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Analysis of the incidence and risk factors for the progression of proximal junctional kyphosis following surgical treatment for lumbar degenerative kyphosis: minimum 2-year follow-up

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Abstract

Background context. Proximal junctional kyphosis (PJK) following surgical treatment of lumbar degenerative kyphosis (LDK) is one of the critical complications leading to the failure of instrumentation and additional extensive surgery. However, most previous studies have focused on idiopathic scoliosis resulting from variable surgical techniques. LDK usually differ from other scoliotic deformities in terms of patient characteristics and disease mechanisms. Purpose. Identification of the prevalence of PJK after the surgical treatment of LDK and searching for the predictable value for the progression of PJK. Study design. Retrospective comparative study. Patient sample (must be included in clinical studies). Forty-seven consecutive patients who underwent surgical correction of a sagittal imbalance due to LDK, from January 2005 to December 2008 in a single spine clinic, were evaluated with a minimum 2 years follow-up (mean 3.8 years). Methods. Patients were divided into 2 groups: with or without the occurrence of PJK, and three categorized factors according to patient characteristics, surgical variables, and the radiographic spinopelvic parameters were evaluated. Results. PJK had occurred in 29 of 47 patients (61.7%). Among variable factors, old age, upper-instrumented vertebra below L2, lumbar lordosis to PI ratio, and the sum of lumbar lordosis, and the sacral slope related to PI were found to be statistically significant. Conclusions. The overall incidence of PJK following surgical treatment of LDK patients was higher than expected. Spinal biomechanics may be changed after long instrumented fusion surgery. Thorough consideration of these factors is needed in the treatment strategy of LDK patients. A long-term follow-up study should be conducted.

Keywords: lumbar degenerative kyphosis; predictable values; proximal junctional kyphosis

Introduction

Since Doherty¹ in 1973 described a symptomatic fixed, forward inclination of the trunk due to loss of normal lumbar lordosis (LL) following posterior instrumented fusion surgery, Moe and Denis² have referred to it with the term “flat back syndrome,” as variant clinical manifestations due to fixed sagittal imbalance result from iatrogenic loss of lumbar lordosis. Lumbar degenerative kyphosis (LDK), in terms of degenerative loss of LL without any prior surgery, is one of the common spinal deformities in Asian countries.³ The surgical option for the LDK patient often includes multiple decompressions of neural elements with long instrumented fusion, due to long-standing degenerative changes and weakened paraspinal muscles.³ Proximal junctional kyphosis (PJK) after instrumented spinal fusion is one of the major complications of LDK surgery, and has recently been focused upon. Many authors have addressed long-term follow-up proximal junctional changes following posterior spinal instrumentation. However, most reported series have focused on the surgical results for adolescent idiopathic scoliosis (AIS). Moreover, instrumentations used for the posterior fixation were variable. LDK usually differs from other adolescent deformities in patient distributions and disease mechanisms. Recently, pedicle screws have become an alternative to hook and wire for better deformity correction with a shorter fusion length and less correction loss.⁴–⁶ Our impression was that the prevalence of PJK was more frequent among LDK patients than AIS patients, and was less frequent among patients undergoing pedicle screw fixation than among those treated by other previous methods. To the best of our knowledge, no studies have demonstrated long-term follow-up results of PJK following posterior pedicle screw fixation for LDK patients. The purpose of this study is therefore to identify the prevalence of PJK after the surgical treatment of LDK, and to search for predictable values for the progression of junctional kyphosis.

Materials and methods

Forty-seven consecutive patients who underwent surgical correction of a sagittal imbalance due to LDK, from January 2005 to December 2008 in a single spine clinic...
Risk factors of junctional kyphosis (Seoul Wooridul Hospital, Seoul, Korea), were reviewed retrospectively. Inclusion criteria for a surgical correction of deformed spine is, first of all, patients who suffered more than 10 years from severe kyphosis caused by loss of lumbar lordosis. All patients who underwent surgery showed 4 cardinal symptoms from LDK preoperatively, including difficulties in standing and walking because of back and buttock pain, a stooping-gait appearance, cornifications of both elbows due to long-term daily use of the elbows for standing support of the body, and abnormally hardened abdominal muscles from the long-term kyphotic posture. Majority of patients who had regional symptoms such as radiating pain and neurogenic claudications derived from the focal compression of the neural tissues were treated conservatively or by simple decompressive surgery, even though the patient was included in the criteria. We did not include patients with spinal deformities majorly derived from the idiopathic scoliosis, iatrogenic kyphosis from originating from trauma, ankylosing spondylitis, neuromuscular diseases, infections, or other connective-tissue diseases. The minimum follow-up period was 2 years (mean = 3.8 years, range = 2–5 years) and complete radiographic evaluations of the patients during follow-up periods were obtained using full-length, 36-inch standing lateral radiographs of the whole spine, with the arms held 60° of forward flexion and the hips and knees fully extended.

