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The Efficacy of Automated Breast Ultrasound Combined with Hand-held Ultrasound in Evaluating MRI-Detected High-Risk Non-Mass Lesions

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Abstract

Objective:

This study aimed to re-evaluate high-risk non-mass lesions (NMLs) detected by magnetic resonance imaging (MRI) via the combined application of automated breast ultrasound (ABUS) and hand-held ultrasound (HHUS), as well as to investigate the sonographic features associated with malignant transformation of these lesions.

Methods:

This study included 160 patients (166 lesions) of breast NMLs classified as BI-RADS 4 or 5 by MRI. All lesions were pathologically confirmed and underwent preoperative ABUS and HHUS examinations. Using pathological results as the gold standard, the diagnostic performance of MRI versus ABUS+HHUS in differentiating benign from malignant NMLs was assessed, and predictive indicators for malignant NMLs on ultrasound were evaluated.

Results:

The sensitivity, specificity, positive predictive value, and negative predictive value for differentiating benign from malignant breast NMLs were 91.4%, 32.3%, 69.3%, and 69.0% for MRI, and 87.5%, 69.4%, 82.7%, and 76.8% for ABUS+HHUS ($P < 0.0001$). Furthermore, the areas under the receiver operating characteristic curves for diagnosing malignant NMLs using BI-RADS classification were 0.618 for MRI and 0.784 for ABUS+HHUS ($P < 0.00001$).

Conclusion:

Compared to MRI, ABUS+HHUS demonstrates improved diagnostic specificity for differentiating benign from malignant NMLs without compromising sensitivity. Notably, this approach can reduce unnecessary biopsies and provide clinicians with a non-invasive, cost-effective, and reliable imaging method. Furthermore, sonographic features such as calcifications, peripheral echogenic halo, rich blood flow signals, and segmental distribution can be positive predictive indicators for malignant breast NMLs.

Introduction

Breast cancer represents the most prevalent type of malignant tumor among women, accounting for 11.6% of all cancer cases [1]. This statistic underscores its position as the foremost cause of cancer-related fatalities in women worldwide [1]. The cornerstone of breast cancer screening involves various imaging modalities, with mammography (MG), ultrasound (US), and magnetic resonance imaging (MRI) serving as principal tools for the evaluation of breast pathologies. Notably, these three imaging

techniques have their respective advantages and disadvantages in diagnosing breast lesions. While they exhibit commendable sensitivity and specificity in identifying breast masses characterized by typical malignant features, the detection of atypical malignant tumors that present as non-mass lesions (NMLs) remains challenging. In ultrasound, NMLs are defined as abnormal sonographic findings present in two or more imaging planes that lack three-dimensional characteristics or distinct features of a mass, such as margins and morphological features [2, 3]. NMLs constitute approximately 9.2% of all breast lesions, with malignancy rates within this category ranging from 6.3% to 53.8% [4–6]. Moreover, it is reported that up to 57% of non-palpable malignant breast NMLs, including ductal carcinoma in situ (DCIS), invasive ductal carcinoma, invasive lobular carcinoma, and mucinous carcinoma, alongside conditions such as breast adenosis and high-risk lesions like atypical ductal hyperplasia, radial scars, and complex adenosis, may manifest as NMLs [7, 8]. These findings emphasize the complexity involved in the diagnosis of such lesions and highlight the necessity for advanced diagnostic approaches.

MG has long been recognized as a crucial tool for the early detection of breast cancer. Nevertheless, its efficacy is notably limited in women with dense breast tissue and in cases of NMLs that lack calcifications [9, 10]. On the other hand, the US serves as an effective complementary approach to MG, particularly beneficial Asiancreening in populations with dense breast tissue [11]. Given that a significant proportion of East-Asia women have dense breasts, the US has emerged as the preferred imaging modality for diagnosing breast diseases in East-Asia [12]. As awareness and understanding of NMLs have expanded, so too has the attention given to the role of the US in their detection and diagnosis. This ambiguity poses a challenge, as there is considerable overlap in the US features of benign and malignant NMLs, leading to hand-held ultrasound (HHUS) exhibiting low specificity in distinguishing between these conditions [13, 14]. Consequently, this limitation underscores the necessity for developing advanced diagnostic strategies to improve the accuracy of differentiating benign from malignant NMLs via US.

Due to the low specificity of HHUS in differentiating between benign and malignant NMLs, despite various attempts by researchers to classify NMLs, there remains a lack of standardized descriptive terminology and classification criteria across the field. Recently, Choi et al. proposed a more refined approach for describing NMLs using ultrasound. Their methodology incorporates several key features, including echogenicity, distribution characteristics, the presence of associated calcifications, ductal abnormalities, architectural distortions, and posterior acoustic features [2, 15]. By employing these descriptive terms, Choi et al. have contributed to the development of a more precise lexicon for the ultrasound evaluation of NMLs [2, 15].

