Uludağ Üniversitesi Tıp Fakültesi Dergisi
Journal of Uludağ University Medical Faculty
52, 1906063, 2026
DOI: https://doi.org/10.32708/uutfd.1906063

ORIGINAL RESEARCH

Multiparametric Ultrasound Evaluation of Axillary Lymph Nodes in Breast Cancer Patients

Başak ERDEMLİ GÜRSEL[1], Rıfat ÖZPAR[1], İlker ERCAN[2], Gökhan GÖKALP[1]

[1] Bursa Uludağ University Faculty of Medicine, Department of Radiology, Bursa, Türkiye.
[2] Bursa Uludağ University Faculty of Medicine, Department of Biostatistics, Bursa, Türkiye.

ÖZET

Bu çalışma, meme kanserli hastalarda çok parametreli Ultrason (US) ile benign ve malign aksiller lenf nodlarını (LN) değerlendirmeyi amaçlamaktadır. Elli iki lenf nodunun morfolojik özellikleri, sertlik ve vasküler indeks (VI) değerleri, biyopsi öncesinde B-mod US, shear wave elastografi (SWE) ve superb microvascular imaging (SMI) teknikleri ile istatistiksel olarak değerlendirildi. Anlamlı cutoff değerler, receiver operating characteristic (ROC) eğri analizi kullanılarak tespit edildi. Malign LN'ları benign LN'larına kıyasla, daha yüksek kısa-aks değerine (KD), daha düşük uzun/kısa-aks oranlarına (UD/KD) ve artmış kortikal kalınlığa sahipti (sırasıyla p=0,026, p=0,044, p=0,004, p=0,000). 3,1 mm'nin üzerindeki kortikal kalınlık (AUC: 0,751, duyarlılık: %94,1, özgüllük: %51,4, p=0,0003), 8,4 mm'nin üzerindeki KD (AUC: 0,692, duyarlılık: %41,1, özgüllük: %91,4, p= 0,0141), ≤2 UD/KD (AUC: 0,664, duyarlılık: %76,5, özgüllük: 48,6%, p=0,0355) ve 26,2 kPa'nın üzerinde ortalama elastikiyet değeri (AUC: 0,861, duyarlılık: 70,6%, özgüllük: 91,4%, p<0,0001) metastazı tespit etmek için en iyi cutoff değerler olarak belirlendi. Multiparametrik US ile lenf nodlarının değerlendirilmesi tanı ve tedavinin belirlenmesinde değerli bilgiler sağlamaktadır. Bu nedenle tek başına B-mod US inceleme yerine multiparametrik US değerlendirmeyi önermekteyiz.

Anahtar Kelimeler: Meme kanseri. Aksiller lenf nodu. Multiparametrik ultrason. Shear wave elastografi (SWE). Superb microvascular imaging (SMI).

Multiparametric Ultrasound Evaluation of Axillary Lymph Nodes in Breast Cancer Patients

ABSTRACT

This study aims to evaluate benign and malignant axillary lymph nodes (LN) in breast cancer using multiparametric ultrasound (US). The morphological characteristics, stiffness, and VI differences between 52 benign and malignant LNs were statistically evaluated using B-mode US, shear wave elastography (SWE), and superb microvascular imaging (SMI) before biopsy. Significant cutoff values were determined using receiver operating characteristic (ROC) curve analysis. Malignant lymph nodes had higher short-axis diameters (SD), lower long-axis diameter/short axis diameter ratios (LD/SD), and increased cortical thickness (p=0.026, p=0.044, p=0.004, p=0.000, respectively). A cortical thickness above 3.1 mm (AUC: 0.751, sensitivity: 94.1%, specificity: 51.4%, p=0.0003), SD greater than 8.4 mm (AUC: 0.692, sensitivity: 41.1%, specificity: 91.4%, p= 0.0141), LD/SD ≤2 (AUC: 0.664, sensitivity: 76.5%, specificity: 48.6%, p=0.0355) and, a mean elasticity value above 26.2 kPa (AUC: 0.861, sensitivity: 70.6%, specificity: 91.4%, p<0.0001) were identified as the best cutoff values for detecting metastasis. Since multiparametric ultrasound provides valuable information for detecting metastatic lymph nodes, we recommend multiparametric assessment rather than B-mode ultrasound alone.

Keywords: Breast cancer. Axillary lymph node. Multiparametric ultrasound. Shear wave elastography (SWE). superb microvascular imaging (SMI).

