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Relationship between facet joint tropism and degeneration of facet joints and intervertebral discs based on a histological study

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ABSTRACT

Purpose: Evaluate the correlation between lumbar facet joint tropism, lumbar facet joint degeneration, and intervertebral disc degeneration.

Methods: Forty-two of facet joints were evaluated histologically and radiologically.

Results: The correlation between facet joint tropism and histologic, CT, and MRI grading was −0.159 (P = 0.339), 0.025 (P = 0.226) and −0.270 (P = 0.102), respectively. The correlation between facet joint tropism and intervertebral disc MRI grading was 0.346 (P = 0.033), and that between facet joint and intervertebral disc MRI grading was 0.208 (P = 0.210).

Conclusions: Facet joint tropism was correlated with intervertebral disc degeneration but not with facet joint degeneration.

1. Introduction

The facet joint (FJ) is the only synovial joint of the spine and allows articulation between the vertebrae. It plays a crucial role in restricting excessive motion, thereby protecting the disc from mechanical overloading and structural damage.[1,2] Because of lumbar degeneration, it is generally believed that degeneration occurs in the intervertebral disc (IVD), with ensuing malalignment of the spine, followed by FJ degeneration. However, the correlation between IVDs and FJs is controversial, and the actual sequence of events is not well known.[3] Dunlop et al.[4] reported that the pressure between facets increased significantly with the narrowing of the disc space and increasing angles of extension in cadaveric lumbar spine specimens. According to another report, FJ destruction can induce adjacent disc degeneration.[5] In contrast, Gries et al.[6] demonstrated that microscopic changes occur in IVDs and FJs of the lower lumbar spine from an early age, with advanced changes frequently encountered. Moreover, the grade of IVD degeneration did not correlate with that of FJ degeneration.

FJ tropism is defined as asymmetry in both the FJ angles of the lumbar and lumbosacral regions, with one joint having a more sagittal orientation than the other.[7] The role of FJ tropism in the pathogenesis of lumbar IVD degeneration and FJ osteoarthritis is not completely understood, and controversy exists surrounding the question of whether or not any significant relationship exists between facet tropism and the development of IVD or FJ degeneration.[7–9]

Regarding the relationship between FJ tropism and IVD degeneration, Boden et al.[7] and Vanharanta et al.[10] reported no significant correlation between FJ tropism and IVD degeneration. However, Noren et al.[11] documented that patients with lumbar IVD degenerative disease had a higher incidence of FJ tropism than the healthy population. Additionally, Dai[12] reported a significant correlation between FJ tropism and the degree of IVD degeneration in patients with degenerative spondylolisthesis. Kong et al.[13] observed no significant correlation between FJ tropism and IVD degeneration at lower lumbar regions in a large population of patients. However, a higher (but not statistically significant) incidence of highly degenerated IVDs at L4-L5 was observed within the FJ tropism group.

In contrast, regarding the relationship between facet tropism and facet degeneration, Grogan et al.[8] concluded that lumbar FJ tropism does not accelerate degeneration. They reported no significant differences in FJ degeneration between FJs with and without tropism. Furthermore, Kalichman et al.[14] studied a large sample of FJs and concluded that facet tropism was not associated with occurrence of FJ osteoarthritis or degenerative spondylolisthesis, but found a significant

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association between sagittal orientation and osteoarthritis of the lumbar FJs at levels L4-L5. One cadaveric study examining this relationship found an association between FJ tropism and facet sclerosis, but not between FJ tropism and a composite score of cartilage degeneration and sclerosis.[8] Another study found a significant association between FJ orientation and osteoarthritis, but little association between FJ tropism and osteoarthritis.[15] However, Kong et al.[13] suggests that FJ tropism is significantly correlated with FJ degeneration in segments involved with frequent segmental motion.