Automated breast ultrasound (ABUS) represents an innovative imaging technology that ensures standardized image acquisition and provides comprehensive coronal plane images of the entire breast. This technique facilitates multi-planar reconstruction, enabling detailed three-dimensional morphological assessment of lesions. ABUS is particularly advantageous due to its enhanced reproducibility and reduced operator dependence, which contribute to improved diagnostic accuracy for breast lesions [16]. However, it has limitations in evaluating axillary lymph nodes and lesion blood flow [17]. Multiple studies have confirmed that ABUS and HHUS are comparable in accuracy for evaluating breast cancer [18–20].

The integration of ABUS-derived coronal plane features with blood flow signal analysis from HHUS can yield a more objective and thorough evaluation of NMLs. Specifically, the coronal plane characteristics obtained via ABUS play a critical role in assessing breast NMLs, providing essential insights for accurately differentiating between benign and malignant lesions [20, 21]. These findings underscore the value of combining ABUS and HHUS methodologies to enhance diagnostic precision.

This study seeks to re-evaluate high-risk NMLs detected by MRI through the combined use of ABUS+HHUS. It aims to analyze the correlation between various sonographic features and the benign or malignant nature of these NMLs, with the ultimate goal of reducing unnecessary needle biopsies. By integrating these advanced imaging techniques, the study endeavors to enhance diagnostic accuracy and provide a more reliable basis for clinical decision-making.

Materials and Methods

Study Design

A retrospective review was conducted on 580 cases of breast NMLs in MRI examinations performed at the First People's Hospital of Hangzhou, affiliated with Westlake University School of Medicine, from January 2019 to October 2023. In this study, all lesions underwent histological needle biopsy or surgical excision and were pathologically confirmed.

Inclusion criteria and Exclusion criteria

Inclusion criteria:

(1) Cases classified as BI-RADS 4 or 5 by MRI; (2) Patients who completed MRI, ABUS, and HHUS examinations with complete imaging data; (3) NMLs identified by MRI, ABUS, and HHUS, with lesions confirmed by histological biopsy or surgical pathology, and precise pathological results (for benign biopsy results, follow-up imaging for over 2 years without changes was required to be considered benign); (4) Interval between examination and surgery less than 3 months; (5) No needle biopsy performed before examination; (6) Consistent lesion location shown by MRI, ABUS, and HHUS.

Exclusion criteria:

(1) Incomplete MRI, ABUS, or HHUS examination data; (2) Needle biopsy performed before examination; (3) Unclear pathological results; (4) Interval between MRI and ultrasound examinations greater than 1 month; (5) Benign biopsy results without regular follow-up or follow-up less than 2 years.

MRI Examination

A German Siemens Verio 3.0 T superconducting whole-body MRI scanning system with a dedicated breast coil was used. Gadopentetate dimeglumine (Gd-DTPA) contrast agent was injected via the antecubital vein. One pre-contrast scan was performed, followed by 6 consecutive scans starting 25 seconds after contrast injection, with each scan lasting 58 seconds.

ABUS and HHUS Examination

ABUS+HHUS examinations: A Siemens Acuson S2000 color Doppler ultrasound diagnostic system equipped with an ABUS system was used. First, a wide-band high-frequency 5–14 MHz probe was used for ABUS scanning, and the corresponding breast images were transmitted to the workstation system to obtain transverse, reconstructed sagittal, and coronal plane images. Then, an 18L-6HD linear array probe was used to perform radial scanning centered on the nipple, thoroughly examining all quadrants of both breasts, the areola area, and the axillary region.

Ultrasound observation content and evaluation criteria:

1. Internal echo of the lesion: Compared to the echo of the subcutaneous fat layer, classified as hyperechoic, hypoechoic, or heterogeneous.
2. Calcification: Punctate strong echoes within the lesion, categorized by location (intraductal, within hypoechoic areas) and size (coarse or fine, with a cutoff value of 0.5 mm).
3. Echogenic halo: Thick echogenic band surrounding all or part of the breast lesion, with uneven thickness and blurred margins.
4. Ductal abnormalities: Ductal dilation (internal diameter > 2 mm), abnormal echoes within ducts, thickened duct walls.
5. Posterior acoustic attenuation: Echo attenuation behind the lesion, excluding lateral acoustic shadowing and shadowing caused by coarse calcifications.
6. Lesion blood flow grading: Internal blood flow status was graded using Adler's semi-quantitative method [22].
7. Distribution characteristics: Lesion distribution was classified as focal, linear, segmental, and regional [3].
8. Convergence sign: Radially distributed hyperechoic strands converging toward the center of the lesion on the ABUS coronal plane, considered positive if present in some planes [23].

