

The Value of Combination of Dynamic Contrast-Enhanced Magnetic Resonance Imaging and Diffusion-Weighted Imaging in the Evaluation of Breast Masses

Narmein Abdsattar Mahmud, Sahar Basim Ahmed, Ansam Moyaser Othman

Department of Radiological, AL-Yarmouk Teaching Hospital, College of Medicine, Al-Mustansiriya University, Baghdad, Iraq

Abstract

Aim of the study: The aim was to characterize benign and malignant breast lesions on the basis of their magnetic resonance imaging (MRI) morphology and dynamic contrast enhancement in combination with the diffusion-weighted imaging (DWI) and their apparent diffusion coefficient (ADC) values at 1.5 T MRI, along with histopathological correlation. **Patients and Methods:** In this prospective study, 56 patients with suspicious breast mass who underwent 1.5 T MRI and proved by histopathology were included. Morphology was studied depending on the MRI signal intensity and dynamic contrast-enhanced imaging plus kinetic curve of enhancement of breast lesions. DWI and ADC values were calculated at b values of 0, 600, and 850 s/mm. The ADC value and histopathology correlation were analyzed. **Results:** Out of the 56 lesions, 27 lesions were histologically malignant (48.2%) and 29 were histologically benign (51.8%), with age range between 25 and 75 years, with a mean of 54.1 years, and with a standard deviation of ± 12.69 years. The MRI results found a sensitivity (SN) of 85.2%, a specificity (SP) of 72.4%, a positive predictive value (PPV) of 74.2%, a negative predictive value (NPV) of 84%, and an accuracy of 78.6%. The DWI findings were as follows: 100% SN, 82.8% SP, 84.4% PPV, 100% NPV, and 85.3% accuracy. The combined MRI interpretation and DWI and ADC findings were as follows: 100% SN, 92.1% SP, 71.1% PPV, 100% NPV, and 86.4% accuracy. All malignant lesions showed restriction at DWI, while only 17.2% of the benign lesions are restricted at DWI. The mean of ADC value was higher in benign cases as compared to the malignant lesions (0.815 vs. 1.287×10^{-3}) with statistically significant difference ($P = 0.001$). **Conclusions:** The combination of contrast-enhanced breast MRI with DWI and ADC value increases the diagnostic accuracy and SP in the characterization of benign and malignant breast lesions.

Keywords: Apparent diffusion coefficient, breast mass, diffusion-weighted imaging, dynamic contrast-enhanced magnetic resonance imaging

INTRODUCTION

Magnetic resonance imaging breast

Nowadays, magnetic resonance imaging (MRI) of the breast is frequently applied when other diagnostic modalities fail to find a primary source in the breast. Remarkable advances in MRI technology have allowed sensitive detection and anatomic definition of cancer.^[1]

Dynamic contrast-enhanced MRI (DCE-MRI) and diffusion-weighted MRI (DW-MRI) are currently used as an adjunct to mammography and ultrasound (US) in women at high risk, or those with extremely dense breasts, selective “problem-solving” or adjunct diagnosis where standard clinical and imaging evaluation do not provide a clear diagnosis, imaging of breast silicone implants, monitoring response to

neoadjuvant (primary), systemic therapy in locally advanced disease, irradiated breasts, and pre- and post-surgical breasts for staging of highly invasive breast cancers.^[2]

Although the most frequently used techniques for breast imaging are mammography and US, contrast-enhanced MRI is becoming increasingly significant, mainly because of its high sensitivity (SN) for detecting invasive breast cancer the

Address for correspondence: Dr. Sahar Basim Ahmed, Department of Radiological, AL-Yarmouk Teaching Hospital, College of Medicine, Al-Mustansiriya University, Baghdad, Iraq. E-mail: dr_saharbasim@yahoo.com

Submitted: 29-Dec-2020 Revised: 05-May-2021 Accepted: 20-Jul-2021 Published: 15-Dec-2021

This is an open access journal, and articles are distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 4.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as appropriate credit is given and the new creations are licensed under the identical terms.

For reprints contact: WKHLRPMedknow_reprints@wolterskluwer.com

How to cite this article: Mahmud NA, Ahmed SB, Othman AM. The value of combination of dynamic contrast-enhanced magnetic resonance imaging and diffusion-weighted imaging in the evaluation of breast masses. *Mustansiriya Med J* 2021;20:32-8.

