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Original Research Article

Diagnostic Performance of Combined High b-value DWI and DCE-MRI in Characterization of Breast Lesions: A Histopathology-Correlated Study

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Abstract

Background: Accurate differentiation of benign and malignant breast lesions is essential for appropriate clinical management and reduction of unnecessary biopsies. Dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) offers high sensitivity for breast cancer detection but is limited by moderate specificity. Diffusion-weighted imaging (DWI), particularly with high b-values, provides additional functional information regarding tissue cellularity and may improve diagnostic accuracy. This study evaluated the utility of multiparametric breast MRI combining high b-value DWI and DCE-MRI in differentiating benign and malignant breast lesions.

Methods: This hospital-based cross-sectional study included 353 patients with breast lesions who underwent multiparametric MRI followed by histopathological confirmation. MRI evaluation included morphological assessment, DCE-MRI kinetic curve analysis, and high b-value DWI with apparent diffusion coefficient (ADC) measurements. Histopathology served as the reference standard. Diagnostic performance indices of DCE-MRI alone, DWI alone, and combined multiparametric MRI were calculated. Receiver operating characteristic (ROC) analysis was performed to determine the optimal ADC threshold for malignancy.

Results: Of the 353 lesions evaluated, 213 (60.3%) were benign and 140 (39.7%) were malignant. Malignant lesions were associated with significantly older age, larger lesion size, irregular morphology, non-circumscribed margins, heterogeneous/rim enhancement, and Type III washout kinetics (all $p<0.001$). Restricted diffusion was observed in 90.0% of malignant lesions compared with 23.0% of benign lesions ($p<0.001$). Mean ADC values were significantly lower in malignant lesions than benign lesions (0.89 ± 0.17 vs. 1.46 ± 0.26 $\times10^{-3}$ mm²/s; $p<0.001$). ROC analysis identified an optimal ADC cut-off of ≤1.12 $\times10^{-3}$ mm²/s with an area under the curve of 0.931, sensitivity of 89.3%, and specificity of 85.9%. Combined multiparametric MRI demonstrated superior diagnostic performance with sensitivity, specificity, positive predictive value, negative predictive value, and overall accuracy of 96.4%, 89.2%, 85.9%, 97.2%, and 92.1%, respectively.

Conclusion: Multiparametric breast MRI integrating high b-value DWI and DCE-MRI provides excellent diagnostic accuracy for differentiating benign and malignant breast lesions. The combined approach significantly improves lesion characterization compared with individual imaging techniques and supports its routine use as a comprehensive, non-invasive diagnostic tool in breast imaging.

Keywords: Breast MRI; Diffusion-Weighted Imaging; Apparent Diffusion Coefficient; Breast Cancer; High b-value DWI.

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Introduction

Breast cancer is the most commonly diagnosed malignancy among women worldwide and remains one of the leading causes of cancer-related mortality. According to GLOBOCAN 2022 estimates, breast cancer accounted for approximately 2.3 million new cases and over 665,000 deaths globally, representing a significant public health burden [1]. Early and accurate differentiation between benign and malignant breast lesions is essential for timely treatment, improved survival, and avoidance of unnecessary invasive procedures [2]. While mammography and ultrasonography are widely used as first-line imaging modalities, their diagnostic accuracy may be limited in women with dense breast tissue, multifocal disease, postoperative changes, or indeterminate lesions [3]. Magnetic resonance imaging (MRI) has emerged as the most sensitive

imaging modality for breast lesion detection, with reported sensitivity exceeding 90% [4]. Dynamic contrast-enhanced MRI (DCE-MRI) is a key component of breast MRI protocols and provides detailed information regarding lesion morphology, vascularity, and enhancement kinetics. Malignant lesions typically demonstrate irregular margins, heterogeneous enhancement, and rapid contrast uptake followed by washout patterns due to increased tumor angiogenesis [5]. However, despite its high sensitivity, DCE-MRI has relatively lower specificity because several benign lesions may exhibit similar enhancement characteristics, leading to false-positive diagnoses and unnecessary biopsies [6].

