RESEARCH

MR diffusion-weighted imaging precision in BIRADS downstaging

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Abstract

Background Breast cancer is a major cause of both morbidity and mortality. Therefore, it is essential to promptly identify breast cancer in order to implement a more cautious surgical approach for disease treatment. Breast ultrasonography examination has long been used as a supplementary technique to mammography to evaluate palpable or mammographically detectable breast masses. Presently, Breast MRI has become an essential instrument for the detection and analysis of breast cancer. Diffusion-weighted imaging (DWI) is MRI technique that quantifies the movement of water molecules within tissue. It can provide valuable information about the density, viscosity, integrity of membranes, and microstructure of tissues. This study included sixty patients with Equivocal/high BIRADS lesions, underwent Mammography and /or U/S, CEMRI with DWI.

Aim of the work The aim of this study was to disclose MRDWI potency in depiction and assessment of different breast lesions unaccompanied by contrast-enhanced MRI with a view to avoid the high cost of the MRI contrast, lessen the number of needless biopsies and probably reclassify breast lesions of high BIRADS categories.

Results This prospective study included 58 patients (with 60 breast lesions), who came with sono-mammography breast lesions of BIRADS lesions > 2, comparison between sono-mammographic BIRADS and MRI BIRADS was done, where 40 cases were downgraded by MRBIRADS. On paralleling MRDWI unescorted by contrast-enhanced MRI with sono-mammographic BIRADS, 36 cases were downgraded. Correlation between pathology of the biopsied lesions with sono-mammography, MR BIRADS and MRDWI was done as well. Sono–mammography shows 88.9% sensitivity and 61.9% specificity with accuracy of 77.7%. Combined CE –MRI and DWI shows 94% sensitivity and 97.6% specificity with accuracy of 96%. While DWI solely shows 88.9% sensitivity and 90.5% specificity with accuracy of 96%. The cutoff value of ADC for prediction of malignancy was 0.9 with 94% sensitivity, 87% specificity and 83.3 accuracy.

Conclusions CEMRI is un-debatably effective in depicting and discriminating indeterminate breast lesions chiefly when combined with DWI. Yet, with the high expense of the contrast and in the event of contrast contraindications or unavailability, DWI has proven to be a convenient substitute for CE-MRI aiding in rendering the breast lesion BIRADS downgraded with diminishing the unneeded biopsies.

Keywords High BIRADS lesions, MRI breast, DWI, CEMRI

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Introduction

Background

Breast cancer is a major cause of both morbidity and mortality [1]. Therefore, it is essential to promptly identify breast cancer in order to implement a more cautious surgical approach for disease treatment. Breast ultrasonography examination has long been used as a supplementary technique to mammography to evaluate

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palpable or mammographically detectable breast masses. Presently, Breast MRI has become an essential instrument for the detection and analysis of breast cancer [2].

Diffusion-weighted imaging (DWI) is an MRI technique that quantifies the movement of water molecules within tissue. It can provide valuable information about the density, viscosity, integrity of membranes, and microstructure of tissues. Notably, DWI achieves this without requiring the use of contrast injection [3].

Objectives
The aim of this study was to disclose MRDWI potency in depiction and assessment of different breast lesions unaccompanied by contrast-enhanced MRI with a view to avoid the high cost of the MRI contrast, lessen the number of needless biopsies and probably reclassify breast lesions of high BIRADS categories.

Methods
This study was a prospective, observational study, conducted on 58 patients (with 60 breast lesions). The study conducted in oncology institute in EL Minya between July 2022 and September 2023. The 58 patients were either presented by lump ($n=34$, 56.7%), mastalgia ($n=14$, 33.3%) or nipple discharge ($n=4$, 6.7%).The study was approved by the ethical committee of the faculty of medicine, Minia University (Approval No.236:6/2022).

Those patients were subjected to

- Through history taking (name, age,family history, menstrual cycle, operative history, complain).
- Clinical examination.
- Sono-mammographic evaluation**.**
- MRI was performed.
- Biopsy was obtained from all patients.

Inclusion criteria

(1) Positive family history.
(2) Patients those with equivocal breast lesions detected by sono-mammography.

Exclusion criteria

(1) Patients with history of allergic reaction to contrast media.
(2) Patients with history of claustrophobia.
(3) 3-Any patient of BIRADS I and II by sono-mammographic evaluation.

Mammography technique
Patients were guided to do mammography (Digital Fugi,Amullet F, Japan). Patient's breast is positioned on the mammography table to obtain the two standard mammographic views, for the mediolateral oblique view, the breast was placed on the image receptor which lies parallel to the pectoralis muscle. The compression paddle compressed the breast from the superomedial direction.

For the craniocaudal view, the nipple was positioned midline and the length of the PNL(posterior nipple line) was about 1 cm from that of the MLO view, the image receptor was positioned beneath the breast and compression was applied superiorly.

Sonography technique
All patients were guided to do ultrasound (Toshiba, Apllio 500, Japan) by scanning the breast, a linear 5–12 MHz transducer is commonly used. However, in small-breast women (with breast thickness, 3 cm) or when performing targeted US to evaluate a superficial lesion, a linear 5–17 MHz transducer was used.

MRI breast technique
Our patients were scheduled to DCE-MRI and DW-MRI examination using GE Signa Explorer 1.5 T machine, USA. The patients were imaged in prone position using a dedicated double breast coils with patients lying in a prone position. Both the breasts will be placed deep and centrally in the coil, with the nipple facing downwards. The entire breast tissue should be covered in coil with absent of skin folds. Patients were advised to stay immobile until the completion of scan to get images free from movement related artifact.

Patient lied prone on her abdomen with breasts enveloped within the right and left apertures. The arms are placed by the sides with patient's head placed on a prime headset to enhance patient's comfort. An opening on the lateral aspect of each aperture enables the technologist to adjust the position of the breast and avoid skin folds. We have Provided foam pads and wedges below the abdomen facilitates better slouching of both shoulders, pulling the breast as far as possible from the chest wall so that entire breast tissue is encompassed within the coil with downward erection of nipple in the center.

All protocols followed international guidelines and recommendations and included

(1) *Axial T2WI* The acquisition parameters for the scan as following: repetition time (TR) 1702 ms, echo time (TE) 120 ms, slice thickness 2 mm, matrix size

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of 340 by 512, field of view (FOV) 32.2 mm, and a total scan length of 2 min and 22 s.

(2) *Axial T1WI* The acquisition parameters for the scan as following: repetition time (TR) 7.1 ms, echo time (TE) 14 ms, slice thickness 5 mm, matrix size of 340 by 512, field of view (FOV) 32 mm, and a total scan length of 2 min.

(3) *Axial T2WI Fat suppression* The acquisition parameters for the scan as following: repetition time (TR) 6700 ms, echo time (TE) 40 ms, slice thickness 5 mm, matrix size of 340 by 512, field of view (FOV) 34 mm, and a total scan length of 1 min and 50 s.

(4) *DW-MRI* Single-shot echo-planar imaging, fat suppression, with repetition time/echo time of 6800 ms /82.8 ms, 5 mm section thickness, and absent of inter-slice gap and total scan time 5 min and utilizing b values were of 500, 1000 and 1500 s/mm^2. A ROI was drawn on the ADC map to calculate the ADC value (in case there was no signal change seen on ADC map, the ROI was placed over the area of concern on diffusion). Mean ADC for each lesion was calculated by averaging the ADC values from all the voxels enclosed by the ROI.ADC maps used for the evaluation were generated at the highest and lowest b-value data (500, 1000, 1500) by the scanner software.

(5) *Dynamic studies* were performed in the T1-weighted sequences by applying fat-saturated pulses. DCE MRI study were conducted by injecting 10 mL of gadolinium chelate intravenously followed by 10 mL of normal saline. Dynamic post-contrast acquisition was performed using six series of 3D THRIVE (T1 High Resolution Isotropic Volume Examination sequence) acquisition—1 before and 5 after power injection with the parameters (TR/TE 8/4.5 ms) and slice thickness = 2 mm. Kinetic curves were done by placing a region of interest (ROI) at the area of maximum enhancement to measure the amount of contrast uptake, and dynamic curve patterns were prepared.

