Retrolisthesis as a Compensatory Mechanism in Degenerative Lumbar Spine

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Objective: Posterior vertebral translation as a type of spondylolisthesis, retrolisthesis is observed commonly in patients with degenerative spinal problems. Nevertheless, there is insufficient literature on retrolisthesis compared to anterolisthesis. The purpose of this study is to clarify the clinical features of retrolisthesis, and its developmental mechanism associated with a compensatory role in sagittal imbalance of the lumbar spine.

Methods: From 2003 to 2012, 230 Korean patients who underwent spinal surgery in our department under the impression of degenerative lumbar spinal disease were enrolled. All participants were divided into four groups: 35 patients with retrolisthesis (group R), 32 patients with simultaneous retrolisthesis and anterolisthesis (group R+A), 76 patients with anterolisthesis (group A), and 87 patients with non-translation (group N). The clinical features and the sagittal parameters related to retrolisthesis were retrospectively analyzed based on the patients’ medical records.

Results: There were different clinical features and developmental mechanisms between retrolisthesis and anterolisthesis. The location of retrolisthesis was affected by the presence of simultaneous anterolisthesis, even though it predominantly manifests in L3. The relative lower pelvic incidence, pelvic tilt, and lumbar lordosis compared to anterolisthesis were related to the generation of retrolisthesis, with the opposite observations of patients with anterolisthesis.

Conclusion: Retrolisthesis acts as a compensatory mechanism for moving the gravity axis posteriorly for sagittal imbalance in the lumbar spine under low pelvic incidence and insufficient intra-spinal compensation.

Key Words: Spondylolisthesis · Retrolisthesis · Sagittal imbalance · Lumbar spine.
Measurement of slippage

The amount of slippage in retrolisthesis or anterolisthesis was measured as the distance between two posterior perpendicular lines over the transverse line of the upper or lower endplate of each vertebra on a lateral neutral film. Retrolisthesis and anterolisthesis were respectively defined as a backward slippage of ≥2 mm and a forward slippage of ≥3 mm on a static lateral lumbar radiograph.

Evaluation of clinical features related to spondylolisthesis

All radiological evaluation was done by two observers, and inter-observer reliability was analyzed for every measurement. Each group was investigated with respect to age; sex; level of spondylolisthesis; direction of slip (anterior or posterior); LL (the angle between the superior endplates of L1 and S1); PI (defined as the angle between the line connecting the center of rotation of the hip joint to the midpoint of the endplate of S1 and perpendicular to the endplate of S1 at its midpoint); PT (defined as the angle between the superior endplate of S1 and the horizontal plane); SS (defined as the angle between a line joining the midpoint of the superior endplate of S1 and the center of rotation of the hip with the vertical plane); amount of disc (Pfirrmann classification, I–V; based on the T2-weighted mid-sagittal MRI scan of the lumbar spine) and facet joint (Weishaupt grade, 0–3, measured as the angle subtended by a line along the long axis of the facet articulation within the midline on T2-weighted axial scan of MRI of the lumbar spine) degeneration; facet joint angulation in the horizontal plane (defined as the angle between a line along the two points at the anteromedial and posterolateral margins of each facet with respect to a coronal reference plane on the posterior wall of the vertebral body); and the existence of instability (difference of slippage of ≥3 mm or angulation ≥10 degrees on a dynamic lateral lumbar radiograph).

Statistical analysis

Student’s t-test and one-way analysis of variance for each parametric continuous variable, as well as Mann-Whitney U test and Kruskal-Wallis test for each non-parametric continuous variable, were used for comparing statistical differences. Each categorical variable between each study group was compared using chi-square test, Fisher’s exact test, and linear-by-linear association method.

Inter-observer reliability between the measurements of two observers was analyzed using kappa coefficient for categorical variables and Pearson’s correlation coefficient and intra-class correlations (ICC; two-way mixed model with consistency agreement; 95% confidence interval) for continuous variables. ICC and Cohen’s kappa coefficient values determine their classifications: poor (0.00–0.40), fair (0.40–0.59), good (0.60–0.79), and excellent (0.80–1.00). Statistical analysis was carried out using SPSS version 20.0 software (SPSS Inc., Chicago, IL, USA), and probability values of <0.05 were considered statistically significant.

