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Impact of Distal Fusion Level on Sacroiliac Joint Degenerative Change Following Adolescent Idiopathic Scoliosis Surgery

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Purpose: To evaluate the relationship between distal fusion level in correction and fusion surgery for adolescent idiopathic scoliosis (AIS) and radiologic changes in the sacroiliac (SI) joint.

Materials and Methods: This retrospective cohort study evaluated patients who underwent correction and fusion for AIS between 2005 and 2017 with at least 5 years of follow-up. We categorized patients into two groups: Group 1 (distal fusion above L2, 74 patients) and Group 2 (distal fusion at L3 and below, 52 patients). Radiologic parameters and SI joint changes were evaluated on plain radiographs obtained from preoperative to 5 years postoperatively. We also investigated other risk factors for SI joint change.

Results: Analysis of demographic factors revealed no significant difference between the two groups. There was a significant difference in the incidence of SI joint change between Group 1 (5 patients, 6.75%) and Group 2 (18 patients, 34.61%), with Group 2 showing a faster increase in incidence according to the Kaplan-Meier method ($p<0.0001$). Preoperative lumbar lordosis (LL) and ΔLL had a significant relationship with SI joint changes [preoperative LL, hazard ratio (HR)=0.77, 95% confidence interval (CI)=0.64–0.93, $p=0.008$; ΔLL, HR=0.79, 95% CI=0.67–0.95, $p=0.01$).

Conclusion: After AIS surgery, patients who had fusion to the lower lumbar vertebrae (L3 or L4) experienced a higher incidence and faster progression of degenerative changes in the SI joint. Low preoperative LL and inadequate correction of LL during the operation were also risk factors for SI joint degeneration.

Key Words: Adolescent idiopathic scoliosis, postoperative pain, sacroiliac joint, distal fusion level

INTRODUCTION

Postoperative pain following correction and fusion surgery for adolescent idiopathic scoliosis (AIS) is a major concern. Previous studies[1-3] have reported that 0%–20% of patients who underwent scoliosis surgery experienced persistent postoperative pain lasting longer than 12 months. One of those studies investigated the risk factors and revealed a strong association between preoperative pain and postoperative pain persisting for more than 2 years.[2] Another study on the predictors of postoperative pain after AIS surgery identified being overweight, advanced age, and having a large previous thoracic curve as predictors.[3]

However, we also have observed a trend in which patients who undergo distal fusion at a more caudal level, such as L3 or L4, tended to report greater postoperative pain. In comparison to patients who receive fusion to the upper lumbar vertebra or thoracic vertebra distally, the pattern of pain experienced by these individuals was more severe and persisted for a longer duration, thereby hindering their ability to engage in normal daily activities. To the best of our knowledge, no study

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has been conducted to investigate the relationship between distal fusion level and postoperative pain in patients with AIS.

Often, surgeons suspect pathology of the sacroiliac (SI) joint as a potential cause of unexplained back and lower extremity pain after lumbar fusion.[4-8] SI joint pathology may also account for a substantial portion of unexplained general back pain, up to 15%.[9,10] In the context of general lumbar fusion surgeries, a previous study has investigated the relationship between the distal fusion level and SI joint pathology.[11] The authors of this study have discovered that fusion to the sacrum is more likely to result in degeneration of the SI joint compared to fusion cases involving the L5 vertebra. In this regard, we hypothesized that SI joint pathology could plausibly be a cause of differences in postoperative pain based on the distal fusion level in AIS surgery. The complexity of diagnosing SI joint pathology may have previously resulted in its exclusion as a potential source of pain for patients with AIS. We aimed to examine the association between radiographic alterations in the SI joint and the distal fusion level in AIS surgery. Furthermore, we investigated other factors that might influence changes in the SI joint.

