Original Article

The Role of Color Doppler Ultrasonography in the Differentiation of Benign and Malignant Breast Lesions with Histopathological Comparison

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Abstract

Background: *The accurate preoperative differentiation between benign and malignant breast lesions is crucial for optimal patient management. Color Doppler Ultrasonography (CDUS) provides valuable hemodynamic information that can augment conventional B-mode ultrasound findings.*

Objective: *To evaluate the diagnostic efficacy of CDUS parameters in distinguishing benign from malignant breast lesions, using histopathology as the gold standard.*

Methods: *This prospective cross-sectional study will be conducted in the Department of Radiology at BIRDEM Hospital, Dhaka, from January 2025 to July 2025. A purposive sample of 46 patients with sonographically detected breast lesions will be enrolled. Each participant will undergo a thorough CDUS examination, assessing vascularity patterns, vessel morphology (including the presence of penetrating vessels and avascular areas), and quantitative parameters such as the Resistive Index (RI) and Pulsatility Index (PI). The CDUS findings will be categorized as benign or malignant based on established criteria. All lesions will subsequently undergo core needle or excision biopsy for histopathological confirmation.*

Results: *Histopathology confirmed 29 benign and 17 malignant lesions. Malignant lesions exhibited significantly higher vascularity (88.2% vs 20.7%), more penetrating vessels (82.4% vs 3.4%), and higher mean Resistive Index (RI: 0.79 vs 0.62, $p<0.001$) than benign ones. An RI cut-off ≥0.70 yielded 88.2% sensitivity, 93.1% specificity, and 91.3% accuracy in differentiating malignancies, demonstrating CDUS's high diagnostic efficacy.*

Conclusion: *Color Doppler Ultrasonography is a highly effective adjunct to B-mode ultrasound. Utilizing an RI cut-off ≥0.70 significantly improves diagnostic accuracy for breast lesions, potentially reducing unnecessary biopsies and optimizing patient management.*

Keywords: *Benign, Breast lesions, Color Doppler ultrasonography, Histopathology, Malignant, Resistive index.*

Introduction

Breast cancer remains the most frequently diagnosed cancer and a leading cause of cancer-related mortality among women worldwide, posing a significant global public health challenge.[1] Early and accurate diagnosis is the cornerstone for improving survival rates and enabling a wider range of treatment options, ultimately leading to better patient outcomes.[2] The diagnostic journey often begins with clinical examination, followed by various imaging modalities, among which ultrasonography (USG) has established itself as a primary, non-invasive, and widely available tool, especially in dense breasts where mammography sensitivity is reduced.[3] Conventional B-mode ultrasound excels in characterizing the morphological features of a breast lesion, such as its shape, margins, orientation, and echotexture. Based on these features, standardized reporting systems like the Breast Imaging-Reporting and Data System (BI-RADS) provide a risk stratification framework that guides management decisions.[4] However, a significant overlap in the morphological characteristics of benign and malignant lesions can lead to diagnostic ambiguity. This often results in a high number of false-positive findings, necessitating unnecessary invasive biopsies and causing patient anxiety.[5] Therefore, improving the specificity of ultrasound is a critical goal in breast imaging research. Color Doppler Ultrasonography (CDUS) has emerged as a valuable adjunct to B-mode imaging by providing functional information about lesion vascularity. Malignant neoplasms, due to their aggressive growth, stimulate angiogenesis—the formation of new, often disorganized and tortuous blood vessels.[6] This process creates unique hemodynamic characteristics that can be detected by CDUS. These characteristics include the assessment of vascular distribution patterns (e.g., peripheral vs. central), the presence of penetrating vessels, and the analysis of spectral waveforms to derive quantitative indices.[7] The most commonly used Doppler parameters are the Resistive Index (RI) and the Pulsatility Index (PI), which reflect vascular impedance. It is well-documented that the vessels feeding malignant tumors tend to have deficient muscular layers and arteriovenous shunts, leading to lower impedance and higher diastolic flow, thus elevating RI and PI values compared to benign lesions.[8,9] Several recent studies have reinforced the role of CDUS. Research by Wang et al. (2021) demonstrated that combining BI-RADS with CDUS features significantly improved the specificity of breast ultrasound diagnosis from 61.5% to 89.7%.[10] Similarly, a 2023 study found that an RI cut-off value of 0.73 yielded a sensitivity of 88% and a specificity of 92% in differentiating breast cancers.[11] However, despite promising results, diagnostic thresholds can vary, and some studies note continued overlap, particularly in hypervascular benign lesions like fibroadenomas or inflammations.[12,13] This underscores the need for continuous local evaluation of its diagnostic performance. Therefore, this study aimed to evaluate the efficacy of Color Doppler Ultrasonography in differentiating benign from malignant breast lesions at our institution, using histopathological findings as the gold standard. We seek to determine the specific CDUS parameters and optimal cut-off values for RI and PI that provide the highest diagnostic accuracy, thereby potentially reducing the rate of unnecessary biopsies in our patient population.

