Spinal Alignments of Residual Lumbar Curve Affect Disc Degeneration after Spinal Fusion in Patients with Adolescent Idiopathic Scoliosis: Follow-up after 5 or More Years

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Abstract:

Introduction: Despite preserving lumbar disc mobility, spinal sagittal, and/or coronal alignment might ultimately impede surgical success. The purpose of this study was to elucidate the effects of spinal alignment on lumbar disc degeneration after 5 or more years in adolescent idiopathic scoliosis (AIS) patients who underwent spinal fusion.

Methods: Subjects were 49 AIS patients who underwent posterior spinal fusion without lumbar curve fusion. The inclusion criteria were the following: 1) Lenke type 1A, 1B, 2A or 2B, 2) age 10 to 19 years at the time of operation, and 3) minimum 5-year follow-up. The exclusion criteria were the following: 1) diagnosed as other than AIS, 2) history of lumbar disc herniation and spondylolysis, 3) subsequent surgery, and 4) history of surgery before AIS surgery. Nineteen patients agreed to participate in this research. X-rays, lumbar MRI, and questionnaires were evaluated. Disc degeneration in non-fused segments was defined as Pfirrmann grade 3 or higher. Patients with disc degenerations at the final observation (DD[+] group) were compared to those without disc degenerations (DD[−] group).

Results: There were no significant differences in the preoperative or postoperative 1-week X-ray parameters between both groups. The lumbar curve was significantly larger in the DD[+] group compared with the DD[−] group at the final observation (DD[+]: 16.8 degrees, DD[−]: 10.4 degrees, $p = 0.035$). The sagittal vertical axis (SVA) was significantly larger in the DD[+] group compared with the DD[−] group at the final observation (DD[+]: −4.4 mm, DD[−]: −34.3 mm, $p = 0.006$). SRS-22 function, self-image, and satisfaction scores were lower in the DD [+] group compared with the DD[−] group at the final observation.

Conclusions: The patients with DD had significantly larger lumbar curve and SVA with lower SRS-22 function, self-image, and satisfaction scores at the final observation. Even though the non-fused segments were preserved, spinal alignments of non-fused lumbar curve affect the DDs.

Keywords:

adolescent idiopathic scoliosis, long-term follow-up, disc degeneration, selective thoracic fusion

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Introduction

Since spinal fusion in adolescent idiopathic scoliosis (AIS) is often performed during adolescence, it is important to consider long-term outcomes. In spinal fusion, preserving lumbar spine mobility is believed to be advantageous in controlling pain and maintaining functionality[1,2].

Selective thoracic fusion was reported by King et al. in 1983, who stated stable outcomes of preserving lumbar spine mobility[3], and has been used in general for the treatment of Lenke 1 curve[4]. However, Lonstein et al. reported that osteophytes were found in L2-3, 20 years after selective thoracic fusion, despite no progression of the lumbar spine curve[5]. Chang et al. also reported that in selective thoracic fusion, the smaller the lumbar lordosis, the poorer the outcome[6]. These findings suggested that despite preserving lumbar disc mobility, spinal sagittal, and/or coronal alignment might ultimately impede surgical success.

The purpose of this study was to elucidate the effects of spinal alignment on lumbar disc degeneration (DD) after 5 or more years in AIS patients who underwent spinal fusion in which the lumbar curve was not fused. Our hypothesis was that even if discs were not fused and preserved, after 5 or more years, the residual lumbar deformity would affect DD resulting in unfavorable results such as pain or dysfunction.

Materials and Methods

The institutional review board approved the present study. Subjects were 49 AIS patients who underwent posterior spinal fusion without lumbar curve fusion between 2004 and 2010. The inclusion criteria were the following: 1) Lenke type 1A, 1B, 2A, or 2B, 2) age at surgery of 10 to 19 years, and 3) minimum 5-year follow-up. The exclusion criteria were the following: 1) diagnosed as other than AIS, 2) history of lumbar disc herniation and spondylolysis, 3) subsequent surgery, or 4) history of surgery before AIS surgery. We tried to contact all the 49 patients by postal mail. Of these, 20 did not reply, eight refused participation, and two had undergone subsequent surgery and were therefore ineligible. Informed consent was obtained from the remaining 19 patients. These included 17 women and two men. The age at surgery was 15.3 ± 1.8 years (12 to 18 years), the mean age during observation was 23.4 ± 2.6 years (19-28 years), and the mean duration of follow-up was 7.7 ± 1.6 years (5 to 11 years). The lower instrumented vertebra (LIV) was at T11, 1 patient; T12, 2 patients; L1, 11 patients; and L2, 5 patients. Whole-spine X-rays, lumbar spine MRI, and patient-oriented questionnaires were used to evaluate these patients.

