Quantitative In-Vivo Assessment of Intervertebral Disc Degeneration in Lumbar Spine using ADC Measurements

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Purpose:

An in-vivo assessment of the degree of disc degeneration is increasingly relying on the use of MRI more than any other imaging modalities. Implementation of a morphologic grading system such as Pfirrmann's [1] added to the value of MRI by allowing a standardized assessment of IVD degeneration based on T2w imaging. Although found to be reliable [2] and useful, especially in clinical setting, any such grading system is qualitative in nature and ultimately subject to the reader. Moreover, a limited number of grade categories that must be employed in such system (e.g., 5-level grades for Pfirrmann's) inevitably yields a certain range in levels of disc-degeneration to be present in each such category. Measurement of apparent diffusion coefficient (ADC) of IVD via diffusion-weighted MRI (DWI) has been evaluated for its potential role in quantitative assessment of disc-degeneration in vivo by a few investigators previously in conjunction with such grade categories [3-5]. Although promising in results, its role was still somewhat questioned, mainly due to a typically large variation and overlap observed in ADC values when their group-mean values are compared between discs in different degeneration categories. This can be partly attributed to the aforementioned limitation in morphology-based grading system. Presented here is a preliminary result in which we investigated the potential of ADC measurement as means of quantitative assessment of disc-degeneration in vivo via a comparison with classification that uses a combination of Pfirrmann grades and the signal-intensity ratio of disc to CSF in T2w image.

Methods:

The results from 9 volunteers (6-males and 3-females) with no history of back injuries are included here (range: 27–62 yrs). Each subject was scanned on a 3T Philips scanner with Philips' CTL-spine RF-coil (Philips Medical Systems, Best, Netherlands) for 15-sagittally-sliced T2w (TR/TE=5000/120 ms) and DWI. The DWI was based on a single-shot EPI (FOV/thickness=310/3mm, TR/TE=4000/66ms, acquisition-matrix=128x129 (192x192 image-matrix)), and performed with two b factors (b=0 and 600 sec/mm^2) in each of the three orthogonal directions for generation of a rotationally invariant ADC-map (ADC-trace) in identical geometry as that of the T2w. The ROI for the whole IVD was drawn manually on the T2w images (Fig. 1: shown in red) and then overlaid onto the corresponding DWI images for ADC calculation based on the ROI-averaged DWI signal intensities for each IVD as well as for analyses based on the ADC-map (results not shown). Another ROI (Fig. 1: shown in blue) was drawn in the free CSF between the L2 and L4 vertebral levels to determine the ratio between the disc and CSF (IVD/CSF ratio) in the mid-sagittal T2w image. Each Pfirrmann grade was ranked into 10 separate sub-grades based on the range of ratios of the discs belonging to that particular Pfirrmann grade (e.g., 1.6, 1.7.., 2.5 sub-grades, whereby 1.6 is for the highest and 2.5 for the lowest IVD/CSF ratio in Pfirrmann grade II).

Figure 1

Results:

The numbers of discs in each Pfirrmann grade are summarized along with the group-mean ADC values in the table below. Fig. 2 below show the mid-sagittal T2w image and the corresponding ADC maps for six of the subjects. The Pfirrmann grade for each of the lumbar discs is also shown in the figure. The top figure of Fig. 3 shows the distribution of IVD/CSF ratios with respect to the re-ranked grades (Pfirrmann$^+$). The bottom figure of Fig. 3 shows the distribution of ADC values with respect to the Pfirrmann$^+$ grades.

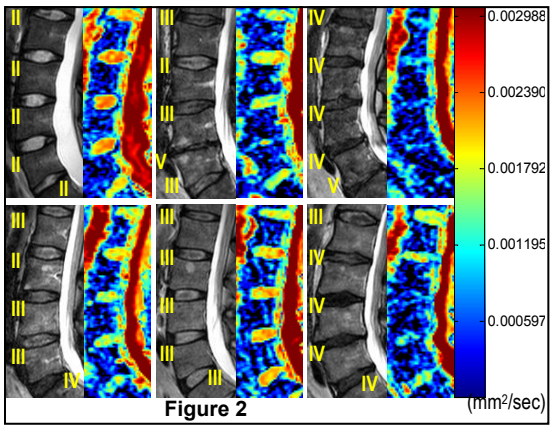
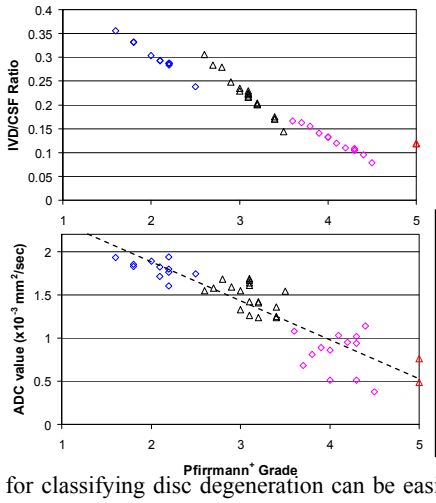


Figure 2



Pfirrmann grade	# of discs	ADC (x10^{-3} mm^2/s) (mean±SD)
I	0	N.A.
II	11	1.81±0.10
III	19	1.48±0.16
IV	13	0.83±0.24
V	2	0.63±0.19

Figure 3 (left, top & bottom): Blue, black, pink, and red symbols represent the discs classified into Pfirrmann grade-II, -III, -IV, and –V, respectively.
Figure 3 (left, bottom): The dashed line represents the fitted correlation between ADC values and Pfirrmann$^+$ grades using Spearman statistics.
(Spearman's ρ = -0.93, p = 1.1 x 10^{-19})

Conclusions:

The difficult nature of applying Pfirrmann's grades for classifying disc degeneration can be easily seen in some of the cases shown in Fig. 2: mainly, an ambiguity between grades (e.g., grade-II and –III) and also a questionable validity in any singular category describing all of the degenerative states of discs classified into that particular grade. Use of IVD/CSF ratio allowed one of the 3 criteria utilized during Pfirrmann grading (disc signal, morphology, height) to be performed in a more quantitative manner, providing a means for the discs in each Pfirrmann grade to be further separated and then correlated with their ADC values. Despite a small number of subjects sampled, a strong correlation was clearly evident between the resulted degenerative grades and ADC values. As different properties and characteristics in degenerative process of IVD are represented in its T2w and DWI, it is very likely that morphologic grading system based on T2w and measurement of ADC serve complementary roles in in-vivo assessment of disc degeneration and calls for further investigation.

References: [1] Pfirrmann et al. Spine 2001; 26:1873-8. [2] Wilke et al. Eur Spine J 2006; 15: 720-30. [3] Kealey et al. Radiology 2005; 235:569-74. [4] Beattie et al. J Orthop Sports Phys Ther 2008; 38:42-9. [5] Niinimäki et al. Magn Reson Imag 2009; 27:641-7.

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