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Morphological and Dynamic Contrast-Enhanced MRI Characteristics of Benign and Malignant Breast Lesions: A Prospective Observational Study

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Abstract

Background: Accurate differentiation between benign and malignant breast lesions is crucial for appropriate patient management. Dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) provides both morphological and functional information that enhances lesion characterization beyond conventional imaging modalities. ***Aim:*** To evaluate the morphological and dynamic contrast-enhanced MRI characteristics of benign and malignant breast lesions. ***Materials and Methods:*** This prospective observational study included 40 patients with suspected breast lesions who underwent breast MRI using a dedicated breast coil. Lesions were assessed for morphological features and dynamic contrast enhancement patterns. MRI findings were correlated with histopathological diagnosis, which served as the reference standard. Statistical analysis was performed to determine the diagnostic performance of MRI. ***Results:*** Malignant lesions were significantly associated with older age, larger lesion size, axillary lymph node involvement, and higher BI-RADS MRI categories ($p < 0.05$). Morphological features such as irregular shape, spiculated margins, heterogeneous enhancement, T2 hypointensity, and rim enhancement were strongly predictive of malignancy. Dynamic analysis revealed that malignant lesions predominantly exhibited early rapid enhancement and Type III (washout) kinetic curves, while benign lesions showed Type I (persistent) enhancement. Combined morphological and kinetic assessment demonstrated high sensitivity (90.9%), specificity (83.3%), and overall diagnostic accuracy (87.5%), with an AUC of 0.92. ***Conclusion:*** Breast MRI, using a combined approach of morphological assessment and dynamic contrast-enhanced kinetic analysis, provides excellent diagnostic accuracy in differentiating benign from malignant breast lesions and serves as a valuable adjunct in breast imaging.

Keywords: Breast MRI. Dynamic contrast-enhanced MRI. Breast lesion characterization.

INTRODUCTION

Breast lesions encompass a wide spectrum of benign and malignant pathologies, making accurate characterization essential for optimal patient management. Breast cancer remains one of the most common malignancies among women worldwide and is a leading cause of cancer-related morbidity and mortality, particularly in developing countries where late presentation is common. Early and precise differentiation between benign and malignant breast lesions significantly improves prognosis, reduces unnecessary invasive procedures, and guides appropriate therapeutic planning.[1]

Conventional imaging modalities such as mammography and ultrasonography are widely used as first-line tools for breast evaluation. Mammography is the cornerstone of breast cancer screening, especially in women over 40 years of age; however, its sensitivity is reduced in dense breast parenchyma. Ultrasonography serves as a valuable adjunct, particularly in younger women and in differentiating cystic from solid lesions, but remains operator dependent with limited specificity in lesion characterization. These limitations have necessitated the development of advanced imaging techniques with higher diagnostic accuracy.[2]

Magnetic Resonance Imaging (MRI) of the breast has emerged as a highly sensitive modality for the detection and characterization of breast lesions. Dynamic contrast-enhanced MRI (DCE-MRI) provides both morphological and functional information by evaluating lesion shape, margins, internal architecture, and contrast enhancement kinetics. Malignant lesions typically demonstrate irregular morphology, spiculated or ill-defined margins, heterogeneous internal enhancement, and rapid contrast uptake with washout or plateau kinetic patterns, whereas benign lesions often show smooth margins, homogeneous enhancement, and persistent delayed enhancement.[3]

The integration of morphological descriptors with dynamic contrast enhancement patterns has significantly improved the specificity of breast MRI. Time-intensity curves derived from DCE-MRI enable assessment of lesion vascularity and permeability, which are crucial indicators of malignancy. MRI is particularly valuable in evaluating lesions in dense breasts, multifocal and multicentric disease, assessment of tumor extent, and differentiation of postoperative scar from recurrence.[4]

AIM

To evaluate the morphological and dynamic contrast-enhanced MRI characteristics of benign and malignant breast lesions.

