Wien Klin Wochenschr (2011) 123: 655–661
DOI 10.1007/s00508-011-0053-5

Printed in Austria

Wiener klinische Wochenschrift
The Central European Journal of Medicine

Value of diffusion-weighted MRI in the differentiation of benign and malign breast lesions

G. Sonmez*, F. Cuce, H. Mutlu, M. Incedayi, E. Ozturk, O. Sildiroglu, M. Velioglu, C.C. Bashekim, E. Kizilkaya

Department of Radiology, GATA Haydarpasa Teaching Hospital, Istanbul, Turkey

Received April 12, 2011, accepted after revision July 18, 2011, published online September 18, 2011

Wertigkeit diffusionsgewichteter MRI in der Differenzierung benigner und maligner Läsionen der Brust

Zusammenfassung. *Einleitung:* Ziel unserer Studie war es, zu prüfen, ob eine diffusionsgewichtete MR Bildgebung (DWI) in der Differenzierung von benignen und malignen Läsionen der Brust nützlich ist.

Material und Methoden: Es wurden 41 Frauen in die Studie eingeschlossen. Bei 45 Läsionen wurde die Diagnose bioptisch gestellt, wobei 25 (55,5 %) malign und 20 (44,5 %) gutartig waren. Der apparente Diffusions Koeffizient (ADC) dieser Läsionen wurde prospektiv mit dem histopathologischem Ergebnis verglichen.

Ergebnisse: Als Schwellenwert zur Erkennung maligner Läsionen wurde ein ADC von $1{,}0 \times 10^{-3}\,mm^2/s$ erhoben. Die Sensitivität dieses Wertes lag bei 95 %, die Spezifität bei 100%. Der positive Voraussagewert bei 100 %, der negative bei 94 %, die Treffsicherheit -Rate bei 97 %.

Schlussfolgerungen: Die DWI verbessert die diagnostische Treffsicherheit der konventionelle MRI der Brust. ADC Messungen können bei der Differenzierung von malignen und benignen Läsionen der Brust nützlich sein.

Summary. *Introduction:* Our purpose was to determine whether diffusion-weighted MR imaging (DWI) could be used in differentiation of benign and malign breast lesions.

Materials and Methods: 41 women patients were included in the study. 45 lesions were diagnosed by biopsy; 25 (55.5%) of these lesions were malignant and 20 (44.5%) were benign. The apparent diffusion coefficient (ADC) values of these lesions were prospectively compared with their histopathological results.

Results: Differentiation of the malignant and benign masses revealed that the threshold value of the ADC was $1.0 \times 10^{-3}\,mm^2/s$, its sensitivity was demonstrated as 95%, specificity as 100%, positive predictive as 100%, negative predictive as 94% and accuracy rate as 97%.

Conclusions: DWI improves diagnostic accuracy of the conventional breast MRI. ADC measurements may be useful for differentiation of the malign and benign masses.

Key words: Breast cancer, breast mass, magnetic resonance imaging, diffusion-weighted imaging, apparent diffusion coefficient.

Introduction

The basic method used for scanning of the breast cancer is conventional mammography. It has been reported that mammography has a sensibility of 69 - 90% in scanning and diagnosis of the breast lesions [1–3]. However, in cases of dense breast parenchyma, the sensibility may be reduced by 48% [2]. On the other hand, only 5 to 40% of the palpable lesions, which can be diagnosed by clinical examination, have a malignant character, and 10% of the cancer cases cannot be diagnosed through mammography [4]. In dense breast tissue where the mammography remains incapable, ultrasonography must be the first imaging technique that must be applied. However, there are certain limitations regarding this technique: it cannot detect the microcalcifications and ductal carcinoma in situ cases; it can be incapable to differentiate the cysts with dense contents from solid lesions and it is a user-dependent technique [2, 4].

Mammography and ultrasonography remain incapable in the evaluation of the cellular and vascular characteristics of the lesions, in the assessment of the real dimensions and extensiveness, in planning of the preventive breast cancer surgery, and in the differentiation of the residue cancer from granulation tissue and fat necrosis [5, 6]. Magnetic resonance imaging (MRI) is a supplementary diagnostic method which is used in imaging of the breast lesions. In the breast, the sensibility of the magnetic resonance (MR) examination in the differentiation of the malignant lesions from the benign ones is 90–95%, and its specificity is between 46% and 97% [5–8].

Correspondence: Guner Sonmez, Assistant Professor, GATA Haydarpasa Teaching Hospital, 81327, Uskudar, Istanbul, Turkey, E-mail: gunersonmez@hotmail.com

Today, the only imaging method which can be used for the purpose of detection of the cellularity of the lesion is the diffusion MRI [8–12].

