Kinematic Evaluation of Association between Disc Bulge Migration, Lumbar Segmental Mobility, and Disc Degeneration in the Lumbar Spine Using Positional Magnetic Resonance Imaging

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Abstract

Degenerative disc disease and disc bulge in the lumbar spine are common sources of lower back pain. Little is known regarding disc bulge migration and lumbar segmental mobility as the lumbar spine moves from flexion to extension. In this study, 329 symptomatic (low back pain with or without neurological symptoms) patients with an average age of 43.5 years with varying degrees of disc degeneration were examined to characterize the kinematics of the lumbar intervertebral discs through flexion, neutral, and extension weight-bearing positions. In this population, disc bulge migration associated with dynamic motion of the lumbar spine significantly increased with increased grade of disk degeneration. Although no obvious trends relating the migration of disc bulge and angular segmental mobility were seen, translational segmental mobility tended to increase with disc bulge migration in all of the degenerative disc states. It appears that many factors, both static (intervertebral disc degeneration or disc height) and dynamic (lumbar segmental mobility), affect the mechanisms of lumbar disc bulge migration.

Keywords

- lumbar disc bulge
- intervertebral disc degeneration
- disc height
- lumbar segmental mobility
- positional MRI

The human spine is subjected to large compressive forces during activities of daily living. Depending on the position of the spine, the axial load to the lumbar intervertebral discs can rise to levels approximately three times the weight of the body.[1] Mechanical loading of the lumbar spine, due to axial compression or dynamic motion, induces mechanical stresses upon the lumbar intervertebral discs. This is an important factor in the etiology of lumbar disc degenerative disease.[2] It is well known that degenerative pathology of the lumbar intervertebral disc can contribute to symptomatology, and recent studies have found that discogenic pain caused by annular tears can be a major cause of low back pain.[3–10] Because of this pathological basis, it may be important to evaluate lumbar disc degenerative disease under mechanical loading.

Positional magnetic resonance imaging (MRI) allows patients to be scanned in multiple weight-bearing positions. Previously, we demonstrated the efficacy of positional MRI for correctly diagnosing lumbar disc herniations typically missed using conventional MRI findings.[11] Because patients may be imaged in the exact positions that elicit symptoms, positional MRI may allow for a more complete evaluation of potential musculoskeletal pathology.

Numerous studies have evaluated the biomechanics of lumbar intervertebral discs.[4,6,8,9,12–15] Because disc degeneration plays an important role in patients with low back

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pain and these patients typically complain of symptoms during physical activity, we hypothesize that disc bulge migration associated with dynamic motion of the lumbar spine may greatly contribute to low back pain. We have previously demonstrated that lumbar disc bulge migration increases with greater disc degeneration.[16] The objective of the current study is to further characterize the motion kinematics of lumbar intervertebral disc bulge migration within different intervertebral disc degenerative states and to evaluate the association between disc bulge migration and translational and angular motion in the lumbar spine.

Materials and Methods

From February 2006 to May 2007, 329 symptomatic patients (212 men and 117 women) with an average age of 43.5 years (range 16 to 80 years) were examined. The subjects comprised consecutive patients experiencing low back pain with or without neurogenic symptoms induced by lumbar spondylosis. None of the subjects had previously undergone spinal surgery. An Institutional Review Board approved this study.

Positional MRI

Lumbar MRIs were obtained from each patient. The scanning was performed on a 0.6-T MRI scanner (Upright Multi-Position™; Fonar Corporation, New York, NY) in three upright, weight-bearing positions including flexion (−40 degrees), neutral (0 degrees), and extension (20 degrees) postures. The data obtained from the images were recorded on a computer for subsequent measurements, and all calculations were automatically performed using magnetic resonance analyzer software (True MRI Corporation, Bellflower, CA).[11] The differences observed between the flexion and extension positions were used to determine sagittal angular motion (in degrees) and sagittal translational motion (in millimeters). In addition, the intervertebral disc height (in millimeters) in the middle of the disc space and the sagittal diameter of the bulging disc (in millimeters) in three different postures at five distinct lumbar intervertebral disc levels (L1–2, L2–3, L3–4, L4–5, and L5-S1) were calculated.

