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Quantitative evaluation of diffusion tensor imaging at 3T in human lumbar intervertebral disc degeneration

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Introduction: Detecting early disc degeneration is of vital importance in order to identify patients with degenerative disc disease (DDD) who are suitable for treatment, as new therapies for DDD are most efficacious in early stages of disc degeneration. However, conventional T2-weighted (T2W) imaging is not sensitive to differences in the disc until morphologic changes are demonstrated. Furthermore, the classification of a disc to one scale or another is not completely objective or perfectly reliable. Therefore, a quantitative assessment of disc degeneration would be a significant improvement in the evaluation of DDD in human intervertebral discs (IVDs). Diffusion, measured as the apparent diffusion coefficient (ADC), is an in vivo technique presently capable of measuring diffusion directly from molecular displacement. It has been shown that the ADC decreases in degenerated discs and that it correlates in a direction dependent manner with disc water and disc matrix integrity [1]. However, there still remain concerns that ADC is not really quantitative, as it only characterizes a single scalar coefficient and is clearly dependent on the choice of directions made for the measurements. Invariant indices are thus required to avoid such biases and provide objective and intrinsic structural information. Diffusion tensor imaging (DTI) can provide more exquisite details on tissue microstructure by fully exploiting a diffusion-driven molecular mobility through diffusion tensor computation. In this study, we performed DTI to investigate its sensitivity to changes in tissue microstructure of human lumbar IVDs, which has never been tried to our knowledge.

Materials and Methods: Twenty-one subjects (gender: 11 males and 10 females; mean age 41.3 years, age range 24-61 years) were recruited to undergo MRI scans after informed written consent was obtained. All studies were approved by the local institutional review board. One hundred and three lumbar IVDs were scanned. Each subject was imaged on a 3T Achieva scanner (Philips Healthcare, Best, The Netherlands) with SENSE spine coil. The DTI protocol was based on a single-shot spin echo (SE) echo planar imaging with the following parameters: TR/TE = 3000/ 71ms, FOV= 180 x 72mm^2, slice thickness= 5mm, acquired pixel size= 1.00 x 1.31 mm^2, reconstructed pixel size= 0.63 x 0.62 mm^2, 15 diffusion directions, and scan time= 6 min.18 sec. Conventional T2W images in identical geometry as DTI were acquired using a standard SE imaging sequence to assess degenerative grade which was classified according to Schneiderman's classification [2] by two raters. The diffusion tensor was estimated as described in Mori et al. [3]. The fractional anisotropy (FA) was derived on a pixel-by-pixel basis using DTI-Studio [4] and then grouped for each Schneiderman grade for comparison. The number of discs at each grade is displayed in table 1. Regions of interest were manually selected in the nucleus pulposus (NP) and the annulus fibrosus (AF) in order to calculate mean FA values.

Results: Figure 1 illustrates a representative T2W image covering from L2/L3 to L5/S1 levels (top to bottom) and the corresponding FA map from a 57-year-old female subject. In L4/L5 and L5/S1 with grade 0, FA value in the NP is lower than that in the AF while FA value in the NP increases in L2/L3 and L3/L4 corresponding to grades 1 and 2, respectively, where signal intensity decreases on the T2W image. Quantitative comparison of such trend is demonstrated in figure 2 where mean FA value in the AF is significantly higher ($p < 0.005$ at grade 0 to 2; $p < 0.05$ at grade 3, using two-tailed student's t-test) than that in the NP. Furthermore, it is observed that mean FA value in the NP increases as the degeneration of IVDs becomes more severe while mean FA value in the AF remains unchanged. Table 1 summarizes the mean and the standard deviation (SD) of FA values, showing the mean FA value at grade 0 is significantly lower than that at grade > 0 ($p < 0.005$) in the NP.

Discussion: To our best knowledge, this is the first report on FA measurement for in vivo human IVDs. The high FA value measured in the AF correlates with the well-organized fibrous collagen structure of the AF [5, 6] while the less structured gelatinous core of the NP [7] is reflected by the low FA values. Interestingly, the increased FA in the NP contrary to unchanged FA in the AF of degenerated discs may indicate different degenerative-related changes taking place in the NP and the AF which are not limited to reflect the morphologic changes seen in T2W images. In conclusion, our results show that FA can quantitatively assess 1) structural difference between the NP and the AF and 2) degenerative changes in human lumbar IVDs, especially in the NP. Therefore, by adding the quantitative capability of DTI to the existing clinical methods it may be possible to develop a better understanding of the early progression of DDD, and thus to more objectively evaluate the effect of therapeutic intervention.

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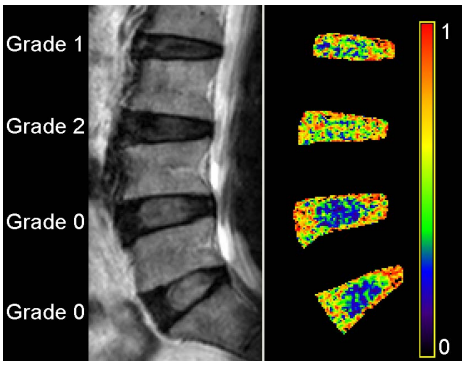

Figure 1. DDD grades classified on T2W image (left) and the corresponding FA map (right) covering from L2/L3 to L5/S1.

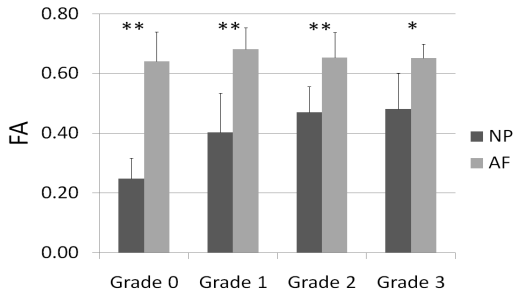

Figure 2. Mean FA values and SD of the NP and AF with different grades, showing an increase in FA in the NP with degeneration. Significant differences between groups are indicated by * $p < 0.05$ and ** $p < 0.005$.

Grade	# of Discs	FA in NP (SD)
0	69	0.25 (0.07)
1	17	0.40 (0.13)
2	10	0.47 (0.09)
3	7	0.48 (0.12)

Table 1. Distribution of IVDs and mean FA values at different grades.