Degenerative lumbar scoliosis (DLS) is characterized by degenerative changes in the spinal column, with coronal plane deformity in elderly patients without any history of adolescent-onset scoliosis.1–3 In elderly patients, the progression of scoliosis curves has been reported to increase variously from 3° to 18° over a period of 10 years.4 In particular, the curve progression of DLS is reported to be more rapid than that of adolescent idiopathic scoliosis.5,6

Owing to the increase in the average life expectancy, the prevalence of DLS is also undoubtedly increasing. A recent study reported an adult scoliosis rate (Cobb angle > 10°) of 68% in adult volunteers older than 60 years.7 Because lateral and rotational deformities with a Cobb angle ≥ 10° in the coronal plane are causative factors of severe low-back pain, the progression of DLS further lowers the patients’ health-related quality of life.8,9

The etiology of DLS is multifactorial and includes genetic predisposition; however, the exact etiology remains unclear.10,11 Curve progression of DLS in the aging spine has been reported to be triggered by degenerative changes, including intervertebral disc degeneration, lateral subluxation, and apical vertebral rotational grade.12–14 In particular, identifying early radiological risk factors associated with curve progression in early DLS may provide pertinent information about patients who need early attention. The various radiological parameters associated with degenerative changes are thought to influence each

**ABBREVIATIONS**
DLS = degenerative lumbar scoliosis.


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other as the curve of DLS progresses. However, among these changes in early DLS, no radiological parameter has been yet reported as the most important prognostic factor through multivariate analysis.

Therefore, the purpose of this study was to determine the natural history of curve progression, investigate radiological parameters that are predictive of curve progression in early DLS over a period of 10 years, and identify the most important predictors through multivariate analysis.

Methods

The study was approved by the institutional review board (IRB) of Samsung Medical Center. After the requirement for informed consent had been waived by the IRB, we reviewed the records of patients older than 50 years who had lumbar deformity with Cobb angles between 5° and 15° at the time of their initial visit. The inclusion criteria were as follows: 1) more than 10 years of follow-up and 2) conservative treatment without surgery from the initial visit to the final follow-up. The exclusion criteria were as follows: 1) history of idiopathic scoliosis, 2) congenital and developmental neuromuscular abnormalities, 3) any previous spinal surgery, and 4) nondegenerative spinal disease (e.g., fracture, infection, tumor, or inflammation).

All patients underwent standing lumbar anteroposterior and lateral plain radiography at least once in 2 years during the follow-up period. The scoliosis angle was determined using the Cobb angle. Radiological parameters measured included the following: 1) scoliosis direction, 2) apical vertebral level, 3) apical vertebral rotational grade (vertebral rotation was classified using the Nash-Moe method), 4) lateral subluxation (distance from the reference line of the laterally translated vertebral body to that of the lower vertebral body), 5) disc space difference (difference between the disc heights on the decreased and opposite sides), 6) osteophyte difference (length of the lateral osteophytes calculated as the sum of the perpendicular distances measured from the reference line to the lateral ends of the osteophytes on the upper and lower endplates), 7) upper and lower disc wedging angles (between the tangential lines of the superior and inferior endplates in the adjacent disc space of the apical vertebra), and 8) relationship between the intercrest line and L5 vertebral body (Fig. 1).

Radiological measurements were performed on a standard PACS system (Centricity, GE Healthcare). All radiographic parameters were measured by one of the authors. The patients were divided into two groups (i.e., a progression group and a nonprogression group) according to a progression of the Cobb angle ≥ 15° at the final follow-up. When comparing the two groups, the risk factors of curve progression were analyzed using the radiological parameters at the initial evaluation.

Statistical Analysis

The independent t-test, chi-square test, and Fisher exact test were used to analyze the differences in the measured factors between the two groups according to the categorized or noncategorized variables. Changes in the radiological parameters were compared using the paired t-test between the initial follow-up and final follow-up. To determine the risk factors of curve progression, univariate logistic regression analysis was performed. A multivariate logistic regression analysis was also conducted for relevant parameters to minimize confounding variables and estimate odds ratios (ORs) and 95% confidence intervals (CIs). Statistical analysis was performed using SPSS software (version 22.0; IBM Corp.). A p value < 0.05 was considered statistically significant.

