Investigation of Intervertebral Disc and Facet Joint in Lumbar Spondylolisthesis using T2 Mapping

Hiroyuki TAKASHIMA1,2*, Tsuneo TAKEBAYASHI1, Mitsunori YOSHIMOTO1, Yoshinori TERASHIMA1, Kazunori IDA1, Hiroki SHISHIDO2, Rui IMAMURA2, Yoshihiro AKATSUKA2, Ryuji SHIRASE2, Hiroyoshi FUJWARA3, Toshikazu KUBO3, and Toshihiko YAMASHITA1

1Department of Orthopedic Surgery, School of Medicine, Sapporo Medical University
2Division of Radiology and Nuclear Medicine, Sapporo Medical University Hospital
South-1, West-16, Chuo-ku, Sapporo, Hokkaido 060–8543, Japan
3Department of Orthopaedics, Kyoto Prefectural University of Medicine

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Purpose: We measured T2 relaxation time of the intervertebral discs (IVD) and facet joints (FJ) in patients with degenerative spondylolisthesis (DS) and no spondylolisthesis (NS) and investigated the characteristics of these parts in DS.

Methods: In 40 patients with DS and 40 patients with NS, we measured T2 relaxation time of the IVD and FJ and compared them between groups. In the group with DS, we also examined the relationship between the degree of slippage using Meyerding grade and T2 relaxation time in each part in the IVD and FJ.

Results: T2 relaxation time of the IVD tended to be lower in the DS than NS group and differed significantly (P < 0.01) within the anterior annulus fibrosus. T2 relaxation time in the FJ was significantly higher in the DS than NS group. T2 relaxation time in the FJ was significantly higher for those assessed Meyerding Grade II than Grade I, although we observed no significant differences in T2 relaxation time in any area of the IVD.

Conclusion: T2 relaxation time decreased in the anterior annulus fibrosus of the IVD and increased in the FJ in patients with DS, suggesting an association of IVD and FJ degeneration with the development of lumbar DS.

Keywords: facet joint, intervertebral disc, lumbar spondylolisthesis, T2 mapping

Introduction

Imaging has an important role in the diagnosis of lumbar degenerative disease, and magnetic resonance (MR) imaging is the most useful modality for characterizing lesions of the intervertebral discs (IVD). Signal variation of the discs on T2-weighted images reflects age and degeneration and allows for the determination of disc degeneration.1–3 Among MR imaging technologies, T2 mapping allows quantification of water content and can be used to detect early abnormalities in the cartilage and track response to therapy.4

Spinal instability, including lumbar degenerative spondylolisthesis (DS), results mainly from degeneration of the IVD as the anterior supporting mechanism and of the facet joints (FJ) as the posterior supporting mechanism.5–7 Thus, degeneration in either structure is considered a causative factor of low back pain. In IVD that are not degenerated, the annulus fibrosus (AF) surrounds the translucent nucleus pulposus (NP) in the center of the disc, which is firmly connected at the epiphysis by an endplate formed of hyaline cartilage.8 However, in IVD with degeneration, stability is compromised on the basis of these tight connections with adjacent vertebral bodies.

FJ are important to the stability and segmentation of the lumbar spinal column5 and possess articular cartilage. Thus, osteoarthritis may occur in these joints as it does in other synovial joints, but it usually occurs later than IVD degeneration.9,10 Regardless, the correlation between lumbar DS and...
the degree of degeneration of IVD and FJ is not clear. Water and proteoglycan content decrease with disc degeneration, but water content increases in articular cartilage as a result of injury. Previous studies have reported decreased T2 values of the NP with disc degeneration. Others have reported decreased or increased T2 values of the AF with degeneration without consensus. In addition, the association of T2 values with FJ and degeneration has not been investigated. Characterization of the relationship between degeneration in the disc and FJ, lumbar DS, and T2 values may be useful for accurate noninvasive evaluation and subsequent treatment and surgical planning (selection of only decompression or fusion surgery). Thus, our objectives were to measure T2 values of the IVD and FJ in cases of both with and without DS and characterize changes in the IVD and FJ in DS.

Materials and Methods

Our ethics committee approved all protocols, and we obtained written informed consent from all subjects. A hundred subjects with DS and with no spondylolisthesis (NS) consecutively underwent MR imaging of the lumbar spine to assess low back pain and leg numbness and tingling including pain with lumbar spondylosis. We excluded 13 subject with previous history of lumbar surgery (13 subjects) and 7 subjects younger than the DS group. The group with DS included 40 subjects (15 men, 25 women; aged 43 to 80 years, average age, 67.2 ± 10.1 years) with L4 spondylolisthesis. The NS group also included 40 subjects (18 men, 22 women; aged 43 to 83 year, average age, 66.1 ± 10.7 years) and were matched with the DS group for gender and age and demonstrated L4/5 advanced disc degeneration or lumbar disc space narrowing but without DS.

