Diffusion-weighted Imaging of the Breast: Comparison of B-values 1000 s/mm² and 1500 s/mm²

Reiko Woodhams1*, Yusuke Inoue1, Saadallah Ramadan2, Hirofumi Hata3, and Masanori Ozaki3

1Department of Diagnostic Radiology, Kitasato University School of Medicine
1-15-1, Kitasato, Minami-ku, Sagamihara, Kanagawa 252-0374, Japan

2School of Health Sciences, Faculty of Health, Hunter Building, University of Newcastle,
University Drive, Callaghan NSW 2308, Australia

3Kitasato University Hospital

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Purpose: We compared diffusion-weighted imaging (DWI) of the breast using 2 different b-values to determine the optimal b-value for greatest signal contrast between tumors and normal tissue of the breast.

Materials and Methods: We performed DWI of the breast at b-values of 1000 s/mm² and 1500 s/mm² in 120 patients (121 lesions, 19 benign, 102 malignant) and visually scored image quality with regard to artifact and visibility of tumors. We quantitatively evaluated the signal-to-noise ratio (SNR) of the tumor and contrast-to-noise ratio (CNR) and contrast ratio (CR) between the tumor and normal breast parenchyma.

Results: The CR of invasive carcinoma (IC), ductal carcinoma in situ (DCIS), and benign tumors significantly improved with \( b = 1500 \) s/mm² compared with \( b = 1000 \) s/mm². The SNR and CNR were significantly lower with \( b = 1500 \) s/mm² than \( b = 1000 \) s/mm² despite the increasing number of excitations at \( b = 1500 \) s/mm². At \( b = 1500 \) s/mm², the difference in SNR, CNR, and CR between IC and DCIS and benign tumors was statistically significant.

Conclusion: DWI may depict breast tumors more clearly with \( b = 1500 \) s/mm² than \( b = 1000 \) s/mm².

Keywords: b-value, breast, diffusion-weighted imaging

Introduction

Diffusion-weighted imaging (DWI) in magnetic resonance (MR) imaging was initially applied for the diagnosis of acute brain ischemic infarction.1,2 Subsequently, DWI was found highly sensitive for malignant tumors and applied for evaluation of various organs, including the breast.3 Previous breast DWI studies employed visual assessment of signal intensities and quantitative analysis of the apparent diffusion coefficient (ADC).3,10,13 The signal intensity of breast DWI has been reported useful for diagnosing breast carcinoma.7,9

In DWI, signal intensity and signal contrast between different tissues depend on b-value. Use of a higher b-value improves image contrast14 and reduces the fractional contribution of perfusion1 but yields a lower signal-to-noise ratio (SNR).15 The choice of b-value is critical in the visual interpretation of images. Recent studies have shown the usefulness of \( b = 1500 \) s/mm² to detect abnormal lesions.9,10,16 Moreover, several studies of brain DWI have reported that higher b-values increased the contrast between different structures.14,17,18 Conversely, \( b = 1000 \) s/mm² has been commonly used in the clinical practice of breast DWI.19

Several studies have investigated the optimal b-value for calculating ADC values,20,21 but the op-
timal b-value with respect to signal contrast between tumors and normal breast tissue has not been evaluated. In our routine practice of breast MR imaging, we have obtained DWI with 2 different b-values, 1000 s/mm² and 1500 s/mm², because of uncertainty regarding an optimal b-value.¹⁹

In this study, we compared signal contrast obtained using 2 b-values to determine which value offered the best contrast between breast tumors and normal breast tissue. For quantitative assessment, we compared the SNR, contrast-to-noise ratio (CNR) between tumors and normal breast parenchyma, and contrast ratio (CR) between tumors and normal breast parenchyma between the 2 b-values.

Materials and Methods

Subjects

Our institutional review board approved this retrospective study, and informed consent was waived. We analyzed 121 breast lesions of 120 female patients (aged 36 to 82 years, average age 53.0 years) with histological diagnoses (one patient had a mass in each breast). The women underwent MR imaging studies conducted on a GE Sigma CV/i 1.5-tesla scanner using an 8-channel breast coil (GE Medical Systems, Milwaukee, WI, USA) with patients in prone position.

After the positioning scan, DWI of both breasts was performed using 2 different b-value sets in the axial plane with a single-shot echo planar imaging sequence. Imaging parameters at \( b = 1000 \text{ s/mm}^2 \) were: b-values, 0 and 1000 s/mm²; repetition time (TR), 6000 ms; echo time (TE), 69.1 ms; number of excitations (NEX), 4; and acquisition time, one minute 36 s.

The parameters at \( b = 1500 \text{ s/mm}^2 \) were: b-values, 0 and 1500 s/mm²; TR, 6000 ms; TE, 75.1 ms; NEX, 5; and acquisition time, 2 min 4 s.