(6) *Image subtraction* was employed to mitigate the presence of fat signal. Subsequently, the subtraction images were examined to identify any enhanced lesions.

Image analysis

- The Mammography and sonographic as well as MR evaluation were done by two radiologists (on consensus, each one with 10 year experience in breast imaging) on a workstation, utilizing mammograms and ultrasound images.

- The interpretation of dynamic contrast-enhanced MR images was performed using the BI-RADS criteria, which involved analyzing both morphologic and kinetic data. The lesions were classified into one of the five BI-RADS groups.

The ADC measurements were conducted using ADC maps. Pilot images were created using T2-weighted and subtracted MR sections to accurately locate the index lesion. The ROI was manually positioned within the dense area of the lesion. For each lesion, a minimum of three measurements were taken at different B values (500, 1000, 1500). The measurement with the lowest value was considered as the approved ADC value.

Results

This prospective study included 58 patients (with 60 breast lesions); presented by lump ($n = 34$, 56.7%), mastalgia ($n = 20$, 33.3%), nipple discharge ($n = 4$, 6.7%) or asymmetry ($n = 2$, 3.3%) Table 1.

Table 1 Distribution of the studied cases regards clinical data

Data	Total No = 60
Age	
Range	21–69
Mean ± SD	45.3 ± 13.8
Sex	
Female	60(100%)
Complain	
Lump	34(56.7%)
Mastalgia	20(33.3%)
Nipple discharge	4(6.7%)
Asymmetry in size	2(3.3%)

Table 2 Comparison between sono-mammographic BIRADS and MR BIRADS (Combined CEMRI and DWI)

Sono-mammographic BIRADS	MR BIRADS				
	BIRADS I	BIRADS II	BIRADS III	BIRADS IV	BIRADS V
BIRADS III (28)	–	23(82%)	3(10.7%)	2(7%)	0
BIRADS IV (26)	0	10(38%)	6(23%)	4(15%)	6(23%)
BIRADS V (6)	0	0	0	0	6(100%)

P value = 0.01*

Table 3 Downgrading by only DWI in MR BIRADS (no = 60)

Downgrading	No
Yes	36
No	24

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Table 4 Mammography and sonography in correlation to final pathology

Mammography/ sonography	Pathology (n = 60)				P
	Nonmalignant Negative No = 42		Malignant Positive No = 18		
	Number	%	No	%	
BIRADS III (28)	26(TN)	62%	2(FN)	11.1%	0.001
BIRADS IV &V (32)	16(FP)	38%	16(TP)	88.9%	

Table 5 DWI in correlation to final pathology

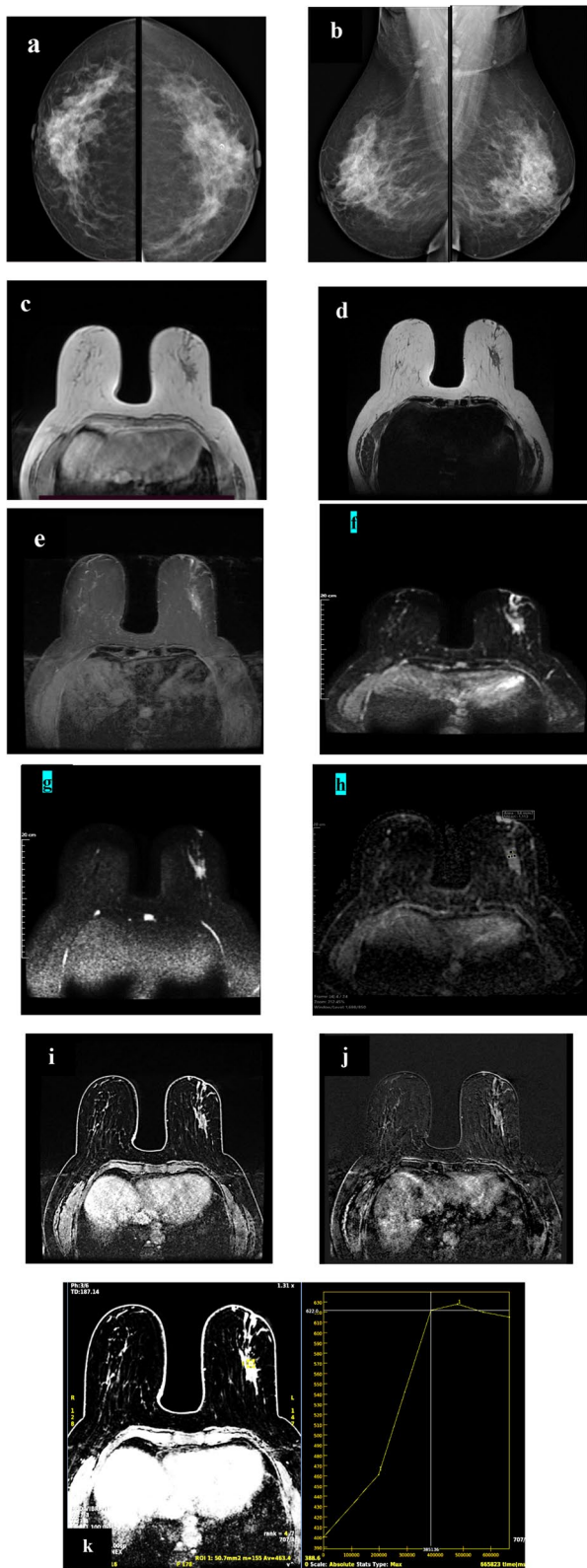| DWI	Pathology (n = 60)				P
	Non-malignant Negative No = 42		Malignant Positive No = 18		
	Number	%	No	%	
ADC > 0.9	38 (TN)	90.5%	2(FN)	11%	0.0001
ADC ≤ 0.9	4 (FP)	9.5%	16 (TP)	88.9%	

Table 8 AUC, Sensitivity, Specificity, PPV, NPV and accuracy percent of ADC cutoff value for prediction of malignancy

Cutoff value	AUC	Sensitivity	Specificity	PPV	NPV	Accuracy %	P
≤ 0.9	0.83 ± 0.1	94%	87%	90%	96%	83.3%	0.01

Table 9 Interobserver reliability

	Agreement (%)	Kappa (95% CI)	P value
MR Imaging	96%	0.12–0.97	0.0001
Sono-mammography	95%	0.89–0.97	0.0001

Table 2 shows comparison between sono-mammographic BIRADS and MRI BIRADS (combined CEMRI and DWI) where 40 cases were downgraded by MRBIRADS.

Table 6 MR BIRADS (combined CEMRI and DWI) in correlation to final pathology

Imaging		Pathology (n = 60)				P
		Non-malignant Negative No = 42		Malignant Positive No = 18		
		Number	%	No	%	
MRI BIRADS	Benign (BIRADS 1,2,3)	40(TN)	95%	1(FN)	5.5%	0.0001
	Malignant (BIRADS 4,5)	2(FP)	4.7%	17(TP)	94%	

Table 7 AUC, Sensitivity, Specificity, PPV, NPV and accuracy percent of ADC, DWI, Curve, BIRADS pre and Post and downgrading value for prediction of malignancy

	AUC	Sensitivity	Specificity	PPV	NPV	Accuracy %	p
DWI	0.88 ± 0.08	88.9%	90.5%	80%	95%	96%	0.005
Sono-mammographic BIRADS	0.77 ± 0.11	88.9%	61.9%	50%	92.8%	77.7%	0.01
Combined CE-MR with DWI BIRADS	0.94 ± 0.05	94%	95%	89.4%	97.5%	96%	0.001

TN (True negative), FN (False negative), FP (False positive), TP (True positive)

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Fig. 1 52-year-old patient, with positive family history and complaining of mastalgia. **a** Mammographic images craniocaudal views, **b** Mammographic images mediolateral oblique views, showing left focal asymmetry with an area of architecture distortion noted at the lower inner quadrant of the left breast at CC image and MLO images. Foci of macro calcifications noted. Sonography: No suspicious lesion could be detected. Sono-mammography BIRADS III. **c, d, e** MR T1WI, T2WI and STIR show an abnormal signal intensity area with irregular outlines seen involving LOQ of left breast and extending to reach the nipple. It attains hypo intense signal at T1WI, **c** hypo intense signal at T2WI (**d**) and hyperintense signal at STIR (**e**). **f, g** DWI on b value 500 and 1000, respectively, **h** ADC map; show that the lesion attains a small focus of diffusion restriction with low ADC values (about 0.9×10^{-3} mm^2/sec), which is better depicted at the b value = 1000. DWI confirmed the suspicious lesion BIRADS IV. **i, j** Post contrast study, with the subtraction image. **k** shows that the lesion attains rapid homogenous mass enhancement with plateau curve kinetic curve type II MRBIRADS IV. Pathology: IDC grade II

On paralleling MRDWI unescorted by contrast-enhanced MRI with sono-mammographic BIRADS, 36 cases were downgraded in their BIRADS classification (Table 3).