Imaging analysis

Breast MRI and US images were independently evaluated by two radiologists with over 10 years of experience in breast diagnostics. Disagreements were resolved through discussion. According to the ACR (American College of Radiology) BI-RADS v2025 Manual, BI-RADS 4A was used as the ultrasound and MRI classification cutoff value. For BI-RADS 4A and below, benign pathology was considered concordant; otherwise, it was defined as discordant.

Pathology

Based on the 2019 WHO classification of breast tumors [24], this study defined ductal carcinoma in situ, solid papillary carcinoma in situ, infiltrating lobular carcinoma, invasive carcinoma of no special type, invasive solid papillary carcinoma, and invasive papillary carcinoma as malignant lesions, categorized into the malignant group. Fibroadenoma, adenosis, sclerosing adenosis, granulomatous mastitis, intraductal papilloma, inflammatory lesions of no special type, and atypical hyperplasia were defined as benign lesions and categorized into the benign group.

Statistical Methods

Statistical analysis was performed using R software (version 4.3.2). Normality tests were conducted on measurement data. Data conforming to a normal distribution were expressed as the mean ± standard deviation (mean ± SD), while non-normally distributed data were represented by the median and interquartile range. Categorical data were analyzed using the chi-square test, with Fisher's exact test applied when the theoretical frequency was less than 5. Univariate logistic regression analysis was performed for each factor, with $P < 0.05$ considered statistically significant. Factors showing statistical significance were included in multivariate logistic regression analysis, with $P < 0.05$ considered as independent predictive factors. Using pathological results as the gold standard, sensitivity, specificity, positive predictive value, and negative predictive value were calculated for MRI and automated breast ultrasound combined with HHUS in differentiating benign from malignant NMLs. Moreover, the DeLong test was used to compare the areas under the curve (AUC) of the two methods. In contrast, the McNemar test was employed to compare their sensitivity and specificity, with $P < 0.05$ considered statistically significant. Receiver operating characteristic curves were plotted with sensitivity as the ordinate and 1-specificity as the abscissa. Finally, the AUCs were compared to evaluate the diagnostic performance of different imaging methods in distinguishing between benign and malignant NMLs.

Results

Pathological results of breast NMLs and demographic data

The study ultimately included 160 cases (166 lesions) based on inclusion and exclusion criteria. Among the included study subjects, malignant NMLs accounted for 62.7% (104/166). Of all cases, while NMLs accounted for 37.3% (62/166). Figure 1 is a case example of a benign lesion detected by MRI and ABUS+HHUS. Figure 2 is a case example of a malignant lesion detected by MRI and ABUS+HHUS.

The specific pathological result distribution is shown in Table 1. The mean age of patients in the malignant group was greater than that in the benign group, with a statistically significant difference between the two groups ($P < 0.0001$). Palpable masses showed a statistically significant difference between benign and malignant groups ($P = 0.0002$), as shown in Table 2.

Table 1
Pathological result distribution of 166 breast NMLs

malignant group	Lesion proportion (%)	benign group	Lesion proportion (%)
ductal carcinoma in situ	25.9% (43/166)	fibroadenoma	1.8% (3/166)
ductal carcinoma in situ with invasive carcinoma	12.7% (21/166)	adenopathy	15.7% (26/166)
non-specific invasive carcinoma	17.5%(29/166)	sclerosing gonadism	6.6%(11/166)
Infiltrating lobular carcinoma	3.0%(5/166)	granulomatous mastitis	0.6%(1/166)
invasive papillary carcinoma	1.2%(2/166)	intraductal papilloma	7.2%(12/166)
solid papillary carcinoma in situ	1.8%(3/166)	non-specific inflammatory lesions	1.8%(3/166)
invasive solid papillary carcinoma	0.6%(1/166)	atypical hyperplasia	3.6%(6/166)

Pathological results corresponding to sonographic features and distribution characteristics of 166 cases

As shown in Table 4 and Table 5, there were significant statistical differences in calcification, surrounding echo halo, rich internal blood flow signals, and segmental distribution between the benign and malignant groups, indicating that ABUS+HHUS has important value in evaluating NML ($\mathbf{p} < 0.05$).