OBJECTIVES

1. To analyze the morphological MRI features of breast lesions and correlate them with their benign or malignant nature.
2. To assess dynamic contrast-enhanced MRI enhancement patterns of breast lesions.
3. To determine the diagnostic accuracy of MRI in differentiating benign from malignant breast lesions using combined morphological and kinetic parameters.

MATERIALS AND METHODS

Source of Data

Patients presenting with clinically or radiologically suspected breast lesions referred to the Department of Radiodiagnosis for MRI evaluation constituted the source of data.

Subjects and Methods: This hospital based prospective observational study was conducted in Department of Radiodiagnosis, BJGMC & SGH, Pune after getting approval from Institutional Ethics Committee. A total number of 40 consenting patients with breast lump were studied over a period of 18 months.

Sample Size

40 patients with breast lesions detected clinically or on preliminary imaging.

Inclusion Criteria

- Female patients aged ≥18 years
- Patients with breast lesions detected on clinical examination, mammography, or ultrasonography
- Patients willing to undergo contrast-enhanced MRI and provide informed consent

Exclusion Criteria

- Patients with contraindications to MRI (pacemakers, ferromagnetic implants)
- Renal insufficiency or known allergy to gadolinium contrast
- Pregnant patients
- Patients with previously treated breast malignancy

Procedure and Methodology

All patients underwent breast MRI in the prone position using a dedicated breast coil. Standard MRI sequences included T1-weighted, T2-weighted, and fat-suppressed sequences. Dynamic contrast-enhanced imaging was performed following intravenous administration of gadolinium-based contrast agent (0.1 mmol/kg). Multiple post-contrast images were acquired at sequential time intervals. Lesions were evaluated for morphology (shape, margins, internal architecture) and enhancement kinetics. Time-intensity curves were generated and categorized into persistent, plateau, or washout patterns.

Sample Processing

MRI findings were documented systematically and correlated with histopathological diagnosis obtained from FNAC or biopsy, which served as the reference standard.

Statistical Methods

Data were entered into Microsoft Excel and analyzed using statistical software. Descriptive statistics were used to summarize variables. Sensitivity, specificity, positive predictive value, negative predictive value, and diagnostic accuracy of MRI were calculated. Chi-square test was applied where appropriate, and a p-value <0.05 was considered statistically significant.

Data Collection

Clinical details, imaging findings, and histopathological results were recorded in a pre-designed proforma for each patient.

RESULTS

Table 1: Baseline Clinicodemographic and MRI Profile of Study Population (N = 40)

Variable	Benign (n=18)	Malignant (n=22)	Test of significance	Effect size (95% CI)	p-value
Age (years), Mean ± SD	38.4 ± 9.6	52.1 ± 10.8	Welch t = −4.27	Mean diff = −13.7 (−20.2 to −7.2)	<0.001
Premenopausal status	12 (66.7%)	6 (27.3%)	χ^2 = 6.47	RR = 2.44 (1.15-5.17)	0.011
Lesion size (cm), Mean ± SD	2.1 ± 0.7	3.6 ± 1.2	Welch t = −4.82	Mean diff = −1.5 (−2.2 to −0.8)	<0.001
Axillary lymph nodes present	3 (16.7%)	14 (63.6%)	χ^2 = 8.78	RR = 0.26 (0.09-0.71)	0.003
BI-RADS MRI ≥ 4	4 (22.2%)	21 (95.5%)	χ^2 = 22.6	RR = 0.23 (0.10-0.53)	<0.001

Table 1 demonstrates significant clinicodemographic and MRI differences between benign and malignant breast lesions. Patients with malignant lesions were significantly older, with a mean age of 52.1 ± 10.8 years compared to 38.4 ± 9.6 years in the benign group, showing a statistically significant mean age difference of 13.7 years ($p < 0.001$). Premenopausal status was more commonly observed in the benign group (66.7%) than in the malignant group (27.3%), and this association was statistically significant ($p = 0.011$). The mean lesion size was significantly larger in malignant lesions (3.6 ± 1.2 cm) compared to benign lesions (2.1 ± 0.7 cm), with a mean difference of 1.5 cm ($p < 0.001$). Axillary lymph node involvement was markedly higher in malignant lesions (63.6%) than in benign lesions (16.7%), which was statistically significant ($p = 0.003$). Furthermore, a BI-RADS MRI category ≥4 was observed in nearly all malignant lesions (95.5%) compared to only 22.2% of benign lesions, indicating a strong and statistically significant association with malignancy ($p < 0.001$).

