Diffusion tensor imaging of the lumbar spine with SSFSE at 1.5 T and 3 T

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Introduction

Diffusion tensor imaging (DTI) is a non-invasive technique that permits in vivo measurement of the self diffusion of water molecules. Line scan diffusion imaging (LSDI) has demonstrated the clinical value of DTI in the spine [1]. However, its long scan time prevents the frequent use of this technique in a clinical setting. DTI with single shot fast spin echo (SSFSE) has the potential of providing quantitative DTI in-vivo images in a shorter period of time, thus making spine DTI a more clinically feasible application. The purpose of this study was to show the feasibility of DTI-SSFSE [2] in the lumbar spine at 1.5 T and 3 T. The validation of the technique at 1.5 T was performed by a statistical comparison to DTI-LSDI [3], which has been previously validated [1]. The validation of DTI-SSFSE measurements at 3 T was based on the DTI-SSFSE data at 1.5 T.

Materials and Methods

Sagittal MR images of the lumbar spine of 6 healthy volunteers were obtained at 1.5 T (Signa scanner; GE Medical Systems, Milwaukee, WI) using a phased array CTL spine coil. Subjects were placed supine in the MR scanner and DTI-SSFSE and DTI-LSDI images were acquired with the following parameters for 8 b values equally spaced from 225 s/mm^2 to 995 s/mm^2: DTI-SSFSE consisted of a matrix of 128 x 128 Freq x Phase, Phase FOV of 1, and 4 NEX for a total of 6 slices in 2'20" per b value. DTI-LSDI images consisted of a matrix of 256 x 128 Freq x Columns, Phase FOV of 0.5, and 1 NEX for a total of 1 slice in approximately 1'7" per b value. All images were acquired with a FOV of 30 cm, 5 mm slice thickness, and reconstructed to a matrix of 256 x 256 for a final in-plane resolution of 1.1719 mm (Fig. 1). Sagittal MR images of the lumbar spine of 3 of the subjects imaged at 1.5 T were also obtained at 3 T on a GE scanner using a phased-array torso coil. Subjects were placed supine in the MR scanner and DTI-SSFSE images were acquired with the following parameters: matrix of 256 x 128 Freq x Phase, Phase FOV of 0.7, FOV of 30 cm, 5 mm slice thickness, 4 NEX, and reconstructed to a matrix of 256 x 256 for a final in-plane resolution of 1.1719 mm (Fig. 1). All images at 3T were acquired for b values of 445 s/mm^2, 665 s/mm^2 and 995 s/mm^2. Images were transferred to a workstation and processed and analyzed with software written in MATLAB (The Mathworks, Inc. Natick, MA). Images were smoothed prior to tensor calculation as suggested in [4] with the anisotropic diffusion algorithm [5] (λ = 0.25, K = 95, 1 iteration) and the tensor was calculated as described in [6]. Maps of the rotationally-invariant apparent diffusion coefficient (ADC) were calculated and ROI's were drawn on the intervertebral discs (nucleus pulposus) and vertebral bodies to obtain average values of ADC's per subject per b value (Fig. 1). To validate the DTI-SSFSE at 1.5 T, the Pearson correlation coefficient (r) was obtained to get an initial estimate of the agreement with DTI-LSDI, and then the Bland-Altman method was used to perform the statistical comparison. Once the validation of DTI-SSFSE was established at 1.5 T, the validation at 3 T was performed in a similar fashion based on the DTI-SSFSE data at 1.5 T.