Lumbar Intervertebral Discs

A comprehensive grading system for lumbar disc degeneration was developed by modifying previously reported systems of classifying lumbar intervertebral disc degeneration based on degenerative changes within the functional spinal unit.[17,18] Accordingly, neutral-position T2-weighted sagittal images of all the 1645 lumbar intervertebral discs from 329 subjects were classified into three grades (►**Table 1**) by the senior author and were judged eligible for inclusion in this study.

Lumbar Disc Bulging

Subjects with extruded or sequestered fragments of herniated discs on the MRIs were excluded from this study. The maximum and minimum sagittal diameters of the bulging disc (in millimeters) from the three different postures were utilized. The migration of disc bulge with dynamic motion of the lumbar spine was determined using the following equation: migration of disc bulge (in millimeters) = (maximum diameter of disc bulge) − (minimum diameter of disc bulge). All 1645 lumbar segments from 329 subjects were classified into three groups based on disc bulge migration: group A, migration of less than 1 mm; group B, migration of 1 to 2 mm; group C, migration of more than 2 mm.

Statistical Analysis

Statistical significance was calculated using the Student *t* test. Data were analyzed using SPSS (Version 13, Chicago, IL). A p value of less than 0.05 was considered statistically significant.

Results

Lumbar Disc Bulging

All of the disc bulge parameters (i.e., migration of disc bulge, maximum value of disc bulge, and minimum value of disc bulge) significantly increased as lumbar disc degeneration progressed. In addition, when each lumbar segment was individually analyzed, all disc bulge parameters also tended to increase with degenerative changes in the lumbar intervertebral discs (►**Table 2**). In each of the disc degenerative states, no significant differences in the minimum disc bulge value were observed between each group, and the values were almost identical. However, the maximum values of disc bulge in groups B and C showed significantly higher values when compared with that in group A (►**Table 3**).

Lumbar Disc Height

As disc degeneration progressed, disc height tended to decrease and a significant difference in disc height was observed between grades 1 and 3 degenerative discs. Additionally, in grade 1 discs, the disc height observed in groups B and C were significantly higher than that observed in group A. This trend was also observed in grade 2 discs; however, only the value corresponding to group C showed a significant difference when compared with that in group A. In grade 3 discs, no

Table 1 The Grading System for Lumbar Intervertebral Disc Degeneration

Grades	Nucleus Signal Intensity	Disc Height	Structure of FSU
1	Hyperintense	Normal	Without disc herniation
2	Intermediate/hypointense	Normal/slight decrease	With/without disc herniation
3	Hypointense	Decreased/collapsed	With disc herniation/osteophyte

FSU, functional spinal unit.

Table 2 Lumbar Disc Bulging for Each Lumbar Disc Degenerative Grade with Each Lumbar Segment

Segment	Disc Grades	*n*	Migration (mm)	Max (mm)	Min (mm)
Total	1	728	0.92 ± 0.63	2.74 ± 1.15	1.82 ± 0.95
	2	425	1.07 ± 0.82^c	3.44 ± 1.40^c	2.37 ± 1.18^c
	3	492	1.39 ± 0.90^c	4.41 ± 1.62^c	3.02 ± 1.37^c
L1–2	1	197	0.85 ± 0.63	2.41 ± 1.05	1.57 ± 0.83
	2	89	0.84 ± 0.48	2.67 ± 0.99	1.83 ± 0.90^a
	3	43	1.04 ± 0.87	3.32 ± 1.25^c	2.28 ± 1.20^c
L2–3	1	195	0.87 ± 0.52	2.57 ± 1.03	1.70 ± 0.91
	2	71	0.95 ± 0.58	3.19 ± 1.20^c	2.24 ± 1.15^c
	3	63	1.20 ± 0.75^c	3.73 ± 1.32^c	2.54 ± 1.10^c
L3–4	1	155	0.96 ± 0.64	2.87 ± 1.16	1.91 ± 0.96
	2	93	1.04 ± 0.81	3.35 ± 1.33^b	2.31 ± 0.99^b
	3	81	1.18 ± 0.70^a	4.25 ± 1.28^c	3.06 ± 1.26^c
L4–5	1	94	0.97 ± 0.54	3.18 ± 1.08	2.21 ± 1.00
	2	92	1.21 ± 0.91^a	4.18 ± 1.56^c	2.97 ± 1.35^c
	3	143	1.49 ± 0.95^c	4.74 ± 1.56^c	3.26 ± 1.28^c
L5-S1	1	87	1.06 ± 0.83	3.11 ± 1.35	2.05 ± 1.05
	2	80	1.29 ± 1.09	3.77 ± 1.33^b	2.48 ± 1.16^a
	3	162	1.59 ± 0.95^c	4.75 ± 1.80^c	3.16 ± 1.52^c