An orthopedic surgeon (T.T.) with 26 years of experience in spine imaging evaluated lateral X-rays and T2-weighted sagittal images of the lumbar spine. Studies were performed using a 1.5-tesla scanner with a spine coil (Sigma HDx, GE Healthcare, Milwaukee, WI, USA). We obtained T2-weighted sagittal cross-sectional images of the lumbar vertebrae (repetition time [TR], 4000 ms; echo time [TE], 102 ms; receive band width (RBW), ± 31.25 kHz; field of view (FOV), 24 cm; matrix, 384 × 288; slice thickness/gap, 4 mm/1 mm; number of excitations [NEX], 4; total scan time, 3 min 4 s) and measured T2 values of the midline lumbar vertebra using optimized 8-echo multi-spin echo sagittal cross-sectional images (TR/first spin echo TE, last echo TE, 1000/14.8, 118.6; RBW, ± 15.63 kHz; FOV, 22 cm; matrix, 320 × 256; slice thickness/gap, 4 mm/4 mm; 5 slices; NEX, 2; total scan time, 8 min 34 s) and axial cross-sectional images parallel to the IVD (TR/first echo TE, last echo TE, 1000/12.9, 103.4; RBW, ± 15.63 kHz; FOV, 15 cm; matrix, 256 × 192; slice thickness/gap: 4 mm/4 mm; 5 slices; NEX, 3; total scan time, 9 min 38 s). We obtained T2 maps of the images using an Advantage Workstation (version 4.4, FuncTool, GE Healthcare) and measured T2 values of the IVD at the L4/5 level in midline sagittal images and those of the FJ at the L4/5 level in axial cross-sectional images. To minimize the influence of stimulated echoes, we excluded the first echo of multi-spin echoes. The T2 map was created to measure TE signal intensity (SI) for each pixel using the following formula:

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SI = e^{-TE/T_2}
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Each IVD was divided into 5 equal areas, with designation of the front fifth of the anterior AF, the middle fifth of the NP, and the last fifth of the posterior AF. A region of interest (ROI) was placed to enclose the area including the joint space of the FJ, and a research scientist (H.T.) with 7 years’ experience in analyzing spine MR images measured average T2 values (Fig. 1). However, T2 values of the IVD were measured on sagittal images to avoid the partial volume effect on axial images in the case of narrowing of the lumbar disc space. ROIs were determined by the second echo image (IVD 2nd TE, 29.6 ms; FJ 2nd TE, 25.8 ms) and copied onto the T2 map. Measurements were made at the L4/5 level for the DS and NS groups (40 discs, 80 bilateral facet joints). We used MedCalc software (version 10.2.0.0, MedCalc Software, Mariakerke, Belgium) for analysis and comparisons and Mann-Whitney U test to compare groups. P < 0.05 was considered statistically significant. A doctor of philosophy (H.T.) with 7 years of experience in MR image analysis analyzed statistics. We used the Meyerding system to grade X-rays in the DS group and investigated the relationship between T2 values and the degree of slippage in the anterior AF, NP, posterior AF, and FJ.

Results

Figure 2 shows measurements of T2 values in the IVD (L4/5) in the DS and NS groups. T2 values were 54.6 ± 5.2 for the DS group and 66.2 ± 10.3 for the NS group for the anterior AF; 63.5 ± 7.3
The DS group was categorized by Meyerding classification as either Grade I (n = 26) or II (n = 14). We had no cases with Grade III slippage. Figure 5 shows the T2 values for the IVD and FJ according to the Meyerding grade. T2 values did not differ significantly in any area of the IVD but were significantly higher in the FJ for Grade II than Grade I.

**Discussion**

The IVD and FJ are important for the function of the lumbar spinal column, and degeneration in either impairs function. Furthermore, IVD degeneration precedes FJ degeneration, but the causal relationship between lumbar DS and degeneration of the IVD and FJ is not well understood.

The present study compared T2 values for the IVD and FJ in the DS and NS groups. Degeneration of the intervertebral disc visually obscures the margins of the central nucleus pulposus and the peripheral annulus. Therefore, in selecting ROIs, we divided the intervertebral disc into 5 equal areas and defined the center area as the nucleus pulposus and the peripheral areas as the anterior and posterior...
annulus. We consider our method more reliably reproducible than the visual manual selection of ROIs used in previous reports for minimizing measurement bias. In the IVD, we observed a significant decrease in T2 values in the DS group for only the anterior AF, which indicated greater degeneration in the DS group. We observed no significant changes in T2 values in either group for the posterior AF and NP. T2 values of the IVD were reported to be subject to daily fluctuations in water content. However, these fluctuations are small in degenerative discs. Regardless, all MR imaging was performed in the afternoon in this study to minimize any effect of diurnal variation in water content, so we considered T2 values of the IVD measured in this study to be reliable.