The nature of the relationship between FJ tropism and degeneration in the lumbar spine remains a controversial topic. Until now, FJ study was considered unequal because the subjects and methods were different, with comparison by simple computed tomography (CT) or magnetic resonance imaging (MRI). To our knowledge, there has not been evaluation of the relationship between FJ tropism and degeneration of FJs and IVDs based on histological study. The purpose of this study was to investigate the relationship between FJ tropism and degeneration of the lower lumbar spine based on the radiologic and histologic findings of FJs.

2. Methods

2.1. Subjects

We recruited 29 patients (14 women and 15 men) with a mean age of 65 years (range: 41–84 years) who underwent posterior lumbar interbody fusion (PLIF) after failed conservative treatment for longer than 3 months (mean: 48 months). All patients underwent routine CT (128-layer, high-speed helical CT, Siemens) and MRI (1.5 Tm, Siemens) before surgery, and 42 inferior articular processes (9 at L3, 23 at L4, and 10 at L5) were resected intraoperatively. We included patients with lumbar spinal stenosis, massive lumbar disc herniation, and degenerative spondylolisthesis. The exclusion criteria were lumbar spinal tumor, infectious disease, fracture, and prior surgical treatment.

2.2. Image evaluation

The criteria proposed by Pathria et al.[16] in estimating the degeneration of the FJ on CT were used: Grade 1, normal; Grade 2, narrowing of the FJ; Grade 3, narrowing plus sclerosis or hypertrophy; and Grade 4, severe osteoarthritis with narrowing, sclerosis, and osteophyte formation. Degeneration of the FJ on MRI was evaluated in accordance with the criteria used by Weishaupt et al.[17]: Grade 1, uniformly thick cartilage covering both articular surfaces completely, and a uniform, thin band of cortical bone; Grade 2, cartilage covering the entire surface with eroded or irregular regions, and a thin band of cortical bone extending into the joint space from the articular surface; Grade 3, cartilage incompletely covering the articular surface, with the underlying bone exposed to the joint space, and dense bone extending into the joint space, but covering less than half of the facet; and Grade 4, complete absence of cartilage, except for traces on the articular surface, with the presence of osteophytes or dense cortical bone covering greater than half of the FJ. We also used the grading system of Pfirrmann et al.[18] to define the degree of IVD degeneration on MRI: Grade I: the structure of the disc is homogeneous, with a bright hyperintense white signal and a normal disc height; Grade II: the structure of the disc is inhomogeneous with a hyperintense white signal, the distinction between the nucleus and annulus is clear, and the disc height is normal, with or without horizontal gray bands; Grade III: the structure of the disc is inhomogeneous with an intermediate gray signal intensity, the distinction between the nucleus and annulus is unclear, and the disc height is normal or slightly decreased; Grade IV: the structure of the disc is inhomogeneous with a hypointense dark gray signal, the distinction between the nucleus and annulus is lost, and the disc height is normal or moderately decreased; and Grade V: the structure of the disc is inhomogeneous with a hypointense black signal.

2.3. Evaluation of facet orientation and tropism

The FJ angle relative to the sagittal plane at L3–L4, L4–L5, and L5–S1 was measured on axial CT images, using bone windows and the method described by Noren et al.[11] On an axial scan that bisected the IVD, one line was drawn in the midsagittal plane of the vertebra and one through each FJ tangential to the superior articular process. Continuous FJ tropism was defined as the absolute difference of the angles between the right and left facets. In addition, according to the method described by Vanharanta et al.[10] for categorical FJ tropism, normal was less than 7° (Grade 1), moderate tropism was a difference of 7°–15° (Grade 2), and severe tropism was more than 15° (Grade 3).

2.4. Pathologic evaluation

The inferior articular processes were resected during PLIF and fixed in 10% neutral buffered formalin. The specimens were immersed in a solution containing 10% nitric acid and 1% ethylenediaminetetraacetic acid for decalcification. After dehydration, the specimens were embedded in paraffin, and a microtome was used to section them into 5-μm thickness, followed by dewaxing and washing. Finally, the sections were stained with Safranin O.