Access this article online

Quick Response Code:



Website:
<http://www.mmjonline.org>

DOI:
10.4103/mj.mj_8_21

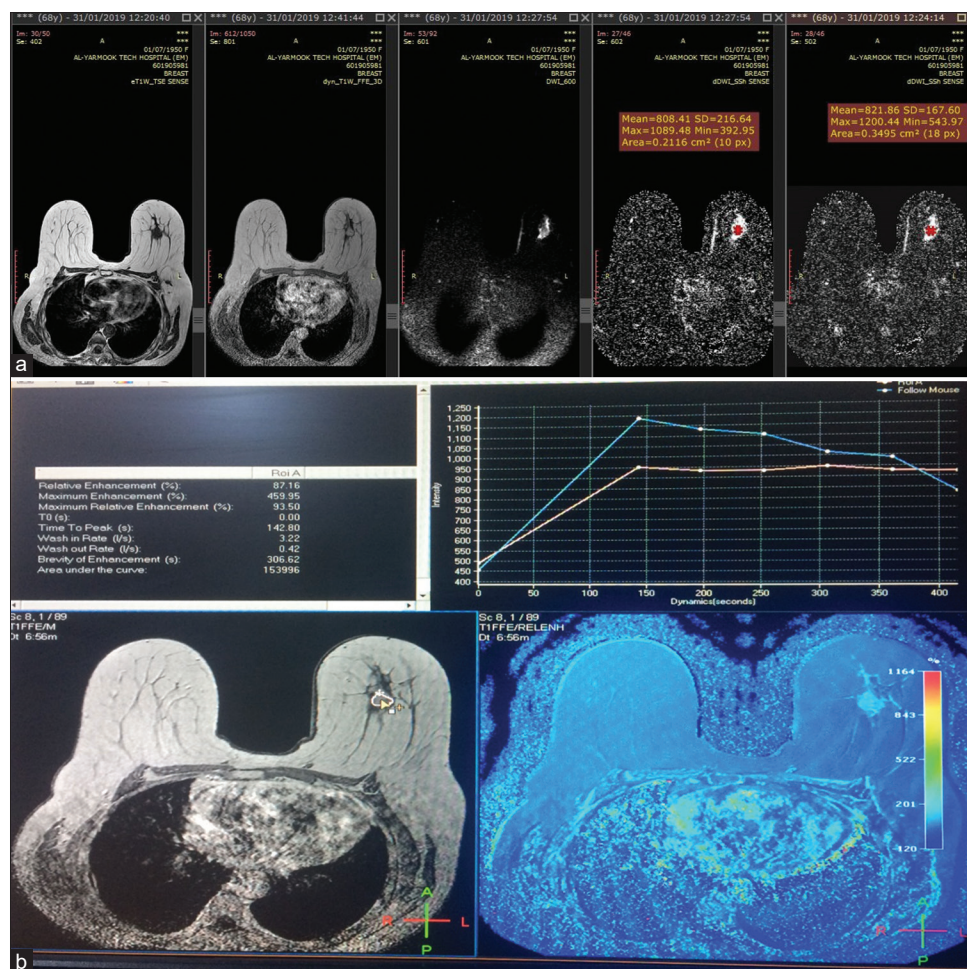


Figure 1: A 77-year-old female presented with rapidly growing right breast mass, (a) T1 weighted image and postcontrast T1 hypointense signal on T1-weighted image, diffusion-weighted imaging and apparent diffusion coefficient map restricted on diffusion-weighted imaging apparent diffusion coefficient value = 0.749×10^{-3} , $0.863 \times 10^{-3} \text{ mm}^2/\text{s}$ on 600 and 850 b value. (b) Dynamic magnetic resonance imaging revealing rim-enhancing mass with irregular outline, the mass shows washout curve, histopathological result was invasive ductal carcinoma

negative predictive value of breast MRI for invasive breast cancer (99)% may help to avoid further investigation and unnecessary biopsies.^[2] There is evidence that MRI does lead to changes in surgical treatment, typically from breast-conserving surgery to mastectomy.

