Image quality evaluation of turbo-spin echo diffusion weighted image (TSE-DWI) : A phantom study

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Aims and objectives

A single shot echo-planer imaging sequence (EPI-DWI) is the most commonly used for DWI; however, it is prone to several artifacts. Image distortion, which is one of the artifacts due to the EPI sequence, is found in the interfaces of tissues with different susceptibility such as skull base [1]. Several artifacts related to the EPI sequence often result in incorrect signal intensity and inaccurate apparent diffusion coefficient (ADC) values [2].

To overcome this problem, Alsop demonstrated that DWI with single shot turbo spin echo sequence (TSE-DWI) reduced image distortion compared with EPI-DWI in human brain imaging [3]. TSE-DWI suffers from low signal-to-noise ratio (SNR) and severe image blur although it avoids the image distortion found in the EPI sequence [4].

It is important to optimize imaging parameters for the high image quality and the accurate ADC measurements in DWI. Generally, a shortest time echo and parallel imaging technique are useful for EPI-DWI [5]. However, to best of our knowledge, no report has revealed the relationship between the image quality of TSE-DWI and acceleration factors. Therefore, the purpose of the present study is to investigate the SNR, image blur, and ADC values of TSE-DWI by using a phantom.
Methods and materials

MRI techniques

All measurements were performed by using a 3.0 T whole-body MRI system (Achieva dStream 3.0T, Philips Healthcare, Best, The Netherlands) with a 32-channel phased array coil (32-channel dS head coil, Philips Healthcare, Best, The Netherlands).

Acquisition parameters of TSE-DWI were as follows: repetition time (TR), shortest; echo time (TE), shortest; flip angle (FA), 90°; field of view (FOV), 230 mm; acquisition matrix, 128 × 128; reconstruction matrix, 512 × 512; slice thickness, 5 mm; bandwidth (BW), 701-762 Hz / pixel; b-value, 0 and 1000; the number of acquisitions (NSA), 2; shot duration, 83-324 ms; half scan factor, 0.6; Acceleration factor (AF), 1, 2, 3, and 4. The phase encoding direction was left to right. Table 1 shows the summary of detailed imaging parameters of TSE-DWI. For comparison of ADC values, EPI-DWI was performed with the following parameters: TR, 8000 ms; TE, 60 ms; FA, 90°; FOV, 230 mm; acquisition matrix, 128 × 128; reconstruction matrix, 512 × 512; slice thickness, 5 mm; BW, 30.5 Hz / pixel; b-value, 0 and 1000; NSA, 1; half scan factor, 0.627; AF, 2.6. The phase encoding direction was anterior to posterior. Sensitivity encoding was used for PI technique. Motion probing gradient was applied to the frequency, phase, and slice direction in both sequences.

Table 1: The summary of imaging parameters of TSE-DWI

<table>
<thead>
<tr>
<th>Acceleration factor</th>
<th>1.0</th>
<th>2.0</th>
<th>3.0</th>
<th>4.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>TR ( ms )</td>
<td>10204</td>
<td>8974</td>
<td>8587</td>
<td>8330</td>
</tr>
<tr>
<td>TE ( ms )</td>
<td>100</td>
<td>73</td>
<td>66</td>
<td>58</td>
</tr>
<tr>
<td>Shot duration ( ms )</td>
<td>324</td>
<td>162</td>
<td>114</td>
<td>83</td>
</tr>
<tr>
<td>Acquisition time (s)</td>
<td>204</td>
<td>179</td>
<td>172</td>
<td>167</td>
</tr>
<tr>
<td>Band width(Hz / pixel)</td>
<td>762.9</td>
<td>715.4</td>
<td>707.6</td>
<td>762.9</td>
</tr>
</tbody>
</table>

* TR : repetition time, TE : echo time

Phantom preparation for the SNR and ADC evaluation (DWI-phantom)
DWI-phantom was used for evaluation of SNR and ADC values. DWI-phantom was made from commercially available granulated sugar and agar. The plastic hemispherical compartment with 200-mm diameter was filled with 1.42 w/v% agar gel (Fig. 1). Four plastic compartments with 20 mm-diameter in the phantom center were filled with the 1.42 w/v% agar and 7.14 w/v%, 14.2 w/v%, 28.5 w/v%, and 42.8 w/v% granulated sugar, respectively. The concentration of granulated sugar was determined to simulate intracranial brain lesions with various ADC values [6]. As shown in Table 2, the T2 values of background and 4 compartments are similar to those of the brain parenchyma [7]. The phantom was scanned with the room temperature (21.0 °C) and it was placed close to the posterior surface of the head coil like a clinical examination.