Date Received: 9.March.2026
Date Accepted: 1.June.2026

Dr. Başak ERDEMLİ GÜRSEL
Bursa Uludağ University Faculty of Medicine,
Department of Radiology, Bursa, Türkiye.
E-mail: basakgursel@uludag.edu.tr

AUTHORS' ORCID INFORMATION
Başak ERDEMLİ GÜRSEL: 0000-0002-0047-1780
Rıfat ÖZPAR: 0000-0001-6649-9287
İlker ERCAN: 0000-0002-2382-290X
Gökhan GÖKALP: 0000-0001-9169-5087

Breast cancer is the most commonly diagnosed malignancy among women worldwide and represents the second leading cause of cancer-related mortality[1]. The status of the axillary lymph nodes (LN) is the most important prognostic factor in breast cancer[2]. The presence of LN metastasis reduces the 5-year survival rate by approximately 40% compared to node-negative patients[3]. In recent years, ultrasound-guided sentinel lymph node biopsy (SLNB) and fine needle aspiration biopsy (FNAB) have gradually replaced axillary lymph node dissection (ALND) due to lower morbidity rates[4]. However, these methods are invasive and require additional time for pathological diagnosis[5]. Furthermore, it should be noted that these

techniques can give false negative results, which is a significant limitation[6].

Ultrasonography is a non-invasive imaging modality with high soft-tissue resolution and is frequently used for the preoperative morphological assessment of axillary LN in patients with breast cancer[7]. In the literature, lymph node size, shape, hilum appearance, cortical thickening, etc., have been evaluated as distinguishing criteria for metastatic involvement[8-10]. However, it has been reported that morphological assessment of LN alone has only moderate sensitivity and may yield false-positive results, leading to unnecessary biopsies[11].

Multiparametric US is an imaging technique that combines methods such as color Doppler, spectral Doppler, shear-wave elastography (SWE), superb microvascular imaging (SMI), etc. Recent advances in these techniques, including shear-wave elastography (SWE) and superior microvascular imaging (SMI), have made it possible to characterise tumour stiffness and vascularity in more detail (12). Shear Wave Elastography (SWE) is an ultrasound (US) technique that measures tissue stiffness using acoustic radiation force, and is widely used to differentiate between benign and malignant tumors[12,13]. Several studies in the literature have examined the use of SWE to identify malignant lymph nodes[14-17]. These studies have shown that elastography, when combined with conventional US, is a helpful parameter in distinguishing between benign and malignant lymph nodes in breast cancer patients[18,19].

Superb microvascular imaging (SMI) is a new imaging technique that uses a series of wall filters to minimize artifacts and visualize low-velocity blood flow. Numerous studies have reported the use of SMI to distinguish benign from malignant lesions in various tissues, including the thyroid, breast, joints, peripheral nerves, and liver[20-23].

In the present study, we aimed to identify parameters that may be significant for detecting metastatic involvement by comparing the findings of conventional ultrasonography, SWE, and SMI with biopsy results in the evaluation of axillary LN in patients with breast cancer.

Materials and Methods

This retrospective study was approved by the Faculty Research Ethics Committee on November 20, 2024 (Approval No. 2024-18/2) and was conducted in accordance with the principles of the Declaration of Helsinki.

Patients diagnosed with breast cancer at our faculty between 2021 and 2022 were retrospectively identified from the hospital archives. Patients who underwent breast ultrasound and axillary lymph node B-Mode US, SWE, and SMI in our department, and who underwent FNAB or core needle biopsy (CNB) of the breast mass and the ipsilateral axillary LN within one week were selected. Sixty-nine LN were identified in 62 patients meeting these criteria. Fifteen patients who had received neoadjuvant chemotherapy and/or radiotherapy prior to imaging were excluded from the study. As a result, 52 lymph nodes in 47 female patients were included in the study.

Patient age and sex were recorded. Breast cancer subtypes were not specified because most of them were unavailable in the pathology archive (most were invasive ductal carcinoma). Ultrasound (US) images were retrieved from the Picture Archiving and Communication System (PACS). All ultrasound examinations were performed by a single operator (with 14 years of experience in ultrasonography and 7 years of experience in SWE) using an Aplio i600 system (Canon Medical Systems, Tokyo, Japan) equipped with a high-frequency linear transducer (4–11 MHz). Morphological characteristics of the axillary LN—including shape (oval or round), long-axis diameters (LD) and short-axis diameters (SD), LD/SD ratio, cortical thickness, presence of lobulated contours, and fatty hilum—were evaluated. Three measurements were taken from the cortex, and the thickest was selected (Figure 1).

