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Motion characteristics and related factors of Modic changes in the lumbar spine

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OBJECT Most studies of Modic changes (MCs) have focused on investigating the relationship between MCs and low-back pain, whereas the kinematic characteristics and degenerative disc disease associated with MCs are not well understood. To the authors' knowledge, no previous study has reported on the kinematics of MCs. The purpose of this study was to elucidate the relationship of MCs to segmental motion and degenerative disc disease.

METHODS Four hundred fifty symptomatic patients underwent weight-bearing lumbar kinematic MRI in the neutral, flexion, and extension positions. Segmental displacement and intervertebral angles were measured in 3 positions using computer analysis software. Modic changes, disc degeneration, disc bulging, spondylolisthesis, angular motion, and translational motion were recorded, and the relationship of MCs to these factors was analyzed using a logistic regression model. To control the influence of disc degeneration on segmental motion, angular and translational motion were analyzed according to mild and severe disc degeneration stages. The motion characteristics and disc degeneration among types of MCs were also evaluated.

RESULTS Multivariate analysis revealed that age, disc degeneration, angular motion, and translational motion were factors significantly related to MCs. In the severe disc degeneration stage, a significant decrease of angular motion and significant increase of translational motion were found in segments with MCs, indicating that a disorder of the endplate had an additional effect on segmental motion. Disc degeneration increased and angular motion decreased significantly and gradually as the type of MC increased. Translational motion was significantly increased with Type 2 MCs.

CONCLUSIONS Age, disc degeneration, angular motion, and translational motion were significantly linked to MCs in the lumbar spine. The translational motion of lumbar segments increased with Type 2 MCs, whereas angular motion decreased as the type of MC increased, indicating that Type 2 MCs may have translational instability likely due to degenerative changes. A disorder of the endplates could play an important role in spinal instability.

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KEY WORDS Modic changes; lumbar spine; kinematic analysis; magnetic resonance imaging; logistic regression analysis; degenerative disc disease

Modic changes (MCs) are bone marrow and endplate changes visible on MRI of patients with degenerative disc disease.[10,11] Modic Type 1 changes are hypointense on T1-weighted MRI and hyperintense on T2-weighted MRI, and are detected in areas with inflammation. Modic Type 2 changes are hyperintense on both T1- and T2-weighted MR images and are detected in areas with fatty degeneration. Modic Type 3 changes are hypointense on both T1- and T2-weighted MR images and detected in areas with sclerosis.

ABBREVIATIONS CI = confidence interval; MC = Modic change; OR = odds ratio.

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Many previous papers[2,10,11,16] associated with MCs in the lumbar spine have been published, but most of them are focused on the relationship between MCs and low-back pain.[5,14,17] Some previous studies[1,8,15] demonstrated the relationship between nonfusion after surgery and MCs, and have reported on the instability related to bone marrow changes without using MCs. To our knowledge, no study has reported on the kinematics of MCs. In addition, few studies have reported on the relationship between MCs and degenerative disc disease.

We hypothesized that lumbar MCs have some relationship to segmental motion and degenerative disc disease in the process of degenerative changes. The objective of this study was to evaluate how MCs relate to segmental lumbar motion and degenerative disc disease using kinematic MRI.

Methods

Patient Population

Four hundred fifty consecutive symptomatic patients (267 men and 183 women) with an average age of 44.6 ± 12.2 years (range 17–77 years) were examined from March 2011 to October 2011. The inclusion criteria were defined as patients who had low-back pain with or without neurological symptoms. The exclusion criteria were trauma, infection, rheumatoid arthritis, spinal tumors, and history of lumbar spine surgery. A total of 2250 lumbar discs from L1–2 to L5–S1 were retrospectively evaluated for all patients in this study. The Institutional Review Board of the University of California at Los Angeles approved this study and informed consent was obtained from all participants.

Kinematic MRI

MRI of the spine was performed using a 0.6-T MRI machine (Upright Multi-Position, Fonar Corp.). Two vertically orientated, opposing magnetic doughnuts placed 18 inches apart were used, allowing scanning of the patient sitting in an upright, axially loaded position. A quad-channel planar coil was used to obtain images. We examined the T1-weighted sagittal spin echo images (TR 671 msec, TE 17 msec, thickness 4.0 mm, field of view 30 cm, matrix 256 × 224, number of excitations 2) and T2-weighted fast spin echo images (TR 3000 msec, TE 140 msec, thickness 4.0 mm, field of view 30 cm, matrix 256 × 224, number of excitations 2) of each patient. All patients were scanned in the flexion, neutral, and extension positions.

