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Early Intervertebral Disc Degeneration Changes in Asymptomatic Weightlifters Assessed by T1 ρ -Magnetic Resonance Imaging

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Abstract

Study Design—Case-control study.

Objective—To evaluate early intervertebral disc degeneration quantified by T1 ρ - and T2-weighted magnetic resonance imaging (MRI) in asymptomatic weightlifters compared with a healthy control group matched for sex and age.

Summary of Background Data—Athletes consistently recruit or transfer high levels of repetitive forces through the spine, and MRI has documented a higher rate of intervertebral disc degeneration in athletes compared with matched controls. This study aims to analyze the potential role of T1 ρ -MRI in the assessment of early degenerative changes occurring in intervertebral discs of young asymptomatic weightlifters compared with healthy controls.

Methods—Twenty-six asymptomatic young male weightlifters *versus* a sedentary control group matched for age and sex, both having no lower back pain nor any spinal symptoms, underwent MRI (1.5 T). Degenerative grade was assessed using T2-weighted images, according to the Pfirrmann scale. T1 ρ mapping and values in the nucleus pulposus ($n = 130$) were obtained. Differences in T1 ρ value between among the groups and linear regression analyses with degenerative grade were determined.

Results—Pfirrmann degenerative grade did not show significant differences among groups. Instead, T1 ρ values were significantly lower in the lumbar spine of weightlifters compared with controls ($P < 0.05$). T1 ρ values decreased linearly with degenerative grade.

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Level of Evidence: 4

Conclusion—T1p values were significantly lower in athletes compared with a sedentary matched control group showing differences in intervertebral disc degeneration onset among individuals with lifestyle and environmental factors leading to back pain. T1p can be potentially used as a valid clinical tool to identify early changes in intervertebral disc on the verge of new emerging intervertebral discs regenerative strategies and treatments.

Keywords

T1p; spine; MRI; weightlifter; athletes

Low back pain in young athletes is one of the most common findings, with an incidence that ranges, according to the literature, from 1% to 30% influenced by sport type, sex, training intensity, and frequency. Almost 85% of people never achieve a specific diagnosis associated with their symptoms, making the treatment very challenging.^{1,2} Moreover, after the first episode, low back pain shows a tendency to become recurrent.^{3,4} Sport activities can play a duplex and opposite role in intervertebral disc (IVD) disease, indeed some sports help to prevent physiological degenerative changes, on the contrary some particular types of excessive movement contribute to the intervertebral disc degeneration (IDD) leading to disc protrusion, prolapse, herniation, or spondylolisthesis.⁵

Athletes consistently recruit or transfer high levels of repetitive force through the spine, and magnetic resonance imaging (MRI) has documented higher rates of IDD in athletes compared with matched controls.⁶ In particular, the positive and negative effects of physical activity are mainly centered on the lumbar region of the spine.⁷

Previous studies have demonstrated that among athletes, weightlifters have a higher lifetime risk of specific spinal pathologies, obviously correlated with loading. Indeed, radiological changes are more common in weightlifters (84%) than in other athletes such as runners, jumpers, and throwers (72%).⁸

Appropriate imaging techniques could be useful to determine early IDD stages in athletes and further help defining physiopathological changes that occur in the disc, in particular in the nucleus pulposus (NP), the gel-like central part with the main load-bearing function. T1p-weighted imaging is an unconventional MRI technique that measures the spin-lattice relaxation time in the presence of a spin-lock radio-frequency field, and has been correlated with proteoglycan loss in degenerated discs.⁹ T1p-MRI shows sensitivity to different diseases such as osteoarticular pathologies, in particular, it can be used to study the NP that is characterized by a high content of proteoglycans, which significantly decrease with IDD progression.¹⁰

This study aims to analyze the potential role of T1p-MRI in the assessment of early degenerative changes occurring in IVDs of young asymptomatic weightlifters compared with a healthy control group matched for age.

