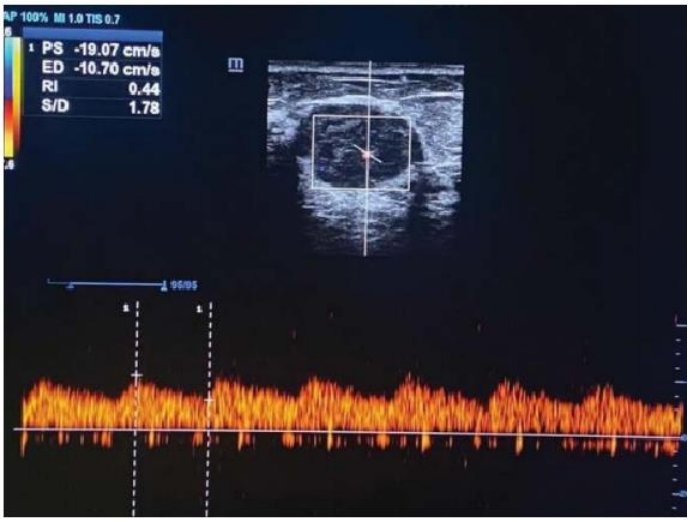

Figure 1: Doppler ultrasound of breast lesion showing RI value of 0.4 suggesting a malignant looking lesion.

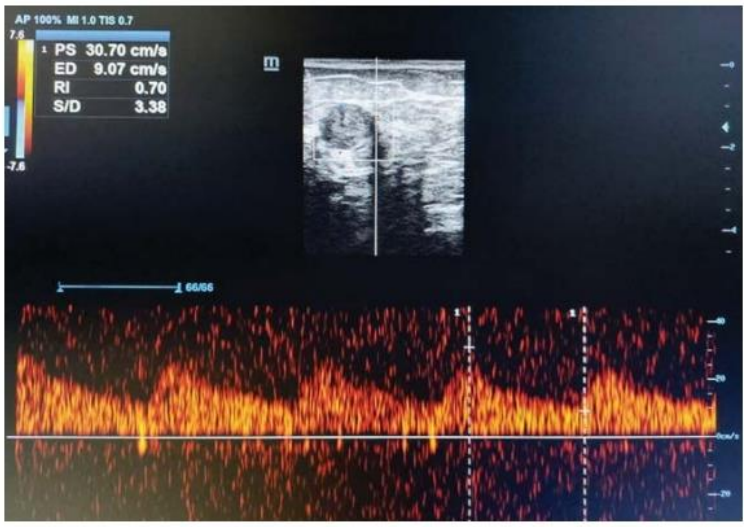

Figure 2: Doppler ultrasound of a breast lesion showing RI values of 0.7 suggesting a benign looking lesion.

RESULTS

The age of participants in this study ranged from 18 to 60 years, with a mean of 42.96 ± 7.66 years. The mean duration of presenting complaints was 4.93 ± 2.03 months. Of the 190 patients, 30.5% (n = 58) were aged between 18 and 40 years, while 69.5% (n = 132) were aged between 41 and 60 years. Based on the BI-RADS classification, 47.4% (n = 90) of the participants were categorized as BI-RADS III, 38.9% (n = 74) as BI-RADS IV, and 13.7% (n = 26) as BI-RADS V, showing a statistically significant distribution ($p < 0.001$). Histopathological examination confirmed malignancy in 47.4% (n = 90) of cases, whereas spectral Doppler ultrasound identified malignancy in 45.3% (n = 86) of the same cohort. The comparison between histopathology and spectral Doppler yielded a non-significant p-value of 0.758, suggesting moderate alignment. Spectral Doppler correctly identified 47 true positive and 128 true negative cases, with 6 false positives and 9 false negatives, resulting in a sensitivity of 83.9%, specificity of 95.5%, positive predictive value (PPV) of 88.7%, negative predictive value (NPV) of 93.4%, and an overall diagnostic accuracy of 92.1%. Stratified analysis by age groups revealed that among women aged 18–40 years (n = 58), spectral Doppler correctly identified 5 true positives and 51 true negatives, with 2 false positives and no false negatives, yielding a sensitivity of 100% and specificity of 96.2% in this subgroup. In the age group of 41–60 years (n = 132), spectral Doppler showed 58 true positives and 66 true negatives, with 2 false positives and 6 false negatives, confirming its diagnostic utility in both age brackets ($p < 0.001$ for both subgroups).