Whole-spine X-rays were taken in the standing position to obtain front and lateral views. The patients were evaluated before surgery, 1 week after surgery, 2 years after surgery, and at the final observation point. In the frontal image, the upper thoracic (UT) curve, main thoracic (MT) curve, lumbar (L) curve, and coronal balance (distance from a perpendicular line from the center of the C7 disc to the central line of the sacrum) were measured. In the frontal image, the disc wedge angle from the L1-2 to the L5-S1 segments (angle formed by the inferior endplate of the superior vertebral body and superior endplate of the inferior vertebral body) and the vertebral body tilt from L1 to L5 (angle formed by the superior endplate of the vertebral body and the horizon) were measured. The following were measured from the lateral view: the thoracic kyphosis angle (TK: T5-T12 angle), the lumbar lordosis angle (LL: L1-S1 angle), and the sagittal vertical axis (SVA; distance between perpendicular line from C7 to the posterior superior corner of the sacrum). On the lateral view, the intervertebral lordotic angle from L1-2 to L 5-S1 (angle formed between the inferior endplate of the superior vertebral body and the superior endplate of the inferior vertebral body) was measured.

Lumbar MRIs were obtained using a 1.5 Tesla MRI (Signa HDxt, General Electric Company, CT, USA), and sagittal plane images of the lumbar spine were obtained using T1- and T2-weighted imaging while coronal plane T2-weighted imaging was obtained. MRIs were evaluated at the final observation time point in all the 19 patients. Because ten patients did not undergo lumbar MRI examinations before surgery, preoperative MRIs were available in 9 out of 19 patients. MRI findings were examined independently by three examiners (U.T., I. M., and A.K.) who did not see the clinical data. DD was evaluated in non-fused discs to determine Pfirrmann disc scores[7]. Scores agreed upon by two out of the three evaluators were used. If no agreement could be reached among the three examiners, the median was used. Pfirrmann grade 3 or higher was defined as DD.

Scoliosis Research Society-22 Patient Questionnaire (SRS-22), Oswestry Disability Index (ODI), and Roland-Morris Disability Questionnaire (RDQ) were used for the patient-oriented questionnaire. Evaluations were conducted at the final observation.

For statistical analyses, SPSS Statistics version 22.0 (International Business Machines Corporation, NY, USA) was used. Patients with DDs at the final observation (DD[+] group) were compared with those without DDs at the final observation (DD[−] group). For comparisons between two groups, we used the Mann-Whitney *U* test or the chi-squared test. The level of significance was set at less than 5%.

Results

1. Overall image findings

On MRI findings, there were no DDs in all patients before surgery. MRIs identified DD in one or more segments in nine patients (47.4%) at the final observation. The discs involved were the following: no DD between L1-2 and L2-3, but DD was found in L3-4 (21.1%), L4-5 (21.1%), and L 5-S1 (21.1%) at the final observation (Fig. 1). The MT curve was 58.3° ± 10.3° before surgery, 23.8° ± 8.2° 1 week

