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SCIENTIFIC ARTICLE

Parametric T2 and T2* mapping techniques to visualize intervertebral disc degeneration in patients with low back pain: initial results on the clinical use of 3.0 Tesla MRI

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Abstract
Objective To assess, compare and correlate quantitative T2 and T2* relaxation time measurements of intervertebral discs (IVDs) in patients suffering from low back pain, with respect to the IVD degeneration as assessed by the morphological Pfirrmann Score. Special focus was on the spatial variation of T2 and T2* between the annulus fibrosus (AF) and the nucleus pulposus (NP).
Materials and Methods Thirty patients (mean age: 38.1 ± 9.1 years; 20 female, 10 male) suffering from low back pain were included. Morphological (sagittal T1-FSE, sagittal and axial T2-FSE) and biochemical (sagittal T2- and T2* mapping) MRI was performed at 3 Tesla covering IVDs L1–L2 to L5–S1. All IVDs were morphologically classified using the Pfirrmann score. Region-of-interest (ROI) analysis was performed on midsagittal T2 and T2* maps at five ROIs from anterior to posterior to obtain information on spatial variation between the AF and the NP. Statistical analysis-of-variance and Pearson correlation was performed.
Results The spatial variation as an increase in T2 and T2* values from the AF to the NP was highest at Pfirmann grade I and declined at higher Pfirmann grades II–IV ($p < 0.05$). With increased IVD degeneration, T2 and T2* revealed a clear differences in the NP, whereas T2* was additionally able to depict changes in the posterior AF. Correlation between T2 and T2* showed a medium Pearson's correlation (0.210 to 0.356 [$p < 0.001$]).
Conclusion The clear differentiation of IVD degeneration and the possible quantification by means of T2 and fast T2* mapping may provide a new tool for follow-up therapy protocols in patients with low back pain.

Keywords Intervertebral disc · T2 mapping · T2* mapping · MRI · Pfirrmann score

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Introduction

Low back pain (LBP) and other spinal impairments are the most common reasons for limitation of activity in patients below the age of 45 years. The lifetime prevalence of LBP is 70–80%; approximately 18% of the population is suffering from LBP at any time [1]. Although the pathophysiological correlations between pain and disc degeneration are not fully understood, degenerative inter-

vertebral disc (IVD) disease is regarded as the most prevalent cause of low back pain.

Morphological magnetic resonance imaging (MRI) is a well-established method for the evaluation of IVDs, allowing for a grading of disc degeneration as assessed by the widely accepted Pfirrmann score [2]. Axial and sagittal T1- and T2-weighted sequences are standard diagnostic methods; however, they are limited in detecting early signs of degeneration [3].

The use of biochemical MRI and parametric mapping techniques is becoming increasingly important. Although techniques like T2 relaxation time mapping are mainly used to assess the composition of articular cartilage [4], their use in the evaluation of the IVD is providing comparably promising results [5]. Quantitative T2 provides information about the interaction of water molecules and the collagen network within the IVD. Besides classical spin-echo-based T2 mapping, gradient-echo-based T2* mapping was recently introduced in the description of articular cartilage [6, 7]. T2* relaxation time mapping may theoretically provide valuable biochemical information on the IVD ultrastructure, to some extent close to standard quantitative T2, but with the additional benefit of three-dimensional acquisition capability together with high signal and high spatial resolution in a short scan time.

The aim of the study was to assess, compare and correlate quantitative T2 and T2* relaxation time measurements of IVDs in patients suffering from low back pain, with respect to the IVD degeneration as assessed by the morphological Pfirrmann score. Special focus was on the spatial variation of the T2 and T2* values between the annulus fibrosus and the nucleus pulposus.

Materials and methods

Patient selection

Ethics approval for this study was provided by the ethics commission of the Medical University, and written, informed consent was obtained from all patients prior to enrolment in the study.

Thirty patients (20 female, 10 male) with a mean age of 38.1±9.1 years (range 21 to 51 years), suffering from LBP were prospectively enclosed between September 2008 and April 2009. Inclusion criteria were the presence of LBP with single or recurrent episodes in the last 6 months. Exclusion criteria were a BMI>30, radicular pain, neurological deficits of the lower limb, previous spine surgery, contraindications for MRI, previous intervertebral disc herniations or other previously diagnosed abnormalities of the lumbar spine.

Image acquisition

All MR examinations were performed on a 3-Tesla MR unit (Magnetom Trio; Siemens Healthcare, Erlangen, Germany) with a gradient strength of 40 mT/m, using a dedicated eight-channel spine coil (3 T Spine Matrix Coil; Siemens Healthcare, Erlangen, Germany). Morphological and biochemical MRI was performed covering the IVDs L1–L2 to L5–S1. For morphological MRI, sagittal T1-weighted fast-spin-echo (FSE) as well as sagittal, axial and coronal T2-weighted FSE sequences were conducted (Table 1).