Materials and methods

Between March 2007 and September 2009, in the patients who have applied with a breast mass pre-diagnosis, or the patients who were diagnosed with lesions during their routine mammographic controls and who were subject to MRI as a further examination technique, the MR diffusion-weighted imaging (DWI) values of the solid lesions were prospectively compared with their histopathological results. 41 women patients with 41 lesions were included in the study. The ages of the patients changed between 23 and 49 (with an average of 34.3). 36 of these 41 patients were subjected to MRI examinations with contrast, whereas 5 patients were examined with MRI without contrast by reason of the risk factors related to nephrotoxicity.

Other breasts of the patients with lesions in one breast were also subjected to evaluation as the control group. The tru-cut biopsies and histopathological diagnoses of all cases were available.

MRI examinations and evaluations

The MR examinations were carried out with 1.5 Tesla MR apparatus (Magnetom Avanto Siemens, Erlangen, Germany) and breast coil. Within the scope of the MR examination protocol, in the axial plan TSE T1-weighted images without fat suppression and T2-weighted images with and without fat suppression; in the axial plan pre-contrast and dynamic post-contrast gradient echo 3D T1-weighted images were acquired from 36 patients. The parameters for the TSE T1-weighted sequences and TSE T2-weighted sequences were as follows, respectively: TR: 550 ms, TE: 8 ms, matrix: 256 × 256, section thickness 3 mm and section interspace 0.3 mm; and TR: 5000 ms, TE: 110 ms, matrix: 256 × 256, section thickness 3 mm and section interspace 0.3 mm. The parameters for the examination with dynamic contrast were: TR: 11 msn, TE: 5 ms, flip angle: 20 degrees, matrix: 256 × 256, section thickness 3 mm and section interspace 0.3 mm. Finally, in the sagittal plan, for the purpose of morphological examination, TSE T1-weighted images with contrast and fat suppression were acquired with the usage of a smaller FOV compared to the previous sequences.

According to the breast MRI examination protocol, routine contrast material containing 0.1 mmol/kg gadolinium was used.

Diffusion-weighted images were acquired before the injection of the contrast. The image parameters in the axial plan were arranged as follows: single-shot SE sequence (TR: 5800 ms, TE: 90 ms), matrix: 256 × 256, section thickness 5 mm and section interspace 2 mm. The b values were determined as 0, 50, 200, 500 and 1000 s/mm^2 for every section.

The MR images were evaluated separately at the workstation by two radiologists who were experienced on breast radiology. First, in the dynamic 3D T1-weighted subtracted images, the lesion localization and its morphology and contrast enhancement kinetics were assessed together with T1-weighted and T2-weighted images. In the ADC (apparent diffusion coefficient) map, despite the standard measurement area (ROI) which was used for the determination of the area where the measurements were performed for the quantitative evaluation of the diffusion limitation value of the lesion, and in the subtracted images, for the evaluation of the contrast kinetics changed due to the dimensions of the lesion, it was between 10 and 25 mm^2.

For the purpose of making the localizations easier in the ADC map, the lesions smaller than 1 cm were not included in the study with the exception of two lesions. Despite the inclusion criteria which required lesions with dimensions bigger than 1 cm, since in one malignant case (0.7 × 0.6 cm) and in one benign case (0.8 × 0.7 cm) the lesions could be localized in ADC, they were included in the study regardless their dimensions smaller than 1 cm.

The necrotic components of the lesions were left out of evaluation; the ADC values for each lesion were measured at 5 different points and the average ADC values of the lesions were determined by the calculation of the arithmetic averages of the 3 values close to each other.

With the purpose of comparison, ADC measurements were performed at the normal fibroglandular tissues at the opposite breasts of all patients which constitute the control group at the same level corresponding with the quadrant and/or localization of the lesion.

Statistical analysis

The acquired ADC values were compared statistically together with the histopathologic results by means of One-Sample Kolmogorov-Simirnov Test, Mann Whitney U and One-Way ANOVA tests. For the purpose of differentiating the malignant lesions from the benign ones, the threshold values were obtained by means of the Receiver Operating Characteristics (ROC) curve. The statistical significance level was accepted as $p < 0.05$. All statistical analyses were carried out with SPSS for Windows (Statistical Package for the Social Sciences) 15.0 version software.