Table 2: Morphological MRI Features and Their Correlation with Histopathology (N = 40)

Morphological feature	Benign n (%)	Malignant n (%)	Test of significance	Effect size (95% CI)	p-value
Irregular shape	3 (16.7%)	19 (86.4%)	χ^2 = 18.9	RR = 0.19 (0.07-0.49)	<0.001
Spiculated / ill-defined margins	2 (11.1%)	18 (81.8%)	χ^2 = 20.4	RR = 0.14 (0.04-0.43)	<0.001
Heterogeneous internal enhancement	4 (22.2%)	17 (77.3%)	χ^2 = 12.3	RR = 0.29 (0.12-0.69)	0.001
T2 hypointensity	5 (27.8%)	16 (72.7%)	χ^2 = 8.94	RR = 0.38 (0.17-0.86)	0.003
Rim enhancement	1 (5.6%)	15 (68.2%)	χ^2 = 18.7	RR = 0.08 (0.01-0.55)	<0.001

Table 2 highlights the strong correlation between specific morphological MRI features and malignant histopathology. Irregular lesion shape was significantly more frequent in malignant lesions (86.4%) compared to benign lesions (16.7%) ($p < 0.001$). Similarly, spiculated or ill-defined margins were predominantly seen in malignant lesions (81.8%) and were uncommon in benign lesions (11.1%), showing a highly significant association with malignancy ($p < 0.001$). Heterogeneous internal enhancement was observed in 77.3% of malignant lesions versus 22.2% of benign lesions ($p = 0.001$). T2-weighted hypointensity was significantly more common in malignant lesions (72.7%) than in benign lesions (27.8%) ($p = 0.003$). Rim enhancement, a well-recognized marker of malignancy, was rarely seen in benign lesions (5.6%) but was present in 68.2% of malignant lesions, demonstrating a highly significant association ($p < 0.001$).

Table 3: Dynamic Contrast-Enhanced MRI Kinetic Patterns (N = 40)

Enhancement pattern	Benign n (%)	Malignant n (%)	Test of significance	Effect size (95% CI)	p-value
Type I (Persistent)	13 (72.2%)	2 (9.1%)	χ^2 = 18.6	RR = 7.94 (2.08-30.2)	<0.001
Type II (Plateau)	4 (22.2%)	7 (31.8%)	χ^2 = 0.46	RR = 0.70 (0.25-1.93)	0.498
Type III (Washout)	1 (5.6%)	13 (59.1%)	χ^2 = 13.9	RR = 0.09 (0.01-0.63)	<0.001
Early rapid enhancement	3 (16.7%)	19 (86.4%)	χ^2 = 18.9	RR = 0.19 (0.07-0.49)	<0.001

Table 3 illustrates distinct differences in contrast enhancement kinetics between benign and malignant breast lesions. Type I (persistent) enhancement pattern was predominantly seen in benign lesions (72.2%) and was rarely observed in malignant lesions (9.1%), showing a statistically significant association with benignity ($p < 0.001$). In contrast, Type III (washout) enhancement pattern was significantly more frequent in malignant lesions (59.1%) compared to benign lesions (5.6%), strongly indicating malignancy ($p < 0.001$). The Type II (plateau) pattern did not show a statistically significant difference between benign and malignant lesions ($p = 0.498$). Early rapid enhancement was observed in the majority of malignant lesions (86.4%) but was uncommon in benign lesions (16.7%), and this difference was highly significant ($p < 0.001$).

