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Acquisition and Interpretation Guidelines of Breast Diffusion-Weighted MRI (DW-MRI): Breast Imaging Study Group of Korean Society of Magnetic Resonance in Medicine Recommendations

Bong Joo Kang[1], Min Jung Kim[2], Hee Jung Shin[3], Woo Kyung Moon[4]

[1]Department of Radiology, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, Seoul, Korea
[2]Department of Radiology, Research Institute of Radiological Science, Yonsei University College of Medicine, Severance Hospital, Seoul, Korea
[3]Department of Radiology and Research Institute of Radiology, Asan Medical Center, Seoul, Korea
[4]Department of Radiology, Seoul National University Hospital, Seoul, Korea

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Correspondence to:
Bong Joo Kang, M.D.
Department of Radiology, Seoul St. Mary's Hospital, College of Medicine, The Catholic University of Korea, 222, Banpo-daero, Seocho-gu, Seoul 06591, Korea.
Tel. +82-2-2258-6253
Fax. +82-2-599-6771
E-mail: lionmain@catholic.ac.kr

The purpose of this study was to establish and provide guidelines for the standardized acquisition and interpretation of diffusion-weighted magnetic resonance imaging (DW-MRI) to improve the image quality and reduce the variability of the results interpretation. The standardized protocol includes the use of high-resolution DW-MRI with advanced techniques and post-processing. The aim of the protocol is to increase the effectiveness of the medical image information exchange involved in the construction, activation, and exchange of clinical information for healthcare use. An organized interpretation form could make DW-MRIs' interpretation easier and more familiar. Herein, the authors briefly review the basic principles, optimized image acquisition, standardized interpretation guidelines, false negative and false positive cases of DW-MRI, and provide a standard interpretation form and examples of various cases to help users become more familiar with the DW-MRI.

Keywords: Breast; Magnetic resonance imaging; Guideline

INTRODUCTION

Dynamic contrast-enhanced magnetic resonance imaging (DCE-MRI) evaluates the morphologic and kinetic features of breast lesions, and it is the most sensitive and accurate imaging modality for the detection and characterization of breast cancer (1-3). However, widespread use of DCE-MRI is limited by its high cost, long duration, and the use of contrast agents (4, 5). Besides DCE-MRI, spectroscopy, diffusion-weighted MRI (DW-MRI), and perfusion MRI are known as supplemental techniques. Among them, DW-MRI has been used in clinical practice for the longest time, because it can create contrast between tissues without contrast injection and obtain images in a short time. Consequently, many DW-MRI studies have been published. DW-MRI has mainly played a role in increasing the specificity and the diagnostic performance of DCE-MRI,

and with the recent development of advanced technology, interest in the role of DW-MRI as a non-contrast cancer screening modality is increasing.

DW-MRI is a fast, unenhanced technique that can be used as a cancer screening and characterization modality. High-resolution DW-MRI using advanced techniques and postprocessing can enable better detection and characterization of subcentimeter cancers and reduce false negatives and positives. Furthermore, optimized DW-MRI acquisition and interpretation guidelines can improve image quality and reduce the variability of the results interpretation (4-8).

Recently, the European Society of Breast Radiology (EUSOBI) issued a consensus statement that describes the acquisition parameters for standard breast DW-MRI sequences and suggests the acquisition protocol for screening DW-MRI (4, 9).

In this article, we provide an optimized acquisition protocol for DW-MR imaging through a literature survey and the opinions of a group of Korean domestic breast-imaging experts. In addition, we have organized a standard interpretation lexicon, verified the developed interpretation guidelines, and provided a standard interpretation form and examples.

Basic Principles and Optimized Image Acquisition

DW-MRI is a non-contrast technique measuring the motion of water particles *in vivo* and analyzing microscopic tissue structure cellularity, membrane integrity, viscosity, fibers, tubules, organelles, and macromolecules (10). During the acquisition, motion-sensitizing gradients are used; B value is the real diffusion weighting or sensitization (s/mm^2). So, DW-MRI settles down its own tissue contrast without the need for contrast injection. Apparent diffusion coefficient (ADC) is the typical extent to which a water molecule of a concerned tissue occupies as square mm per second. This is the quantification of DW-MRI and means the diffusion in biologic tissues is not unrestricted and is controlled by complex appliances (8).

In general, on DW-MRI, malignant lesions show diffusion restriction which is appreciated as bright signal intensity (SI) on DW-MRI and having decreased ADC values. This feature is mostly associated with high cell density and limited extracellular planetary (11). However, visual contrast on DW-MRI is determined by not only diffusion features, but also relaxation times and proton concentration. The best-known example of this problem is the T2 shine-through effect. Notably, on a DW-MRI with an increasing b value, T2 effects will decrease. T2-effects can be mathematically removed from DW-MRI to create a pure parametric image. This set of data is known as the ADC map. For DW-MRI, any plane can be used; it is recommended to choose the same plane as the one used for DCE imaging for synchronized evaluation.

The b value provides data on the level of the diffusion weighting and is proportional to the gradient strength and diffusion time. Certain b values should be used to standardize ADC thresholds. For lesion detection, high b values (800-1500 s/mm^2) are preferred as they create a respectable distinction between the lesion and the neighboring soft tissues (12). On the other hand, when the aim is benign and malignant discrimination, the selection of b value is less critical. Performing DW-MRI with more than two b values provides a more accurate sampling of the signal drop. However, breast studies on the use of more than two b values have not been showing superiority, therefore two b value use in DW-MRI is still considered standard (13). As the first b value, it is also possible to select a b value (b $\geq$ 50 s/mm^2) other than zero to avoid perfusion and flow effects.

Diffusion-weighted imaging of breast is technically challenging because of the breast being off-center within the bore and having intrinsic susceptibility artifacts. However, many technical improvements can be used: proper b value choice, adequate signal-to-noise ratio, satisfactory fat suppression, and artifact reduction tools (14).

The standardization of DW-MRI acquisitions is challenging but essential to ensure reliable sensitivity and specificity. According to the EUSOBI guidelines, breast DW MRI should be performed on a closed bore magnet using a dedicated breast coil with at least four channels at a field strength of at least 1.5T, a maximum gradient strength of at least 30 mT/m, and if possible, prior to administration of the contrast agent administration (4, 9) (Table 1). Single-shot or multishot echo-planar imaging (EPI) with spin-echo should be used as a readout sequence in axial planes of bilateral breasts with a minimum in-plane resolution of 2 × 2 mm^2 and a section thickness of 4 mm or less. To reduce susceptibility artifacts, the echo time should be minimized to the lowest possible value, and the repetition time should be at least 3000 msec. All the EPI sequences are fat-suppressed to prevent ghosting and the potential underestimation of ADC values; spectral adiabatic inversion recovery (SPAIR) fat suppression method is preferred over the short tau inversion recovery (STIR). Parallel imaging with an acceleration factor of 2 is recommended to reduce

Table 1. Requirements for Diagnostic, Screening Breast DW-MRI, and Optimized Aqcusition Protocol

Parameter	Diagnostic examination*	Screening examination‡
Equipment		
Magnet field strength	≥ 1.5 T	3.0 T
Type of coil	≥ 4 channels	16 or 18 channels
Acquisition parameter		
In-plane resolution	≤ 2 × 2 mm^2	≤ 1.3 × 1.3 mm^2
Slice thickness	≤ 4 mm	≤ 3 mm
Number of b values	2	3
Lowest b value	0-50 s/mm^2	0 s/mm^2
High b value	800 s/mm^2	800 and 1200 s/mm^2
Post-processing		
ADC map	Low b and 800 s/mm^2	0 and 800 s/mm^2
MIP	Not required	Axial and sagittal MIP
Optimized aqcusition protocol	Magnetic field strength (≥ 1.5T) Coil: Dedicated breast coil Axial DWI before contrast injection B value = 0 and more than one high b values (800-1500 s/mm^2) Less than 3 mm in thickness and less than 1.5 mm^2 in-plane pixel resolution MIP and fusion image (if possible)	

*Recommendation of the European Society of Breast Radiology (EUSOBI)
‡Recommended in Korean multicenter screening DW MRI study group
ADC = apparent diffusion coefficient; MIP = maximum intensity projection

distortion due to susceptibility artifacts (4, 9).