Tables 4, 5 and 6 show correlation between pathology of the biopsied lesions with sono-mammography, MR BIRADS (combined CEMRI and DWI) and MRDWI;along with generation of the sensitivity, specificity and accuracy of sono-mammography, CEMRI, DWI, as well as combined DWI and CEMRI (Table 7). Sono-mammography shows 88.9% sensitivity and 61.9% specificity with accuracy of 77.7. Combined CE–MRI and DWI shows 94% sensitivity and 97.6% specificity with accuracy of 96. While DWI solely shows 88.9% sensitivity and 90.5% specificity with accuracy of 96.

As for the cutoff value of ADC for prediction of malignancy, it was 0.9 with 94% sensitivity, 87% specificity and 83.3 accuracy as shown in Table 8.

Inter-rater reliability

The percent agreement was excellent between readers of Dixon images; the inter-reader reliability was calculated at 96% and 95% for sono-mammographic and MRI interpretation (Table 9).

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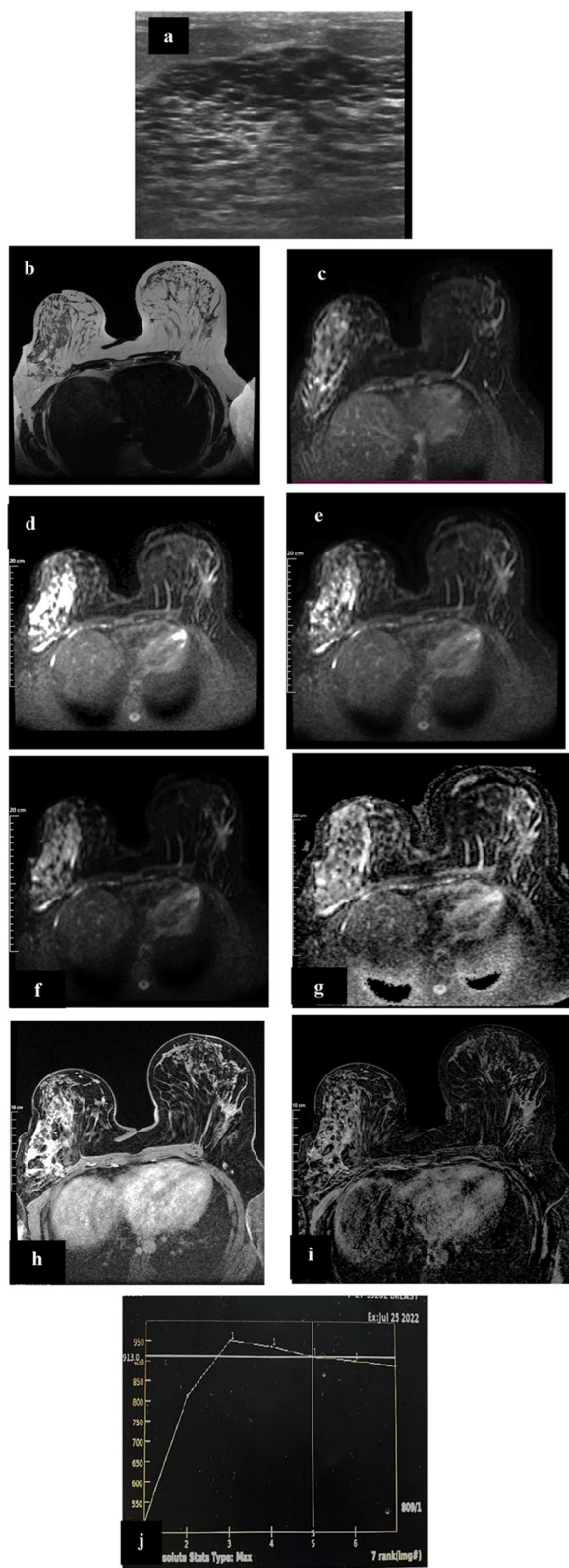
◀ **Fig. 2** 27-year-old female with negative family history, complaining of painful right breast lump, not lactating and not pregnant at the time of study. **a** Sono-mammography images showed asymmetrical enlargement of both breasts. The outer half of right breast shows prominent condensed glandular tissue with no underlying solid lesions could be detected. Sono-mammography BIRADS III. **b**, **c** MR T2WI and STIR show an abnormal signal intensity area with indistinct borders seen involving the LOQ of right breast which attains hypo intense signal at T2WI (**b**) and hyper intense signal at STIR (**c**). The left breast shows a faint abnormal signal intensity seen involving the low outer quadrant, attaining mildly hypointense signal in T1WI and T2WI with hyperintense signal in STIR. **d**, **e**, **f** DWI on b value 500, 1000 and 1500, respectively, and **g** The ADC map; show that the lesion attains patchy diffusion restriction with ADC value around 0.9×10^{-3} mm.^{2}/sec. which is better demonstrated at the b-value = 1000 DWI BIRADS IV. The abnormal signal intensity area at the left breast shows small portion of mild restriction in diffusion and corresponding mildly low ADC values BIRADS III. **h**, **i** Post contrast study, with the subtraction image showing that the lesion at the LOQ of the right breast attaining heterogeneous segmental non-mass enhancement. **j** shows that the lesion enhancement performs kinetic curve type III MRBIRADS IV. The abnormal signal intensity area at the left breast shows faint minimal non-mass enhancement only detected in subtraction images with Kinetic curve type II MRBIRADS III. Pathology confirmed to be Bilateral Chronic granulomatous mastitis (early at the left side)

Discussion

The National Cancer Institute (NCI) in Egypt reports that there are 28,000 confirmed instances of breast cancer per year, making it the most frequent malignancy among females [4]. In order to reduce mortality rates and mitigate the effects of the illness, World Health Organization (WHO) currently suggests that screening for breast cancer should begin for women at a young age [5].

With the goal of improving 28 million women's access to early cancer detection and treatment, the Egyptian Breast Health Presidential Initiative got underway in early 2019. In addition, it sought to provide supplementary medical care and increase public awareness of the disease's risk factors [6]. From this vantage point, we never stop trying to find better ways to diagnose breast cancer.

This prospective study included fifty eight patients (with sixty breast lesions) who were chosen based on the sono-mammography examination of high BIRADS

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breast lesions (BIRADS III, IV and V), they all underwent CE-MRI with spot light on diffusion-weighted imaging (DWI) sequences, all cases were confirmed by true cut biopsy to be used as a reference.

The aim of this study was to disclose MRDWI potency in depiction and assessment of different breast lesions unaccompanied by contrast-enhanced MRI with a view to avoid the contraindications and high cost of the MRI contrast, with probably reclassifying breast lesions of high BIRADS categories rendering the number of needless biopsies less.

The average age of the female participants in the study was 45.3 ± 13.8 years, and their ages ranged from 21 to 69. The research carried out by Hashem et al. [7] focused on female patients ranging in age from 25 to 70, with a mean age of 42 ± 12.9.

A positive family history was found in 50% of the research participants. Breast conservative surgery (BCS) was performed in just four patients, or 13.3% of the total. The main symptoms of the included patients in the study were asymmetry in breast size ($n = 2/60$ 3.3%), lump ($n = 34/60$ 56.7%), mastalgia ($n = 20/60$, 33.3%), and nipple discharge ($n = 4/60$, 6.7%). On the other hand, in the study conducted by Hashem et al. [7], 52.3% of 86 patients had breast lumps ($n = 45/86$), 7% had inflammatory symptoms ($n = 6/86$), and 40.7% had postoperative follow-up ($n = 35/86$).