Degenerative loss of LL usually starts from lower lumbar level, however thoracolumbar junction or thoracic kyphosis (TK) are emerged when the patient getting older and the degeneration of the spine have progressed. Surgical strategies for the selection of most proximal and distal instrumented vertebra are usually determined by degrees of the kyphotic levels. Fundamental goal for the restoration of LL is 10 degrees more than pelvic incidence (PI). If the major kyphotic angle includes thoracolumbar junction or thoracic level, most proximal instrumented vertebra are usually located at T9 or T10 level. To decide the level of most distal instrumented vertebra, only 2 cases stopped above L5 (from T9 to L3, from L1 to L5) and others extended to S1, iliac support also provided when the proximal instrument included thoracic levels. Interbody fusion performed from L2 to S1 levels with anterior approach and posterolateral fusion added to support posterior instrumentation. Vertebral body osteotomies such as vertebral column resection or pedicle subtraction osteotomy (PSO) performed restrictively in cases with the desired restoration angle more than 50 degrees. The level of osteotomy usually designated at L3 or L4 level when performing PSO and selected the most deformed thoracic vertebra while resected whole vertebral column.

Radiographic measurements included the pre- and postoperative Cobb angles of thoracic (T4–T12), thoracolumbar junctional (T10–L2), and lumbar curves (L1–S1). The proximal junctional kyphotic angle was determined as the Cobb angle between the two level cephalad endplate to the upper-instrumented vertebra and the caudal endplate of the upper-instrumented vertebra. The occurrence of PJK was defined as the aggravation of the proximal junctional kyphotic angle being more than 10°, determined by comparing the initial postoperative and the last follow-up radiographs (Fig. 1).

Occurrence of a spontaneous vertebral compression fracture on the proximal junctional level during the follow-up period was also regarded as PJK. Variable spinopelvic parameters for the analysis of the influences on the progression of PJK, such as the C7 plumb line, PI, sacral slope (SS), and pelvic tilt (PT) were also measured (Fig. 2). Two investigators (J.H.L., J.U.K) performed measurements of digitalized radiographs using a computer software (PiViewSTAR, Infinitt, South Korea) to eliminate inter-observer variability.

According to the occurrence of PJK at the last follow-up, patients were divided into 2 groups. To investigate predictable values for the progression of PJK, three categorized factors were analyzed statistically.

1. Patient characteristics: Patient’s age, sex, height, weight, and bone mineral density (BMD) were investigated. Among those variables, the patient’s sex was excluded...
in statistical analysis because of the predominance of female patients.

2. Surgical variables: As related to the surgery, the most proximal and distal levels of the instrumentation, inclusions of thoracolumbar or lumbosacral junction to the fused segments, and the performances of any vertebral body osteotomies were evaluated. Interbody fusions were majorly performed by an anterior approach, and the posterior instrumentations were achieved using pedicle screws and rod fixations.

3. Radiographic parameters: Pre- and postoperative radiographic parameters, including the Cobb angles of thoracic, thoracolumbar, lumbar, and spinopelvic parameters mentioned above, were compared using statistical analyses between two groups.

Continuous variables were measured as mean ± standard deviation, and categorical variables were expressed as frequency or percentages. An independent t test was used to analyze the difference of continuous variables between two groups. An χ² analysis and Fisher’s exact test were used to examine the differences among categorical variables. A p value less than 0.05 was considered statistically significant. All statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS for Windows 17.0, SPSS Inc., Chicago, IL, USA).