Breast magnetic resonance imaging interpretation

Each lesion should be evaluated regarding its shape, margin, precontrast T1 and T2-weighted images (T1 and T2 WI) signal intensity, enhancement characters, as well as any change from the previous study. In general, bright signal on T1 and T2 WI is suggestive of benign finding with the exception of colloid carcinoma which can demonstrate high signal intensity on T2 WI, while most invasive carcinomas demonstrate low or intermediate signal intensity on T2 WI.^[3,4]

There are certain morphologic and kinetic characteristics of the lesions, such as irregular shape, irregular or spiculated margin, rim enhancement (in the case of mass enhancement), linear or segmental enhancement (in nonmass enhancement), and with wash-out curve, which are considered to be suggestive of malignancy.^[4]

The morphological features of breast masses at MRI include shape, margin and pattern of internal enhancement and non enhancing septa (in mass enhancement) and (nonmass enhancement lesions) presents as a focal, regional in distribution, with persistent pattern of dynamic curve are considered to be suggestive of benign disease.^[4] Finally, MRI studies are classified into one of the six Breast Imaging-Reporting and Data System (BI-RADS) categories depending on the combined interpretation of both morphological and kinetic analysis, and appropriate recommendation is made.^[4]

The kinetic information is typically expressed as a time intensity curve (TIC). TICs can be divided into three main shapes according to the initial enhancement phase within the 1st 2 min and the delayed enhancement phase after 2 min. The delayed-phase enhancement pattern is usually used to describe the curve shape.^[3]

Diffusion weighted imaging

Diffusion weighted imaging (DWI) is considered the way of characterizing tissue properties by providing information about the free movement of water molecules (Brownian) in various tissue of the body. Hence in cysts, blood vessels, bladder,

Table 1: Distribution of study patients by histopathological results (n=56)

Histopathological results	n (%)
Type of lesion	
Malignant lesion (n=27)	
Invasive ductal carcinoma	24 (88.9)
Ductal carcinoma <i>in situ</i>	1 (3.7)
Malignant phylloid	1 (3.7)
Atypical ductal hyperplasia	1 (3.7)
Benign lesion (n=29)	
Fibroadenoma	12 (41.4)
Fibrocystic changes	7 (24.3)
Abscess	3 (10.4)
Fat necrosis	2 (6.9)
Intraductal papilloma	1 (3.4)
Hematoma	1 (3.4)
Duct ectasia	1 (3.4)
Lipoma	1 (3.4)
Galactocele	1 (3.4)

and tissues with big intercellular spaces, water move freely without any restriction and will show signal loss after the application of diffusion gradients.^[5] On the contrary, in the case of solid tumors with high cellularity, there will be a significant reduction in the extracellular space, and free water movement will be restricted. Therefore, the signal will be greater after the application of diffusion gradients.^[1,6]

MRI can measure the diffusion of water *in vivo*. DW-magnetic resonance (MR) pulse sequence measures the apparent diffusion coefficient (ADC) value of water molecules in tissue voxels.

Diffusion-sensitizing gradients are placed along a single axis to alter the signal intensity of the diffusing water.^[7]

Analysis of diffusion-weighted imaging

ADC can be calculated during postprocessing by the use of at least two different b values, and the final image with different ADC values measured for each pixel of the image is known as an ADC map.^[8]

A low ADC value indicates restricted diffusion, typically seen in malignancies.^[8]

The signal intensity seen in the DWI sequence is produced by the movement of water molecule and the T2 relaxation time. The “T2 effect” that can be mistaken with diffusion restriction is known as “shine-through.” Therefore, the ADC map permits quantifying DWI and is helpful to avoid this pitfall, as a region with truly restricted diffusion will show low signal intensity on the ADC map, but lesions with high fluid content will demonstrate high signal intensity on T2-weighted and on diffusion images.^[8] This unwanted effect can be decreased by reducing the echo time which is basic pulse sequence parameter^[7-10] and increasing the b-value, but it can never be totally eliminated.^[7]

DW breast MRI has been mainly applied to differentiate breast lesions and to add a new parameter for the diagnosis, with the

hope of avoiding unnecessary biopsies, especially for lesions that are visible only on MRI that require sampling under MRI guidance, a time-wasting and high-cost procedure.^[9]

