Optimum Spatial Resolution and Number of Averages of Diffusion Tensor Imaging in Prostate Cancer Detection

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Abstract
This study aimed to investigate the diagnostic performance of trace apparent diffusion coefficient (tADC) maps in prostate cancer (PCA) detection at different spatial resolutions and number of averages (NAV), and to determine a practical protocol that could provide satisfactory diagnostic performance for PCA detection. The tADC maps were reconstructed into three different isotropic resolutions, i.e. 1 mm, 2 mm and 3 mm. For each resolution there were three different NAVs, i.e. 2, 4, and 6 averages. The diagnostic performance of tADC maps for each data set was determined by comparing with the TRUS biopsy results core by core. We found that the voxel size of (2 mm)³ with two number of averages showed satisfactory diagnostic performance. Acquisition time for this protocol was around 4 to 5 minutes and could be a practical tool for PCA detection.

Introduction
Magnetic resonance (MR) diffusion imaging has been applied to the detection of prostate cancer [1]. Recently we have shown that trace apparent diffusion coefficient (tADC) value was significantly lower in prostate cancer (PCA) than that in normal peripheral zone tissue, and that 1-mm isotropic tADC maps were feasible for PCA detection [2]. To obtain tADC maps at 1-mm isotropic resolution, however, requires multiple averages to attain sufficient SNR, inevitably prolonging the scanning time. In this study, nine combinations of image resolution and number of averages of diffusion-weighted images (DWI) were investigated. By comparing with transrectal ultrasound guided (TRUS) biopsy results, we aimed to determine a practical protocol that could provide satisfactory diagnostic performance for PCA detection.

Materials and Methods
Fifteen male patients (57-74 years; average, 63 years; median, 63 years) with elevated prostate specific antigen (PSA, mean: 9.7 ng/ml) were recruited. They received endorectal MRI study followed by TRUS biopsy within one month. MR images were acquired on a 1.5T scanner (GE, Echo Speed, Milwaukee, WI, USA). Diffusion tensor imaging (DTI) was acquired using spin-echo echo planar imaging (EPI) with multiple transaxial slices of the prostate from base to apex. Imaging parameters: TR/TE = 1700/79 ms; slice thickness = 1mm; slice gap = 0; in-plane resolution = 1mm × 1mm; six diffusion-sensitive gradients at ±1.0, 1, [±1.0,1], [±1.0,1], [±1.0,1] with b = 500 s mm⁻²; number of averages (NAV) = 6. The acquired DWI images were reconstructed into three different isotropic resolutions, i.e. 1 mm, 2 mm and 3 mm. For each resolution there were three different NAVs, i.e. 2, 4, and 6 averages. The DWI data sets were entitled as D₁, D₂, D₃, D₄, D₅, D₆, D₇, D₈, and D₉, where Dᵢ represented the data set with isotropic resolution = i mm and NAV = j. TRUS biopsy was performed by sampling 12 cores systematically in the prostate gland, from right lateral, right medial, left medial to left lateral aspects at three levels at base, mid and apex. For image analysis, the peripheral zone of the prostate was identified and categorized into 12 regions as those in the TRUS biopsy. Trace ADC was determined by calculating the mean of the eigenvalues of the diffusion tensor. According to our previous work, a tADC value of 1.0 μm²/ms rendered from 9 data sets of DWI with different combinations of spatial resolution and number of averages {±1,0,1}, {0,1,±1},{±1,1,0} with b = 500 s mm⁻² represented the data set with isotropic resolution = i mm and NAV = j. TRUS biopsy was performed by sampling 12 cores systematically in the prostate gland, from right lateral, right medial, left medial to left lateral aspects at three levels at base, mid and apex. For image analysis, the peripheral zone of the prostate was identified and categorized into 12 regions as those in the TRUS biopsy. Trace ADC was determined by calculating the mean of the eigenvalues of the diffusion tensor. According to our previous work, a tADC value of 1.0 μm²/ms was used as a threshold for PCA detection [2]. The diagnostic performance of tADC maps for each data set was determined by comparing with the TRUS biopsy results core by core.

Results
In a total of 180 cores, 39 cores in 7 patients were found to contain PCA in pathological results. Figure 1 shows tADC maps of one patient derived from 9 DWI data sets. The positive nodules (indicated by arrows) are those detected based on tADC < 1.0 μm²/ms rendered from 9 data sets of DWI with different combinations of spatial resolution and number of averages.

Discussion and Conclusions
In this study, we have compared diagnostic performance of PCA detection among nine DWI data sets with different combinations of image quality, three spatial resolutions and three NAVs. From Fig. 1, the tADC positive nodules decrease with the voxel sizes. This can be explained by the partial volume effect. Increased NAV could reduce the number of positive nodules on tADC maps especially at 1-mm resolution. High NAV used at 1-mm resolution, however, would prolong the acquisition time and lead to higher failure rate and more motion artifacts. Comparing with the TRUS biopsy results (Table 1), we can see that as NAV increases, false positive nodules decrease but false negative nodules increase. Although the data set at 3-mm resolution has better signal-to-noise ratio, it does not help in increasing the sensitivity under the condition of inadequate spatial resolution. To conclude, higher NAV yields higher specificity whereas smaller voxel sizes yield higher sensitivity. In this study, the voxel size of (2 mm)³ with two number of averages showed satisfactory diagnostic performance. This protocol only requires 4–5 minutes acquisition time and could serve as a practical tool for PCA detection.

Table 1 The results of 9 imaging resolution levels using tADC value of 1.0 μm²/ms.

<table>
<thead>
<tr>
<th>Resolution</th>
<th>True positive</th>
<th>False positive</th>
<th>False negative</th>
<th>True negative</th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
<th>Accuracy</th>
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<td>86</td>
<td>100%</td>
<td>61%</td>
<td>41%</td>
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<td>69%</td>
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<td>72%</td>
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<tr>
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<td>81%</td>
<td>59%</td>
<td>98%</td>
<td>84%</td>
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<tr>
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</tbody>
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Fig.1 Positive nodules (yellow arrows) with quantitative tADC value of less than 1.0 μm²/ms rendered from 9 data sets of DWI with different combinations of spatial resolution and number of averages.

References
2. Chen YJ et al. Prostate Cancer Detection in Patients with Intermediate Prostate Specific Antigen Level Using Combined Trace Apparent Diffusion Coefficient and Nodular Size: Comparison with Transrectal Core Biopsy. ISMRM 2006;2930.