MATERIALS AND METHODS

Patient Recruitment

The ethics committee of Campus Bio-Medico University of Rome approved the study, and all participants provided written informed consent prior to enrollment. Between February 2008 and March 2011, 26 Caucasian subjects, ranging in age from 18 to 32 years, with an average age of 25 years, were enrolled at Campus Bio-Medico University Hospital, Rome, Italy. The study population was divided in 2 groups: group (A) 13 asymptomatic young male weightlifters (mean age, 25.3 ± 4.4 yr; age range, 18–29 yr; mean BMI, 23.6 ± 1.5 ; BMI range, 21.9–26.8), considered as an athlete who has engaged in regular training for up to 2 years with an average weightlifting experience of 17.7 ± 1.2 months (3–4 times a week), that has some degree of specialization in the exercises (1 hr of cardiovascular and strength training and 1 hr of skill training per day) and a high performance at the recreational level (at the time of the study, the subjects were all capable of lifting at least 1.5 times their body weight). Group (B) 13 asymptomatic young males with sedentary lifestyle, age and BMI matched (mean age 23.5 ± 1.3 yr; age range, 21–25 yr; mean BMI, 23.3 ± 2.8 ; BMI range, 17–27.4), with no previous or current organized competitive sporting activities. Patients were recruited for the study according to the following inclusion criteria in both groups: absence of back pain using Short Form-36 score system, negative physical orthopedic examination, no prior back surgery, no spine trauma, no metabolic diseases, no autoimmune diseases, no osteoarticular diseases, no morphological alteration, and no diabetes. Subjects were excluded if they failed to meet the above criteria.

MR Image Acquisition

Each participant underwent MRI on a clinical 1.5-T scanner (Siemens MAGNETOM Avanto 76 × 18; Campus Bio-Medico University Hospital of Rome, Rome, Italy) according to 2 protocols. First, conventional T1- and T2-weighted images were acquired using a standard spin-echo imaging sequence with the following parameters (T2-weighted: field of view, 320 mm; slice thickness = 4 mm; acquisition matrix = 514; and echo time/repetition time, = 83/5560 ms; inversion time, 150 milliseconds; T1-weighted images were acquired echo time/repetition time = 8.1/400 ms, turbo spin echo, field of view, 400 mm; slice thickness = 4 mm; matrix = 384). Next, a series of T1 ρ -weighted images were acquired using a turbo spin-echo pulse sequence with fat suppression, with the following parameters (field of view = 280 mm; slice thickness = 4 mm; acquisition matrix = 358; flip angle = 30°; and echo time/repetition time = 5.24/3030.96 ms; inversion time 1700 milliseconds). Spin-lock durations were in the range from 15 to 75 milliseconds with spin-lock pulse amplitude set to correspond to a spin-lock frequency of 400 Hz. Both axial and sagittal images were acquired. Total time for each examination was about 15 minutes each.

Data Processing

Sagittal T2-weighted images and corresponding quantitative T1 ρ -weighted images were used to evaluate the degenerative grades and T1 ρ values of the discs, respectively. The degenerative grade of each lumbar disc (n = 130, IVDs between L1 and S1 in 13 subjects each group) was assessed from T2-weighted images, by 2 radiologists to reach a consensus, according to the classification system described by Pfirrmann *et al.*¹¹ According to this

classification, grades were assigned as grade 1 (normal shape, no horizontal bands, distinction of annulus fibrosus [AF] and NP is clear); grade 2 (nonhomogeneous shape with horizontal bands, some blurring between NP and AF); grade 3 (nonhomogeneous shape with blurring between NP and AF, AF shape still recognizable); grade 4 (nonhomogeneous shape with hypointensity, AF shape not intact and distinction between NP and AF impossible, disc height usually decreased); and grade 5 (same as grade 4 but collapsed disc space). Independent results from the 2 reviewers were tabulated and compared (2 musculoskeletal radiologists [S.B., F.M.M.]). If the readers agreed on the Pfirrmann grade for a disc, that grade was recorded for analysis. If the readers disagreed, they reviewed the images together and reached a consensus, without knowledge of the T2 measurements.