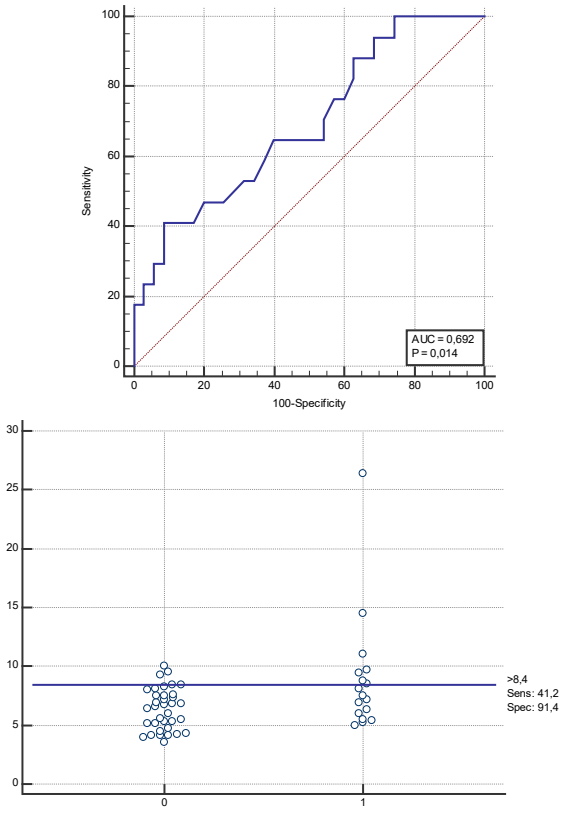


Figure 1:
Receiver operating characteristic (ROC) curve demonstrating the diagnostic performance (above) and scatter plot showing the distribution of short-axis values in benign and malignant LN (below).

Furthermore, we evaluated the effectiveness of the classification system developed by Bedi et al., based on morphological findings, in predicting axillary LN metastasis in breast cancer patients[9]. Lymph nodes were categorized into six groups according to their morphological characteristics. Lymph node types: Type 1, completely hyperechoic, no visible cortex; Type 2, thin hypoechoic cortex (< 3 mm); Type 3, hypoechoic cortex thicker than 3 mm; Type 4, lobulated hypoechoic cortex; Type 5, focal hypoechoic cortical lobulation; Type 6, hypoechoic lymph node without hilum. According to this study, Type 1-4 LNs with a high probability of being benign are classified as Group A, while Type 5-6 lymph nodes suspected of being malignant are classified as Group B[9]. The likelihood of LN being benign or malignant was evaluated according to these groups.

The stiffness of LN was calculated in kilopascals (kPa) using SWE. The SWE display scale was set to a range of 0–100 kPa for each lesion. An elastographic region of interest (ROI) was placed in the cortex. ROI size was selected based on cortical thickness. Elasticity indices were measured using three Q-boxes placed over the hardest part of the cortex. The system automatically calculated and displayed the SWE elasticity indices. The average of the three measurements (E-mean) was used (Figure 2). The difference in stiffness between benign and malignant LNs was compared.

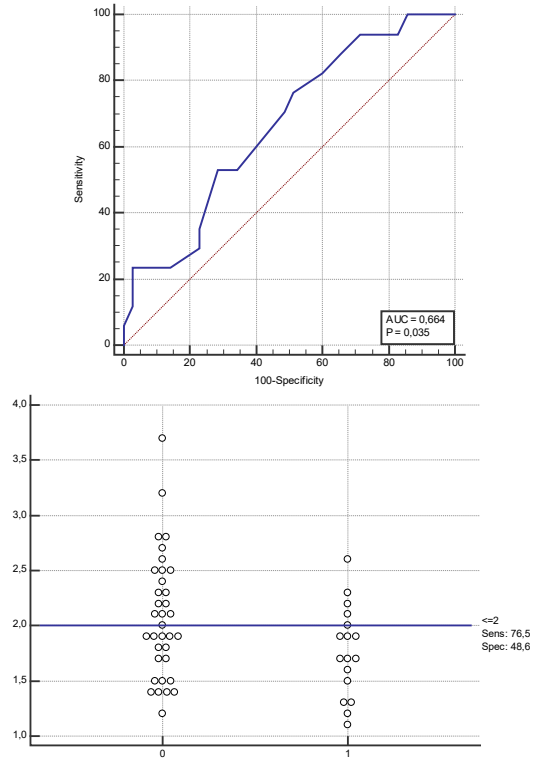


Figure 2:
Receiver operating characteristic (ROC) curve demonstrating the diagnostic performance (above) and scatter plot showing the distribution of LD/SD values in benign and malignant LN (below).

Lesion vascularization was assessed using SMI. The device parameters used in superb microvascular imaging were as follows: scale, 1.5 to 2.5 cm/s; mechanical index, 1.3; wall filter, 50 to 100 Hz; and square speed, greater than 30 Hz. Quantitative vascularization measurement was performed manually using an ROI from the most vascular part of the lesion (Figure 3). The vascular index (VI) was calculated to quantify lesion vascularization (the ratio of Doppler signal pixels to the total number of lesion pixels).