MATERIALS AND METHODS

Patient design

This retrospective, single-center, cohort study surveyed patients who underwent mechanical correction and fusion for AIS between 2005 and 2017. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (IRB) (or Ethics Committee) of Severance Hospital, College of Medicine, Yonsei University (IRB No. 3-2023-0032 and 9 April 2023). The rationale for solely focusing on AIS in this study was that other types of scoliosis, such as neuromuscular scoliosis, can affect the SI joint regardless of surgical intervention. Patients with pre-existing SI joint pathology resulting from other conditions, such as a history of delivery,[12] autoimmune/rheumatic diseases that affect the SI joint, or a history of lower lumbar or pelvic bone trauma, were also excluded. Additionally, patients with pre-existing lower lumbar pathology or new lower lumbar pathology discovered during the follow-up period were excluded to ensure clarity regarding the cause of pain. The inclusion criteria comprised patients with 1) at least 5 years of follow-up; 2) absence of pathology on SI joint in preoperative computed tomography (CT) images; 3) adequate plain radiographs at each follow-up period; and 4) successful fusion of the posterior bone graft. Fusion was defined as a reduction in radiographic transparency in the region surrounding the posterior bone graft site.[13] Finally, 126 patients were included in this study.

Furthermore, we divided the patients into two groups. The first group consisted of patients who underwent distal fusion to the upper lumbar spine (above and L2), which was named Group 1. The second group consisted of patients who underwent distal fusion to the lower lumbar spine (L3 and below), which was named Group 2. The number of patients in each group was 74 for Group 1 and 52 for Group 2 (Fig. 1).

Surgical indication and technique

All patients underwent mechanical correction and fusion surgery based on precise surgical indications and criteria in accordance with the health insurance policies of South Korea. Our institution determined that surgery was necessary for growing children with a major curve Cobb's angle over 40–50, those that have finished growing with a major curve Cobb's angle over 50–60, or those with rapidly progressive curves. Additionally, we considered surgery for patients experiencing severe functional limitations, such as respiratory difficulties. Our fusion surgery approach adhered to strict principles, including complete fusion of the major curve, distal fusion to the neutral vertebrae, and correction of sagittal alignment to a normal level whenever possible. The level of proximal and distal fusion end was determined using the Suk classification.[14] Intraopera-

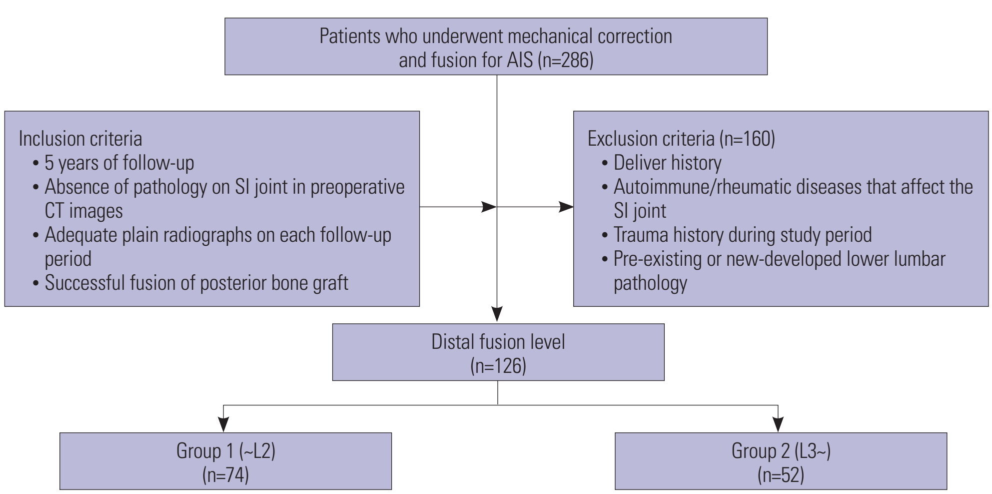

Fig. 1. Flowchart of the study. AIS, adolescent idiopathic scoliosis; SI, sacroiliac.

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tive motor evoked potential monitoring was consistently performed to examine any cord or root injury.

Radiologic assessment

In our institution, plain anteroposterior (AP)/lateral whole-spine radiographs and lumbosacral spine AP/lateral views were routinely obtained during preoperative and postoperative follow-up periods. Among them, preoperative and postoperative radiographs obtained immediately, at 1 year, 2 years, and 5 years after the procedure were selected for this study. All images were retrieved from the Picture Archiving and Communication System of our institution and analyzed using the Centricity program by General Electric Healthcare. In this study, osteochondral changes, such as sclerosis, erosion, joint widening, or narrowing of the SI joints, were evaluated. Based on a previous study,[15] sclerosis was defined as an increase in subchondral bone density greater than those at adjacent joints or disk endplates, erosion as an irregularity of the osteochondral inter-

Fig. 2. Plain radiographs of sacroiliac joint changes defined in this study. (A) Normal. (B) Sclerosis. (C) Erosion. (D) Joint space narrowing.

face, and widening/narrowing as a change in the expected joint width (Fig. 2).