T2 relaxation time measurements were prepared by a multi-echo spin-echo (SE) sequence; T2* relaxation time measurements were performed by a multi-echo gradient-echo (GRE) sequence. Sequence parameters are provided in Table 1; field-of-view, pixel matrix, slice thickness and thus voxel size were kept consistent for the T2 and the T2* sequences to guarantee the same in-plane and out-of-plane resolution for better comparability. T2 and T2* relaxation times were obtained from in-line reconstructed T2 and T2* maps using a pixel-wise, mono-exponential, non-negative, least squares (NNLS) fit analysis (MapIt, Siemens Healthcare, Erlangen, Germany).

Image analysis

All image evaluations were performed by two radiologists in consensus, one with more than 6 years' experience and a special interest in musculoskeletal radiology, and one with more than 15 years' experience in musculoskeletal radiology. All IVDs were morphologically classified using the Pfirrmann score [2] on the basis of the sagittal T2-weighted morphological images. The grading of the IVDs according to Pfirrmann classifies a homogeneous, bright white disc as grade I, a heterogeneous disc, with or without horizontal bands, as grade II, a heterogeneous grey disc with normal to slightly decreased height and unclear distinction of the nucleus and the annulus as grade III, a heterogeneous grey to black disc, with a normal to moderate decrease in height and lost distinction of the nucleus and the annulus, as grade IV, and a heterogeneous black, collapsed disc as grade V.

Region-of-interest (ROI) analysis was performed on two midsagittal T2 and T2* maps at five ROIs from anterior (ROI 1) to posterior (ROI 5) to obtain information on spatial variation between the annulus fibrosus (~ROI 1 and 5) and the nucleus pulposus (~ROI 2 to ROI 4). Because there is a gradual transition from the annulus fibrosus to the nucleus pulposus, with difficulty in defining a clear border, ROIs were standardised in a reproducible way with five equally sized rectangular ROIs on the two adjacent central slices. Each ROI measured 20% of the disc diameter in the midsagittal plane to exclude partial volume effects. These different ROIs are visualised in Fig. 1. Exemplary T2 and

Table 1 Parameters of the morphological and biochemical sequences

	T1w-FSE sagittal	T2w-FSE sagittal	T2w-FSE transversal	T2w-FSE coronal	T2 mapping sagittal	T2* mapping sagittal
Repetition time (ms)	900	4,400	5,080	4,500	1,200	600
Echo time (ms)	8.3	105	94	105	13.8; 27.6; 41.4; 55.2; 69.0; 82.8	5.7; 9.8; 14.0; 18.1; 22.2; 26.4
Field of view (mm)	300×300	280×280	210×210	280×280	220×220	220×220
Pixel matrix	320×320	320×320	384×288	320×320	256×256	256×256
Voxel size (mm)	0.9×0.9×3	0.9×0.9×3	0.7×0.5×3	0.9×0.9×3	0.9×0.9×5	0.9×0.9×5
Slice thickness (mm)	3	3	3	3	5	5
Interslice gap (mm)	0.3	0.3	0.3	0.3	1	1
Number of slices	15	15	8×5	15	10	10
Echo trains/slice	111	20	18	20	–	–
Turbo factor	3	32	26	32	–	–
Acquisition time	03:23	01:34	06:16	01:36	07:45	03:52

T2* cropped maps of the lumbar spine are provided in Fig. 2. The semi-automated ROI assessment takes about 10 min per patient for the quantitative T2, and for the T2* evaluation.

To describe the T2 and T2* values with regard to the IVD degeneration, quantitative values of ROIs 1 to 5 were provided based on the Pfirrmann score of the underlying IVD. To assess the spatial variation of the T2 and T2* values, two additional evaluations were performed. For the spatial differentiation between the different ROIs (i.e. to assess and quantify the spatial variation between the annulus fibrosus and the nucleus pulposus) all ROIs (1 to 5) were compared with each other (hence ROI 1 with 2, ROI 2 with 3, ROI 3 with 4, ROI 4 with 5, ROI 1 with 5, ROI 1 with 3, ROI 3 with 5 and ROI 2 with 4). For the differentiation with regard to the Pfirrmann score, the single ROIs were compared with other ROIs based on the underlying morphological Pfirrmann score. Hence, for example, ROI 1 (Pfirrmann 1) was compared with ROI 1 (Pfirrmann 2), to ROI 1 (Pfirrmann 3), and to ROI 1 (Pfirrmann 4). This evaluation was achieved to visualise in which part of the IVD the degeneration takes place, as assessed by quantitative T2 or T2* mapping.