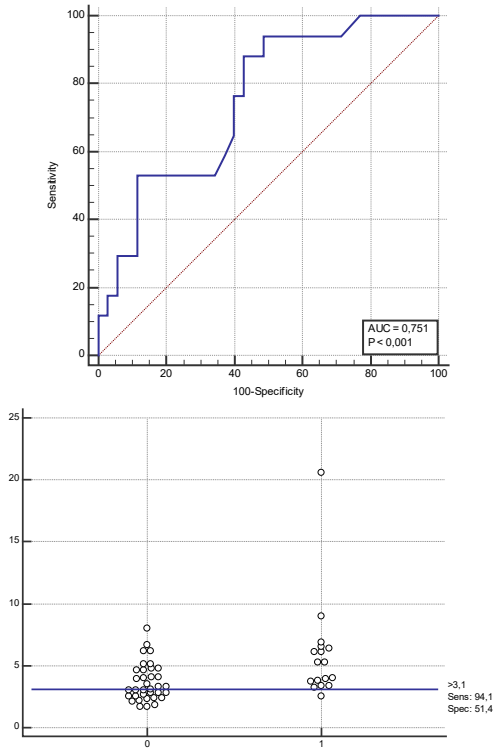


Figure 3:
Receiver operating characteristic (ROC) curve demonstrating the diagnostic performance (above) and scatter plot showing the distribution of cortical thickness in benign and malignant LN (below).

The morphological characteristics, stiffness, and VI differences between benign and malignant LN were statistically evaluated. Potentially significant cutoff values were determined using receiver operating characteristic (ROC) curve analysis. Significant cutoff values for LN metastasis risk were determined using logistic regression.

Biostatistical Analysis

The normality of the data distribution was assessed using the Shapiro-Wilk test. Descriptive statistics were presented as mean ± standard deviation for data following a normal distribution and as median (min-max) values for data not following a normal distribution. Descriptive statistics for categorical data were presented as ratios and percentages. The cutoff value for variables that could be risk factors was

evaluated using ROC analysis, and the cutoff value was determined based on the Youden J index. Risk factors were evaluated using univariate logistic regression analysis. SPSS v27 and MEDCALC v 22.016 were used for statistical analysis. The statistical significance level was set at $\alpha = 0.05$.

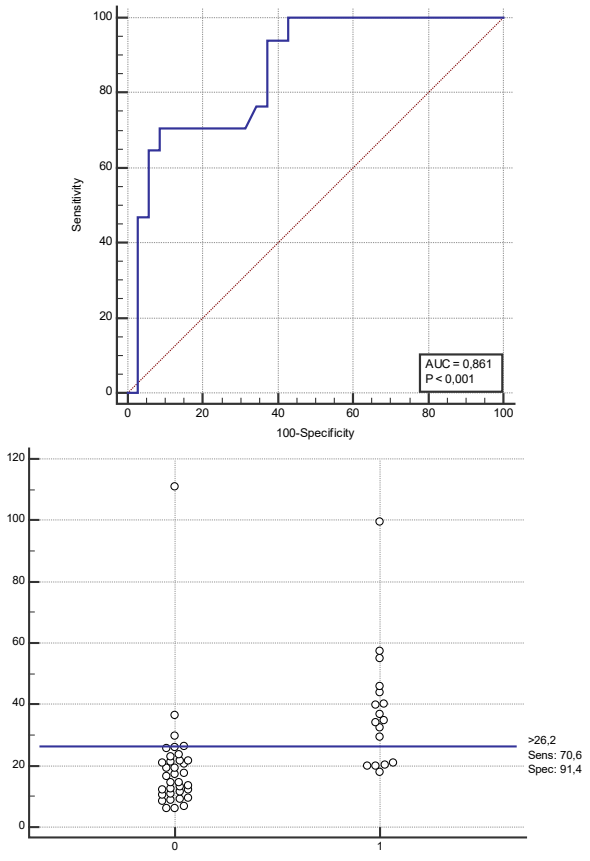


Figure 4:
Receiver operating characteristic (ROC) curve demonstrating the diagnostic performance (above) and scatter plot showing the distribution of stiffness values in benign and malignant LN (below).

Results

Four of the 52 lymph nodes were diagnosed by fine needle aspiration biopsy (FNAB), while 48 were diagnosed by core needle biopsy (CNB). According to histopathological results, 35 (67%) LN were benign and 17 (33%) were malignant (metastatic). All patients were female, and the mean age of the 47 patients was 52±12.5 (range 28-78 years). The mean age of patients with benign LN was 52.03±12.6, and malignant LN was 52.03±12.6. There was no statistically significant difference between the groups (p=0.944).

The morphological characteristics, stiffness, and VI values of the LN are shown in Table I. There is no statistically significant difference between benign and malignant LNs in terms of shape, contour lobulation, presence of fatty hilum, LD, or VI (p=0.181, p=0.56, p=0.496, p=0.364, and p=0.079, respectively). However, statistically significant differences were found in SD, LD/SD ratio, cortical thickness, and stiffness (p=0.026, p=0.044, p=0.004, p=0.000, respectively).