Results

In 41 patients, mammography and ultrasound can be observed in 40 of the 41 lesions. But in MRI, totally 67 lesions were diagnosed. In 40 lesions, mamographic and mammosonographic BIRADS values are; BIRADS 2: 1 lesion (2.5%), BIRADS 3: 13 lesions (32.5%), BIRADS 4: 9 lesions (22% , 5), BIRADS 5: 17 lesions (42.5%) (Table 1). The 41 lesions included in the study, only 1 lesion which was detected MRI but could not be localized in the mammography images and not mentioned result of ultrasound. The histo-

Table 1. Comparison of the results of histopathology with mammographic/ mammosonograhic - MRI BIRADS value

Mammographic/ USG	Lesion number	Mri	Lesion number	Biopsy
BIRADS 2	1	BIRADS 3	1	benign
BIRADS 3	13	BIRADS 0 / no contrast	2	benign
		BIRADS 2	4	
		BIRADS 3	5	
		BIRADS 4	2	
BIRADS 4	9	BIRADS 2	2	1 benign 1 malignant
		BIRADS 4	4	1 benign 3 malignant
		BIRADS 5	3	malignant
BIRADS 5	17	BIRADS 0 / no contrast	3	malignant
		BIRADS 4	2	
		BIRADS 5	12	

Table 2. Number of the malignant and benign lesions and their distribution in percentages

Histopathogy	Number	%
Malignant	25	55.5
Benign	20	44.5
Total	45	100

Table 3. Number of the malignant and benign lesions and their distribution in percentages, according to their histopathologies

Histopathlogic	Diagnosis	Number	Sub-Group%	General Group%
Malignant	IDC*	19	76	42.22
	ILC*	4	16	8.88
	Apocrine carsinoma	2	8	4.44
Benign	Fibroadenoma	15	75	33.33
	Other (Adenosis, fibrocystic disease)	5	25	11.11
Total		45		100

*IDC: Invasive ductal carcinoma, * ILC: Invasive lobuler carcinoma.

pathology of the lesion was reported as fibroadenoma as mammographic BIRADS was accepted "0". In retrospective study 24 months follow-up results of BIRADS 3 lesions could not be obtained.

45 lesions were diagnosed by biopsy; 25 (55.5%) of these lesions were malignant and 20 (44.5%) were benign (Table 2). According to the number of the patients, in 18 patients (43.3%) who were subjected to biopsy benign lesions, in 21 patients (51.21%) malignant lesions and in 2 patients (4.87%) both benign and malignant lesions were detected. Among the 45 lesions, ADC measurements could not be performed in 2 benign and 2 malignant lesions due to the artifacts; for this reason, these cases were not included in the statistics. In the remaining 22 of the 67 lesions, since the histopathological diagnoses of the patients demonstrated similar morphological characteristics to the biopsy results of the benign lesions, the patients were followed up without being subjected to biopsy.

The dimensions of the 41 lesions which were subjected to examination were measured and in the benign group the diameters of these lesions were calculated as 0.7 cm minimum and 6 cm maximum, and in the malignant group 0.6 cm minimum and 5.5 cm maximum. The average dimension of the lesions was 1.49 cm.

Despite the inclusion criteria which required lesions with dimensions bigger than 1 cm, since in one malignant case (0.7 × 0.6 cm) and in one benign case (0.8 × 0.7 cm) the lesions could be localized in ADC, they were included in the study regardless of their dimensions smaller than 1 cm.

The histopathologies of the lesions are presented in Table 3.

The average ADC value of the 23 lesions with a malign histopathological diagnosis was calculated as $0.82 \pm 0.07 \times 10^{-3}$ mm²/s (the minimum ADC value was

Table 4. Comparison of ADC values of the malignant and benign lesions and the normal breast parenchyma

	Malignantlesion	Benign lesion	Normal breast parenchyma
Number	23	18	38
Lowest ADC ($\times 10^{-3}$ mm²/s)	0.4	1.1	1.1
Highest ADC ($\times 10^{-3}$ mm²/s)	1.1	2.2	2.35
Average ADC ($\times 10^{-3}$ mm²/s)	0.82	1.49	1.65
Standard deviation	0.07	0.16	