On juxtaposing the Sono-mammographic BIRADS by the pathology of the biopsied lesions, the sono-mammography sensitivity and specificity were 88.9% and 61.9%, respectively. That was superior to the sensitivity and specificity reported by Mehnati et al. in [8], which were 30–60 and 40–80, respectively. Nevertheless, the results in the current study were in reproachment to the findings recorded by Eisa et al. in [9] and Hashem et al. [7] in their studies, who demonstrated a specificity of 74% and 80%, with sensitivity of 68% and 73%, respectively. These paralogisms in the mammography are mainly attributed to the dense breast cases (ACR III and IV), where the fibro glandular tissue almost conceal any breast lesions, yet aided by ultrasound; their sensitivity and specificity to detect and characterize lesions are relatively higher.

The current study disclosed that MRI significantly influenced the BIRADS classification on analogizing the breast lesions MRBIRADS by those from sono-mammography, where 40 cases out of 60 were downgraded by the MRI.

To depict and differentiate benign from malignant lesions, the internal enhancing features of a focal mass lesion are undeniably important; notwithstanding, they could be confusing and deceitful. In the current study. The most prevalent morphological finding among all the malignant lesions evaluated was lesions with heterogeneous internal enhancement. Pathological correlation confirmed the malignancy nature of all the ten cases with heterogeneous enhancement. These findings were rivaling to the results of the studies conducted by Rausch et al. [10] and Shah et al. [11], who stated that the lesions with heterogeneous enhancement were all confirmed to be malignant. On the other hand, this went against what Youssef et al. [12] stated in his study, where out of the fifteen cases with heterogeneous enhancement, only six were determined to be benign and nine to be malignant.

(See figure on next page.)

Fig. 3 51-year-old female patient with positive family history, complaining of right breast lump with retracted nipple. **a** mammographic images in Craniocaudal views, **b** mammographic images in mediolateral views: There was focal asymmetrical increase in density seen involving the UOQ of right breast with heterogeneity of parenchyma. It is seen associated with increased skin thickness overlying the right breast with retracted nipple. **c** Sonographic image of the right breast shows an ill-defined area of heterogeneous echogenicity seen involving the UOQ of right breast. It was associated with diffuse increase skin thickness and subcutaneous edema. In addition, multiple enlarged axillary LNs were also noted, some of the seen globular in shape with loss of fatty hilum and others with thickened cortex with eccentric fatty hilum. Sono-mammography BIRADS IV. **d**, **e** MR T1WI and T2WI, **f**, **g** STIR images show an abnormal signal intensity area of distortion seen involving the UOQ of right breast. It attains hypo intense signal at T2WI, with hyper intense signal at STIR, associated with increase skin thickness and subcutaneous edema as well as multiple distorted enlarged axillary LNs (level III). **h**, **i** DWI on b-value 500 and 1000, respectively and **j** the corresponding ADC map, show that the lesion attains only focus of diffusion restriction with corresponding low ADC value measuring 0.8×10^{-3} mm^2/sec. DWI confirmed being suspicious lesion BIRADS IV. **k**, **l** Post contrast study, with the subtraction image shows that the lesion attains heterogeneous non-mass enhancement at early phases with plateau curve and kinetic curve type II. **m** MRI BIRADS IV. Pathology: IDC grade II
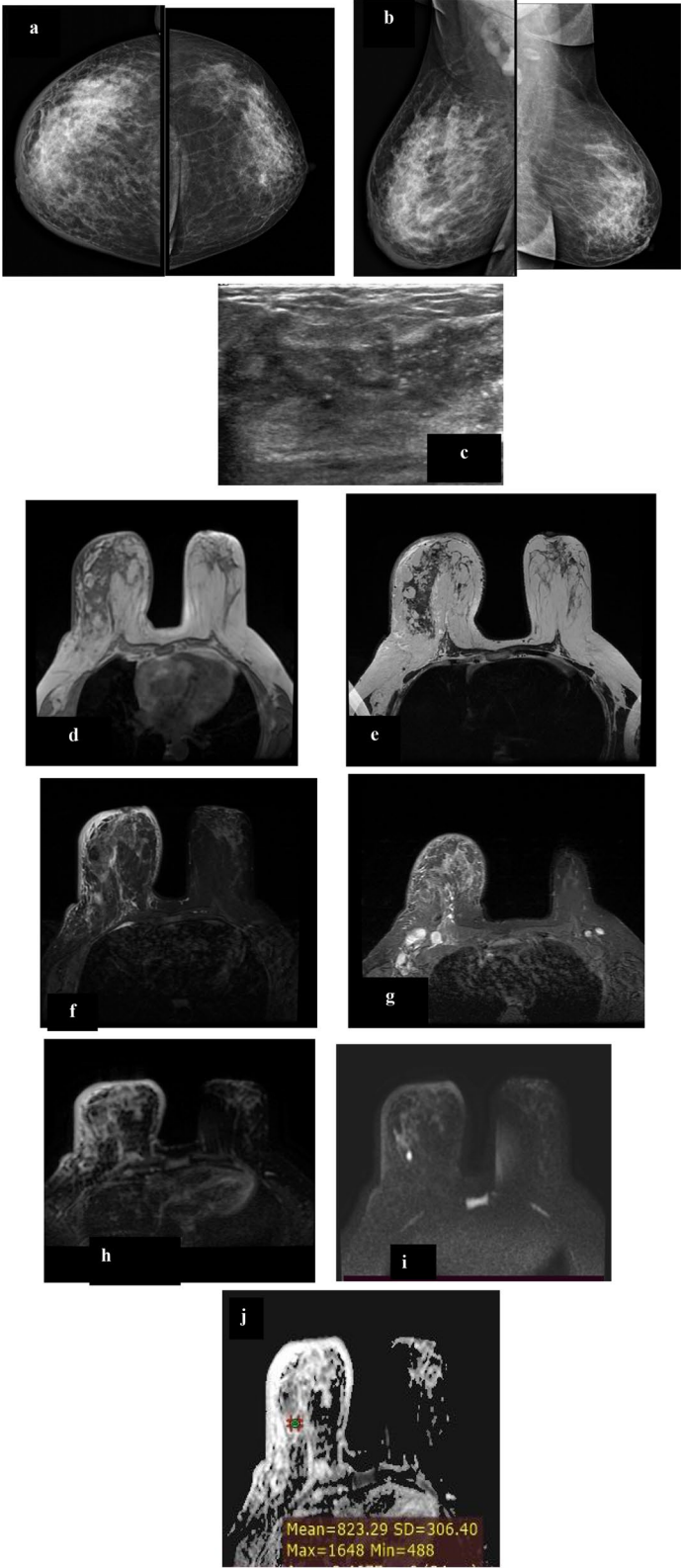
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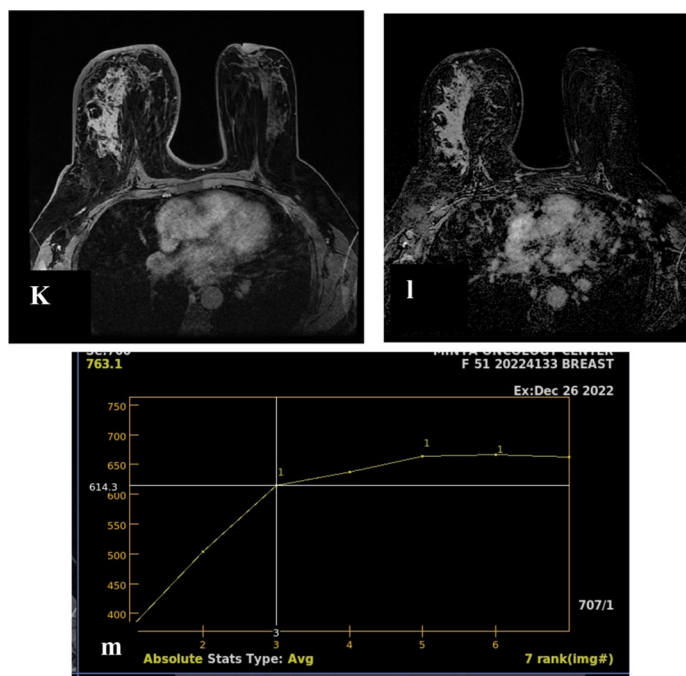**Fig. 3** (See legend on previous page.)

