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ROLE OF DIFFUSION WEIGHTED IMAGING AND DYNAMIC CONTRAST ENHANCED MAGNETIC RESONANCE IMAGING IN CHARACTERIZING BENIGN AND MALIGNANT BREAST LESIONS

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Abstract

Background: Accurate differentiation between benign and malignant breast lesions is crucial for early diagnosis and optimal management. Multiparametric MRI, combining diffusion-weighted imaging (DWI) and dynamic contrast-enhanced MRI (DCE-MRI), offers both anatomical and functional assessment, potentially improving diagnostic accuracy.

Objective: To evaluate the role of DWI and DCE-MRI in characterizing benign and malignant breast lesions and to determine optimal ADC cut-off values for lesion differentiation.

Materials and Methods: This prospective, observational study included 100 female patients with breast lesions. All participants underwent mammography, ultrasound, and 3.0T MRI with DWI (b = 400, 800 s/mm²) and DCE sequences. Lesions were evaluated for morphology, size, margins, signal intensity, diffusion restriction, and contrast enhancement. ADC values were calculated, and MRI findings were correlated with histopathology or FNAC results. Statistical analysis included sensitivity, specificity, predictive values, accuracy, and ROC curve analysis for ADC thresholds.

Results: Malignant lesions demonstrated significantly lower ADC values compared to benign lesions (mean ADC: 0.93 $\times 10^{-3}$ mm²/s vs. 1.45 $\times 10^{-3}$ mm²/s, $p < 0.001$). DWI alone achieved 88.5% sensitivity and 81.3% specificity, while DCE-MRI showed 92.3% sensitivity and 79.2% specificity. Combined DWI and DCE-MRI improved sensitivity to 96.2%, specificity to 87.5%, and overall accuracy to 92.0%. ROC analysis identified a mean ADC cut-off $\leq 1.00 \times 10^{-3}$ mm²/s with 92.3% sensitivity and 87.5% specificity. Higher BI-RADS categories and morphological features such as irregular shape and spiculated margins were strongly associated with malignancy.

Conclusion: Multiparametric MRI integrating DWI and DCE-MRI provides excellent diagnostic performance for differentiating benign and malignant breast lesions. ADC quantification enhances specificity, and combined imaging improves overall accuracy, supporting its use in routine clinical practice to optimize early detection and management of breast cancer.

Keywords: Breast cancer, Diffusion-weighted imaging, Dynamic contrast-enhanced MRI, Apparentdiffusion coefficient, Multiparametric MRI, Lesion characterization

Introduction

Breast cancer is the most common malignancy among women worldwide, accounting for substantial morbidity and mortality, and represents nearly one-fourth of all cancer diagnoses in women [1]. In India, it is the second most frequent cancer, with roughly 52,000 new cases annually, largely due to urbanization, lifestyle changes, delayed childbearing, and limited awareness regarding early detection [1]. Despite advances in therapy, many patients present at advanced stages, emphasizing the need for accurate and early diagnosis to optimize management and improve survival.Early detection is an important for appropriate therapeutic planning and long-term outcomes. Imaging remains central to identifying and characterizing breast lesions. Mammography is the standard screening tool but has reduced sensitivity in dense breast tissue due to overlapping parenchyma [2]. Ultrasonography serves as a useful adjunct, providing real-time guidance for biopsies; however, its diagnostic accuracy is operator-dependent and may not reliably differentiate benign from malignant lesions.

Magnetic Resonance Imaging (MRI) has emerged as a superior modality, offering high soft-tissue contrast, multiplanar capabilities, and functional evaluation [3]. The American Cancer Society recommends MRI along with mammography for high-risk populations, including those with strong family history, BRCA mutations, or prior chest irradiation [3]. MRI enables detailed assessment of lesion morphology, vascularity, and perfusion, surpassing conventional imaging in diagnostic comprehensiveness.While standard MRI sequences primarily provide anatomical information, functional techniques such as Dynamic Contrast-Enhanced MRI (DCE-MRI) and Diffusion-Weighted Imaging (DWI) enhance lesion characterization [4–6]. DCE-MRI evaluates contrast kinetics post-gadolinium administration, reflecting tumor angiogenesis and vascular permeability. Malignant lesions typically show rapid initial enhancement with early washout due to increased microvessel density. The BI-RADS MRI lexicon categorizes enhancement curves as Type I (persistent), Type II (plateau), or Type III (washout), aiding differentiation [7]. Sensitivity for invasive malignancies is high (88–100%), while specificity varies (37–97%) because benign lesions such as fibroadenomas may display overlapping enhancement patterns [8,9].