In addition, DW-MRI can be used to detect breast cancer with higher performance at 3.0T with read-out segmented EPI and b values of 1000-1500 s/mm^2 than at 1.5T with basic EPI and b values of 600-850 s/mm^2 (11, 13, 15-23). The recently published articles recommend a b value of 800 for ADC value measurement and a b value of 1200 for breast cancer screening (5, 14, 22) (Table 1). Moreover, unenhanced magnetic resonance screening using fused diffusion-weighted imaging and maximum-intensity projection was known to be useful (23).

Lesion Interpretation Guidelines

At present, there is no adequate explanation of background diffusion signals or qualitative analysis of lesions within DW-MRI. In the ACR BI-RADS MRI section, standard read-out terms regarding the background diffusion signal or qualitative techniques for lesions within DWI have not yet been established. In order to develop standardized interpretation criteria, it is necessary to understand the appearance and normative range of ADCs in the breast parenchyma on DW-MRI. A normal breast parenchymal tissue exhibits a high SI on DW-MRI with low b values, as the low b value image is primarily T2-weighted. As the b value increases, the SI of normal breast tissue becomes suppressed. The degree of background diffusion signal on DW-MRI with high b values can vary among women and can be visually assessed according to the four-point scale of minimum, mild, moderate, and marked, similar to the background parenchymal enhancement in DCE-MRI (24, 25) (Table 2). Although hormonal fluctuations may influence the breast ADC values, a recent study reported that in the DW-MRI, the ADC values of normal breast parenchyma are not significantly affected by the menstrual cycle, unlike in the contrast-enhanced MRI (26) (Fig. 1).

When DW-MRI is employed as a stand-alone screening or diagnostic tool, lesions, defined as unique areas of high SI that are distinct from background signals, must be detected on DW-MRI with high b values (5), although the reported ADC values for breast carcinoma show great variations. In addition, the morphologies of the lesions on DW-MRI can be categorized as foci, masses, or non-mass lesions (Table 2). In the cases of the masses lesions, the shape (round/oval or irregular) and internal signal pattern (homogeneous,

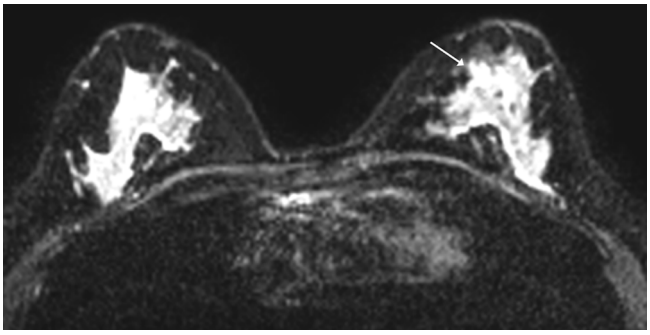
Table 2. Interpretation Lexicon and Interpretation Criteria

MRI sequence	Classification	Terms		Suspicious or non-suspicious criteria
High b value DWI	Background diffusion signal (BDS)	Minimal/mild/moderate/marked		
		Symmetric or asymmetric		
	Focus	Focus/foci		
	Mass	Shape	Oval/round	Non-suspicious
			Irregular	Suspicious
		Margin	Circumscribed	Non-suspicious
			Not circumscribed	Suspicious
		Internal signal characteristics	Homogeneous	Non-suspicious
			Heterogeneous/rim	Suspicious
	Nonmass	Distribution	Focal/regional/diffuse	Non-suspicious
			Linear/segmental	Suspicious
		Internal signal characteristics	Homogeneous	Non-suspicious
			Heterogeneous	Suspicious
ADC map	Diffusion level	Very high	> 2.1 × 10^{-3} mm^2/s	Non-suspicious
		High	1.7–2.1 × 10^{-3} mm^2/s	Non-suspicious
		Intermediate	1.3–1.7 × 10^{-3} mm^2/s	Non-suspicious
		Low	0.9–1.3 × 10^{-3} mm^2/s	Susspicious
		Very low	< 0.9 × 10^{-3} mm^2/s	Suspicious
Lesion location	Detail which breast (right, left, or bilateral) Location: quadrant, clock face, subareolar, central, axillary tail, axilla Depth: anterior, middle, posterior, Distance from nipple, skin, or chest wall (in cm) as appropriate			
Lesion size at ADC map or high b value DWI	ADC map is calculated from b = 0 and 800 mm^2/sec DWI Measure in at least 2 dimensions - X: Longest measurement on axial image best depicts lesion (AP or trans) - Y: Measurement orthogonal to X using same image (trans or AP) - Z: Measurement CC length (if measurable)			

ADC = apparent diffusion coefficient; DWI = diffusion weighted imaging

heterogeneous, or rim) can be reported, whereas in non-mass lesions, the distribution (focal, regional, linear, or segmental) and internal signal pattern (homogeneous or heterogeneous) can be reported (25) (Table 2).

Lesions detected on high b value DW-MRI require cross-correlation with the ADC map, to rule out "T2 shine-through" effects and the lesions with true restricted diffusion should exhibit low ADCs. Quantitative ADC values (expressed in the units of 10^{-3} mm^2/s) are measured by drawing a region of interest (ROI) on the lesion on the ADC map. The ROI should be drawn completely within the lesion, consistent with the hyperintense areas on high b value DW-MRI, while avoiding normal tissue and areas of necrosis, hemorrhage, or fat (14). ADC value was measured by small (3-6 mm^2) regions of interest within the darkest part of the lesion's on the ADC map using PACS software (27) (Fig. 2). The selection of the most appropriate ADC threshold depends on the expectations from the DW-MRI. For breast cancer screening, the threshold selected must be high. However, to increase the specificity of DCE-MRI, a lower threshold is preferred (14). The recommended ADC threshold values for benign-malignant distinction vary between 0.90 and 1.76 × 10^{-3} mm^2/s (28, 29). In general, benign lesions show a higher mean of ADC than malignant



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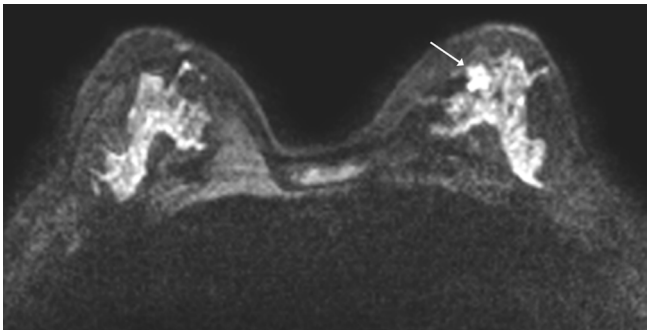