The subgroup analysis of diagnostic performance across BI-RADS categories revealed notable variations in sensitivity, specificity, and overall diagnostic accuracy of spectral Doppler ultrasonography. In BI-RADS III patients (n = 90), the sensitivity was 77.8% and

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specificity was 97.2%, with a diagnostic accuracy of 93.3%. For BI-RADS IV patients (n = 74), sensitivity increased to 82.8% with a specificity of 93.3%, while overall accuracy was slightly lower at 89.2%. Interestingly, the BI-RADS V group (n = 26) demonstrated the highest diagnostic accuracy at 96.2%, with perfect sensitivity (100%) and high specificity (94.1%). These findings suggest that spectral Doppler ultrasonography yields progressively better diagnostic performance as the BI-RADS classification becomes more suspicious for malignancy. However, the slightly reduced negative predictive value in BI-RADS IV underscores the need for cautious interpretation in intermediate-risk lesions. This subgroup analysis strengthens the case for incorporating spectral Doppler metrics into routine breast lesion assessments, particularly in higher BI-RADS categories.

Table 1: Percentage and frequency of patients according to BIRADS category scale=190

BI-RADS Category Scale	No. of Patients	Percentage (%)	P-value
III	90	47.4%	
IV	74	38.9%	
V	26	13.7%	<0.001
TOTAL	190	100%	

Table 2: Spectral Doppler and Histopathology of Malignant breast lesion (n=190)

Malignant Breast Lesions	Spectral Doppler Ultrasound	Histopathology	P-value
Present	86(45.3%)	90(47.4%)	
Absent	104(54.7%)	100(52.6%)	0.758
Total	190(100%)	190(100%)	

Table 3: Comparison of Spectral Doppler and Histopathology of Malignant breast lesion (n=190)

Spectral Doppler Ultrasound	Histopathology		Total	p-Value
Positive	47 (TP)	6 (FP)	53	0.000
Negative	9 (FN)	128 (TN)	137	
Total	56	134	190	

Table 4: With age range 18-40 years, Spectral Doppler and Histopathology of Malignant breast lesion (n=58)

Spectral Doppler Ultrasound	Histopathology		Total	p-Vlaue
Positive	5 (TP)	2 (FP)	7	0.000
Negative	0 (FN)	51 (TN)	51	
Total	5	53	58	

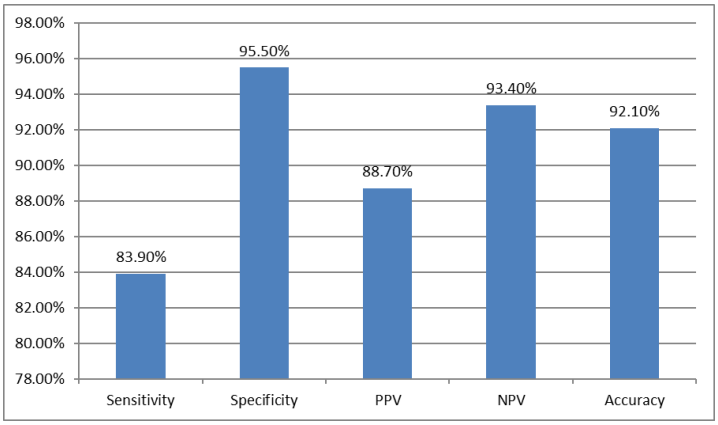
Table 5: With age range 41-60 years, Spectral Doppler and Histopathology of Malignant breast lesion (n=132)

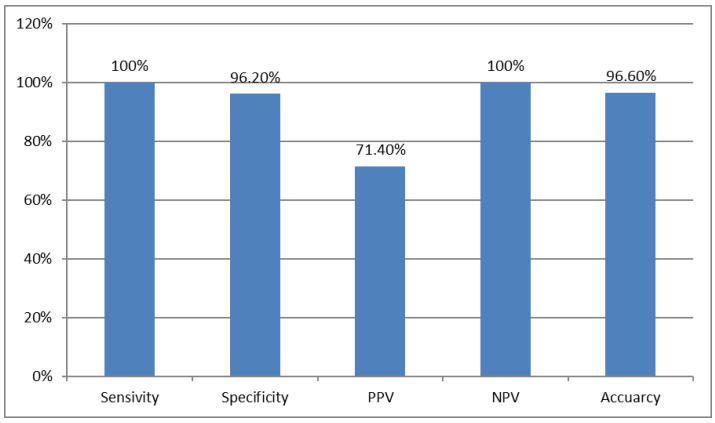
Spectral Doppler Ultrasound	Histopathology		Total	p-Value
Positive	58 (TP)	2 (FP)	60	0.000
Negative	6 (FN)	66 (TN)	72	
Total	64	68	132	