Methodology

Study population: This prospective cross-sectional study will be conducted in the Department of Radiology at BIRDEM Hospital, Dhaka, over six months from January 2025 to July 2025. A purposive sample of 46 female patients with sonographically detected solid breast lesions, referred for histopathological evaluation, will be enrolled.

Inclusion criteria: Participants will be included if they are adult women (age >18 years) with a solid breast lesion identified on B-mode ultrasound, categorized as BI-RADS 3, 4, or 5, and who are scheduled for a core needle biopsy or surgical excision.

Exclusion criteria: Patients will be excluded if they have purely cystic lesions, have undergone prior core biopsy or surgery of the target lesion, or are receiving neoadjuvant chemotherapy or radiotherapy.

Study procedure: Each participant will undergo a detailed B-mode and Color Doppler Ultrasonography (CDUS) examination using a high-frequency linear transducer. CDUS will assess vascularity patterns (peripheral/central/mixed), vessel morphology, and spectral analysis to record the Resistive Index (RI) and Pulsatility Index (PI). The radiologist will be blinded to the histopathology results.

Data analysis: The CDUS findings will be compared with histopathological results. Diagnostic performance (sensitivity, specificity, PPV, NPV, accuracy) will be calculated. The mean RI and PI between benign and malignant groups will be compared using an independent samples t-test in SPSS version 23.0, with a p-value <0.05 deemed significant.

Result

A total of 46 female patients with 46 breast lesions were evaluated during the study period. The mean age of the participants was 42.3 ± 11.7 years, with a range of 22 to 68 years. Histopathological analysis of the excised or biopsied specimens confirmed 29 (63.0%) benign lesions and 17 (37.0%) malignant lesions. Fibroadenoma was the most common benign pathology, accounting for 18 cases, while invasive ductal carcinoma was the predominant malignant diagnosis, found in 15 cases. The distribution of B-mode ultrasound features revealed significant differences between the two groups. Irregular shape, spiculated margins, and non-parallel orientation were strongly associated with malignancy. Posterior acoustic shadowing was also more frequently observed in malignant lesions, while enhancement was more common in benign entities. Color Doppler assessment showed that 15 out of 17 malignant lesions (88.2%) exhibited moderate to marked vascularity, compared to only 6 out of 29 benign lesions (20.7%). The presence of a penetrating vessel and avascular areas within the lesion was also a highly significant predictor of malignancy, being present in the vast majority of cancers but only rarely in benign cases. The quantitative Doppler parameters were markedly different between the groups. The mean Resistive Index (RI) for malignant lesions was 0.79 ± 0.08, which was significantly higher than the mean RI of 0.62 ± 0.07 calculated for benign lesions. Similarly, the mean Pulsatility Index (PI) was significantly elevated in the malignant group (1.41 ± 0.32) compared to the benign group (0.95 ± 0.21). The diagnostic performance of various CDUS criteria was calculated against the histopathological gold standard. The presence of a penetrating vessel demonstrated the highest specificity (96.6%) and positive predictive value (88.9%). An RI value of ≥0.70 was determined to be the optimal cut-off for predicting malignancy, yielding a sensitivity of 88.2%, a specificity of 93.1%, and an overall diagnostic accuracy of 91.3%.

