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Can early post-operative MRI describe a predictor model for the likelihood of early breast cancer recurrence after conservative surgery?

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Abstract

Background Breast-conserving surgery is becoming more commonly used in breast cancer treatment. However, after surgery, the breast may undergo rapid changes that can sometimes hide signs of tumor recurrence. Breast MRI is highly sensitive and specific in detecting any residual or recurrent tumors after breast-conserving therapy, making it an effective tool in the management of breast cancer. We aimed to assess the detectability of DCE-MRI in breast cancer female patients following breast conservative surgery (after a minimum of 1–4 months post-operative) to confirm complete tumor removal and differentiate between post-procedural complications and metachronous cancer in the ipsilateral or contralateral breast.

Methods This retrospective study was conducted from March 2017 to December 2023 on 269 patients. All cases had undergone breast conservative surgery and were suspected of either recurrence or post-operative complications by clinical examination and/or sono-mammography. DCE-MRI was performed at 1.5T. The findings were correlated with the histopathological results in all cases.

Results Patients' mean age was 50.7 years with 389 suspected breast lesions, post-surgical traumatic fat necrosis was the most common benign finding (75.8%), and most common histological type in malignant cases was invasive mammary carcinoma (15.2%). Sensitivity and specificity of MRI BI-RADS to differentiate benign from malignant lesions were 100%. The best ADC cutoff value to differentiate between benign and malignant lesions was 1.25×10^{-3} mm^2/s. The model of predictors of likelihood of malignant lesion nature had sensitivity 77%, specificity 77.8%, PPV 90% and NPV 96.7%.

Conclusions MRI proved crucial in assessing patients after BCS. DWI can be included in patients with negative sono-mammographic examination for initial lesions detection without the need of contrast media, yet DCE MRI is mandatory in case of lesion characterization to delineate its nature, thus it cannot be replaced by DWI alone.

Keywords Breast cancer, Sono-mammogram, MRI breast, Time–intensity curve, Post-conservative breast surgery

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Background

Breast conservative surgery is being integrated into the management of breast cancer in an increasing manner [1].

After breast surgery, the treated breast undergoes rapid changes. These changes can include masses, traumatic fat necrosis, fluid collections, architectural distortion, scarring, edema, skin thickening, and calcifications. These changes can sometimes mimic or mask local tumor recurrence. Radiation therapy can worsen these changes and delay their resolution. Therefore, there is a significant overlap between post-operative changes and local tumor recurrence, making it difficult to differentiate between the two [1].

When a tumor reappears in a breast that has been treated conservatively, it may come recure at the site where the original lump was removed, at the edge of the surgical area, or in other areas of the breast. Studies have shown that the ability of mammography to detect tumors in a breast that has been treated with radiation therapy may be somewhat reduced due to increased density, surgical changes, and the presence of dense breast tissue, especially in younger patients. However, in some cases, the presence of microcalcifications may make it easier to diagnose the recurrence [1].

Mammography and breast ultrasound are two common methods used for the detection of breast cancer. However, these methods have limited sensitivity in differentiating between spiculated scar and tumor recurrence or between therapy-induced edema and lymphangitic spread of the cancer. In addition, breast US may also be problematic due to hypoechoic areas, fat necrosis, and insufficient distinction between diffuse acoustic shadowing caused by scar tissue and breast cancer. Furthermore, the sensitivity of these methods is limited when evaluating small or noninvasive lesions [2].

Breast MRI has high sensitivity and specificity for detecting residual and recurrent tumors after breast-conserving therapy [3, 4].

Breast MRI is useful in distinguishing between scar tissue and tumor recurrence. Non-enhancing areas have a high negative predictive value for cancer [5].

The dynamic enhancement pattern, combined with morphology on contrast-enhanced MRI, allows precise lesion characterization [2]. Some researchers have explored the use of DWI (diffusion-weighted imaging) as a potential way to address the limitations of MRI (magnetic resonance imaging) in certain assessments [6].

Aim of work

To evaluate the detectability of DCE-MRI in breast cancer female patients following breast conservative surgery (after a minimum of 1–4 months post-operative) to confirm complete removal of the tumor and differentiate between post-procedural complications and metachronous cancer in the ipsilateral or contralateral breast.

Methods

This is a retrospective study that was approved by the institutional Research Board.

Study population

We reviewed the reports in the period from March 2017 and December 2023 and found that there were 269 cases (15% of total breast MRI scans) underwent breast MRI scans within 1–4 months after breast-conserving surgery after being pathologically diagnosed with breast cancer. The patients were referred from the Oncology Center and Outpatient Surgery Clinic. These cases had 389 suspected breast lesions. The patients' ages ranged from 30 to 70 years, with a mean age of 50.7 years.

Patients' selection

The study included patients who met certain criteria, such as those who showed BI-RADS 2 or 3 on follow-up radiology, or those with suspicious breast lesions that were suspected to be a recurrence, either ipsilateral or contralateral. The suspicion could be either clinical, such as patients with bloody nipple discharge, hard palpable mass, or palpable axillary lymph nodes, or radiological, such as those with mammography and/or sonographic examination BI-RADS 4 or 5.

The exclusion criteria for this study were as follows: patients with poor general health, uncooperative patients, those suffering from severe claustrophobia, patients with a contraindication to contrast media, patients who have undergone a breast biopsy within the past month, and patients who have a contraindication for MRI due to a cardiac pacemaker, cochlear implant, or ocular foreign body.

Imaging

All patients underwent:

Clinical assessment

All patients underwent a comprehensive clinical assessment, including age, complaints, and medical history. The evaluation included a thorough examination of the breast and axillary lymph nodes. Past treatments, such as surgery, chemotherapy, radiotherapy, and hormonal therapy, were also recorded.