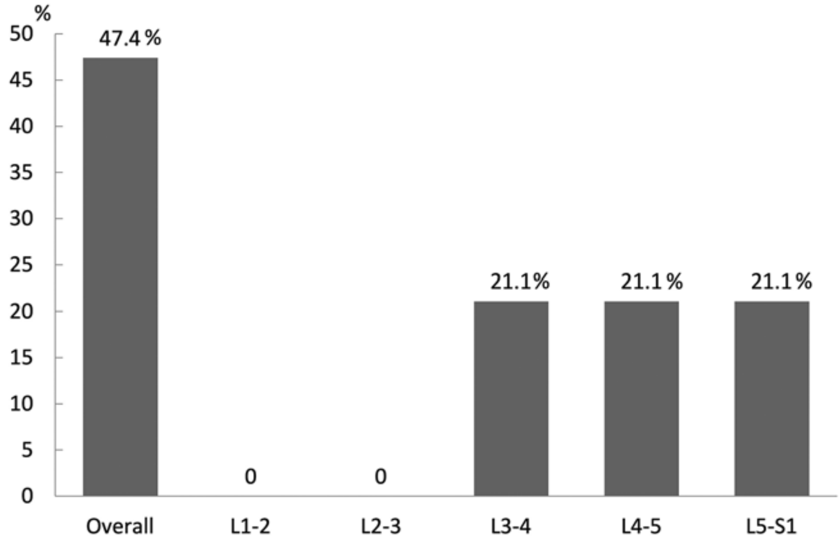

Figure 1. MRIs identified disc generation (DD) in one or more segments in nine patients (47.4%) at the final observation. Discs involved were: no DD between L1-2 and L2-3, but DD was found in L3-4: 21.1%; L4-5: 21.1%; and L5-S1: 21.1%.

after surgery, 26.4° ± 9.5° 2 years after surgery, and 27.0° ± 7.9° at the final observation. The UT curve was 34.5° ± 8.0° before surgery, 21.5° ± 7.6° 1 week after surgery, 21.2° ± 7.3° 2 years after surgery, and 21.2° ± 6.2° at the final observation. The L curve was 31.2° ± 9.3° before surgery, 12.8° ± 7.3° 1 week after surgery, 14.5° ± 8.2° 2 years after surgery, and 13.4° ± 7.0° at the final observation. The coronal balance was 4.2 ± 9.3 mm before surgery, −4.1 ± 11.8 mm 1 week after surgery, −2.2 ± 10.2 mm 2 years after surgery, and −1.7 ± 13.3 mm at the final observation. TK was 13.6° ± 9.2° before surgery, 12.9° ± 4.2° 1 week after surgery, 16.4° ± 8.0° 2 years after surgery, and 19.1° ± 8.2° at the final observation. LL was 46.2° ± 11.6° before surgery, 38.4° ± 10.8° 1 week after surgery, 50.1° ± 11.0° 2 years after surgery, and 54.6° ± 11.0° at the final observation. SVA was −1.1 ± 21.6 mm before surgery, 14.1 ± 38.9 mm 1 week after surgery, −12.0 ± 33.4 mm 2 years after surgery, and −20.2 ± 25.1 mm at the final observation.

2. Comparison of DD[+] and DD[−] groups

Nine patients were DD[+] and 10 were DD[−]. The number of lumbar mobile segments did not differ significantly between the DD[+] and DD[−] groups (DD[+]: 4.7 segments, DD[−]: 4.6 segments, p = 0.661). The preoperative X-ray parameters did not differ significantly between the DD[+] and DD[−] groups. The groups also did not differ at 1-week post-surgery. However, the L curve in the DD[+] group was significantly larger at 2 years post-surgery (DD [+]: 18.1° ± 8.4°, DD[−]: 11.3° ± 6.8°, p = 0.043). No other differences were noted at 2 years post-surgery. At the final observation, the DD[+] group had a significantly larger L curve compared with the DD[−] group (DD[+]: 16.8° ± 7.6°, DD[−]: 10.4° ± 5.1°, p = 0.035), and the SVA was significantly larger (DD[+]: −4.4 ± 22.9 mm, DD[−]: −34.3 ± 18.2 mm, p = 0.006) (Fig. 2, 3). No other differences in X-ray parameters were noted at the final observation (Table 1).