Fig. 3 continued

Regarding the cases that show non-mass enhancement in this study, two cases turned out to be invasive lobular cancer, one case was ductal carcinoma in-situ, three cases were mastitis and one case was adenosis. On the other hand, the study conducted by Youssef et al. [12] recorded six cases of benign nature with non-mass enhancement. In addition, Hashem et al. [7] disclosed five cases with non-mass enhancement, all turned out to be of benign nature.

When the internal enhancement kinetic curve was assessed in this study, Curve type I (progressive or persistent curve) was seen in benign lesions only. Curve type II was observed in seven cases (representing 11.6% of the total), three of them were proven to be invasive duct carcinoma, two cases were chronic granulomatous mastitis, one case was acute mastitis while the last one was identified as fibro adenoma. As for Curve III (washout pattern curve), it was shown in thirteen cases (21.6% of the total), one of them was determined to be chronic mastitis while all of the other lesions were confirmed to be malignant. Likewise the study conducted by Amandeep Singh et al. [13], where Type I curve was noted in 20 benign lesions (71.4%) and none of the malignant lesions. Type II curve was noted in four lesions, two were confirmed to be benign, while the other two were malignant. A Type III

(See figure on next page.)

Fig. 4 69-year-old female with negative family history, complaining of nipple discharge. **a** Craniocaudal views of mammographic images, **b** Mediolateral oblique views of mammographic images; show an focal ill-defined area of distortion seen at right retro-areolar region compared to left side (**a**, **b**). No retracted nipple. No microcalcification detected at either side. **c** Sonographic image, shows retro-areolar duct dilation (of caliber around 4 mm) with inspissated content, where no soft tissue component detected. On application of color Doppler, no vascularity was detected. Sono-mammography BIRADS III. **d**, **e** MR T2WI and STIR show few retro-areolar duct dilation (4 mm), which attains hyper intense signal at T2WI (**d**) and STIR (**e**). No abnormal signal intensity soft tissue component detected. **f**, **g**, **h** DWI on b value 500, 1000 and 1500, respectively, and **i** ADC map, show no diffusion restriction or suspicious lesions. Where the DWI down staged the lesion to BIRADS II. **j**, **k** Post contrast study, with the subtraction image, shows no appreciable enhancement with no suspicious lesions, hence no kinetic curve was obtained BIRADS II. Pathology: Duct ectasia with no malignant cells
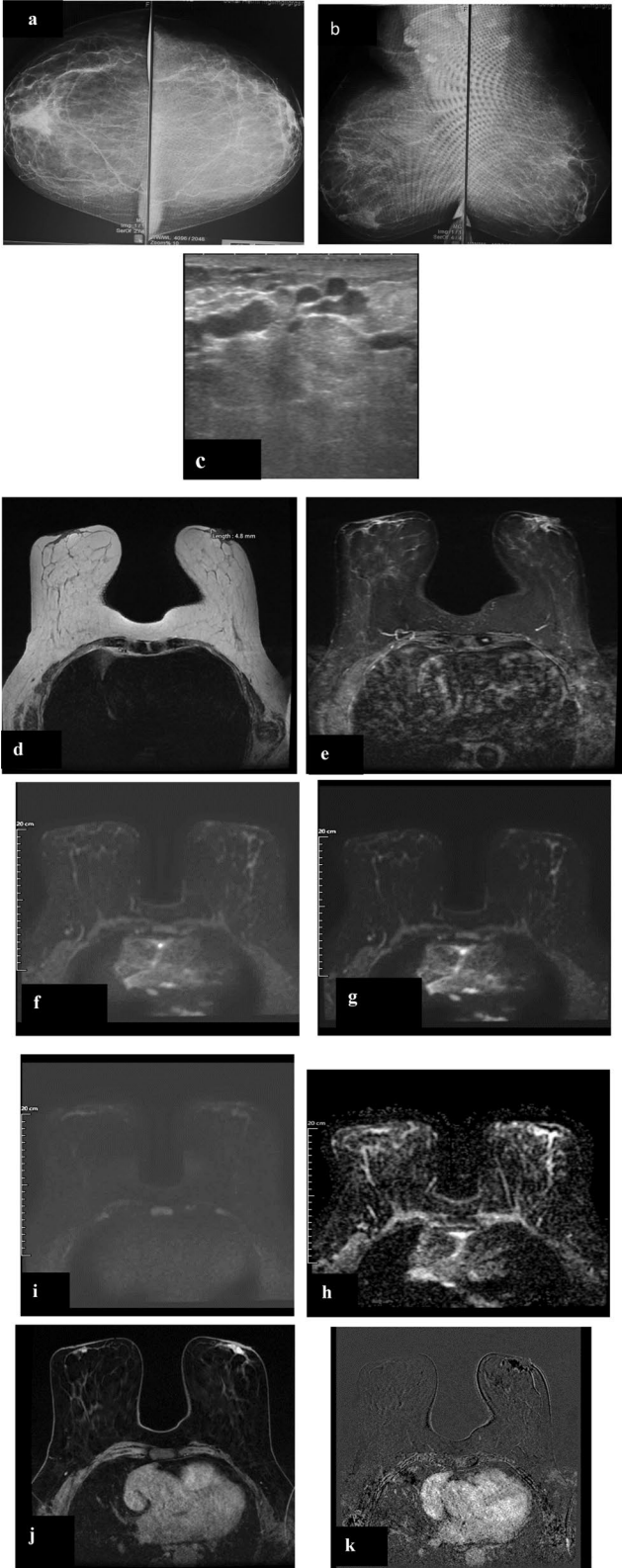
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Fig. 4 (See legend on previous page.)

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enhanced kinetic curve was present in the malignant lesions.

This research found that a sensitivity of 88.9% and a specificity of 88% were achieved when CE-MRI was used alone. That was comparable to the study carried out by El Bakry et al. in [14] where the sensitivity and specificity were of 84.2% and 91.7%, respectively. Nonetheless these results were relatively different from Amandeep Singh et al. [13] study where the sensitivity and specificity were 97.9% and 75.7%, respectively. The decreased specificity in the current study was attributed to failure of properly classifying some lesions as benign or malignant, with the low specificity rate found to be attributed to the non-mass enhancement of the benign breast lesions as mastitis and adenosis, as well as to the diversity of breast lesions attaining type II kinetic curve enhancement.

On adding DWI to the MR examination of the cases in the current study, we observed a notable boost in the sensitivity and specificity of the combined CE-MRI and the DWI, reaching up to 94% and 95%, respectively. That was comparable to the results of the study of Aribal et al. [15] which reported a sensitivity of 97% and specificity of 88.9%, and also that reported by Ebrahim et al. [16] which was able to achieve a sensitivity of 100% and specificity of 76%. Likewise, Hashem et al. [7] study reported sensitivity of 73.1% and specificity of 83.6%.

On paralleling the DWI sequence accompanied by unenhanced conventional MRI with the pathology of the biopsied lesions, the sensitivity and specificity were akin to those of combined DWI with enhanced MRI, for they were 88.9% and 90.5%, respectively. The specificity was also noted to be notably higher than that of combined sonography and mammography. This was in rapprochement to the study conducted by Hashem et al. [7] that scored sensitivity and specificity of 73.1% and 83,6%, respectively, and also the study conducted by Telegrafo et al. [17] that reached a sensitivity and specificity of 94% and 79%, respectively.

In this study, the DWI was based on b-value 1000 s/mm^2, as we found out that the optimal b-value in discrimination between benign and malignant breast lesions was 1000 s/mm^2 in breast DWI. It was also reported in other studies that high b-values over 1000 s/mm^2 should be averted, as the accuracy of ADC to distinguish between malignant and benign lesions is greatest when using values of $b < 1000$ s/mm^2 and also DWI has lower sensitivity on increasing the b-value > 1000 s/mm^2. Furthermore, Dorrius et al. [18] and Pereira et al. [19] both revealed that the b value of 1000 s/mm^2 is beheld as the gold standard for identifying benign from malignant tumors and maximizes the accuracy of ADC in their differentiation.