Table 6: Subgroup Analysis Based on BI-RADS Category

BI-RADS Category	Total Patients	TP	FP	FN	TN	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
III	90	14	2	4	70	77.8	97.2	87.5	94.6	93.3
IV	74	24	3	5	42	82.8	93.3	88.9	89.4	89.2
V	26	9	1	0	16	100.0	94.1	90.0	100.0	96.2

Note: TP: True Positives, FP: False Positives, FN: False Negatives, TN: True Negatives





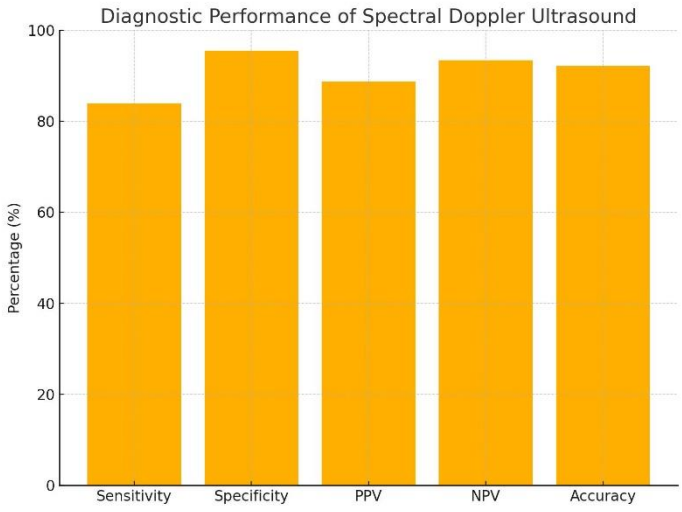


Figure 1 Diagnostic Performance of Spectral Doppler Ultrasound

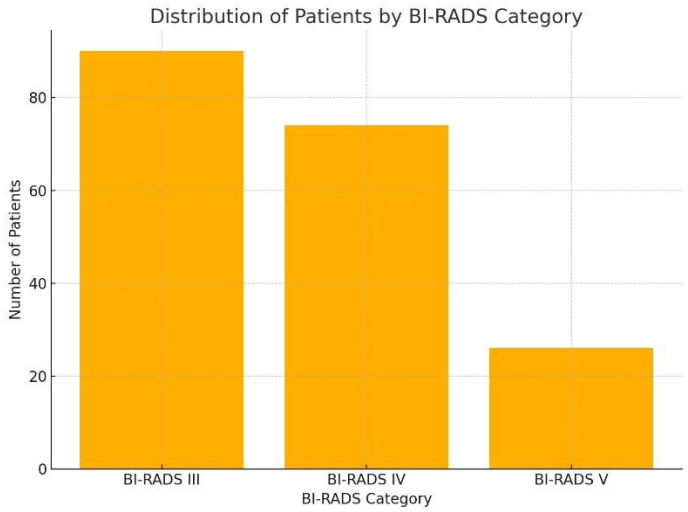


Figure 2 Distribution of Patients by BI-RANDS category

DISCUSSION

In this study, spectral Doppler ultrasonography demonstrated commendable diagnostic performance in identifying malignant breast lesions, with a sensitivity of 83.9%, specificity of 95.5%, and diagnostic accuracy of 92.1%. These values align closely with prior research, where similar imaging techniques reported sensitivity rates around 85% and specificity near 74% in distinguishing benign from malignant breast lesions (12,13). The present study further reinforces the notion that spectral Doppler imaging serves as a valuable adjunct to conventional B-mode ultrasound, especially in settings where mammography may be limited by patient age or breast density. The observed malignancies in this cohort were generally larger than benign counterparts and exhibited characteristic features such as uncircumscribed margins, mixed echogenicity, and solid-cystic components—sonographic traits consistent with malignancy as highlighted in earlier works (14–17). The study also confirmed that malignant lesions frequently exhibited increased vascularity with intralesional blood flow on Doppler imaging, a hallmark of tumor neoangiogenesis. This finding supports previous observations that central vascularity is more commonly detected in malignant than benign lesions, where color Doppler revealed intratumoral blood flow in up to 71% of malignant masses and only 6.6% of benign ones (18). The integration of B-mode ultrasound findings with Doppler vascular patterns resulted in enhanced predictive value, with some studies citing a PPV of up to 92% for malignancy detection when both modalities were combined (19).

Further analysis of Doppler parameters revealed significantly higher values of peak systolic velocity (PSV), resistive index (RI), and pulsatility index (PI) in malignant tumors compared to benign ones. These findings are in line with earlier investigations which

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emphasized the utility of these hemodynamic indices in tumor characterization, particularly when RI thresholds approached or exceeded 0.73–0.80 for malignancy prediction (20). Nevertheless, it was noted that vascular patterns alone are not always reliable. Some benign hypervascular tumors may mimic malignant blood flow profiles, introducing a margin of diagnostic uncertainty and potential overlap between benign and malignant findings on Doppler (21). The heterogeneity of breast tumors, particularly with respect to histological grade and vascular supply, contributes to this diagnostic complexity. High-grade, hypercellular malignancies often show prominent neovascularization due to the presence of dedicated feeding vessels, while low-grade or in situ carcinomas may lack conspicuous Doppler signals (20,21). This variability underscores the importance of integrating spectral Doppler findings with grayscale ultrasound and clinical context to enhance diagnostic precision.