MRI procedure

A breast MRI was conducted on a 1.5 Tesla machine with a dedicated breast coil, with patients in a prone position. The imaging protocol involved a conventional MR study, which included axial T1 and T2 weighted imaging, with suppression of the signal from adipose tissue by STIR. Additionally, DWI was acquired using a multi-section single-shot SE EPI sequence with b values of 0, 500, and 1000 mm^2/sec, including the calculation of the ADC map. Furthermore, dynamic post-contrast imaging was performed using axial GRE-T1W1 with the FAT-SAT technique after administration of a contrast agent. A bolus of gadopentetate dimeglumine in a dose of 0.1–0.2 mmol/kg was injected using an automated injector at a rate of 3–5 ml/s through an 18–20 gauge intravenous cannula inserted in the antecubital vein, followed by a bolus injection of saline (total of 20 ml at 3–5 ml/s). The dynamic study consisted of one pre-contrast and 5 post-contrast series, each of which took about 1.15 min.

Post-processing of images includes creating time-to-signal intensity curves to enhance lesions and subtracting images in-line using the MIP algorithm in axial, coronal, and sagittal projections.

Imaging analysis

The analysis of breast images was carried out by a minimum of two experienced radiologists ranging from 7 to 12 years of experience. They evaluated not only the detectability of the lesions but also their imaging characteristics such as their morphology (mass or non-mass like enhancement) and enhancement dynamics (kinetics). The signal-to-time curve was defined to assess the enhancement dynamics. Based on these characteristics, the lesions were classified as suspicious or non-suspicious findings according to the BI-RADS 5th edition.

- *Category 2*: Benign finding.
- *Category 3*: Probably benign finding.
- *Category 4*: Suspicious for malignancy (4A: low suspicious, 4B: moderate suspicious, 4C: high suspicious).
- *Category 5*: Highly suggestive of malignancy.

The reported diagnosis was confirmed by histopathology of specimens obtained by excision biopsy or core biopsy.

Statistical analysis

The data were tabulated, coded and then analyzed using the SPSS version 25.0.

Descriptive statistics were calculated in the form of: Mean ± Standard deviation (SD), Median and IQR (Minimum–maximum) and frequency (Number-percent).

Analytical statistics: In the statistical comparison between the different groups, the significance of difference was tested using one of the following tests: Student's *t* test, Whitney U-test, Chi square test or Fisher's exact test, Shapiro–Wilk's test, Spearman's correlation, Binary Logistic regression (Univariate logistic regression) or Multivariate logistic regression.

The sensitivity, specificity, positive predictive value, negative predictive value and accuracy were calculated. ADC was examined at different cutoff points using receiver operating characteristic (ROC) curve analysis to determine the best cutoff point as well as the diagnostic power of each test. The P value ≤ 0.050 was considered statistically significant.

Results

Between March 2017 and December 2023, 1784 breast MRI scans were conducted on 1542 women. Of these, 269 women (15% of total breast MRI scans) underwent breast MRI scan within 1–4 months of breast-conserving surgery. The average age of the patients was 50.7 years (ranging from 30 to 70 years).

After reviewing the breast MRI scans of these patients, it was discovered that 35% of them had one lesion only, while 65% had two or more lesions. Out of the total lesions found, 90.4% (352 lesions) were benign, while 15.2% (37 lesions) were malignant. The mean age for malignant lesions was slightly higher 50 (43–62) than that for benign lesions 48 (44–57) and the difference was not statistically significant (P value 0.647) as well as there was no statistically significant correlation between patients' age and number of lesions. The average time from BCS until post-operative breast MRI was 48.5 days (ranging from 22 to 115 days). Please refer to Table 1 for the demographic of the study population.

Lesions detectability

Two cases that were pathologically proved to be benign by surgical biopsy were excluded as there was marked

Table 1 Baseline demographics

Parameter	Frequency (%)
Average patient age	50.7 (range 30–70)
Presentation type	
Follow-up	300 (77.1%)
Symptomatic: Palpable lesion	69 (17.7%)
Increase breast size	10 (2.5%)
Bloody nipple discharge	5 (1.3%)
Clear nipple discharge	5 (1.3%)
Histopathological type of benign lesions	352 (90.4%)
Traumatic fat necrosis	295 (75.8%)
Fibroadenoma	20 (5.1%)
Scar tissue post-conservative changes	37(9.5%)
Histopathological type of malignant lesions	37 (15.2%)
Invasive mammary carcinoma	13 (3.3%)
Grade II invasive ductal carcinoma	6 (1.6%)
Grade III invasive ductal carcinoma	6 (1.6%)
Invasive lobular carcinoma	6 (1.6%)
Nodal recurrence	6 (1.6%)

breast edema in early post-operative breast MRI and no definite underlying lesions could be detected.