Table 2
Demographic characteristics of 166 NMLs

characteristic	pathological results		*P value*
	benign group (n = 62) N (%)	malignant group (n = 104) N (%)	
BMI (kg/m$^{2)}$			0.2093
Mean ± SD	21.98 ± 2.78	22.76 ± 3.22	
Median	21.61	22.90	
age (years)			< 0.0001
Mean ± SD	39.69 ± 10.30	50.07 ± 10.70	
Median	38.00	50.00	
< 40	33(53.23%)	19(18.27%)	
≥ 40	29(46.77%)	85(81.73%)	
palpable masses			0.0002
No	45(72.age (year58%)	44(42.31%)	
Yes	17(27.42%)	60(57.69%)	
pain			0.3648
No	54(87.10%)	85(81.73%)	
Yes	8(12.90%)	19(18.27%)	
nipple discharge			0.9613
No	55(88.71%)	92(88.46%)	
Yes	7(11.29%)	12(11.54%)	
family history of breast cancer			0.9950
No	60(96.77%)	102(98.08%)	
Yes	2(3.23%)	2(1.92%)	
whether menopause			0.4501
No	54(87.10%)	86(82.69%)	
Yes	8(12.90%)	18(17.31%)	
lesion location			0.5657
inner-upper quadrant	10(16.13%)	16(15.38%)	

characteristic	pathological results		*P value*
	benign group (n = 62) N (%)	malignant group (n = 104) N (%)	
inner-lower quadrant	6(9.68%)	4(3.85%)	
areola area	3(4.84%)	5(4.81%)	
outer-upper quadrant	29(46.77%)	58(55.77%)	
outer-lower quadrant	14(22.58%)	21(20.19%)	

BMI, body mass index

Table 3
Comparison of diagnostic performance between two different imaging techniques for breast NMLs

diagnostic method	MRI	ABUS and HHUS	*P value*
sensitivity (95% CI)	0.914(0.842, 0.959)	0.875(0.796, 0.932)	0.0001
specificity (95% CI)	0.323(0.209, 0.453)	0.694(0.564, 0.804)	
AUC (95% CI)	0.618(553,0.683)	0.784(0.718,0.850)	0.00001
NPV (95% CI)	0.690 (0.521, 0.858)	0.768(0.657,0.878)	/
PPV (95% CI)	0.693 (0.616, 0.771)	0.827(0.757,0.898)	/

AUC, area under the curve; NPV, negative predictive value; PPV, positive predictive value; CI, confidence interval

Table 4 Pathological results corresponding to the HHUS sonographic features and ABUS distribution characteristics of 166 cases.

Table 4
Pathological results corresponding to the HHUS sonographic features and ABUS distribution characteristics of 166 cases.

sonographic characteristics	**pathological results**		***P value***
	benign group (n = 62) N(%)	**malignant group (n = 104) N(%)**	
internal echo			0.0926
heterogeneous echo	11(17.74%)	32(30.77%)	
hypoechoic	50(80.65%)	67 (64.42%)	
hyperechoic	1 (1.61%)	5(4.81%)	
calcifications			< 0.0001
No	46(74.19%)	33(31.73%)	
Yes	16(25.81%)	71(68.27%)	
echogenic halo			0.0426
No	62(100%)	95(91.35%)	
Yes	0(0.00%)	9(8.65%)	
acoustic shadowing			0.2650
No	61(98.39%)	97(93.27%)	
Yes	1(1.61%)	7(6.73%)	
ductal abnormalities			0.3932
No	44(70.97%)	80(76.92%)	
Yes	18(29.03%)	24(23.08%)	
blood flow classification			0.0009
0	4(6.45%)	11(10.58%)	
I	32(51.61%)	35(33.65%)	
II	21(33.87%)	23(22.12%)	
III	5(8.06%)	35(33.65%)	
distribution characteristics			0.0086
segmental	0(0.00%)	10(9.62%)	
focal	31(50.00%)	30(28.85%)	

sonographic characteristics	pathological results		*P value*
	benign group (n = 62) N(%)	malignant group (n = 104) N(%)	
region	16(25.81%)	31(29.81%)	
striation	15(24.19%)	33(31.73%)	
coronal convergence sign			0.2214
No	43(69.35%)	81(77.88%)	
Yes	19(30.65%)	23(22.12%)	

Table 5
Univariate logistic regression analysis of internal blood flow grading in NMLs

factor	coefficient of regression	Standard error	z	*p*	OR	OR 95% CI	
	b	S_b				lower limit	upper limit
	0.78 (0.39,1.27)	0.21	3.70	0.0002	2.19	1.47	3.41
Blood flow classification	1.39(0.59,2.27)	0.42	3.27	0.0011	4.01	1.80	9.70

OR, odds ratio; CI, confidence interval.