Other imaging parameters identical between the 2 b-value acquisitions were: section thickness, 6.0 mm; no interslice gap; slice number, 30; field of view (FOV), 320 mm × 256 mm; and matrix size, 128 × 128. The diffusion gradients were applied equally along the read, slice, and phase orthogonal directions. The TEs were set to minimum and were different for different b-values. Frequency-selective fat suppression was also employed to reduce chemical-shift artifacts. To simplify SNR determination of DWI, parallel imaging was not used.²²

After completion of DWI, unilateral examination of the breast was undertaken. First, sagittal, fast spin-echo T₁WI with fat suppression was performed using parameters: TR, 4000 ms; TE, 90 ms; section thickness, 5 mm; interslice gap, one mm; NEX, 2; FOV, 200 mm × 200 mm; matrix size, 256 × 192; and acquisition time, 2 min 55 s. Next, contrast-enhanced sagittal 3-dimensional T₁WI was performed using a fast spoiled-gradient echo sequence and active fat suppression (TR, 16.3 ms; TE, 2.1 ms; flip angle, 15°; section thickness, 2.0 mm; NEX, 1.5; FOV, 200 mm × 200 mm; matrix size, 256 × 160; and acquisition time, one min 54 s). Images were obtained before and at 90 and 300 s after injection of 0.10 mmol/kg of gadopentetate dimeglumine (Bayer Health Care Pharmaceuticals, Osaka, Japan). Subsequently, fat-suppressed axial 2-dimensional T₁WI was performed 450 s after the injection (TR, 200 ms; TE, 1.8 ms; flip angle, 90°; section thickness, 5 mm; interslice gap, one mm; FOV, 200 mm × 200 mm; and matrix size, 512 × 192).

Image quality assessment

We compared image quality between \( b = 1000 \text{ s/mm}^2 \) and \( b = 1500 \text{ s/mm}^2 \) by visual assessment. Two readers with 6 years’ or more experience in breast MR imaging and blinded to the b-value used evaluated the patients’ breast DWI data. Any disagreements between the readers were resolved by discussion between them.

The readers were asked to rate the image quality of DWI for each image set using a 4-point scale, considering the visual SNR, artifacts, image distor-
tion, and quality of fat suppression. Image sets of \( b = 1000 \text{ s/mm}^2 \) and \( b = 1500 \text{ s/mm}^2 \) from all patients were randomly presented to the readers. A score of one was assigned when poor image quality precluded assessment of the target lesion; a score of two, when image quality was not good but usable for evaluation; a score of three, when the image suffered from only minor degradation and was suitable for evaluation; and a score of four, when no problems were noticed in the image.

### Quantitative assessment

A radiologist with 6 years’ experience in breast MR imaging calculated SNR, CNR, and CR on a workstation (Advantage Windows ver. 4.2, GE Medical Systems) and detected the tumor with reference to clinical information, \( T_2WI \), and contrast-enhanced \( T_1WI \). Regions of interest (ROIs) were placed to avoid hemorrhage, necrosis, or cystic components. Hemorrhage was determined by referring to high signal intensity on pre-contrast \( T_1WI \).

Circular ROIs were placed on all slices that showed tumor, and the average signal intensity was determined. The same set of ROIs was applied to the images obtained at \( b = 0, 1000, \) and \( 1500 \text{ s/mm}^2 \), and the signal intensity of the tumor was obtained for each \( b \)-value. All tumors but one were visible on DWI at \( b = 1000 \text{ s/mm}^2 \) and \( 1500 \text{ s/mm}^2 \). For the visible lesions, we could place ROIs at the same position on DWI at \( b = 1000 \text{ s/mm}^2 \) and \( 1500 \text{ s/mm}^2 \). For a fibroadenoma that was invisible on DWI at both \( b \)-values, we placed an ROI on the DWI at \( b = 1000 \text{ s/mm}^2 \) and \( 1500 \text{ s/mm}^2 \). For the visible lesions, we could place ROIs at the same position on DWI at \( b = 1000 \text{ s/mm}^2 \) and \( 1500 \text{ s/mm}^2 \). For a fibroadenoma that was invisible on DWI at both \( b \)-values, we placed an ROI on the DWI at \( b = 1000 \text{ s/mm}^2 \) and \( 1500 \text{ s/mm}^2 \), on which the lesion was visible with high signal intensity.

To analyze the signal intensity of normal breast parenchyma, we referred to the DWI obtained at \( b = 0 \text{ s/mm}^2 \) to select a slice that showed the most dense normal breast parenchyma, within which we then placed a circular ROI to minimize inclusion of fat tissue. To determine the background noise, we placed 3 circular ROIs of 2-cm diameter outside the body (right, front, and left side of the breast) at the middle level of the tumor in the craniocaudal axis. We averaged the standard deviations for the 3 ROIs to calculate the SNR and CNR. Preliminary inspection showed little variation by increasing their number or area or by changing their position.