Previous studies have reported that more sagittal alignment of the FJ leads to anterior gliding as a result of reduced resistance to anterior shear forces. In this situation, more mechanical stress loaded at the anterior part of the IVD may lead to pressure on the anterior AF. Collectively, it was suggested that the pressure of the anterior AF preceded or triggered the lumbar DS. At the same time, it might be speculated that degeneration of other IVD components such as the posterior AF and NP did not play a causative role in the development of lumbar DS.

Because signal strength in MR imaging is related to water and proteoglycan content, degeneration of the NP can be classified based on visual evaluation. We have previously validated the reliability of Pfirrmann’s classification using T2-weighted images for evaluation. On the other hand, visual evaluation of the AF is difficult with ordinary MR imaging. However, this strategy using T2 values enables us to quantify the water content of the AF and notice that T2 values of the anterior AF may be a prognostic factor for lumbar DS.

This study demonstrated that water content increased as a result of degeneration in the FJ and that T2 values increased significantly in the DS group. Previous studies have reported that degeneration of the lumbar FJ is related to IVD degeneration, which has important implications for spinal instability. According to biomechanical studies using cadavers, the lumbar FJ suppresses the movement of vertebrae and protects the IVD from slipping force and excessive bending and rotation. Hung and associates reported that the angular instability of the IVD may play a more important role than neurological compromise in the pathogenesis of disability in lumbar DS. This suggests that degeneration of the FJ may result in degenerative spondylolisthesis (DS). In previous reports for minimizing measurement bias. In the IVD, we observed a significant decrease in T2 values in the DS group for only the anterior AF, which indicated greater degeneration in the DS group. We observed no significant changes in T2 values in either group for the posterior AF and NP. T2 values of the IVD were reported to be subject to daily fluctuations in water content. However, these fluctuations are small in degenerative discs. Regardless, all MR imaging was performed in the afternoon in this study to minimize any effect of diurnal variation in water content, so we considered T2 values of the IVD measured in this study to be reliable.

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Fig. 4. T2 mapping of the intervertebral disc and facet joints in subjects with and without degenerative spondylolisthesis (DS). (a), (b) Sagittal and axial T2 mapping of subjects with DS. A 71-year-old woman with L4 spondylolisthesis, Meyerding Grade I. T2 values of anterior annulus fibrosis (AF): 46.4 ms, nucleus polposus (NP): 64.5 ms, posterior AF: 58.8 ms, and facet joints (FJ): 230.4 ms. (c), (d) Sagittal and axial T2 mapping of subjects with NS. A 73-year-old woman. T2 values of anterior AF: 65.6 ms, NP: 61.6 ms, posterior AF: 69.7 ms and FJ: 103.2 ms.

Fig. 5. T2 values of intervertebral discs and facet joints with Meyerding classification in subjects with degenerative spondylolisthesis (DS). Between Grades I and II, T2 values of intervertebral discs did not differ significantly but T2 values of facet joints in grade II were significantly higher than that of grade I.
In the current study, T2 values in the FJ were significantly higher for Meyerding Grade II than Grade I although there was no significant difference in grades of the anterior AF. These results suggested that progression of spondylolisthesis should be closely related to the degeneration of the lumbar FJ. Jayakumar and colleagues\(^7\) reported progression of spondylolisthesis with failure of a locking mechanism constituted by the facet joints. We speculated that in the early stage, degeneration of the anterior AF develops related to the onset of lumbar spondylolisthesis, and in the late stage, degeneration of the FJ influences the progression of spondylolisthesis. Figure 5 presents a schematic representation of the onset and process of lumbar DS from our study. Prospective study of chronological changes in T2 values during the evolution of lumbar DS is needed to verify these inferences. This will help characterize the relationship between anterior AF degeneration and FJ degeneration in lumbar DS. Our study also suggested the possibility of early diagnosis of lumbar degenerative spondylosis and expected prediction of adjacent segmental disease after posterior spinal fusion.

Our study has several limitations. Realistic imaging times and signal-to-noise ratios make it difficult to improve spatial resolution using a 1.5T device. Therefore, we included the joint spaces in measuring T2 values for the FJ. Spatial resolution in the present study is insufficient for strict placement of the ROI within only the cartilage of the FJ. Because FJ effusion has been reported related to spondylolisthesis,\(^7\) in this study, the amount of liquid in the joint may affect T2 values.

In summary, we evaluated the extent of degeneration of the IVD and FJ compared with T2 values between patients with DS and with no spondylolisthesis. T2 values decreased in the anterior AF of the IVD and increased in the FJ. Further study is needed to elucidate how these changes relate to the development of lumbar DS.

References