SRS-22 scores did not differ between the DD[+] and DD [−] groups in any of the following domains: function (DD [+]: 4.6 ± 0.3, DD[−]: 4.8 ± 0.3, p = 0.079), pain (DD[+]: 4.4 ± 0.5, DD[−]: 4.3 ± 0.7, p = 0.905), self-image (DD[+]: 3.4 ± 0.5, DD[−]: 3.9 ± 0.6, p = 0.079), mental (DD[+]: 4.0 ± 1.0, DD[−]: 4.2 ± 0.8, p = 0.720), and satisfaction (DD [+]: 4.0 ± 0.4, DD[−]: 4.5 ± 0.6, p = 0.095), while the DD [+] group showed a tendency for lower function, self-image, and satisfaction. No statistical differences were noted between the DD[+] and DD[−] groups in RDQ (DD[+]: 0.6 ± 1.0, DD[−]: 1.7 ± 2.9, p = 0.661). No statistical differences between the DD[+] and DD[−] groups were noted in ODI (DD[+]: 8.0 ± 5.9, DD[−]: 6.9 ± 8.2, p = 0.447) (Table 2).

3. Association between local intervertebral alignment and non-fused DD

A moderate positive correlation was observed between the L3-4 Pfirrmann disc grade and the L3-4 wedge angle at 2 years post-surgery (r = 0.561, p = 0.012), L4 tilt at 2 years post-surgery (r = −0.533, p = 0.019), and L3-4 wedge angle (r = 0.543, p = 0.016) at the final observation (Fig. 4, 5, 6). No other significant correlations were noted including intervertebral lordotic angle. A moderate negative correlation was noted between L4-5 Pfirrmann disc grade and preoperative L4-5 wedge angle (r = −0.494, p = 0.032), with no other significant correlations noted. A moderate negative correlation was noted between the L5-S1 Pfirrmann disc grade and the preoperative L4-5 wedge angle (r = −0.494, p = 0.032), but no other significant correlations were noted. The L1-2 and L2-3 intervertebral discs were grade 2 in all patients with no correlations between DD and local intervertebral alignments (disc wedging angle, vertebral body tilt, or intervertebral lordotic angle).

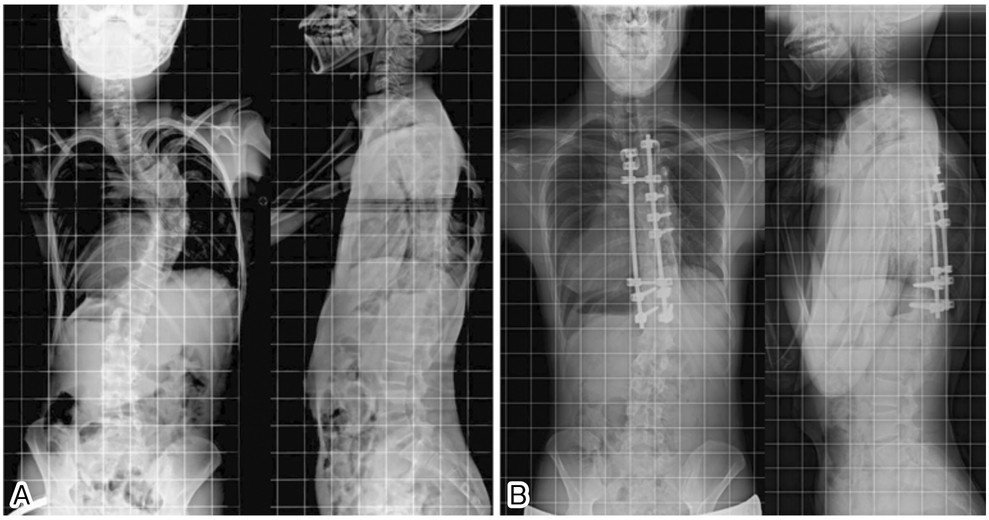

Figure 2. Case 1: A 14-year-old male presented with Lenke type 1A adolescent idiopathic scoliosis (AIS). (A) A preoperative frontal whole-spine X-ray revealed a 68-degree main thoracic (MT) curve and a 28-degree lumbar (L) curve. (B) As the MT curve had been corrected to 35 degrees, non-fused L curve had been corrected 10 degrees at the final observation (9 years after surgery). A lateral view showed the positive sagittal vertical axis with 43 mm.