The ADC values recorded in the study extended from 0.5 to 2×10^{-3} mm^2 /sec, with a cutoff value of 0.9×10^{-3} mm^2/sec, which achieved a sensitivity of 94%, specificity of 87% and accuracy of 83.3% ($P = 0.01$). These findings approached those of Sibel Kul et al. [20] study, who in similar fashion found a threshold value of 0.9×10^{-3} mm^2/sec as a cutoff value to discriminate benign from malignant breast lesions. However, these results were a bit divergent from those of Hashem et al. [7] who established a cutoff value of 1.3×10^{-3} mm^2/sec, with a sensitivity of 73% and a specificity of 83.7%. In addition, a cutoff value of 1.3×10^{-3} mm^2/sec was attained by both El Bakry et al. [14] and Yadav et al. [21], where the former demonstrated a sensitivity of 92.1% and a specificity of 91.6%.The difference in the ADC cutoff values may be owing to the small sample size ($n = 60$) in this study compared to the larger samples used by the other researches.

(See figure on next page.)

Fig. 5 56-year-old female patient with positive family history and history of previous breast operation (local excision) upon right breast cancer (pathology: IDC). **a** sonographic image, showing heterogeneous ill-defined area of architecture distortion seen at site of operative bed reaching the chest wall associated with diffuse increase in skin thickness and subcutaneous edema. The mammography showed no microcalcifications BIRADS IVa. **b**, **c** MR T2WI and STIR show an abnormal signal intensity area of architectural distortion seen at site of operative bed resting upon chest wall (blue arrow), which attains hyper intense signal at T2WI (**b**) & STIR (**c**). associated with diffusely thickened skin with subcutaneous and interstitial parenchymal edema. **d**, **e**, **g** DWI on b value 500, 1000and 1500, respectively, with **f**; corresponding ADC map, showing the lesion with facilitated diffusion. Hence, DWI downgraded the lesion to BIRADS II. **h**, **i** Post contrast study, with the subtraction image demonstrating the lesion attaining no appreciable enhancement with no suspicious features and therefore, no kinetic curve obtained MRI BIRADS II. Pathology: No malignant cells
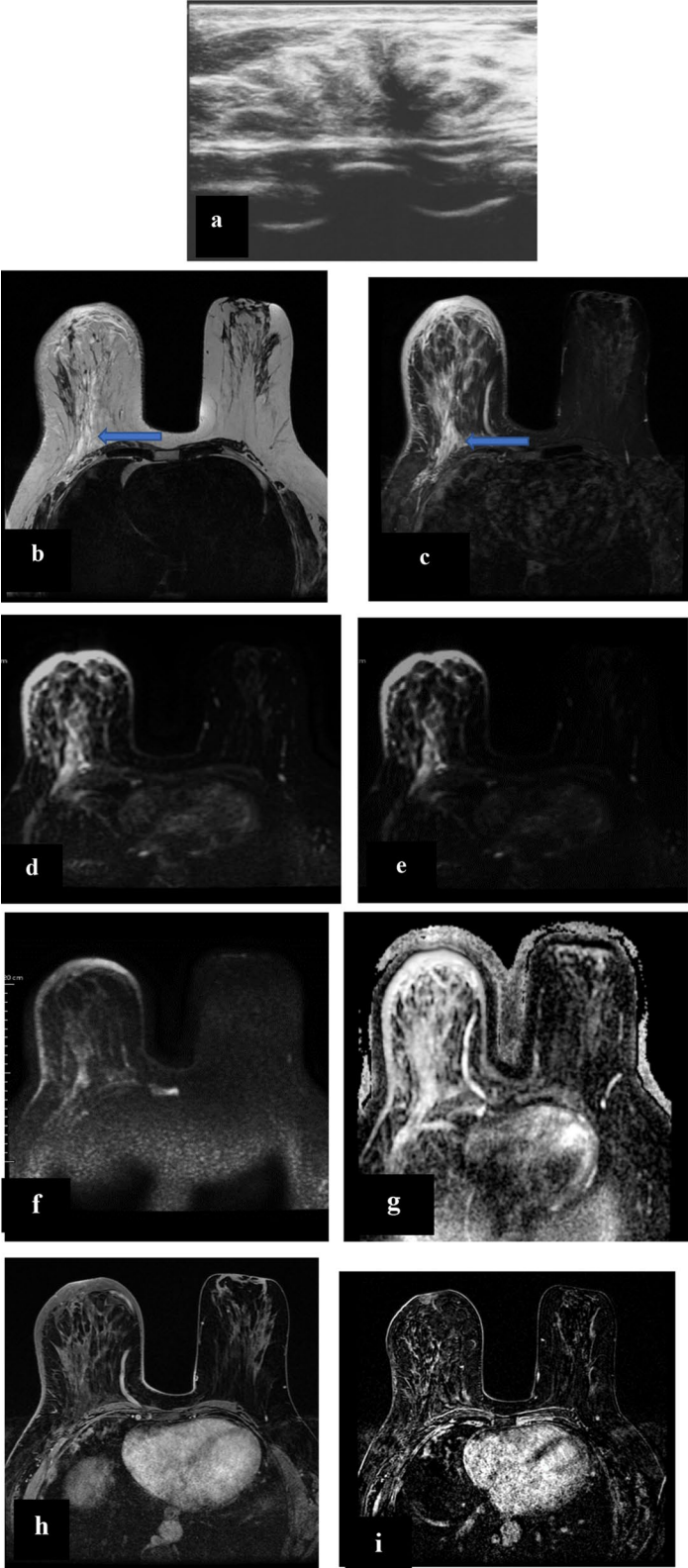
Fig. 5 (See legend on previous page.)

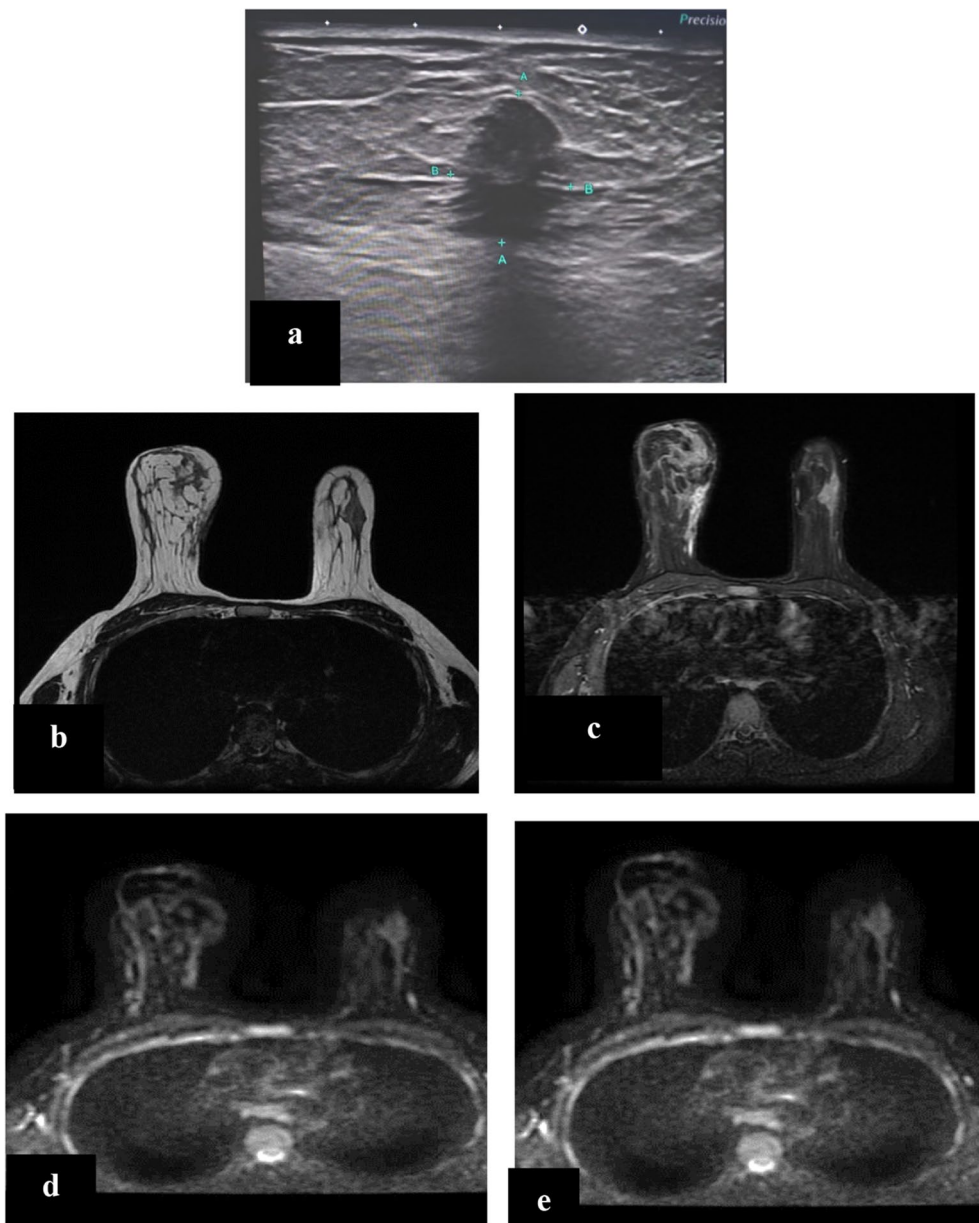Mohamed *et al. Egypt J Radiol Nucl Med*   (2024) 55:107