DWI assesses water molecule diffusion, reflecting cellular density and membrane integrity without contrast administration [4,5]. The Apparent Diffusion Coefficient (ADC) quantifies diffusion restriction; malignant tumors generally have lower ADC values than benign lesions [6,7]. Sensitivity ranges from 80% to 96% and specificity from 46% to 91%, highlighting DWI's potential in improving diagnostic precision [6,10]. Combining DWI with DCE-MRI improves positive predictive value and reduces false positives, supporting more accurate lesion assessment [11].Breast lesions may appear as masses, foci, or non-mass enhancements (NME), the latter lacking defined three-dimensional structure and showing variable internal patterns, complicating differentiation [9]. Accurate characterization is crucial to prevent overtreatment or delayed management. Multiparametric MRI, integrating DCE-MRI and DWI, provides simultaneous evaluation of vascular, perfusional, and microstructural features, optimizing diagnostic accuracy [10,11]. However, ADC thresholds, imaging protocols, and interpretive criteria vary across studies, often limited by small sample sizes or older BI-RADS versions. Advances in imaging technology and standardized guidelines necessitate reevaluation of DWI and DCE-MRI's combined role in differentiating benign from malignant breast lesions.

This study aims to assess the diagnostic performance of diffusion-weighted imaging and dynamic contrast-enhanced MRI in characterizing breast lesions.

Materials and Methods

The present study was conducted in the Department of Radiodiagnosis, Geetanjali Medical College & Hospital, Udaipur.This study was designed as a comparative, observational, descriptive, hospital-based study aimed at evaluating the diagnostic performance of diffusion-weighted imaging (DWI) and dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) in characterizing breast lesions.Female patients presenting with a breast lump either on self-examination or clinical evaluation, or those in whom a lesion was identified on ultrasound or mammography, were considered for inclusion.

Inclusion Criteria

1.Patients with palpable breast lesions or incidental/positive findings on ultrasound or mammography.
2.Patients willing to participate and provide informed consent.

Exclusion Criteria

1.Patients who had received prior treatment (chemotherapy, radiotherapy, or surgery).
2.Pregnant or lactating women.
3.Patients with impaired renal function.
4.Patients with known allergy to contrast medium.
5.Patients with a cardiac pacemaker or any contraindication to MRI.
6.Patients who had already undergone biopsy with histopathological results.
7.Patients with lesions measuring less than 1 cm in size.

Data Collection

A detailed history and clinical examination were performed for all participants. Relevant laboratory investigations were recorded. All patients underwent film-screen sonomammography for baseline evaluation.

Imaging Equipment and Protocol

1.Ultrasonography (USG): USG examinations were performed using GE VOLUSON E10 and SAMSUNG V8 ultrasound machines equipped with linear and convex probes.
2.Magnetic Resonance Imaging (MRI): MRI examinations were conducted on a GE SIGNA Architect 3.0T wide-bore scanner with a dedicated breast array coil. The imaging protocol included:
oT1-weighted, T2-weighted, and fat-suppressed T2-weighted sequences (SPAIR) in appropriate planes.
oDWI sequences obtained with b-values of 400 and 800 s/mm², from which ADC values were calculated.
oDCE-MRI using fat-suppressed 3D T1-weighted images following intravenous administration of gadolinium-based contrast. A single pre-contrast scan was followed by four post-contrast acquisitions.
oTime-intensity curves (TICs) were generated from DCE images, and conventional MRI along with DWI images were evaluated for lesion detection, signal characteristics, and diffusion restriction.

Radiological Assessment

MRI findings, including morphology, signal intensity, diffusion restriction, and contrast enhancement patterns, were recorded in a predesigned proforma. Lesions were categorized as benign or malignant based on imaging features. Mammographic features such as lesion shape, margins, and density were documented. Lesion size was classified as <2 cm, 2–5 cm, or ≥5 cm. Signal intensity patterns were assessed on T1- and T2-weighted images, and margins were classified as circumscribed, indistinct, spiculated, or heterogeneous.