Results

A total of 51 patients who met the inclusion criteria were enrolled. Their mean age was 61.6 ± 7.1 years; 7 patients were men and 44 were women. The mean Cobb angle at the initial evaluation was 8.8° ± 3.2°, and that at the final follow-up was 19.4° ± 8.9°. During the 13.7 ± 3.0 years of follow-up, the mean Cobb angle increased by 10.6° ± 8.0° (0.8° every year). Seventeen of the 51 patients (33.3%) had ≥ 15° of curve progression at the final follow-up. These patients had a mean initial Cobb angle of 9.4° ± 3.4° and a final follow-up angle of 28.8° ± 7.5°. Thirty-four of 51 patients showed a curve progression < 15° and had a mean initial Cobb angle of 8.5° ± 3.1° and a final follow-up angle of 14.7° ± 4.8°. There were no significant differences in age or sex between the two groups (p = 0.232 and p = 0.774). There were also no significant differences in the initial Cobb angles or the durations of the follow-up periods between the groups (p = 0.341 and p = 0.672) (Table 1). The changes in the radiological parameters according to curve progression between the initial and final follow-ups are shown in Table 2. The apical vertebral rotational grade, lateral subluxation, disc space difference, osteophyte difference, and upper and lower disc wedging angles in relation to degenerative changes in the aging spine significantly differed according to curve progression (Table 2).

Comparison of Initial Radiological Parameters

There were no significant differences between the scoliosis direction, apical vertebral level, or intercrest line position between the two groups. Although 82.4% (41/17) of the patients in the progression group had apical vertebral rotation, compared with 64.7% (22/34) in the nonprogression group, there was no significant difference between the two groups (p = 0.242). The progression group had a mean of 2.2 ± 2.4 mm of lateral subluxation, which was significantly greater than the 0.8 ± 1.7 mm in the nonprogression group (p = 0.024). Furthermore, the progression group had a mean of 4.6 ± 1.5 mm of disc space difference, which was also significantly greater than the 3.2 ± 1.8 mm in the nonprogression group (p = 0.009). The progression group showed a mean of 3.3 ± 2.3 mm of osteophyte difference, which was smaller than the 4.6 ± 3.7 mm in the nonprogression group; however, the difference was not significant (p = 0.206). The mean upper disc wedging angle in the progression group was 3.1° ± 2.4°, which was greater than the 2.3° ± 1.4° in the nonprogression group; however, the difference was also not significant (p = 0.122). The mean lower disc wedging angle in the progression group was 4.3° ± 1.4°, which was significantly greater than the 2.8° ± 1.9° in the nonprogression group (p = 0.005) (Table 3).
Risk Factor Analysis

In the univariate logistic regression analysis, lateral subluxation, disc space difference, and upper and lower disc wedging angles were considered as risk factors of curve progression (p = 0.035, p = 0.016, p = 0.051, and p = 0.011, respectively). The multivariate logistic regression analysis showed that only the upper and lower disc wedging angles were significant risk factors of curve progression of scoliosis (p = 0.035 and p = 0.004). The upper and lower disc wedging angles were positively correlated with curve progression (OR 1.55, 95% CI 1.03–2.33 and OR 1.89, 95% CI 1.22–2.94, respectively) (Table 4).

<table>
<thead>
<tr>
<th>TABLE 1. Demographic comparison according to curve progression</th>
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<tr>
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<td></td>
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<tr>
<td>Age, yrs</td>
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<tr>
<td>Sex</td>
</tr>
<tr>
<td>Male</td>
</tr>
<tr>
<td>Female</td>
</tr>
<tr>
<td>Follow-up period, yrs</td>
</tr>
<tr>
<td>Initial Cobb angle</td>
</tr>
<tr>
<td>Final Cobb angle</td>
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</table>

Values are presented as numbers of patients or means ± SDs unless otherwise indicated.

FIG. 1. Radiographs showing the measurement methods for the sections indicated by white dashed lines and black arrows. A: Lateral listhesis. B: Osteophyte difference = (a + b) − (c + d) (millimeters). C: Disc space difference = (g + h) − (e + f) (millimeters). D: Upper and lower disc wedging angles.
Discussion

This study investigated patients with early DLS and Cobb angles between 5° and 15° for over 10 years. Seventeen of the 51 patients showed ≥ 15° of curve progression and had a 1.4° increase every year during an average follow-up period of 13.4 years. Thirty-four of the 51 patients who had < 15° of curve progression had a 0.4° increase every year during 13.8 years of follow-up. In the initial radiological evaluations, there were differences in the lateral subluxation, disc space difference, and upper and lower disc wedging angles between the two groups, reflecting degenerative changes. In particular, degenerative changes in the lower apical vertebral disc were considered the most important risk factors of curve progression according to the multivariate regression analysis.