Statistical analysis

Statistical evaluation was performed with SPSS 17.0 (SPSS, Chicago, Illinois, USA). To account for multiple measurements within one disc univariate ANOVA with random factors and post-hoc tests according to Games–Howell was applied for the comparison based on the Pfirrmann grading. Paired two-tailed t-tests were performed to observe changes between T2 variation according to the different ROIs. Pearson correlation was furthermore performed to correlate between T2 and T2*, as well as to assess dependencies of the T2 values due to age, gender and Pfirrmann scoring. A p value less than 0.05 was seen as significant.

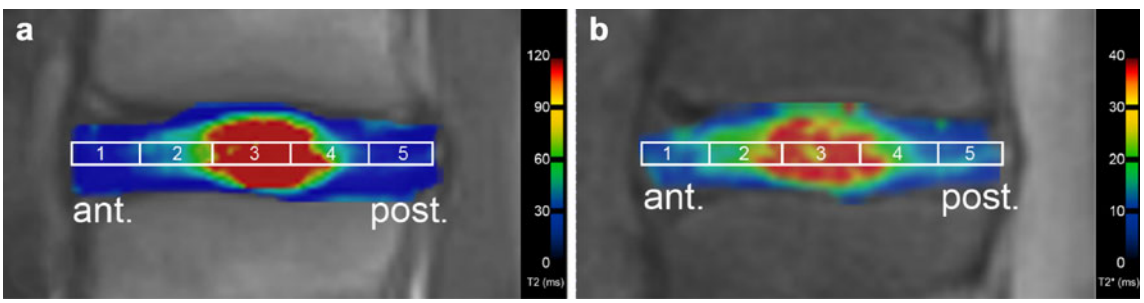

Fig. 1 Evaluation of sagittal quantitative **a** multi-echo spin-echo T2 and **b** multi-echo gradient-echo T2* values (ms) of the intervertebral disc based on a region of interest analysis from anterior (ROI 1) to posterior (ROI 5) to obtain information on spatial variation between the annulus fibrosus (~ROI 1 and 5) and the nucleus pulposus (~ROI 2 to ROI 4). Each ROI measured 20% of the disc diameter in the midsagittal plane on the basis of semi-automated segmentation

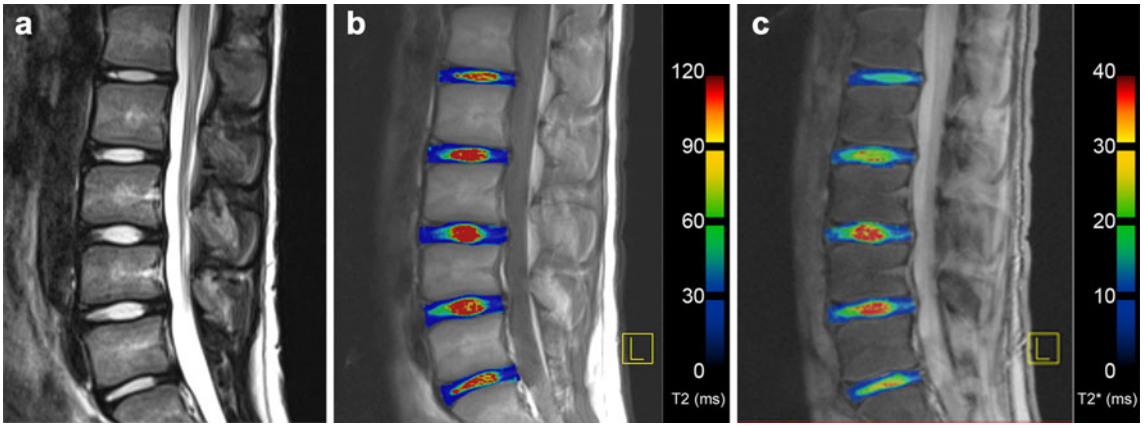

Fig. 2 Sagittal **a** T2-weighted FSE image and corresponding overlaid quantitative **b** multi-echo spin-echo T2 and **c** multi-echo gradient-echo T2* maps (midsagittal plane) of the IVDs L1/L2 to L5/S1 in one patient with low back pain. The spatial pattern as an increase from the annulus fibrosus anterior to the nucleus pulposus and the annulus fibrosus posterior becomes apparent with comparable behaviour for T2 and T2*. Based on the Pfirrmann score, L2/L3, L3/L4 and L4/L5 were graded as Pfirrmann score I, whereas L1/L2 and L5/S1 were graded as Pfirrmann score II

Results

Basic evaluations

Altogether 150 IVDs were analysed, including 1,500 ROIs for T2 and T2* with a mean pixel count of 34.2±7.1. According to the Pfirrmann score, four discs (2.7%) were classified as grade I, 96 (64.0%) as grade II, 37 (24.7%) as grade III, 13 (8.7%) as grade IV and none of the discs had a collapsed disc space (grade V).