MRI Analysis

Midsagittal T2-weighted MR images were marked for digitization by 3 spine surgeons on the flexion, neutral, and extension position images. Vertebral bodies were marked at 4 points (anterior-inferior, anterior-superior, posterior-superior, and posterior-inferior) from L-1 to S-1. The lowest lumbar vertebra was defined as L-5. All MRI parameters were recorded by computer-based measurements, and all calculations were performed with the MRI Analyzer anatomical software (version 3, Truemetric Corp.) for objective quantification as described in prior publications.[6,13,19,20]

Disc bulging was measured as the extension of the disc beyond the intervertebral space, with a greater value representing greater posterior bulging.[19,20] Spondylolisthesis was measured as the displacement of 1 vertebral body on the adjacent level below in the anterior or posterior direction as observed on the neutral image.[13]

Segmental mobility was measured in terms of translational motion and angular motion (Fig. 1). Translational motion was defined as an anterior to posterior shift of the vertebral body during translation and was calculated by measuring the distance of one segment over another in millimeters using T2-weighted sagittal images.[3,6,13] Angular motion was defined as the angle of difference between each vertebral body in flexion and extension.[3,6,13] This was measured by drawing lines along the superior borders of adjacent vertebrae of each motion segment and extending them until they joined. The difference between the two angles, which were not direction dependent, was then calculated.

Assessment of MCs

Modic changes were also evaluated for 2250 segments from L1–2 to L5–S1 and classified into none or Types 1, 2, and 3, according to their signal patterns on T1- and T2-weighted sagittal MR images. Type 1 MCs had a hypointense signal on T1-weighted sequences and a hyperintense signal on T2-weighted sequences. Type 2 MCs had a hyperintense signal on T1-weighted sequences and hyper- or isointense signal on T2-weighted sequences. Type 3 MCs had a hypointense signal on T1- and T2-weighted sequences.[10,11] The intra- and interobserver reliability of the ratings for MCs were assessed using the κ value with a subset of 50 cases (250 intervertebral levels).

Assessment of Degenerative Disc Change

Disc degeneration was classified into 5 grades using T2-weighted sagittal MR images according to the grading system proposed by Pfirrmann et al.[12] Grade I indicated normal, whereas Grade V indicated the most advanced disc degeneration. Intra- and interobserver reliability for this grading system was previously reported.[13]

Statistical Analysis

The Mann-Whitney U-test was used for comparisons of disc degeneration, disc bulging, spondylolisthesis, angular motion, and translational motion. According to correction with Bonferroni's inequality in the Kruskal-Wallis test, a p value less than 0.0125 (0.05/4) was considered statistically significant for comparison among types of MCs. After the variables were categorized, the chi-square test was used for the comparisons. Logistic regression analyses were used to compute odds ratios (ORs) and 95% confidence intervals (CIs) and detect the association between the existence of MCs and related factors. The variables in the multivariate model were clinically important from previous reports, regardless of statistical significance.[9,14] Disc degeneration grade was categorized into mild (Grades I–III) and severe (Grades IV and V). Age, spondylolisthesis, disc bulging, angular motion, and translational motion were di-