RESULTS

Clinical characteristics of retrolisthesis and anterolisthesis

Disc degeneration

There was no significant statistical difference between the mean Pfirrmann’s scores at the level of either retrolisthesis and anterolisthesis in group R+A (p=0.797 in observer 1, p=0.587 in observer 2) (Table 1).

Facet joint degeneration

There was a significant statistical difference between the mean Weishaupt grades at the level of either retrolisthesis and anterolisthesis in group R+A (p=0.000 in observers 1 and 2) (Table 1).
The degeneration gap among disc and facet joint (Pfirrmann’s score minus Weishaupt grade) at the level of either retrolisthesis or anterolisthesis

There was a significant statistical difference between the degeneration gap among disc and facet joint at the level of either retrolisthesis or anterolisthesis in group R+A ($p=0.000$ in observer 1, $p=0.136$ in observer 2) (Table 1).

Facet joint angulation in the horizontal plane

There was no significant statistical difference between the mean facet joint angles at the level of retrolisthesis and anterolisthesis in group R+A ($p=0.108$ in observer 1, $p=0.016$ in observer 2) (Table 1).

Incidence of instability

There was a significant statistical difference in the incidence of instability between group R (3/40 in observer 1, 4/40 in observer 2) and anterolisthesis (18/38 in observer 1, 17/38 in observer 2) in group R+A ($p=0.000$ in observer 1, $p=0.001$ in observer 2) (Table 1).

Prevalence level of retrolisthesis

L3 was the level with the most frequently developing retrolisthesis in groups (group R and R+A), and there was a significant statistical difference of prevalence level between two groups ($p=0.022$ in observers 1 and 2). The retrolisthesis has a tendency to dominate on L3 and below level in group R, and L3 and above level in group R+A (Table 2).

Sagittal parameters related to spondylolisthesis

**Age**

There was no significant statistical difference in age between four groups ($p=0.633$) (Table 3).

**Sex**

There was a significant difference in sex distribution across the four groups ($p=0.001$). Females dominated group A (Table 3).

**Pelvic incidence**

There was a significant statistical difference in the mean PI across the four groups ($p=0.002$ in observer 1, $p=0.000$ in observer 2). Group A has a tendency of greater PI compared to that of the other three groups (Table 3).

**Sacral slope**

There was a significant statistical difference in the mean LL across the four groups ($p=0.002$ in observer 1, $p=0.019$ in observer 2). Group R (in observer 1) or group R and N (in observer 2) has a tendency towards lower SS compared to that of other groups (Table 3).

**Pelvic tilt**

There was a significant statistical difference in the mean PT among disc and facet joint (Pfirrmann’s score minus Weishaupt grade) at the level of either retrolisthesis or anterolisthesis in group R+A ($p=0.000$ in observer 1, $p=0.001$ in observer 2) (Table 1).

**Facet joint angulation in the horizontal plane**

There was no significant statistical difference between the mean facet joint angles at the level of retrolisthesis and anterolisthesis in group R+A ($p=0.108$ in observer 1, $p=0.016$ in observer 2) (Table 1).

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**Prevalence level of retrolisthesis**

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### Table 1. Clinical characteristics of retrolisthesis and anterolisthesis in group R+A

| Clinical characteristics | Retrolisthesis (total=40 levels) | Anterolisthesis (total=38 levels) |
|--------------------------|----------------------------------|----------------------------------|
|                          | Observer 1                       | Observer 2                       |
|                          | [ICC (95% CI)/PC]                | [ICC (95% CI)/PC]                |
| Disc degeneration        | 4.08±0.47                       | 4.10±0.44                       |
|                          | [0.900 (0.811–0.947)/0.820]      | [0.952 (0.907–0.975)/0.915]      |
| Facet joint degeneration*| 1.75±0.74                       | 1.87±0.75                       |
|                          | [0.922 (0.852–0.959)/0.855]      | [0.938 (0.881–0.968)/0.892]      |
| Disc-facet joint degeneration* | 2.32±0.80               | 2.27±0.93                       |
|                          | [0.717 (0.465–0.850)/0.566]      | [0.517 (0.07–0.749)/0.348]       |
| Facet joint angulation*  | 62.44±20.09                     | 65.13±20.12                     |
|                          | [0.887 (0.786–0.940)/0.798]      | [0.809 (0.632–0.901)/0.690]      |
| Incidence of instability (%)* | 3/40 (7.5)            | 4/40 (10)                       |
|                          | 18/38 (47.3)                    | 17/38 (44.7)                    |
|                          | Kappa=0.844                     | Kappa=0.947                     |