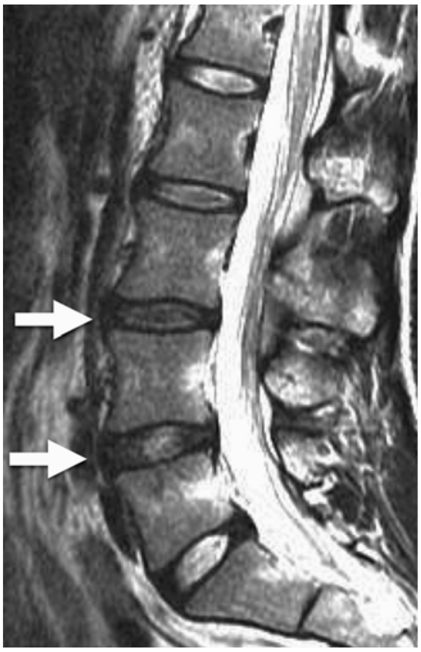

Figure 3. Case 1: Postoperative T2-weighted image showed L3-4 and L4-5 disc generations (Pfirrmann grade 3) at the final observation (white arrows).

4. Incidence of DD in each intervertebral disc level and in relation to distance from the LIV

The percentage of DD involvement at each intervertebral disc level was 0% at L1-2, 0% at L2-3, 21.1% at L3-4, 21.2% at L4-5, and 21.1% at L5-S1. The percentage of DD involvement based on distance from LIV was 0% at LIV+1, 11.1% at LIV+2, 5.2% at LIV+3, 26.3% at LIV+4, and 28.6% at LIV+5.

5. Reliability of MRI readings among examiners

Inter-examiners reliability was calculated using intra-class correlation coefficients (ICC). The ICC was reliable at 0.591 (95% confidence interval: 0.420-0.717), indicating moderate agreement.

6. Comparison between participants and non-participants

Demographics of the 19 participants enrolled in this survey were compared with those of the 30 non-participants. No statistically significant differences were noted in patient age at surgery (participants: 15.3 ± 1.8 years; non-participants: 15.6 ± 1.9 years; p = 0.803), number of fused vertebral bodies (participants: 10.3 ± 1.3; non-participants: 9.7 ± 1.1; p = 0.069), or number of non-fused segment below LIV (participants: 5.0 ± 0.8; non-participants: 5.2 ± 0.6; p = 0.194). When the percentages of participants and non-participants were compared by sex, there was no significant difference between these groups in percentage of females (participants: 89.5%; non-participants: 93.3%; p = 0.631).

Discussion

Disc degeneration after AIS spinal fusion was reported to be affected by various factors such as the number of mobile intervertebral discs, coronal X-ray parameters, and sagittal X-ray parameters[1,2,5,6,8]. The fewer non-fused discs, the more likely DD was to occur, and LIV fusing below L4 was generally not recommended[2,8]. The coronal parameters lumbar curve size and interbody tilt have been associated with DD. In particular, cut-off points have been suggested to keep LIV tilt at 5 degrees[9], L3 or L4 tilt at 16 degrees[10] and lumbar curve at 39.5 degrees[11]. Conversely, Bernstein et al. have found that sagittal view thoracic flat back was a risk factor

Table 1. X-ray Parameters of the DD[+] and DD[−] Groups.

	DD[+]	DD[−]	p value
Preoperative			
UT curve (°)	35.0±9.2	34.0±7.1	0.968
MT curve (°)	60.3±12.0	56.5±8.8	0.549
L curve (°)	31.7±10.6	30.7±8.6	0.780
Coronal balance (mm)	0.7±6.2	7.3±10.2	0.278
TK (°)	14.3±11.9	13.0±6.6	0.968
LL (°)	43.7±14.9	48.4±8.0	0.278
SVA (mm)	−2.5±24.0	0.1±20.4	0.720
1-week			
UT curve (°)	23.0±6.8	20.1±8.4	0.479
MT curve (°)	27.0±9.7	21.0±5.8	0.182
L curve (°)	15.3±8.6	10.5±5.1	0.211
Coronal balance (mm)	−9.6±12.7	0.9±8.9	0.079
TK (°)	13.4±4.0	12.5±4.5	0.720
LL (°)	36.4±14.3	40.2±6.7	0.156
SVA (mm)	3.1±37.5	24.0±39.3	0.182
2-year			
UT curve (°)	22.8±7.7	19.7±6.9	0.356
MT curve (°)	31.1±11.3	22.2±5.1	0.113
L curve (°)	18.1±8.4	11.3±6.8	0.043*
Coronal balance (mm)	−6.3±8.2	1.6±10.6	0.053
TK (°)	16.9±10.0	16.0±6.3	0.905
LL (°)	47.4±13.9	52.5±6.5	0.315
SVA (mm)	−1.8±42.2	−21.2±21.2	0.400
Last follow-up			
UT curve (°)	21.0±6.9	21.4±5.9	0.968
MT curve (°)	29.8±10.1	24.5±4.4	0.278
L curve (°)	16.8±7.6	10.4±5.1	0.035*
Coronal balance (mm)	−3.9±17.6	0.2±8.3	0.842
TK (°)	18.3±10.5	19.7±6.0	0.905
LL (°)	52.9±13.2	56.2±9.0	0.604
SVA (mm)	−4.4±22.9	−34.3±18.2	0.006*