According to the study by Bedi et al., 52 LNs classification based on the morphological characteristics as follows: 10 LNs (10/52, 19%) were Type 2, 18 LN (18/52, 35%) were classified as Type 3, 4 LN (4/52, 8%) as Type 4, 9 LN (9/52, 17%) as Type 5, and 11 LN (11/52, 21%) as Type 6. There were no Type 1 nodes. Based on this classification, 35 LN (67%) were assigned to Group A (Types 1–4), and 17 LN (33%) to Group B (Types 5–6). Histopathologically, 25 LN in Group A (25/35, 71%) were benign, 10 (10/35, 29%) were malignant, while 7 (7/17, 41%) in Group B were benign and 10 (10/17, 59%) were malignant. A statistically significant difference was found between the groups according to this classification (p=0.035).

Table I. Morphological, elastographic, and vascular characteristics of lymph nodes

	Benign	Malignant	*p*
Shape			
Oval	28	10	0.181
Round	7	7	
Lobulation			
Yes	7	8	0.56
No	28	9	
Fatty hilum			
Yes	28	12	0.496
No	7	5	
Long-axis diameter (mm) (median, min-max)	12.4 (6.8-25)	13.1 (6.8-31.4)	0.364
Short-axis diameter (mm) (med, min-max)	6.6 (3.5-10)	7.5 (5-26.4)	0.026*
LD/SD (mm, std dev)	2.1 ±0.56	1.8 ±0.41	0.044*
Cortical thickness (mm) (med, min-max)	3.1 (1.7-8)	5.3 (2.5-20.6)	0.004*
Stiffness (kPa), (med, min-max)	16.6 (5.9-111)	34.8 (17.8-99.6)	0.000*
SMI (vascular index) (med, min-max)	3.2 (0.4-10.4)	6 (0.5-45.2)	0.079

Statistically significant results are marked with an asterisk (*). LD/SD: Long-axis diameter/short-axis diameter

Receiver operating characteristic (ROC) curve analysis evaluated cutoff values that were statistically significant for metastasis. These data are presented in Table II and scatter plots of these data are shown in Figure 1, Figure 2, and Figure 3. Accordingly, a mean elasticity value above 26.2 kPa (AUC: 0.861, sensitivity: 70.6%, specificity: 91.4%, p<0.0001), a cortical thickness above 3.1 mm (AUC: 0.751,

sensitivity: 94.1%, specificity: 51.4%, p=0.0003), SD greater than 8.4 mm (AUC: 0.692, sensitivity: 41.2%, specificity: 91.4%, p= 0.0141) and, LD/SD ratio ≤2 (AUC: 0.664, sensitivity: 76.5%, specificity: 48.6%, p=0.0355) were identified as the best cutoff values with statistical significance for detecting metastasis.

Stiffness, cortical thickness, and LD/SD ratio, which may be effective in predicting metastasis and have significant cutoff values according to ROC analysis, were evaluated using univariate logistic regression. It was observed that the LD/SD ratio did not significantly increase the risk. Stiffness and cortical thickness parameters were identified as significant risk factors. Stiffness above 26.2 kPa increased the likelihood of metastasis by OR=43.4, while cortical thickness above 3.1 mm increased the risk by OR=32.8. The relevant data are shown in Table III.

Table II. ROC analysis results

	n	AUC±SE	p-value	Youden Index	Cut-off value	Sensitivity	Specificity	Figure
Short-axis	52	0.692±0.07	0.0141	0.32	>8.4	41.2	91.4	Figure 1
Long-axis	52	0.58±0.08	0.3550	-	-	-	-	-
LD/SD	52	0.664±0.08	0.0355	0.25	≤2	76.5	48.6	Figure 2
Cortical thickness	52	0.751±0.07	0.0003	0.46	>3.1	94.1	51.4	Figure 3
Stiffness	52	0.861±0.05	<0.0001	0.62	>26.2	70.6	91.4	Figure 4

Table III. Assessment of risk factors for metastasis

	p-value	OR	CI 95% OR
Stiffness (ref: <26.2)	<0.001	43.383	4.66-404.24
Cortical thickness (ref: <3.1)	0.015	32.753	1.96-547.83
LD/SD (ref: <2)	0.363	2.682	0.32-22.42

Discussion and Conclusion

Morphological features on B-mode ultrasound (US) play a crucial role in metastatic axillary lymph nodes in breast cancer. However, there are still no standard B-mode criteria for diagnosing metastasis[20,21]. Choi et al. reported that the short-axis diameter was the most sensitive for detecting metastasis[14]. Although Choi et al. reported that long-axis measurement is the most sensitive parameter, many studies have not evaluated this parameter alone[8,24,26,27]. Uslu et al. found that neither long axis nor short axis diameter were not significant[28]. In our study, SD, and LD/SD are sensitive parameters, but LD is not significant. Choi et al., Choi et al., and Esen et al. reported an optimal cutoff value of 2.0 for the LD/SD ratio in predicting axillary lymph node metastasis[8,14,25]. In our study, the optimal cutoff value was likewise 2.0, which is quite similar to the literature. Therefore, we believe that the LD/SD ratio can be used as a more reliable parameter compared to the discrepancy in LD and SD.

