Study of the Reduced Field-of-View Diffusion-Weighted Imaging of the Breast

Haibo Dong, Yadi Li, Hui Li, Bo Wang, Bin Hu

Abstract

Reduced field-of-view diffusion-weighted imaging (rFOV DWI) is rarely used in magnetic resonance breast imaging. In this pilot study, we prospectively compared the imaging quality, apparent diffusion coefficient values, and application values between rFOV and single-shot echo-planar-imaging (SS-EPI) DWI in 87 cases: rFOV DWI presented images with higher resolution, lower mean ADC value and less distortion. Our findings may help clinicians improve the diagnosis of breast diseases.

Background: This study aimed to compare the imaging quality, apparent diffusion coefficient (ADC) values, and application values between reduced field-of-view diffusion-weighted imaging (rFOV DWI) and single-shot echo-planar-imaging diffusion-weighted imaging (SS-EPI DWI) of breast tissue. Patients and Methods: For 87 cases (75 with normal breast tissue, 12 with mammary cancer), breasts were scanned with SS-EPI DWI and rFOV DWI (b values, 800 s/mm²). Image quality and ADC values of breast tissue images were compared between SS-EPI DWI and rFOV DWI. Results: The average image quality score for the 87 cases was 4.73 in rFOV DWI and 3.62 in SS-EPI DWI. The difference was statistically significant (P < .01). The resolution of rFOV DWI was 2.25 mm/C² 1.23 mm, which was higher than the resolution of SS-EPI DWI (2.25 mm 2.25 mm). The mean ADC value of 75 cases with normal breast tissue was 1.696 × 10⁻³ mm²/s by rFOV DWI and 1.832 × 10⁻³ mm²/s by SS-EPI DWI, and the difference was statistically significant (P < .01). The mean ADC value for the 12 cases with breast cancer was 1.065 × 10⁻³ mm²/s by rFOV DWI and 1.192 × 10⁻³ mm²/s by SS-EPI DWI, which was a statistically significant difference (P < .05). Conclusion: rFOV DWI presented images with higher resolution and less distortion than SS-EPI DWI, and this difference may be helpful in disease diagnosis.

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Introduction

The value of diffusion-weighted imaging (DWI) in the diagnosis of benign and malignant breast foci has been receiving increasing attention. Currently, the single-shot echo-planar—imaging (SS-EPI) sequence is the most-used sequence in DWI. However, its image resolution is greatly limited by magnetic resonance imaging (MRI) artifacts and magnetic susceptibility. Artifacts and image distortions lead to unavailable images in some situations for diagnosis or the detection of small foci.1-6 Reduced field-of-view diffusion-weighted imaging (rFOV DWI) employs 2-dimensional radiofrequency (2DRF) to just excite interest areas of small range, which not only help diminish artifacts but obtain better quality and higher resolution in DWI images. This technique has been used most often in mapping the spine and brain,7-10 but less often in breast studies.11-12 rFOV DWI could improve the diagnosis of breast diseases, including the detection of small cancers. This study compares the image quality, ADC values, and clinical values of SS-EPI DWI and rFOV DWI in magnetic resonance (MR) breast imaging.

Patients and Methods

Patients

MRI was performed on 87 cases of female patients with suspicious breast masses enrolled at our hospital from August 2012 to May 2013. The patients’ ages ranged from 26 to 65 years, with a mean of 45.91 years. In all, 75 cases were diagnosed as normal breast tissue after MRI scanning; 12 cases were indicated to be breast cancer by MRI, and diagnoses of these cases were confirmed by surgical pathology as infiltrative ductal carcinoma (9 cases), ductal carcinoma in situ (2 cases), or invasive micropapillary carcinoma (1 case). Patients who had undergone previous breast surgery,
breast biopsy and breast cancer chemotherapy were excluded. Patients who had breast masses without surgical pathology were also excluded. This study was authorized by the hospital ethics committee. All patients were informed and signed the consent form.

**MRI Method**

MRI scanning was performed using a 3.0-T MR (Discovery 750, GE Healthcare), together with an 8-channel dedicated breast coil. Patients lay in prone position, with the breasts being overhung inside the breast coil.