Values are mean (±: standard division). * indicates significant difference between groups. DD: disc degeneration, UT: upper thoracic, MT: main thoracic, L: lumbar, TK: thoracic kyphosis, TLK: thoracolumbar kyphosis, LL: lumbar lordosis, SVA: sagittal vertical axis

for lumbar DD and that coronal parameters and LIV selection were irrelevant[12]. In our study, we found that in patients with DD, the lumbar curve and SVA were large at the final observation and that both the coronal and sagittal were involved.

Although the X-ray parameters did not differ significantly between the DD[+] and DD[−] groups at 1-week post-surgery, the L curve at 1-week post-surgery was not statistically significant but was larger in the DD[+] group than in the DD[−] group. Furthermore, the L curve in the DD[−] group did not change from 1-week post-surgery to the final observation (10.5 to 10.4 degrees), while the L curve in the DD[+] group increased from 1-week post-surgery to the final observation (15.3 to 16.8 degrees). We could not rule out the possibility that the lumbar scoliosis progressed because of DD. However, although there was no statistically significant difference, the L curve at 1-week post-surgery was larger in the DD[+] group. Therefore, we recommended that lumbar curves should be minimized after AIS surgery to

Table 2. Questionnaire Scores of DD[+] and DD[−] Groups.

	DD[+]	DD[−]	p value
SRS-22			
Function	4.6±0.3	4.8±0.3	0.079
Pain	4.4±0.5	4.3±0.7	0.905
Self image	3.4±0.5	3.9±0.6	0.079
Mental	4.0±1.0	4.2±0.8	0.720
Satisfaction	4.0±0.4	4.5±0.6	0.095
RDQ	0.6±1.0	1.7±2.9	0.661
ODI	8.0±5.6	6.9±8.2	0.447

Values are mean (±: standard division). DD: disc degeneration, SRS-22: Scoliosis Research Society-22 Patient Questionnaire, ODI: Oswestry Disability Index, RDQ: Roland-Morris Disability Questionnaire