2.5. Statistical analysis

The consistency of radiographic and pathologic grading, as well as of CT and MRI grading based on histologic examination, was evaluated by consistent percentage and weighted kappa statistics. The kappa scores were classified into six categories: less than 0.00 (poor), 0.00 to 0.20 (slight), 0.21 to 0.40 (fair), 0.41 to 0.60 (moderate), 0.61 to 0.80 (substantial), and 0.81 to 1.00 (almost perfect).[19] All radiographic and pathologic grading was performed by two independent professionals, and the inter- and intra-observer agreement was estimated. Grading was reevaluated up to 4 weeks after the first assessment. Spearman's correlation statistical analysis was performed to compare FJ tropism and degeneration grading of FJ (histologic and radiologic) and IVD (MRI). SPSS (version 13) was used for the statistical analyses. For all computations, statistical significance was determined by $p < 0.05$.

3. Results

3.1. Histologic grading

The FJ samples acquired were classified into four different pathologic grades based on their inferior articular processes, loss of articular cartilage depth, chondrocyte shape, and subchondral bone morphology: Grade 1, smooth and intact surface, orderly chondrocyte distribution, a uniform lamellar subchondral bone plate, and an intact and uniform bone-cartilage junction (Fig. 1A); Grade 2, a cartilage surface showing flaking and fibrillation, minimal chondrocyte death, minor thickening of the trabeculae, and small fissures at the bone-cartilage junction (Fig. 1B); Grade 3, fissures with < 1/2 total depth, loss of cartilage with < 1/2 the normal depth, moderate chondrocyte death and hypertrophy, moderate trabecular thickening, and woven bone formation (Fig. 1C); and Grade 4, deep fissures, areas of total cartilage loss, extensive chondrocyte death, eburnation of exposed bone, bone sclerosis, cysts, and extensive fibrosis (Fig. 1D).

3.2. Inter-observer and intra-observer agreements

The agreement for radiologic FJ grading between readers 1 and 2 ranged from “moderate” to “almost perfect.” The weighted kappa coefficients by reader 1 for tropism, histologic, CT, and MRI grading of the FJ were 0.94, 0.74, 0.69, 0.49, and 0.85, respectively. The weighted kappa coefficients by reader 2 for tropism, histologic, CT and MRI grading of the FJ were 0.96, 0.78, 0.67, 0.49, and 0.87, respectively.