Many previous studies have reported a variety of radiological parameters as risk factors of the curve progression of DLS. For instance, intervertebral disc degeneration, lateral subluxation, apical vertebral rotational grade, and intercrest line location were all believed to be such risk factors. However, the number of subjects, definitions of DLS and curve progression, and follow-up period varied among studies. Owing to such discrepancies, all previous studies had varied conclusions with regard to the risk factors. This study strictly defined early DLS. Moreover, this study is, to our knowledge, the first to report the risk factors analyzed using a multivariate logistic regression analysis while including a relatively large number of subjects.

This study did not find any significant correlation between the apical vertebral rotational grade and curve progression. Since this study included patients with early DLS with a mean Cobb angle of 8.8°, the degree of rotation in the apical vertebra was not severe during the initial evaluation, showing no significant association with curve progression (only 3 patients had a rotation grade of 2 or higher). However, in the last follow-up, 23 patients (45.1%) had a rotational grade of apical vertebra > 2 as degenerative changes progressed, showing statistically significant curve progression. In previous research, some investigators reported that rotation of apical vertebra was a significant factor in predicting curve progression, while others reported that it was not related to curve progression. This means that the relationship between radiological parameters and curve progression may change depending on the progression of degenerative changes. Therefore, while the apical vertebral rotational grade may not be a risk factor of curve progression in early DLS, it may be a risk factor in advanced DLS.

In this study, osteophyte difference was not a risk factor of curve progression, as it had an even higher rate in the nonprogression group. A previous study concluded that the presence of osteophytes ≥ 5 mm in size increases the incidence of DLS. However, this study did not find any significant correlation between the apical vertebral rotational grade and curve progression.
tors of DLS with a curve angle > 10°, rather than on those of curve progression. As DLS is related to degenerative changes, the presence of osteophytes may be considered a risk factor of DLS. Nevertheless, degenerative changes in the spine are known to progress in three processes, including dysfunction, instability, and stability. The development of osteophytes around the disc and facet joint yields segmental stiffness and stability (i.e., a stabilizing process). Therefore, osteophytes of larger size after the initiation of DLS would actually counteract the instability resulting from curve progression.

The lateral subluxation, disc space difference, and upper and lower disc wedging angles, which reflect degenerative changes in the spinal segment, are known to be the risk factors of curve progression. Such results had been supported by many studies in the past. This study also confirmed that these degenerative radiological parameters were significant risk factors associated with curve progression. However, different degenerative changes occur simultaneously and interact with one another in one spinal segment. Hence, altering the course of such changes may affect the risk factors of curve progression; however, no study has investigated such a relationship to control confounding effects. By utilizing a multivariate logistic regression analysis, this study proved that asymmetrical changes in the lower apical vertebral disc are the most significant risk factors of curve progression in early DLS.

Many past studies demonstrated that the intercrest line passing the L5 vertebra was a risk factor of curve progression. The associated rationale was that there is a higher risk of the L4 being shifted or tilted than of the L5 passing lower than the intercrest line. However, in this study, the intercrest line did not have a significant correlation with curve progression. When taken at the posteroanterior view, the intercrest line may be located at a lower level to compensate for the sagittal imbalance if a patient has pelvic retroversion. Older patients with adult spinal deformity have a high rate of sagittal imbalance and pelvic retroversion. Therefore, further research that would also consider pelvic retroversion is needed.