Histopathological Correlation

For each patient, histological or fine-needle aspiration cytology (FNAC) findings were documented and classified as benign or malignant. Specific histopathological diagnoses included abscess, DCIS, fat necrosis, fibroadenoma, invasive ductal carcinoma, invasive lobular carcinoma, intraductal papilloma, malignant phyllodes tumor, sclerosing adenosis, and undifferentiated carcinoma.
Imaging results were then statistically correlated with histopathological outcomes to evaluate diagnostic performance.

Statistical Analysis

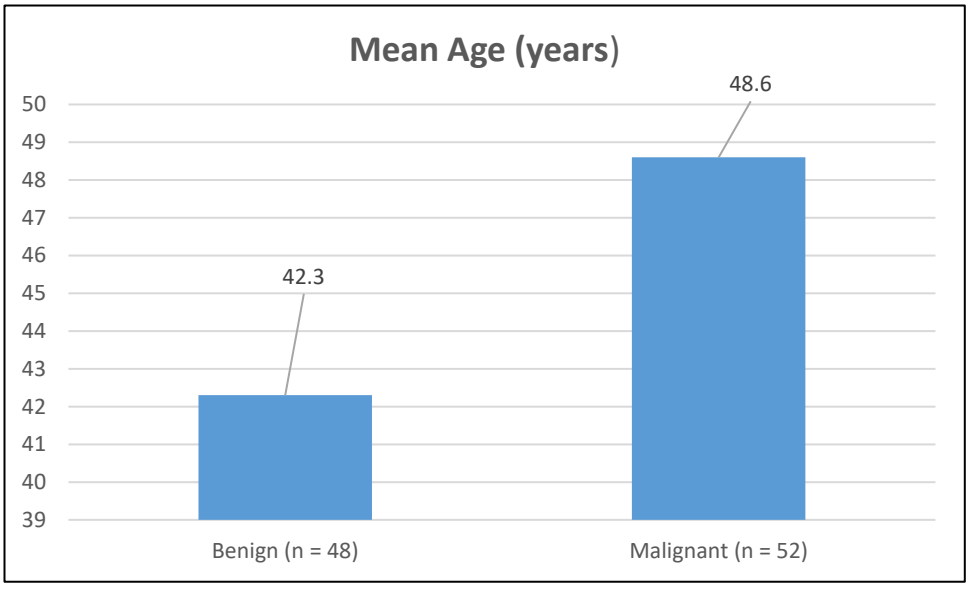
Data were recorded on physical proformas and compiled in a master chart using Microsoft Excel. Statistical analysis was performed using SPSS version 27.0 (IBM, Trialware, USA). Quantitative variables were expressed as mean ± standard deviation (SD), and qualitative variables were expressed as frequencies and percentages. Comparison of quantitative variables between groups was performed using the unpaired t-test, while qualitative variables were compared using the Chi-square test. Pearson's correlation coefficient was used to assess relationships between continuous variables. A p-value <0.05 was considered statistically significant, and results were presented using appropriate tables and graphs.

RESULT

A total of 100 female patients with breast lesions fulfilling the inclusion and exclusion criteria were included in the study. The mean age of the study population was 45.6 ± 11.2 years (range 22–68 years), with a median age of 46 years (IQR: 37–54). No statistically significant differences were observed in marital status or urban/rural residence between benign and malignant lesions (Table 1, Figure 1).

Table 1. Demographic and Clinical Characteristics of Study Population (n = 100)

Parameter	Benign (n = 48)	Malignant (n = 52)	Total (n = 100)	p-value	Statistical Test
Mean Age (years ± SD)	42.3 ± 10.6	48.6 ± 11.1	45.6 ± 11.2	0.004	Independent t-test
Married, n (%)	39 (81.3)	46 (88.5)	85 (85.0)	0.32	Chi-square
Urban residence, n (%)	31 (64.6)	36 (69.2)	67 (67.0)	0.62	Chi-square