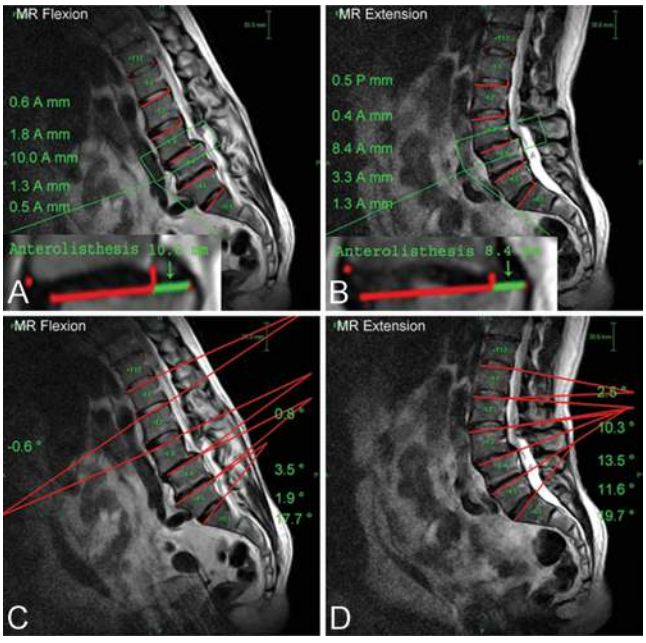

FIG. 1. Examples of translational and angular motion from flexion to extension as measured by MR Analyzer computer-based software on sagittal MR images. **A:** Translational motion in flexion. **B:** Translational motion in extension. Total translational motion was calculated as the absolute value of the difference between flexion and extension. **C:** Angular motion in flexion. **D:** Angular motion in extension. Total angular motion was calculated as the absolute value of the difference between the angle between adjacent vertebral bodies in flexion and in extension in degrees. Tan et al: Kinetic magnetic resonance imaging analysis of lumbar segmental mobility in patients without significant spondylosis. *Eur Spine J 21:*2673–2679, 2012. Copyright Springer. Reproduced with kind permission from Springer Science and Business Media. Figure is available in color online only.

vided into 2 groups, establishing the cutoff points at the median because no definitive cutoff point was found in a previous paper. Statistical analyses were performed using SPSS computer software (version 20, IBM Corp.) and values were expressed as mean ± SD. A p value less than 0.05 was considered statistically significant. According to Landis and Koch,[7] the reliability of diagnosis was assessed as follows: $\kappa = 0$–0.2 indicated slight agreement, 0.21–0.4 fair agreement, 0.41–0.6 moderate agreement, 0.61–0.8 substantial agreement, and 0.81–1 excellent agreement.

Results

Prevalence of MCs

Modic changes were observed in 129 (28.7%) of 450 patients. One hundred sixty-four (7.3%) of 2250 lumbar segments had MCs: Type 1 in 43 segments, Type 2 in 115, and Type 3 in 6. Modic changes were most frequent at L5–S1 followed by L4–5 and L3–4.

Reliability of Diagnosis of MCs

The interobserver agreement was substantial with a κ value of 0.77. Also, the intraobserver agreement was excellent with a κ value of 0.82.

Link to Disc Degeneration, Disc Bulging, Spondylolisthesis, Angular Motion, and Translational Motion at Each Level

The relationship between MCs and disc degeneration grade, disc bulging, spondylolisthesis, angular motion, and translational motion at each level are shown in Table 1. Analysis of disc degeneration revealed significant differences between the group with MCs and the group without MCs in all segments, indicating that the segments with MCs had more severe disc degeneration. A significant increase in disc bulging was observed at all segments except L5–S1 between units with MCs and those without MCs. Also, a significant increase in spondylolisthesis was observed at L1–2, L4–5, and L5–S1 in the group with MCs. In terms of kinematic analyses, a significant decrease in angular motion was found at L2–3, L3–4, and L4–5 in units with MCs, and a significant increase in translational motion was observed at all segments with MCs except L5–S1.

TABLE 1. Comparison between patients with and without MCs at each level

Variable	MCs	No MCs	p Value
Disc degeneration grade			
L1–2	3.7 ± 1.3	2.1 ± 0.7	0.001
L2–3	4.1 ± 0.9	2.2 ± 0.8	<0.001
L3–4	4.0 ± 1.0	2.3 ± 0.9	<0.001
L4–5	4.1 ± 0.7	2.6 ± 1.3	<0.001
L5–S1	4.2 ± 0.7	2.7 ± 1.2	<0.001
Disc bulge (mm)			
L1–2	3.5 ± 1.1	2.6 ± 0.9	0.038
L2–3	3.7 ± 1.2	2.9 ± 1.0	0.01
L3–4	3.7 ± 1.3	3.2 ± 1.1	0.03
L4–5	4.3 ± 1.7	3.6 ± 1.3	0.006
L5–S1	4.3 ± 1.9	4.1 ± 1.7	0.39
Spondylolisthesis (mm)			
L1–2	1.5 ± 0.9	0.6 ± 0.6	0.001
L2–3	1.1 ± 1.0	0.8 ± 0.7	0.24
L3–4	2.0 ± 2.5	0.8 ± 0.7	0.07
L4–5	2.1 ± 2.3	1.2 ± 1.1	0.02
L5–S1	3.3 ± 2.7	2.4 ± 1.7	0.007
Angular motion (°)			
L1–2	7.8 ± 4.8	6.6 ± 3.7	0.44
L2–3	6.0 ± 2.8	8.1 ± 3.9	0.03
L3–4	5.5 ± 3.5	8.2 ± 4.3	0.002
L4–5	6.0 ± 3.5	7.9 ± 5.0	0.039
L5–S1	5.2 ± 3.9	5.8 ± 4.5	0.31
Translational motion (mm)			
L1–2	2.6 ± 1.4	1.3 ± 0.9	0.003
L2–3	2.3 ± 1.7	1.4 ± 1.0	0.03
L3–4	2.3 ± 2.7	1.1 ± 0.9	0.03
L4–5	1.7 ± 2.0	1.0 ± 0.9	0.03
L5–S1	1.2 ± 1.4	1.0 ± 0.9	0.47