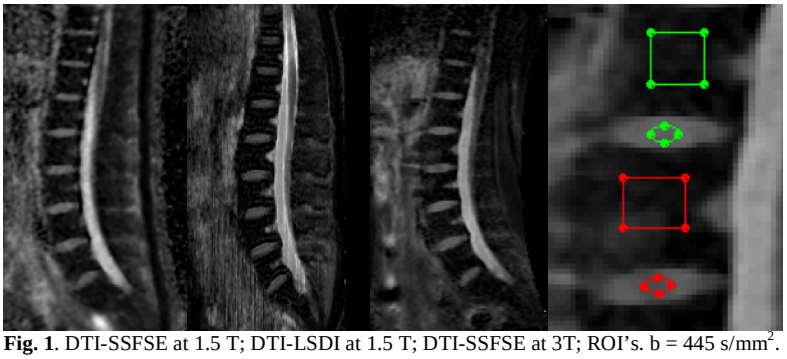

Fig. 1. DTI-SSFSE at 1.5 T; DTI-LSDI at 1.5 T; DTI-SSFSE at 3T; ROI's. b = 445 s/mm^2.

Results

Table 1 summarizes the results for the comparison of DTI-SSFSE at 1.5 T to DTI-LSDI at 1.5 T and DTI-SSFSE at 3 T, whilst Fig. 2 visually shows a subset of these results. In the statistical analysis (Bland Altman method) of the intervertebral discs at 1.5 T (DTI-SSFSE vs DTI-LSDI), only two points (both at b = 225 s/mm^2) out of 48 (6 subjects x 8 b values) were out of the range of 2 standard deviations (SD) above and below the mean difference of ADCs, suggesting good quantitative agreement between the 2 techniques. Higher mean ADC values with DTI-SSFSE at 1.5 T were consistently observed for the intervertebral discs and the vertebral bodies in 81.25% and 79.16% occasions, respectively. However this difference was not significant as demonstrated by the Bland Altman method analysis. For the vertebral bodies comparison only 2 points (b = 225 s/mm^2 and b = 335 s/mm^2) out of 48 were out of the range of 2SD above and below the mean difference of ADC's, again suggesting good quantitative agreement. For the comparison at 3 T (DTI-SSFSE vs DTI-SSFSE) there were no points out of the 2 SD range for the intervertebral discs analysis, and only 1 point (b = 665 s/mm^2) out of 9 (3 subjects x 3 b values) was out of this range in the vertebral bodies case, which showed good preliminary results. In general, although the Pearson correlation coefficient was low (Table 1), the Bland Altman method showed a good quantitative agreement for all comparisons.

Table 1.	**Comparison of DTI-SSFSE at 1.5 T to DTI-:**	
	LSDI 1.5 T (n=6)	**SSFSE 3 T (n=3)**
Intervertebral discs		
r	0.723	0.832
Mean of differences	113.188 x 10^{-6} mm^2/s	118.016 x 10^{-6} mm^2/s
SD of differences	140. 774 x 10^{-6} mm^2/s	99.096 x 10^{-6} mm^2/s
Vertebral bodies		
r	0.635	0.662
Mean of differences	70.434 x 10^{-6} mm^2/s	53.744 x 10^{-6} mm^2/s
SD of differences	81.494 x 10^{-6} mm^2/s	62.900 x 10^{-6} mm^2/s

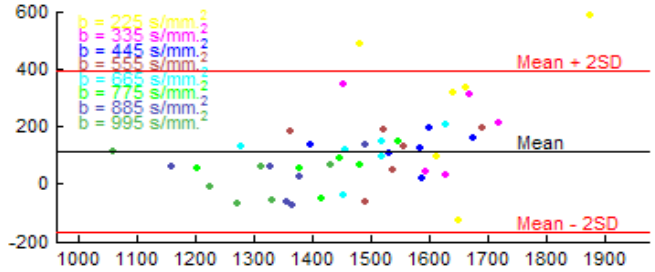

Fig 2. Difference of ADC's [mm^2/s] against means of ADC's [mm^2/s] of intervertebral discs for DTI-SSFSE and DTI-LSDI at 1.5 T.

Conclusions

In this work we have demonstrated the feasibility of DTI-SSFSE as an alternative fast DTI technique for the lumbar spine at 1.5 T and 3 T. This offers more opportunities to perform clinical DTI studies due to the fact that SSFSE is widely available and significantly faster for multiple slice acquisitions than LSDI.

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Acknowledgments This work was supported by NIA-RO1-AG17762.