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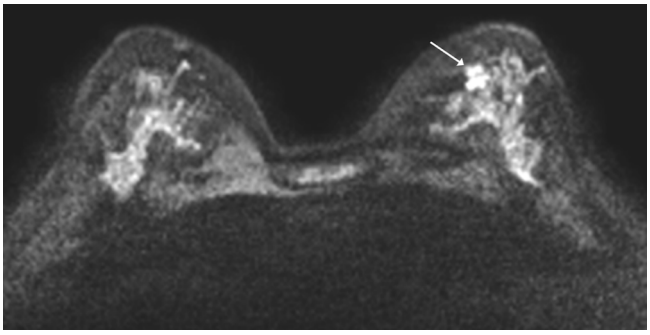

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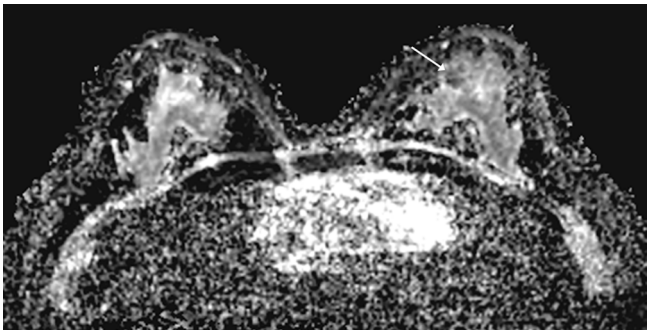

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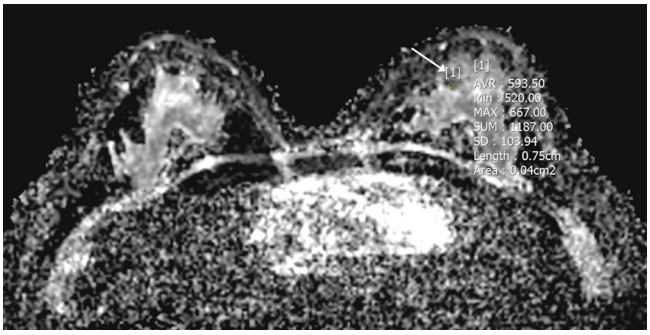

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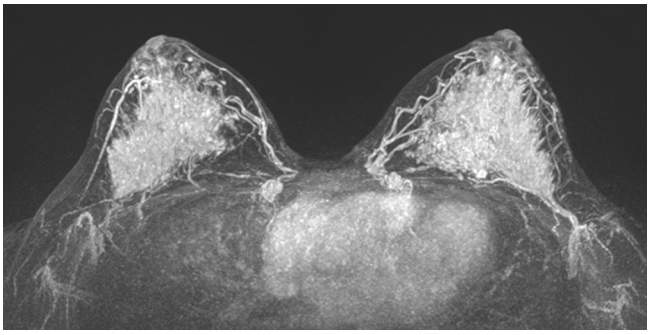

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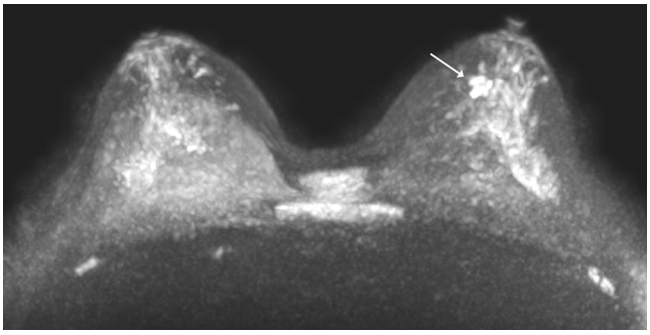

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Fig. 1. A 46-year-old woman with ductal carcinoma *in situ*. (a-c) On diffusion-weighted images with b values of (a) 0, (b) 800, and (c) 1200 s/min^2, there was a 1-cm, irregular, not circumscribed, heterogeneous, high signal intensity mass (arrows) at the middle portion (distance from nipple: 2.3 cm) in the 11 o'clock direction of the left breast. (d, e) The apparent diffusion coefficient values of the apparent diffusion coefficient map were very low (0.7×10^{-3} mm^2/s) (arrows). (f, g) On a maximal intensity projection image of contrast enhancement MRI (f), mass was obscured by breast parenchymal enhancement, but the high signal intensity mass was prominent on a diffusion maximal intensity projection image (arrow) (g).