Previous studies demonstrated an inverse relationship between the cellularity of breast malignancy and ADC value.^[10,11]

Most of these studies have shown a significant difference in ADC value between benign and malignant tumors. Each of them defines the cutoff point for the ADC value that provides a high SN and specificity (SP) for the detection of breast cancer. However, an overlap between benign and malignant diseases was demonstrated.^[10,12,13]

A lot of studies have revealed the usefulness of breast DWI in the differentiation of benign from malignant lesions of the breast. These studies proved that the SN of breast DWI was in the range of 80%–96% and its SP was in the range of 46%–91%.^[13-15] Partridge *et al.* concluded that there is 10% improvement in the positive predictive value (PPV) when combining DWI with DCE-MRI in the differentiation of breast masses.^[13]

When measuring ADC value, the lesion must be identified on the ADC map and DW images, and then the region of interest (ROI) must be placed carefully over the solid part of the tumor to ensure that cystic or necrotic parts as well as the normal breast parenchyma are not included in this region.^[15]

The aim of the study

The aim was to evaluate the role of DWI and DCE MRI in the characterization of breast lesions and comparing the results with the histological finding.

PATIENTS AND METHODS

This prospective study was performed at Al-Yarmouk Teaching Hospital in Baghdad from January 2018 to 2019.

From a total of 56 female patients, with the age range between 25 and 75 years and with a mean of 54.1 years, 56 lesions classified by physician and $\pm$ US and/or mammography were included.

Inclusion criteria

Patients with suspicious breast lesions at mammography or breast US or with suspicious clinical findings.

Exclusion criteria

1. Patients with contraindication to MRI examination or its contrast media
2. Patients who refused MRI examination
3. Patients who refused biopsy or surgery
4. Patients with inconclusive MRI study.

Data collection

All the patients underwent full history taking and general and local examination. All patients underwent DW MRI and DCE MRI examination, and the results of breast MRI were compared with the histopathological results that were used as the standard diagnostic method.

Magnetic resonance imaging protocol

All patients were subjected to MRI examination in prone position on 1.5 tesla Acheiva philips medical system in Eindhoven -Best /Netherlands, setup in Baghdad /Iraq, at AL-Yarmouk teaching hospital with a dedicated breast coil. MRI was done within 7–14 days of menstrual cycle in premenopausal women. Examination included image acquisition followed by image postprocessing.

The following sequences were done:

- Axial T1 WI: Slice thickness = 3 mm
- Axial T2 fat suppression WI: Slice thickness = 3 mm
- DW image: It was done before contrast administration in the axial plane at spin-echo sequence using breast surface coil at the following b values: 0, 600, 850 s/mm², slice thickness = 3 mm
- ADC map was derived automatically in the MR system
- Dynamic T1 postcontrast fat suppressed image: Dynamic study with intravenous contrast; dimeglumine Gadopentetate (each mL = 469 mg); the dose given to the patient about 1 mmol/kg by manual injection, slice thickness = 3 mm.

Image analysis

All the images were evaluated on the workstation by two specialized radiologists.

Each lesion was identified on the dynamic subtracted image, and T1, T2, and T2 fat suppression WIs.

The size, signal intensity, enhancement pattern, as well as the morphologic features of each lesion were analyzed. The time–signal intensity curves were obtained on dynamic MR images by placing the ROI at the most enhancing area of the lesion.

The morphologic features were assessed. The shape, margin, enhancement characteristics, and signal intensity on both T1- and T2-WIs were analyzed.

The enhancement kinetics of each lesion were evaluated, and the types of curves were determined according to delayed-phase enhancement as type I = persistent, II = plateau, and III = washout curves.

DWI was then evaluated regarding the signal intensity, and the mean ADC of each lesion was measured by placing the ROI manually within the solid portion of the lesion.

Histopathological diagnosis was done in all patients, considering it as a gold standard for the study.

RESULTS

The total number of patients recruited in this study was 56. All of them had palpable breast lesion and investigated by MRI.

Histopathological types and results

Of all the 56 participants, 29 females (51.8%) were complaining of benign lesion, while the remaining 27 females (48.2%) complained of malignant lesion.