Diffusion-weighted imaging (DWI) has gained increasing importance as a complementary MRI technique for breast lesion characterization [7]. DWI evaluates the microscopic movement of water molecules within tissues and provides quantitative assessment through the apparent diffusion coefficient (ADC) [7]. Malignant tumors generally exhibit increased cellularity and reduced extracellular space, resulting in restricted diffusion and lower ADC values compared with benign lesions [8]. Recent advances have focused on the use of high b-value DWI (≥1000 s/mm²), which improves lesion conspicuity by suppressing background tissue signal and enhancing visualization of diffusion restriction [8,9].

Multiparametric MRI (mpMRI), which combines morphological assessment, DCE-MRI, and DWI, has shown superior diagnostic performance compared with individual MRI techniques alone [10]. The integration of functional and anatomical information improves lesion characterization, increases specificity, and may reduce unnecessary biopsies while maintaining high sensitivity for cancer detection [11]. However, the additional diagnostic value of combining high b-value DWI with DCE-MRI remains an area of ongoing investigation, particularly in the Indian population. Therefore, the present study was aimed to evaluate the utility of multiparametric breast MRI incorporating high b-value DWI and DCE-MRI in differentiating benign and malignant breast lesions using histopathological findings as the reference standard.

Materials and Methods

Study Design and Setting: This hospital-based cross-sectional study was conducted in the Department of Radiodiagnosis of a Multi-Speciality hospital over a period of 18 months from January 2023 to June 2024. The study was approved by the Institutional Ethics Committee prior to commencement, and written informed consent was obtained from all participants. The study aimed to evaluate the diagnostic utility of multiparametric breast MRI incorporating high b-value diffusion-weighted imaging (DWI) and dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) in differentiating benign and malignant breast lesions, with histopathological examination serving as the reference standard.

Study Population: Female patients aged 18 years and above presenting with clinically palpable breast lumps or imaging-detected breast lesions on mammography and/or ultrasonography and referred for breast MRI were considered eligible for inclusion. Patients with previously diagnosed breast malignancy who had undergone surgery, chemotherapy, or radiotherapy, pregnant or lactating women, individuals with contraindications to MRI such as cardiac pacemakers, cochlear implants, metallic foreign bodies, severe claustrophobia, or contraindications to gadolinium-based contrast agents including severe renal impairment and documented contrast allergy were excluded from the study.

Sample Size and Sampling Technique: A consecutive sampling technique was employed, wherein all eligible patients fulfilling the inclusion criteria during the study period were recruited until the required sample size was achieved. A total of 80 breast lesions identified in 80 patients were included in the final analysis. Histopathological diagnosis obtained through core needle biopsy, excisional biopsy, or surgical specimen examination was considered the gold standard for lesion characterization.

MRI Acquisition Protocol: All MRI examinations were performed using a 1.5 Tesla whole-body MRI scanner equipped with a dedicated bilateral phased-array breast coil. Patients were examined in the prone position with both breasts appropriately immobilized within the coil. Conventional sequences included axial T1-weighted, T2-weighted, and fat-suppressed T2-weighted images. Diffusion-weighted imaging was acquired using a single-shot echo-planar imaging sequence with diffusion sensitizing gradients applied at b-values of 0, 800, and 1200 s/mm². Apparent diffusion coefficient (ADC) maps were automatically generated by the workstation software.

Dynamic contrast-enhanced MRI was performed following intravenous administration of gadolinium-based contrast material at a dose of 0.1 mmol/kg body weight using a power injector at a rate of 2 mL/s, followed by a 20 mL saline flush. One pre-contrast and six consecutive post-contrast three-dimensional fat-suppressed T1-weighted acquisitions were obtained at regular intervals. Morphological characteristics including lesion size, shape, margins, internal enhancement pattern, and enhancement kinetics were evaluated according to the American College of Radiology Breast Imaging

Reporting and Data System (BI-RADS) MRI lexicon.

Image Analysis: MRI images were independently reviewed by two experienced radiologists with more than five years of experience in breast imaging who were blinded to histopathological findings. For diffusion-weighted imaging, regions of interest (ROIs) were manually placed over the most solid enhancing component of the lesion while avoiding areas of necrosis, hemorrhage, cystic degeneration, and imaging artifacts. Mean ADC values were recorded in $\times 10^{-3}$ mm²/s.