MRI imaging analysis

Breast MRI results showed that patients with right sided BCS had 95.6% lesions on right side and 4.4% lesions on left side (were fibroadenomas on histopathology) and those with left sided BCS had 96.4% lesions on left side and 3.6% lesion on right side (was also fibroadenoma on histopathology). While those with bilateral BCS had 67.7% lesions on right side and 33.3% lesions on the left side (all were traumatic fat necrosis on histopathology) (Fig. 1). In this study, the most common site for breast lesions was the UOQ were 44 (55.7%) lesions followed by the UIQ were 8 (10.1%) lesions. After BCS was found that 340 lesions were related to the surgical bed & 47 lesions away from the surgical bed. The 340 lesions related to surgical bed included were 312 benign and 28 malignant & the 47 lesions away from the surgical bed included 38 were benign and 9 were malignant. The mean size for malignant lesions (1.85 ± 1.4) cm^3 was slightly higher than that for benign Lesions (1.66 ± 1.07) cm^3 & the difference was not statistically significant. Regarding the form of the lesions, 357 cases were mass lesions (329 cases were benign and 28 cases were malignant) and 30 cases were non-mass lesions (21 cases were benign and 9 cases were malignant), showing that non-mass lesions are more likely to be associated with malignancy, as compared to mass lesions. In the case of mass lesions, the MRI features of benign lesions showed that as regards the lesion's shape it could be irregular, oval, or rounded in the case of benign lesions the most common shape was the most round-shaped masses (77.2%) & in case of malignant lesions the most common shape was irregular shaped masses (77.8%). As regards lesions margins could be non-circumscribed, partially circumscribed, or well-circumscribed in the case of benign lesions the most common were well-circumscribed margins (77.1%) and in the case of malignant lesions the most common were non-circumscribed margins (77.2%). As regards the enhancement patterns could be either homogeneous, heterogeneous, homogeneous progressive, marginal, thick marginal, or non-enhancing in the case of benign lesions the most common pattern was marginal enhancement (50.7%), and in the case of malignant lesions, most common were heterogeneous enhancement (77.2%). In the case of non-mass lesions, MRI features of benign lesions showed that the most common appearance was non-enhancing linear distribution (75%), while MRI features of malignant lesions showed that the most common appearance was heterogeneous segmental distribution (66.7%) (Figs. 2 and 3). As regards the associated enlarged axillary lymph nodes (LNs) out of the 350 benign cases, 63 of them had enlarged axillary LNs; on the other hand, out of 37 malignant cases, 34 of them had enlarged axillary LNs either ipsilateral or contralateral. As regards lesions' enhancement kinetics, the most common curve in the benign lesions was type I curve 198 (56.5%) while in the malignant lesions the most common curve with type II curve 21 (56.8%). On diffusion study most of the

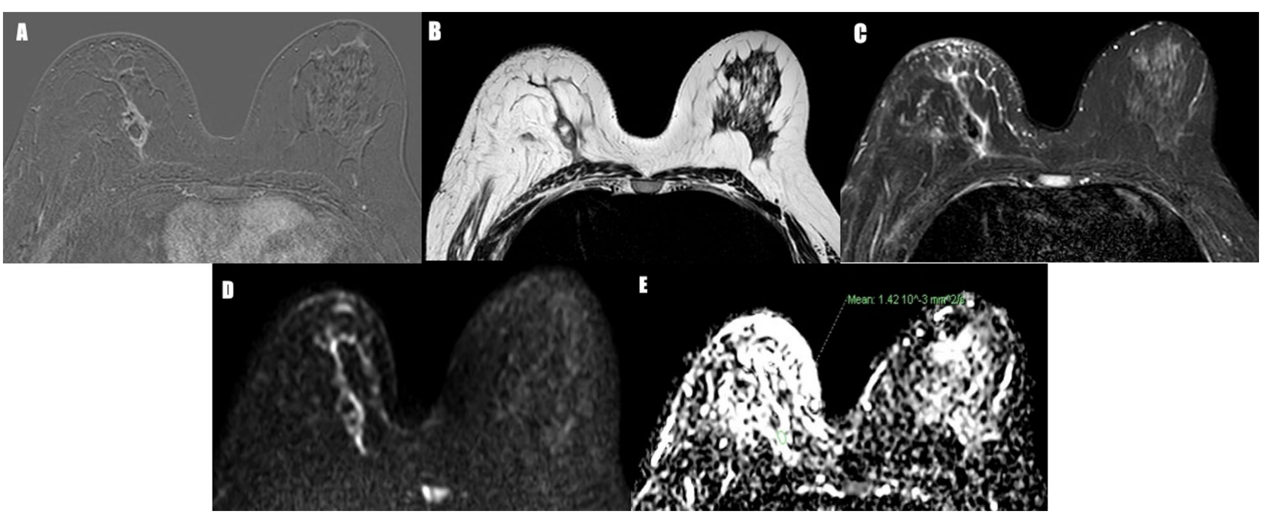

Fig. 1 45 years old female with a history of right breast mastectomy with latissimus dorsi flap reconstruction 2 months ago, complained of right breast pain and hardness, ultrasound was done revealing an intact flap with marked edema and shadowing at the operative bed, MRI was done, and revealed: **A** STIR image: The right breast shows minimal subcutaneous and interstitial edema with a posteriorly located lesion of low SI. **B** T2WI: The right breast post-operative lesion of high SI with a medially related area of low SI. **C** Subtracted image: The right breast post-operative lesion shows smooth marginal enhancement with non-enhancing low SI at the central part of it. **D** DWI: The right breast lesion shows free diffusion. **E** ADC map: The right breast lesion shows a high ADC value = 1.42×10^{-3} mm^2/s. Pathologically proved to be traumatic fat necrosis. No malignancy