We measured multiple sagittal parameters and parameters related to scoliosis at each period to perform a related-factor analysis. Additionally, we calculated the change ratio of each parameter from the preoperative period to the 2-year postoperative period. The relationship between SI joint degenerative changes and these multiple parameters was evaluated statistically.

One orthopedic surgeon and a musculoskeletal radiologist independently evaluated all available images. Another musculoskeletal radiologist and spine surgeon, who were blinded to and uninvolved in this study, analyzed the images, and the intraclass correlation coefficient was calculated. The calculated coefficient exceeded 0.85, indicating excellent correlation.

Statistical analysis

Continuous variables were compared using the independent t-test (for normally distributed data) or the Mann–Whitney U test (for non-normally distributed data), after Shapiro–Wilk test between the two groups. The data are presented as means± standard deviations. Categorical variables were compared using Fischer's exact test and presented as percentages. To compare the occurrence of SI joint change events during the follow-up period between the two groups, the Kaplan–Meier method was employed. The results are presented as a cumulative incidence function plot, and *p*-values were calculated. To assess the impact of the distal fusion level and other parameters on SI joint change, the Cox proportional hazards regression model was used. The results are expressed as hazard ratios (HRs) and 95% confidence intervals (CIs). All statistical analyses were performed using R Studio (Version 2023.06.0+421 "Mountain Hydrangea" Release [© 2009–2023 Posit Software, PBC], Boston, MA, USA). Statistical significance was defined as $p<0.05$.

RESULTS

Patient profiles

The total sample size was 126 patients, with 74 patients in Group 1 and 52 patients in Group 2. Analysis of demographic factors are summarized in Table 1, revealing no significant difference between the two groups in terms of sex ratio (83.8% female ratio in Group 1 vs. 82.7% in Group 2; $p=0.871$) and age (16.04±4.78 in Group 1 vs. 15.02±3.10 in Group 2; $p=0.178$). However, there were statistically significant differences in the number of fused vertebrae (10.17±2.07 in Group 1 vs. 11.46±2.87 in Group 2; $p=0.004$) and distribution of Lenke classification ($p<0.001$).

In terms of sagittal parameters, there were significant differences in preoperative pelvic tilt (PT) and the change in global tilt (GT) (ΔGT), as well as preoperative thoracolumbar kyphosis (TLK) and ΔTLK. Specifically, the preoperative PT values were

Table 1. Summary of Demographic Factors of Study Patients

	Group 1 (~L2) (n=74)	Group 2 (L3~) n=52)	*p* value
Age (yr)	16.04±4.78	15.02±3.10	0.178
Sex			0.871
Male	12 (16.2)	9 (17.3)	
Female	62 (83.8)	43 (82.7)	
Lenke classification			<0.001
1A	40 (54.1)	10 (19.2)	
1B	1 (1.4)	6 (11.5)	
1C	0	1 (1.9)	
2A	5 (6.8)	0	
3A	10 (13.5)	1 (1.9)	
3B	12 (16.2)	2 (3.8)	
3C	4 (5.4)	7 (13.5)	
5A	1 (1.4)	0	
5B	0	1 (1.9)	
5C	1 (1.4)	24 (46.2)	
Fusion number	10.17±2.07	11.46±2.87	0.004
LL			
Pre	51.64±9.77	52.47±14.75	0.725
ΔLL	-7.82±9.42	-5.07±15.20	0.252
TK			
Pre	18.14±12.16	20.88±11.61	0.206
ΔTK	-3.55±10.99	-7.09±11.33	0.082
PI			
Pre	47.23±9.89	50.02±11.75	0.152
ΔPI	-0.29±4.02	-1.48±6.69	0.259
PT			
Pre	9.33±6.70	11.97±6.78	0.032
ΔPT	2.34±5.23	0.92±5.92	0.158
SS			
Pre	38.25±7.66	38.21±9.11	0.977
ΔSS	-2.83±5.90	-2.37±7.71	0.705
GT			
Pre	6.16±8.24	8.51±8.30	0.119
ΔGT	3.69±5.62	1.04±6.96	0.020
T1PA			
Pre	4.74±7.00	6.65±6.94	0.132
ΔT1PA	2.80±5.42	1.02±5.94	0.084
TLK			
Pre	5.98±6.05	10.60±8.93	0.002
ΔTLK	0.82±6.88	-3.38±9.76	0.009
C7 SVA			
Pre	-9.27±26.94	-10.11±29.45	0.869
ΔC7 SVA	11.36±28.04	3.52±28.37	0.127
Cobb's angle			
Pre	51.20±12.15	57.80±13.04	0.004
ΔCobb's angle	-32.21±8.73	-40.87±10.21	<0.001
Iliolumbar angle			
Pre	7.24±4.70	16.07±8.24	<0.001
ΔIliolumbar angle	-1.93±4.44	-10.17±7.82	<0.001