Asymmetric cortical thickening remains a confusing factor in terms of malignancy. Choi et al., Abe et al., and Zhao et al. have reported asymmetric cortical thickening as a criterion for malignancy[14,22,29]. However, Kurt et al. noted that asymmetric thickening was more common in benign LNs[24]. In our study, asymmetric thickening was not a significant parameter. However, diffuse cortical thickening has been reported to be a highly significant finding in most malignant LNs[22,24,26,27]. Choi et al. found this parameter to be insignificant and attributed this to their assessment of the parameter as a benign finding[14]. In our study, the cortical thickness was significantly higher in malignant LN, and the most significant cutoff value was 3.1 mm. This cutoff value is quite similar to those in the literature. Saffar et al. and Choi et al. found that a cortical thickness >3 mm was the most reliable ultrasound feature for predicting metastasis[8,26]. Amonkar et al. also found that a cortical thickness of 3 mm was the most sensitive[3]. The ideal theory proposed for lymph node metastasis is that tumor cells first infiltrate the marginal sinus and then the cortex via afferent lymphatic vessels. Therefore, eccentric cortical thickening has been proposed as the earliest ultrasonographic finding of metastatic involvement[32]. However, this parameter was insignificant in many studies, including ours. This finding may be due to its observation in the very early stages of malignancy and inadequate histopathological evaluation with FNAB and CNB. In more advanced stages, the cortex becomes more infiltrated with malignant cells, and the resulting diffuse thickening may have facilitated a more straightforward diagnosis with US and biopsy. Additionally, in our regression analysis, cortical thickness greater than 3.1 mm increased the risk of metastasis by 32.8 times.

Bedi et al. suggested that biopsy should be universally applied in the preoperative staging of breast cancer in the presence of Type 5 (asymmetric focal hypoechoic lymph node with cortical lobulation) and Type 6 (completely hypoechoic lymph node) lymph nodes based on these morphological features[9]. In our study, the malignancy rate in the group consisting of Type 5 and Type 6 lymph nodes was 59%, and this difference was significant compared to the group consisting of Type 1-4 lymph nodes (p = 0.035). Therefore, we also consider this classification to be valuable for evaluating axillary lymph nodes.

Hilar vascularity is disrupted, and cortical vascularity increases due to peripheral neovascularization in metastatic lymph nodes[33]. The literature reports that axillary lymph nodes' VI significantly elevated in breast cancer patients[24,28,34,35]. In our study, VI values were higher in the metastatic group, but there was no

significant difference between the metastatic and benign groups. Xiao et al. reported, in their study comparing SMI with contrast-enhanced ultrasonographic microvascular imaging, that vessel visibility with SMI was difficult in lesions deeper than 25-30 mm[23]. Similarly, Kurt et al. reported that, despite appropriate pre-settings, poor vascularity was detected in several LNs with deep localization in all Doppler imaging methods[24]. The results of our study may be related to factors such as the depth of the lymph node, the number of cases, differences in the profiles of randomly selected patients, and device settings.

We found that the median stiffness in metastatic lymph nodes was significantly higher than in benign lymph nodes ($p = 0.000$). This result is consistent with other studies on the SWE of axillary lymph nodes[12-15,29,35,36]. Although maximum and median stiffness scores have generally been evaluated in studies, Wang et al. reported in their meta-analysis that median stiffness measurement had the highest overall specificity[36]. In our study, the median cutoff value significant for metastasis differentiation was 26.2 kPa. This value is quite similar to the results of Seo et al. (23.8 kPa) and Uslu et al. (31.8 kPa)[12,28]. Other studies report different cutoff values in the literature[15,38]. This difference may be due to tissue compression, device differences, lesion depth, and disease progression. Therefore, despite different cutoff values, using a cutoff based on each clinic's device parameters may help distinguish metastasis. Additionally, in our logistic regression analysis, we found that values > 26.2 kPa increased the risk of metastasis by 43.4 times. Although stiffness and cortical thickness were significantly associated with the outcome, the wide confidence intervals may reflect the small sample size.

Our study has some limitations. Some of these include the small number of patients, the lack of subgrouping of breast malignancies, and the fact that the lymph node depth was not taken when evaluating VI.

In conclusion, morphological findings of axillary lymph nodes (particularly cortical thickness and LD/SD) in breast cancer patients provide valuable information. However, their diagnostic value is insufficient to identify metastatic regional lymph nodes reliably. Multiparametric assessment (especially elastography) significantly increases accuracy rates. We recommend multiparametric US evaluation for detecting axillary LN metastasis.