Table 2: T1 and T2 values of the DWI-phantom

<table>
<thead>
<tr>
<th></th>
<th>T1 ( ms )</th>
<th>T2 ( ms )</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.G</td>
<td>2701</td>
<td>92</td>
</tr>
<tr>
<td>Comp 1</td>
<td>2142</td>
<td>72</td>
</tr>
<tr>
<td>Comp 2</td>
<td>1576</td>
<td>66</td>
</tr>
<tr>
<td>Comp 3</td>
<td>948</td>
<td>67</td>
</tr>
<tr>
<td>Comp 4</td>
<td>523</td>
<td>65</td>
</tr>
</tbody>
</table>

* B.G: Background, Comp: compartment

Signal-to-noise ratio (SNR)

The SNR was calculated by using subtraction method in which two images with identical parameters were used [8]. The SNRs were calculated by the equation as follows:

$$\text{SNR} = \frac{\#2 \cdot S}{\#} \quad (1).$$

Where, S is the mean signal value of the two images and # is the standard deviation. S and # was derived from the same region of interest (ROI) on the signal and subtracted images. The SNRs were calculated from TSE-DW images with b = 1000 s / mm$^2$.

Image blur

A pin phantom (90-401 type, Nikko. Fines, Tokyo, Japan) was used for evaluate of the image blur. The diameter and interval of the pins are 0.5, 0.75, 1.0, and 2.0 mm, respectively as shown in Fig 2. The arrangement of the pin pattern with the same size is orthogonal each other. One of the pin patterns corresponds to the phase encoding direction and the other corresponds to the frequency encoding direction. The pin pattern images of TSE-DWI were obtained when varying the AFs of 1 to 4.
ADC values

ADC values of each sequence were calculated by using two-point techniques, which is described as below;

\[
ADC = \frac{\# \ln(SI(b) / SI(b_0))}{(b - b_0)} \tag{2}
\]

Where, SI (b) and SI (b₀) were the signal intensities with b = 1000 and b = 0 s / mm², respectively. ADC values were measured on TSE-DW images with AF of 1 to 4 and EPI-DW images. A coefficient of variance (CV) was used for evaluation of the repeatability of ADC values obtained from different acquisition techniques.

Image analysis

Image analysis was performed by using ImageJ 1.45 image-processing software (National Institutes of Health, Bethesda, MD, USA) and magnitude images were recorded in the Digital Imaging and Communications in Medicine (DICOM) format. 45-pixel radius circular ROIs were placed on the center of the each compartment and background region for the calculation of the SNR and ADC values.
Fig. 1: The photograph (left) and T2WI image (right) of DWI-phantom. The hemispherical plastic bottle was filled with 1.42 w/v % agar gel. Four compartments were filled with 1.42 w/v% agar gel contained several concentrations of granulated sugar. The concentrations of granulated sugar of compartment 1, 2, 3, and 4 corresponded to 7.14 w/v% , 14.2 w/v% , 28.5 w/v% , and 42.8 w/v% , respectively.

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**Fig. 2:** T2WI axial image of the pin pattern phantom. The image was obtained with T2 weighted turbo spin echo sequence. The diameters and intervals of each pin pattern were 0.50, 0.75, 1.0, and 2.0 mm.

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Results

Figure 3 shows the relationship between the SNR of each compartment and AFs. The SNRs of all compartments and background decreased as the AF increasing.

Figure 4 shows the pin pattern images of TSE-DWI obtained with AFs of 1 to 4. The pin patterns of 1.0 mm or less in the both frequency and phase direction were not separated in the all images. The pin pattern of 2.0 mm in the frequency direction was separated but that in the phase direction was not separated when the AF of 1 was set.

Figure 5 shows the images of TSE-DWI with $b = 0$ and $b = 1000$. Signal intensity of the compartments were high in the TSE-DWI image with $b = 1000$ as the concentration of granulated sugar was high.

Figure 6 shows the ADC maps calculated from TSE- and EPI-DWI. Table 3 shows the mean and standard deviation of the ADC values obtained with both sequences. The ADC values of TSE-DWI had tendency to decrease compared to those of EPI-DWI, regardless of the selected AFs. The ADC values of each compartment were varied with the AF but those of compartment3 were similar regardless of the AFs. The CVs of the ADC values were shown in Table 4. The repeatability of the ADC values was good at both sequences. The CVs were less 1.0% in TSE-DWI and less 1.6% in EPI-DWI.