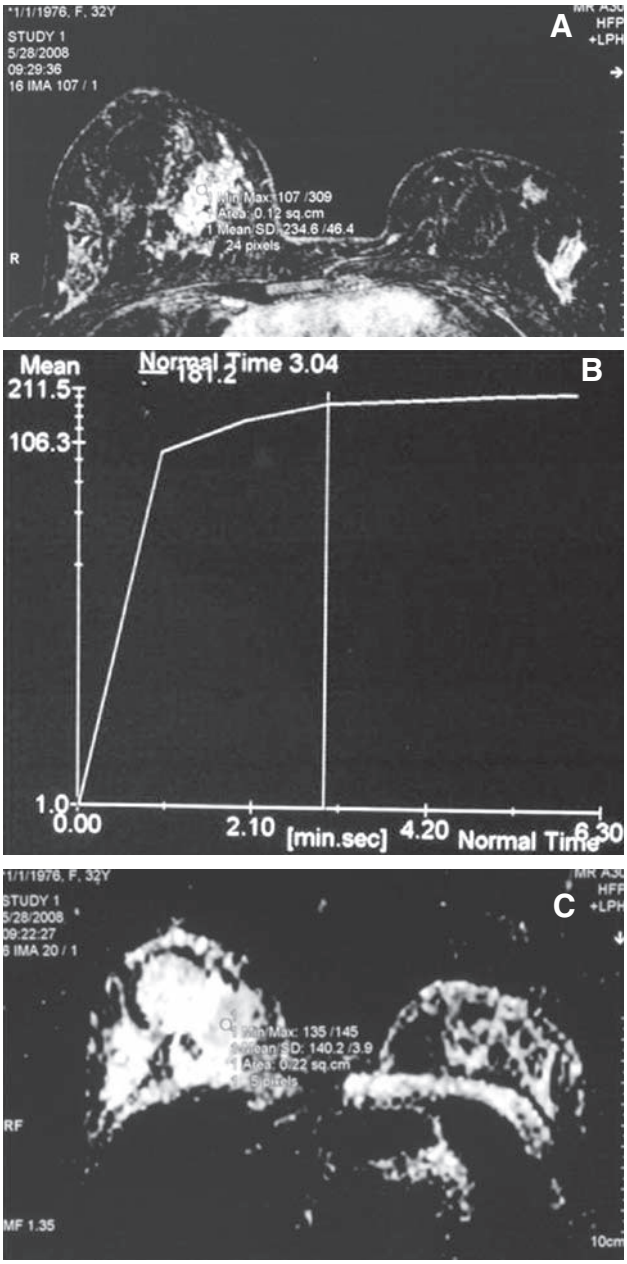

Fig. 1. In a subtracted image with dynamic contrast (**A**) and contrasting kinetic (**B**). ADC (**C**) value 1.35×10^{-3} mm²/s. (fibroadenoma)