**MR Unenhanced Scanning.** After the conventional 3-plane positioning scanning, cross section fast spin echo (FSE) sequence T1 weighted image (WI) (500 ms of repetition time [TR], shortest of echo time [TE], 360 mm × 360 mm of field of view [FOV], 320 × 256 of matrix, 4 mm of layer thickness, 1 mm of gap, number of signals acquired [NEX] = 2) and IDEAL (iterative Dixon water-fat separation with Echo Asymmetry and Least-squares estimation) fat suppression T2WI (258 ms of TR, shortest TE, 360 mm × 360 mm of FOV, 320 × 256 of matrix, 4 mm of layer thickness, 1 mm of gap, 62.5 kHz of bandwidth) were performed.

The scanning parameters of SS-EPI DWI were 3600 ms of TR, shortest TE, 360 mm × 360 mm of FOV, 160 × 160 of matrix, 4 mm of slice thickness, 1 mm of gap, 250 of BW, NEX = 6, b value of 800 s/mm². The scanning time was 76 s. Before the scanning, a combined sequence with array spatial sensitivity encoding technique (ASSET) was conducted.

The scanning parameters of rFOV DWI were 3600 ms of TR, shortest TE, 360 mm × 180 mm of FOV, 160 × 160 of matrix, 4 mm of slice thickness, 1 mm of gap, 250 of BW, NEX = 6, b value of 800 s/mm². The scanning time was 164 s.

**Dynamic Contrast-Enhanced MRI.** For dynamic contrast-enhanced (DCE) MRI, the contrast agent gadolinium-diethylenetriaminepentaacetic acid (Magnevist, Schering) was injected as a bolus at the dose of 0.1 mmol/kg body weight and a flow rate of 2 mL/s, and then 20 mL of saline was used to rinse the residual contrast agent in the catheter at the same rate. Before the injection, a mask was scanned. After the injection, 6 time phases of volume imaging for breast assessment (VIBRANT-Flex) were continuously acquired with about 50 s of, 60 s of interval between the fifth and sixth phase, and a total scanning of 410 s (TR 3.9 ms, shortest TE, flip angle 12°, FOV 360mm × 360mm, matrix 320 × 320, layer thickness 1.4 mm).

**MR Image Analysis**

All image analyses were carried out in an ADW4.5 workstation by 2 senior doctors engaging in breast imaging. The 2 doctors were blinded to sequence type. SS-EPI DWI and rFOV DWI images were referred to as sequence 1 and sequence 2. Sequence number varied from case to case to improve blinding, but complete blinding of sequence type was not possible because of the visible FOV differences between sequence 1 and sequence 2 images.

**The Assessment of Imaging Quality.** According to the susceptibility artifacts, chemical shift artifacts, and image distortion on the display of anatomical details, images were scored as levels 1 to 5: 1 is nondiagnostic, as the images cannot be used in diagnosis; 2 is poor, as lots of artifacts influence diagnosis but not all anatomical structures; 3 is moderate, as there are a few magnetic susceptible artifacts or opacities or reconstructed artifacts, but the diagnoses based on MR breast images are trustable; 4 is good, with comparatively clear anatomical details, and few susceptibility artifacts or reconstructed artifacts; 5 is excellent, with distinct anatomical details and no artifacts (Fig. 1).

Circular regions of interest (ROIs) of 10 to 20 mm² were used to measure the breast ADC values of SS-EPI DWI and rFOV DWI images. When the ROI signal value of normal glands was measured, a nipple slice with plenty of glandular tissues was selected in order to avoid artifacts. On each slice, 3 ROIs of bilateral breasts were randomly chosen to calculate the mean value (the 2 DWI sequence positions were consistent). When a breast cancer ROI signal value was detected, the substantial part with the greatest slice of pathologic changes was selected, avoiding cystic necrosis and bleeding areas, and then the mean value of 3 ROIs was taken.

**Statistical Analysis**

The comparison of image quality of SS-EPI DWI and rFOV DWI was conducted by nonparametric Wilcoxon paired signed-rank test. The comparison of mean breast ADC values was conducted by paired t test. P < .05 refers to a significant difference, while P < .01 means the difference is extremely significant.

**Results**

**Comparison of Image Quality of SS-EPI DWI and rFOV DWI**

The subjective image scores of 2 sequences of 87 cases are listed in Table 1. The average score of SS-EPI DWI image quality was 3.62 and that of rFOV DWI was 4.73. The image quality of rFOV DWI was significantly better than that of conventional SS-EPI, and the difference was of great significance (Z = −7.135, P = .000 to .01).

