Interobserver and test-retest reproducibility of T1ρ and T2 measurement of lumbar intervertebral disc by using 3T Magnetic Resonance Imaging

Yeon Hwa Yoo

Department of Medicine

The Graduate School, Yonsei University

Interobserver and test-retest reproducibility of T1ρ and T2 measurement of lumbar intervertebral disc by using 3T Magnetic Resonance Imaging

Directed by Professor Sungjun Kim

The Master's Thesis

submitted to the Department of Medicine,

the Graduate School of Yonsei University

in partial fulfillment of the requirements

for the degree of Master of Medical Science

Yeon Hwa Yoo

June 2016

This certifies that the Master's Thesis of
Yeon Hwa Yoo is approved.

Thesis Supervisor : Sungjun Kim

Thesis Committee Member#1 : Choon-Sik Yoon

Thesis Committee Member#2 : Sung-Uk Kuh

The Graduate School
Yonsei University

June 2016

ACKNOWLEDGEMENTS

I would like to thank Professor Sungjun Kim, Department of Radiology, Gangnam Severance hospital for the invaluable guidance and encouragement for this research. I am also very grateful to professor Choon-Sik Yoon and professor Sung-Uk Kuh, thesis committee members for sincere advice.

As a radiology trainee in Gangnam Severance hospital, I would like to express my gratitude to every professor in the department. I would like to express my special appreciation and thanks to my beloved husband and daughter. Finally, I owe thanks to a very special person, my mother, Young-Hee Lee, for her unfailing love, understanding and support.

<TABLE OF CONTENTS>

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Interobserver and test-retest reproducibility of T1ρ and T2 measurement of lumbar intervertebral disc by using 3T Magnetic Resonance Imaging

Yeon Hwa Yoo

Department of Medicine
The Graduate School, Yonsei University

(Directed by Professor Sungjun Kim)

Objective:

To investigate the interobserver and test-retest reproducibility of T1ρ and T2 measurements of lumbar intervertebral discs using 3T magnetic resonance imaging (MRI).

Material and Methods:

A total of 51 volunteers (female, 26; male, 25; mean age, 54 ± 16.3 years) underwent lumbar spine MRI with a 3.0 T scanner. Of these subjects, 40 underwent repeat T1ρ and T2 measurement acquisitions with identical image protocol. Two observers independently performed the region of interest (ROI) measurements in the nuclei pulposi of the discs from L1–2 through L5–S1 levels. The discs were then assigned to either non-degenerated (grades 1 and 2) or degenerated (grades 3 and 4) disc groups

according to the Pfirrmann grading system, excluding grade 5 discs. The mean T1ρ and T2 measurements of the lumbar intervertebral discs were compared between the two groups. Statistical analysis was performed using the Student's t-test and intraclass correlation coefficient (ICC). Statistical significance was defined at *p*-value < 0.05.

Results:

The ICCs of interobserver reproducibility were 0.951 and 0.672 for T1ρ and T2 mapping, respectively. The ICCs of test-retest reproducibility (40 subjects) for T1ρ and T2 measurements were 0.922 and 0.617 for observer A and 0.914 and 0.628 for observer B, respectively. The T1ρ and T2 values in the degenerated intervertebral disc group were significantly lower than those of the non-degenerated group ($p < 0.001$).

Conclusions:

The interobserver and test-retest reproducibility of T1ρ mapping were superior to those of T2 mapping for the quantitative assessment of nuclei pulposi of lumbar intervertebral discs.

Key words : T1ρ measurement, intervertebral disc, reproducibility, spin-lock, Magnetic resonance imaging

Interobserver and test-retest reproducibility of T1ρ and T2 measurement of lumbar intervertebral disc by using 3T Magnetic Resonance Imaging

Yeon Hwa Yoo

Department of Radiology
The Graduate School, Yonsei University

(Directed by Professor Sungjun Kim)

I. INTRODUCTION

Intervertebral disc degeneration (IDD) is the leading cause of low back pain worldwide[1]. It is a complex multi-systemic disease with unclear etiology[2]. The early changes in IDD are primarily associated with the loss of proteoglycan in the nucleus pulposus; the reduction of their water-binding capacity can cause alterations in the water content, leading to the loss of hydration and osmotic pressure[3]. Currently, early detection of IDD has been an important issue for the appropriate medical or surgical management of the disease in order to prevent further progression[4,5]. Therefore, a reliable quantitative parameter for the detection of early biochemical changes in IDD has been requested.

Magnetic resonance imaging (MRI) has been the most important noninvasive diagnostic tool for the assessment of IDD. Although T2-weighted MRI has been considered a well-established

method for the semi-quantitative evaluation of disc degeneration according on the morphological grading system[6], conventional MRI technique has limited abilities in the quantification of early changes in IDD. Therefore, researchers have been focusing on the development of quantitative MRI techniques that can analyze the biochemical composition of intervertebral discs[7].