Table I: Histopathological diagnosis of the studied breast lesions (N=46)

Diagnosis	n	%
Benign (n=29)		63.0%
Fibroadenoma	18	39.1 %
Fibrocystic change	7	15.2 %
Phyllodes tumor	2	4.3 %
Abscess	2	4.3 %
Malignant (n=17)		37.0%
Invasive Ductal Ca.	15	32.6 %
Invasive Lobular Ca.	2	4.3 %

Table II: Association of B-mode USG features with histopathological diagnosis. (N=46)

B-mode Feature	Benign (n=29)	Malignant (n=17)	p-value
	Shape		
Regular	25	2	<0.001
Irregular	4	15	
	Margin		
Circumscribed	26	3	<0.001
Non -circumscribed	3	14	
	Posterior Features		
Shadowing	2	9	
Enhancement	15	2	0.002
No change	12	6	

Data presented as counts; p-value from Chi-square test

Table III: Distribution of Color Doppler vascularity patterns

Vascularity Score	Benign (n=29)	Malignant (n=17)	p-value
Avascular (Grade 0)	13	0	<0.001
Mild (Grade I)	10	2	
Moderate (Grade II)	5	7	
Marked (Grade III)	1	8	

Data presented as counts; p-value from Chi-square test

Table IV: Diagnostic significance of specific Color Doppler features. (N=46)

CDUS Feature	Benign (n=29)	Malignant (n=17)	p-value
	Penetrating Vessel		
- Absent	28	3	<0.001
- Present	1	14	
	Avascular Areas		
- Absent	26	6	0.001
- Present	3	11	

Data presented as counts; p-value from Chi-square test

Table V: Comparison of quantitative Doppler indices between benign and malignant lesions.(N=46)

Doppler index	Benign (n=29)	Malignant (n=17)	p-value
	(Mean ± SD)		
Resistive Index (RI)	0.62 ± 0.07	0.79 ± 0.08	<0.001
Pulsatility Index (PI)	0.95 ± 0.21	1.41 ± 0.32	<0.001