The histopathological results of malignant lesions were as follows: invasive ductal carcinoma (88.9%), one lesion (3.7%) was each of ductal carcinoma *in situ*, atypical ductal hyperplasia, and malignant phylloid tumor. Regarding the 29 benign lesions, 41.4% of lesions were fibroadenoma, 10.4% were abscess, 24.3% were fibrocystic changes, 6.9% were fat necrosis, while one lesion (3.4%) was each of intraductal papilloma, hematoma, lipoma, duct ectasia, and galactocele [Table 1].

Magnetic resonance imaging findings

On the right side, there were 48.3% benign lesions and 37% malignant lesions, whereas 51.7% of benign lesions and 63% of malignant lesions were on the left side.

Type of enhancement

Concerning type of enhancement, the highest proportion of both benign and malignant lesions was with mass enhancement (88.9% and 65.5%, respectively). Nonmass enhancement was seen in 11.1% of benign lesions and 34.5% of malignant lesions. Table 2 shows the distribution of breast lesions by type of enhancement.

Shape of lesion

According to MRI findings, 65.5% of benign masses were of regular shape or margin, whereas majority of the malignant masses (96.3%) were of irregular shape and margin.

Type of curve

Regarding the type of curve, plateau curve (Type II) was seen in the highest proportion of benign and malignant lesions (69% and 74.1%, respectively). Nine benign lesions (31%) and two malignant lesions (7.4%) were with persistent curve (Type I). While washout curve (Type III) was seen in 18.5% of malignant lesions, no benign lesions were with this curve type.

Enhancement pattern of lesion

A homogeneous internal enhancement pattern occurred in 44.8% of benign lesions, whereas 44.4% of malignant lesions were with heterogeneous internal enhancement pattern.

Diffusion-weighted imaging findings

Regarding DWI findings, most of the benign cases (82.8%) showed no restriction, whereas all of the patients with malignant lesions showed restricted DWI findings.

Depending on MRI findings' interpretation, 31 patients who represented 55.4% of the study patients were with malignant lesion, whereas the remaining 25 patients (44.6%) suffered from benign lesion of breast.

Comparison in apparent diffusion coefficient value between benign and malignant lesions

On comparison in the means of ADC value between both types of breast lesions, it was found that ADC value was higher in benign cases compared to that in malignant cases (0.815 vs. 1.287×10^{-3}) with a statistically significant difference ($P = 0.001$) [Figure 1].

Table 2: Distribution of study patients by histopathology and magnetic resonance imaging findings

MRI findings	Histopathology (%)	
	Benign lesions	Malignant lesions
Type of lesions	44.6	55.4
Side of lesion		
Right side	48.3	37
Left side	51.7	63
Type of enhancement		
Mass	88.9	65.5
Nonmass	11.1	34.5
Shape of lesions		
Regular	65.5	34.5
Irregular	3.7	69.3
Type of curve		
Type I	31	7.4
Type II	69	74.1
Type III	-	18.5
Enhancement pattern		
Homogenous	44.8	37
Rim	10.3	11.1
Focal	20.7	3.7
Regional	13.8	-
Heterogeneous	6.9	44.4
Clumped	3.4	3.7
DWI findings		
Restricted	17.2	100
Nonrestricted	82.8	-
ADC values	1.287±0.404	0.815±0.258

MRI: Magnetic resonance imaging, DWI: Diffusion-weighted imaging, ADC: Apparent diffusion coefficient

Sensitivity, specificity, and accuracy of diffusion-weighted imaging and apparent diffusion coefficient study

The DWI study was of 100% SN, 82.8% SP, 84.4% PPV, 100% NPV, and 85.3% accuracy.

Sensitivity, specificity, and accuracy of routine magnetic resonance imaging interpretation

The MRI findings were as follows: SN of 85.2%, SP of 72.4%, PPV of 74.2%, NPV of 84%, and accuracy of 78.6%.

SN, SP, and accuracy of combined findings (routine MRI Interpretation and DWI) were as follows: 100% SN, 92.1% SP, 71.1% PPV, 100% NPV, and 86.4% accuracy.