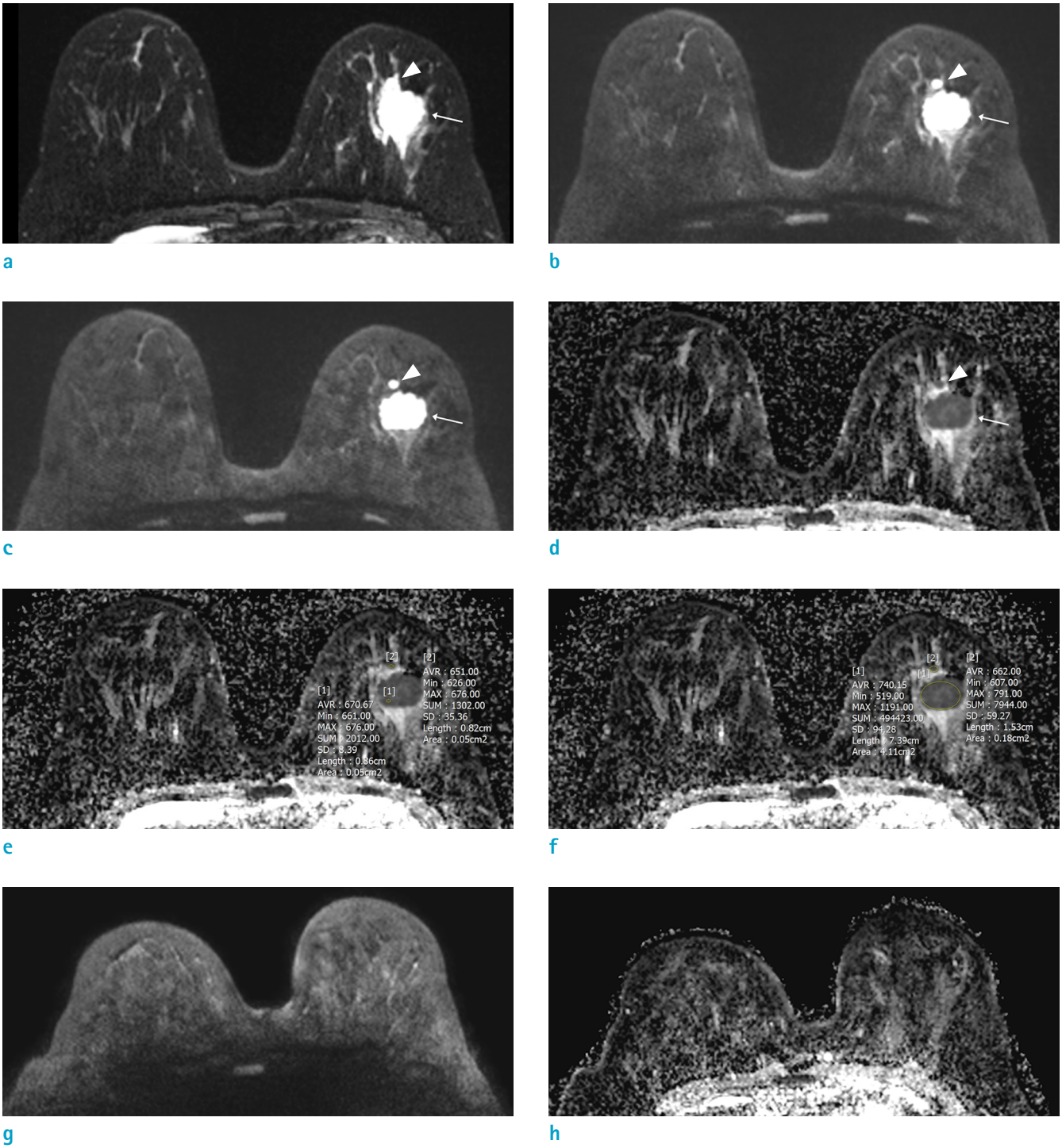


Fig. 2. A 36-year-old woman with invasive ductal carcinoma (triple-negative). (a-c) On diffusion-weighted images with b values of (a) 0, (b) 800, and (c) 1200 s/min^2, there was a 3.5-cm, oval, not circumscribed, homogeneous, high signal intensity mass (arrows) with a small daughter mass (arrowheads) at the middle portion (distance from nipple: 2.8 cm) in the 5 o'clock direction of the left breast. (d-f) The apparent diffusion coefficient values of the apparent diffusion coefficient map were very low (0.7×10^{-3} mm^2/s). It was preferred to measure ADC values in a small region of interest within the darkest part of the lesion's ADC map (e) rather than using the entire lesion (f). (d arrow, arrowhead) (g, h) On diffusion-weighted images with b values of 1200 s/min^2 (g) and on the apparent diffusion coefficient map (h) after neoadjuvant chemotherapy, there was no residual lesion, which was evaluated as a complete response according to the Solid Tumor Response Evaluation Criteria (RECIST) criteria.

lesions, but there is a significant overlap with malignant lesions (14). In a consensus and mission statement, the EUSOBI International Breast Diffusion-Weighted Imaging working group suggested a diffusion level lexicon based on lesion appearance on b = 800 s/mm^2 images, ADC maps, and ADC values: very low (≤ 0.9 × 10^{-3} mm^2/s), low (9-1.3 × 10^{-3} mm^2/s), intermediate (1.3-1.7 × 10^{-3} mm^2/s), high (normal, 1.7-2.1 × 10^{-3} mm^2/s), and very high (> 2.1 × 10^{-3} mm^2/s) (9) (Table 2). For qualitative evaluation without an ADC threshold, the lesion is compared to normal fibroglandular tissues on both DW-MRI and ADC maps. If the lesion is brighter on DW-MRI and darker on ADC than normal fibroglandular tissue, it is classified as a diffusion-restricting area (8). An ongoing multicenter prospective clinical trial (clinicaltrials.gov Identifier: NCT03835897) in South Korea, which employs the DW-MRI for primary breast cancer screening in high-risk women, used an interpretation algorithm that combines quantitative b value measurements with qualitative morphology evaluation and uses an ADC cutoff value of 1.3 × 10^{-3} mm^2/s (6). The reading forms according to Tables 2 and 3 are presented as an example (25) (Fig. 3).

Clinical Application and Performance

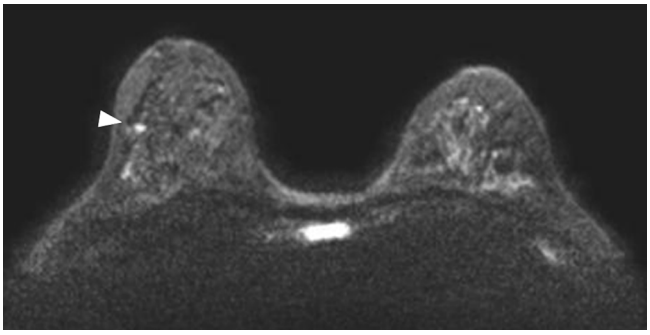
Breast DW-MRI has been reported to reduce false-positive consequences, excessive interventions, and improve the positive predictive value (11, 14). It has been shown to have the potential to increase the accuracy of lesion characterization and diagnosis with multiple studies (30). In addition, DW-MRI has the potential for the monitoring and prediction of treatment response, axillary lymph node evaluation to improve the diagnostic performance in nodal staging, prediction of axillary lymph node metastasis, and breast cancer screening (4, 31) (Figs. 2, 4).

In a meta-analysis of 14 studies with 1140 patients, DW-MRI alone showed a pooled sensitivity and specificity of 86.0% and 75.6%, respectively, compared to 93.2% and 71.1%, respectively, for DCE-MRI alone (32). Multiple studies including one prospective multi-center trial have shown that DW-MRI can reduce unnecessary benign

Table 3. Definition and Examples of Assessment

Category 0: Incomplete assessment, additional imaging needed	
Category 1: Negative, routine follow-up	No lesion found
Category 2: Benign, routine follow-up	No suspicious finding or typical benign findings
	Mass/focus: oval/round and homogeneous – ADC > 1.3 Nonmass: focal or regional, homogeneous – ADC > 1.3
Category 3: Probable benign, short-interval (6-month) follow-up	Probable fibroadenoma, complicated cyst or fibrocystic change with suspicious findings in only 1 criterion
	Mass/focus: oval/round and homogeneous – ADC ≤ 1.3 Mass/focus: oval/round, rim or heterogeneous – ADC > 1.3 Mass/focus: irregular and homogeneous – ADC > 1.3 Nonmass: focal or regional, homogeneous – ADC ≤ 1.3 Nonmass: focal or regional, heterogeneous – ADC > 1.3 Nonmass: segmental or linear, homogeneous – ADC > 1.3
Category 4: Suspicious abnormality, tissue diagnosis	A combination of suspicious and non-suspicious findings with more than 2 suspicious criteria
	Mass/focus: oval/round, rim or heterogeneous – ADC ≤ 1.3 Mass/focus: irregular and homogeneous – ADC ≤ 1.3 Mass/focus: irregular, rim or heterogeneous – ADC > 1.3 Nonmass: focal or regional, heterogeneous – ADC ≤ 1.3 Nonmass: segmental or linear, homogeneous – ADC ≤ 1.3 Nonmass: segmental or linear, heterogeneous – ADC > 1.3
Category 5: Highly suggestive of malignancy, tissue diagnosis	Typical characteristic findings of breast cancer in all criteria
	Mass/focus: irregular, rim or heterogeneous – ADC ≤ 1.3 Nonmass: segmental or linear, heterogeneous – ≤ 1.3
Category 6: Known biopsy-proven malignancy, appropriate action should be taken	

ADC = apparent diffusion coefficient



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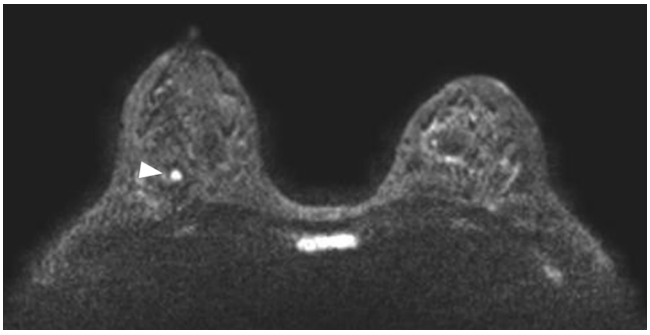