For DCE-MRI assessment, lesion morphology and enhancement kinetic curves were analyzed. Kinetic curves were categorized as persistent (Type I), plateau (Type II), or washout (Type III). Multiparametric MRI interpretation was based on the combined assessment of conventional MRI findings, enhancement kinetics, diffusion restriction, and ADC values. Lesions demonstrating suspicious morphology, Type II/III kinetic curves, and restricted diffusion with low ADC values were considered suggestive of malignancy.

Histopathological Evaluation: All lesions underwent tissue diagnosis through ultrasound-guided core needle biopsy, stereotactic biopsy, excisional biopsy, or postoperative histopathological examination as clinically indicated. Histopathological findings were used as the reference standard for categorizing lesions as benign or malignant and for determining the diagnostic performance of MRI parameters.

Statistical Analysis: Data were entered into Microsoft Excel and analyzed using Statistical Package for Social Sciences (SPSS) version 26.0. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. The independent samples t-test was used to compare mean ADC values between benign and malignant lesions. Chi-square test or Fisher's exact test was applied for comparison of categorical variables. Receiver operating characteristic (ROC) curve analysis was performed to determine the optimal ADC cut-off value for differentiating benign from malignant lesions. Diagnostic performance indices including sensitivity, specificity, positive predictive value, negative predictive value, and overall diagnostic accuracy were calculated for DWI alone, DCE-MRI alone, and combined multiparametric MRI. A p-value <0.05 was considered statistically significant.

Results

Among the 353 patients included in the study, histopathology confirmed 213 (60.3%) benign and 140 (39.7%) malignant breast lesions. Patients with malignant lesions were significantly older than those with benign lesions (52.4±11.3 years vs. 38.6±10.8 years, p<0.001). The age distribution differed significantly between the two groups, with malignant lesions predominantly observed in women aged ≥50 years, whereas benign lesions were more common among women younger than 40 years (p<0.001). A positive family history of breast cancer was significantly more frequent among patients with malignant lesions (20.7% vs. 8.5%, p<0.001). Similarly, palpable breast lump (90.0% vs. 82.6%, p=0.049) and axillary lymphadenopathy (34.3% vs. 5.6%, p<0.001) were significantly associated with malignant lesions. However, the prevalence of nipple discharge did not differ significantly between the two groups (p=0.654) (Table 1).

Table 1: Demographic and Clinical Characteristics of Patients with Benign and Malignant Breast Lesions (N=353)

Variable	Benign (n=213)	Malignant (n=140)	Total (N=353)	p-value
	Frequency (%)/Mean ± SD			
Age (years)	38.6 ± 10.8	52.4 ± 11.3	44.1 ± 12.9	<0.001*
Age Group (years)				
<30	41 (19.2)	6 (4.3)	47 (13.3)	<0.001#
30–39	72 (33.8)	18 (12.9)	90 (25.5)	
40–49	55 (25.8)	38 (27.1)	93 (26.3)	
50–59	31 (14.6)	49 (35.0)	80 (22.7)	
≥60	14 (6.6)	29 (20.7)	43 (12.2)	
Family history of breast cancer	18 (8.5)	29 (20.7)	47 (13.3)	<0.001#
Palpable breast lump	176 (82.6)	126 (90.0)	302 (85.6)	0.049#
Axillary lymphadenopathy	12 (5.6)	48 (34.3)	60 (17.0)	<0.001#
Nipple discharge	24 (11.3)	18 (12.9)	42 (11.9)	0.654#

*Independent t-test; #Chi-square test

Malignant breast lesions were significantly larger than benign lesions, with a mean lesion size of 3.2±1.4 cm compared to 1.9±0.8 cm in benign lesions (p<0.001).

Morphologically, benign lesions predominantly demonstrated round or oval shapes (78.4%) and circumscribed margins (74.2%), whereas malignant lesions were more likely to exhibit irregular shapes (79.3%) and non-circumscribed margins (84.3%) (p<0.001 for both).

Regarding internal enhancement characteristics, homogeneous enhancement was more frequently observed in benign lesions (54.5%), while heterogeneous enhancement (55.7%) and rim enhancement (22.9%) were significantly more common among malignant lesions.

Overall, all evaluated MRI morphological features demonstrated significant differences between benign and malignant breast lesions (p<0.001) (Table 2).