The distribution of the T2 and T2* values with respect to the Pfirrmann grading is provided in Fig. 3 and Table 2. The T2 and T2* values are provided with respect to the anatomical localisation in the sagittal view from the anterior annulus fibrosus (~ROI 1) to the nucleus pulposus (~ROI 2 to ROI 4) to the posterior annulus fibrosus (~ROI 5).

Spatial differentiation between the ROIs

The different ROIs were statistically distinguished to assess the spatial variation between the annulus fibrosus and the nucleus pulposus as a possible sign of the integrity of the IVDs' biochemical properties. A comparison was performed between ROIs 1 and 2, ROIs 2 and 3, ROIs 3 and 4, ROIs 4 and 5, ROIs 1 and 5, ROIs 1 and 3, ROIs 3 and 5, and ROIs 2 and 4. For standard T2 relaxation times, based on this spatial pattern, the statistical differentiation between the single ROIs was comparable for Pfirrmann grades I to II. Except between ROI 3 and ROI 4 ($p=0.574$ and $p=0.518$) all ROIs could be differentiated ($p<0.05$). For Pfirrmann grade III, all ROIs showed significantly different results ($p<0.05$); whereas for Pfirrmann grade IV no differentiation was possible between ROIs 3 and 4, 2 and 4, and 3 and 5. When evaluating the results of the T2* relaxation times, a comparable pattern could be assessed. For Pfirrmann grades I to III, only ROIs 3 and 4 could not be distinguished ($p=0.164$, $p=0.0.326$ and $p=0.069$), whereas all other ROIs could be differentiated from each other ($p<0.05$). The IVDs with a diagnosed Pfirrmann grade IV, showed only a differentiation between ROIs 1 and 2 and ROIs 1 and 3 ($p<0.05$); all other ROIs could no longer be distinguished ($p\geq0.05$).

Differentiation with regard to the Pfirrmann score

The possible differentiation among the single ROIs was assessed as based on the underlying morphological Pfirrmann score. Hence, all ROI 1s were compared among Pfirrmann grades I–IV; the same was performed for ROIs 2, 3, 4 and 5. This evaluation was done to assess which anatomical part of the IVDs changes during degeneration. For standard quantitative T2, no significant differentiation could be assessed for ROI 1 with respect to the different Pfirrmann grades ($p\geq0.05$). The T2 values of ROI 2 showed no significant difference between Pfirrmann grades I and II ($p=0.393$); among all other Pfirrmann grades, the ROI 2 was significantly different. The ROIs 3 and 4 showed significant differences in their T2 values among all Pfirrmann grades ($p<0.05$). The ROI 5 only showed significant differences between Pfirrmann grades II and III and Pfirrmann grades II and IV ($p<0.05$). For the T2* evaluation, this pattern was roughly comparable to that of standard T2. No differentiation was possible among the ROIs 1 ($p\geq0.05$). The ROIs 2, 3, and 4 showed comparable behaviour, and all higher Pfirrmann grades II–IV could be distinguished ($p<0.05$) from each other. The ROI 5 showed significant differences among Pfirrmann grades 1 and 2, 1 and 3, 2 and 3, and 2 and 4 ($p<0.05$).