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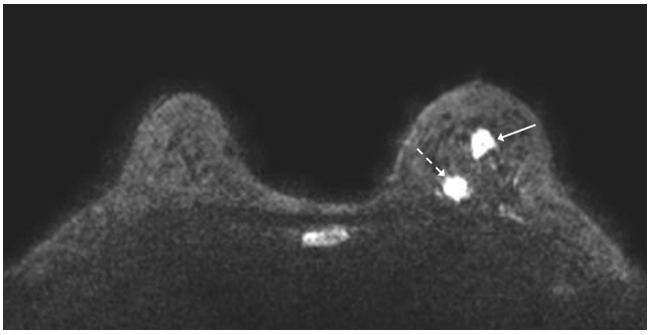

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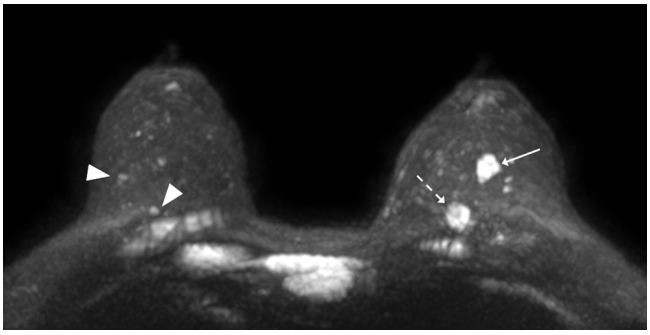

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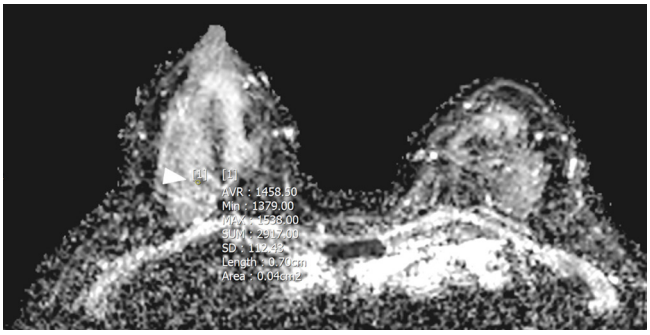

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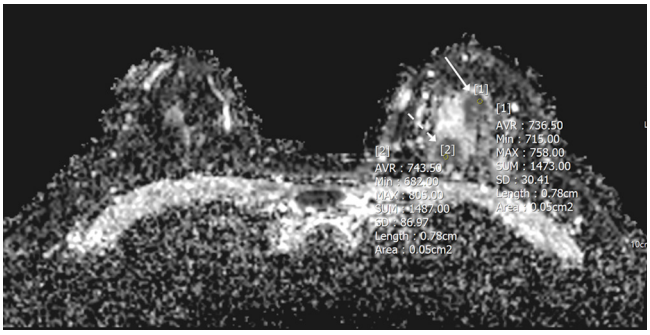

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Indication for examination: preoperative evaluation (known biopsy-proven malignancy).
MR sequence: DWI (b=0, 800, 1200) / ADC map / DWI MIP
Amount of fibroglandular tissue (FGT): d. extreme fibroglandular tissue
Background parenchymal signal (BPS): mild, symmetric
Findings:
1) A 1.6-cm, oval, not circumscribed, heterogeneous, high SI mass (bx. proven IDC) at the middle portion (distance from nipple: 4.3 cm) in the 12 o'clock direction of the left breast. ADC value is very low (0.7×10^{-3} mm^2/s).
- Category 6, known biopsy proven malignancy
2) A 1.3-cm, irregular, not circumscribed, heterogeneous, high SI mass at the upper portion (distance from nipple: 6.1 cm) in the 11 o'clock direction of the left breast. The ADC value is very low (0.7×10^{-3} mm^2/s).
- Category 5, highly suggestive of malignancy
3) Several, oval, circumscribed, homogeneous, high Si masses/foci in the right breast. The ADC values are intermediate ($1.3\text{-}1.7 \times 10^{-3}$ mm^2/s).
- Category 2, benign finding
Assessment category: Category 5, highly suggestive of malignancy, biopsy recommended

g

Fig. 3. A 45-year-old woman underwent breast diffusion-weighted MRI for preoperative evaluation (known biopsy-proven invasive ductal carcinoma). (a-d) On diffusion-weighted images (b = 1200 s/min^2 in a-c) and (d) a maximal intensity projection image, two suspicious high SI masses (arrows, dashed arrows) were visible in the left breast and several high SI masses/foci (arrowheads) were visible in the right breast. (e, f) The apparent diffusion coefficient values of the apparent diffusion coefficient map show low signal intensity (< 0.9×10^{-3} mm^2/s) at two suspicious masses in the left breast (arrow, dashed arrow), but, show intermediate signal intensity ($1.3\text{-}1.7 \times 10^{-3}$ mm^2/s) at several masses/foci in the right breast (arrowhead). (g) The reading form of this case.

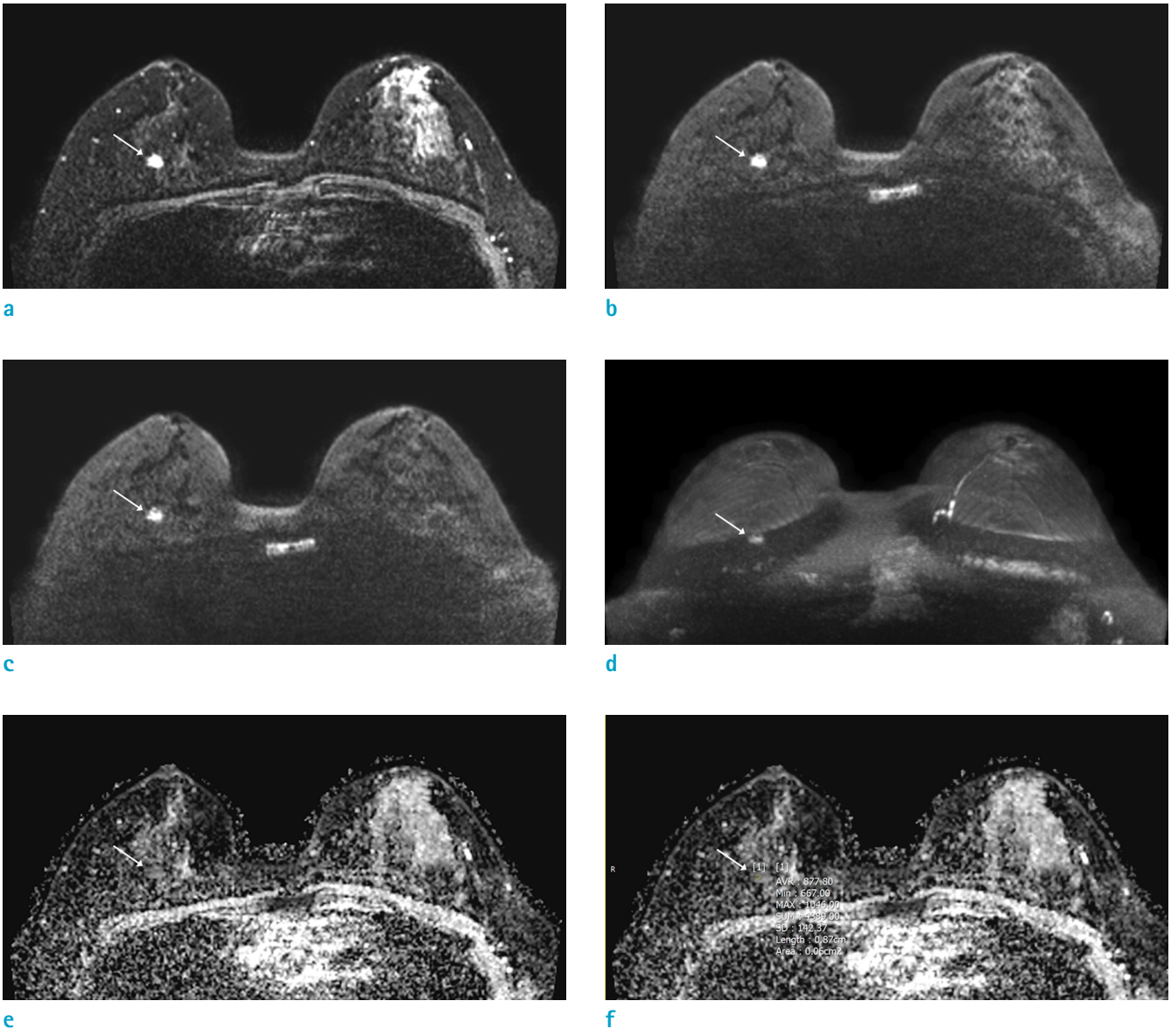
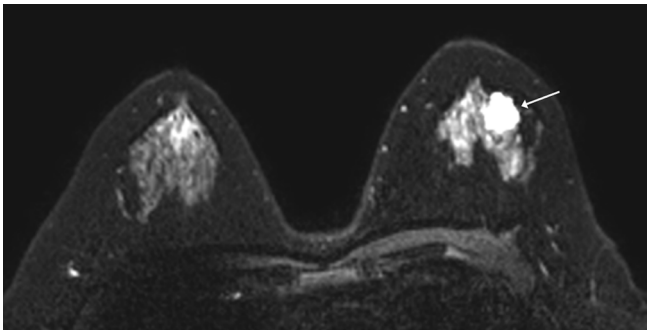