More recently, several noninvasive quantitative MRI techniques such as T1ρ and T2 mapping sequences have emerged, which meet the expectations for detection of early biochemical changes in IDD; however, the targets of focus of these two techniques are different from each other. While quantitative T1ρ mapping[8] is sensitive to the proteoglycan content, quantitative T2 mapping[9] is sensitive to the water content and collagen fiber network of the intervertebral discs. However, the acquisition of accurate and clinically valuable quantitative data using T1ρ and T2 mapping sequences has been considered to be challenging. Therefore, the reproducibility of these two quantitative mapping techniques requires evaluation before application[10]. To our knowledge, there have been no studies on the evaluation of both interobserver and test-retest reproducibility of T1ρ and T2 measurements in lumbar intervertebral disc degeneration by 3T MRI. Therefore, the purpose of our study was to investigate the interobserver and test-retest reproducibility of T1ρ and T2 measurements of lumbar intervertebral discs measured from the corresponding mapping sequences using 3T MRI.

II. MATERIALS AND METHODS

Subjects

This prospective study was approved by our institutional review board prior to patient recruitment and written informed consent was obtained from each patient before the enrollment. A total 51 patients (female, 26; male, 25; mean age, 54 ± 16.3 years; age range, 27–76 years) were enrolled in this study between December 2013 and February 2015. The inclusion criteria were: (1) patients who had low back pain for more than 2 months and (2) patients who had agreed to participate in the study enrollment. The exclusion criteria were: (1) previous surgical history that may affect image quality, (2) problems with claustrophobia and (3) scoliosis of lumbar spines that can cause geometrical variability in image acquisition. Every lumbar intervertebral discs from L1-2 through L5-S1 levels were assessed in all of the patients. A total of 51 patients underwent MR imaging in the first scanning session including T1ρ and T2 mapping sequences, which is detailed below. Of the 51 subjects, 40 patients who also agreed to undergo repeat imaging with the T1ρ and T2 mapping sequences for the evaluation of the test-retest reproducibility, underwent the repeat scanning session immediately after the first scanning session.

Magnetic Resonance Imaging Acquisition

All MR images were acquired using a 3.0 T MRI scanner (Discovery MR750, General Electric

Healthcare, Milwaukee, WI, USA) with a spine matrix coil. All MR images of the lumbar spine including levels L1–2 through L5–S1 were acquired in the supine position between 10 A.M. and 2 P.M., considering diurnal variation[11]. The study MRI protocol includes the procedures followed in both the first and second scanning sessions.

The MR protocol for the first scanning session includes three different MR sequences: two-dimensional (2D) fast spin-echo (FSE) T2-weighted images were acquired in the sagittal plane; three-dimensional (3D) fast spin-echo (FSE) pulse sequence with parallel imaging and long echo train, low flip angle, and low specific absorption rate acquisition (3D-CUBE) T1-weighted images were acquired in the sagittal plane for T1ρ mapping; and, finally, 2D-multisection FSE images were acquired in the sagittal plane for T2 mapping. The second scanning session involved image acquisition using just the two mapping sequences mentioned above, with the same parameters.

The details of imaging parameters are as follows; 2D FSE protocol (Field of view (FOV)= 38 cm, repetition time (TR)/ echo time (TE)=3973 ms/102 ms, acquisition matrix=320 x 512, slice thickness; 3 mm, slice spacing; 4 mm, number of excitations (NEX)= 1, scan time = 1 min 59 s). T1ρ protocol (The fat-saturated 3D CUBE, spin-lock pulse amplitude=440 Hz (w1=rB1/2), spin-lock pulse length (TSL)=1, 10, 30, 60 ms, FOV= 28 cm, TR/TE=2.3 ms/4.7 ms, acquisition matrix=192 x 288, bandwidth = 0.7 kHz/pixel, slice thickness=4 mm, NEX=1, scan time = 7

min 6 s) and T2 map protocol (2D FSE protocol, FOV= 28 cm, TR = 1836 ms and TEs = 6.0, 12.4, 25.3, 38.1 ms, acquisition matrix=192 x 288, slice thickness; 3 mm, slice spacing; 2 mm, NEX = 0.5, scan time = 5 min 34 s). The total scan time for first scanning session was 14 min 39 s and for second scanning session was 12 min 40 s. The imaging parameters are summarized in Table 1.

Table 1. Summary of the Imaging Parameters for the Study Protocol

Imaging parameters	T2-weighted 2D FSE imaging in the sagittal plane	T1ρ-weighted 3D CUBE imaging in the sagittal plane for T1ρ mapping	T2-weighted 2D FSE imaging in the sagittal plane for T2 mapping
Repetition time (ms)	3973	1263	3430
Echo time (ms)	102	60	120
Number of echoes	1	4 (0, 10, 30, 60)	4 (6.0, 12.4, 25.3, 38.1)
Number of excitations	1	1	0.5
Matrix size	320 x 512	192 x 288	192 x 288
Field of view (cm)	28	28	28
Acquisition pixel size (mm^2)	0.742 x 0.742	0.547 x 0.547	0.547 x 0.547
Section thickness (mm)	3	4	4
Slice spacing	4	2	2
Number of slices	26	17	26
Fat suppression	None	Chemical fat saturation	Chemical fat saturation
Total scan time	1min 59 s	7 min 6 s	5 min 34 s

2D-FSE†, 2-dimensional fast spin-echo pulse sequence

3D-CUBE‡, three-dimensional fast spin-echo pulse sequence with parallel imaging, long echo train, low flip angle, and low specific absorption rate image acquisition.