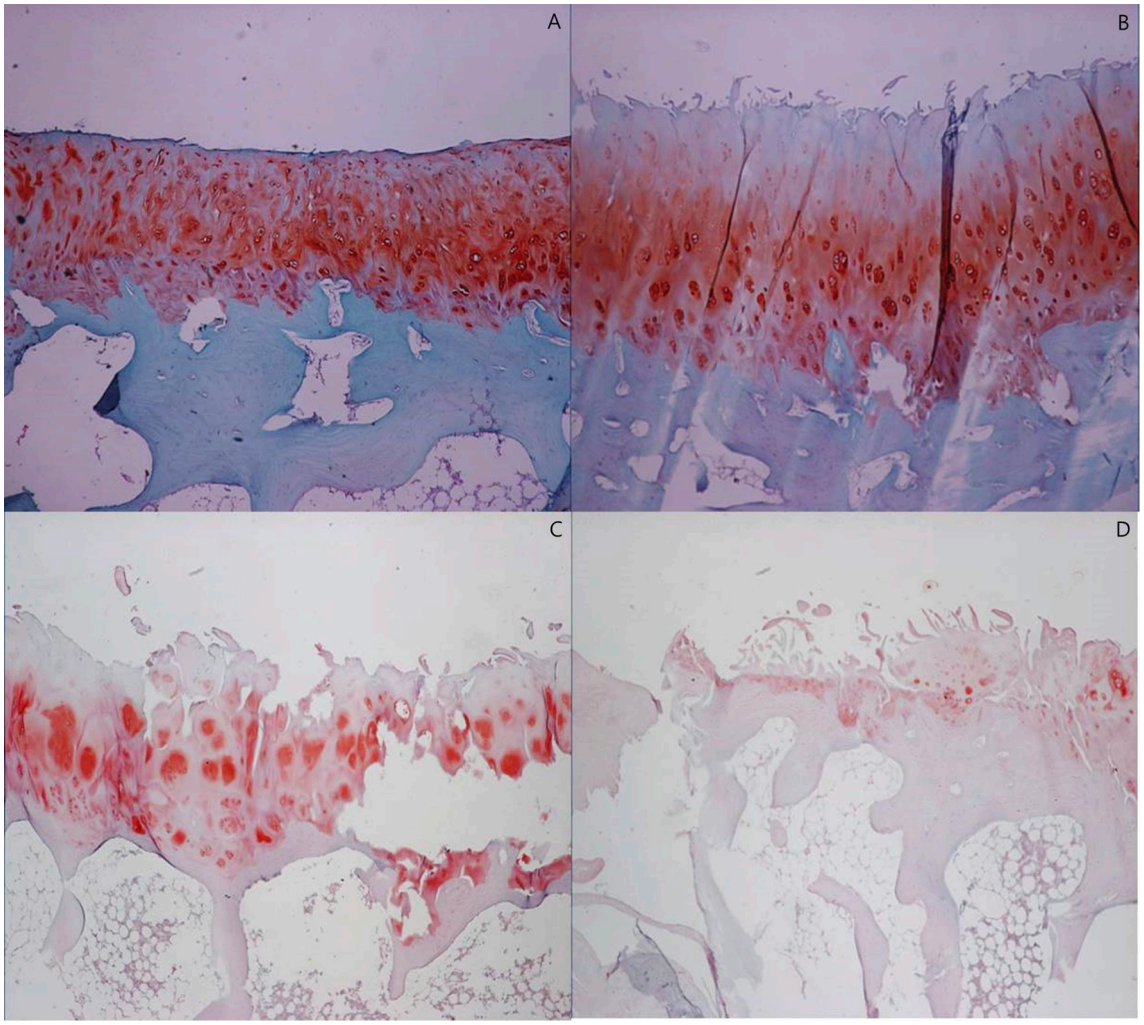

Fig. 1. The facet joints were classified into four different pathologic grades based on their inferior articular processes, loss of articular cartilage depth, shape of chondrocytes, and subchondral bone morphology. A: Grade 1, B: Grade 2, C: Grade 3, and D: Grade 4.

Table 1
Intraobserver agreement.

	Tropism (facet joint)		Histology (facet joint)		CT (facet joint)		MRI (facet joint)		MRI (disc)	
Reader	1	2	1	2	1	2	1	2	1	2
Exact estimate	40	41	35	36	35	34	32	30	38	38
	95.23	97.6	83.3	85.7	83.3	80.9	76.1	71.4	90.1	91.6
Wk	0.94	0.96	0.74	0.78	0.69	0.67	0.53	0.49	0.85	0.87

The weighted kappa coefficients by the two readers for IVD MRI grading were 0.85 and 0.87, respectively (Table 1).

Reader 1 assessed radiologic and histologic gradings twice to determine intra-observer agreement. In the first assessment, the weighted kappa coefficients for FJ tropism, histologic, CT, MRI, and IVD MRI grading were 0.94, 0.74, 0.69, 0.53, and 0.85, respectively. In the second assessment, the weighted kappa coefficients for FJ tropism, histologic, CT, MRI, and IVD MRI grading were 0.94, 0.78, 0.67, 0.49, and 0.87, respectively (Table 2).

Table 2
Interobserver agreement.