Compared with disc grade 1: $^a p < 0.05$, $^b p < 0.01$, $^c p < 0.001$.

significant differences in disc height were observed between each group (►**Table 3**).

Lumbar Segmental Mobility

With respect to angular segmental mobility, the values tended to decrease as lumbar disc degeneration progressed, and a significant difference was observed between grade 1 and 3 discs. In grade 1 discs, no significant differences in angular mobility were observed between each group. In grade 2 discs, angular mobility in groups B and C tended to be larger than that observed in group A, and only the value in group C showed a significant difference when compared with that in group A. In grade 3 discs, no significant differences in angular mobility were observed between each group (►**Table 3**).

With respect to translational segmental mobility, the values tended to increase as lumbar disc degeneration progressed, and a significant difference was observed between grades 1 and 3 discs. In grade 1 discs, translational mobility in groups B and C were significantly higher than that observed in group A. In grade 2 discs, translational mobility in group C tended to be higher than that in group A, although the difference was not significant. In grade 3 discs, translational mobility in group C was significantly larger than that in group A (►**Table 3**).

Discussion

The intervertebral disc, which is composed of the annulus fibrosus, nucleus pulposus, and the cartilaginous end plates, is the major anterior axial load-bearing element of the spine.[2] In addition, the spinal ligaments are important structures for stabilizing intervertebral discs, specifically the anterior and posterior longitudinal ligaments (ALL and PLL) respectively.[13] The ALL strongly buttresses the annulus fibrosus anteriorly, whereas the PLL offers only weak reinforcement to the tension of the posterior annulus fibrosus.[19]

In the nondegenerated state, applied forces to the intervertebral discs are distributed equally in all directions from within the nucleus, placing tension upon the annulus fibrosus. However, degenerative processes of the lumbar spine cause intervertebral discs and PLL to undergo changes that affect their load-bearing and tension-bearing characteristics. In the degenerated state, axial loads are transmitted through the thickened annular fibers without generating increased hydrostatic pressure in the relatively less hydrated nucleus.[2] The PLL may easily be affected by increased tension from the posterior annulus fibrosus. In our results, the maximum and minimum values corresponding to disc bulge in lumbar intervertebral discs significantly increased with degenerative changes, results consistent with previous studies.[16,20,21] In addition, disc bulge migration associated with dynamic motion of the lumbar spine significantly increased with degeneration. These results suggest that the degenerated discs may lose their ability to distribute mechanical loads properly in all directions, and tension upon the posterior annulus fibrosus may increase with degenerative changes. We hypothesize that the tension-bearing function of the PLL may not be able to withstand the increased tension from the posterior annulus fibrosus, which may lead to increased disc bulging.

Table 3 Lumbar Disc Bulging, Lumbar Disc Height, and Lumbar Segmental Mobility for Each Group with Each Lumbar Disc Degenerative Grade