One of the key strengths of this study is its robust sample size and structured, blinded comparison against histopathology as the gold standard. Additionally, stratified subgroup analysis by age and BI-RADS category allowed for more nuanced assessment of Doppler performance across different clinical profiles. However, certain limitations should be acknowledged. The study did not account for tumor size and histological subtype in correlation with Doppler indices, which could have provided deeper insights. Moreover, although the resistive index threshold of ≤0.68 was used operationally, a spectrum-based approach rather than a fixed cutoff might offer greater diagnostic flexibility, especially in borderline or complex lesions. Incorporating Doppler ultrasound as a routine component of breast imaging protocols, particularly in resource-constrained settings, may offer a non-invasive and cost-effective method for early malignancy detection. Future research should explore the integration of Doppler parameters with emerging technologies such as elastography or machine learning models to refine diagnostic algorithms. Furthermore, longitudinal studies evaluating the prognostic implications of Doppler vascular patterns, including treatment response and metastasis risk, could expand its clinical utility beyond initial diagnosis.

CONCLUSION

Spectral Doppler ultrasonography has proven to be a valuable tool in the diagnostic evaluation of breast lesions, offering reliable differentiation between benign and malignant tumors. Its ability to assess vascular characteristics non-invasively enhances diagnostic confidence, supports clinical decision-making, and may reduce the need for unnecessary biopsies. By integrating Doppler findings with conventional ultrasound, clinicians can guide appropriate treatment strategies more effectively, particularly in settings where access to advanced imaging or histopathology is limited. This study underscores the practical significance of incorporating spectral Doppler imaging into routine breast assessments to improve early detection and management outcomes.

AUTHOR CONTRIBUTION

Author	Contribution
Muhammad Ahmad Raza*	Substantial Contribution to study design, analysis, acquisition of Data Manuscript Writing Has given Final Approval of the version to be published
Saira Ghaffar	Substantial Contribution to study design, acquisition and interpretation of Data Critical Review and Manuscript Writing Has given Final Approval of the version to be published
Muhammad Kaleem Akhter	Substantial Contribution to acquisition and interpretation of Data Has given Final Approval of the version to be published
Syeda Alina Sherazi	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Sidra Ghazanfar	Contributed to Data Collection and Analysis Has given Final Approval of the version to be published
Noor Fatima	Substantial Contribution to study design and Data Analysis Has given Final Approval of the version to be published
Muhammad Yasir Aziz	Contributed to study concept and Data collection Has given Final Approval of the version to be published
Raheel Abrar	Writing - Review & Editing, Assistance with Data Curation

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