TABLE 2. Difference between segments with and without MCs in the mild and severe disc degeneration groups

Motion	Mild (Grade I–III)			Severe (Grade IV & V)		
	No MCs	MCs	p Value	No MCs	MCs	p Value
Angular	7.5 ± 4.3	6.8 ± 3.6	NS	6.8 ± 4.6	5.3 ± 3.7	0.002
Translational	1.2 ± 0.9	1.5 ± 1.3	NS	1.2 ± 1.0	1.6 ± 2.0	0.04

NS = Not significant.

Segmental Motion With and Without MCs in Mild and Severe Disc Degeneration Stage

To control the influence of disc degeneration on segmental motion, angular and translational motion were analyzed according to mild (Grades I–III) and severe (Grades IV and V) disc degeneration stage (Table 2). No significant differences were observed between the groups without and with MCs with mild disc degeneration, whereas a significant decrease of angular motion and significant increase of translational motion were found in the group with MCs with severe disc degeneration. This result indicates that segmental motion is affected by the presence of MCs in patients with severe disc degeneration. The disorder of the endplate would have an additional effect on segmental motion.

Factors Related to MCs

Factors potentially related to the changes were evaluated using the chi-square test and logistic regression analysis to control confounding factors (Table 3). Using univariate analysis, significant differences were found in age, disc degeneration, spondylolisthesis, disc bulging, and angular motion. Next, a multiple logistic regression model was used to adjust for age, sex, levels, disc degeneration, spondylolisthesis, disc bulging, angular motion, and translational motion, which were factors likely to relate to MCs and segmental motion. After adjustment for potential confounding factors, significantly elevated ORs were observed in segments with age > 45 years (OR 2.11, 95% CI 1.41–3.15), severe disc degeneration (OR 11.3, 95% CI 7.33–17.4), angular motion ≤ 6.8° (OR 1.70, 95% CI 1.17–2.48), and translational motion > 1.0 mm (OR 1.45, 95%

TABLE 3. Analysis of related factors to MCs

Factor	No. of Discs (%)		p Value*	Crude OR (95% CI)	Adjusted OR†† (95% CI)
	No MCs (n = 2086)	MCs (n = 164)			
Age (yrs)					
≤45	1108 (53)	42 (26)		Reference	Reference
>45	978 (47)	122 (74)	<0.001	3.29 (2.29–4.72)†	2.11 (1.41–3.15)†
Disc degeneration					
Mild (Grades I–III)	1704 (82)	31 (19)		Reference	Reference
Severe (Grades IV–V)	382 (18)	133 (81)	<0.001	19.1 (12.7–28.7)†	11.3 (7.33–17.4)†
Spondylolisthesis (mm)					
≤0.8	1123 (54)	45 (27)		Reference	Reference
>0.8	963 (46)	119 (73)	<0.001	3.08 (2.16–4.39)†	1.47 (0.98–2.20)
Disc bulge (mm)					
≤3.1	1100 (53)	46 (28)		Reference	Reference
>3.1	986 (47)	118 (72)	<0.001	2.86 (2.01–4.07)†	1.10 (0.74–1.65)
Angular motion (°)					
≤6.8	1026 (49)	112 (68)		2.23 (1.58–3.13)†	1.70 (1.17–2.48)†
>6.8	1060 (51)	52 (32)	<0.001	Reference	Reference
Translational motion (mm)					
≤1.0	1120 (54)	84 (51)		Reference	Reference
>1.0	966 (46)	80 (49)	0.541	1.10 (0.80–1.52)	1.45 (1.01–2.09)†

* Calculated using the chi-square test.

† $p < 0.05$, calculated by the univariate and multivariate analyses.

†† The logistic regression model was adjusted for age, sex, level, disc degeneration, spondylolisthesis, disc bulge, angular motion, and translational motion.