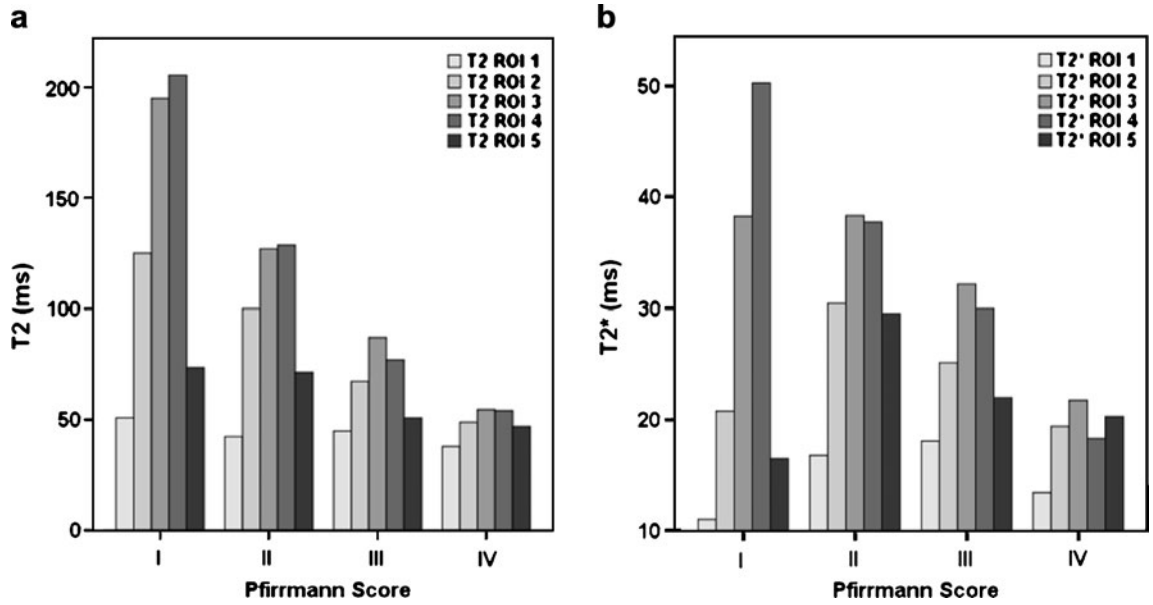

Fig. 3 The spatial pattern from the ROI 1 (annulus fibrosus anterior; *light grey*) to the ROI 5 (annulus fibrosus posterior; *dark grey*) for quantitative **a** multi-echo spin-echo T2 and **b** multi-echo gradient-echo T2* measurements according to the morphological Pfirrmann score of the underlying intervertebral disc. The differences between the annulus fibrosus and the nucleus pulposus assimilate with increasing Pfirrmann grades I to IV. Hence, the difference in quantitative T2 or T2* between the annulus fibrosus (~ROI 1 and 5) and nucleus pulposus (~ROI 2 to ROI 4) clearly reduces with increasing degeneration

Correlations

The correlation between the standard T2 evaluation and the T2* evaluation revealed a highly significant correlation ($p<0.001$) for all ROIs 1 to 5; however, with a low to moderate Pearson correlation coefficient of between 0.210 and 0.356. Correlation plots of the single ROIs (1–5) with 95% confidence intervals are shown in Fig. 4.

With respect to the gender, no significant correlation could be assessed ($p\geq0.05$).

No clear correlation was shown between the Pfirrmann score and age. However, between the Pfirrmann score and the T2 and the T2* values significant results were revealed. For quantitative T2, a significant negative correlation with the Pfirrmann score could be assessed for the ROIs 2 to 5 with medium to high correlation coefficients of between −0.409 and −0.724 ($p<0.001$). For quantitative T2*, a significant negative correlation could also be depicted for ROIs 2–5; however, only with clearly lower correlation coefficients of between −0.220 and −0.334 ($p<0.001$). The highest negative Pearson correlation coefficient could be assessed within the T2 as well as the T2* evaluation for ROI 3 and ROI 4. The correlation between the quantitative T2 and T2* evaluation and the Pfirrmann score is depicted in Fig. 5 with the respective regression lines.

Table 2 Quantitative T2 and T2* relaxation times provided as mean and standard deviation (StDv) in milliseconds

Pfirrmann score		T2 ROI 1	T2 ROI 2	T2 ROI 3	T2 ROI 4	T2 ROI 5	T2* ROI 1	T2* ROI 2	T2* ROI 3	T2* ROI 4	T2* ROI 5
I	Mean	50.8	125.0	195.0	205.5	73.5	11.0	20.8	38.3	50.3	16.5
	StDv	24.1	26.6	13.7	32.3	39.3	2.9	7.4	17.4	27.4	1.3
II	Mean	42.7	100.0	128.3	128.7	71.9	17.2	30.4	38.7	37.4	29.5
	StDv	17.9	33.1	38.9	29.9	24.6	9.8	15.7	22.4	17.5	14.3
III	Mean	44.8	67.2	86.7	76.7	50.7	18.1	25.1	32.2	30.0	22.0
	StDv	17.8	23.7	40.7	21.6	13.2	7.2	9.4	12.5	13.7	11.7
IV	Mean	38.0	48.9	54.5	54.0	46.9	13.3	19.3	21.6	19.2	20.3
	StDv	13.3	20.9	16.6	9.2	11.0	6.5	5.7	8.0	6.6	6.6

Regions-of-interest (ROI) according to the location within the intervertebral discs from the anterior annulus fibrosus (ROI 1) to the nucleus pulposus (ROIs 2–4) and the posterior annulus fibrosus (ROI 5)