Researcher Contribution Statement:
Idea and design: B.E.G.; Data collection and processing: B.E.G.; Analysis and interpretation of data: B.E.G., R.Ö., İ.E., G.G.; Writing of significant parts of the article: B.E.G.
Support and Acknowledgement Statement:
Conflict of Interest Statement:
--The authors of the article have no conflict of interest declarations.

Ethics Committee Approval Information:
Approving Committee: T.C. Bursa Uludağ Üniversitesi Sağlık Araştırmaları Etik Kurulu
Approval Date: 20.11.2024
Decision No: 2024-18/2

References

1. Siegel RL, Miller KD, Jemal A. Cancer statistics, 2019. CA Cancer J Clin 2019;69(1):7.
2. Fisher B, Bauer M, Wickerham DL, et al. Relation of number of positive axillary nodes to the prognosis of patients with primary breast cancer: an NSABP update. Cancer 1983; 52:1551–1557.
3. Carter CL, Allen C, Henson DE. Relation of tumor size, lymph node status, and survival in 24,740 breast cancer cases. Cancer1989; 63:181–187.
4. Kim T, Giuliano AE, Lyman GH. Lymphatic mapping and sentinel lymph node biopsy in early-stage breast carcinoma: a metaanalysis. Cancer2006; 106:4–16.
5. Balasubramanian I, Fleming CA, Corrigan MA, et al. Meta-analysis of the diagnostic accuracy of ultrasound-guided fine-needle aspiration and core needle biopsy in diagnosing axillary lymph node metastasis. Br J Surg 2018;105(10):1244.
6. Lyman GH, Giuliano AE, Somerfield MR, et al. American Society of Clinical Oncology guideline recommendations for sentinel lymph node biopsy in early-stage breast cancer. J Clin Oncol 2005; 23:7703–7720
7. Gipponi M, Fregatti P, Garlaschi A, et al. Axillary ultrasound and fineneedle aspiration cytology in the preoperative staging of axillary node metastasis in breast cancer patients. Breast 2016;30:146
8. Choi YJ, Ko EY, Han BK, Shin JH, Kang SS, Hahn SY. High-resolution ultrasonographic features of axillary lymph node metastasis in patients with breast cancer. Breast 2009; 18:119–122.
9. Bedi DG, Krishnamurthy R, Krishnamurthy S, et al. Cortical morphologic features of axillary lymph nodes as a predictor of metastasis in breast cancer: in vitro sonographic study. AJR Am J Roentgenol 2008; 191:646– 652.
10. Moore A, Hester M, Nam MW, et al. Distinct lymph nodal sonographic characteristics in breast cancer patients at high risk for axillary metastases correlate with the final axillary stage. Br J Radiol 2008; 81:630–636.
11. Alvarez S, Añorbe E, Alcorta P, López F, Alonso I, Cortés J. Role of sonography in the diagnosis of axillary lymph node metastases in breast cancer: a systematic review. AJR Am J Roentgenol 2006; 186:1342–1348
12. Seo M, Sohn Y. Differentiation of benign and metastatic axillary lymph nodes in breast cancer: additive value of shear wave elastography to Bmode ultrasound. Clin Imaging 2018;50:258
13. Luo S, Yao G, Hong Z, et al. Qualitative classification of shear wave elastography for differential diagnosis between benign and metastatic axillary lymph nodes in breast cancer. Front Oncol 2019 Jul 2;9:533.
14. Choi JJ, Kang BJ, Kim SH, et al. Role of sonographic elastography in the differential diagnosis of axillary lymph nodes in breast cancer. J Ultrasound Med 2011;30(4):429.
15. Chang W, Jia W, Shi J, Yuan C, Zhang Y, Chen M. Role of Elastography in Axillary Examination of Patients With Breast Cancer. J Ultrasound Med. 2018 Mar;37(3):699-707.
16. Luo H, Yin L. Diagnostic value of superb microvascular imaging and color doppler for thyroid nodules: A meta-analysis. Front Oncol. 2023 Apr 5;13:1029936.