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Fig. 6 37-year-old female patient with negative family history, history of right conservative breast surgery (pathology: ILC and LCIS). **a** Sonographic image, showing rather defined hypo echoic soft tissue lesion with irregular outlines seen involving UIQ of right breast and not respecting surrounding tissue planes BIRADS IV. No abnormality detected at left breast BIRADS I. **b**, **c** MR T2WI and STIR show an abnormal signal intensity soft tissue lesions seen at UIQ of right breast as well as at the UOQ of left breast, they attain hypo intense signal at T2WI (**b**) and hyper intense signal at STIR (**c**). **d**, **e**, **f** DWI on b value 500, 1000 and 1500, respectively, ADC map **g** the lesion on the right breast shows T2 black out effect, while the suspicious area at the left side shows no diffusion restriction with high ADC values. So the DWI was equivocal in the right breast lesion and denied any suspicious lesion in the left breast. **h**, **i** Post contrast study, with the subtraction image, the lesion on right breast attains non-mass heterogeneous enhancement at early phases with wash out at delayed phases with kinetic curve III. Regarding the suspicious area on left breast, it attains focal area of non-mass faint heterogeneous enhancement with kinetic curve type I (RT MR BIRADS IV Lt MR BIRADS II). Pathology: Right breast: ILC. Left breast: Adenosis
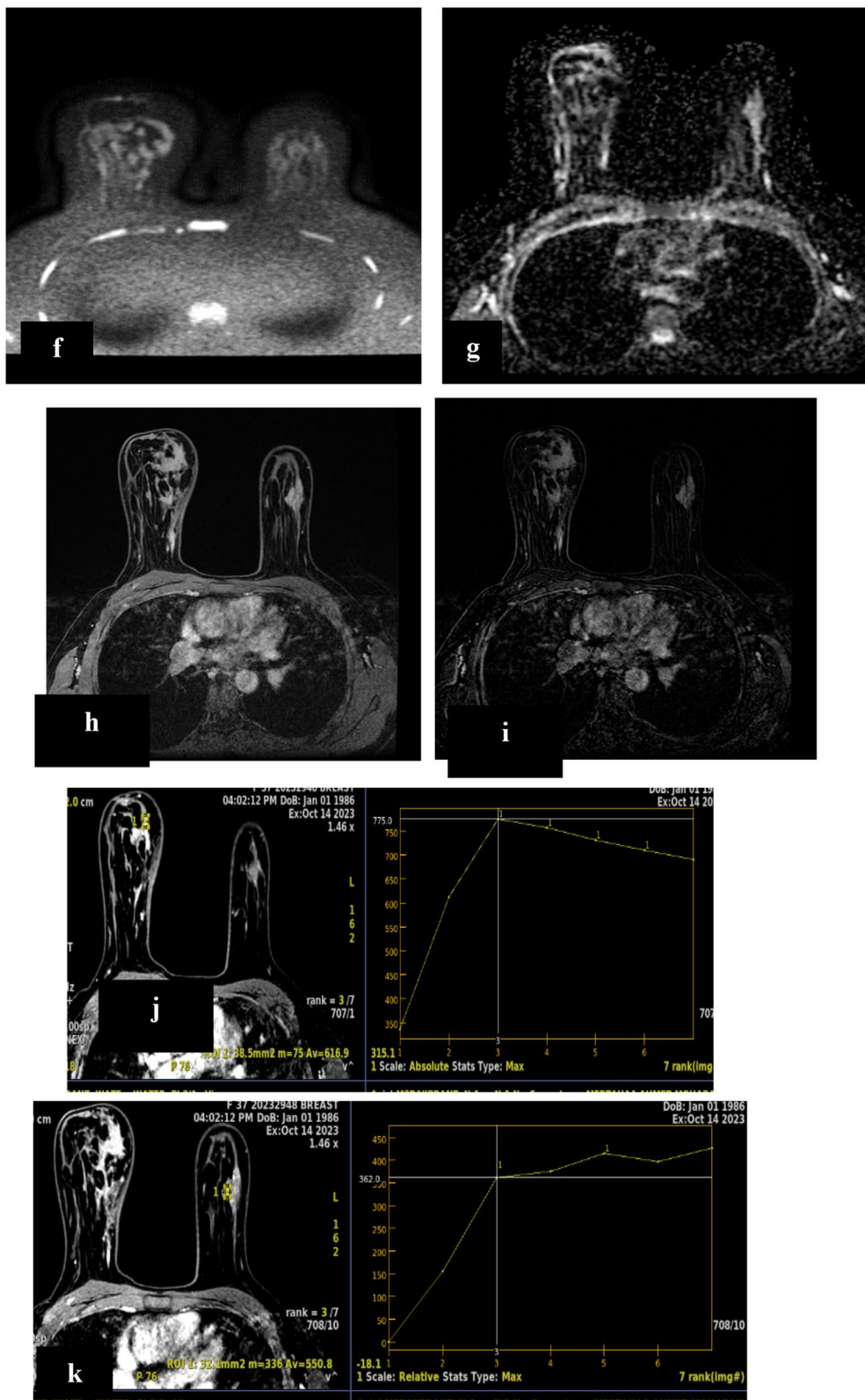
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Fig. 6 continued

Even supposing that DWI proved to be efficacious in determining the nature of the lesions in breast, yet on taking DWI alone as an underpinning in interpretation, we were confronted by element of misapprehension in some cases. That was distinctly conspicuous when false positive and negative cases were shown up. Examples of the false positive cases were as follows; a complicated cystic lesion with thick irregular wall that attained ADC values of 0.6×10^{-3} mm^2/sec, yet turned out to be acute mastitis when biopsied. Besides, two lesions with patchy restriction in diffusion and corresponding ADC value around 0.9×10^{-3} mm^2/sec, later on confirmed to be chronic granulomatous mastitis after biopsy. Also, a case of papilloma, which attained restriction in diffusion with ADC value about 0.7×10^{-3} mm^2/sec. This resembled the study by Telegrafo et al. [17] that revealed a false positive case that turned out to be complicated cyst too. Also, that was in rapprochement to the study conducted by Sibel Kul et al. [20] that reported five false positive cases; one turned to be mastitis and the others confirmed to be papillomas, fibrocystic and fat necrosis) (Figs. 1, 2, 3, 4, 5, 6, 7 and 8).

On the subject of the false negative cases, one case with non-mass enhancement, attained no true diffusion restriction, which was first thought to be of benign nature when assessed by the DWI and ADC values. Therewith, when biopsied, it was proved to be invasive lobular carcinoma. Also the case of DCIS was missed when assessed by DWI alone. Likewise, the study conducted by Avendano et al. [22] who reported that DWI with ADC mapping has low diagnostic accuracy in non-mass enhancement lesions, where they found out that roughly one-third of all NMEs cannot be assessed by diffusion-weighted imaging (DWI). That was also in agreement with the study conducted by McDonald et al. [23], where a false negative case was noted, and confirmed to be invasive lobular carcinoma too. On the other hand the study conducted

by Hashem et al. [7] who reported false negative cases that were confirmed to be DCIS & IDC as well as the study conducted by Telegrafo et al. [17] that found out false negative case that was proven to be mucinous carcinoma.