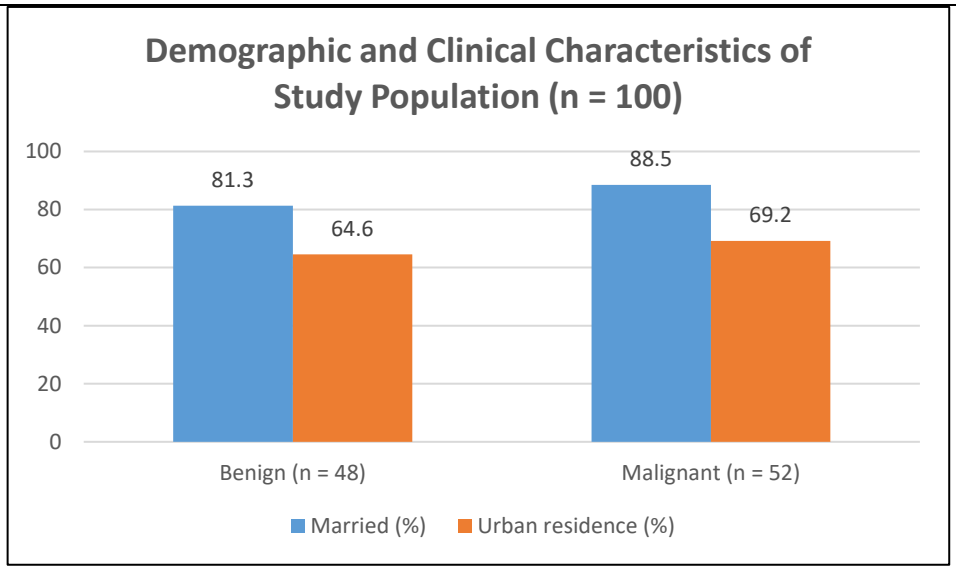


Figure 1 Demographic and Clinical Characteristics of Study Population (n = 100)

On mammography, irregular lesion shape was significantly more common in malignant cases, whereas oval and round shapes predominated in benign lesions. On MRI, malignant lesions were significantly larger and more often demonstrated spiculated margins compared to benign lesions (Table 2, Figure 2).

Table 2. Mammographic and MRI Features of Breast Lesions

Feature	Benign n (%)	Malignant n (%)	p-value	Statistical Test
Mammography – Shape			<0.001	Chi-square
Irregular	6 (12.5)	38 (73.1)		
Oval	28 (58.3)	9 (17.3)		
Round	14 (29.2)	5 (9.6)		
MRI – Lesion Size			<0.001	Chi-square
<2 cm	26 (54.2)	7 (13.5)		
2–5 cm	19 (39.6)	28 (53.8)		
≥5 cm	3 (6.2)	17 (32.7)		
MRI – Margins			<0.001	Chi-square
Circumscribed	29 (60.4)	5 (9.6)		
Spiculated	2 (4.2)	19 (36.5)		

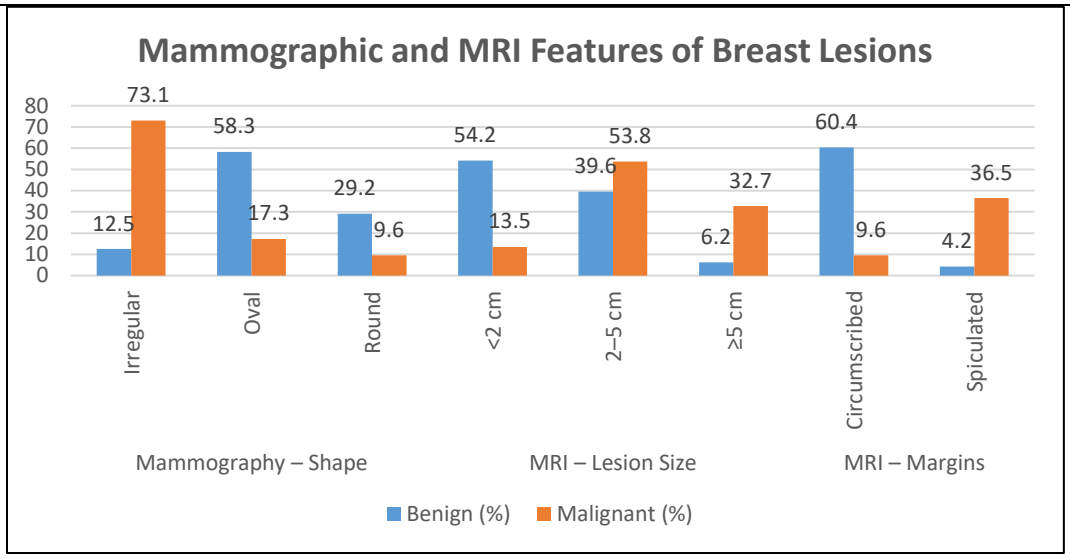


Figure 2 Mammographic and MRI Features of Breast Lesions

The diagnostic performance of the imaging modalities was assessed against histopathological findings. DWI demonstrated a sensitivity of 88.5%, specificity of 81.3%, and an overall diagnostic accuracy of 85.0%. DCE-MRI showed higher sensitivity (92.3%) but slightly lower specificity (79.2%) with an accuracy of 86.0%. The combined evaluation of DWI and DCE-MRI improved both sensitivity (96.2%) and specificity (87.5%), resulting in the highest diagnostic accuracy of 92.0% (Table 3).