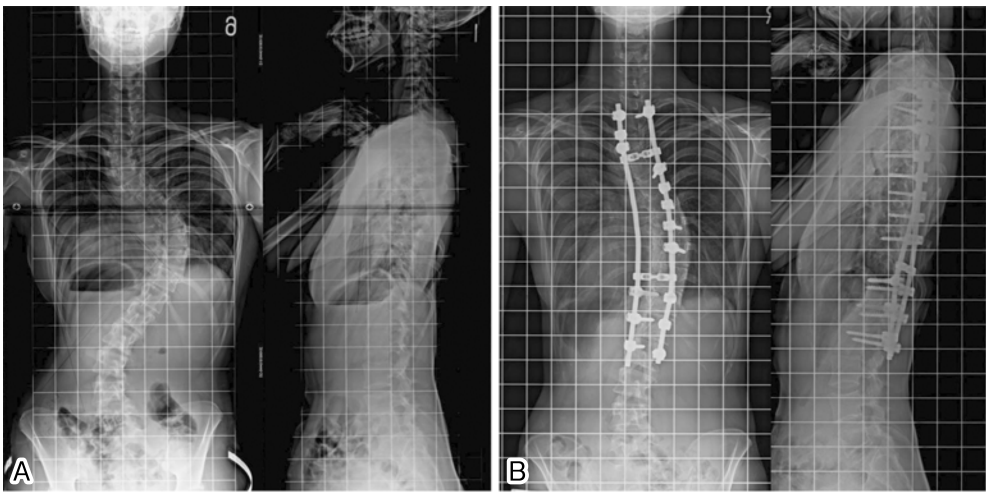

Figure 4. Case 2: A 17-year-old female presented with Lenke type 2B AIS. (A) A preoperative frontal whole-spine X-ray revealed a 50-degree upper thoracic curve, 67-degree MT curve, and 44-degree L curve. (B) Posterior spinal fusion was performed from T2 to L3. Although the MT curve had been corrected to 46 degrees, the 22-degree L curve remained at the final observation (6 years after surgery).

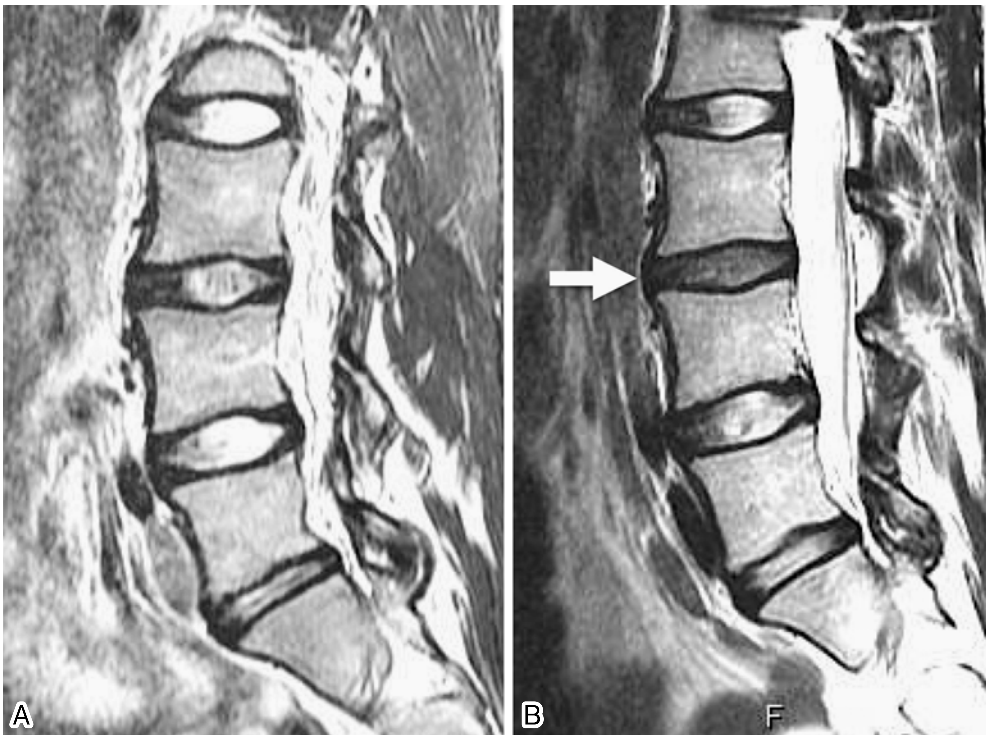

Figure 5. Case 2: (A) Preoperative sagittal T2-weighted image of the MRI showed no disc degeneration. (B) Postoperative T2-weighted image showed L3-4 disc generation (Pfirrmann grade 3) at the final observation (white arrow).