DISCUSSION

The MRI BI-RADS lexicon recommends that a breast MRI protocol should contain T2-weighted and DCE MRI sequences. The addition of diffusion-DWI significantly improves diagnostic accuracy.

In this study, the two most common benign lesions were fibroadenoma and fibrocystic changes, which represented 41.4% and 24.3% of benign lesions, respectively, whereas the most common malignant lesion was invasive ductal carcinoma which represented 88.9% of malignant lesions.

These results were consistent with those of Ali *et al.*,^[15] who mentioned that most of the benign lesions were fibroadenoma and fibrocystic changes, which represented 36.8% and 15.8% of benign lesions, respectively, whereas the two most common malignant lesions were invasive ductal carcinoma and invasive lobular carcinoma, which represented 55.6% and 16.7% of malignant lesions, respectively.

In this study, the most common shape of benign lesions was regular, which represented 56.5% of benign lesions, whereas the shape of all malignant lesions was irregular with high incidence for irregular-shaped lesions (96.3%) of all malignant lesions included in this study.

These results were consistent with those of Tozaki and Fukuma,^[12] who showed that most benign lesions were of ovoid or round shape, while malignant lesions were of irregular shape.

In this study, according to enhancement pattern, homogenous enhancement was seen in 44.8% of benign lesions and 37% of malignant lesions, heterogeneous enhancement was seen in 6.9% of benign lesions and 44.4% of malignant lesions, rim enhancement was seen in 10.3% of benign lesions and 11.1% of malignant lesions, and nonmass enhancement was seen in 34.5% of malignant lesions and 11.1% of benign lesions, comparable with other studies.

Morris concluded that homogeneous enhancement is suggestive of a benign process; however, in small lesions, one must be careful as spatial resolution may limit evaluation. In addition, he concluded that the most frequent enhancement pattern among the malignant lesions was heterogeneous enhancement (96%).^[16]

In this study, according to the shape of time/signal intensity curve, Type I persistent curve was seen in 31% of benign lesions and 7.4% of malignant lesions, Type II plateau curve was seen in 69% of benign lesions and 74.1% of malignant lesions, and Type III washout curve was seen in none of the benign lesions and 18.5% of malignant lesions.

These results were consistent with those of Kul *et al.*,^[17] who showed that Type I persistent curve was seen in 81.1% of benign lesions and 12.8% of malignant lesions, Type II plateau curve was seen in 10.8% of benign lesions and 40.4% of malignant lesions, and Type III washout curve was seen in 8.1% of benign lesions and 44.7% of malignant lesions.

The conventional contrast-enhanced breast MRI interpretation mainly relies on the integrated analysis of lesion morphology as well as the enhancement kinetics of the lesion. Hence, we obtain information regarding tumor vascularity and vascular permeability in addition to tumor physics. This method demonstrated high SN for breast malignancy (85.2%) but with moderate SP (72.4%). An overlap is noted between the morphological characteristics and the enhancement kinetics of some malignant and benign lesions, leading to misclassification of these lesions.^[3,5,17,18]

Table 3: Sensitivity, specificity, and accuracy of combined findings of dynamic contrast-enhanced magnetic resonance imaging I and diffusion-weighted imaging and apparent diffusion coefficient study in 27 malignant and 29 benign breast lesions

Results	DCE-MRI (%)	DWI (%)	Combined (%)
Sensitivity	85.2	100	100
Specificity	72.4	82.8	92.1
PPV	74.2	84.4	71.1
NPV	84	100	100
Accuracy	78.6	85.3	86.4

DWI: Diffusion-weighted imaging, DCE-MRI: Dynamic contrast-enhanced magnetic resonance imaging, PPV: Positive predictive value, NPV: Negative predictive value

In this study, we obtained 85.2% of SN and 72.4% of SP for contrast-enhanced breast MRI and in order to increase the diagnostic accuracy of breast MRI, we evaluated the complementary role of DWI (100 SN and 82.8 SP).

The combined analysis of CE-MRI and the DWI increased the SN of CE breast MRI by 14.8% and the SP by 19.7% with the resultant SN and SP of 100% and 92.1%, respectively, which is comparable to the study by Kul *et al.*,^[19] who mentioned that the combination of DCE-MRI with DWI provided 95.7% SN and 89.2% SP. The SP of breast MRI improved by 13.5%; in addition, the results of Ali *et al.*^[15] show results higher than that by Kul *et al.* who provided 95.7% SN and 89.2% SP for combined DCE-MRI and DWI protocols [Table 3].