Table 3. Diagnostic Performance of MRI Modalities

Modality	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	Accuracy (%)	p-value
DWI	88.5	81.3	83.6	86.7	85.0	<0.001
DCE-MRI	92.3	79.2	82.8	90.5	86.0	<0.001
Combined DWI + DCE-MRI	96.2	87.5	89.3	95.5	92.0	<0.001

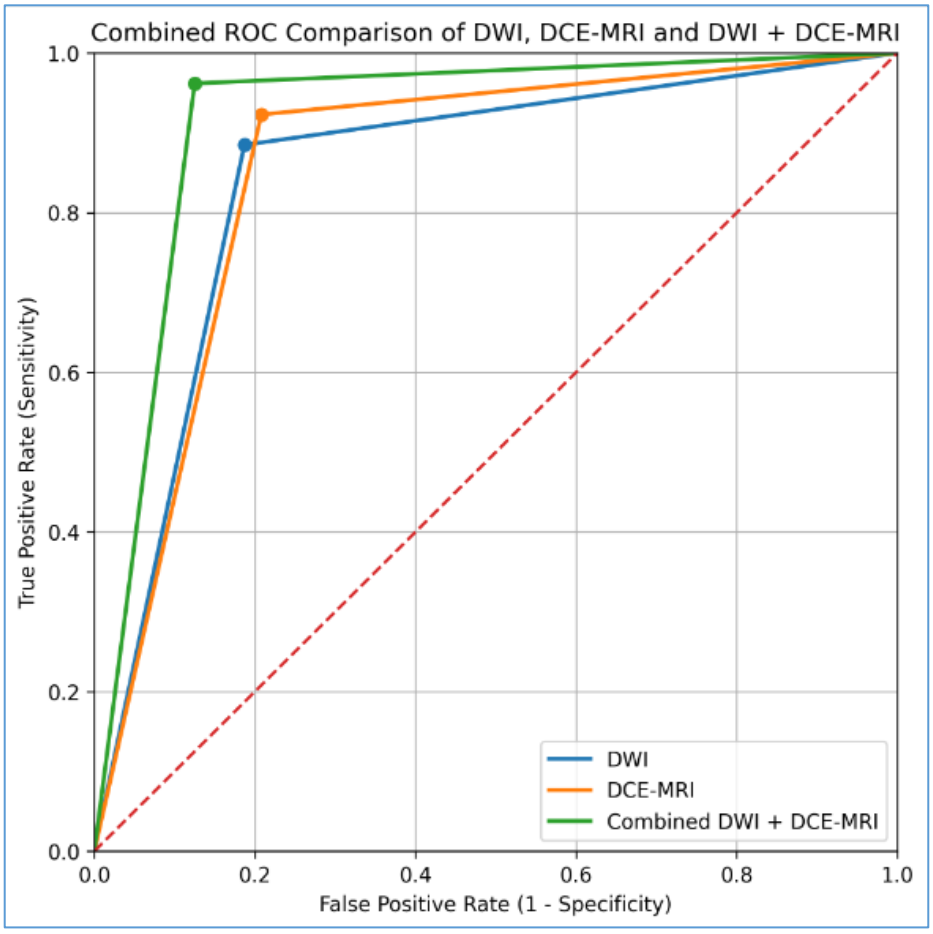


Figure 3: Diagnostic Performance of MRI Modalities

Quantitative analysis using ADC values revealed significantly lower values in malignant lesions compared to benign lesions across all b-values. The mean ADC for malignant lesions was 0.93 $\times 10^{-3}$ mm²/s compared to 1.45 $\times 10^{-3}$ mm²/s for benign lesions. ROC curve analysis demonstrated excellent discriminative ability, with an AUC of 0.94 for the mean ADC. A cut-off value of $\leq 1.00 \times 10^{-3}$ mm²/s provided a sensitivity of 92.3% and specificity of 87.5% (Table 4).