Post-processing of magnetic resonance images

The MR images were transferred to the Advantage Workstation (Version 4.5, General Electric Healthcare, Milwaukee, WI, USA) for the calculation of the T1ρ and T2 relaxation times of the intervertebral discs using the Functool software (Version 9.3.02e). Digital Imaging and Communications in Medicine (DICOM) images of each series were calculated pixel by pixel. The case-by-case threshold parameter was applied for each scan to remove trailing echoes that are sufficiently low amplitude to be classified as noise. Then, T1ρ maps were reconstructed by fitting the image intensity, pixel-by-pixel, to the equation below using a mono-exponential non-negative least square fitting algorithm; S (TSL) = S0* exp (-TSL/T1ρ), where TSL is Time of spin-lock, and S is the signal intensity of T1ρ-weighted image with a given TSL. In the same manner, the mono-exponential fitting algorithm used in Functool iteratively estimates the relaxation parameter with a confidence level of 0.01. The following equation was used for the reconstruction of T2 maps: S (TE) = S0* exp (-TE/T2).

Image Analysis and Region of Interest measurement

After the acquisition of mapping sequences, all image evaluations were performed by two radiologists (Y.H.Y. and N.L.E.) respectively. On the basis of the sagittal T2-weighted MR imaging findings, rectangular regions of interests were placed at the nuclei pulposi of lumbar discs from L1–2 through L5–S1 levels in the T1ρ mapping images of the discs (Fig. 1).

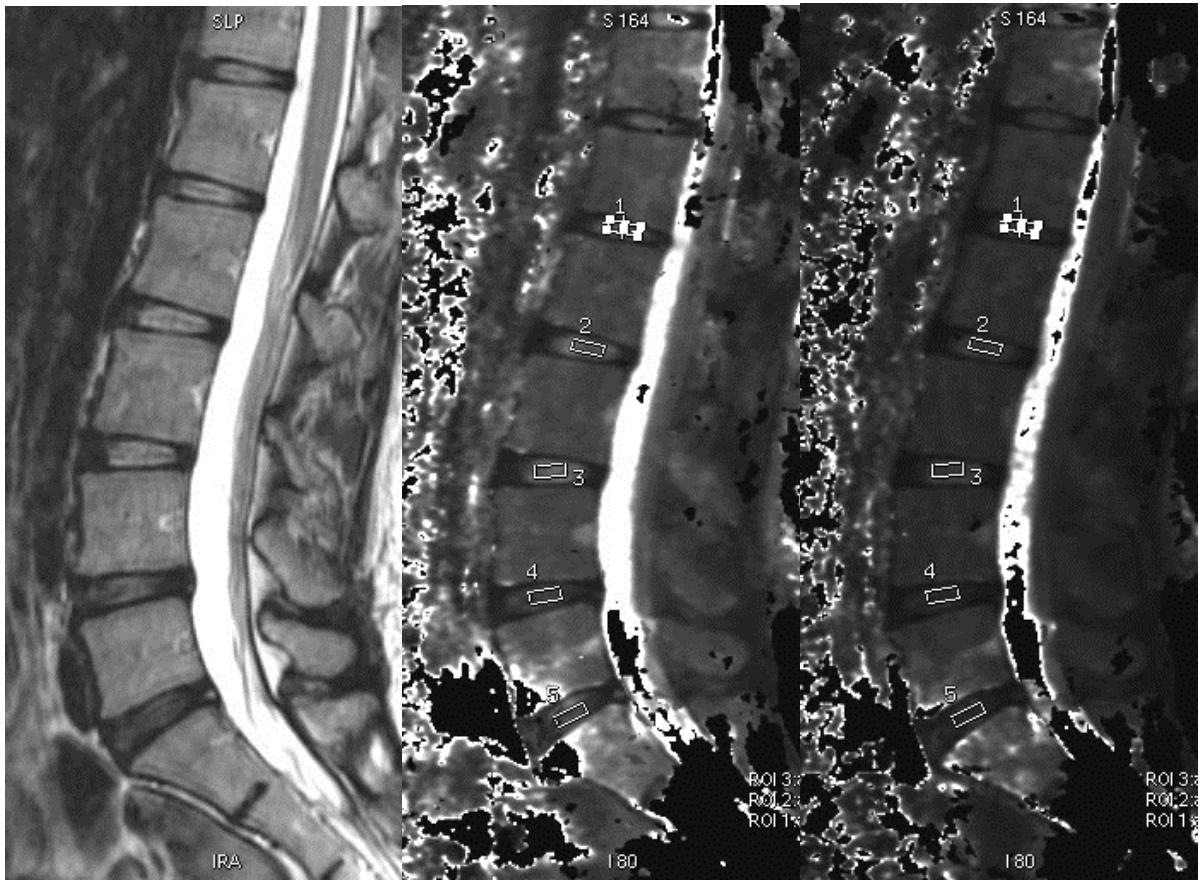


Figure 1. Representative image of Region of interest (ROI) placement in T1ρ and T2 maps.