DW image is a functional noninvasive MRI technique. It directly reflects the Brownian motion of water molecules in the body tissues, and it can obtain the physiological feature of the body tissue by quantitative analysis of water molecules (ADC).^[20]

Malignant tumors tend to demonstrate ADC value lower than benign tumors, which is because malignant tumors show restricted diffusion. This is related to increased cellular density, larger nuclei, and less extracellular space in malignant tumors.^[21]

In this study, according to the lesion signal in DW image, free diffusion showed 82.8% of benign lesions and no malignant lesions, while restricted diffusion showed 17.2% of benign lesions and 100% of malignant lesions, which is comparable with the results of Kul *et al.*'s study.^[19]

Previous studies over the last decade demonstrated that the mean ADC for malignant tumor is lower than those of benign tumor with variable results of SN and SP, and DWI had a promising role in the differentiation between benign and malignant breast lesions.^[2]

In this study, the mean ADC value of malignant lesions was $0.815 \pm 0.258 \times 10^{-3} \text{ mm}^2/\text{s}$, whereas the mean ADC of benign lesion was $1.287 \pm 0.404 \times 10^{-3} \text{ mm}^2/\text{s}$, demonstrating significant difference ($P=0.001$).^[22] In this study, breast lesions differentiated with high SN (100%) and high SP (82.8%) as

benign or malignant with the aid of ADC readings. Our result were relatively in agreement with those of Ibrahim *et al.*,^[22] who found that in agreement with Ibrahim *et al.* (22), who found that the median ADC value was $0.93 \times 10^{-3} \text{ mm}^2/\text{s}$ for malignant lesions, whereas the median ADC value for benign breast lesions was $1.51 \times 10^{-3} \text{ mm}^2/\text{s}$.

CONCLUSIONS

The diagnostic accuracy of DCE MRI can be increased if it is combined with DWI, thus reducing unnecessary breast biopsies.

The DWI and ADC value had high SN and SP in the characterization of benign and malignant breast lesions.

Recommendations

Incorporating the DWI parameter to the standard of breast MRI protocol to increase the SN and SP for diagnosis of breast lesions is recommended.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

- Chen M, Zhan WW, Han BS, Fei XC, Jin XL, Chai WM, *et al.* Accuracy of physical examination, ultrasonography, and magnetic resonance imaging in predicting response to neo-adjuvant chemotherapy for breast cancer. *Chin Med J (Engl)* 2012;125:1862-6.
- Kuhl C. The current status of breast MR imaging. Part I. Choice of technique, image interpretation, diagnostic accuracy, and transfer to clinical practice. *Radiology* 2007;244:356-78.
- Adam A, Dixon AK, Gillard AH, Schaefer-Prokop G, Grainger RG, Allison DJ. Grainger and Allison's Diagnostic Radiology: A Textbook of Medical Imaging. Edinburgh: Churchill Livingstone/Elsevier; 2015.
- Glassman L, Hazewinkel M. The Radiology Assistant: Breast – MRI. Radiology Assistant; 2009. Available from: <http://www.bing.com/cr?ig=0e527b02227c4c5bbb4c31397a09f5bd&cid=110a1d7ffed26850210716dffd7d6986&rd=1&h=0xvrrbk0jzqvm366jrsorw6yy9kakz7i115fc4bf4&v=1&r=http%3a%2f%2fwww.radiologyassistant.nl%2fen%2fp47a585a7401a9%2fbreastmri.html> and $P=\text{devex}$, 5136.1. [Last accessed on 2018 Dec 30].
- Dorsi CJ, Mendelson EB, Ikeda DM, Sickles EA, Morris EA, Comstock CE, Lee CH. ACR Breast Imaging and Reporting Data System: Breast Imaging Atlas. Reston, VA: American College of Radiology; 2013.
- Kolb TM, Lichy J, Newhouse JH. Comparison of the performance of screening mammography, physical examination, and breast US and evaluation of factors that influence them: An analysis of 27,825 patient evaluations. *Radiology* 2002;225:165-75.
- Hendrick RE. Breast MRI: Fundamentals and Technical Aspects.