Discussion

Due to the considerable overlap in imaging features between benign and malignant NMLs, MRI specificity is relatively low, leading to unnecessary biopsies for some NMLs and an increased psychological burden on patients [25, 26]. In this study, MRI showed a sensitivity of 91.4% and a specificity of only 32.2% in differentiating benign from malignant NMLs, similar to other reports [26]. Furthermore, ABUS + HHUS demonstrated a sensitivity of 87.5% and a specificity of 69.4% in differentiating benign from malignant NMLs, improving specificity without significantly reducing sensitivity. Therefore, this study used ABUS+HHUS to re-evaluate high-risk NMLs identified by MRI, aiming to improve diagnostic specificity and reduce unnecessary biopsies.

In this study, the median age for benign NMLs was 38 years, while for malignant NMLs, it was 50 years, consistent with the median age of breast cancer onset in Chinese women [27]. Moreover, 57.69% of malignant NMLs presented clinically as palpable masses, a proportion lower than that reported in some studies [28]. This discrepancy may be attributed to the inclusion of both mass-type and non-mass-type breast cancers in the previous studies, whereas our research focused solely on NMLs. Therefore, when

patients present with palpable masses but ultrasound images do not show corresponding mass-like sonographic features in clinical practice, we should be vigilant about the possibility of NMLs.

In this study, we utilized ABUS + HHUS to evaluate the sonographic features of NMLs. Analysis revealed that echogenic halos surrounding NMLs, calcification, internal blood flow grading of the lesion, and distribution characteristics of NMLs on ABUS showed statistically significant differences between benign and malignant groups.

Breast microcalcifications are one of the critical imaging manifestations of breast cancer. MG has limited sensitivity in screening for microcalcifications in dense breasts [11, 29]. As such, US is an essential complementary examination method for detecting microcalcifications in dense breasts [11, 30]. Malignant microcalcifications detected by ultrasound are often located within hypoechoic areas or ducts [2]. They generally appear as linear or segmental distributions on the ABUS coronal plane. In this study, the detection rate of calcifications in malignant NMLs reached 68.27%. Therefore, the presence of calcifications in NMLs may serve as one of the positive predictive indicators for malignant NMLs.

In our study, the detection rate of echogenic halo in the malignant NML group was 8.65%, significantly lower than previously reported [31]. This discrepancy may be attributed to the following factors: previous studies focused on mass-type lesions. However, our study focused on NMLs. These two types of lesions exhibit different biological behaviors, resulting in a significantly higher detection rate of echogenic halo in mass-type malignant breast lesions compared to our findings. In our study, all 9 cases of echogenic halo were from the malignant NML group, showing a statistically significant difference between benign and malignant NML groups. The presence of an echogenic halo may serve as a positive predictive indicator for malignant NMLs.

Internal echo is one of the primary sonographic features for identifying NMLs [15]. However, the relationship between NML internal echo and pathological benign or malignant outcomes remains unclear. It has been reported that patchy hypoechoic areas are the primary sonographic manifestation of malignant NMLs [32]. In this study, hypoechoic lesions accounted for 70.48% of cases. However, there was no statistically significant difference in internal echo between benign and malignant NML groups. This may be related to the fact that both benign NMLs and malignant NMLs can present as hypoechoic, leading to overlapping sonographic features.

The ACR BI-RADS® v2025 Manual has defined ductal abnormalities; however, the significance of various sonographic manifestations in evaluating NMLs requires further investigation. In this study, 42 lesions with ductal abnormalities were identified, with the primary pathological types being DCIS and intraductal papilloma, accounting for 50% and 28.57%, respectively. No statistically significant difference was observed in ductal abnormalities between benign and malignant NML groups.

Color Doppler flow imaging (CDFI) can detect neovascularization in lesion tissues and measure hemodynamic parameters such as blood flow velocity and resistance index within the lesion [33]. Studies have also shown that the degree of internal blood flow signals in malignant breast lesions is

significantly higher than in benign lesions [22]. This study showed 40 cases of grade III blood flow signals. Moreover, univariate logistic regression analysis suggested a positive correlation between blood flow abundance and malignancy risk. Therefore, rich internal blood flow signals can serve as one of the positive predictive indicators for malignant NMLs.

In the ACR BI-RADS lexicon, posterior acoustic shadowing is also listed as one of the descriptive terms for malignant breast tumors. A previous study of 715 NMLs indicated that posterior acoustic shadowing is one of the independent risk factors for NMLs [5]. This study observed posterior acoustic shadowing in 8 lesions, with malignancy accounting for 87.5%. In contrast, posterior acoustic shadowing related to benign NMLs occurred in cases of sclerosing adenosis. Although there was no statistical difference in posterior acoustic shadowing between benign and malignant NML groups in this study, it remains a sonographic feature worthy of attention.