Disc Grades	Groups	*n*	Max Value (mm)	Min Value (mm)	Disc Height (mm)	Angular Mobility (Degrees)	Translational Mobility (mm)
1		728			11.24 ± 1.92	7.94 ± 4.39	1.35 ± 1.04
	A	459	2.39 ± 1.00	1.82 ± 0.97	11.06 ± 1.90	7.92 ± 4.41	1.25 ± 1.00
	B	227	3.14 ± 0.94[c]	1.84 ± 0.91	11.41 ± 1.91[a]	7.96 ± 4.32	1.46 ± 1.08[a]
	C	42	4.29 ± 1.58[c]	1.71 ± 0.99	12.36 ± 1.75[c]	8.04 ± 4.63	1.80 ± 1.18[c]
2		425			11.07 ± 1.86	7.71 ± 4.49	1.47 ± 1.21
	A	225	2.94 ± 1.20	2.39 ± 1.18	10.92 ± 1.93	7.39 ± 4.14	1.43 ± 1.18
	B	150	3.68 ± 1.16[c]	2.39 ± 1.14	11.07 ± 1.79	7.68 ± 4.67	1.46 ± 1.19
	C	50	5.00 ± 1.53[c]	2.27 ± 1.27	11.74 ± 1.61[b]	9.26 ± 5.16[b]	1.72 ± 1.38
3		492			10.12 ± 2.21[c]	7.02 ± 4.36[c]	1.52 ± 1.37[a]
	A	184	3.66 ± 1.32	3.07 ± 1.31	10.12 ± 2.19	6.76 ± 4.34	1.42 ± 1.26
	B	207	4.46 ± 1.39[c]	3.03 ± 1.33	10.29 ± 2.21	7.42 ± 4.56	1.41 ± 1.28
	C	101	5.68 ± 1.75[c]	2.90 ± 1.53	9.77 ± 2.24	6.67 ± 3.91	1.91 ± 1.64[b]

Compared with disc grade 1 or group A: [a]$p < 0.05$, [b]$p < 0.01$, [c]$p < 0.001$.

Moreover, the minimum disc bulge values corresponding to each of the degenerative disc grades were nearly identical between each group despite the fact that the disc heights were vastly different. The maximum disc bulge values, however, significantly differed between groups, and a significant relationship between disc volume and maximum value of disc bulge was observed in the normal and moderately degenerated discs. These results suggest that the tension-bearing function of the PLL for a given disc degenerative state may be able to substantially withstand the tension of the posterior annulus fibrosus under minimal mechanical loading (i.e., weight-compressive force). However, under maximal mechanical loading (which includes weight-compressive and dynamic motion forces) upon normal and mildly degenerated discs, the extent of disc bulging is greatly affected by the volume of the disc, but in severely degenerated discs, no significant relationship was observed between maximum value of disc bulge and disc volume. We hypothesize that severe degenerative changes in lumbar intervertebral discs may lead to dysfunction of the anterior load-bearing element of the spine. As a result, the kinematics of disc bulge migration may be less influenced by disc volume and may be more influenced by other factors.

It is generally accepted that intervertebral disc degeneration progresses in three separate clinical stages: temporary dysfunction, instability, and stabilization.[22] In our results, angular segmental mobility tended to decrease with degenerative changes in the intervertebral disc, and translational segmental mobility tended to increase with degenerative changes in the intervertebral discs. No clear trends relating the migration of disc bulge and angular segmental mobility were observed. However, translational segmental mobility tended to increase with disc bulge migration in all of the degenerative disc states. These results suggest that translational segmental mobility, rather than angular segmental mobility, may play an important role in disc bulge migration resulting from dynamic motion of the lumbar spine. We hypothesize that a large translational segmental mobility may lead to increased annulus fibrosus strain in the lumbar intervertebral discs and that these changes can result in increased disc bulging.

In this study, we have demonstrated the kinematics associated with lumbar disc bulge migration using multi-position MRI. There were, however, certain limitations associated with the current study. We did not discuss the clinical manifestations associated with disc bulge migration such as degree of low back pain, degree of axial loading in each of the study groups (i.e., body weight or surface of the intervertebral discs), or pathology of posterior elements of the lumbar spine. Using the current investigation as a pilot study, we believe that further research involving a larger patient population may help resolve several unanswered issues associated with this study and clarify the details pertaining to the kinematics of lumbar disc bulge migration accompanied with low back pain.

Conclusions

We have shown that many factors (static factors, such as intervertebral disc degeneration or disc height, and dynamic factors, such as lumbar segmental mobility) affect the mechanisms of lumbar disc bulge migration. The ability of positional MRI to provide images of the lumbar spine with dynamic motion allows for perhaps a more complete evaluation of lumbar disc degenerative disease.

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