	Tropism (facet joint)		Histology (facet joint)		CT (facet joint)		MRI (facet joint)		MRI (disc)	
Reader	1	2	1	2	1	2	1	2	1	2
Exact estimate	40	40	35	36	35	34	32	30	38	38
	95.23	95.23	83.3	85.7	83.3	80.9	76.1	71.4	90.1	91.6
Wk	0.94	0.94	0.74	0.78	0.69	0.67	0.53	0.49	0.85	0.87

Table 3
Correlation between the FJ tropism, histologic, radiographic and IVD MRI gradings.

		FJ Histology	FJ MRI	FJ CT	FJ tropsim	Disc MRI
FJ Histology	CC	1.0	0.557	0.217	−0.159	0.018
	P		0.000	0.191	0.339	0.915
FJ MRI	CC	0.557	1.0	0.481	−0.270	0.208
	P	0.000		0.002	0.102	0.210
FJ CT	CC	0.217	0.481	1.0	0.025	0.226
	P	0.191	0.002		0.881	0.146
FJ tropism	CC	−0.159	−0.270	0.025	1.0	0.346
	P	0.339	0.102	0.881		0.033
Disc MRI	CC	0.018	0.208	0.226	0.346	1.0
	P	0.915	0.210	0.146	0.033	

3.3. Correlation between FJ tropism, facet histologic and radiographic grading, and IVD MRI grading

The correlation of FJ tropism with histologic, CT, and MRI grading was −0.159 (P = 0.339), 0.025 (P = 0.226) and −0.270 (P = 0.102), respectively. The correlation between FJ tropism and IVD MRI grading was 0.346 (P = 0.033). The correlation between FJ histologic grading and FJ CT, FJ MRI, and IVD grading was 0.317 (P = 0.031), 0.557 (P = 0.000), and 0.018 (P = 0.915), respectively. The correlation of FJ MRI grading with CT and IVD MRI grading was 0.481 (P = 0.002) and 0.208 (P = 0.210), respectively. The correlation between FJ CT and IVD MRI grading was 0.226 (P = 0.146) (Table 3).

4. Discussion

In this study, the degeneration of FJs were classified into four grades based on loss of articular cartilage depth, shape of chondrocytes, and subchondral bone morphology. However, this histologically detected degeneration was not associated with tropism of the FJ. However, tropism was correlated with MRI detected degeneration of the IVD from the same vertebral level. The degree of degeneration of FJs was consistent with that of histologic, CT, and MRI. There was no correlation between degeneration of the FJ and the IVD at the same vertebral level.

The criteria for determining facet tropism have varied greatly, although the actual definition of facet tropism is asymmetry between the right and left FJs. Noren et al.[11] defined facet asymmetry as a bilateral angle difference greater than 5°. In other biomechanical studies, facet asymmetry was defined as a difference in facet angles greater than 1–10° or one SD.[20] Karacan et al.[21] determined tropism when the angular difference of FJs on both sides was at least 4°, and Boden et al.[7] reported no facet tropism if the mean asymmetry was 6° or less, mild tropism if it was 6–10°, moderate tropism if it was 10–16°, and severe tropism if it was more than 16°. Vanharanta et al.[10] and Grogan et al.[8] divided FJ tropism into three distinct classifications, which were used in the current study: normal was less than 7°, moderate tropism was 7°–15°, and severe tropism was more than 15°.

A relationship between asymmetry of the lumbar facets and disc abnormality was suggested by many authors. As early as 1980, Cyron et al.[20] postulated that tropism could lead to instability, with the joints rotating toward the most oblique facet. Van Schaik et al.[22] used CT to measure tropism and found a relationship between facet tropism and disc herniation at the level of the fourth and fifth lumbar vertebrae. Noren et al.[11] used MRI to determine IVD degeneration, and CT to measure facet tropism, and reported an association between disc degeneration and facet tropism at all lumbar levels. Recently, Liu et al.[23] reported that the facet angles of a population with spinal stenosis were smaller than those of the control group and suggested that sagittalization of FJs may play a role in the pathology of degeneration lumbar spinal stenosis. Karacan et al.[21] demonstrated that the orientation of the FJ changed from the coronal to the sagittal plane (sagittalization) in patients with herniation of lumbar IVDs and facet asymmetry. Increases in body height were associated with decreased bilateral FJ angles and increased FJ asymmetry. Sagittal orientation resulting from lumbar disc herniation further reduces the cross-sectional area of the dural sac, which aggravates lumbar spinal stenosis.