SD = Standard Deviation; p-value from Independent Samples t-test

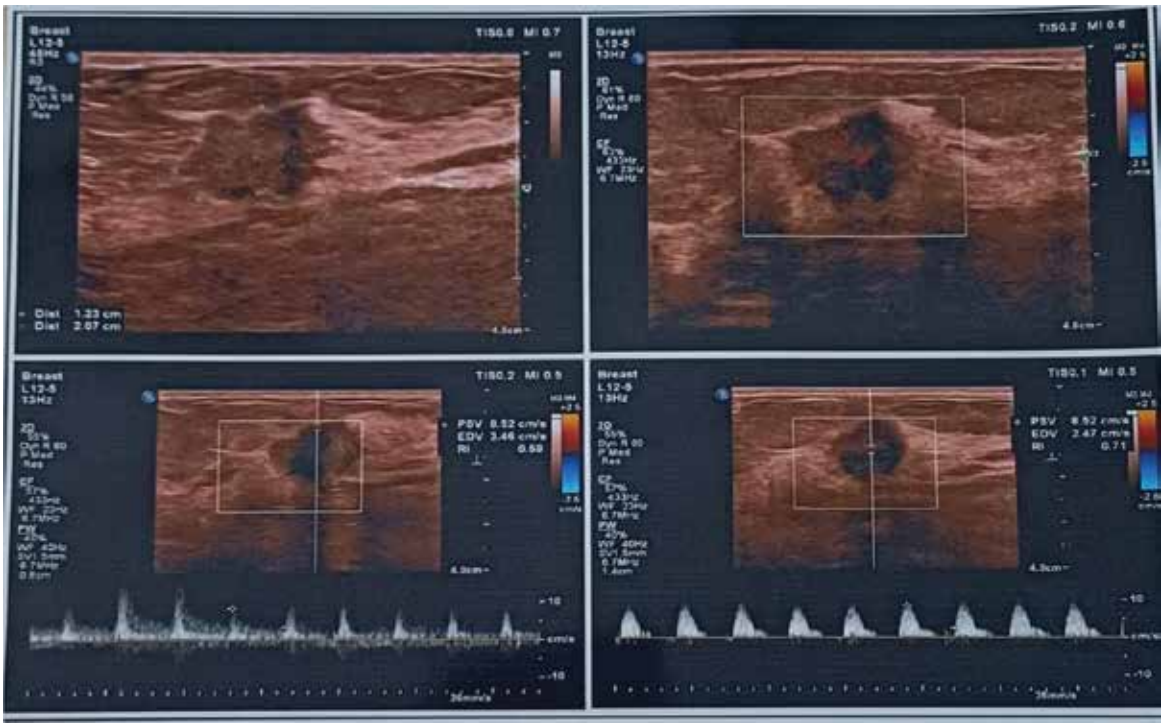

Figure 1: Color Doppler USG Image of Breast showing an irregular hypoechoic mass having a penetrating vessel and a high resistive index (RI) value (Sample image)

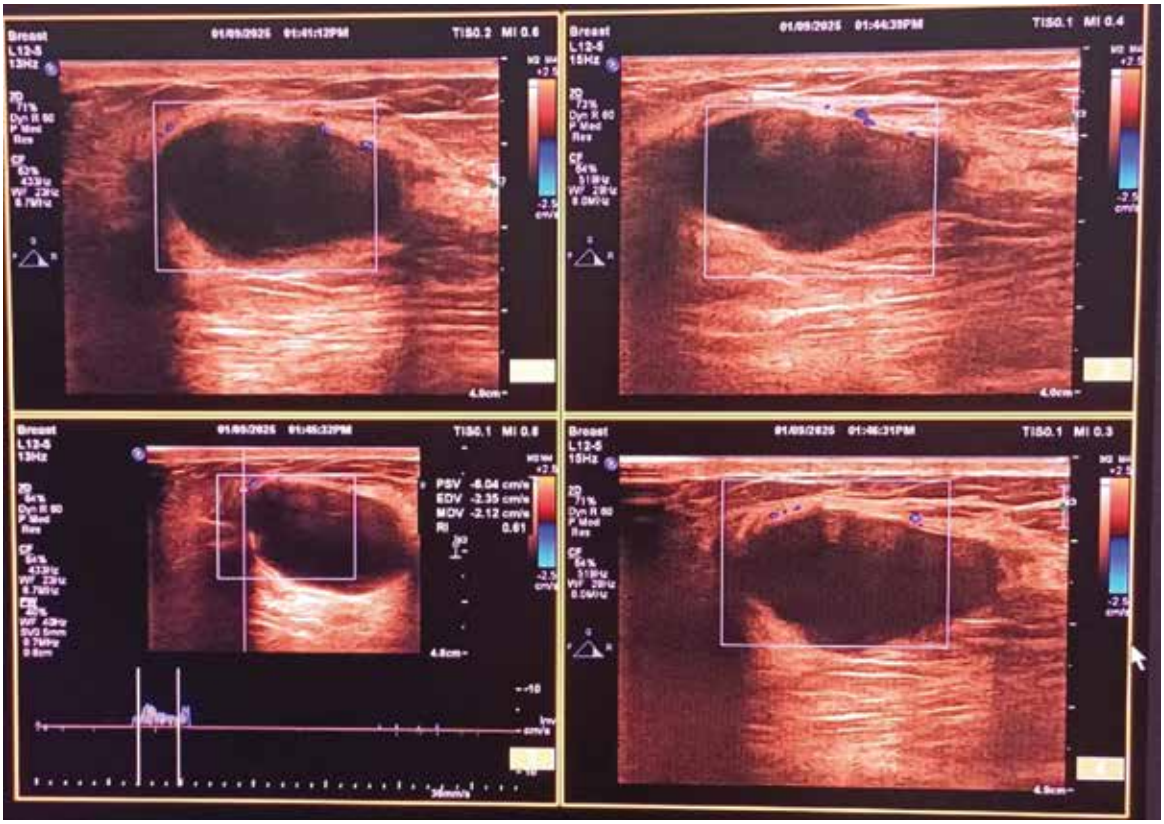

Figure 2: Color Doppler USG Image of Breast showing a well-defined cystic lesion having marginal vascularity and a low resistive index (RI) value - suggests a benign lesion (Sample image)