ΔA, postoperative A – preoperative A; LL, lumbar lordosis; TK, thoracic kyphosis; PI, pelvic incidence; PT, pelvic tilt; SS, sacral slope; GT, global tilt; T1PA, T1 pelvic angle; TLK, thoracolumbar kyphosis; C7 SVA, C7 sagittal vertical axis.
Data are presented as mean±standard deviation or n (%).

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9.33±6.70 in Group 1 and 11.97±6.78 in Group 2 (p=0.032), while ΔGT was 3.69±5.62 in Group 1 and 1.04±6.96 in Group 2 (p=0.020). Additionally, the preoperative TLK values were 5.98±6.05 in Group 1 and 10.60±8.93 in Group 2 (p=0.002), with ΔTLK being 0.82±6.88 in Group 1 and -3.38±9.76 in Group 2 (p=0.009).

Cobb's angle and iliolumbar angle also showed differences in both the preoperative period and the change ratio. The preoperative Cobb's angle values were 51.20±12.15 in Group 1 and 57.80±13.04 in Group 2 (p=0.004), while ΔCobb's angle was -32.21±8.73 in Group 1 and -40.87±10.21 in Group 2 (p<0.001). Similarly, the preoperative iliolumbar angle values were 7.24±4.70 in Group 1 and 16.07±8.24 in Group 2 (p<0.001), with Δiliolumbar angle being -1.93±4.44 in Group 1 and -10.17±7.82 in Group 2 (p<0.001).

Distal fusion level and the change of SI joint

The pattern of SI joint change in both groups is presented in Table 2. The mean follow-up periods for both groups were not significantly different (5.82±2.11 years vs. 5.38±2.59, p=0.298). The total number of patients who exhibited SI joint change was 5 (6.75%) in Group 1 and 18 (34.61%) in Group 2, indicating a statistically significant difference. There was no variation in the distribution of SI joint change side and type. Fig. 3 illustrates the cumulative incidence plot of SI joint change over the follow-up period. In Group 2, the incidence increased at a faster rate and the final incidence was higher, as confirmed by the Kaplan–Meier method with a p-value of less than 0.0001.

Table 2. Pattern of SI Joint Change for Each Group

	Group 1 (~L2) (n=74)	Group 2 (L3~) (n=52)	*p* value
Follow-up period (yr)	5.82±2.11	5.38±2.59	0.298
Total number of SI joint change	5 (6.75)	18 (34.61)	<0.001
Side			0.848
Left	2	6	
Right	1	6	
Both	2	6	
Type of change			0.726
Sclerosis	5	18	
Erosion	2	11	
Widening/narrowing	1	5	

SI, sacroiliac.
Data are presented as mean±standard deviation, n (%), or n.