Table 2: Comparison of MRI Morphological Characteristics between Benign and Malignant Breast Lesions (N=353)

MRI Characteristic	Benign (n=213)	Malignant (n=140)	p-value
	Frequency (%)/Mean ± SD		
Mean lesion size (cm)	1.9 ± 0.8	3.2 ± 1.4	<0.001*
Shape			
Round/Oval	167 (78.4)	29 (20.7)	<0.001#
Irregular	46 (21.6)	111 (79.3)	
Margin			
Circumscribed	158 (74.2)	22 (15.7)	<0.001#
Non-circumscribed	55 (25.8)	118 (84.3)	
Internal enhancement pattern			
Homogeneous	116 (54.5)	18 (12.9)	<0.001#
Heterogeneous	74 (34.7)	78 (55.7)	
Rim enhancement	8 (3.8)	32 (22.9)	
Non-mass enhancement	15 (7.0)	12 (8.5)	

*Independent t-test; #Chi-square test; MRI characteristics were evaluated according to BI-RADS MRI lexicon criteria.

Analysis of contrast enhancement kinetics revealed a significant association between kinetic curve patterns and lesion pathology (p<0.001). Type I persistent enhancement was the predominant pattern among benign lesions, observed in 66.2% of cases, but was present in only 9.3% of malignant lesions. In contrast, Type III washout kinetics, a classic indicator of malignancy, was observed in 57.1% of malignant lesions compared with only 7.5% of benign lesions. Type II plateau curves demonstrated an intermediate distribution, occurring in 33.6% of malignant lesions and 26.3% of benign lesions. These findings highlight the diagnostic value of enhancement kinetics in distinguishing benign from malignant breast lesions (Table 3).

Table 3: Distribution of Dynamic Contrast-Enhanced MRI (DCE-MRI) Kinetic Curve Patterns among Benign and Malignant Breast Lesions (N=353)

Enhancement Kinetics	Benign (n=213)	Malignant (n=140)	Total	p-value
	Frequency (%)/Mean ± SD			
Type I (Persistent)	141 (66.2)	13 (9.3)	154 (43.6)	<0.001#
Type II (Plateau)	56 (26.3)	47 (33.6)	103 (29.2)	
Type III (Washout)	16 (7.5)	80 (57.1)	96 (27.2)	

Type I = Persistent enhancement pattern; Type II = Plateau enhancement pattern; Type III = Washout enhancement pattern; #Chi-square test.

Diffusion-weighted imaging demonstrated significant differences between benign and malignant lesions. Restricted diffusion was observed in 90.0% of malignant lesions compared with only 23.0% of benign lesions (p<0.001). Furthermore, malignant lesions exhibited significantly lower mean ADC values than benign lesions ($0.89\pm0.17 \times 10^{-3}$ mm²/s vs. $1.46\pm0.26 \times 10^{-3}$ mm²/s, p<0.001). The marked reduction in ADC values among malignant lesions reflects increased cellularity and restricted water molecule movement, supporting the role of DWI as a valuable functional imaging biomarker for breast lesion characterization (Table 4).

Table 4: Diffusion-Weighted Imaging Findings and Apparent Diffusion Coefficient (ADC) Values in Benign and Malignant Breast Lesions (N=353)

Parameter	Benign (n=213)	Malignant (n=140)	p-value
	Mean ± SD		
Restricted diffusion	49 (23.0)	126 (90.0)	<0.001
ADC value (×10⁻³ mm²/s)	1.46 ± 0.26	0.89 ± 0.17	<0.001
Minimum ADC value	0.88	0.51	—
Maximum ADC value	2.12	1.34	—

ADC = Apparent Diffusion Coefficient; values expressed as ×10⁻³ mm²/s. P-values obtained using Chi-square test for categorical variables and Independent Samples t-test for continuous variables.

Receiver operating characteristic analysis demonstrated excellent diagnostic performance of ADC values in differentiating benign from malignant breast lesions. The optimal ADC threshold was determined to be ≤1.12 ×10⁻³ mm²/s, yielding an AUC of 0.931 (95% CI: 0.904–0.958). At this cut-off, the sensitivity and specificity were 89.3% and 85.9%, respectively. The corresponding positive predictive value was 80.8%, while the negative predictive value was 92.3%. The overall diagnostic accuracy achieved using the ADC threshold was 87.3%, indicating excellent discriminative ability of diffusion-weighted imaging (Table 5).