An example of region of placement (ROI) in the T1ρ (1B) and T2 (1C) mapping images of a 33-year-old female subject with low back pain. On the basis of the sagittal T2-weighted MR image (1A), a rectangular ROI was placed at the nucleus pulposus of the intervertebral disc in the T1ρ mapping image (1B). Once ROI placement at a portion of a disc in the T1ρ mapping images was performed, simultaneous ROI placement at the corresponding nearest disc portion in the T2 mapping images was automatically obtained. The area of ROI was 30 mm^2.

1A, T2-weighted 2D-FSE (two-dimensional fast spin-echo) images acquired in the sagittal plane.

1A. T2-weighted 2D FSE (Fast spin echo) imaging in sagittal plane

1B. T1ρ mapping in sagittal plane (L1-2, L2-3, L3-4, L4-5, L5-S1)

1C. T2 mapping in sagittal plane (L1-2, L2-3, L3-4, L4-5, L5-S1)

Once region of interest (ROI) placement on the T1ρ mapping images was done for a nucleus pulposus of intervertebral disc, simultaneous ROI placement at the corresponding disc portion in the T2 mapping images was automatically obtained except in the cases with geometry mismatch; in such cases, the ROIs were manually placed on the basis of the corresponding ROI locations in the T1ρ images. After randomization of the subjects, two radiologists placed all of the ROI measurements independently, blinded to clinical information as well as the result of Pfirrmann grading session. Rectangular ROIs were used for computing average T1ρ and T2 relaxation times. The mean area of the ROIs was 23.3±4.4 (range, 14.4–34.3)㎟. As a result, two ROI measurements for each of the mapping sequences were obtained for every pixel location at each level of lumbar discs from L1–2 through L5–S1. Discs classified as grade 5 based on the Pfirrmann grading system, described below, were excluded because of the difficulty in accurate ROI placement within their nuclei pulposi owing to severely decreased disc height[12]. In order to obviate bias due to recall memory, the observers analyzed the retest mapping images 2 weeks after the analysis of the first set of images.

All lumbar intervertebral discs from L1-2 through L5-S1 levels were graded according to the Pfirrmann grading system[13] by a single observer (S.K), who did not participate in the T1ρ and T2 measurements. The discs were graded on the basis of the sagittal T2-weighted MR images, which provide MR-based semi-quantitative evaluations of the discs. The discs were assigned

into one of two groups based on the grading — non-degenerated (Pfirrmann grades 1 and 2) or degenerated (Pfirrmann grades 3 and 4) disc groups, in order to evaluate the significance of the differences between the normal/early and later stages of disc degeneration in terms of the T1ρ and T2 measurements[14,15].

Statistical Analysis

All statistical analyses were performed using statistical software (SAS Institute, version 9.2, Cary, NC, USA and MedCalc Software, version 12.7.0, Ostend, Belgium). A total of 255 ROI measurements of 51 patients from the first scanning session and 200 ROI measurements of 40 patients from the second scanning session were assessed.

To investigate the interobserver reproducibility between observer A and B in T1ρ and T2 measurements from each mapping sequence, we used the intraclass correlation coefficient (ICC) with a two-way random model of absolute agreement. This evaluation included 371 measurements, including all of the data from the first (255 measurements from 51 patients) and second (200 measurements from 40 patients) scanning sessions and excluded the data concerning grade 5 discs (n = 84).

To determine the test-retest reproducibility of T1ρ and T2 measurements from each mapping sequence in observer A and B, we used ICC using 163 measurements from 40 patients who underwent both the first and second scan sessions, excluding grade 5 discs (n=37). Values of

ICC < 0.40 were considered as indicating poor reproducibility, those within the range of 0.40–0.75 as indicating fair to good reproducibility, and those > 0.75 as indicating excellent reproducibility[16].

The mean T1ρ and T2 measurements of the lumbar intervertebral discs were compared between the degenerative and non-degenerative discs according to Pfirmann grading system. Student T-test was used to assess whether there was a significant difference in the mean measurements between degenerative and non-degenerative discs from each mapping sequences. P-values <0.05 were considered to be statistically significant. All continuous data were expressed as the mean ± standard deviation (SD), along with the range of the values.

III. RESULTS

Evaluation of the ICC values for interobserver reproducibility of both measurements from the first and second scanning sessions indicated excellent reproducibility in the T1ρ measurements (ICC = 0.951) and fair to good reproducibility in the T2 measurements (ICC = 0.672; Table 2). The overall ICC values for test-retest reproducibility of the T1ρ measurements indicated excellent reproducibility in the measurements of both observers A (ICC = 0.922) and B (ICC = 0.914), while those of the T2 measurements indicated fair to good reproducibility in the measurements of both observers A (ICC = 0.672) and B (ICC = 0.628).