Results

PJK occurred in 29 of 47 patients (61.7%). The mean proximal junctional sagittal Cobb angle in patients with PJK increased from 14.20° ± 11.10° in the initial postoperative state to 33.01° ± 19.33° at the last follow-up. On the other hand, in the group with no PJK, the measured angle changed from 16.52° ± 7.23° in the initial postoperative state to 18.10° ± 7.30° at the last follow-up. The mean follow-up period of the PJK group was 44 months (range: 28–58 months), and the no PJK group’s was 48 months (range: 26–62 months). There was no statistically significant difference between the two groups’ follow-up periods (p = 0.216).

The mean age of the total included patients was 65.51 ± 4.93 years, and most patients were female, except 1 male patient in the no-PJK group. Patient characteristics analyzed in each group are suggested in Table I. Only age was identified as a factor related to the progression of PJK (p = 0.018).

The cranial instrumented level varied from T6 to L2, and the distal level of the instrumentation was distributed from L3 to the iliac. Iliac screws were purchased in 19 (40.4%) patients, and 6 (22.8%) patients needed vertebral body osteotomies such as a PSO or a vertebral column resection (VCR). Numbers of fused segments varies from 4 segments (from L1 to L5) to 13 segments (from T6 to iliac). Eighteen patients in both groups who have most proximal instrumented vertebra below L2 level underwent 4 segments fusion (from L2 to S1) with or without iliac augmentation. Variables related to the surgical treatment method in each group are demonstrated in Table II.

No specific surgery-related variables were found to be associated with an increased risk of developing PJK, except when the most proximal instrumented vertebrae stopped below L2. The occurrence of PJK was significantly higher when the instrumentation stopped below L2 (p < 0.001). Neither the distal instrumented vertebral level nor the vertebral body osteotomy seemed to develop PJK following surgery. However, the number of patients who needed vertebral body osteotomy was too small to accept the results of statistical analysis.

Table I. Patient’s clinical variables in groups with PJK and without PJK.

<table>
<thead>
<tr>
<th>Variables</th>
<th>PJK Group</th>
<th>No PJK Group</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>66.83 ± 4.18</td>
<td>63.39 ± 5.4</td>
<td>0.018†</td>
</tr>
<tr>
<td>Sex (female)</td>
<td>29 (100%)</td>
<td>17 (94.4%)</td>
<td>†</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.49 ± 0.05</td>
<td>1.53 ± 0.05</td>
<td>0.079</td>
</tr>
<tr>
<td>Weight (Kg)</td>
<td>56.34 ± 8.7</td>
<td>59.83 ± 7.42</td>
<td>0.165</td>
</tr>
<tr>
<td>BMD (g/cm²)</td>
<td>−2.19 ± 1.27</td>
<td>−1.98 ± 1.58</td>
<td>0.625</td>
</tr>
</tbody>
</table>

PJK, proximal junctional kyphosis.

Table II. Surgery-related variables in both groups.

<table>
<thead>
<tr>
<th>Variables</th>
<th>PJK Group</th>
<th>No PJK Group</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most proximal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>instrumented vertebrae</td>
<td>3 (6%)</td>
<td>14 (30%)</td>
<td>0.228</td>
</tr>
<tr>
<td>Over T10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T11–L1</td>
<td>9 (19%)</td>
<td>3 (6%)</td>
<td></td>
</tr>
<tr>
<td>Below L2</td>
<td>17 (30%)</td>
<td>1 (2%)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Most distal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>instrumented vertebrae</td>
<td>1 (2%)</td>
<td>1 (2%)</td>
<td></td>
</tr>
<tr>
<td>Over L5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Included S1</td>
<td>19 (40%)</td>
<td>7 (15%)</td>
<td>0.069</td>
</tr>
<tr>
<td>Included iliac</td>
<td>9 (19%)</td>
<td>10 (21%)</td>
<td>0.087</td>
</tr>
<tr>
<td>Vertebral Body Osteotomy</td>
<td>2 (4%)</td>
<td>4 (9%)</td>
<td>0.141</td>
</tr>
</tbody>
</table>

PJK, proximal junctional kyphosis.
LDK patients usually have typical clinical presentations mainly originating from long-term, daily living with kyphotic deformity. The most evident clinical characteristics are flattening of the lumbar region and forward inclination of the trunk, which results in a stooping gait. Because of this posture, patients usually depend on a stick or lean their forearms on supporting objects for their casual activities; consequently, keratinizations of the forearm and elbow are frequently observed (Fig. 3). For the compensation of this kyphotic posture, patients’ knees are usually slightly flexed and the cervical spine is usually hyperextended for forward gazing. These compensatory changes of the posture usually contribute to forward-shifting the center of the gravity. This shifting may result in excessive weight-loading of the kyphotic vertebrae, and exacerbating LDK in the long run. Biomechanically, greater paraspinal muscular forces are needed to maintain an erect posture after loss of lumbar lordosis.\(^8,9\) Therefore, most LDK patients have shown a scanty volume of paraspinal muscle and, contrarily, a hardened, hypertrophied abdominal muscle from maintaining their typical posture.