Table 4. ADC Values and Optimal Cut-offs for Differentiating Benign and Malignant Lesions

ADC Parameter (×10⁻³ mm²/s)	Benign Mean ± SD	Malignant Mean ± SD	Cut-off	Sensitivity (%)	Specificity (%)	AUC (95% CI)	p-value
ADC (b = 400)	1.54 ± 0.28	1.02 ± 0.21	≤1.15	84.6	81.3	0.88 (0.81–0.94)	<0.001
ADC (b = 800)	1.41 ± 0.24	0.94 ± 0.18	≤1.05	88.5	83.3	0.91 (0.85–0.96)	<0.001
Mean ADC	1.45 (1.32–1.58)	0.93 (0.84–1.05)	≤1.00	92.3	87.5	0.94 (0.89–0.98)	<0.001

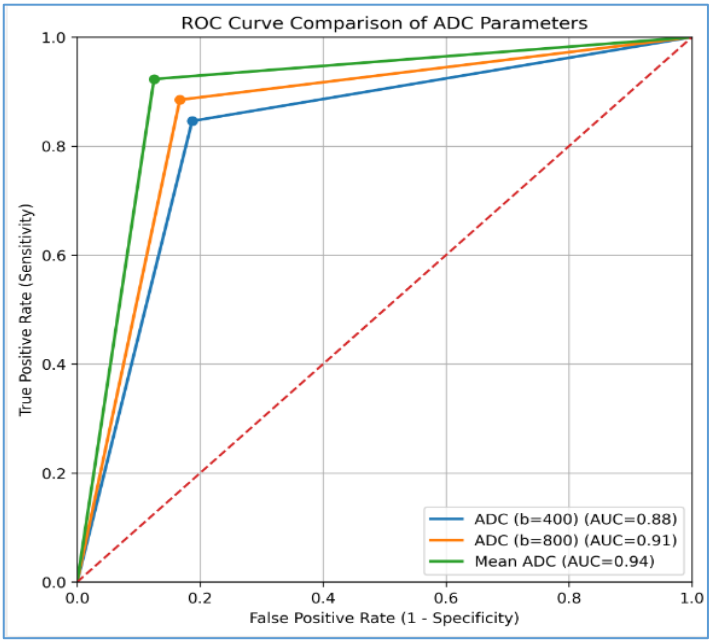


Figure 4: ADC Values and Optimal Cut-offs for Differentiating Benign and Malignant Lesions

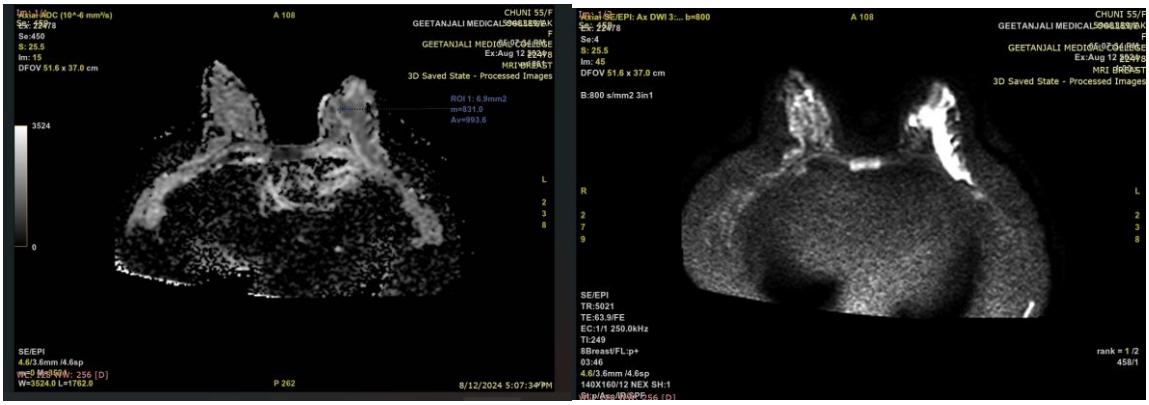


Figure 6: A well defined nodular lesion is noted in right breast with restricted diffusion and low values on ADC (0.9 x 10^6). On post contrast images lesion shows heterogenous enhancement with mild washout on delayed images (Type III DCE CURVE)