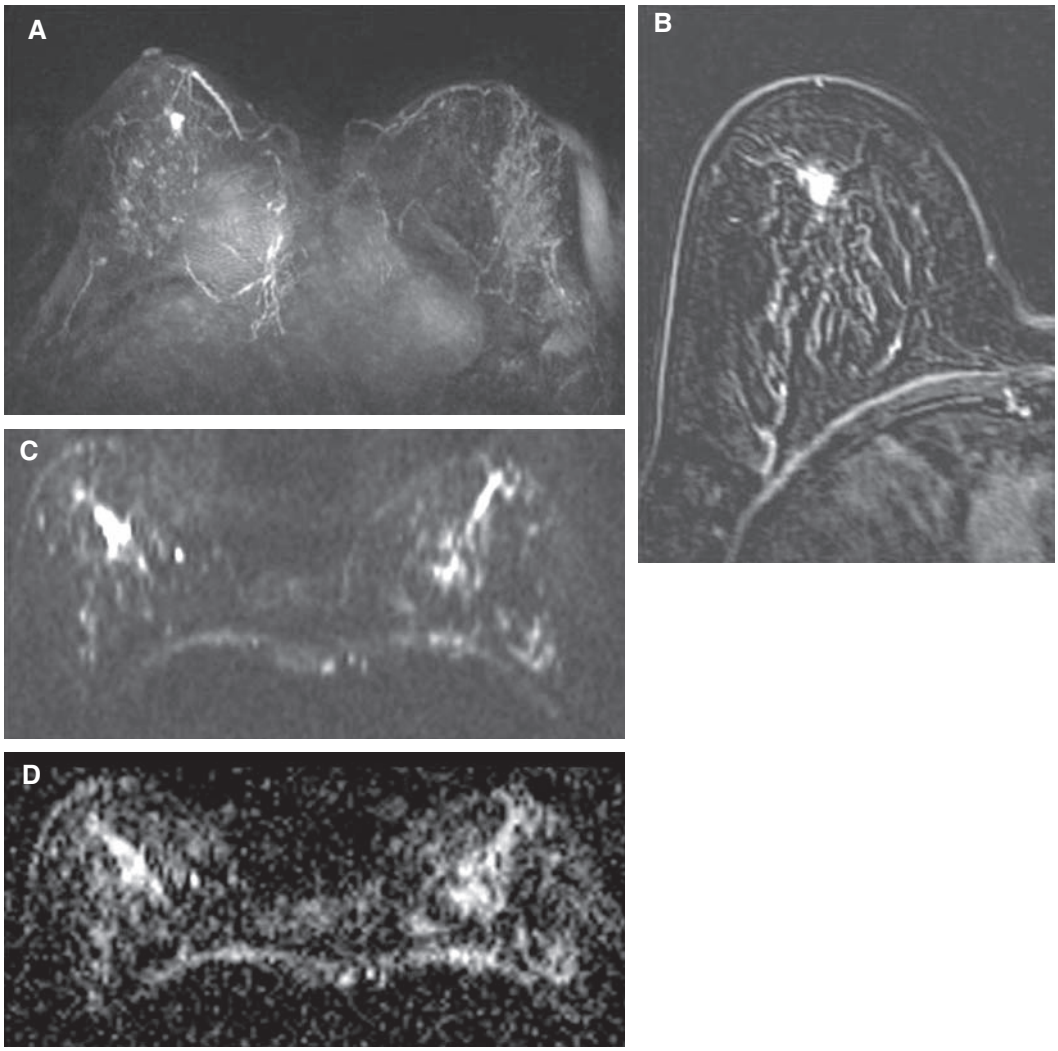

Fig. 2. A retroareolar located lesion in a 3D image (**A**). Speculations at the anterior contour of the lesion in a subtracted image with dynamic contrast (**B**). "b" 1000 DWI (**C**) images. A diffusion restriction image at ADC (**D**) due to hypointensity but correlation with histopathology with at quantitative evaluation ADC with 1.19×10^{-3} mm²/s (fibroadenoma)

0.4×10^{-3} mm²/s and the maximum ADC value was 1.1×10^{-3} mm²/s). The average ADC value of the 18 lesions with a benign histopathological diagnosis was calculated as $1.49 \pm 0.16 \times 10^{-3}$ mm²/s (the minimum ADC value was 1.1×10^{-3} mm²/s and the maximum ADC value was 2.2×10^{-3} mm²/s).

In 38 of the 41 patients, the measurements performed at the normal parenchyma of the opposite breast at the localization which corresponds with the quadrant of the lesion, the minimum ADC value was calculated as 1.1×10^{-3} mm²/s, the maximum ADC value as 2.35×10^{-3} mm²/s, and the average value as $1{,}605 \times 10^{-3}$ mm²/s (Table 4).

Differentiation of the malignant and benign masses revealed that the threshold value of the ADC was 1.0×10^{-3} mm²/s, its sensitivity was demonstrated as 95%, specificity as 100%, positive predictive as 100%, negative predictive as 94% and accuracy rate as 97%.

In one of the cases of our study, in the subtracted series with dynamic contrast, the lesion was oval-shaped and with its lobulated contour it carried benign morphological characteristics; its ADC value was 0.9×10^{-3} mm²/s and it was included in the malignant group with a contrasting kinetics type-3; and its histopathology result revealed apocrine carcinoma.

In another case, the irregular-shaped lesion was characterized by a malignant morphology with irregular contours; its ADC value was 1.35×10^{-3} mm²/s and it was included in the benign group with a contrasting kinetics type-1; and its histopathology was reported as fibroadenoma (Fig. 1).

Another case was characterized by its irregular shape and irregular anterior contours; with its type-3 contrasting curve the lesion demonstrated malignant characteristics; since its ADC value was measured as 1.19×10^{-3} mm²/s, it was included in the benign group; and its histopathology was reported as fibroadenoma correlated with ADC (Fig. 2).

The MRI examinations performed on 5 patients without contrast, who were in the risk group by reason of nephrotoxicity, the histopathologies of 4 patients were reported as fibroadenoma, IDC, ILC and fibroadenoma, respectively; their ADC values which were calculated as 2.2×10^{-3} mm²/s,

0.8×10^{-3} mm²/s, 0.7×10^{-3} mm²/s and 1.62×10^{-3} mm²/s, respectively, correlated with the histopathology.

In our study, the ADC values of the 40 lesions out of the 41 demonstrated a correlation with the histopathology; only in 1 patient who was in the nephrotoxicity risk group speculations supporting malignity at the lesion contours were made at the T1–T2-weighted images; the ADC value which was calculated as 1.1×10^{-3} mm²/s was assessed in the benign group; and the histopathology was reported as IDC in correlation with the morphology.