The images obtained by SS-EPI DWI presented deformation, distortion, chemical shift artifacts, and susceptibility artifacts to varied degrees, whereas there was no deformation, distortion, or obvious artifact on the images of rFOV DWI, and the latter presented clear details (Figs. 2 and 3). Based on the formula image resolution = FOV/matrix, the image resolution of SS-EPI DWI and rFOV DWI was 2.25 mm × 2.25 mm ([360 mm × 360 mm]/[160 × 160]) and 2.25 mm × 1.23 mm ([360 mm × 180 mm]/[160 × 160]), respectively. The cancers were all visible on SS-EPI DWI and rFOV DWI images. The SS-EPI DWI images of the foci showed moderately strong signals with blurred details, a few artifacts, and distortion, whereas the rFOV DWI images of the foci showed strong signals with clear anatomic details and no artifacts. The details of definition of focus in breast cancer of rFOV DWI were better than those of SS-EPI DWI (Figs. 4 and 5).

**Comparison of ADC Values of SS-EPI DWI Group and rFOV DWI Group**

The average ADC value of SS-EPI DWI and rFOV DWI in 75 cases with normal breast tissue was 1.832 × 10⁻³ mm²/s and 1.696 × 10⁻³ mm²/s respectively, with significant difference.
The average ADC value of SS-EPI DWI and rFOV DWI in 12 cases of breast cancer was $1.192 \times 10^{-3}$ mm$^2$/s and $1.065 \times 10^{-3}$ mm$^2$/s, respectively, with significant difference ($t = 2.839; P = .019$ to .05).

**Discussion**

Currently, SS-EPI is the DWI method most frequently used in clinics. However, the EPI sequence is limited by a long TE with a narrow bandwidth in the direction of phase encoding, which likely produces susceptibility and chemical shift artifacts, leading to low image quality, low signal-to-noise ratio (SNR), and low resolution. The array spatial sensitivity encoding technique (ASSET) can not only accelerate scanning and reduce acquisition times and accordingly shorten examination times, but also diminish artifacts, blurred images, and distortion, leading to an improvement in imaging quality of breast DWI. But the advantages of ASSET are also limited. Because of the interlacing acquisition of k-space, the imaging SNR decreases as the acquisition speed increases. As a consequence, the MR device automatically removes the areas valueless to signal during ASSET imaging reconstruction (mainly beyond the images) so as to increase SNR.1,6,13-18 Because SNR could not be detected in the blank area, this study did not compare the 2 groups’ SNRs and only subjectively assessed the imaging quality.

As for breast SS-EPI DWI, the FOV cannot be reduced arbitrarily, or else the breast cannot be displayed in view. The only choice for increasing image resolution is to increase the acquisition matrix size, which directly determines the length of the overall readout window. The larger acquisition matrix leads to the longer overall readout window and more artifacts. With air in front of the breast and heart and lung tissues in the posterior part, susceptibility artifacts and even B1 fields are easily generated, which increase the deformation of DWI images and decrease SNR. Consequently, the DWI commonly used clinically can provide images only with

**Table 1** The Scores of the Single-Shot Echo-Planar–Imaging Diffusion-Weighted Imaging Group and the Reduced Field-of-View Diffusion-Weighted Imaging Group. According to the Susceptibility Artifacts, Chemical Shift Artifacts and Image Distortion on the Display of Anatomical Details, Image Distortion or not, Images Were Scored to be 1 to 5

<table>
<thead>
<tr>
<th>Score</th>
<th>SS-EPI DWI</th>
<th>rFOV DWI</th>
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<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>0</td>
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<tr>
<td>2</td>
<td>6</td>
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<td>5</td>
<td>15</td>
<td>69</td>
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Abbreviations: DWI = diffusion-weighted imaging; rFOV = reduced field-of-view; SS-EPI = single-shot echo-planar–imaging.
resolutions that lead to worse partial volume effect and limit the display and assessment of small pathological changes.

The Principle of rFOV DWI and Its Advantages in Breast DWI

rFOV DWI uses 2-dimensional selective excitation frequency technology to achieve strip excitation during slice selection excitation. It has no radiofrequency cross talk among slices in multi-scanning, thus decreasing the readout of phase encoding (PE) line and TE time, comparatively increasing the bandwidth in the direction of PE but also decreasing image deformation and artifacts; in addition, it decreases FOV while maintaining a large acquisition matrix, so the resolution is increased.1,10-12,19-21 ASSET shortens scanning time by increasing the acquisition gap of k-space (that is, decreasing the sampling steps of PE), whereas rFOV DWI obtains images of high spatial resolution through decreased sampling steps of PE. If rFOV DWI adopts ASSET simultaneously, SNR will significantly decrease, indicating that current rFOV DWI sequences are not compatible with ASSET.