Fig. 4. A 48-year-old woman with screening-detected invasive ductal carcinoma. (a-d) On diffusion-weighted images with b values of (a) 0, (b) 800, and (c) 1200 s/min^2 and (d) a maximal intensity projection image, there was a 1-cm, irregular, not circumscribed, heterogeneous, high signal intensity mass (arrows) at the posterior portion (distance from nipple: 5.6 cm) in the 12 o'clock direction of the right breast. (e, f) The apparent diffusion coefficient values of the apparent diffusion coefficient map were very low (0.9 × 10^{-3} mm^2/s) (arrows).

biopsies of suspicious mammographic or DCE-MRI-detected lesions, and it is now considered an important part of multiparametric breast MRI protocols (33).

False Negative and False Positive Findings

False negatives or false positives can be caused by various factors including the characteristics of carcinoma, such as low cellularity or non-mass morphologic types, and the limited resolution of the DW-MRI technique. In addition, there could be other technical issues including artifacts, inadequate fat suppression, or a low signal-to-noise ratio. Mucinous carcinoma is a well-known cause of false-negative results, owing to the low cellularity and high mucin content (34, 35) (Fig. 5). Moreover, triple-negative cancer with extensive necrosis can present with high ADC values (36). Ductal carcinoma *in situ* (DCIS) and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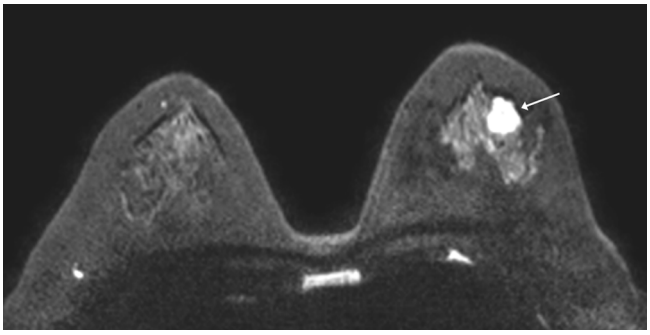
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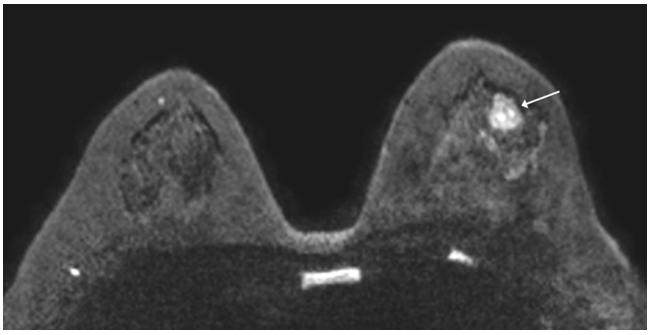
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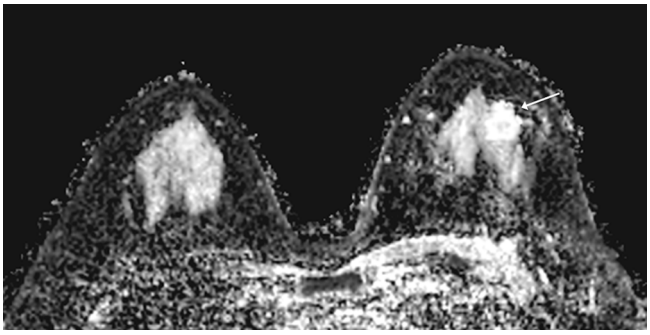
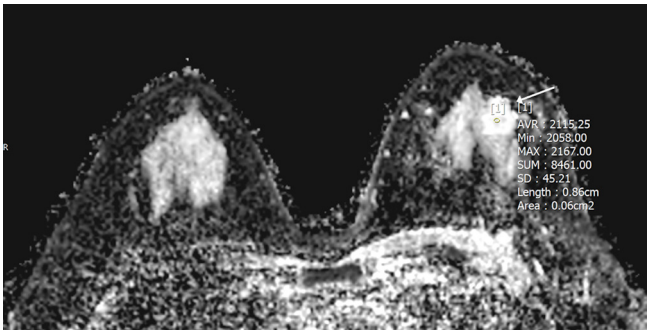

d



e

Fig. 5. A 48-year-old woman with mucinous carcinoma. (a-c) On diffusion-weighted images with b values of (a) 0, (b) 800, and (c) 1200 s/min^2, there was a 2.2-cm, oval, circumscribed, high signal intensity mass (arrows) at the middle portion (distance from nipple: 3.9 cm) in the 2 o'clock direction of the left breast. (d, e) The apparent diffusion coefficient values of the apparent diffusion coefficient map were high (2.1 × 10^{-3} mm^2/s) (arrows).

invasive lobular carcinoma are typically non-mass type carcinomas and are more likely to be missed by DW-MRI, compared to the invasive ductal carcinoma, owing to the low conspicuity (17, 21, 23) (Fig. 6). Finally, considering the typical in-plane spatial resolution (2 × 2 mm^2) and section thickness (3-5 mm) of DW-MRI, small cancers (1 cm or less in size) are expected to be less detectable or incorrectly characterized on account of the partial volume effects (35). We recommended less than 3 mm thickness in the optimized acquisition protocol (Table 1), so this limitation was overcome (Fig. 4).