T1 ρ values were calculated on a pixel-by-pixel basis by a linear regression of intensity data to an exponential decay function of spin lock time (TSL): $S(TSL) = S_0 e^{-(TSL/T1\rho)}$. Values were used to create 3D spatial maps of T1 ρ using MATLAB (Math Works, Cupertino, CA). A circular region of interest of 5-mm diameter was manually positioned by 2 independent investigators on the map in the center of the NP, and mean T1 ρ values were computed within that region (Figure 1). Moreover, T1 ρ values of NP were also calculated by manually segmenting different regions of the disc using a custom-written MATLAB software (<http://cmroi.med.upenn.edu/index.php/software/downloads>).

Statistical Analysis

Calculation of the sample size was based on an expected difference between T1 ρ values (mean and SD), calculated on grade 1 and grade 2 discs according to Pfirrmann scale as shown in the study by Zobel *et al.*¹² This was considered as the minimal significant difference to assess a change between health and pathological discs. With a power of 0.80 and $\alpha = 0.05$, a sample size of 20 patients per group was obtained. Because of the exploratory character of the study, the restricted inclusion criteria and the limited study period and resources, a sample size of 26 (13 patients per group) was selected. The study has raised the 65% of the subjects required thus the results can be consider as preliminary.

Cohen's kappa test was performed to assess interobserver variability of T1 ρ values obtained through the region of interest positioned by the 2 operators ($k = 0.80$, $P = 0.91$, $p = 0.58$).

We compared median T1 ρ values of NPs of healthy volunteers and weightlifters according to the anatomic level of each disc, using the Student *t* test. The Jonckheere-Terpstra test, a nonparametric test for trends in ordered groups, was used to evaluate the decreasing trend of the relationship between NP and level of the disc. Scatter plots were mapped and the Spearman rank correlation coefficient applied to determine the relationship between NP and Pfirrmann grade. A $P < 0.05$ was considered statistically significant.

Statistical analyses were performed using statistical analysis software (StataCorp 2007 Stata Statistical Software: Release 10; StataCorp LP, College Station, TX).

RESULTS

Representative sagittal T2-weighted images and corresponding quantitative T1 ρ maps (overlaid in color on the corresponding grayscale MRI) are shown in Figures 2 (A–D) and 3 (A–D) reporting the degenerative grade as Pfirrmann grading and T1 ρ values. The T1 ρ map is a spatial representation of the quantitative T1 ρ parameter calculated at each pixel location.

Morphological assessment of discs using T1- and T2-weighted conventional MRI, including the Pfirrmann degenerative grade, revealed no significant abnormalities among groups. Instead, T1 ρ maps showed significant lower T1 ρ values in weightlifters rather than volunteers. T1 ρ values of NPs of both groups are listed in Table 1 according to the anatomic level of each disc. Evaluation of group differences at each level showed significantly ($P < 0.05$) lower T1 ρ values in all lumbar spinal segments of weightlifters (Figure 4), except for L1–L2 level. A significant decreasing trend in T1 ρ values of NP, from the upper to lower lumbar levels, was found in both sedentary and weightlifters (trend P values were < 0.0001).

The scatter plot for T1 ρ values and Pfirrmann grades indicates that the 2 variables were inversely and linearly related, as shown in Figure 5. The correlation between T1 ρ values and Pfirrmann grades was -0.70 ($P < 0.0001$) in the sedentary group, and -0.49 ($P < 0.0001$) in the weightlifters group. However, in accordance with previous data,¹² the bivariate scatter diagram shows the wide heterogeneity distribution of T1 ρ values, especially for the nondegenerated discs, as evaluated according to the Pfirrmann scale; in fact T1 ρ values of the whole population was in the range from 65.3 to 172.5 milliseconds for discs classified as grade 1, from 50.32 to 108.89 milliseconds for discs classified as grade 2, and from 59.08 to 83.62 milliseconds for discs of grade 3.