We calculated SNR, CNR, and CR of DWI for each lesion using the following equations: 

\[
\text{SNR} = \frac{S_{\text{tumor}}}{S_{\text{background}}}, \quad \text{CNR} = \frac{(S_{\text{tumor}} - S_{\text{normal breast parenchyma}})}{S_{\text{background}}}, \quad \text{and CR} = \frac{(S_{\text{tumor}} - S_{\text{normal breast parenchyma}})}{S_{\text{normal breast parenchyma}}}
\]

where \( S_{\text{tumor}} \) is the signal intensity of the breast tumor and \( S_{\text{normal breast parenchyma}} \) is the signal intensity of the normal breast parenchyma, and \( S_{\text{background}} \) is the standard deviation of the background signal.

### Statistics

We analyzed statistics using JMP 7.0 software (2007 SAS Institute Inc., Cary, NC, USA), compared \( b = 1000 \text{ s/mm}^2 \) and \( b = 1500 \text{ s/mm}^2 \) using Wilcoxon signed-rank, and compared histologic types using Steel-Dwass test after Kruskal-Wallis test. \( P < 0.05 \) was deemed statistically significant.

### Results

#### Assessment of image quality

The median image quality score was 3 for both \( b \)-values, with no significant difference between them (\( P > 0.05 \)). Quality of all images was scored 2 or above (Table).

### Quantitative assessment

In all patients, there was sufficient normal breast parenchyma to place the ROI on DWI at \( b = 0 \text{ s/mm}^2 \). The average diameter of ROIs for tumors was 28.2 mm (range, 4 to 90 mm). The median number of ROIs placed on a given tumor was three (range, one to 16).

Figure 1 shows the SNR, Fig. 2, the CNR, and Fig. 3, the CR at \( b = 1000 \text{ s/mm}^2 \) and \( 1500 \text{ s/mm}^2 \) for each histologic type. In all histologic types, the SNR in normal breast \( (17.1 \pm 6.1) \), benign tumors \( (36.1 \pm 15.6) \), DCIS \( (55.9 \pm 23.5) \), and IC \( (73.7 \pm 30.6) \) and CNR at \( b = 1500 \text{ s/mm}^2 \) in benign tumors \( (18.2 \pm 15.8) \), DCIS \( (39.4 \pm 20.4) \), and IC \( (56.9 \pm 29.3) \) were significantly lower than the SNR and CNR at \( b = 1000 \text{ s/mm}^2 \) (SNR in normal breast tissue, \( 34.2 \pm 14.3 \), in benign tumors, \( 55.2 \pm 14.6 \), in DCIS, \( 78.6 \pm 34.4 \), and in IC, \( 12.4 \pm 49.2 \), and CNR in benign tumors, \( 22.8 \pm 12.4 \), in DCIS, 46.8

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<tr>
<th>Score</th>
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<td>( b = 1000 \text{ s/mm}^2 )</td>
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Score one, poor image quality precluded assessment of the target lesion; Score 2, image quality not good but usable for evaluation; Score 3, only minor degradation of image and suitable for evaluation; Score 4, no problems noted in image.

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The signal-to-noise ratio (SNR) on diffusion-weighted imaging (DWI) at $b = 1000$ s/mm$^2$ and $1500$ s/mm$^2$ in normal breast parenchyma, benign tumors, ductal carcinoma in situ (DCIS), and invasive carcinoma (IC). The mean and standard deviation (SD) are indicated.

The contrast-to-noise ratio (CNR) on diffusion-weighted imaging (DWI) at $b = 1000$ s/mm$^2$ and $1500$ s/mm$^2$ in benign tumors, ductal carcinoma in situ (DCIS), and invasive carcinoma (IC).

The contrast ratio (CR) on diffusion-weighted imaging (DWI) at $b = 1000$ s/mm$^2$ and $1500$ s/mm$^2$ in benign tumors, ductal carcinoma in situ (DCIS), and invasive carcinoma (IC).

The most important finding of the present study was that CRs of all histologic types at $b = 1500$ s/mm$^2$ were higher than those at $b = 1000$ s/mm$^2$, indicating that DWI at $b = 1500$ s/mm$^2$ provides better signal contrast between breast tumors and normal breast parenchyma than DWI at $b = 1000$ s/mm$^2$. The better conspicuity of breast tumors against normal breast parenchyma of DWI at $b = 1500$ s/mm$^2$ may aid interpretation of breast MR imaging.