Architectural distortion is seen as thin lines radiating from a point or focal retraction or straightening of the breast parenchyma, representing distortion of tissue planes. It may be associated with a mass or NML[3]. It is often manifested as the coronal convergence sign in ABUS. The convergence sign on the coronal plane is a unique sonographic feature of ABUS. Studies have shown that this sign represents a radial structure formed by malignant tumor cells invading and pulling on surrounding tissues. It has a specificity of 74% to 100% for diagnosaremalignant breast tumors, with an accuracy of 85% and a positive predictive value of 90%, making it a vital imaging feature of malignant breast tumors [23]. In this study, 42 lesions exhibited the convergence sign, with malignancy accounting for 54.8%. In the benign NML group, there were 9 cases of sclerosing adenosis, likely related to the pathological basis of sclerosing adenosis. The pathological characteristics of sclerosing adenosis include increased glandular components of breast parenchyma and stromal proliferation, leading to glandular compression and deformation. Furthermore, this study found that the distribution characteristics of NMLs on ABUS were closely related to their benign or malignant nature. Focal distribution was detected in 50% of benign cases and 28.85% of malignant cases, showing a significant statistical difference between the two groups. Segmental distribution was detected in 9.62% of malignant NMLs. In contrast, none of the 62 benign NMLs showed segmental distribution, indicating that segmental distribution can be used as a positive predictive indicator for assessing the malignant risk of NMLs. This is consistent with some scholars' studies [34].

This study has several limitations: Firstly, it is a retrospective, single-center study. Secondly, only lesions diagnosed as BI-RADS 4 or 5 by MRI were included, which may lead to potential data bias.

Conclusion

Compared to MRI, ABUS+HHUS demonstrates improved diagnostic performance in differentiating between benign and malignant NMLs, effectively enhancing specificity without compromising sensitivity and potentially reducing unnecessary needle biopsies. The main sonographic features of malignant NMLs include calcifications, rich internal blood flow signals, an echogenic halo surrounding the lesion,

and segmental distribution. Importantly, these features are an essential positive predictive indicator for malignant NMLs.

Declarations

Ethics approval and consent to participate

The Ethics Review Committee of Hangzhou First People's Hospital Affiliated to Westlake University School of Medicine approved this retrospective study and waived the requirement for patient informed consent.

Competing interests

The authors declare no competing interests.

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Author Contribution

XB.C., YX.Q., and LY.B. designed the study and drafted the manuscript; XJ.X.,YX.Q.,and B. L. helped interpret the results; HM.R, KY.L, and H.L contributed to the clinical data collection; YX.Q. and B. L. helped in the statistical analysis; XB.C.and LY.B. take responsibility for the paper as a whole. All authors critically reviewed and approved the final manuscript.

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Data Availability

The data that support the findings of this study are subject to privacy and ethical restrictions and therefore cannot be shared publicly. Data may be available from the corresponding author upon reasonable request.