In addition, in EPI (DWI included), a 180°selective excitation radiofrequency pulse of rFOV narrow bandwidth excites the water signal of the scanning slice only and inhibits the fat signal, thereby eliminating chemical shift artifacts, which is beneficial to the detection of small lesions.

In this study, the vision field of rFOV DWI is 360 mm in the left-to-right direction (frequency-encoding direction) and 180 mm
in the fore-and-aft direction (PE direction), which includes the bilateral breast glands completely; furthermore, in the reduced vision field in the fore-and-aft direction, there are fewer motion artifacts in breast tissue that are caused by heartbeat and lung motion.

Zaharchuk et al.7 applied rFOV DWI to studies of spine and spinal cord lesions and found that rFOV DWI is characteristic of high spatial resolution, high SNR, and less deformation, which conduces to spine and spinal cord lesion diagnosis. von Morze et al.9 compared rFOV DWI and SS-EPI DWI of 7 T MR scanner of brain diseases and obtained the results that rFOV DWI considerably decreases susceptibility artifacts and increases the quality of images of the frontotemporal brain. They concluded that rFOV DWI is valuable in the diagnosis of dementia, traumatic encephalopathy, and epilepsy. Singer et al.11 applied rFOV DWI and SS-EPI DWI to progressive breast cancer, finding that rFOV DWI can increase image resolution and decrease susceptibility artifacts and chemical shift artifacts and concluding that it has great value in assessing neoadjuvant chemotherapy of breast cancer.

SS-EPI DWI and rFOV DWI in this study use the same parameters of b value, matrix, slice thickness, bandwidth, and TR. Image quality scores indicate that, even when ASSET has been used in SS-EPI DWI to shorten scanning time and improve image quality, the rFOV DWI group still has remarkably better image quality and less deformation than the SS-EPI DWI group. Hence, rFOV DWI is better in assessing the restricted breast lesion diffusion.

The Investigation of the Different ADC Values of rFOV DWI

The ADC value reflects the physical properties of tissues and is influenced by various factors, such as b value, magnetic field intensity, and impulse train. Singer et al.11 considered that rFOV DWI reduces the partial volume effect between tumors and normal breast gland tissues, so the ADC value of breast cancer detected by rFOV DWI is lower than that detected by SS-EPI DWI, and is possibly a more accurate ADC value.

The ADC values of rFOV DWI in 12 cases of breast cancer are lower than those of SS-EPI DWI in our study, and the same goes for the 75 cases in the control group, with the same parameters of b value, matrix, slice thickness, bandwidth, and TR. We hold that rFOV DWI can increase spatial resolution and shorten TE, which reduces susceptibility artifacts and the influence of...
microscopic blood flow, whereas microscopic blood flow is believed to contribute to the higher ADC, so rFOV DWI could result in a lower ADC value of normal breast tissue. It is a new challenge how to make use of the ADC value of rFOV DWI to distinguish benign and malignant lesions.

Here are limitations to our study: (1) Only 12 cases of breast cancer are included. The number of cancer cases is relatively small in comparison with those of prior studies, and the cancers are of widely varying histology, which will affect the ADC value. More lesions overall will be included in future studies to achieve better results; (2) The scanning time of rFOV DWI is longer than that of SS-EPI; (3) The study is just a single-center study.

Conclusion
rFOV DWI can present breast images with higher resolution and less distortion than SS-EPI DWI, which may be helpful in disease diagnosis.

Clinical Practice Points
- The usefulness of SS-EPI DWI has already been established in the field of breast imaging. However, SS-EPI DWI has the disadvantage of susceptibility to chemical shift artifacts that greatly limit its resolution.
- We found higher resolution and less distortion on rFOV DWI images than on SS-EPI DWI images, which may be helpful in disease diagnosis, particularly for coregistering with DCE. This would be an interesting future direction of study.
- The ADC value of breast cancer detected by rFOV DWI was lower than that detected by SS-EPI DWI. It is a new challenge how to make use of the ADC value of rFOV DWI to distinguish benign and malignant lesions.

Disclosure
The authors have stated that they have no conflicts of interest.

References