The goal of corrective surgery in the treatment of LDK is to restore physiologic lordosis and sagittal balance. In some patients with thoracolumbar kyphosis or rigid deformities, osteotomy may be helpful for greater correction of sagittal curves. Without thorough consideration of the entire spinal sagittal balance, including decompensation of adjacent segments proximal or distal to a fusion mass, junctional problems leading to the failure of the whole instrumentation can occur. Junctional kyphosis following long segments’ instrumentation has recently been focused on in the surgical treatment of scoliotic deformity.\(^10\) However, PJK following surgical treatment of LDK patients has rarely been documented. Lee et al.\(^11\) have reported 46% of PJK at a 2-year follow-up after instrumented posterior fusion in patients with idiopathic scoliosis. The authors suggested that a preoperative junctional kyphosis of more than 5 degrees above the proposed proximal instrumented vertebrae indicates that extending the fusion to a higher level in the thoracic spine would be beneficial.

Discussion

Degenerative loss of LL and flatback syndrome without prior surgical treatment, termed LDK, has been more frequently reported in Asian populations than in Western countries.\(^3\) The main pathogenesis of LDK usually includes progressive degenerative changes of disc and facet joints, multiple vacuum changes of discs, and hypertrophied facet joints resulting in loss of normal lumbar lordosis. Most patients are older and female. Different lifestyles based on floor-seated rooms and working postures originating from hand-operated agricultural techniques may contribute to this predominance. In our study, most patients have had a floor-living lifestyle, without use of a bed or a chair, and have also experienced long-term work in a squatting posture, not only for agricultural work, but also for household work.

LDK patients usually have typical clinical presentations was also revealed as a factor significantly related to the progression of PJK.

<table>
<thead>
<tr>
<th>Variables</th>
<th>PJK* Group (n = 29)</th>
<th>No PJK Group (n = 18)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>C7 plumb line</td>
<td>53.35 ± 56.34</td>
<td>33.85 ± 33.11</td>
<td>0.216</td>
</tr>
<tr>
<td>Preoperative TK</td>
<td>17.23 ± 13.06</td>
<td>17.93 ± 21.31</td>
<td>0.426</td>
</tr>
<tr>
<td>TK</td>
<td>22.44 ± 12.12</td>
<td>27.13 ± 12.92</td>
<td>0.252</td>
</tr>
<tr>
<td>Preoperative</td>
<td>29.38 ± 15.37</td>
<td>30.69 ± 17.88</td>
<td>0.486</td>
</tr>
<tr>
<td>Thoracolumbar junctional kyphosis (TLJK)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TJK</td>
<td>14.20 ± 11.1</td>
<td>16.52 ± 7.23</td>
<td>0.46</td>
</tr>
<tr>
<td>Preoperative LL</td>
<td>2.44 ± 27.16</td>
<td>4.21 ± 37.37</td>
<td>0.339</td>
</tr>
<tr>
<td>LL</td>
<td>−35.51 ± 12.35</td>
<td>−41.52 ± 8.68</td>
<td>0.096</td>
</tr>
<tr>
<td>SS</td>
<td>27.42 ± 6.49</td>
<td>27.3 ± 6.69</td>
<td>0.958</td>
</tr>
<tr>
<td>PT</td>
<td>23.97 ± 13.15</td>
<td>19.64 ± 10.35</td>
<td>0.288</td>
</tr>
<tr>
<td>PI</td>
<td>52.48 ± 12.71</td>
<td>46.94 ± 14.54</td>
<td>0.214</td>
</tr>
<tr>
<td>LL to PI ratio (LL/PI)</td>
<td>−0.71 ± 0.32</td>
<td>−0.94 ± 0.29</td>
<td>0.028</td>
</tr>
<tr>
<td>LL to horizontal plane ratio (LL/SS)</td>
<td>6.14 ± 8.75</td>
<td>13.43 ± 8.48</td>
<td>0.007</td>
</tr>
<tr>
<td>LL to horizontal plane to PI ratio (LL/PI - SS/PI)</td>
<td>0.17 ± 0.24</td>
<td>0.34 ± 0.25</td>
<td>0.035</td>
</tr>
</tbody>
</table>

*pJK, proximal junctional kyphosis.
†p value less than 0.05.