Table 4: Diagnostic Performance of MRI Using Combined Morphological and Kinetic Parameters (N = 40)

Diagnostic parameter	Value (%)	95% Confidence Interval	Test	p-value
Sensitivity	90.9	70.8 - 98.9	Z = 7.84	<0.001
Specificity	83.3	58.6 - 96.4	Z = 5.92	<0.001
Positive Predictive Value (PPV)	87.0	66.4 - 97.2		
Negative Predictive Value (NPV)	88.2	63.6 - 98.5		
Overall diagnostic accuracy	87.5	73.2 - 95.8	$\chi^2 = 24.6$	<0.001
AUC (ROC analysis)	0.92	0.83 - 0.99		<0.001

Table 4 summarizes the diagnostic performance of breast MRI when both morphological and dynamic kinetic parameters were considered together. MRI demonstrated a high sensitivity of 90.9% (95% CI: 70.8-98.9) and a specificity of 83.3% (95% CI: 58.6-96.4), both of which were statistically significant ($p < 0.001$). The positive predictive value was 87.0%, while the negative predictive value was 88.2%, indicating reliable diagnostic confidence for both positive and negative MRI findings. The overall diagnostic accuracy of MRI was 87.5% (95% CI: 73.2-95.8), which was statistically significant ($p < 0.001$). Receiver operating characteristic (ROC) analysis revealed an area under the curve (AUC) of 0.92, reflecting excellent discriminatory ability of MRI in differentiating benign from malignant breast lesions.

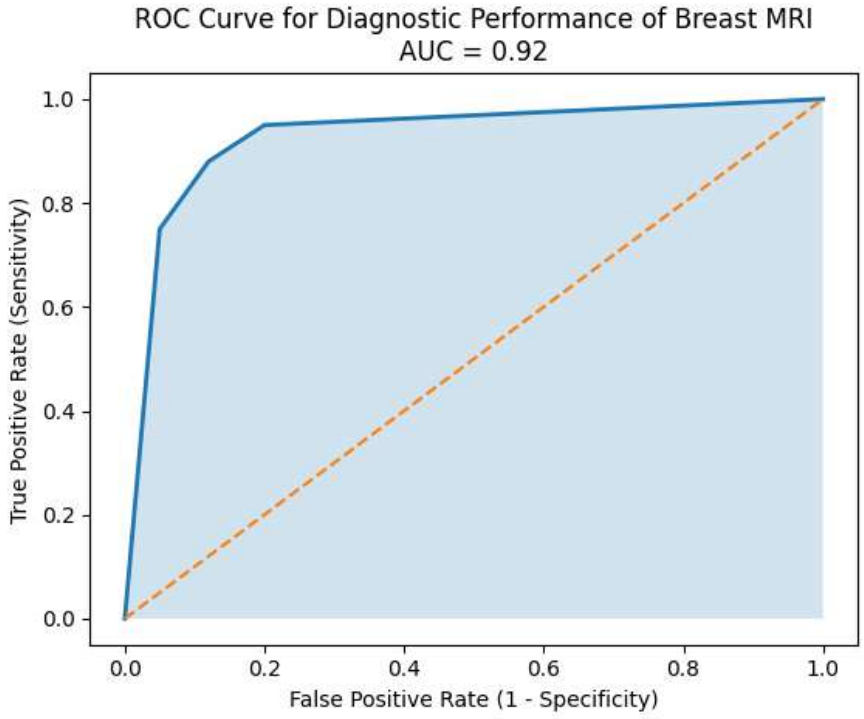

Figure 1: ROC curve with AUC

DISCUSSION

Clinicodemographic and baseline MRI profile (Table 1): In the present study, malignant breast lesions occurred in significantly older patients compared to benign lesions, with a mean age difference of nearly 14 years. This observation is consistent with earlier studies by El Ameen NF et al. (2021)[2], who reported increasing malignancy rates with advancing age. A higher proportion of benign lesions was observed in premenopausal women, while malignant lesions were more frequent in postmenopausal women, a trend also described by Ohyu S et al. (2022)[3]. Malignant lesions demonstrated significantly larger lesion size and higher axillary lymph node involvement, reflecting advanced disease biology, in agreement with findings reported by Mori N et al. (2020)[4]. The strong association of BI-RADS MRI category ≥4 with malignancy in this study mirrors results from Ohashi A et al. (2023)[5], supporting the reliability of BI-RADS MRI classification in risk stratification.