Discussion

It is known that the evaluation of the morphological characteristics of the breast lesions together with the dynamic contrast retention pattern increases the MRI specificity [7]. However, it must be taken into consideration that the morphologies of certain malignant lesions, such as mucinous carcinoma, lymphoma and metastases to the breast bear resemblance to the benign lesions. The inflammatory breast carcinoma which constitutes a special group of breast cancers is not differentiated from the mastitis by means of the dynamic breast MR examination with contrast. Besides, MRI remains incapable for the differentiation of the malignant and benign in hypervascular benign lesions and in cases where the lesion contours cannot be observed clearly by insufficient MRI resolution.

The technique based on the dynamic contrast is directly related to the vascularity of the lesions; however, any direct relationships do not exist between the tumor cellularity and contrast retention pattern.

In the breast, DWI is administered for the determination of the cellular density of the solid lesion and the width of the interstitial space. The malignant tumors are developed by the dense and disorganized cells. The cellular density narrows the extracellular space in the tumor tissue and as a result, the movement of the water molecules between the cells is restricted and a signal loss occurs in the ADC images. The signal loss measured *in vivo* is not only correlated with the water diffusion, but also with certain factors, such as intravascular flow, cerebrospinal fluid flow and cardiac pulsation. The ADC term is used for this reason. [13].

In the literature there are several studies with respect to the ADC values of the malignant breast lesions (Table 5). In the study where Guo et al. [14] assessed the "b" value as 0 and 1000 s/mm², the average ADC value of the 31 malignant lesions was reported as $0.97 \pm 0.20 \times 10^{-3}$ mm²/s and the average ADC value of the 24 benign lesions was reported as $1.57 \times 0.23 \times 10^{-3}$ mm²/s. In addition, in this study it has also been reported that the malignant and benign lesions can be diagnosed with 93% sensibility, 88% specificity and 91% accuracy with the application of a threshold value of 1.30×10^{-3} mm²/s. In their study carried on 52 patients, 27 malignant and 33 benign lesions, Luo JD et al. [15] with a "b" value determined as 0 and 1000 s/mm², the average ADC value of the malignant lesions was reported as $0.87 \pm 0.23 \times 10^{-3}$ mm²/s and the average ADC value of the benign lesions was reported as $1.59 \pm 0.26 \times 10^{-3}$ mm²/s; and the sensibility, specificity and accuracy were reported as 88.9%, 87.9% and 83.3%, respectively with a threshold value of 1.22×10^{-3} mm²/s between the malignant and benign lesions. The data obtained in the study of Guo et al. with the application of the same "b" values, is similar to our data.

Table 5. ADC values of the malignant lesions in the literature

Reference data	Study method		Adc values
	Sequence	b value	Malignant
Our study	EPI	0–1000	0.82 ± 0.07
Guo et al. (14)	EPI	0–1000	0.97 ± 0.27
Zhang Yili et al.	EPI	0–1000	1. 01 ± 0.20
Palle et al. (16)	EPI	0–1000	0.95 ± 0.18
Luo JD et al. (15)	EPI	0–1000	0.87 ± 0.23

The common result acquired from all studies demonstrates that the ADC values of the malignant tumors are significantly low compared to the values of the benign tumors. In our study, a significant relationship was demonstrated between the lesion histopathology and the ADC values ($p < 0.05$).

In our study, in three patients the lesion morphology and in one patient the contrasting kinetics did not correlate with the histopathology, whereas the ADC value was correlated with the histopathology in three patients. Only one out of 41 lesions did not correlate with the histopathology in terms of the ADC value (ADC 1.1×10^{-3} mm²/s, histopathologic result was invasive ductal carcinoma) (Fig. 3).

We speculate that the maximum specificity and accuracy rates calculated in our study according to the data in the literature may be reduced if the sample group is enlarged and diversified. Because, the ADC values of the lesions are correlated with the tumor cellularity and especially the specificity is lower in the different malignity subtypes and higher threshold values indicated in the literature [14, 16–18].

In their study, Reiko W. et al. [9] have reported that ADC is a criteria which is still insufficient in qualitative evaluation of the lesion; the ADC values are unreliable especially in cases of fibrocystic diseases, ductal ectasy, intraductal papilloma and some types of fibroadenoma; and it is possible to obtain high ADC values also in mucinous carcinoma, DCIS and malign filloid tumor cases. And they have asserted that the reasons of this situation are indistinctive small necrotic focuses or conditions which cause sensitivity artifacts such as bleeding. In our study, we evaluated the lack of correlation between the ADC value and the histopathological result which was observed only in one patient as a secondary condition arising due to the unseen necrotic focuses.