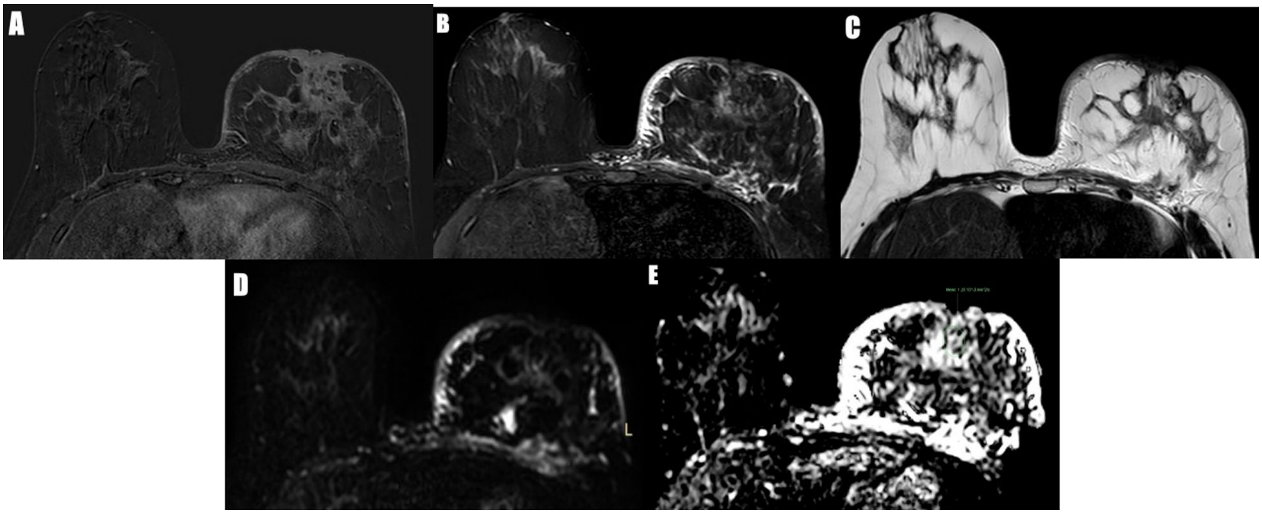

Fig. 2 40-year-old female with a history of left breast ductal carcinoma in situ underwent left breast conservative surgery 3 months ago, and complained of acute left breast edema, ultrasound was done revealing edema with operative bed marked shadowing with no detected definite breast masses or axillary nodes. The patient was given antibiotic treatment for 2 weeks but with no response, then a post-contrast MRI was done and revealed: **A** Subtracted image: shows enhanced left breast skin and nipple associated with heterogeneous non-mass enhancement in the left retro areolar region extending to the posterior third. **B** STIR image: shows thickened edematous skin associated with underlying non-mass area of mixed low and intermediate SI. **C** T2WI image: shows: thickened high SI skin associated with underlying non-mass area of mixed high and intermediate SI. **D** DWI: shows restricted diffusion of the skin of the left breast associated with underlying large non-mass that shows mainly free diffusion except in a small area of the posterior third. **E** ADC map: shows high ADC value = 1.25 × 10^{-3} mm^2/s. Pathologically proved to be left breast grade II invasive ductal carcinoma, ER positive 7/8, PR positive 8/8, KI 67 15%, HER 2 positive 1. (STIR: short T1 inversion recovery, SI: signal intensity, WI: weighted imaging, DWI: diffusion weight imaging, ADC: apparent diffusion coefficient, ER: estrogen receptor, PR: progesterone receptor, HER2: human epidermal growth factor receptor 2)

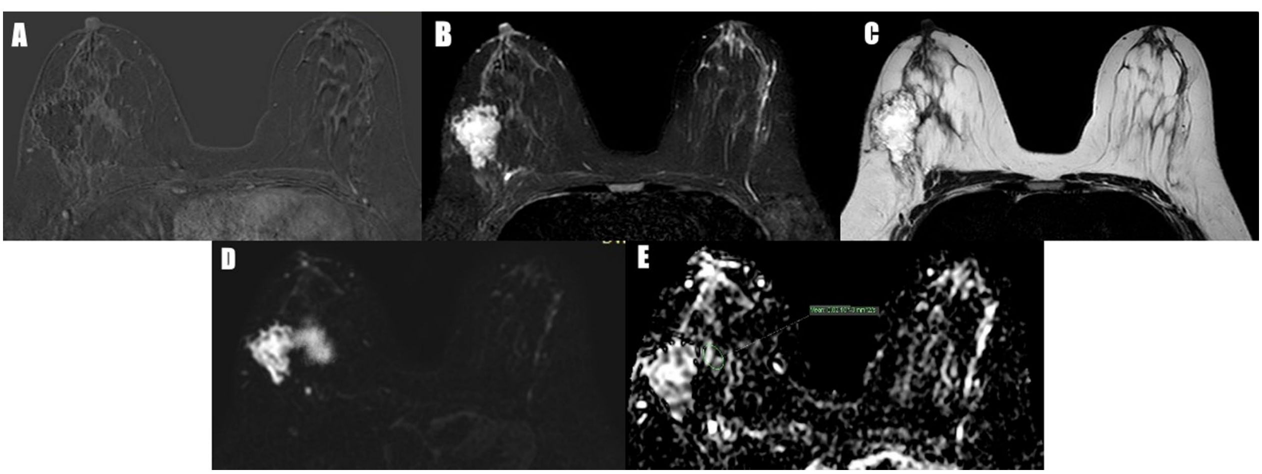

Fig. 3 34 years old female with a history of right breast grade II infiltrating ductal carcinoma underwent breast conservative surgery 4 months ago and complained of persistent operative bed pain and heaviness, ultrasound was done revealing a post-operative hematoma with a medially located small area of parenchymal heterogeneity, post-contrast MRI was done and revealed: **A** Subtracted image: shows enhanced right nipple associated with right breast post-operative hematoma which shows thick ring enhancement associated with heterogeneous non-mass enhancement just medially to the hematoma. **B** STIR image: shows bright SI of the hematoma with a medially related area of intermediate SI. **C** T2 WI: The right breast post-operative hematoma shows mixed high and intermediate SI with medially related area of low SI. **D** DWI: The hematoma as well as the related non-mass shows restricted diffusion. **E** ADC map: The hematoma as well as the medially related non-mass enhancement shows low ADC value = 0.82 × 10^{-3} mm^2/s. Pathologically proved to be right breast grade II invasive ductal carcinoma, ER negative, PR negative, KI 67 42%, HER 2 positive 3. (STIR: short T1 inversion recovery, SI: signal intensity, WI: weighted imaging, DWI: diffusion weight imaging, ADC: apparent diffusion coefficient, ER: estrogen receptor, PR: progesterone receptor, HER2: human epidermal growth factor receptor 2)