Table VI: Diagnostic performance of key CDUS parameters. (N=46)

Parameter	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
RI ≥ 0.70	88.2 %	93.1 %	88.2 %	93.1 %	91.3 %
Penetrating Vessel	82.4 %	96.6 %	93.3 %	90.2 %	91.3 %
Mod -Marked Vascularity	88.2 %	79.3 %	71.0%	92.0%	82.6 %

Discussion

The primary objective of this prospective study was to evaluate the efficacy of Color Doppler Ultrasonography (CDUS) in differentiating benign from malignant breast lesions, with histopathology serving as the gold standard. Our findings strongly support the role of CDUS as a valuable adjunct to conventional B-mode ultrasound, significantly improving diagnostic confidence by providing crucial hemodynamic information. The study cohort's demographic and histopathological profile, with a mean age of 42.3 years and a higher prevalence of benign lesions (63.0%), is consistent with similar diagnostic imaging studies conducted in tertiary care settings in this region.[14] The predominance of fibroadenoma among benign lesions and invasive ductal carcinoma among malignancies is a well-documented pattern globally, reinforcing the representativeness of our sample.[15] Our results demonstrate that specific CDUS features are powerful discriminators. The significantly higher prevalence of moderate to marked vascularity in malignant lesions (88.2% vs. 20.7% in benign) aligns with the fundamental principle of tumor angiogenesis, wherein malignant tumors stimulate the development of new, often abundant, blood vessels to support their rapid growth.[6, 16] The presence of a penetrating vessel was the most specific indicator of malignancy (96.6%), a finding corroborated by recent studies, which suggest that this feature reflects the anarchic and invasive vascular architecture of cancers.[13, 17] Furthermore, the presence of intratumoral avascular areas, often corresponding to necrosis, was also significantly associated with malignancy, a feature more commonly observed in aggressive, fast-growing tumors.[10] The quantitative analysis provided even more objective criteria. The mean Resistive Index (RI) and Pulsatility Index (PI) values were significantly higher in malignant lesions (0.79 and 1.41, respectively) compared to benign ones (0.62 and 0.95). These elevated indices are attributed to the structural abnormalities of tumor vasculature, which include rigid walls, arteriovenous shunts, and a lack of smooth muscle, leading to increased downstream resistance.[8, 18] Our determined optimal RI cut-off value of 0.70 yielded an excellent balance between sensitivity (88.2%) and specificity (93.1%), with an overall accuracy of 91.3%. This finding is in close agreement with several other studies that have reported cut-off values ranging from 0.68 to 0.75, validating the robustness of this parameter.[11, 12] The high negative predictive value (NPV) of 93.1% for an RI < 0.70 is particularly noteworthy. This implies that a lesion with low vascular impedance is highly unlikely to be malignant, which could be instrumental in clinical decision-making. By leveraging these CDUS parameters, particularly the RI, radiologists can potentially downgrade certain indeterminate B-mode lesions (e.g., BI-RADS 4a), thereby reducing the number of unnecessary benign biopsies without compromising cancer detection rates.[10, 19] This study has some limitations. The sample size, though adequate for a preliminary analysis, was relatively small. The purposive sampling technique may introduce selection bias, and the results, particularly the specific RI cut-off, should be validated in a larger, multicenter cohort. Furthermore, CDUS performance can be technically limited in very small lesions (<5mm) or those located deep in the breast.[20] This study confirms that Color

Doppler Ultrasonography is a highly effective, non-invasive, and readily available tool that significantly enhances the diagnostic accuracy of breast ultrasound. The integration of vascularity patterns, specific features like penetrating vessels, and quantitative indices, especially a Resistive Index ≥ 0.70, into the sonographic evaluation provides a reliable means to distinguish between benign and malignant breast lesions. We recommend its routine use as an adjunct to B-mode imaging to refine BI-RADS categorization and minimize unnecessary invasive procedures.

Conclusion

Color Doppler ultrasonography is a highly effective adjunct to B-mode ultrasound for differentiating breast lesions. Key parameters, particularly a Resistive Index ≥ 0.70 and the presence of penetrating vessels, demonstrated high diagnostic accuracy. The integration of these CDUS features into routine practice can significantly improve specificity, refine BI-RADS categorization, and reduce the rate of unnecessary benign biopsies, thereby optimizing patient management and alleviating anxiety.