In the breast lesions, when the sensitivity of the MRI is high, its specificity is low. The parameters which are capable of increasing the specificity are the kinetic and morphological values of the lesion and the DWI. All three parameters had insufficiencies with respect to the differentiation of the benign and malignant masses, and in the literature we could not find any studies carried out on

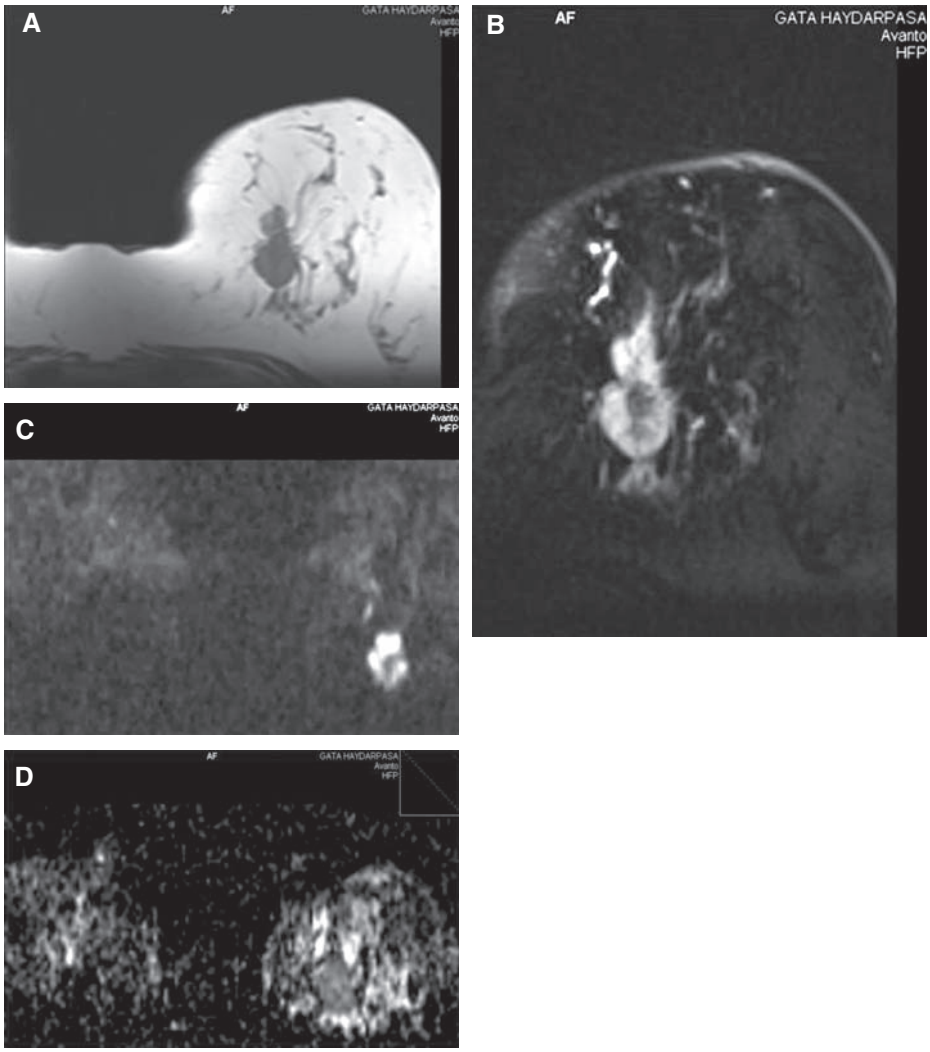

Fig. 3. Lesion confirming a malignity in the images without fat suppression T1W (**A**) and with fat suppression T2W (**B**), speculations at the anterior and lateral contours. b" 1000 DWI (**C**) image. At ADC (**D**) an image supporting malignity with hypointensity, but wrong negative 1.1×10^{-3} mm²/s value. Histopathology: IDC

large-scale histopathological series with the application of the three parameters.

In our study, we experienced certain limitations. The most important limitations were the insufficiency of the patients and the constitution of the patient group with the selected patients. Besides, within the malignant and benign groups the lesion diversity was insufficient histopathologically. In our study, we did not have any ductal ectasy or intraductal papilloma cases or subtypes of fibroadenoma which are claimed to be the causes of an erroneous positivity especially in the DWI images; and scirrhous carcinoma, DCIS or mucinous carcinoma which are claimed to be the causes of an erroneous negativity.