In contrast, in 1981, Adams et al.[24] performed a biomechanical analysis and concluded that axial torsion was not important in the development of disc degeneration. Vanharanta et al.[10] studied the CT scans and discograms of 108 patients who had lower-back pain and concluded that there was no association between facet tropism and disc degeneration or provocation of pain. Kong et al.[13] did not observe significant correlation between lumbar facet tropism and disc degeneration or translational segmental motion. In the current study, the degenerative pathology grade on IVD MRI and FJ tropism were statistically related. This difference is thought to be due to variation in the subjects and comparative analysis methods in each study, as well as a lack of uniform standard for defining facet tropism and grading degeneration of IVDs. This study included patients with degenerative spinal disease who underwent PLIF, which could limit the natural correlation between facet and IVD degeneration.

Kong et al.[13] reported that facet tropism was shown to be significantly associated with the presence of high grades of FJ degeneration at L4-L5. This suggests that at sites of active segmental motion, facet tropism may predispose the FJ to degeneration. One cadaveric study examining this relationship found an association between facet tropism and facet sclerosis.[9] Fujiwara et al.[15] found a significant association between facet orientation and OA, but little association between facet tropism and OA. However, Kalichman et al.[14] did not find an association between facet tropism and occurrence of FJ OA or DS at L4-S1. It has been reported in several studies that the orientation of the facet rather than tropism has a greater effect on the degenerative changes of the disk and facet. However, since there is no standard definition of the degree of degenerative coronary classification by orientation, we selected tropism in this paper. In addition, we categorized the histopathologic classification of degeneration and the classification of tropism into three grades and the degree of histologic degeneration of the FJ was consistent with that of CT and MRI.

Tropism of the FJ is not correlated with the degeneration of the facet and the mechanism causing degeneration of the IVD is uncertain. Coronally facing FJs offer little resistance to shear intervertebral force, so that the joints tend to rotate toward that side, possibly leading to additional rotational stress on the annulus fibrosus.[20] When tropism was present, segmental motion was found to have a tendency to rotate towards the more oblique joint when axial loads were applied. This asymmetric axial rotation can place additional torsional loads on the IVDs, which can lead to injury and degeneration. There are two sides to this debate, one advocating that facet tropism leads to degeneration and the other claiming that certain degenerative conditions (i.e., degenerative spondylolisthesis) lead to facet tropism. Kong et al.[13] reported that, at active functional spine units, facet tropism partially influences the development of FJ degeneration. This gives legitimacy to the theory that facet tropism can lead to FJ degeneration, although further investigation into the nature of this relationship is necessary.

The current study only investigated patients who underwent PLIF and had severe posterior FJ and disc degenerations, including only a small number of patients with Grades 0 and 1 (FJ and IVD degeneration grade); further, the study also failed to account for potential age-related changes. The histologic analysis only included the inferior articular processes, and axial plane imaging was only conducted on visually severe portions of the samples, which limited pathologic analysis and prevented quantification of the data.

5. Conclusion

The current study showed that the FJ tropism was correlated with IVD degeneration, but not with FJ degeneration. In the same spinal

segment, FJ and disc degeneration do not necessarily match each other based on histologic and radiographic analysis. Finally, FJ histologic and radiologic findings were correlated with each other.

Conflicts of interest

The authors declare no conflict of interest in this study.

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