CI 1.01–2.09). Although the crude OR for translational motion was not significant (OR 1.10, 95% CI 0.80–1.52), it increased to significance after adjustment for several potential confounders.

Motion Characteristics of Types of MCs

The mean value of the disc degeneration grade in each MC type was 2.4 ± 1.0 for Type 0, 3.8 ± 0.9 for Type 1, 4.2 ± 0.7 for Type 2, and 5.0 ± 0.0 for Type 3. The analysis of disc degeneration among types of MCs showed a significant increase between Type 0 and Type 1, Type 1 and Type 2, and Type 2 and Type 3 ($p < 0.001$, $p = 0.004$, and $p = 0.004$, respectively) (Fig. 2). The analysis of angular motion among types of MCs showed Type 3 had significantly less than other types, and Type 2 was significantly less than Type 0 (Type 1 and 3, $p = 0.003$; Type 2 and 3, $p = 0.003$; Type 0 and 3, $p = 0.004$; Type 0 and 2, $p < 0.001$), indicating Types 2 and 3 had less angular motion (Fig. 3). The analysis of translational motion among types of MCs revealed a significant increase between Type 0 and 2 ($p = 0.006$), indicating Type 2 changes had more translational instability than Type 0 (Fig. 4).

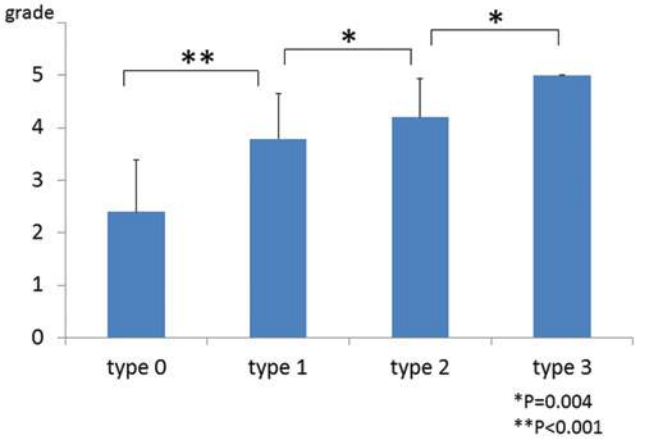

FIG. 2. Bar graph of disc degeneration grade (1–5) and types of MC. A significant increase of disc degeneration grade was observed between Type 0 and Type 1, Type 1 and Type 2, and Type 2 and Type 3. Figure is available in color online only.

Discussion

A thorough understanding of lumbar segmental motion is valuable to treat patients with degenerative lumbar disease, but kinematics associated with MCs in the lumbar spine have not been well understood. Our multivariate analysis showed MCs were significantly related to angular motion and translational motion. In addition, we were able to identify the details of the motion change among the types of MCs. Our study showed significant decreases in angular motion of Type 2 and Type 3 MCs and a significant increase in translational motion of Type 2. To the best of our knowledge, this is the first study assessing the relationship between segmental motion and MCs.

The reason for the decreased angular motion of Type 2 and Type 3 may be related to the disc degeneration grade. The relationship between disc degeneration and motion was studied by Kong et al.,[6] who reported a kinematic analysis of the relationship between the grade of disc degeneration and motion of the segmental unit of the lumbar spine, and demonstrated that angular motion significantly decreased in severely degenerated segments (Grade V). Their study was consistent with our results because we showed a significant increase of disc degeneration grade associated with an increase in the type of MCs (Fig. 2). Decreased or collapsed disc height due to degenerative change would result in decreased angular motion.

The reason for the increased translational motion also might be related to the disc degeneration grade. Translational motion was reported to be significantly increased in more advanced disc degeneration grade except for Grade V.[6] In addition, Kirkaldy-Willis and Farfan[4] postulated 3 stages with different conditions of stability and motion in the degenerative lumbar spine: dysfunction, instability, and stabilization. Their reports were consistent with our results of translational motion. Increased translational motion at Type 2 may indicate the stage of instability. The mean values of angular motion and translational motion in Type 3 were least among all types, suggesting that the segments with Type 3 may tend to ankylose and lose mobility with severe degeneration.

Interestingly, the significant difference of segmental motion between groups with and without MCs in the severe disc degeneration group suggests that segmental motion may not only be affected by disc degeneration but also by MCs themselves. Spinal instability associated with endplate disruption was reported by Zhao et al.[18] in a cadaveric motion segment experiment. They demonstrated that endplate disruption contributed more to instability than disc dehydration. Thus, in addition to disc degeneration, a disorder of the endplate would also play an important role in segmental instability and have an additional effect on segmental motion.