Discussion

In this study of 100 female patients with breast lesions, we found that diffusion-weighted imaging (DWI) combined with dynamic contrast-enhanced MRI (DCE-MRI) markedly improved the diagnostic distinction between benign and malignant lesions. Our mean ADC values were significantly lower in malignant compared with benign lesions (0.93×10^{-3} mm²/s vs. 1.45×10^{-3} mm²/s, $p < 0.001$), aligning closely with large published evidence. A comprehensive meta-analysis by Surov, Meyer, and Wienke et al(2019)[12] reported mean ADC values of 1.03×10^{-3} mm²/s for malignant lesions and 1.5×10^{-3} mm²/s for benign lesions across 13,847 lesions, and recommended an ADC threshold of approximately 1.00×10^{-3} mm²/s for differentiation, independent of field strength or b-values used .Several individual studies similarly support the discriminatory value of ADC. For example, Quinghua Min and colleagues found that using an ADC cut-off of 1.23×10^{-3} mm²/s produced high sensitivity and specificity for distinguishing malignant from benign lesions . Likewise, Cai et al.(2014)[13] demonstrated that ADC contributed significantly to diagnostic performance, particularly when combined with other imaging features in multiparametric evaluation . Our ROC analysis, showing an AUC of 0.94 for mean ADC with a cut-off $\leq 1.00 \times 10^{-3}$ mm²/s, supports these findings and suggests that quantitative diffusion metrics are robustbiomarkers in clinical practice.

Regarding diagnostic performance, DWI alone in our cohort showed sensitivity of 88.5% and specificity of 81.3%, and DCE-MRI alone had sensitivity of 92.3% and specificity of 79.2%. When combined, multiparametric MRI achieved improved sensitivity (96.2%) and specificity (87.5%), with diagnostic accuracy of 92.0%. These results are consistent with the work of Partridge et al.,(2011)[14] who demonstrated that combining ADC values with DCE-MRI kinetic parameters yields higher diagnostic accuracy than either technique alone, supporting the complementary nature of diffusion and perfusion imaging . Similarly, Pinker et al(2013)[15] and colleagues showed that combined DCE and DWI improved lesion classification when incorporated into BI-RADS-adapted multiparametric reading systems in larger cohorts at 3 T scanners .Our findings also resonate with the prospective study. Summarized in the meta-analysis by Surov et al.(2019)[12], wherein an ADC threshold around 1.00×10^{-3} mm²/s was recommended across varied study designs and protocols, highlighting the clinical utility of standardized ADC criteria. Tezcan et al.(2021)[16] demonstrated that an ADC cut-off of 0.89×10^{-3} mm²/s significantly improved the specificity of DCE-MRI for washout kinetic curve lesions, further emphasizing that ADC optimisation enhances diagnostic confidence and can reduce unnecessary biopsies .Although the role of ADC in non-mass enhancement (NME) lesions remains debated, with some authors reporting limited accuracy in such cases, these challenges were outside the primary focus of our cohort, which included predominantly mass lesions . Our results nevertheless underscore that DWI adds value beyond conventional contrast imaging, particularly when integrated into a multiparametric approach.
Published Literatur suggests some variability in optimal ADC thresholds based on scanner strength, b-value selection, and ROI technique. For instance, Wu et al.(2014)[13] and collaborators noted that different b-value combinations influenced ADC cut-off estimates but did not alter overall diagnostic performance markedly, echoing our choice of b-values (400 and 800 s/mm²) on a 3 T scanner.

Conclusion

Our study demonstrates that diffusion-weighted imaging (DWI) and dynamic contrast-enhanced MRI (DCE-MRI) are highly effective in differentiating benign from malignant breast lesions. Malignant lesions showed significantly lower ADC values, larger size, and spiculated margins, while combining DWI and DCE-MRI improved overall diagnostic accuracy to 92%. The mean ADC cut-off of $\leq 1.00 \times 10^{-3}$ mm²/s provided excellent sensitivity and specificity, reinforcing ADC as a reliable quantitative biomarker. Multiparametric MRI offers a noninvasive, reproducible approach that enhances lesion characterization and reduces unnecessary biopsies. These findings support the integration of DWI with DCE-MRI in routine breast imaging to optimize early detection and management of breast cancer.

Limitations

This study was conducted at a single center with a relatively small sample size, which may limit the generalizability of the findings. ADC values can be influenced by scanner parameters, b-values, and ROI placement, potentially introducing variability. Non-mass enhancement lesions were underrepresented, limiting assessment in this subgroup. Long-term follow-up to evaluate clinical outcomes and recurrence was not performed. Future multicenter studies with standardized protocols and larger cohorts are needed to validate these results.

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