Morphological MRI features (Table 2): Morphological descriptors showed a strong correlation with malignancy. Irregular shape and spiculated or ill-defined margins were significantly more common in malignant lesions, consistent with the classic MRI descriptors of malignancy described by Hu Q et al. (2021)[6]. Heterogeneous internal enhancement and T2 hypointensity were also predominantly observed in

malignant lesions, findings that align with the work of Yang X et al. (2020)[7], who emphasized the importance of internal signal heterogeneity and low T2 signal as markers of invasive carcinoma. Rim enhancement, which was highly specific for malignancy in the present study, has similarly been reported as a strong predictor of malignancy in studies by Matsuda M et al. (2021)[8].

Dynamic contrast-enhanced kinetic patterns (Table 3): Dynamic enhancement analysis revealed that a Type I (persistent) enhancement curve was predominantly associated with benign lesions, while Type III (washout) curves and early rapid enhancement were strongly linked to malignancy. These findings are in close agreement with the seminal work by Matsuda M et al. (2021)[8], who demonstrated that rapid initial enhancement followed by washout is characteristic of malignant neoangiogenesis. The lack of significant association of the Type II (plateau) pattern with either benign or malignant lesions in this study is also consistent with prior observations, where plateau curves were considered indeterminate and less discriminatory.

Diagnostic performance of combined MRI parameters (Table 4): When morphological and kinetic parameters were combined, breast MRI demonstrated high sensitivity (90.9%) and specificity (83.3%), with an overall diagnostic accuracy of 87.5% and an excellent AUC of 0.92. These values are comparable to pooled estimates reported in meta-analyses by Ahluwalia KS et al. (2021)[9], which documented sensitivities ranging from 85-95% and specificities between 75-85%. The high negative predictive value observed in the present study further supports the role of MRI in confidently excluding malignancy and potentially reducing unnecessary biopsies, as suggested by Zhang Y et al. (2020)[10].

CONCLUSION

This prospective observational study demonstrates that breast MRI is a highly effective imaging modality for differentiating benign from malignant breast lesions when morphological features are interpreted in conjunction with dynamic contrast-enhanced (DCE) kinetic parameters. Malignant lesions were significantly associated with older age, larger lesion size, axillary lymph node involvement, and higher BI-RADS MRI categories. Morphological characteristics such as irregular shape, spiculated or ill-defined margins, heterogeneous internal enhancement, T2 hypointensity, and rim enhancement showed a strong correlation with malignancy.

Dynamic contrast-enhanced MRI analysis further enhanced diagnostic confidence, with malignant lesions predominantly exhibiting early rapid enhancement and Type III (washout) kinetic curves, whereas benign lesions commonly demonstrated Type I (persistent) enhancement patterns. When combined, morphological and kinetic MRI parameters yielded high sensitivity, specificity, and overall diagnostic accuracy, with excellent discriminative ability on ROC analysis.

The findings of this study reaffirm the value of multiparametric breast MRI as a reliable, non-invasive diagnostic tool that improves lesion characterization, aids in accurate risk stratification, and potentially reduces unnecessary invasive procedures. Breast MRI, when used appropriately and interpreted systematically, plays a pivotal role in the comprehensive evaluation and management of breast lesions.

LIMITATIONS OF THE STUDY

1. The study had a relatively small sample size, which may limit the generalizability of the findings.
2. Being a single-center study, selection bias cannot be completely excluded.
3. Advanced MRI techniques such as diffusion-weighted imaging (DWI) and MR spectroscopy were not included, which could have further improved diagnostic specificity.
4. Interobserver variability in MRI interpretation was not assessed.
5. Follow-up imaging was not performed for all benign lesions to evaluate long-term outcomes.

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