benign lesions show free diffusion (84.1%) and most of the malignant lesions show restricted diffusion (81.1%). We found that the best ADC cutoff value to differentiate between benign and malignant lesions was 1.25×10^{-3} mm^2/s, and the difference was statistically significant (P value < 0.001). Table 2 shows detailed MRI characters of benign versus malignant lesions and their correlation.

ADC cutoff value to discriminate benign versus malignant lesions

A ROC curve demonstrates that ADC cut-off value of ≤ 1.25 has a perfect accuracy (AUC = 1.0, 100% sensitivity and specificity) in discriminating malignant from benign lesions (Fig. 4).

MRI BI-RADS to discriminate malignant from benign lesions showed excellent accuracy in discriminating malignant from benign lesions: Sensitivity = 100%, Specificity = 100%, NPV = 100%, PPV = 100%. Table 3 shows MRI BI-RADS of lesions in benign versus malignant lesions.

Predictors of the likelihood of the malignant nature of the lesion

Binary logistic regression analysis was run to assess the effect of a non-circumscribed margin, irregular shape of mass lesion & a lesion away from the surgical bed as well as lesions' ADC on the likelihood that the lesion will exhibit a malignant nature.

The model is statistically significant ($\chi^2 = 26.82$, $P < 0.001$) and correctly classifies 94.3% of cases. The sensitivity, specificity, PPV, and NPV of this model are 77, 77.8, 90, and 96.7%, respectively.

Discussion

Breast cancer is the most diagnosed type of cancer as well as the most common cause of cancer death among women worldwide [7].

Breast-conserving surgery (BCS) is a multidisciplinary approach to treating breast cancer that involves removing the tumor while preserving the appearance and shape of the breast. Typically, BCS is followed by radiation therapy and may include additional chemotherapy [8].

Studies have shown that there is no significant difference in survival rates between patients treated with mastectomy or breast-conserving therapy (BCS), and success depends on appropriate patient selection [9]. Contraindications for BCS include diffuse or multicentric disease, positive surgical margins, prior breast irradiation, and unfavorable tumor-to-breast size ratio [8].

Breast imaging post-surgery is challenging due to alterations in breast tissue [10].

After surgery, some post-operative changes can appear similar to cancerous growths and can hide or imitate signs of malignancy. It is crucial to detect recurring tumors as soon as possible to have a chance for curative surgery. However, it is also essential to avoid overdiagnosis to prevent unnecessary biopsies of irradiated tissues that can disrupt the healing process [10].

The conservatively treated breast and the contralateral breast are at a higher risk for developing carcinoma. Regardless of whether the original tumor was invasive, recurrent tumors can be invasive or in situ [2].

Mammography is the primary imaging modality for the early detection of breast cancer. Despite recent advances in mammographic techniques (digital), mammography still has its limitations [11].

Ultrasound (US) is an important tool to complement mammography in detecting breast cancers [12]. It can distinguish between a solid and cystic mass and visualize masses that were previously not evident on mammogram [13].

DCE MRI of the breast is a useful diagnostic tool for distinguishing between benign and malignant lesions. It provides information about the morphology and enhancement kinetics of the lesions and can detect obscured lesions that may not be visible on other imaging modalities, particularly in cases of dense breast tissue [14].

DW MRI produces images that reflect water diffusion in biological tissues, enabling the measurement of ADC for quantitative assessment of water diffusion [15].

This study was performed on patients with histopathological proven cancer breast underwent CBS after a minimum of 1 to 4 months post-operative for detection of residual or early recurrent tumor. This was also recommended by Healy and Benson who stated that it is useful to evaluate the treated breast within 4 months post-treatment to detect any changes resulting from therapy. These changes are most prominent during this time and can be helpful in future follow-ups. Any increase in these findings later could be associated with recurrence and should be investigated [10].

This study was conducted as a routine follow-up in 77.2% of cases, while 17.7% of cases had palpable lesions. This matches the findings of Mansour and Behairy, who stated that MRI was done for most cases as a routine post-operative follow-up (for 6 months up to 2 years). The indication for MRI in 39.4% of cases was the presence of a palpable abnormality at the site of the operative bed [16].

In our study, 352 (84.4%) lesions were benign and 37 (15.2%) lesions were malignant, 31 were breast recurrence and 6 were nodal recurrence. Histopathological types after CBS which were previously detailed in our results in which invasive mammary carcinoma representing 13%, while grade II Invasive ductal carcinoma