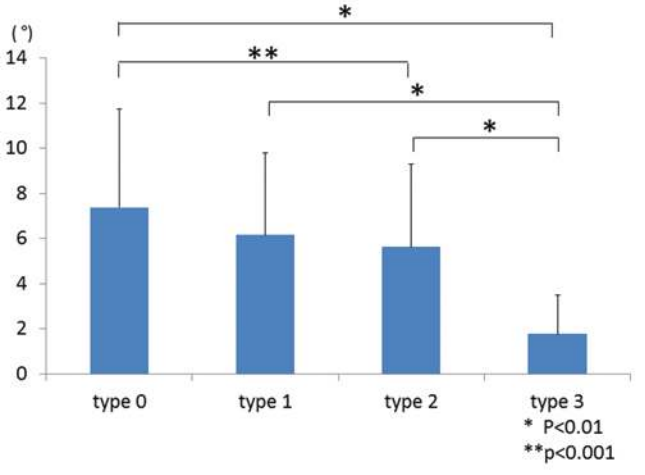

FIG. 3. Bar graph of angular motion (°) and types of MC. A significant decrease in angular motion was found between Type 3 and the other types, and between Type 2 and Type 0. Figure is available in color online only.

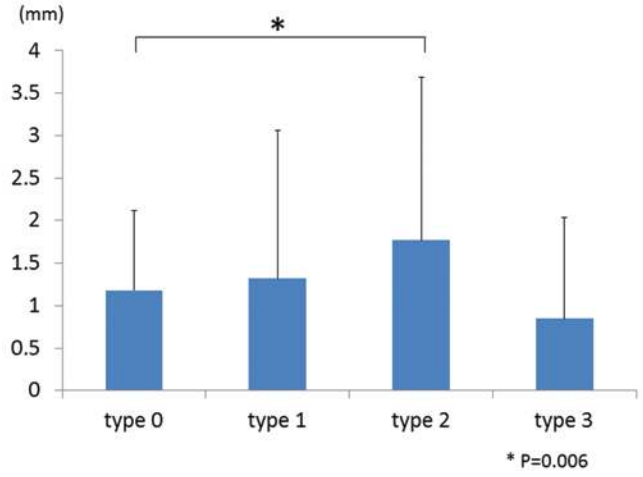

FIG. 4. Translational motion (mm) and types of MC. A significant increase in translational motion was found between Type 0 and 2. Figure is available in color online only.

Although MCs are widely accepted as the change associated with degenerative disc disease or spondylosis, few previous papers have reported on the relationship between MCs and disc bulging and between MCs and spondylolisthesis. Thompson et al.[14] reported that Type 1 MCs show some value in predicting disc herniation and spondylolisthesis compared with non–Type 1 MCs. Jensen et al.[2] reported that bulges or herniations at 40 years of age were the only predictors of new vertebral endplate signal changes at 44 years of age. Mann et al.[9] reported in their study of cervical MCs that patients with MCs are more likely to have a disc herniation at the same level. Our study showed disc bulging and spondylolisthesis were significantly related to MCs using the chi-square test and univariate regression analyses; however, after adjustment for confounding factors, the significant difference disappeared. Because disc degeneration would be the most influential factor in any kind of degenerative disc disease, the variables of disc bulging and spondylolisthesis may be statistically skewed in the multivariable analysis.

The present study has certain limitations. A relatively small number of segments with MCs, especially Type 3, may have reduced the statistical power, although the prevalence of MCs was consistent with previous studies.[17] Larger numbers of older patients in future research may resolve this limitation. Although the common method to assess the motion would be flexion and extension radiographs, we evaluated segmental motion with MRI. This difference might affect the values of measurements.

Clinically, our study suggests that the segments with MCs should be evaluated carefully because MCs may be a sign of a disc bulge or herniation. Moreover, MCs are one of the factors associated with segmental motion. The presence and status of MCs should be taken into consideration when evaluating stability in the lumbar spine. Characterizing the type of MCs observed on MRI may be one of the important factors to take into account when making a decision for or against spinal fusion.

Conclusions

Patient age, disc degeneration, angular motion, and translational motion are significantly linked to MCs in the lumbar spine. Disc degeneration grade increased significantly as the type of MC increased. Angular motion decreased as the type of MC increased, and translational motion significantly increased with Type 2 MCs compared with Type 0 MCs.

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