Overall, a total of 255 discs of 51 patients from the first scanning session and 200 discs of 40 patients from the second scanning session were assessed (grade 1= 87, grade 2= 81, grade 3= 77, grade 4= 126, and grade 5= 84). As the T1 rho and T2 values for each disc were inherently different for every each measurement, we considered the number of discs as 455 (sum of 255 discs from the first scanning session and 200 discs from the second scanning session) for correlation analysis of T1 rho and T2 with the Pfirrmann's grade. Among the 455 intervertebral discs from the images, after excluding grade 5 discs (n=84), the discs were categorized into degenerative disc group (grade 3, 4, n=168) and non-degenerative disc group (grade 1, 2, n=203). There was a significant difference between the mean values of T1ρ and T2 measurements, with the mean values of the degenerative intervertebral disc group (mean T1ρ; 94.6±40.1 ms, mean T2; 70.0±33.1 ms) being significantly lower than the mean values of the non-degenerative disc group (mean T1ρ; 105.2±41.6 ms, mean T2; 77.4±35.0 ms) ($p<0.001$) (Fig. 3). In addition, we could observe inverse correlation between the T1ρ and T2 values of the discs and Pfirrmann grades of the corresponding discs (Fig. 4 and Table 3).

Table 2. Intraclass Correlation Coefficient (ICC) of the Interobserver and Test-Retest Reproducibility

	T1ρ mapping	T2 mapping
ICC* of interobserver reproducibility (observers A and B)	0.951	0.672
ICC† of measurement reproducibility (observer A)	0.922	0.617
ICC‡ of measurement reproducibility (observer B)	0.914	0.628

All continuous data are expressed as the mean values.

*The ICC is a measure of comparison of the reproducibility of measurement with each mapping sequence between the two observers (observers A and B).

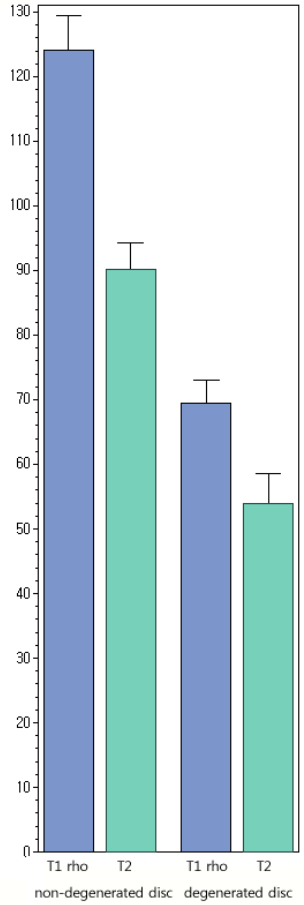
†The ICC is a measure of comparison of the reproducibility of measurement between the first and second scans with each mapping sequence for observer A.

‡The ICC is a measure of comparison of the reproducibility of measurement between the first and second scans with each mapping sequence for observer B

Table 3. Mean measurements of T1ρ, T2 maps according to Pfirrmann grading system in observer A and B.

	Mean measurement of T1ρ mapping (ms)	Mean measurement of T2 mapping (ms)
Grade 1	138.1±34.3 (66.8–244.9)	99.3±31.4 (52.1–322.2)
Grade 2	109.9±29.6 (52.66–220.7)	81.3±22.5 (44.3–157.1)
Grade 3	82.6±24.1 (42.3–174.6)	63.1±17.6 (33.7–115.1)
Grade 4	59.0±17.8 (29.0–162.1)	45.4±24.8 (24.5–402.3)

Note. — All continuous data were expressed as the mean value ± standard deviation (SD)



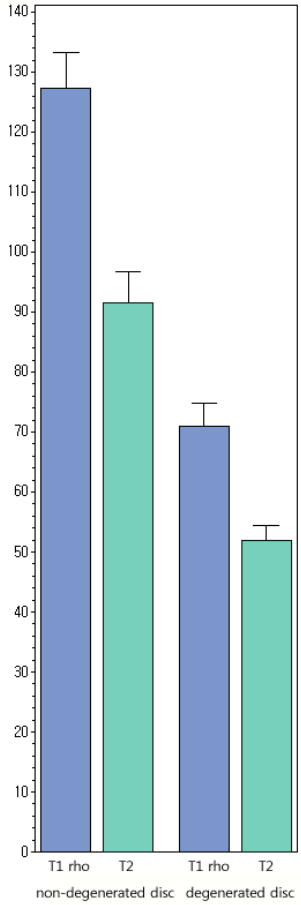


Fig.2A Observer A **Fig.2B Observer B**

Figure 2. Bar graphs of the T1ρ and T2 measurements of each observer according to the severity of intervertebral disc degeneration graded according to the Pfirrmann grading system.

Bar graphs of mean values of T1ρ and T2 measurements of nucluei pulposi graded according to Pfirmann grading system, measured by observer A (Fig.2A) and B (Fig.2B). Grade 5 (n=84) discs were excluded. The mean measurements of the two mapping sequence are depicted in

different colors. The graphs indicate significantly lower T1ρ and T2 value in the degenerative discs group compared to those in the non-degenerated disc group (p <0.05).