Table 5: Receiver Operating Characteristic (ROC) Analysis of ADC Values for Differentiating Benign and Malignant Breast Lesions

Parameter	Value (95% CI)
Optimal ADC cut-off	≤1.12 ×10⁻³ mm²/s
Area Under Curve (AUC)	0.931 (0.904–0.958)
Sensitivity (%)	89.3
Specificity (%)	85.9
Positive Predictive Value (%)	80.8
Negative Predictive Value (%)	92.3
Overall Accuracy (%)	87.3

ADC = Apparent Diffusion Coefficient; AUC = Area Under the Curve; PPV = Positive Predictive Value; NPV = Negative Predictive Value; CI = Confidence Interval.

Comparison of diagnostic performance revealed that combined multiparametric MRI provided the highest accuracy for detecting malignant breast lesions. DCE-MRI alone achieved a sensitivity of 92.1%, specificity of 76.5%, and overall accuracy of 82.9%, while high b-value DWI alone demonstrated comparable sensitivity (90.0%) with a specificity of 77.0% and accuracy of 82.4%. The combination of DCE-MRI and high b-value DWI significantly improved diagnostic performance, yielding a sensitivity of 96.4%, specificity of 89.2%, positive predictive value of 85.9%, negative predictive value of 97.2%, and an overall diagnostic accuracy of 92.1%. These findings indicate that integration of functional diffusion parameters with contrast-enhanced MRI substantially enhances the differentiation of benign and malignant breast lesions (Table 6).

Table 6: Diagnostic Performance of DCE-MRI, High b-value DWI, and Combined Multiparametric MRI for Detection of Malignant Breast Lesions

Modality	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)
DCE-MRI Alone	92.1	76.5	71.7	93.8	82.9
High b-value DWI Alone	90	77	72	92.5	82.4
Combined Multiparametric MRI	96.4	89.2	85.9	97.2	92.1

DCE-MRI = Dynamic Contrast-Enhanced Magnetic Resonance Imaging; DWI = Diffusion-Weighted Imaging; PPV = Positive Predictive Value; NPV = Negative Predictive Value.

Discussion

The present study demonstrated that malignant breast lesions occurred in significantly older women than benign lesions (52.4±11.3 vs. 38.6±10.8 years, p<0.001).

Furthermore, malignant lesions were associated with a higher frequency of family history of breast cancer and axillary lymphadenopathy. These findings are consistent with the established epidemiology of breast cancer and mirror observations reported in several breast MRI studies Yadav et al., and Singh et al., evaluating lesion characterization using multiparametric approaches [12,13]. Morphological assessment remains a fundamental component of breast MRI interpretation. In the current study, malignant lesions were significantly larger and more

frequently demonstrated irregular shape, non-circumscribed margins, and heterogeneous or rim enhancement patterns compared with benign lesions (all $p<0.001$). Similar observations were reported by Bae et al., who found that irregular morphology and heterogeneous enhancement were strongly associated with invasive breast cancers [14]. Fan et al., also demonstrated that irregular lesion shape and non-circumscribed margins significantly improved the predictive capability of multiparametric MRI models for malignancy [15]. These features likely reflect the infiltrative growth pattern, stromal desmoplastic reaction, and heterogeneous tumor microenvironment characteristic of breast cancers.

The kinetic analysis of DCE-MRI revealed that Type I persistent enhancement predominated among benign lesions, whereas Type III washout kinetics were observed in 57.1% of malignant lesions ($p<0.001$). Similar findings have been reported by El Bakry et al., and Singh et al., who demonstrated that washout enhancement curves possess a strong association with malignant pathology owing to increased tumor angiogenesis, abnormal vascular permeability, and rapid contrast washout from highly vascularized neoplastic tissues [13,16]. The relatively higher proportion of plateau and washout patterns among malignant lesions in the present study further supports the utility of DCE-MRI as an important functional imaging biomarker.