DISCUSSION

Sports with great loads on the spine, like weightlifting, cause more back pain than any other sport and such athletes have more radiological abnormalities in the thoracolumbar spine than nonathletes.^{13,14} Several studies have shown a direct correlation between back pain and IDD in athletes,^{14–16} and an increased frequency of IDD has been also reported among them.¹⁷ The frequency of IDD varies between different sports because the physical loading on the lumbar spine depends on different actions and postures specific to each sport. Videman *et al*¹⁷ have widely investigated long-term effects of different sports, during adolescence and early adulthood, on spinal pathology and back-related symptoms. They have studied 7 sports groups based on occurrence of back pain, sciatica, and hospitalization compared with a control population, and subsequently, evaluated the degree of lumbar spinal pathology. Weightlifting was one of the most investigated sports because it requires an increased axial loading across the entire thoracolumbar spine associated to an increased loading in flexion and extension. Their MRI degenerative findings were more severe among weightlifters rather than other athletes, with a mean signal intensity score significantly worse and a mean disc bulging score significantly higher. Moreover, they reported greater changes in scores for disc dehydration and contour changes at the lumbar levels compared with other groups.¹⁷

However, mechanical factors leading to early disc degeneration as that seen in weightlifters cannot be considered the only cause of degeneration. Indeed, IDD is influenced by genetic or other factors such as disc nutrition and metabolism that we are not addressed in this study.^{18,19}

In our study, the young asymptomatic weightlifters and the healthy sedentary group matched for age did not differ in terms of IDD grade assessed by Pfirrmann scale, which is based on the NP signal intensity. However, T1 ρ -MRI data showed that early degenerative changes were already present in asymptomatic weightlifters, as shown by the lower T1 ρ values of NPs compared with control group (Figures 2 and 3). These results suggest that proteoglycan loss of the NP begin earlier when the lumbar spine is overloaded.

According to our data, in a previous cross-sectional study using T1 ρ -MRI to assess early IDD in asymptomatic young adults, T1 ρ values correlated with Pfirrmann degenerative grade. However, the wide distribution of values in healthy IVDs highlighted the low sensitivity of Pfirrmann grade to detect early IDD changes.¹²

Generally, the evaluation of patients affected by IDD begins with conventional radiography that mainly shows bone injuries of spine and disc narrowing, followed by T1- and T2-weighted MRI to assess IVD structural changes. However, standard MRI is highly sensitive to detect advanced stages of IDD (*i.e.*, changes in disc morphology, height, dehydration, bulge, and herniation)^{20,21} but it is not able to assess early degenerative changes of IVDs.²² Indeed, early IDD is characterized by biochemical changes such as collagen degradation, proteoglycan loss, and dehydration that ultimately lead to morphological and biomechanical impairment of the IVD. In fact, the main biochemical change occurs mostly into the NP where the proteoglycan content decreases.²³ T1 ρ -weighted MRI can generate tissue contrast based on variations in protein content and provide a noninvasive method to detect proteoglycan content and early stages of degeneration.^{9,24} Such a method would improve diagnostic capabilities at the early stages of the disease. As more disc treatment options are developed, including biological treatments, NP replacements and total disc replacement,^{25–29} better diagnosis of early degeneration and the ability to noninvasively quantitatively evaluate their efficacy will be required to direct the surgeon toward the appropriate treatment. T1 ρ and other advanced techniques such as T2 mapping and diffusion MRI are opening new frontiers, giving more information about IDD and helping to better understand its pathophysiology. In particular, T1 ρ may be helpful to diagnose this common pathology because its ability to evaluate early lumbar disc aging and degeneration.

The major limitations of this study are the small number of patients enrolled due to the complexity of the assessment and the costs of MRI examination of healthy young volunteers and athletes. Therefore, the data must be considered as preliminary; and future studies with higher sample size will be performed. The study is also limited by the lack of further advanced imaging techniques such as T2 mapping for comparison.