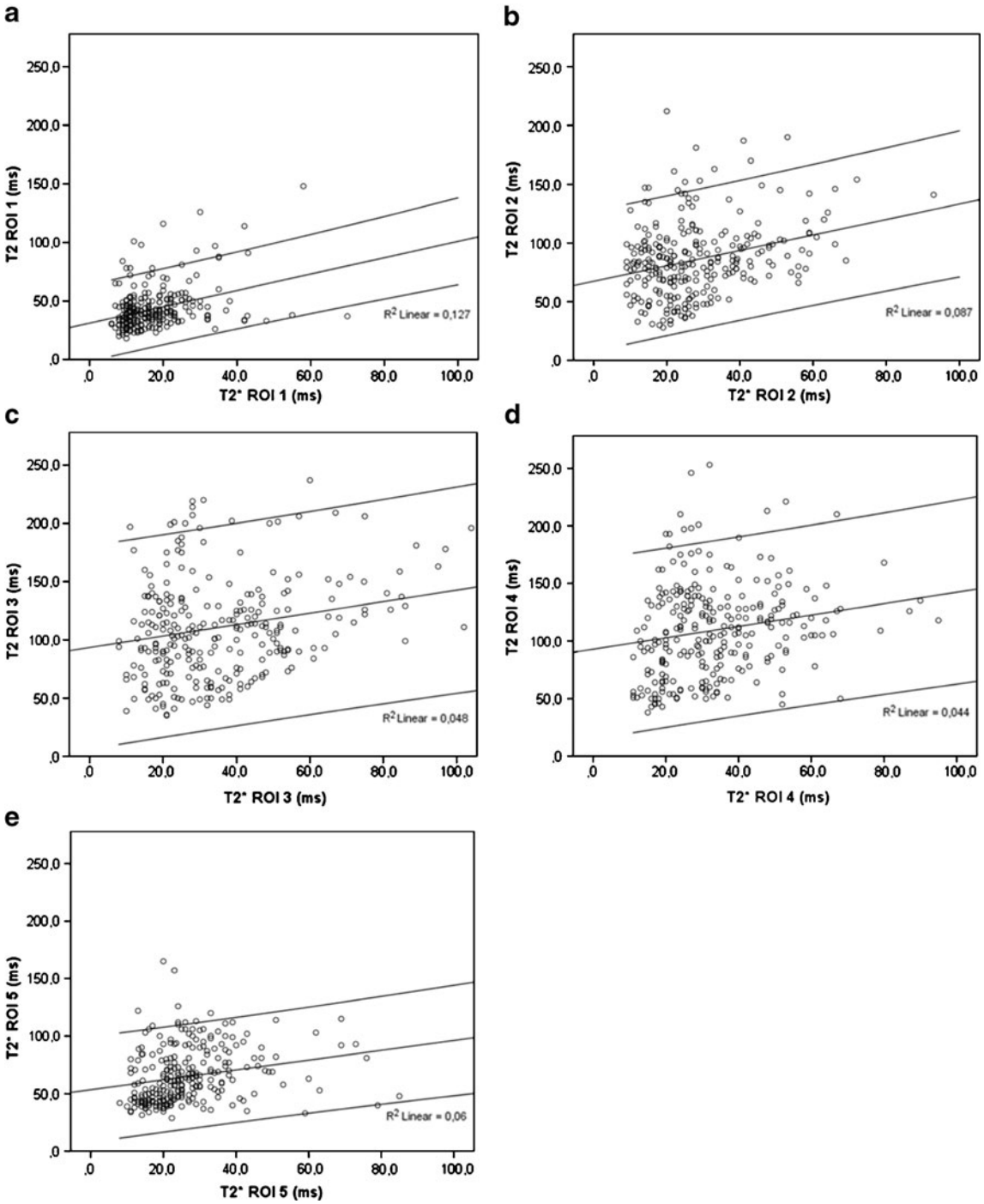

Fig. 4 Correlation plots with regression lines and 95% confidence intervals of the quantitative T2 and T2* evaluations. The single regions from the **a** annulus fibrosus anterior (~ROI 1), **b**–**d** the nucleus pulposus (~ROI 2 to ROI 4) and **e** the annulus fibrosus posterior (~ROI 5) are provided. The 95% confidence interval is clearly increased in the ROIs 2–4, where the clearest changes in T2 as well as T2* due to degeneration take place

Discussion

The results of this study showed a comparable pattern between the annulus fibrosus and the nucleus pulposus for both T2 and T2* relaxation time mapping. Hence, the typical sagittal antero-posterior pattern of an IVD, as an increase in T2 or T2* values from the anterior annulus fibrosus (~ROI 1) to the nucleus pulposus (~ROI 2 to ROI 4) and the subsequent decrease from the nucleus pulposus to the posterior annulus fibrosus (~ROI 5), decreased with increasing degeneration as assessed by the Pfirrmann score. Nevertheless, due to the very small number of completely