Table 3: ADC values of EPI- and TSE-DWI

<table>
<thead>
<tr>
<th>B.G</th>
<th>Comp 1</th>
<th>Comp 2</th>
<th>Comp 3</th>
<th>Comp 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ADC values ($\times 10^{-3}$ mm$^2$/s)</td>
<td>ADC values ($\times 10^{-3}$ mm$^2$/s)</td>
<td>ADC values ($\times 10^{-3}$ mm$^2$/s)</td>
<td>ADC values ($\times 10^{-3}$ mm$^2$/s)</td>
</tr>
<tr>
<td>TSE-DWI</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AF1</td>
<td>1.97 ± 0.008</td>
<td>1.68 ± 0.005</td>
<td>1.31 ± 0.008</td>
<td>0.932 ± 0.004</td>
</tr>
<tr>
<td>AF2</td>
<td>1.85 ± 0.004</td>
<td>1.59 ± 0.005</td>
<td>1.32 ± 0.004</td>
<td>0.943 ± 0.004</td>
</tr>
<tr>
<td>AF3</td>
<td>1.82 ± 0.009</td>
<td>1.58 ± 0.005</td>
<td>1.29 ± 0.004</td>
<td>0.903 ± 0.003</td>
</tr>
<tr>
<td>AF4</td>
<td>1.75 ± 0.015</td>
<td>1.59 ± 0.006</td>
<td>1.29 ± 0.009</td>
<td>0.983 ± 0.005</td>
</tr>
<tr>
<td>EPI-DWI</td>
<td>1.92 ± 0.005</td>
<td>1.70 ± 0.005</td>
<td>1.43 ± 0.005</td>
<td>1.04 ± 0.015</td>
</tr>
</tbody>
</table>

* ADC values were mean and standard deviation.
Table 4: Coefficient of variation (CV) of ADC values

<table>
<thead>
<tr>
<th></th>
<th>B.G</th>
<th>Comp 1</th>
<th>Comp 2</th>
<th>Comp 3</th>
<th>Comp 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSE-DWI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AF1</td>
<td>0.384</td>
<td>0.287</td>
<td>0.569</td>
<td>0.418</td>
<td>0.627</td>
</tr>
<tr>
<td>AF2</td>
<td>0.220</td>
<td>0.305</td>
<td>0.265</td>
<td>0.417</td>
<td>0.841</td>
</tr>
<tr>
<td>AF3</td>
<td>0.511</td>
<td>0.299</td>
<td>0.339</td>
<td>0.332</td>
<td>0.571</td>
</tr>
<tr>
<td>AF4</td>
<td>0.878</td>
<td>0.396</td>
<td>0.664</td>
<td>0.506</td>
<td>0.971</td>
</tr>
<tr>
<td>EPI-DWI</td>
<td>0.271</td>
<td>0.315</td>
<td>0.368</td>
<td>1.41</td>
<td>1.55</td>
</tr>
</tbody>
</table>

*CVs were calculated from 5 measurements for each sequence.*
Fig. 3: The SNR of background and each compartment as a function of AFs. Each symbol represented the mean SNR value.

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Fig. 4: The pin phantom images (upper row) and magnitude images (lower row). The pin pattern in the traverse direction and longitudinal direction corresponded to the phase encoding direction and frequency direction, respectively.

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Fig. 5: The images of TSE-DWI obtained with various AFs. The upper and lower rows showed the images acquired with $b = 0$ (mm$^2$/s) and $b = 1000$, respectively. The same window level and window width were selected to compare images.

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**Fig. 6:** The ADC maps of the DWI-phantom (a-d, TSE-DWI with AF1 to 4; e, EPI-DWI). All ADC maps were calculated with the image of $b = 0$, and $b = 1000$ (mm$^2$/s). The same window level and window width were selected to compare images.

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Conclusion

The SNR of TSE-DWI showed the highest value when the AF set to 1. In this study, the AF of 1 provides the longest TE value compared to the other AFs. However, the high AF not only shortens the TE value but also increases g-factor, which is the noise amplification related to the parallel imaging reconstruction [9]. Therefore, these results suggest that the increase in the g-factors of the coil has a significant influence on the SNR of TSE-DWI than the decrease in TE value.

Generally, spatial resolution in magnetic resonance imaging is determined by the pixel size, which is calculated by dividing FOV by acquisition matrix. Therefore, the pin pattern of 1.0 mm or less is not distinguished in all images. With regard to the pin pattern of 2.0 mm, image blur in the phase encoding direction increased when the AF was set to 1. This result suggests that the low AF prolongs the shot duration and the long shot duration causes blur due to T₂ decay in the phase encoding direction.

ADC values obtained with TSE-DWI were lower than those obtained with EPI-DWI. The result suggests that the ADC values are different among the acquisition techniques and is consistent with the previous reports [10, 11]. The repeatability of the ADC values is good at both sequences as shown in a previous report [2]. Contrary to our expectation, the CVs of EPI are small because the homogeneity phantom is used.
Personal information

Tsukasa Yoshida is a Radiological Technologist (R. T.) at the Department of Diagnostic Imaging, Shizuoka Cancer Center Hospital.
References