17. Hu, B., Zhao, Y., & Wang, L.. Superb Microvascular Imaging for the Differentiation of Benign and Malignant Breast Lesions: A System Review and Meta-Analysis. Journal of Ultrasound in Medicine, 2023;42(7), 1385-1399.
18. (2019). Clinical Applications of Superb Microvascular Imaging in the Liver, Breast, Thyroid, Skeletal Muscle, and Carotid Plaques. Journal of Ultrasound in Medicine, 38(11), 2811-2820.
19. Dubinsky TJ, Revels J, Wang S, et al. Comparison of superb microvascular imaging with color flow and power Doppler imaging of small hepatocellular carcinomas. J Ultrasound Med. 2018; **37**(12): 2915-2924.
20. Nori J, Vanzi E, Bazzocchi M, et al. Role of axillary ultrasound examination in the selection of breast cancer patients for sentinel node biopsy. Am J Surg 2007; 193:16-20.
21. Chae BJ, Bae JS, Kang BJ, Kim SH, Jung SS, Song BJ. Positron emission tomography-computed tomography in the detection of axillary lymph node metastasis in patients with early stage breast cancer. Jpn J Clin Oncol 2009;39:284–289.
22. Abe H, Schmidt RA, Kulkarni K, Sennett CA, Mueller JS, Newstead GM. Axillary lymph nodes suspicious for breast cancer metastasis: sampling with US-guided 14-gauge core-needle biopsy—clinical experience in 100 patients. Radiology 2009; 250:41–49.
23. Xiao XY, Chen X, Guan XF, et al. Superb microvascular imaging in diagnosis of breast lesions: a comparative study with contrast-enhanced ultrasonographic microvascular imaging. Br J Radiol. 2016;89:20160546.
24. Kurt SA, Eryurekli AE, Kayadibi Y, Samanci C, Velidedeoglu M, Onur I, Arslan S, Taskin F. Diagnostic Performance of Superb Microvascular Imaging in Differentiating Benign and Malignant Axillary Lymph Nodes. Ultrasound Q. 2023 Jun 1;39(2):74-80.
25. Esen G, Gurses B, Yilmaz MH, et al. Gray scale and power Doppler US in the preoperative evaluation of axillary metastases in breast cancer patients with no palpable lymph nodes. Eur Radiol 2005; 15:1215–1223.
26. Saffar B, Bennett M, Metcalf C, Burrows S. Retrospective preoperative assessment of the axillary lymph nodes in patients with breast cancer and literature review. Clin Radiol. 2015 Sep;70(9):954-9.
27. Xu Y, Bai X, Chen Y, Jiang L, Hu B, Hu B, Yu L. Application of Real-time Elastography Ultrasound in the Diagnosis of Axillary Lymph Node Metastasis in Breast Cancer Patients. Sci Rep. 2018 Jul 6;8(1):10234.
28. Uslu H, Tosun M. The benefit of superb microvascular imaging and shear wave elastography in differentiating metastatic axillary lymphadenopathy from lymphadenitis. Clin Breast Cancer. 2022 Aug;22(6):515-520.
29. Zhao, Q.-L. et al. Elastosonography and two-dimensional ultrasonography in diagnosis of axillary lymph node metastasis in breast cancer. Clinical Radiology, Volume 73, Issue 3, 312–318.
30. Amonkar SJ, Oates E, McLean L, et al. Pre-operative staging of the axilla in primary breast cancer. By redefining the abnormal appearing node can we reduce investigations without affecting overall treatment? Breast 2013;22:1114e8.
31. Carmeliet P, Jain RK. Angiogenesis in cancer and other diseases. Nature. 2000;407:249–257.
32. Nathanson SD. Insights into the mechanisms of lymph node metastasis. Cancer. 2003;98:413–423.
33. Ryoo I, Suh S, You SH, Seol HY. Usefulness of Microvascular Ultrasonography in Differentiating Metastatic Lymphadenopathy from Tuberculous Lymphadenitis. Ultrasound Med Biol. 2016 Sep;42(9):2189-95.
34. Tokur O, Aydin S, Kilinc F, Degirmenci T, Oztekin PS. Diagnostic value of super microvascular imaging in differentiating axillary lymph nodes: semi-quantitative and qualitative approach in primary breast cancer and suspicious axillary nodes. BMC Cancer. 2025 Nov 4;25(1):1705.
35. Bulut, Iclal Nur MD∗; Kayadibi, Yasemin MD∗; Deger, Enes∗; Kurt, Seda Aladag∗; Velidedeoglu, Mehmet†; Onur, Irem‡; Ozturk, Tulin‡; Adaletli, Ibrahim∗. Preoperative Role of Superb Microvascular Imaging and Shear-Wave Elastography for Prediction of Axillary Lymph Node Metastasis in Patients With Breast Cancer. Ultrasound Quarterly 40(2), June 2024:p 111-118.
36. Ji Hyun Youk, Eun Ju Son, Jeong-Ah Kim, Hye Mi Gweon. Pre-Operative Evaluation of Axillary Lymph Node Status in Patients with Suspected Breast Cancer Using Shear Wave Elastography, Ultrasound in Medicine & Biology, Volume 43, Issue 8, 2017, Pages 1581-1586.
37. Wang RY, Zhang YW, Gao ZM, Wang XM. Role of sonoelastography in assessment of axillary lymph nodes in breast cancer: a systematic review and meta-analysis. Clin Radiol. 2020 Apr;75(4):320.e1-320.e7.
38. Kritcharoen W, Pradaranon V, Rohitopakarn P, Kaewpiboon W. Accuracy of shear wave elastography in diagnosing axillary lymph node metastasis in patients with suspicious axillary lymph nodes: development of a predictive nomogram. J Ultrasound. 2025 Sep;28(3):627-633.