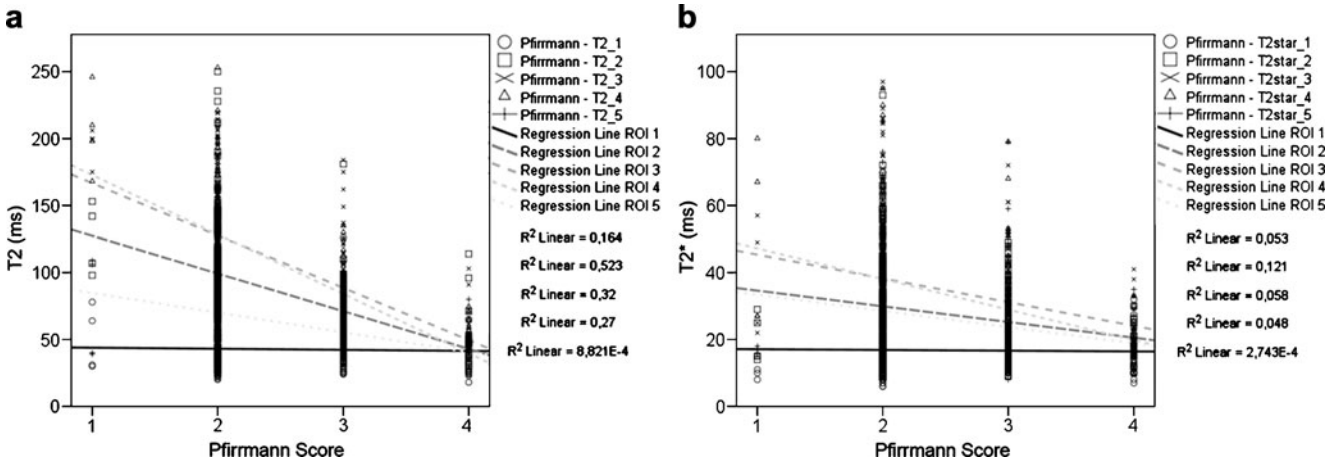

Fig. 5 The correlation plots show the regression lines of the quantitative **a** T2 values and **b** T2* values with respect to the morphological Pfirrmann score. Whereas within ROI 1 (annulus fibrosus anterior, *black*, *continuous line*), no significant correlation could be described, within ROI 5 (annulus fibrosus posterior, *light grey*, *dotted line*) a low to moderate correlation could be assessed. Within the ROI 2, and especially the ROIs 3–4 (nucleus pulposus, *dark grey to light grey*, *dotted lines*) the correlations were remarkably greater. This pattern is comparable for T2 and T2*; however, T2 provides clearly greater correlations between quantitative and morphological scoring

healthy IVDs (Pfirrmann score 1), all results concerning the Pfirrmann grade 1 have to be viewed with caution.

In IVDs, the annulus fibrosus consists of fibro-cartilage; its function as a rigid containment for the nucleus pulposus accounts for its fibrous structure with collagen lamellae and low water content. The gelatinous structure of the nucleus pulposus, however, consists mostly of water and proteoglycan aggrecan. With the degeneration of the IVD, the collagen lamellae of the annulus increase in thickness and become fibrillated.

The Pfirrmann score, a grading system reported to provide a standardised and reliable assessment of MRI disc morphology [2], may nevertheless be limited in the important evaluation of biochemical and biomechanical properties of the IVDs. Schultz et al. [8] reported that the biomechanical results appeared to be better correlated with collagen structure than with the Pfirrmann score. Hence, biochemical MRI methodologies that are more sensitive to the ultra-structure of the IVDs, like T2 or T2* mapping, might provide superior information on the real biomechanical properties of the IVDs. An in vitro study by Chiu et al. [9] used a comparable ROI analysis to our approach and T2 relaxation time values were shown to provide a comparable spatial antero-posterior pattern and correlation with morphological scoring, as assessed in the present study. Within two in vivo approaches [10, 11], this spatial pattern within the IVDs, as an increase in the quantitative T2 values between the anterior annulus fibrosus and the nucleus pulposus and a decrease between the nucleus pulposus and the posterior annulus fibrosus, was assessed in a small number of healthy volunteers. These studies suggested that IVDs can be characterised and classified accurately by means of T2 mapping and that changes in the integrity of the discs can be assessed before there is a change in the Pfirrmann score [10, 11].

In the present study, this spatial pattern was studied in detail in a group of patients with LBP. Special interest was in the reported ability of quantitative T2 to characterise or classify the IVDs biochemically; hence, to use the biochemical antero-posterior pattern within the IVD to assess possible early degeneration. Thus comparable to the initial results of Perry et al. [11] and Krueger et al. [10], both relaxation time methods were able to provide a spatial antero-posterior variation between the nucleus pulposus and the annulus fibrosus for the lower degeneration grades. In contrast to the classification system as introduced by Watanabe et al. [5] based on axial T2 mapping and a qualitative distinction between the nucleus pulposus and the annulus fibrosus, comparable results could be obtained with the benefit of a quantitative differentiation in between the ROIs. By sagittal T2 and T2* mapping five IVDs could be quantified within one sequence, which might be beneficial for the clinical use of these techniques; furthermore, possible partial volume effects could be reduced.