The expected disadvantage of $b = 1500$ s/mm$^2$ was reduced SNR compared with $b = 1000$ s/mm$^2$. Quantitative analysis demonstrated lower SNR and CNR at $1500$ s/mm$^2$ than $1000$ s/mm$^2$ in all histologic types, though the number of excitations was larger at $b = 1500$ s/mm$^2$ (NEX = 5) than $b = 1000$ s/mm$^2$ (NEX = 4). However, visual assessment showed sufficient image quality for evaluation at normal breast parenchyma (Fig. 4). Regarding the difference between histologies at each $b$-value, the SNR, CNR, and CR were highest for IC followed by DCIS and benign tumors, and the SNR was lowest for normal breast parenchyma. Significant differences were found for all pairs ($P < 0.05$) except for the SNR between DCIS and benign tumors at $b = 1000$ s/mm$^2$ and the SNR, CNR, and CR between IC and DCIS at $b = 1500$ s/mm$^2$ ($P > 0.05$).

Discussion

The most important finding of the present study was that CRs of all histologic types at $b = 1500$ s/mm$^2$ were higher than those at $b = 1000$ s/mm$^2$, indicating that DWI at $b = 1500$ s/mm$^2$ provides better signal contrast between breast tumors and normal breast parenchyma than DWI at $b = 1000$ s/mm$^2$. The better conspicuity of breast tumors against normal breast parenchyma of DWI at $b = 1500$ s/mm$^2$ may aid interpretation of breast MR imaging.
Fig. 4. Results for a 34-year-old woman with ductal carcinoma in situ (DCIS). Diffusion-weighted imaging (DWI) at $b = 1000 \text{s/mm}^2$ (a) shows a small DCIS with high signal intensity (arrow) that is obscured because of the high signal intensity of surrounding breast tissue. In DWI at $b = 1500 \text{s/mm}^2$ (b), the signal intensity of the normal breast parenchyma is diminished, and the signal intensity of DCIS is highlighted against the surrounding breast tissue.

Comparison of B-values for Breast DWI

Both $b = 1000 \text{s/mm}^2$ and $b = 1500 \text{s/mm}^2$. The low SNR at $b = 1500 \text{s/mm}^2$ does not appear to cause serious problem in evaluating breast tumors. We did not employ parallel imaging and used a 1.5T scanner. Application of parallel imaging will decrease image distortion, and a higher magnetic field can improve SNR. These technical improvements would further increase the usefulness of DWI at a high b-value.

Kuroki and associates note that a diagnosis based on the signal intensity of DWI and short inversion time inversion recovery (STIR) may be more useful than analysis of ADC values for the differential diagnosis of breast tumors. In the present study, we confirmed the relationship between DWI signals and histologic types at both 1000 s/mm$^2$ and 1500 s/mm$^2$, a finding that supports the potential of DWI signals for discriminating histologic types. However, the differences between the SNR, CNR, and CR values in IC and those in DCIS were not significant at 1500 s/mm$^2$ but were at 1000 s/mm$^2$. This arouses concern that despite of high ability of detection, DWI at 1500 s/mm$^2$ has a lower ability for differential diagnosis between IC and DCIS than does DWI at 1000 s/mm$^2$. Considering the limited number of DCIS cases examined in the present study, further study is required. Some previous reports raised the possibility that DCIS may be overlooked on DWI, especially non-mass DCIS at $b = 1500 \text{s/mm}^2$. There is an inverse correlation between ADC value and cellularity of the tumor, and low grade DCIS is expected to have low cellularity. Some low grade DCIS may have an inherently higher ADC value and lower signal intensity on DWI. DWI at a higher b-value may increase the risk of overlooking DCIS with low cellularity. This remains to be investigated.

Our study has several limitations. Because clinical breast MR imaging in our institution is mainly performed in patients with suspected breast cancer, our study population was biased by the extremely low number of benign lesions compared to malignant lesions. The difference in numbers of excitations between $b = 1000 \text{s/mm}^2$ and $b = 1500 \text{s/mm}^2$ is also limiting. We determined a higher NEX at $b = 1500 \text{s/mm}^2$ to maintain a diagnostically sufficient SNR at routine MR imaging of the breast based on the speculation that a higher NEX may compensate for the decrease in SNR at higher b-value. Because we used the data from routine clinical breast MR imaging, the NEX of b-values differed between the 2 b-values in this study. It is speculated that the difference of SNR and CNR between $b = 1000 \text{s/mm}^2$ and $b = 1500 \text{s/mm}^2$ would be larger if the same NEX was used for both b-values.

In conclusion, the implementation of DWI including $b = 1500 \text{s/mm}^2$ may aid visual analysis of breast tumors. Further studies to optimize and standardize DWI parameters should be conducted to expand the application of breast DWI and define the role of DWI in clinical settings.

References