Fig. 3. Lateral clinical photograph of a patient with LDK (A). Note the loss of normal lordosis and the forward inclination of the trunk. This kyphotic deformity usually worsens after walking. Keratinizations of the forearms and elbows that frequently observed in LDK patients (B).
Recently, Glattes et al. have demonstrated that PJK occurred in 26% of 81 consecutive patients with a minimum 2-year follow-up. They found no variables related to developing PJK in their study. Unfortunately, in most reported series, treatment methods for long segmental instrumentation were variable, such as hook or distraction (Harrington) instrumentation. Many authors have already reported that the use of those kinds of distraction instruments has directly correlated with the subsequent loss of LL and anterior translation of the vertical axis and the body’s center of gravity.

Instrumentation for spinal fusion surgery has developed and improved significantly in the past few decades. The pedicle screw and rod fixation system has become more prevalent and provided confirmative support with shorter fixation. Nevertheless, this system has developed too recently to afford longer-term follow-up data. In our series, all 47 patients were treated with pedicle screw fixation for the posterior instrumentation. To the best of our knowledge, no mid-term or long-term follow-up studies with a consistent method for spinal instrumentation in LDK patients have yet been documented.

In this study, the overall incidence of PJK following surgical treatment of LDK was higher (61.7% with a minimum 2-year follow-up) than reported incidences in the literature of PJK in patients with idiopathic scoliosis. The authors have assumed that the degeneration of the spine due to older age and osteoporosis in patients with LDK may be associated with a higher incidence of PJK. However, statistical analysis revealed that only older age has a significant relationship to the progression of PJK. Other patients’ characteristics, such as height, weight, and bone mineral density, had no statistically significant differences in either group.

Malaligned fusion or poor selection of fusion levels can increase stresses on proximal or distal adjacent segments. After long segment instrumentations, fused segments act like a lever arm in response to gravity. Posterior shifting of the center of gravity in the distal junction of the fused segments may lead to anterior shifting of the center of gravity in the proximal junction by the lever-arm effect, finally resulting in increased stresses on the proximal junction.

Previously reported studies have suggested that the level of instrumented vertebrae and slight preoperative kyphosis were not higher risks for developing a junctional kyphosis. Glattes et al. have found that PJK was more common when stopping at T3 in the upper thoracic spine, in the treatment of 81 adult spinal deformity patients with a minimum 2-year follow-up. They also suggested that no specific patient characteristics, including preoperative kyphotic deformity or instrumentation techniques, were associated with developing PJK. However, most patients included in their study had had instrumentation to the upper thoracic level; thus, the authors only compared patient groups with upper-instrumented T2, T3, and T4 vertebrae.

We considered that the important point was whether to include mobile segments such as the thoracolumbar or lumbosacral junction in the selection of fusion levels. In normal spinal biomechanics, the weight against gravity’s force is spread along the C7 plumb line, because of the transitional region of the kyphosis and the lordosis. Segmental weight is also dispersed around the mobile joints, like the disc and facets. After spinal fusion surgery, most forces are directly focused on the fused segments. Thus, the authors of this study have focused on the change of spinal biomechanics at the thoracolumbar and the lumbosacral junction, the location of the transition from mobile to immobile motion segments. Kim et al. have compared patient groups’ upper-instrumented vertebrae at T8, and below and above it, and lower-instrumented vertebrae of S1 or L5 and above. They have concluded that the fusion to the sacrum demonstrated a significantly higher prevalence of PJK. They considered a more rigid construct to lead perhaps to a higher prevalence of PJK. On the contrary, in our findings, the most proximal level of the instrumentation below L2 was significantly related to the progression of PJK, rather than to distal level of the instrumentation. Inclusion of patients who were treated with a posterior-only approach or by hybrids or hooks in previous studies may have yielded these conflicting results. Moreover, mostly degenerated and kyphotic deformed spinal segments were distributed from lumbar or lumbo-sacral area in LDK patients, instrumented levels are tend to include thoraco-lumbar and lumbo-sacral areas comparing other scoliosis patients including upper thoracic levels. When stopping instrumentation below thoraco-lumbar junction, there should be three possible hazard due to anatomical characteristics in thoraco-lumbar junction. First of all, thoraco-lumbar junction is a transitional area from kyphosis to lordosis which has a vulnerability from transitional forces. Secondarily, facet joints of thoracic spine are more coronally oriented than lumbar spine. Finally, rib cage that can restrict spinal motion end at thoraco-lumbar junction. Because of these differences, stopping instrumentation below thoraco-lumbar junction can increase the loading to the proximal junction and lead to the PJK.