Table 2 MR characteristics of benign versus malignant lesions

Parameter	Benign (*N* = 350)	Malignant (*N* = 37)	*P* value
Lesion size			
Mean ± SD	1.66 ± 1.07	1.85 ± 1.40	0.336
Location-related to surgical bed (*N*, %)			
At	312 (89.1%)	28 (75.7%)	0.017*
Away	38 (10.9%)	9 (24.3%)	
Form of lesions (*N*, %)			
Mass	329 (94%)	28 (75.5%)	0.002
Non-mass	21 (6%)	9 (24.3%)	
Features of mass lesions (*N*, %)	329 (94%)	28 (75.5%)	
Shape			
Irregular	15 (4.6%)	29 (77.2%)	*P* < 0.001
Oval	60 (18.2%)	0	
Round	254 (77.2%)	8 (22.8%)	
Margins			
Non-circumscribed	16 (4.9%)	29 (77.8%)	*P* < 0.001
Partially circumscribed	59 (18%)	0	
Well-circumscribed	254 (77.1%)	8 (22.2%)	
Enhancement patterns			
Homogeneous	16 (4.9%)	8 (22.8%)	*P* < 0.001
Heterogeneous	0	29 (77.2%)	
Homogeneous progressive	12 (3.6%)	0	
Marginal	167 (50.7%)	0	
Thick marginal	6 (1.8%)	0	
No enhancement	129 (39.1%)	0	
Features of non-mass lesions (*N*, %)	21 (6%)	9 (24.3%)	
Morphology			
Focal	5 (25%)	0	*P* < 0.001*
Linear	16 (75%)	0	
Regional	0	3 (33.3%)	
Segmental	0	6 (66.7%)	
Enhancement patterns			
Heterogeneous regional	0	3 (33.3%)	*P* < 0.001*
Heterogeneous segmental	0	6 (66.7%)	
Marginal	5 (25%)	0	
No enhancement	16 (75%)	0	
Axillary lymph node			
Present	63 (17.9%)	34 (91.9%)	*P* < 0.001
Absence	287 (82.1%)	3 (8.1%)	
Type of signal/intensity curve			
No curve	46 (13.1%)	0	*P* < 0.001*
Type I	198 (56.5%)	12 (32.4%)	
Type II	83 (23.9%)	21 (56.8%)	
Type III	23 (6.5%)	4 (10.8%)	
Diffusion			
Free	294 (84.1%)	7 (18.9%)	*P* < 0.001*
Restricted	56 (15.9%)	30 (81.1%)	
ADC			
Value	1.5 (1.4–1.8)	0.8 (0.7–1.1)	*P* < 0.001*

*: statistically significant

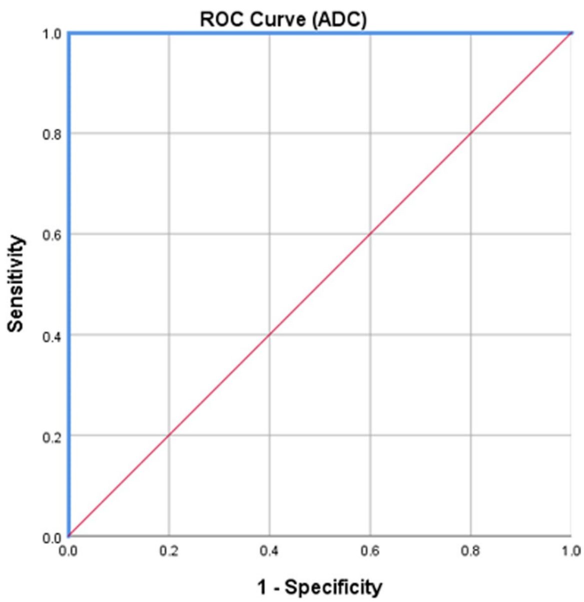

Fig. 4 ROC Curve of (ADC value). Demonstrates that ADC cutoff value of ≤ 1.25 has a perfect accuracy (AUC = 1.0, 100% sensitivity and specificity) in discriminating malignant from benign lesions

Table 3 MRI BI-RADS of lesions in benign versus malignant lesions

MRI BI-RADS	Lesions		*P* value
	Benign (*n* = 352)	Malignant (*n* = 37)	
BI-RADS 2	278(78.9%)	(0%)	*P* < 0.001
BI-RADS 3	74(21.0%)	(9%)	
BI-RADS 4	(0%)	23 (62.2%)	
BI-RADS 5	(0%)	14(37.8%)	

Data are presented as frequency (percentage). *P* value by Fisher's exact test

(IDC), grade III IDC, invasive lobular carcinoma (ILC), and axillary nodal recurrence are equally distributed as 1.6% for each. Our results were mismatched with the results of Seely and his colleagues who reported that in post-operative breast out of 10 malignant cases, 7 had IDC, two of whom also had foci of DCIS, and one had ILC [17].

Out of 352 benign lesions, histopathological types after BCS which were previously detailed in our results in which traumatic fat necrosis represented 75.8%, while fibroadenoma and scar tissue post-conservation changes represented 5.1% and 9.5%, respectively. Our results matched Kerridge and his colleagues, who reported that after BCS fat necrosis (21–70%) is the most common lesion [18]. And mismatched with the results of Mansour and Behairy who reported that in post-operative breast fat necrosis was 17.6% [16].

In this study, out of the 37 malignant cases, 6 lesions (16% of malignant lesions) were diagnosed as nodal recurrence. This was agreed with the results of the study of Yoon and his colleagues who found approximately 10–35% of patients who have been treated for breast cancer have metastasis in the axillary, internal mammary, and supraclavicular nodes [3].

In this study, after BCS was found that 340 lesions were related to the surgical bed & 47 lesions away from the surgical bed. Of the 340 lesions related to the surgical bed included were 312 benign and 28 were malignant & of the 47 lesions away from the surgical bed 38 were benign and 9 were malignant. This was illustrated by the study of Chansakul and his colleagues who stated that recurrent cancers at the original tumor site are because of the failure to eradicate the original cancer. In contrast, recurrence more than 10 years after therapy will likely occur outside the treated area and will likely represent new malignancies. Tumor recurrence rarely occurs earlier than in the first 2 years after treatment [2].