Conclusion

DWI improves diagnostic accuracy of the conventional breast MRI. Its most prominent superiority in comparison with the other imaging methods is the fact that currently it is the only imaging method which provides information about the tumor cellularity. When it is combined especially with the lesion morphology and contrasting kinetics, DWI can increase the specificity of the breast MRI significantly with respect to the differentiation of the malignant and benign masses.

Conflict of interest

We don't have a financial relationship with the organization that sponsored the research.

References

1. Denise RA, Caroline C, Bruce JH, et al. Imaging and cancer: Research strategy of the American College of Radiology İmaging Network. Radiology 2005;235:741–51.
2. Leung JWT. Screening mammography reduced morbidity of breast cancer treatment. AJR 2005;184:1508–9.
3. Miho I, Shozo O, Shigenori S, Masaaki K, Shigemitsu T, Keiichi K, Teruhito M. Comparison of breast cancer detection by diffusion – weighted magnetic resonance imaging and mammography. Radiat Med 2007;25:218–23.

4. Mahesh M. Digital Mammography: An Overview. Radiographics 2004;24:1747–60.
5. Berg WA, Gutierrez L, NessAiver MS, Carter WB, Bhargavan M, Lewis RS, Ioffe OB. Diagnostic Accuracy of mammography, clinical examination, US, and MR imaging in preoperative assessment of breast cancer. Radiology 2004;233:830–49.
6. Kuhl CK, Bielin HB, Gieseke J, Kreft BP, Sommer T, Lutterybey G, Schild HH. Healthy premenopausal breast parenchyma in dynamic contrast- enhanced MR imaging of the breast: normal contrast medium enhancement and cyclical- phase dependency. Radiology 1997;203:137–44.
7. Mitsuhiro T. Interpretation of breast MRI: Correlation of kinetic and morphological parameters with pathological findings. Magnetic Resonance in Medical Sciences 2004;3:189–1979.
8. Reiko W, Keiji M, Keiichi I, Shinichi K, Hirofumi H, Masaru K, Masahiko W, Kazushige. ADC mapping of benign and malignant breast tumors. H. J Comput Assist Tomogr 2005;29:644–9.
9. Heywang SH, Wolf A, Pruss E, Hilbertz T, Eiermann W, Permanetter W. MR imaging of the breast with Gd-DTPA: use and limitations. Radiology 1989.
10. Mi J, Eun Suk C, Bong Joo K, Yon Kwon I, Jun Hyun B. The role of diffusion- weighted imaging and the apparent diffusion coefficient (ADC) values for breast tumors. Korean J Radiol 2007;8:390–6.
11. Erika R, Anne- Sophie G, Viviane De M, Thierry M, Shih- Li C, Marc L. Quantitive diffusion imaging in breast cancer: a clinical prospective study. Journal of magnetic resonance imaging 2006;24:319–24.
12. Masamitsu H, Hiroyasu S, Hidetake Y, Yoshio M, Takeshi K, Yoshinao O, Masazumi T, Hiroshi H. Magnetic Resonance In Medical Sciences 2008:7;23–9.
13. Grant PE. Diffusion imaging in clinical practice. In: Diagnostic radiology postgraduate course. UCSF, San Francisco 1998:102–45.
14. Yong G, You Q, Zu- Long C, Yuan- Gui G, Ning-Yu, Lin Ma, Srikanth M, Jia- Hong G. Differentiation of clinically benign and malignant breast lesions usign DWI. Journal of magnetic resonance imaging 2002;16:172–8.
15. Luo JD, Liu YY, Zhang XL, Shi LC. Application of diffusion weighted magnetic resonance imaging to differential diagnosis of breast diseases. Chinese Journal of Cancer 2007;26:168–71.
16. Lalitha P, Balaji R. Role of diffusion MRI in characterizing benign and malignant breast lesions. Indian J Radiol Imaging 2009;19:287–90.
17. Partridge SC, Mullins CD, Kurland BF, Allain MD, DeMartini WB, Eby PR, Lehman CD. Apparent diffusion coefficient values for discriminating benign and malignant breast MRI lesions: effects of lesion type and size. AJR Am J Roentgenol 2010;194:1664–73.
18. Peters NH, Vincken KL, van den Bosch MA, Luijten PR, Mali WP, Bartels LW. Quantitative diffusion weighted imaging for differantiation of benign and malignant breast lesions: the influence of the choice of b-values. J Magn Reson Imaging 2010;31:1100–5.