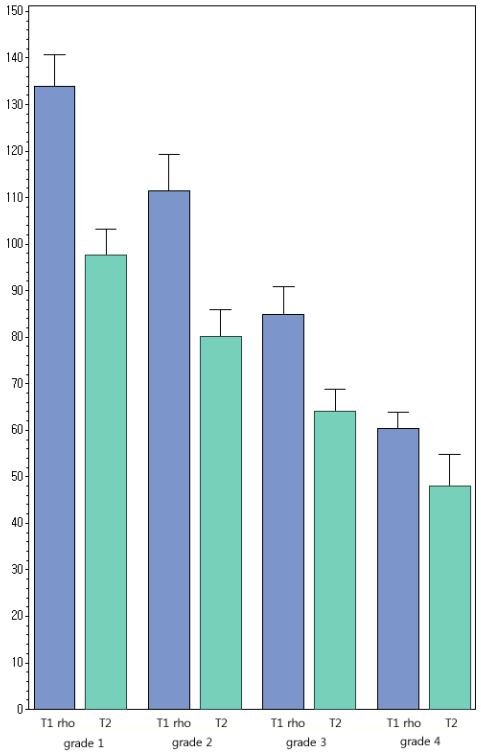


Fig.3A Observer A

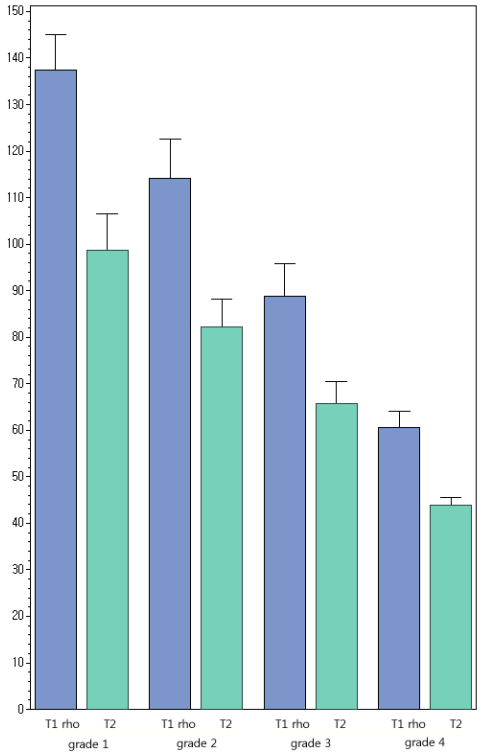


Fig.3B Observer B

Figure 3. Bar graphs of the T1ρ and T2 measurements according to the severity of intervertebral disc degeneration graded according to the Pfirrmann grading system.

There was an inverse correlation between the mean values of T1ρ and T2 measurements of the discs graded according to Pfirrmann grading system, measured by observers A (Fig.3A) and B (Fig.3B).

IV. DISCUSSION

The main goal of this study was to evaluate the reproducibility of MRI-based quantitative measurements of the lumbar intervertebral discs using T1ρ and T2 mapping sequences with 3T MRI. Our results showed excellent reproducibility of T1ρ measurement in the assessment of the IDD using 3T MRI, which was superior to the reproducibility of T2 measurement in terms of both interobserver and test-retest reproducibility. Several studies have explored the reproducibility of T1ρ and T2 measurements obtained from the images acquired using the corresponding mapping sequences in the assessment of IDD[17,18,19]. A investigation showed excellent reproducibility of T1ρ and T2 measurements in the intervertebral disc, with higher ICC values compared to those obtained in our study[19]. However, this report was based on ROI measurement in axial plane using a 1.5 T scanner. Also, there was no statement on whether they considered diurnal variation in their study. Another report recently revealed excellent ICC value

for T1ρ and T2* measurements in nuclei pulposi of the intervertebral discs by 3T MRI; however, the results of this study were based on single-observer measurement[17]. To the best of our knowledge, our study is the first to assess both interobserver and test-retest reproducibilities of T1ρ and T2 measurements obtained from images acquired using each of the mapping sequences with 3T MRI in patients with IDD.

In this study, the T1ρ measurements exhibited superior reproducibility than the T2 measurements, which was consistent with previously reported results in the meniscus[20] and hip cartilage[21] using 3T MRI. Several previous reports have noted that, the wider dynamic range of T1ρ than T2 could be one possible explanation for higher reproducibility of T1ρ measurement compared to that of T2[21,22].

Meanwhile, the reproducibility of the T2 measurements was found to be fair to good in terms of both interobserver and test-retest reproducibility. Previous studies on intervertebral discs reported high levels of reproducibility for T2 measurements comparable to that of T1ρ measurements[19]. In contrast, relatively low ICC values of T2 measurements were observed in our study, which may be attributed to several reasons as follows. Since the T2 mapping images were acquired after the acquisition of the T1ρ mapping images in the present study, it is possible that there were higher chances of appearance of motion artifacts in the former, which might have influenced the reproducibility of the T2 values. Another plausible explanation is that the

echo time for T2 mapping might not have been long enough for the acquisition of long-TE images, which might have resulted in the underestimation of the T2 values, thus potentially affecting their reproducibility. Additionally, since image acquisition was performed using a 3T MRI scanner, the T2 values might have been affected because of increased noise, greater SD of T2 values, or possible magnetization transfer effects[17,21,23].