It is worth mentioning that DWI solely unescorted by contrast-enhanced MRI and together with non-enhanced conventional MRI was capable of downstaging 36 cases out of 60 cases. That obviously rendered potential reduction in cases with needed biopsy by 30%. That tallied the study conducted by Paola Clauser et al. [24] where the DWI sequence decreased the false positive results by 32.6%, likewise the study conducted by Partridge et al. [25] that potentially reduced 33% of the false-positive results.

Limitations of the study and recommendations

Limitations in our study include that it needed to be applied on larger cohort of patients, with the high cost of MRI.

Our recommendation in future

- A larger group of patients can be included in the study.
- Extending the area of application to include more postoperative cases.
- Adding MR spectroscopy to the analysis of the breast lesions.

Conclusions

CEMRI is un-debatably effective in depicting and discriminating indeterminate breast lesions chiefly when combined with DWI. Yet, with the high expense of the contrast and in the event of contrast contraindications or unavailability, DWI has proven to be a convenient substitute for CE-MRI aiding in rendering the breast lesion BIRADS downgraded with diminishing the unneeded biopsies.

(See figure on next page.)

Fig. 7 60-year-old female patient with history of cerebral SOL (pathology: meningioma) complaining of enlarged right breast. **a** Craniocaudal view of mammographic imaging, **b** Mediolateral oblique view of mammographic imaging show bilateral dense breast (ACR III), with global asymmetry in size and density of right breast compared to left breast, with dense breast (non-compatible with the age). This is associated with multiple rod shaped and rounded shaped of microcalcification seen scattered at both breasts. **c** shows Sonographic image, where retro- areolar duct dilation (caliber 6 mm) with inspissated content were noted. No soft tissue component. No vascularity on application of color doppler. Sono-mammography BIRADS IVa. **d**, **e** MR T2WI and STIR show global asymmetricity in size (right breast larger than left breasts). Both breasts show few retro areolar dilated ducts, more evident at right side which attain hypo intense signal at T2W (**d**) and hyper intense at STIR (**e**. **f**, **g**, **h** DWI on b value 500, 1000and 1500, respectively, with corresponding ADC map **i** reveal that there is no diffusion restriction noted. The DWI downgraded the lesion to BIRADS II. **j** Post contrast study, with the subtraction image. **k** shows speckled areas of background enhancement with kinetic curve (type I) BIRADS III. Pathology: No malignant cells
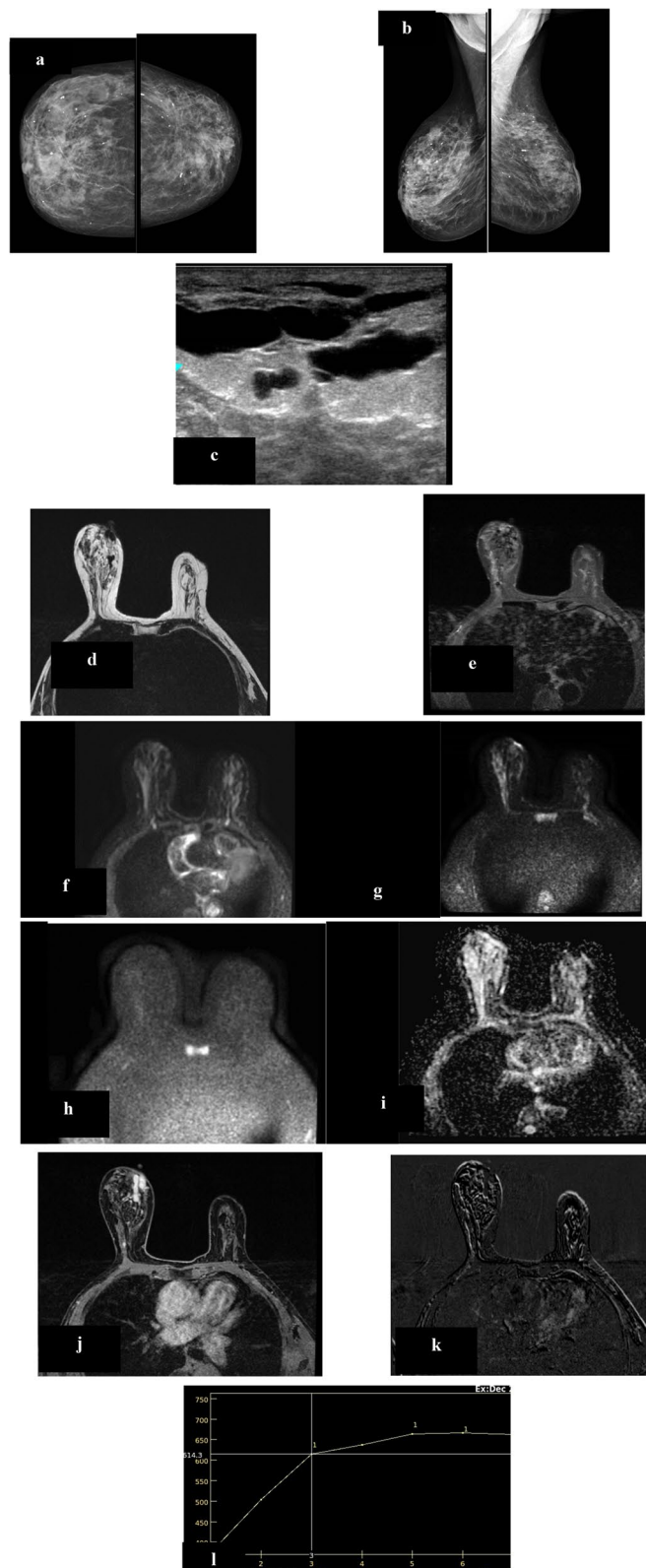
Fig. 7 (See legend on previous page.)

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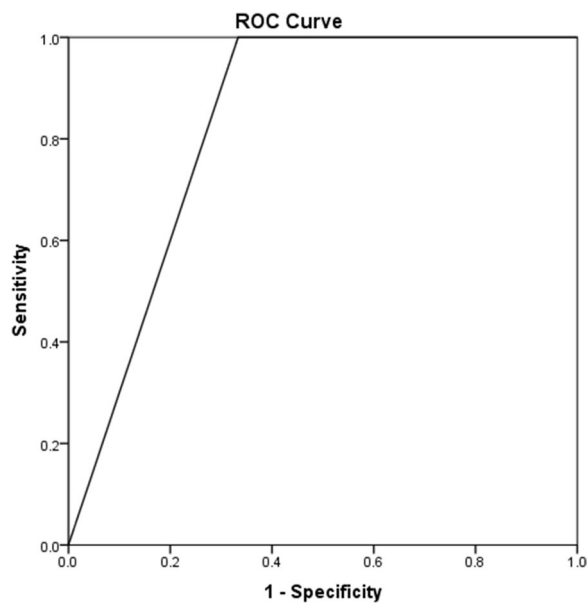
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Fig. 8 ROC curve of ADC value for the true-positive rate (sensitivity) was plotted against false-positive rate (specificity) analysis

Abbreviations

CEMRI   Contrast-enhanced MRI
DCIS   Ductal carcinoma insitu
DWI   Diffusion-weighted image
ILC   Invasive lobular carcinoma

Author contributions

SMR and MAK carried out the manuscript preparation and editing, study concepts as well as the experimental studies and data analysis, design and literature research, TOM was responsible for the clinical studies and also shared in the statistical analysis. While YMA and SSE is the Guarantor of integrity of the entire study and carried out the statistical analysis. All authors read and approved the final manuscript.

Availability of data and materials

The datasets used and analyzed during the study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate

This study was approved by the Research Ethics Committee (REC) under number 305 in 2018, Faculty of Dentistry, Minia University. Written and informed consent was obtained for all participants.

Consent for publication

All patients included in this research gave written informed consent to publish the data contained within this study according to our institution rules for ethics committee.

Competing interests

The authors declare that there is no conflict of interest.

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