To date, there have been few reports of false-positive findings on DW-MRI, and the most known are mastitis, abscesses, hematomas, complicated cysts, intramammary lymph nodes, intraductal papillomas, atypical ductal hyperplasias, fibroadenomas with high cellularity, and artifactual lesions (17, 21). The diffusion of water molecules is not only restricted in the environments with high cellularity, but also in the regions of intracellular and extracellular edema, regions of high viscosity in abscesses and hematomas, coagulated blood, or proteinaceous debris within ducts and cysts, and areas with a high degree of fibrosis. Hematomas having intracellular oxyhemoglobin, deoxyhemoglobin, or methemoglobin, fibroepithelial lesions with high cellularity, breast abscess, mastitis, cyst with thick content, intramammary lymph nodes, DCIS, intraductal

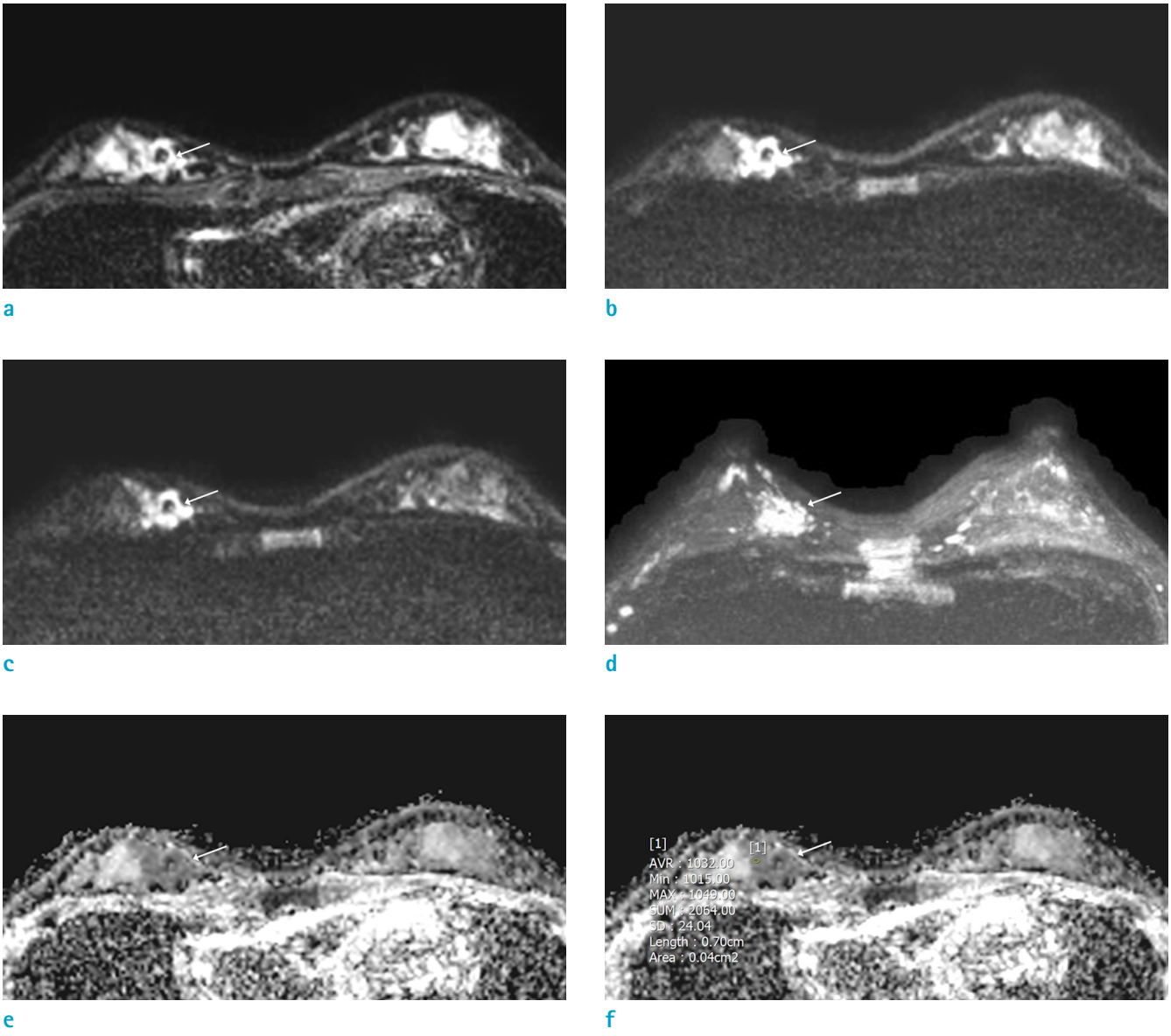


Fig. 6. A 31-year-old woman with DCIS underwent breast diffusion-weighted MRI for screening for high risk, based on family and personal history (previous excision for intraductal papilloma, atypical ductal hyperplasia, flat epithelial atypia). (a-d) On diffusion-weighted images with b values of (a) 0, (b) 800, and (c) 1200 s/min^2 and (d) a maximal intensity projection image, there was a 2.9 × 2.7 × 6.2 cm (anteroposterior × transverse × craniocaudal), regional, heterogeneous, high SI nonmass (arrows) at the middle portion (distance from nipple: 1.2 cm) in the 3 o'clock direction of the right breast. (e, f) The apparent diffusion coefficient values of the apparent diffusion coefficient map were low (1.0 × 10^{-3} mm^2/s) (arrows).

papilloma, and atypical ductal hyperplasia may show diffusion restriction as well (11).

Finally, the artifactual signal at the nipple, an area prone to susceptibility-based distortion on DW-MRI, may cause false-positive findings (21).

SUMMARY

Breast DW-MRI is emerging as a key imaging technique to complement DCE-MRI of the breast. DW-MRI is a safe, fast, unenhanced technique that allows a higher volume of patient throughput, thus being more cost-effective while maintaining a high diagnostic accuracy ("high-value

imaging"). It is therefore a potential breast cancer screening modality and can be used in the accurate differential diagnosis of benign and malignant breast lesions and the monitoring of breast cancer response to neoadjuvant chemotherapy. A major strength of DWI is that it doesn't need a contrast agent.

DW-MRI not only has the potential to be used as a stand-alone image modality for screening or diagnostic imaging, but also employs T1 and T2WI analyses, which are non-contrast images, this enables further analyses of shape. When used together with DCE-MRI, the two modalities can complement each other; it is expected that the specificity will be increased and it will be less affected by breast parenchymal enhancement.

High-resolution DW-MRI using advanced acquisition techniques and post-processing will facilitate better detection and characterization of sub-centimeter cancers and reduce the false-negative and false-positive findings. An optimized acquisition protocol and interpretation lexicon can improve the DW-MRI image quality and reduce results variability.