Group R+A : simultaneous retrolisthesis and anterolisthesis (32 patients). Student’s t-test, Mann-Whitney U test, and chi-square test were used for statistical analysis. *$p<0.05$; interclass correlation (ICC), Cohen’s kappa coefficient, and Pearson’s coefficient (PC) were used for the reliability of sagittal parameter between two observers. CI : confidence interval

### Table 2. Prevalence level of developing retrolisthesis depends on the presence of anterolisthesis

| Groups | Location of retrolisthesis (kappa=1)* |
|--------|--------------------------------------|
|        | L1 | L2 | L3 | L4 | L5 | Total |
| Group R (%) | 2 (4.3) | 8 (17.0) | 23 (48.9) | 9 (19.2) | 5 (10.6) | 47 |
| Group R+A (%) | 7 (17.5) | 13 (32.5) | 12 (30) | 5 (12.5) | 3 (7.5) | 40 |
| Total (%)   | 9 (10.3) | 21 (24.2) | 35 (40.2) | 14 (16.1) | 8 (9.2) | 87 |

Group R : only retrolisthesis (35 patients), Group R+A : simultaneous retrolisthesis and anterolisthesis (32 patients). Linear by linear association test was used for statistical analysis. *$p<0.05$; Cohen’s kappa coefficient was used for the reliability of location of retrolisthesis between two observers.
across the four groups (p=0.002 in observer 1, p=0.001 in observer 2). Group A has a tendency towards greater PT compared to that of the other three groups (Table 3).

Lumbar lordosis
There was a significant statistical difference in the mean LL across the four groups (p=0.002 in observer 1, p=0.000 in observer 2). Group A has a tendency towards more LL compared to that of the other three groups (Table 3).

The difference of LL in patients with L4 anterolisthesis in the presence of L3 retrolisthesis
There was a significant statistical difference of LL in patients with L4 anterolisthesis due to the presence of L3 retrolisthesis (p=0.03 in observer 1, p=0.005 in observer 2). The patients with L3 retrolisthesis presented a lower LL (Table 4).

Correlations between sagittal parameters in all patients
The relations between parameters were presented as Pearson’s coefficient (r). There were positive correlations between PI and other parameters including PT, SS, and LL; SS and LL; and negative correlations between PT and SS with statistical significance (p<0.05). However, there was no coincidence in statistical significance between observers (p=0.065 of observer 1 and p=0.022 of observer 2), although there was a negative correlation between PT and LL (Table 5).

**DISCUSSION**

The patterns of degeneration in the lumbar spine have been extensively studied. Some studies have demonstrated that disc degeneration occurs first. Then, an increase in the rotational and transitional forces leads to the overloading of the facet joints. This, in turn, leads to a progressive degenerative change in the facet joint with a lag of over two decades following the onset of disc degeneration. Some studies have demonstrated that disc degeneration is believed to precede facet joint degeneration, and to be a primary cause of anterolisthesis. Love et al. have concluded that a sagittal-oriented facet angle is the result of arthritic remodeling and not a primary cause of anterolisthesis. We also found that there was no statistically significant difference in the sagittal facet angle between anterolisthesis and retrolisthesis in this study.

Recent studies have suggested that factors such as global spinal sagittal alignment and pelvic parameters account for variations in degenerative patterns, including facet and disc pathology. We think that the factors related to spinal sagittal balance may have a strong influence on the development of a different kind of spondylolisthesis, including retrolisthesis and anterolisthesis, based on the results in this study. Under specific conditions such as greater LL and high PI, anterolisthesis might develop with more overloaded power on the facet joint, which leads to facet joint degeneration as well as to disc degeneration. In contrast to the development of anterolisthesis, there was a