Since this study focused on the evaluation of reproducibility of T1ρ and T2 measurements, we excluded the annulus fibrosus from the ROI measurement for the acquisition of reliable quantitative data due to the following reason. In the degenerated disc groups (Pfirrmann grades 3 and 4), it can be hard to distinguish the nucleus pulposus from the annulus fibrosus, which might affect precise ROI placement. For the same reason, we did not include Pfirrmann grade 5 intervertebral discs for evaluation in the present study. Considering technical difficulty to put ROI placement in nuclei pulposi in severely degenerated discs, the quantitative measurements in the present study are less likely to have been affected by noise.

In addition, we have demonstrated that both T1ρ and T2 measurements in patients with IDD differed significantly between the degenerated and non-degenerated disc groups, which is in accordance with the results of previous studies[24]. The T1ρ and T2 measurements obtained in our study were consistent with previous reported values[11,24] in the intervertebral discs. We also have shown that measurements obtained from both T1ρ and T2 mapping sequences were significantly

correlated with the Pfirrmann grades of intervertebral disc, showing an inverse correlation with degeneration grades[7]. There are several limitations to this study. First, there were variations in the sizes of the individual ROIs. However, considering the variations in disc height, the placement of ROIs of variable sizes at the nuclei pulposi of intervertebral discs appears to be a more precise way of evaluation. Second, we did not correlate our study results of T1ρ and T2 measurements with glycosaminoglycan or collagen water content of the intervertebral disc, since we focused on the reproducibility of T1ρ and T2 measurements itself. Further research supported by histological and biochemical findings will be helpful for the validation of the T1ρ and T2 measurements of intervertebral discs in patients with IDD.

V. CONCLUSION

In conclusion, T1ρ mapping was superior to T2 mapping in terms of interobserver and test-retest reproducibilities in the quantitative assessment of the nuclei pulposi of lumbar intervertebral discs. Therefore, we believe T1ρ mapping to be a more reliable tool than T2 mapping for the detection of early changes as well as the monitoring of degenerative changes of the nucleus pulposus in IDD by 3T MRI.

REFERENCES

1. Luoma K, Riihimaki H, Luukkonen R, Raininko R, Viikari-Juntura E, Lamminen A. Low back pain in relation to lumbar disc dege neration. Spine 2000;25:487-92
2. Hadjipavlou AG, Tzermiadianos MN, Bogduk N, Zindrick MR. Th e pathophysiology of disc degeneration: A critical review. J Bone Joint Surg Br 2008;90:1261-70
3. Cassinelli EH, Hall RA, Kang JD. Biochemistry of intervertebral disc degeneration and the potential for gene therapy applications. Spine J 2001;1:205-14
4. Carl A, Ledet E, Yuan H, Sharan A. New developments in nucle us pulposus replacement technology. Spine J 2004;4:325s-29s
5. Urban JP, Roberts S. Degeneration of the intervertebral disc. Arthr itis Res Ther 2003;5:120-30
6. Pfirrmann CW, Metzdorf A, Zanetti M, Hodler J, Boos N. Magne tic resonance classification of lumbar intervertebral disc degenerati on. Spine 2001;26:1873-78
7. Auerbach JD, Johannessen W, Borthakur A, Wheaton AJ, Dolinsk as CA, Balderston RA et al. In vivo quantification of human lum bar disc degeneration using t(1rho)-weighted magnetic resonance i maging. Eur Spine J 2006;15 Suppl 3:S338-44

8. Wang L, Regatte RR. T(1)rho mri of human musculoskeletal syste m. J Magn Reson Imaging 2015;41:586-600

9. Liess C, Lusse S, Karger N, Heller M, Gluer CC. Detection of c hanges in cartilage water content using mri t2-mapping in vivo. O steoarthritis Cartilage 2002;10:907-13

10. Surowiec RK, Lucas EP, Ho CP. Quantitative mri in the evaluatio n of articular cartilage health: Reproducibility and variability with a focus on t2 mapping. Knee Surg Sports Traumatol Arthrosc 201 4;22:1385-95

11. Zhu T, Ai T, Zhang W, Li T, Li X. Segmental quantitative mr i maging analysis of diurnal variation of water content in the lumb ar intervertebral discs. Korean J Radiol 2015;16:139-45

12. Zobel BB, Vadala G, Del Vescovo R, Battisti S, Martina FM, Stel lato L et al. T1rho magnetic resonance imaging quantification of early lumbar intervertebral disc degeneration in healthy young adul ts. Spine (Phila Pa 1976) 2012;37:1224-30

13. Pfirrmann CW, Metzdorf A, Zanetti M, Hodler J, Boos N. Magne tic resonance classification of lumbar intervertebral disc degenerati on. Spine (Phila Pa 1976) 2001;26:1873-78

14. Antoniou J, Epure LM, Michalek AJ, Grant MP, Iatridis JC, Mwa le F. Analysis of quantitative magnetic resonance imaging and bio mechanical parameters on human discs with different grades of de

generation. J Magn Reson Imaging 2013;38

15. Zhou Z, Jiang B, Zhou Z, Pan X, Sun H, Huang B et al. Interve rtebral disk degeneration: T1ρ mr imaging of human and animal models. Radiology 2013;268:492-500