Additionally, the differentiation among the single Pfirrmann grades was assessed, based on the different ROIs, to evaluate which anatomical part of the IVD changes during its degeneration. Again T2 and T2* mapping provided roughly comparable results. In particular, ROIs 3 and 4 seemed to be able to distinguish among the different Pfirrmann scores. This clear decrease in the quantitative T2 and T2* values of the nucleus pulposus (ROIs 2–4) during IVD degeneration was correlated with dehydration in an animal experiment by Niinimäki et al. [12]. These findings

were confirmed by Marinelli et al. [13], who reported that quantitative T2 values correlated significantly with the water content in the human nucleus pulposus.

In the lumbar spine, the posterior annulus fibrosus in particular is a target for disc abnormalities. When looking at the differentiation of the single ROIs with regard to the Pfirrmann score, within the present study, changes in the posterior annulus fibrosus (ROI 5) are able to distinguish between the different grades of degeneration especially for T2* mapping.

The only low to moderate correlation between T2 and T2* might mirror different biomechanical properties assessed by both parameters. When looking at the results, the decrease in T2 values is more pronounced in the nucleus pulposus, whereas the decrease in T2* values is more pronounced in the posterior annulus fibrosus. Hence, standard T2 mapping might be more sensitive to tissue hydration, whereas T2* mapping might be more sensitive to collagen integrity. Additionally, when looking at the clearly higher correlation of quantitative T2 with the Pfirrmann score, compared with quantitative T2*, the dehydration, as one main reason for IVD degeneration, might be better visualised by standard T2 mapping. If the poor correlation of the Pfirrmann score with the laminar collagen structure is now taken into account, as reported by Schultz et al. [8], T2* mapping might have its potential in the visualisation of this collagen fibre organisation. Thus, the lower correlation of the quantitative/biochemical parameter with the morphological scoring might not be seen as a drawback of T2*.

The biochemical MR methodologies presented may also have the potential to provide a quantitative measurement of the grade of degeneration of an IVD against a clinical background. Additionally, the differentiation between healthy and degenerated IVDs might be improved by these techniques. Especially in the longitudinal follow-up of patients with low back pain (e.g. after physical therapy), quantitative T2 or T2* mapping might enable a diagnosis of longitudinal changes in the biochemical and biomechanical profile of a degenerated IVD. Multi-echo spin-echo T2 relaxation time mapping is increasingly used in the evaluation of cartilage degeneration or cartilage repair to assess the collagen integrity and the hydration of the cartilage. A comparable quantification might be possible in the IVD and an additional parameter in the clinical evaluation of patients as well as early degenerative changes might be visualised. Hence, clinical symptoms of patients with low back pain might be correlated with changes in the biochemical composition of the IVD. Multi-echo gradient-echo T2* relaxation time mapping is increasingly used in the description of cartilage ultra-structure within different joints [6, 7, 14]. The biochemical content assessed by quantitative T2* is only roughly comparable to quantitative T2. This assumption is strengthened by the results of the present study. Thus, T2* might mirror the macromolecule integrity of the IVDs as a possible measure of IVD degeneration. The benefits of T2* are based on the possible 3D acquisition and shorter acquisition times.

The T2 and the T2* maps are prepared inline without any time delay. The ROI analysis takes about 10 min for each patient and ongoing efforts with promising initial results may enable an automated segmentation of the IVDs in the future. Hence, the additional, quantitative information on the biochemical composition of the IVDs can be provided with no extensive increase in time needed.

One limitation of the present study is the lack of a gold standard. Understandably, no histological samples could be obtained; nevertheless, especially for T2*, the biochemical properties demonstrated by this biochemical parameter are unclear. These have to be provided in future studies, as the high signal together with the short scan times and possible 3D acquisition, enabling automatic post-processing algorithms, are beneficial for the clinical use of T2*. In future studies, the role of the magic angle also has to be resolved for T2 as well as for T2* relaxation time mapping, as this might play a role, especially in patients with pronounced lordosis or kyphosis. Studies in larger patient cohorts and with different age and activity levels are needed to clarify the absolute values of these biochemical approaches. When referring to the Pfirrmann score, it must be pointed out as another limitation that this scoring was performed at 1.0 T and that changes due to higher fields may occur.

In conclusion, this study assessed the antero-posterior pattern of the lumbar IVDs using T2 and for the first time T2* relaxation time mapping. The results of both methodologies identify valuable biochemical parameters in the parametric evaluation and quantification of IVD degeneration with existing differences between T2 and T2* mapping.

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