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**Table 3.** Sagittal parameters related with spondylolisthesis

| Groups | n (sex;M/F)* | Mean age (SD) | SS ° (SD) | PT ° (SD) | LL ° (SD) |
|--------|--------------|---------------|-----------|-----------|-----------|
| Group R | 35 (21/14)   | 66.83±10.51   | 47.78±5.38 | 48.22±7.29 |
| Group R-A | 32 (17/15) | 64.81±10.16 | 50.53±8.67  | 51.17±8.90 |
| Group N | 76 (48/28) | 64.66±10.32 | 60.51±11.51 | 57.00±10.00 |
| Total | 287 (164/123) | 64.17±10.19 | 59.70±11.45 | 56.37±10.79 |

| Groups | SS ° (SD) | PT ° (SD) | LL ° (SD) |
|--------|-----------|-----------|-----------|
| Group R | 47.78±5.38 | 48.22±7.29 | 47.82±5.38 |
| Group R-A | 50.53±8.67 | 51.17±8.90 | 47.78±5.38 |
| Group N | 60.51±11.51 | 57.00±10.00 | 47.78±5.38 |
| Total | 59.70±11.45 | 56.37±10.79 | 47.78±5.38 |

**Table 5.** Differences of sagittal parameters between the four groups

| Parameters | Group A | Group N | Group R-A | Group R |
|-----------|--------|--------|----------|--------|
| PI ° | 51.55±9.51 | 53.68±10.82 | 50.53±8.67 | 47.53±8.90 |
| PT ° | 34.21±7.98 | 34.21±7.98 | 34.21±7.98 | 34.21±7.98 |
| SS ° | 35.07±8.88 | 35.07±8.88 | 35.07±8.88 | 35.07±8.88 |
| LL ° | 66.83 (±10.51) | 66.83 (±10.51) | 66.83 (±10.51) | 66.83 (±10.51) |

**Table 6.** Differences of sagittal parameters between the two observers

| Parameters | Observer 1 | Observer 2 | p value |
|-----------|-----------|-----------|---------|
| PI ° | 51.55±9.51 | 51.55±9.51 | 0.805 |
| PT ° | 34.21±7.98 | 34.21±7.98 | 0.065 |
| SS ° | 35.07±8.88 | 35.07±8.88 | 0.805 |
| LL ° | 66.83 (±10.51) | 66.83 (±10.51) | 0.805 |

**Table 7.** Correlations between parameters

| Parameters | PI ° | PT ° | SS ° | LL ° | ICC (95% CI) | PC | p value |
|-----------|-----|-----|-----|-----|-------------|----|---------|
| PI ° | 0.72 (0.60–0.84)/0.57 | 0.72 (0.60–0.84)/0.57 | 0.78 (0.72–0.83)/0.61 | 0.81 (0.72–0.89)/0.64 | 0.73 (0.47–0.86)/0.60 | 0.78 (0.72–0.83)/0.61 | 0.007 |
| PT ° | 0.74 (0.62–0.85)/0.59 | 0.74 (0.62–0.85)/0.59 | 0.80 (0.72–0.87)/0.64 | 0.81 (0.72–0.89)/0.64 | 0.76 (0.54–0.87)/0.59 | 0.80 (0.72–0.87)/0.64 | 0.001 |
| SS ° | 0.74 (0.62–0.85)/0.59 | 0.74 (0.62–0.85)/0.59 | 0.80 (0.72–0.87)/0.64 | 0.81 (0.72–0.89)/0.64 | 0.76 (0.54–0.87)/0.59 | 0.80 (0.72–0.87)/0.64 | 0.001 |
| LL ° | 0.74 (0.62–0.85)/0.59 | 0.74 (0.62–0.85)/0.59 | 0.80 (0.72–0.87)/0.64 | 0.81 (0.72–0.89)/0.64 | 0.76 (0.54–0.87)/0.59 | 0.80 (0.72–0.87)/0.64 | 0.001 |
greater aggravation of disc degeneration than of facet degeneration with lower overload power on the facet joints in retrolisthesis under contrasting conditions of sagittal profiles.

Retrolisthesis may be observed in any spinal segment, but a specifically high incidence has been reported in the lower lumbar spine. In contrast, other authors have reported that retrolisthesis was more common in men and in the upper lumbar (L2 and 3) spine. Retrolisthesis is typically limited to 2–3 mm of slippage in the lumbar spine, and sometimes results in foraminal stenosis, and more rarely in central stenosis. Reduced disc height, spinal sagittal alignment, endplate inclination, and the traction of erector spine muscles have been considered as causative factors related to retrolisthesis.