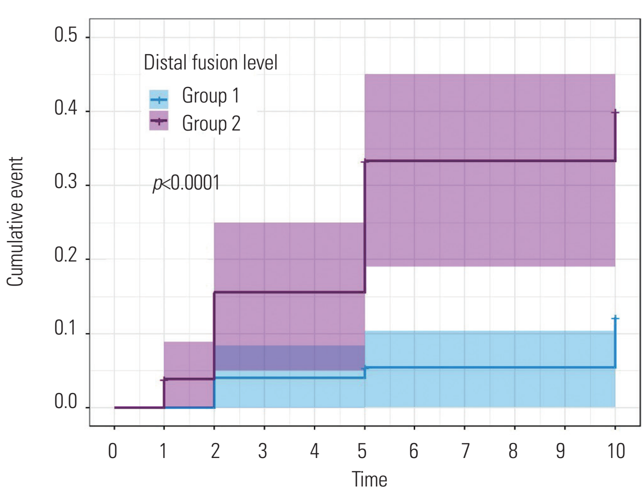

Fig. 3. Cumulative incidence of sacroiliac (SI) joint changes after fusion procedures for adolescent idiopathic scoliosis. The changes in the SI joint were more rapid and the number of patients who underwent SI joint change was greater in Group 2 (p<0.0001).

Analysis of demographic and radiologic factors associated with the change of SI joint

Fig. 4 demonstrates the results of Cox proportional regression analysis for multiple factors associated with changes in the SI joint. Age, sex ratio, and the number of fused vertebrae did not influence changes in the SI joint. Analysis of radiologic parameters revealed that almost all the parameters did not show an association with changes in the SI joint. Only preoperative lumbar lordosis (LL) and ΔLL had a significant relationship with SI joint changes (preoperative LL, HR=0.77, 95% CI=0.64–0.93, p=0.008; ΔLL, HR=0.79, 95% CI=0.67–0.95, p=0.01). The distal fusion level significantly contributed to changes in the SI joint (HR=22.58, 95% CI=3.59–142.22, p<0.001).

DISCUSSION

Postoperative pain is a major consideration for patients who undergo correction and fusion surgery for AIS. According to a previous study, the prevalence of postoperative pain was found to be high in patients with AIS, with nearly 10% experiencing pain after discharge and 7% still reporting pain 6 months post-surgery.[2] Additionally, another study highlighted a significant usage of analgesics among AIS surgery patients.[3] Previous literature has referred to preoperative pain as a dominant predictor of postoperative pain after correction of AIS.[2,16-19] Mimura, et al.[20] also reported the significance of preoperative pain and postoperative kyphotic angle. However, previous studies have been limited in their investigation of risk factors for AIS correction, and more conditions should be considered.

In the present study, we investigated the correlation between the distal fusion level and degenerative changes in the SI joint during a follow-up period of at least 5 years, which exceeded the duration of previous studies on SI joint changes.[4,5,7,8,11,21] Our rationale for focusing on this relationship stemmed from the observation that patients who underwent distal fusion to the lower lumbar vertebrae reported experiencing more intense pain. We hypothesized that SI joint pathology might play a role in exacerbating this pain. Consequently, we observed a larger number of changes in the SI joint in the group that received fusion to L3 or L4 distally. Furthermore, in this group, the change of SI joint occurred more rapidly compared to the other group, as deter-