References

1. Sung, Hyuna. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA: a cancer journal for clinicians. 2021; 71(3): 209-249.

2. Freer, Phoebe E. Mammographic breast density: impact on breast cancer risk and implications for screening. Radiographics. 2015; 35(2): 302-315.

3. Berg, Wendie A. Ultrasound as the primary screening test for breast cancer: analysis from ACRIN 6666. Journal of the National Cancer Institute. 2016; 108(4): 367.

4. American College of Radiology, ed. ACR BI-RADS®-Atlas der Mammadiagnostik: Richtlinien zu Befundung, Handlungsempfehlungen und Monitoring. Springer-Verlag. 2016.

5. Spak, David Allen. BI-RADS® fifth edition: A summary of changes. Diagnostic and interventional imaging. 2017; 98(3): 179-190.

6. Bielenberg, Diane R. and Bruce R. Zetter. The contribution of angiogenesis to the process of metastasis. The Cancer Journal. 2015; 21(4): 267-273.

7. Oezdemir, Ipek. Multiscale and morphological analysis of microvascular patterns depicted in contrast-enhanced ultrasound images. Journal of Medical Imaging. 2020;7(3): 034001-034001.

8. Wang, Liang, and Zhen-Hong Qi. Automatic breast volume scanner versus handheld ultrasound in differentiation of benign and malignant breast lesions: a systematic review and meta-analysis. Ultrasound in Medicine & Biology. 2019; 45(8): 1874-1881.

9. Ma, Huijuan. Value of contrast-enhanced ultrasound combined with elastography in differential diagnosis of thyroid imaging reporting and data system 4 thyroid nodules. Chinese Journal of Medical Ultrasound (Electronic Edition). 2016;13(12): 911.

10. Wang, Bin. Combined use of shear wave elastography, microvascular Doppler ultrasound technique, and BI-RADS for the differentiation of benign and malignant breast masses. Frontiers in Oncology. 2022; 12: 906501.

11. Chen, Si-han. Superb microvascular imaging for the differentiation of benign and malignant breast lesions: a systematic review and meta-analysis. Journal of Ultrasound in Medicine. 2023; 42(7): 1385-1399.

12. Sudeep B and Ranadheer B. Abstracts-USICON. Indian Journal of Urology. (2018);34(1): 7-72.

13. Park, Ah Young and Bo Kyoung Seo. Up-to-date Doppler techniques for breast tumor vascularity: superb microvascular imaging and contrast-enhanced ultrasound. Ultrasonography. 2018; 37(2): 98-106.

14. Ahmed, Istiak. Outcome and Evaluation of Mastectomy with Axillary Dissection in Stage-II Breast Cancer: Tertiary Level Multicentered Study in Rajshahi, Bangladesh. SAS J Surg. 2021;6: 267-274.

15. Bray, Freddie. Global cancer statistics 2018: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA: a cancer journal for clinicians. 2018; 68(6): 394-424.

16. Xu, Ping. Breast non-mass-like lesions on contrast-enhanced ultrasonography: feature analysis, breast image reporting and data system classification assessment. World Journal of Clinical Cases. 2020; 8(4): 700.

17. Pillai, Aishwarya K. Utility of Shear Wave Elastography in Breast Cancer Diagnosis: A Systematic Review and Meta-Analysis. Diss. Yale University. 2023.

18. Xiao, Xiao-yun. Superb microvascular imaging in diagnosis of breast lesions: a comparative study with contrast-enhanced ultrasonographic microvascular imaging. The British journal of radiology. 2016; 89(1066): 20160546.

19. Du, Jing. Correlation of real-time gray scale contrast-enhanced ultrasonography with microvessel density and vascular endothelial growth factor expression for assessment of angiogenesis in breast lesions. Journal of Ultrasound in Medicine. 2008; 27(6): 821-831.

20. Scheel, John R.. ACR BI-RADS use in low-income countries: an analysis of diagnostic breast ultrasound practice in Uganda. Journal of the American College of Radiology. 2016; 13(2): 163-169.