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Figures

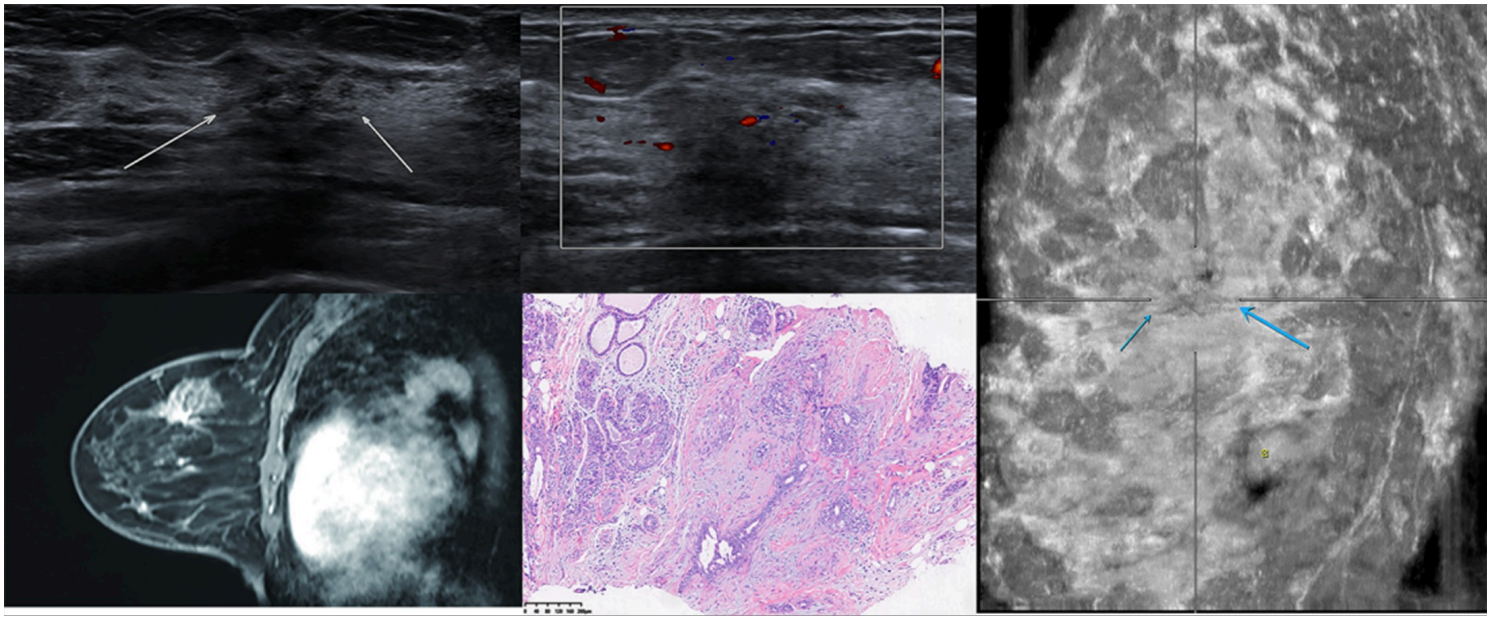


Figure 1

51y, Female. 2D US hypoechoic area in the upper quadrant of the left breast, with local distribution. CDFI showed a star-shaped blood flow signal (grade I) in the lesion. A convergence sign was seen on the local level of the ABUS coronal plane, and ultrasound was BI-RAD 4A. MRI showed that the non-mass lesions of the left breast were unevenly enhanced, and MRI was BI-RADS 4B. Pathological display sclerosing adenosis.

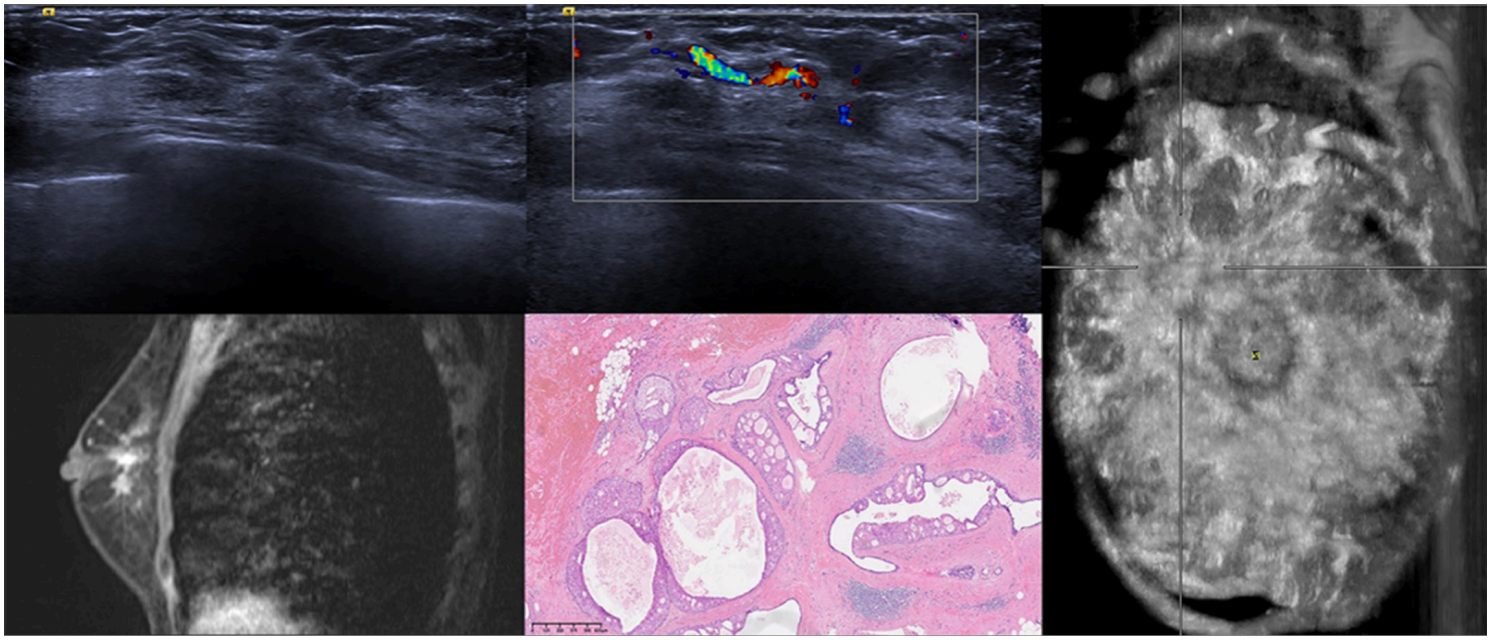


Figure 2

63 y, Female. 2D US hypoechoic area in the external upper quadrant of the right breast, local distribution. CDFI showed that there were thick twisted strip blood flow signals in the lesion (grade Ⅲ). The ABUS coronal plane shows a convergence sign, and the ultrasound is BI-RADS 4B. MRI showed that the non-

mass lesions of the right breast were unevenly enhanced, and MRI BI-RADS 4B. Pathology showed moderate ductal carcinoma in situ.