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REFERENCES

1. Lehman CD, Blume JD, Weatherall P, et al. Screening women at high risk for breast cancer with mammography and magnetic resonance imaging. Cancer 2005;103:1898-1905
2. Saslow D, Boetes C, Burke W, et al. American Cancer Society guidelines for breast screening with MRI as an adjunct to mammography. CA Cancer J Clin 2007;57:75-89
3. Mann RM, Kuhl CK, Kinkel K, Boetes C. Breast MRI: guidelines from the European Society of Breast Imaging. Eur Radiol 2008;18:1307-1318
4. Lee SH, Shin HJ, Moon WK. Diffusion-weighted magnetic resonance imaging of the breast: standardization of image acquisition and interpretation. Korean J Radiol 2021;22:9-22
5. Amornsiripanitch N, Bickelhaupt S, Shin HJ, et al. Diffusion-weighted MRI for unenhanced breast cancer screening. Radiology 2019;293:504-520
6. Shin HJ, Lee SH, Park VY, et al. Diffusion-weighted magnetic resonance imaging for breast cancer screening in high-risk women: design and imaging protocol of a prospective multicenter study in Korea. J Breast Cancer 2021;24:218-228
7. Radovic N, Ivanac G, Divjak E, Biondic I, Bulum A, Brkljacic B. Evaluation of breast cancer morphology using diffusion-weighted and dynamic contrast-enhanced MRI: intermethod and interobserver agreement. J Magn Reson Imaging 2019;49:1381-1390
8. Durur-Subasi I. DW-MRI of the breast: a pictorial review. Insights Imaging 2019;10:61
9. Baltzer P, Mann RM, Iima M, et al. Diffusion-weighted imaging of the breast-a consensus and mission statement from the EUSOBI International Breast Diffusion-Weighted Imaging working group. Eur Radiol 2020;30:1436-1450
10. Durur-Subasi I, Durur-Karakaya A, Karaman A, Seker M, Demirci E, Alper F. Is the necrosis/wall ADC ratio useful for the differentiation of benign and malignant breast lesions? Br J Radiol 2017;90:20160803
11. Brandao AC, Lehman CD, Partridge SC. Breast magnetic resonance imaging: diffusion-weighted imaging. Magn Reson Imaging Clin N Am 2013;21:321-336
12. Woodhams R, Ramadan S, Stanwell P, et al. Diffusion-weighted imaging of the breast: principles and clinical applications. Radiographics 2011;31:1059-1084
13. Pereira FP, Martins G, Carvalhaes de Oliveira Rde V. Diffusion magnetic resonance imaging of the breast. Magn Reson Imaging Clin N Am 2011;19:95-110
14. Partridge SC, McDonald ES. Diffusion weighted magnetic resonance imaging of the breast: protocol optimization, interpretation, and clinical applications. Magn Reson Imaging Clin N Am 2013;21:601-624
15. Baltzer PA, Benndorf M, Dietzel M, Gajda M, Camara O, Kaiser WA. Sensitivity and specificity of unenhanced MR mammography (DWI combined with T2-weighted TSE imaging, ueMRM) for the differentiation of mass lesions. Eur Radiol 2010;20:1101-1110
16. Yabuuchi H, Matsuo Y, Sunami S, et al. Detection of non-palpable breast cancer in asymptomatic women by using unenhanced diffusion-weighted and T2-weighted MR imaging: comparison with mammography and dynamic contrast-enhanced MR imaging. Eur Radiol 2011;21:11-17
17. Trimboli RM, Verardi N, Cartia F, Carbonaro LA, Sardanelli F. Breast cancer detection using double reading of unenhanced MRI including T1-weighted, T2-weighted STIR, and diffusion-weighted imaging: a proof of concept study. AJR Am J Roentgenol 2014;203:674-681
18. McDonald RJ, McDonald JS, Kallmes DF, et al. Intracranial

gadolinium deposition after contrast-enhanced MR imaging. Radiology 2015;275:772-782
19. Telegrafo M, Rella L, Stabile Ianora AA, Angelelli G, Moschetta M. Unenhanced breast MRI (STIR, T2-weighted TSE, DWIBS): an accurate and alternative strategy for detecting and differentiating breast lesions. Magn Reson Imaging 2015;33:951-955
20. Bickelhaupt S, Laun FB, Tesdorff J, et al. Fast and noninvasive characterization of suspicious lesions detected at breast cancer X-ray screening: capability of diffusion-weighted MR imaging with MIPs. Radiology 2016;278:689-697
21. McDonald ES, Hammersley JA, Chou SH, et al. Performance of DWI as a rapid unenhanced technique for detecting mammographically occult breast cancer in elevated-risk women with dense breasts. AJR Am J Roentgenol 2016;207:205-216
22. Shin HJ, Chae EY, Choi WJ, et al. Diagnostic performance of fused diffusion-weighted imaging using unenhanced or postcontrast T1-weighted MR imaging in patients with breast cancer. Medicine (Baltimore) 2016;95:e3502
23. Kang JW, Shin HJ, Shin KC, et al. Unenhanced magnetic resonance screening using fused diffusion-weighted imaging and maximum-intensity projection in patients with a personal history of breast cancer: role of fused DWI for postoperative screening. Breast Cancer Res Treat 2017;165:119-128
24. Hahn SY, Ko ES, Han BK, Lim Y, Gu S, Ko EY. Analysis of factors influencing the degree of detectability on diffusion-weighted MRI and diffusion background signals in patients with invasive breast cancer. Medicine (Baltimore) 2016;95:e4086
25. Amornsiripanitch N, Partridge S, Shin HJ. Diffusion MRI as a stand-alone unenhanced breast imaging approach and screening. In Iima M, Partridge SC, Le Bihan D. Diffusion MRI of the breast. Elsevier Health Sciences, 2022.
26. Kim JY, Suh HB, Kang HJ, et al. Apparent diffusion coefficient of breast cancer and normal fibroglandular tissue in diffusion-weighted imaging: the effects of menstrual cycle and menopausal status. Breast Cancer Res Treat 2016;157:31-40
27. Ha SM, Chang JM, Lee SH, et al. Diffusion-weighted MRI at 3.0 T for detection of occult disease in the contralateral breast in women with newly diagnosed breast cancer. Breast Cancer Res Treat 2020;182:283-297
28. Partridge SC, DeMartini WB, Kurland BF, Eby PR, White SW, Lehman CD. Quantitative diffusion-weighted imaging as an adjunct to conventional breast MRI for improved positive predictive value. AJR Am J Roentgenol 2009;193:1716-1722
29. Partridge SC, Demartini WB, Kurland BF, Eby PR, White SW, Lehman CD. Differential diagnosis of mammographically and clinically occult breast lesions on diffusion-weighted MRI. J Magn Reson Imaging 2010;31:562-570
30. Partridge SC, Nissan N, Rahbar H, Kitsch AE, Sigmund EE. Diffusion-weighted breast MRI: clinical applications and emerging techniques. J Magn Reson Imaging 2017;45:337-355
31. Jeong EH, Choi EJ, Choi H, Park EH, Song JS. Prediction of axillary lymph node metastasis in early breast cancer using dynamic contrast-enhanced magnetic resonance imaging and diffusion-weighted imaging. Investig Magn Reson Imaging 2019;23:125-135
32. Zhang L, Tang M, Min Z, Lu J, Lei X, Zhang X. Accuracy of combined dynamic contrast-enhanced magnetic resonance imaging and diffusion-weighted imaging for breast cancer detection: a meta-analysis. Acta Radiol 2016;57:651-660
33. Rahbar H, Zhang Z, Chenevert TL, et al. Utility of diffusion-weighted imaging to decrease unnecessary biopsies prompted by breast MRI: a trial of the ECOG-ACRIN Cancer Research Group (A6702). Clin Cancer Res 2019;25:1756-1765
34. Baltzer PAT, Bickel H, Spick C, et al. Potential of noncontrast magnetic resonance imaging with diffusion-weighted imaging in characterization of breast lesions: intraindividual comparison with dynamic contrast-enhanced magnetic resonance imaging. Invest Radiol 2018;53:229-235
35. Pinker K, Moy L, Sutton EJ, et al. Diffusion-weighted imaging with apparent diffusion coefficient mapping for breast cancer detection as a stand-alone parameter: comparison with dynamic contrast-enhanced and multiparametric magnetic resonance imaging. Invest Radiol 2018;53:587-595
36. Youk JH, Son EJ, Chung J, Kim JA, Kim EK. Triple-negative invasive breast cancer on dynamic contrast-enhanced and diffusion-weighted MR imaging: comparison with other breast cancer subtypes. Eur Radiol 2012;22:1724-1734