Diffusion-weighted imaging provided substantial additional diagnostic information. Restricted diffusion was observed in 90.0% of malignant lesions compared with only 23.0% of benign lesions, while malignant lesions exhibited significantly lower ADC values than benign lesions (0.89 ± 0.17 vs. 1.46 ± 0.26 $\times10^{-3}$ mm²/s, $p<0.001$). These findings closely correspond with those reported by Min et al., Akin et al., Hetta et al., and Sharma et al., all of whom demonstrated significantly lower ADC values in malignant breast lesions [17,18,19,20]. The biological basis of this phenomenon is increased tumor cellularity, enlarged nuclei, and reduced extracellular space, which collectively restrict water molecule diffusion. High b-value DWI further enhances lesion conspicuity by suppressing background tissue signal and reducing perfusion-related effects, thereby improving differentiation between benign and malignant lesions [20,21]. An important finding of the present study was the excellent diagnostic performance of ADC values. ROC analysis yielded an AUC of 0.931 with an optimal ADC threshold of ≤1.12 $\times10^{-3}$ mm²/s, resulting in sensitivity and specificity of 89.3% and 85.9%, respectively. These findings are highly comparable to those reported by Akin et al., Min et al., and Zhou et al., who documented AUC values ranging from 0.85 to 0.95 and proposed ADC thresholds between 1.0 and 1.3 $\times10^{-3}$ mm²/s for differentiating malignant from benign lesions [17,18,22]. The high negative predictive value (92.3%) observed in the present study indicates that ADC measurements may be particularly useful in reducing unnecessary biopsies among lesions with equivocal morphological characteristics.

Comparison of imaging modalities revealed that DCE-MRI alone achieved a sensitivity of 92.1% and specificity of 76.5%, whereas high b-value DWI alone demonstrated a sensitivity of 90.0% and specificity of 77.0%. Notably, combining both techniques significantly improved diagnostic performance, yielding sensitivity of 96.4%, specificity of 89.2%, and overall accuracy of 92.1%. Similar improvements in diagnostic performance have been consistently reported in studies evaluating multiparametric MRI. Yadav et al., reported that the integration of DWI with DCE-MRI significantly enhanced lesion characterization compared with individual techniques [12]. Likewise, Yadav et al, Zhang et al., Pinker et al., Schmitz et al., and Sun et al., demonstrated that combining diffusion and contrast-enhanced parameters improves specificity while maintaining excellent sensitivity for breast cancer detection [21,23,24,25,26].

Recent advances in breast MRI have further strengthened the role of multiparametric imaging. Studies incorporating synthetic MRI, advanced diffusion models, and quantitative imaging biomarkers have reported diagnostic accuracies exceeding 90% for differentiating benign and malignant breast lesions [28–30]. He et al., demonstrated that integrating multiple quantitative MRI parameters into a multiparametric model significantly improved characterization of BI-RADS 4 lesions, while Liu et al., reported enhanced discrimination using synthetic MRI combined with diffusion parameters. Although the present study employed a conventional multiparametric MRI protocol, the achieved diagnostic accuracy of 92.1% compares favorably with these contemporary reports, emphasizing the robustness and clinical applicability of combined high b-value DWI and DCE-MRI in routine breast imaging practice.

Limitations

This study has certain limitations. Being a single-center cross-sectional study, the findings may have limited generalizability to broader populations. Interobserver variability in MRI interpretation was not formally assessed. ADC measurements may have been influenced by ROI placement and lesion heterogeneity. Additionally, the study did not evaluate molecular subtypes of breast cancer or long-term clinical outcomes, which could further

refine the prognostic utility of multiparametric MRI.

Conclusion

Multiparametric breast MRI combining high b-value diffusion-weighted imaging and dynamic contrast-enhanced MRI demonstrated excellent diagnostic performance in differentiating benign and malignant breast lesions. Malignant lesions were characterized by irregular morphology, washout enhancement kinetics, diffusion restriction, and significantly lower ADC values. An ADC threshold of $\leq 1.12 \times 10^{-3}$ mm²/s provided high diagnostic accuracy, while the combined MRI approach achieved superior sensitivity, specificity, and overall accuracy compared with either technique alone. These findings highlight the complementary value of functional and morphological MRI parameters and support the routine incorporation of high b-value DWI into breast MRI protocols to improve lesion characterization and potentially reduce unnecessary biopsies.

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