Disc height was significantly reduced in segments with retrolisthesis, which underscores the importance of the disc for segmental stability (“flat tire syndrome”). According to a previous study, the relative kyphotic disposition of the lumbo-sacral segment (L5–S1) could be a trigger for a local compensatory mechanism such as retrolisthesis at L4–5. In our study, L3 was the dominant level that was prone to developing retrolisthesis, and the upper lumbar levels including L3 were the main sites at which anterolisthesis combined at the L4 level. In terms of the lumbar lordotic curve, anterolisthesis was associated with a relatively greater LL than with retrolisthesis. We assume that there is a different developmental mechanism between retrolisthesis and anterolisthesis. The greater LL leads to the development of anterolisthesis, especially on L4, because of the shearing force towards the anterior-inferior direction and the overloading power on the facet joint.

The most common opinion is that LL flattens out with spinal problems and subsequent age-related degenerative changes. However, most studies did not find a significant association between age and lumbar lordotic curvature. In addition, Oliver and Middleditch found no difference in the LL between males and females until middle age, but some studies found that females have a significantly greater lordosis angle (2–5 degrees) than males. There is evidence of a difference based on gender, with female dominance in group A exhibiting greater LL than that of other groups, which supports the theory above. LL is significantly greater in individuals with a high body mass index, and also increases in the late stages of pregnancy.

Many researchers have found a high correlation between LL and pelvic and thoracic parameters in the sagittal profile. Greater LL correlates with a more horizontally inclined sacrum (increased sacral slope, more vertical sacral endplate), increased PI, and increased PT. This tendency among the lumbar and pelvic parameters was also found in our results, and it can be understood from the view of hyperextension as a compensatory mechanism. The hyperextension of adjacent segments is a very common compensatory mechanism that limits the consequences of lumbar kyphosis in terms of gravity axis shift. Hyperextension can be global (multi-segmental) or local (monosegmental), and efficient for placing the upper spine posteriorly.

We found that lower degrees of LL and PI were noted in patients with anterolisthesis. As mentioned above, retrolisthesis may act in a compensatory role to move the gravity axis posteriorly in cases with low PI, which cannot increase a PT sufficiently as a compensatory mechanism. In patients with high PI, an increase in PT occurs as a compensatory mechanism when LL flattens out and the gravity axis moves anteriorly. In addition, an increase in SS according to the change in PT leads to an increase in LL and hyperextension as a compensatory mechanism.

In conclusion, we presumed two compensatory mechanisms, including lumbar hyperextension and increase of PT, in the case of a flattened lumbar spine. The group with high lumbar

| Groups | n | Mean LL* | Observer 1 | Observer 2 |
|---|---|---|---|---|
| Without L3 retrolisthesis | 39 | 41.03±11.25 | 46.59±9.72 |
| With L3 retrolisthesis | 11 | 33.72±7.31 | 37.40±5.56 |

Patients with L4 anterolisthesis were selected from group A (only anterolisthesis) and R+A (simultaneous retrolisthesis and anterolisthesis). Student’s t-test was used for statistical analysis. *p<0.05; interclass correlation (ICC) and Pearson’s coefficient (PC) were used for the reliability of lumbar lordosis (LL) between two observers. CI : confidence interval

| Sagittal parameters | PI | SS | PT | LL |
|---|---|---|---|---|
| PI | 1 | 0.384*/0.515* | 0.694*/0.604* | 0.305*/0.420* |
| SS | 0.384*/0.515* | 1 | -0.269*/-0.243* | 0.489*/0.737* |
| PT | 0.694*/0.604* | -0.269*/-0.243* | 1 | -0.065/-0.151* |
| LL | 0.305*/0.420* | 0.489*/0.737* | -0.065/-0.151* | 1 |

Pearson’s coefficient (r) was used for statistical analysis. *p<0.05. PI : pelvic incidence, PT : pelvic tilt, SS : sacral slope, LL : lumbar lordosis
lordosis (group A) exhibited high PI and PT, and developed anterolisthesis because of their high lumbar lordotic curvature. In contrast, the group with low PI (group R) could not compensate for their sagittal imbalance by increasing their PT and hyperextension sufficiently. Retrolisthesis substitutes hyperextension as a compensatory mechanism by moving the upper or middle level lumbar vertebra directly in the posterior direction.

This study also has some limitations. We assumed that none of the patients who participated in this study had associated lumbar degenerative kyphosis, which shows excessive positive sagittal imbalance, or incongruent intraspinal compensation.

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