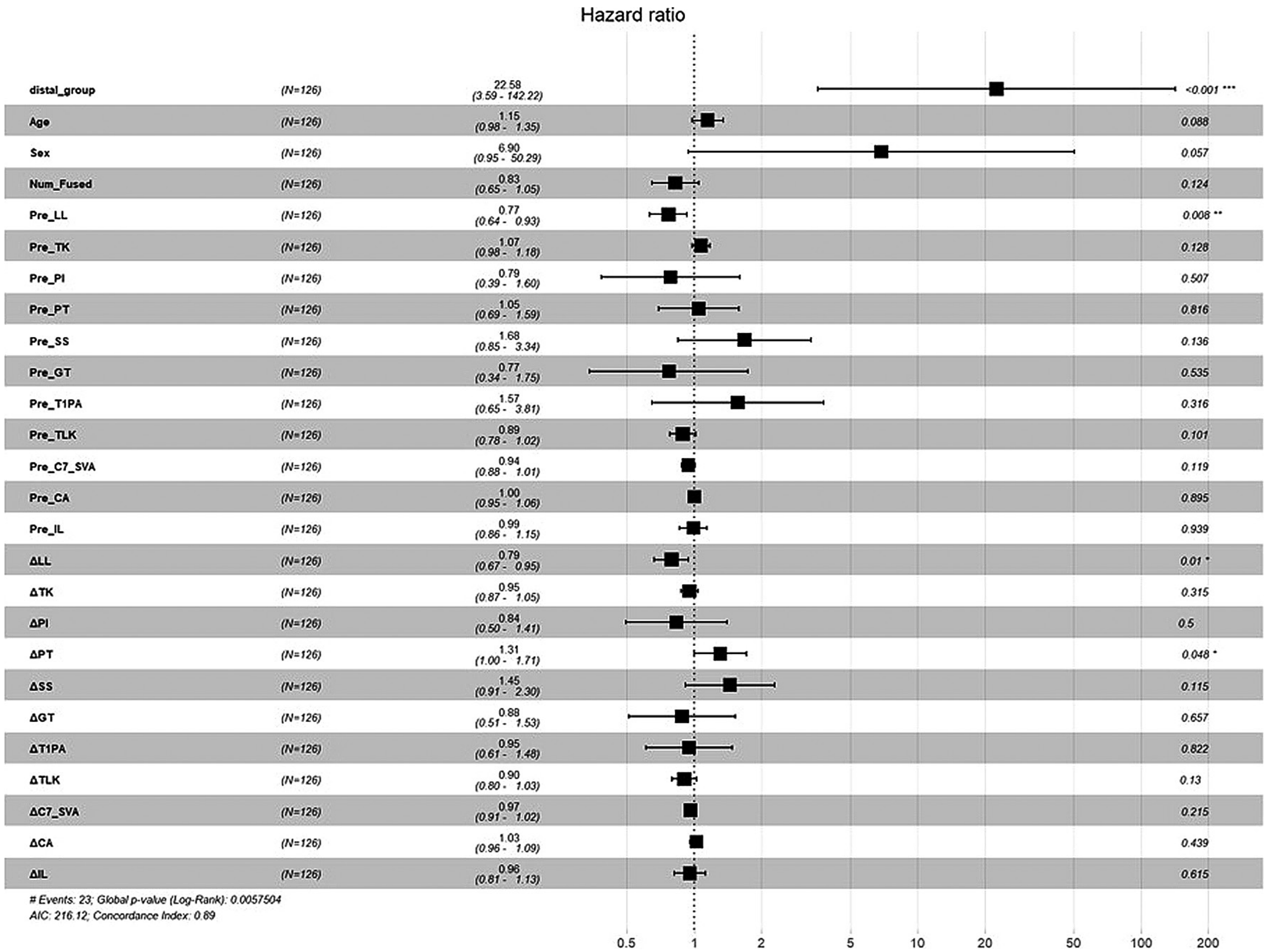

Fig. 4. Multi-factor analysis of SI joint change using Cox proportional hazards regression. The distal fusion level, preoperative lumbar lordosis (LL), and LL change during operation showed statistical relationship [distal fusion level, hazard ratio (HR)=22.58, $p<0.001$; preoperative LL, HR=0.77, $p=0.008$; LL change, HR=0.79, $p=0.01$].

mined by the Kaplan–Meier method. The HR for distal fusion level was approximately,[22] which was a significant finding. The important aspect of this finding is that we can exclude the natural degenerative process as a cause of SI joint change, since the age of patients with AIS who underwent surgery was around.[15] Although there were differences in the TLK, Cobb's angle, iliolumbar angle, and fusion levels between the two groups, these differences were attributed to the pattern of the curve, as classified by Lenke. The fusion level inevitably varied according to Lenke classification.

This finding was highly consistent with previous research and can be explained by similar patterns. Frymoyer initially discussed the long-term effects of spinal fusion on the SI joint, and subsequent studies have reported similar effects.[22] Ha, et al.[11] examined SI joint degeneration following spinal fusion and found that fusion to the S1 resulted in more degeneration of the SI joint compared to fusion to the L5. They suggested that this difference could be attributed to adjacent segmental pathology, as the distal fusion level is in closer proximity to the SI joint, leading to increased degeneration. In line with this study, Ivanov, et al.[23] conducted a Finite Element Model (FEM) study and reported that more distal fusion resulted in greater angular stress on the SI joint articular surface. Yoshihara[4] reviewed SI joint pain following fusion, while Longo, et al.[6] conducted a meta-analysis on SI joint degeneration after fusion; both studies concluded that increased axial load after spinal fusion mechanically transfers to the SI joint and causes degeneration. Unoki, et al.[5] investigated cases of multiple-segment fusion and found similar results. In summary, these studies suggest that after surgery for AIS, more distal fusion on the lumbar vertebra leads to increased angular stress and axial load on the SI joint, resulting in SI joint degeneration similar to adjacent segmental pathology. However, Mimura, et al.[20] examined patients who underwent surgery for AIS and found no association between lower instrumented vertebra and postoperative pain. Further research is needed to explore the relationship between SI joint pathology and postoperative pain in AIS, including in vitro studies such as FEM analysis. These studies could provide insights into the causes of postoperative pain in patients who undergo fusion to the lower lumbar vertebrae distally. Additionally, they could aid