TABLE 3. Comparison of radiologic parameters between the groups with progression of Cobb angles of ≥15° or <15° at the initial evaluation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Curve Progression</th>
<th>p Value</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>≥15° (n = 17)</td>
<td>&lt;15° (n = 34)</td>
</tr>
<tr>
<td>Scoliosis direction</td>
<td></td>
<td>0.824</td>
</tr>
<tr>
<td>Rt</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Lt</td>
<td>12</td>
<td>25</td>
</tr>
<tr>
<td>Apical vertebral level</td>
<td></td>
<td>0.967</td>
</tr>
<tr>
<td>L2</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>L3</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>L4</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Apical vertebral rotation (Nash-Moe grade)</td>
<td></td>
<td>0.242</td>
</tr>
<tr>
<td>0</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>1</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lateral listhesis, mm</td>
<td>2.2 ± 2.4</td>
<td>0.8 ± 1.7</td>
</tr>
<tr>
<td>Disc space difference, mm</td>
<td>4.6 ± 1.5</td>
<td>3.2 ± 1.8</td>
</tr>
<tr>
<td>Osteophyte difference, mm</td>
<td>3.3 ± 2.3</td>
<td>4.6 ± 3.7</td>
</tr>
<tr>
<td>Wedging angle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper disc</td>
<td>3.1° ± 2.4°</td>
<td>2.3° ± 1.4°</td>
</tr>
<tr>
<td>Lower disc</td>
<td>4.3° ± 1.4°</td>
<td>2.8° ± 1.9°</td>
</tr>
<tr>
<td>Intercrest line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L4</td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>L4–5</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>L5</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>
| Values are presented as numbers of patients or means ± SDs unless otherwise indicated.

TABLE 4. Multivariate regression analysis of the risk factors of curve progression

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>OR</th>
<th>95% CI</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral listhesis</td>
<td>1.23</td>
<td>0.89–1.71</td>
<td>0.209</td>
</tr>
<tr>
<td>Disc space difference</td>
<td>0.97</td>
<td>0.75–1.24</td>
<td>0.793</td>
</tr>
<tr>
<td>Wedging angle (upper disc)</td>
<td>1.55</td>
<td>1.03–2.33</td>
<td>0.035</td>
</tr>
<tr>
<td>Wedging angle (lower disc)</td>
<td>1.89</td>
<td>1.22–2.94</td>
<td>0.004</td>
</tr>
</tbody>
</table>
According to the present study, the initial cause of curve progression in early DLS was asymmetrical degeneration of the disc space, which leads to lower apical vertebral disc wedging angles. The loading of weight is concentrated on one side only in the asymmetrical disc space. The formation of osteophytes develops in the area of high pressure. When osteophytes develop to a certain extent, stability is achieved and eventually rotation occurs as the weight loading moves to the other axis from the point where the osteophyte formed. The area of low pressure is then destined for angulation, and rotation consequently progresses. If the curve advances further, the increased osteophyte formation at the lower segment of the apical vertebra becomes more stable and results in further curve formation at the adjacent segment of the apical vertebra (Fig. 2).

Study Limitations

This study has a few limitations. First, this study is a retrospective observational study and has the inherent limitations of such a study design. Although there was no significant correlation between curve progression and the duration of follow-up, the various follow-up periods (from 10 years to 18 years) may create bias. In addition, this study may not have included patients who sought surgical treatment owing to the rapid advancement of curve progression. As this study was a historical rather than a prospective study, such potential bias was inevitable. Second, this study did not consider clinical symptoms but instead aimed to recognize the natural history of curve progression in patients with DLS and to confirm the most important early prognostic radiological factor for curve progression. This study focused radiologically on the prognostic factor of curve progression. Furthermore, this study excluded cases of surgical treatment due to exacerbation of clinical symptoms during the follow-up period. Therefore, additional research with regard to the relationship between the extent of curve progression and its clinical course is needed. Finally, although some patients might not show true curves, patients with Cobb angles between 5° and 10° were included to identify predictors at an early stage. Since all curves were started with a low-magnitude curve, cases with an asymmetrical wedging angle of the disc and an angle > 5° with arthritis were included.

Conclusions

The degenerative changes in the spinal column in early DLS, such as lateral subluxation, disc space difference, and adjacent disc wedging angle, are related to curve progression. In particular, asymmetrical disc degeneration in the lower disc space, which leads to a lower apical vertebral disc wedging angle, is the most important factor in predicting early curve progression.

References


Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: SJ Park, JS Park, Lee. Acquisition of data: SJ Park, JS Park, Yum, Kim. Analysis and interpretation of data: all authors. Drafting the article: SJ Park, JS Park, Lee. Critically revising the article: SJ Park, JS Park, Lee. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: SJ Park. Statistical analysis: JS Park, Yum, Kim. Administrative/technical/material support: JS Park, Yum, Kim. Study supervision: SJ Park, Lee.

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