- New York, NY: Springer; 2010.
8. Rodrigues JC, Duh MM, Lacabra AR. Diffusion-weighted imaging (DWI): Clinical application in oncologic disease. *Eur Soc Radiol* 2012. Available form: <https://dx.doi.org/10.1594/escr2012/C-1488>.
9. Sardanelli F, Carbonaro LA, Montemezzi S, Cavedon C, Trimboli RM. Clinical breast MR using MRS or DWI: Who is the winner? *Front Oncol* 2016;6:217.
10. Woodhams R, Kakita S, Hata H, Iwabuchi K, Umeoka S, Mountford CE, *et al.* Diffusion-weighted imaging of mucinous carcinoma of the breast: Evaluation of apparent diffusion coefficient and signal intensity in correlation with histologic findings. *AJR Am J Roentgenol* 2009;193:260-6.
11. Yoshikawa MI, Ohsumi S, Sugata S, Kataoka M, Takashima S, Mochizuki T, *et al.* Relation between cancer cellularity and apparent diffusion coefficient values using diffusion-weighted magnetic resonance imaging in breast cancer. *Radiat Med* 2008;26:222-6.
12. Tozaki M, Fukuma E. 1H MR spectroscopy and diffusion-weighted imaging of the breast: Are they useful tools for characterizing breast lesions before biopsy? *AJR Am J Roentgenol* 2009;193:840-9.
13. Partridge SC, Rahbar H, Murthy R, Chai X, Kurland BF, DeMartini WB, *et al.* Improved diagnostic accuracy of breast MRI through combined apparent diffusion coefficients and dynamic contrast-enhanced kinetics. *Magn Reson Med* 2011;65:1759-67.
14. Woodhams R, Ramadan S, Stanwell P, Sakamoto S, Hata H, Ozaki M, Kan S, Inoue Y. Diffusion-weighted imaging of the breast: Principles and clinical applications. *Radiographics* 2011;31(1):1059-84. [doi: 10.1148/rg.314105160. PMID: 21768239].
15. El Bakry MH, Sultan AA, El-Tokhy NA, Yossif TF, Ali AC. Role of Diffusion weighted imaging and dynamic contrast enhanced magnetic resonance imaging in breast tumors. *Egypt J Radiol Nucl Med* 2015;46(3):791-804.
16. Morris EA, Luara L, editors. *Breast Atlas Diagnosis and Intervention*. New York: Springer Science; 2005. p. 329-448.
17. Kul S, Cansu A, Alhan E, Dinc H, Reis A, Çan G. Contrast-enhanced MR angiography of the breast: Evaluation of ipsilateral increased vascularity and adjacent vessel sign in the characterization of breast lesions. *AJR Am J Roentgenol* 2010;195:1250-4.
18. Belli P, Costantini M, Buffi E, Magistrelli A, La Torre G, Bonomo L. Diffusion-weighted imaging in breast lesion evaluation. *Radiol Med* 2010;115(1):51-69. [English, Italian. doi: 10.1007/s11547-009-0430-6. Epub 2009 Nov 9. PMID: 19902330].
19. Kul S, Cansu A, Alhan E, Dinc H, Gunes G, Reis A. Contribution of diffusion-weighted imaging to dynamic contrast-enhanced MRI in the characterization of breast tumors. *AJR Am J Roentgenol* 2011;196:210-7.
20. Stadlbauer A, Bernt R, Gruber S, Bogner W, Pinker K, van der Riet W, *et al.* Diffusion-weighted MR imaging with background body signal suppression (DWIBS) for the diagnosis of malignant and benign breast lesions. *Eur Radiol* 2009;19:2349-56.
21. Chen F, Chen P, Hamid Muhammed H, Zhang J. Intravoxel incoherent motion diffusion for identification of breast malignant and benign tumors using chemometrics. *Biomed Res Int* 2017;2017:3845409.
22. Ibrahim YA, Habib L, Deif A. Role of quantitative diffusion weighted imaging in characterization of breast masses. *Egypt J Radiol Nucl Med* 2015;46:805-10.