Future T1 ρ -MRI studies on the lumbar spine will include a larger population consisting of both symptomatic and asymptomatic patients and may increase the knowledge of IDD pathophysiology. Prospective studies on athletes as well as subjects with high prevalence of

IDD (*i.e.*, heavy workers and obese individuals) may provide further information on preventive strategies. Moreover, T1 ρ -weighted images may be a useful guide to enroll and evaluate patients in future clinical trials of IVD regeneration strategies, such as stem cell therapy, for the treatment of early IDD.

CONCLUSION

Early IDD was evaluated in asymptomatic young weightlifters through the new T1 ρ -MRI. T1 ρ values were significantly lower in athletes compared with a sedentary matched control group showing difference in IDD onset among the groups. T1 ρ can be potentially used as a clinical tool to identify early changes in the IVD in individuals with lifestyle and environmental factors leading to IDD such as weightlifters, on the verge of the emerging disc regenerative strategy treatments.

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➤ Key Points

- ❑ IDD was evaluated in asymptomatic young weightlifters compared with healthy controls with the new T1 ρ -MRI.
- ❑ T1 ρ values were significantly lower in the lumbar spine of weightlifters compared with controls showing differences in IDD onset among groups.
- ❑ T1 ρ can be potentially used as a clinical tool to identify early changes in the IVD in individuals with lifestyle and environmental factors leading to IDD such as weightlifters.

Figure 1.
Flowchart of processing data. Normal spine of a volunteer (23-yr-old-male control).

Figure 2.

Representative T2-weighted images (**A** and **C**) and T1ρ map overlaid on T1ρ image (**B** and **D**) of a 23-year-old male with sedentary lifestyle (**A** and **B**) and a 19-year-old weightlifter (**C** and **D**). Both subjects show nondegenerated disc on T2-weighted images assessed as grade 1 of Pfirrmann. T1ρ mapping analysis shows lower values of T1ρ in athlete's IVDs compared with the matched control, due to an increased proteoglycan loss.

Figure 3.

Representative T2-weighted images (**A** and **C**) and T1 ρ map overlaid on T1 ρ image (**B** and **D**) from a 23-year-old male with sedentary lifestyle (**A** and **B**) and a 21-year-old weightlifter (**C** and **D**). Both subjects show degenerated disc on T2-weighted images, in particular at level L5–S1 graded as 3 (**A**) and 4 (**C**), and grade 2 the rest of discs. T1 ρ mapping analysis showed a lower values of T1 ρ in the athlete's discs than those of the control.

Figure 4.

Box plots of T1 ρ value of nucleus pulposus according to the anatomic level of each disc. Gray denotes athletes; white, sedentary. The boxes represent the median and the interquartile range, with the vertical lines showing the range. The graph shows a significant lower T1 ρ value in the weightlifter discs at all levels than that in the sedentary discs. * $P < 0.05$.

Figure 5. Scatter plot for the bivariate linear regression on the T1ρ value of the NP and Pfirrmann grade, showing differences in the T1ρ values in the discs of the 2 groups. NP indicates nucleus pulposus.

TABLE 1

T1p Value of the NP of Athletes (group A) and Sedentary Young Male (group B) According to the Anatomic Level of Each Disc, Expressed as Median and Interquartile Range

Disc Levels	T1p Value (ms) of the NP			P
	Group A	Group B		
L1-L2	103.19 (86.0–118.41)	102.6 (100.8–144.8)		
L2-L3	102.55 (87.5–108.9)	114.17 (101.4–128.6)		P < 0.05
L3-L4	93.64 (84.5–104.4)	109.17 (96.7–130.6)		P < 0.05
L4-L5	74.33 (66.7–91.4)	108.88 (98.6–124.6)		P < 0.05
L5-S1	79.73 (66.7–92.9)	103.43 (84.4–114.4)		P < 0.05

Mean value of T1p for each levels of discs.
NP indicates nucleus pulposus