In this study, the most common combination of post-conservation changes was post-surgical scar, increased skin thickness & edema 48.1% followed by post-surgical scar, increased skin thickness, edema & seroma 26.6%. Thus, our results match with that of Mansour and Behairy who reported that combined post-conservation changes in the form of increased skin thickness & edema were 48.8% [16].

We found that the sensitivity & specificity of MRI BI-RADS in discriminating malignant from benign lesions were 100% (correlation of morphology and enhancement features with the BI-RDAS category) and the difference was statistically significant (*P* value < 0.001). Seely and his colleagues reported that MRI had a sensitivity of 88.8% and specificity of 77.1% in the evaluation of post-operative breasts [17].

In our study, lesions are classified into mass lesions 357 (92.2%) and non-mass lesions 30 (7.8%). The mass lesions were classified according to their morphologic criteria where the shape of the lesions was classified into rounded, oval, or irregular. Lesions' margin was classified into well-circumscribed, partially circumscribed, or non-circumscribed. Internal enhancement pattern was classified into homogeneous, heterogeneous, homogeneous progressive, marginal, thick marginal, or no enhancement. The non-mass lesions were classified according to their morphologic criteria where lesions' distribution was classified into focal, linear, regional, or segmental while the internal enhancement pattern was classified into heterogeneous regional, heterogeneous segmental, marginal, or no enhancement. We also assessed the enhancement kinetics; evaluation had two parts: early phase (wash-in rate) and late phase (wash-out rate) which defined 3 types of time/signal intensity curves: type I persistent curve, type II plateau curve and type III wash-out curve. DWI was also included in our study, where lesions had either free or restricted diffusion on DWI and ADC value was measured.

Regarding the lesions' form in our study, there were either mass or non-mass lesions; mass lesions were 329 benign and 28 malignant, while the non-mass lesions were 21 benign and 9 malignant. According to these results, non-mass lesions are more associated with malignancy than mass lesions. Thus, our results were in concordance with those of Seely and his colleagues who found that non-mass lesions showed a higher malignancy rate [16]. Our results were also in agreement with the results of the study of Spick and his colleagues [19].

As regards the mass lesions morphology, our results showed that irregularly shaped masses were more described with malignancy (77.2% of malignant masses) and were described in benign masses to a much lesser extent (4.6% of benign masses). On the other hand, the oval shape was only associated with benign masses (18.2% of benign masses), while the round shape was seen mainly in benign masses (77.2% of benign masses) and was described in malignant masses to a much lesser extent (22.8% of malignant masses) which were mainly in nodal recurrence cases. That was also found by Seely and Drukteinis and their colleagues who found that masses that possessed features that were predictive of malignancy usually had irregular shapes [5, 17].

As regards the lesions' margins in our study, our results showed that well-circumscribed margins predominated in benign masses (77.1% of benign masses) and were described in malignant masses to a much lesser extent (22.2% of malignant masses) while partially circumscribed margins were described only in benign lesions (18% of benign lesions). On the other hand, non-circumscribed margins predominated in malignant lesions (77.8% of benign masses) and were described in benign masses (4.9% of benign masses). These results matched with Gokalp, Mahoney and Seely and their colleagues who reported that malignant lesions showed non-circumscribed, irregular, or speculated margins, while most benign lesions showed well-circumscribed margins [17, 20, 21].

According to the lesions' enhancement pattern in our study, homogeneous enhancement was seen in 16 benign masses (4.9%) and 8 malignant ones (22.8%), while heterogeneously enhancing lesions were all malignant (77.2%). This showed agreement with Morris who concluded that heterogeneous enhancement was the most frequent enhancement pattern among malignant breast lesions and homogeneous enhancement was suggestive of a benign process; however, in the case of small breast lesions, special care should be taken not to miss lesions as spatial resolution may limit small lesion detection. Also, our results following that of Hammersley and his colleagues regarding the non-enhancing lesions concluded that the absence of enhancement in lesions strongly favors benignity, this can be problem-solving especially in challenging cases like lesions in post-operative breast cancer patients [22].

As regards non-mass lesions' morphology, focal distribution was seen at 5 benign lesions (25%) and linear distribution was noted in 16 benign lesions (75%), while regional distribution was seen at 3 malignant lesions (33.3%) and finally segmental distribution was the most observed enhancing pattern in malignant non-mass lesions which were 6 lesions (66.7%). That was relevant to the results of Aydin who reported that segmental distribution was significantly associated with malignancy representing 40% of all malignant lesions in his study while the remaining 60% were distributed among all the other types [23].

According to the non-mass enhancement pattern in our study, heterogeneous regional and heterogeneous segmental patterns were noted only in malignant lesions (33.3 and 66.7%, respectively), while marginal pattern and non-enhancing lesions were noted only in benign lesions (25 and 75%, respectively). That showed an agreement with Drukteinis and his colleagues who reported that heterogeneous segmental enhancement is highly suspicious and is associated with a 78% likelihood of cancer [5].

In our study, according to the type of time/signal intensity curve which is described according to the wash-in rate at the initial enhancement phase and wash-out rate at the delayed phase, type I persistent curve was seen in 56.5% of benign lesions, type II plateau curve was seen in 56.8% of malignant lesions, and type III curve was seen in 10.8% of malignant lesions. These results matched with Kul and his colleagues who showed that type I persistent curve was seen in benign lesions, but type II plateau predominates in malignant lesions than benign and type III washout curves were more common in malignant lesions [24].

Kul, Partridge and Hetta and their colleagues studied the additional role of DWI in an attempt to increase the diagnostic efficacy of breast MRI [24–26]. Mansour and Behairy studied the rule of DW MRI in differentiation between residual breast cancer and post-operative changes [16].