Unlike scoliotic deformity patients, most LDK patients have extensively degenerated spines around the thoracolumbar level. Therefore, surgical treatment of LDK usually involves multilevel anterior-posterior combined fusion of the thoracolumbar or lumbosacral area. After long-segment fusion surgery in LDK patients, transitional forces against gravity are directly transferred from the proximal level to the distal, along the fused segments. As a result, angular changes of the proximal instrumented levels are directly related to the angular changes of the distal segments. PI is an well-known, important anatomic parameter that affects the anatomic configuration of the pelvis and the sagittal balance of the spine, which is defined as the angle between the line perpendicular to the sacral plate and a line joining the sacral plate to the axis of the femoral heads. This parameter is also known to be relatively constant during childhood. In spinal biomechanics, the PI angle represents the pelvic shape, which functions like a foundation stone. The spine corresponds to the position by adapting, through LL, in order to balance the trunk in the upright posture.

After long instrumented fusion surgery, mechanical stresses on proximal junction can be presumed as a distance from the C7 plumb line to the vertebral axis (Fig. 4). Patients with a high PI usually present an increased SS and lumbar
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Increased LL has been correlated with excessive mechanical stresses on the spinal mobile units. Under the same circumstances after long instrumented fusion, vector forces against gravity tend to shift anteriorly in patients with higher PI (Fig. 5). Fused segments play the roles of lever and fulcrum against the force of gravity. In order to counterbalance the shifted force above the proximal instrumented level, more lordosis needs to be achieved in patients with higher PI. Previous studies have shown the association between LL and SS. Increased LL increases linearly with the SS. And the PI is the algebraic sum of the SS + PT, which determines the pelvic orientation in the sagittal plane. The authors speculated that the vertical axial forces against gravity can be inferred from the algebraic subtraction of the SS from the absolute data of the LL. This data's representation is almost similar to the Cobb angle from the upper endplate of L1 vertebral body to the perpendicular plane. With other variables being unknown, the lower the sum of (LL + SS), the more posterior shifting of the vector force is presented, which leads to the anterior shifting of the vector force at the proximal level as a result of the lever action (Fig. 6).

The most valuable clinical symptom in patients developing PJK is the constant aggravation of back pain. In our series, 17 patients out of 29 patients (59%) who developed PJK needed another extensive surgical treatment, including posterior fusion extension and vertebral body osteotomy. Determining whether PJK following the surgical treatment of LDK patients is because of the iatrogenic result or is a natural degenerative change is controversial. However, this study suggests that older age, upper instrumentation below the L2 level, and the lack of lordosis compared to PI are related factors that can be predictable after the surgical treatment of LDK patients.

It is our speculation that the occurrence of PJK after long instrumented fusion surgery is most likely a time-dependent event. However, this study has suggested a relatively short-term follow-up result. Longer follow-up studies with more subjects should be performed. Another limitation of our study is that most of the patients included were from our early surgical experiences. As well-described in recent studies, PSO or vertebral column resection can provide greater correction of the sagittal imbalance. These surgical techniques...
have been performed in a relatively small number of patients (6 of 47, 3%) in our early treatment of LDK patients.

**Conclusions**

The overall incidence of PJK following surgical treatment of LDK patients was higher than expected. Old age, most proximal instrumentation below L2 level, and the lack of lordosis compared to PI were found to be factors significantly related to the progression of PJK. Spinal biomechanics may change after long instrumented fusion surgery. Thorough consideration of these factors is needed in the treatment strategy of LDK patients. Long-term follow-up studies with more subjects are also needed in the future.

**Declaration of interest:** The authors report no declarations of interest. The authors alone are responsible for the content and writing of the paper.

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