16. Lin LI. A concordance correlation coefficient to evaluate reproduci bility. Biometrics 1989;45:255-68

17. Nishii T, Sugano N, Sato Y, Tanaka H, Miki H, Yoshikawa H. T hree-dimensional distribution of acetabular cartilage thickness in pa tients with hip dysplasia: A fully automated computational analysis of mr imaging. Osteoarthritis and Cartilage;12:650-57

18. Wang YX, Zhao F, Griffith JF, Mok GS, Leung JC, Ahuja AT et al. T1rho and t2 relaxation times for lumbar disc degeneration: An in vivo comparative study at 3.0-tesla mri. European radiology 2013;23:228-34

19. Menezes-Reis R, Salmon CE, Carvalho CS, Bonugli GP, Chung C B, Nogueira-Barbosa MH. T1rho and t2 mapping of the interverte bral disk: Comparison of different methods of segmentation. AJN R Am J Neuroradiol 2015;36:606-11

20. Rauscher I, Stahl R, Cheng J, Li X, Huber MB, Luke A et al. Meniscal measurements of t1rho and t2 at mr imaging in healthy subjects and patients with osteoarthritis. Radiology 2008;249:591-6 00

21. Carballido-Gamio J, Link TM, Li X, Han ET, Krug R, Ries MD et al. Feasibility and reproducibility of relaxometry, morphometric, and geometrical measurements of the hip joint with magnetic res onance imaging at 3t. J Magn Reson Imaging 2008;28:227-35

22. Akella SV, Regatte RR, Wheaton AJ, Borthakur A, Reddy R. Red uction of residual dipolar interaction in cartilage by spin-lock tech nique. Magn Reson Med 2004;52:1103-09

23. Juras V, Zbyn S, Szomolanyi P, Trattnig S. Regression error estim ation significantly improves the region-of-interest statistics of noisy mr images. Med Phys 2010;37:2813-21

24. Blumenkrantz G, Zuo J, Li X, Kornak J, Link TM, Majumdar S. In vivo 3.0-tesla magnetic resonance t1rho and t2 relaxation mapp ing in subjects with intervertebral disc degeneration and clinical s ymptoms. Magn Reson Med 2010;63:1193-1200

ABSTRACT(IN KOREAN)

요추간판에서 3T 자기공명영상의 T1ρ , T2 mapping 을 이용한 측정치의 분석 및 재현성평가

<지도교수 김 성 준>

연세대학교 대학원 의학과

유 연 화

목적: 요추간판에서 3T **자기공명영상의** T1ρ , T2 mapping **을 이용**하여 요추간판의 **측정치**를 **분석**하여 관찰자간 및 검사간 **재현성**을 **평가**하고자 하였다.

대상 및 방법: 총 51명의 환자를 대상으로 (여성; 26명, 남성; 25명, 평균나이; 16.3세; 범주 27-76세) 요추간판에서 3T 자기공명영상을 시행하였다. 그 중에서, 40명의 환자들은 같은 기계에서 T1ρ 와 T2 mapping 을 이용하여 검사를 다시하여 검사간 재현성을 관찰하고자 하였다. 두명의 관찰자가 T1ρ , T2 mapping 자료를 이용하여 요추 L1-2번부터 L5-S1까지 요추간판의 수핵부분에 사각형의 region of interest (ROI)를 위치시켜 ROI 를 독립적으로 측정하였다. 모든 추간판은 Pfirrmann grading system 을 기준으로 비퇴행성 그룹 (grade 1, 2) 과 퇴행성 그룹 (grade 3, 4) 으로 나누었고, grade 5 에 해당하는 추간판은 제외하였다. 요추간판에서 비퇴행성 그룹과 퇴행성

그룹간의 평균 T1ρ 와 T2 값을 비교하여 분석하였다. 통계학적 방법으로 Intraclass Correlation Coefficient (ICC) 와 Student T-test 를 이용하였으며, P-value 가 0.05 보다 낮은경우 통계학적으로 유의하다고 판단하였다.

결과: 관찰자간 재현성을 보았을 때, T1ρ mapping (ICC=0.951) 을 이용한 경우 T2 mapping (ICC=0.672) 보다 재현성이 우수하였다. 검사간 재현성을 보았을 때, 관찰자 A 의 경우 T1ρ mapping 을 이용한 경우 ICC=0.922, T2 mapping 에서 ICC=0.617 였고, 관찰자 B 의 경우도 ICC=0.914, T2 mapping 에서 ICC=0.628 로 T1ρ mapping 에서 더 우수하였다. 요추간판에서 퇴행성 그룹의 평균 T1ρ 와 T2 값은 (mean T1ρ; 94.6±40.1, mean T2; 70.0±33.1) 비퇴행성 그룹의 평균 T1ρ 와 T2 값보다 통계학적으로 유의하게 더 낮은 값을 보였다 (mean T1ρ; 105.2±41.6, mean T2; 77.4±35.0) ($p<0.001$).

결론: T1ρ mapping 은 요추간판에서 3T 자기공명영상을 이용한 정량적 측정방법에서 관찰자간, 검사간 재현성을 보는데 있어서 T2 mapping 에 비해 더 유리하였다.

핵심되는 말 : T1ρ, 추간판, 재현성, Spin-lock, 자기공명영상