In our study, we used a combination of b values (0, 500, and 1000 s/mm^2) for breast DWI. A relatively similar technique was used by Eghtdari and his colleagues who stated that in the case of usage of low *b* value (< 400 s/mm^2) the ADC value was greatly affected by perfusion effect and became higher. In contrast, it was noted that in the case of usage of high *b* values (1000 s/mm^2), the SNR is reduced which also affects the ADC value. They also reported that the ADC calculation errors were decreased by the usage of a combination of b values. They concluded that the best diagnostic accuracy of 96% resulted from the use of a *b* value of 1000 s/mm [27].

Arponent and his coworkers reported that *b* value 1000 s/mm^2 was considered optimal for DWI of the breast as the normal mammary gland signals are suppressed and the high signal of the malignant lesion is detected. This matches with our results when using *b* value 1000 s/mm^2 as the glandular signal from breast parenchyma is suppressed and the signal of the malignant lesion is easily detected [28].

In our study according to the lesion signal in DWI, free diffusion was seen in 294 (84.1%) of the benign lesions, while restricted diffusion was noted in 30 (81.1%) of the malignant lesions. The ADC values were automatically calculated by placing the single ROI within the lesion, the apparent necrotic or cystic components were avoided by referring to conventional MRI, and the fatty glandular breast parenchyma which shows homogeneous signal intensity on the ADC map was used as a reference. This matches with the study of Woodhams and Choi and their colleagues who used also the same single ROI and method of application [29, 30].

Our study showed that the best ADC cutoff value to differentiate between benign and malignant lesions was 1.25×10^{-3} mm^2/s and the difference was statistically significant (*P* value < 0.001). Surov and his colleagues stated that benign lesions exhibited higher mean ADC values compared with those of malignant lesions [25]. Our results compared with Mansour and Behairy that showed a slightly lower cutoff value, they demonstrated ADC value less than 1.04×10^{-3} mm^2/s is the strongest indicator of malignancy [16]. Tan and his colleagues demonstrated the cutoff value of ADC for differentiating benign from malignant lesions was 1.21×10^{-3} mm^2/s for $b = 500$ s/mm^2 and 1.22×10^{-3} mm^2/s for $b = 1000$ s/mm^2, respectively [31].

Azab and his colleagues concluded that the variation in cutoff values in these different studies may be due to the affection of different scanning parameters on the calculated ADC value [32]. Due to these variations Kul and his colleagues recommended that all MRI sites should detect their own cutoff values according to the DWI sequence used for breast imaging [24].

In our study, the model of predictors of the likelihood of the malignant nature of the lesion showed that a non-circumscribed margin, irregular shape of mass lesion & a lesion away from the surgical bed, as well as lesions' ADC of a cutoff value of ≤ 1.25, had higher odds that the lesion will exhibit malignant nature. Seely and his colleagues stated that mass lesions that possessed features that were predictive of malignancy irregular shape and non-circumscribed margins and were classified as BI-RDAS 4 or 5 category [17].

Conclusions

The MRI BI-RADS system has a high degree of sensitivity and specificity in differentiating between malignant and benign lesions after BCS. Diffusion-weighted imaging (DWI) can be used as an initial detection tool as it has high sensitivity and specificity in characterizing breast lesions BCS. However, DCE MRI after BCS is mandatory for lesion characterization and delineation of its nature and cannot be replaced by DWI alone in cases of visualizing a lesion.

Based on our research, we have identified certain predictors that can increase the likelihood that a lesion will be malignant, including a non-circumscribed margin, an irregular shape of the mass, a lesion away from the surgical bed, and a lesion's apparent diffusion coefficient (ADC) of a cutoff value of $\leq 1.25 \times 10^{-3}$ mm^2/s.

Limitations

The retrospective nature of the study has some limitation as some desired clinical data would have been available if the study had been prospective.

Abbreviations

MRI	Magnetic resonance imaging
DCE-MRI	Dynamic contrast enhanced magnetic resonance imaging
BI-RADS	Breast imaging reporting and data system
MRI BI-RADS	Magnetic resonance imaging breast imaging reporting and data system
PPV	Positive predictive value.
NPV	Negative predictive value.
BCS	Breast conservative surgery
DWI	Diffusion weighted imaging
US	Ultrasound
SE EPI	Spin-echo echo-planer imaging
ADC	Apparent diffusion coefficient
GRE	Gradient
FAT-SAT	Fat saturation
MIP	Maximum intensity projection
SPSS	Statistical Package for Social Science
ROC	Receiver operating characteristic curve
P	Probability
UIQ	Upper inner quadrant
UOQ	Upper outer quadrant
IDC	Invasive ductal carcinoma
ILC	Invasive lobular carcinoma
SNR	Signal-to-noise ratio

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Author contributions

All authors have read & approved the manuscript. The study concept and design were proposed by AE, SS, and MZ. Statistical analysis of data done by SS, MM and MZ. Writing the original manuscript was done by AE and SS. Figure preparation was done by MZ and SS. Revision of the manuscript for important intellectual content was done by AE, MM and MZ.

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Availability of data and materials
All the scientific data are available and presented in the manuscript. The source data are available on request.

Declarations

Ethics approval and consent to participate
Written informed consent was waived by the Institutional Review Board (IRB), Institutional Review Board (IRB) was obtained, IRB approval: R.23.11.2375.R2.

Consent for publication
All the patients were consented and informed of possible research publication. All authors hereby confirm all the copyrights if such work will be accepted in the Egyptian Journal of Radiology and Nuclear Medicine (EJRNM).

Competing interests
The authors declare that they have no competing interests.

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