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in the development of a treatment plan, such as the use of SI joint block for moderate pain and arthrodesis for severe pain.[24-28]

In this study, we also found that low preoperative LL and less change of LL (ΔLL) were associated with SI joint changes. Additionally, we observed no effect from coronal parameters, such as Cobb's angle or iliolumbar angle. These findings were consistent with those of previous studies. Ivanov, et al.[23] discovered that angular motion and stress on the articular surface showed more variation in flexion and extension compared to lateral bending and rotation after spinal fusion. This suggested that the SI joint is more significantly affected by sagittal motion than coronal motion, and emphasized the importance of lordosis in sagittal motion and load transfer. Another study by Dreyfuss, et al.[10] reported similar results. Kwon, et al.[29] investigated lumbar spinal fusion cases and found more degeneration in the sagittal imbalance group. Consequently, insufficient LL represents sagittal imbalance, leading to increased axial load transfer and angular motion on the SI joint, ultimately resulting in degeneration.

This study had some limitations. First, clinical information, such as current back or pelvic pain or life disability, was unavailable; thus, the connection between radiologic changes in the SI joint and clinical symptoms could not be estimated. Therefore, it is recommended that a subsequent clinical study be conducted to address this matter. Second, imaging modalities used to evaluate the SI joint were limited to simple radiographs. Imaging of the SI joint is performed using CT or magnetic resonance imaging (MRI) owing to the lower sensitivity and specificity of plain radiographs.[15,30-33] Previous studies have reported significant inter-reader variations, even among experienced readers, making radiograph interpretation of the SI joints challenging.[34-36] However, plain radiographs were chosen as the imaging modality for evaluating the SI joint for several reasons. Our institution did not routinely obtain CT or MRI scans after the operation due to damage on fertility by radiation exposure. Furthermore, our hospital possesses a comprehensive database of X-ray data for patients who have undergone surgery for AIS and have been followed up for more than 5 years, captured under a rigorous protocol, ensuring consistency and comparability across different time points.

Conclusively, after performing mechanical correction and fusion for AIS, we observed a higher incidence and rapid progression of degenerative changes in the SI joint in patients who underwent fusion to the lower lumbar vertebrae (L3 or L4), compared to those who received fusion to the thoracic or upper lumbar vertebrae. Another risk factor for SI joint degeneration was a low preoperative LL, as well as inadequate correction of LL during the operation. Therefore, management of SI joint pathology should be considered for patients with persistent postoperative pain following AIS correction.

AUTHOR CONTRIBUTIONS

Conceptualization: Sang-Ho Kim, Jae-Won Shin, and Hak-Sun Kim. Data curation: Sang-Ho Kim, Jae-Won Shin, and Hak-Sun Kim. Formal analysis: Sang-Ho Kim and Jae-Won Shin. Methodology: Sang-Ho Kim, Jae-Won Shin, and Hak-Sun Kim. Project administration: Sang-Ho Kim, Jae-Won Shin, and Hak-Sun Kim. Resources: Hak-Sun Kim. Software: Sang-Ho Kim and Jae-Won Shin. Supervision: Hak-Sun Kim, Seong-Hwan Moon, Kyung-Soo Suk, Joong-Won Ha, Yung Park, Si-Young Park, Byung-Ho Lee, and Ji-Won Kwon. Validation: Hak-Sun Kim. Visualization: Sang-Ho Kim and Jae-Won Shin. Writing—original draft: Sang-Ho Kim and Jae-Won Shin. Writing—review & editing: all authors. Approval of final manuscript: all authors.

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