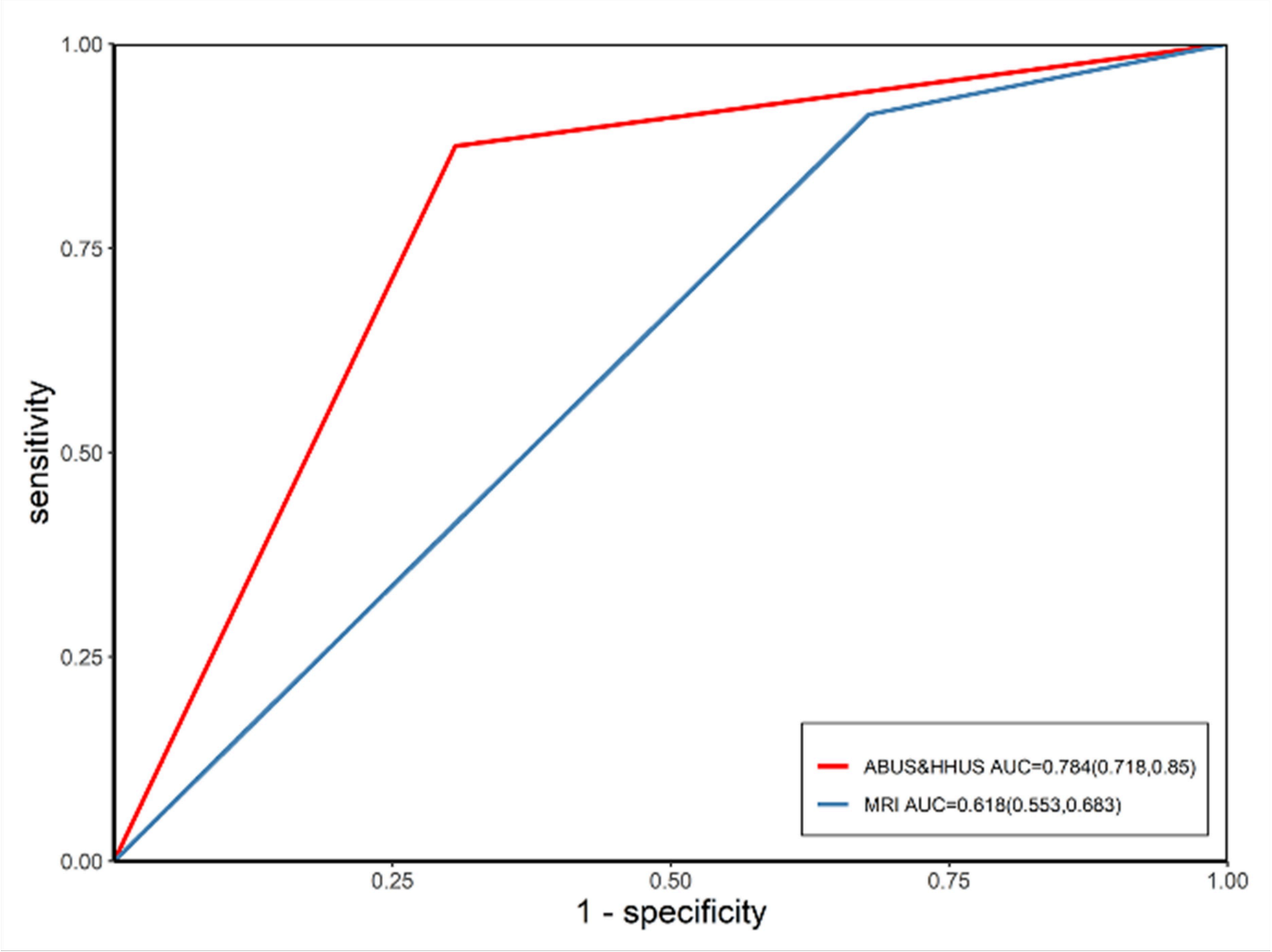


Figure 3

ROC curve of MRI and US (ABUS+HHUS) in differential diagnosis of NMLs.