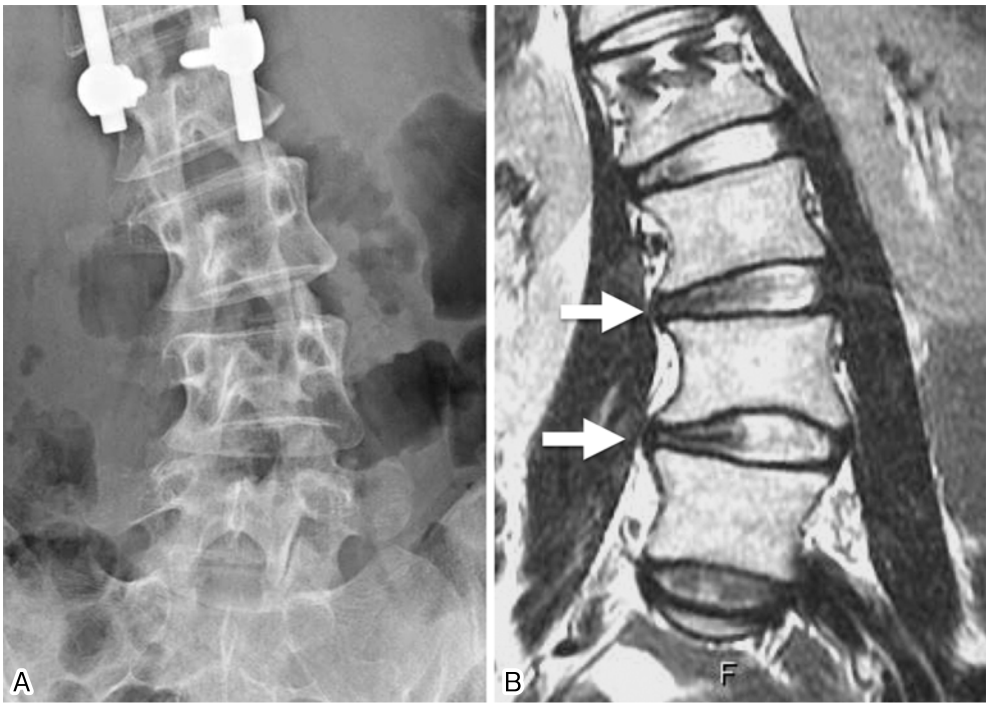

Figure 6. Case 2: (A) An anteroposterior lumbar X-ray showed L3-4 disc wedging with 11 degrees. (B) Postoperative coronal T2-weighted image showed disc generation at concave sides at the final observation (white arrows).

maintain better quality of life over the long-term.

Our study has the following limitations. The long-term follow-up rate for five or more years after surgery is low (38.8%). Since no statistically significant differences were noted in demographics between participants and non-participants, the patients who participated in this study can be considered representative of the entire patients. Lumbar MRIs were not obtained in all patients before surgery and so it is impossible to determine if DD occurred after surgery. No comparative control group was established and so a comparative cohort where fusion extended to the lumbar spine is needed. Since DD may occur as part of the natural clinical course of this disease, a comparative study with healthy individuals is necessary in order to clearly determine how much of an effect deformity may have had on DD. In recent years, PI-LL and PT, which are spino-pelvic parameters, have attracted attention in the field of adult spinal deformity surgery. The relationship between spinal deformities and the spino-pelvic parameter has been clarified since 2009 (Rose, et al.[13]) or 2011 (Schwab, et al.[14]). Since the patients in this study had undergone surgery from 2004 to 2010, the femoral heads were not included in the preoperative X-ray images. Unfortunately, we could not clarify the relationship between spino-pelvic parameters and DDs.

Conclusions

DD was noted in 47.4% of AIS patients who underwent spinal fusion without lumbar curve fusion five or more years prior. The lumbar curve and SVA at the final observation were significantly larger in patients with DD, and SRS-22 function, self-image, and satisfaction tended to be worse. It is recommended that lumbar curves should be minimized after AIS surgery to maintain a better quality of life over the long-term.

Disclaimer: Sumihisa Orita is one of the Editors of Spine Surgery and Related Research and on the journal's Editorial Committee. He was not involved in the editorial evaluation or decision to accept this article for publication at all.

Conflicts of Interest: The authors declare that there are no relevant conflicts of interest.

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References

1. Danielsson AJ, Cederlund CG, Ekholm S, et al. The prevalence of disc aging and back pain after fusion extending into the lower lumbar spine. A matched MR study twenty-five years after surgery for adolescent idiopathic scoliosis. Acta Radiol. 2001;42(2):187-97.
2. Akazawa T, Kotani T, Sakuma T, et al. Spinal fusion on adolescent idiopathic scoliosis patients with the level of L4 or lower can increase lumbar disc degeneration with sagittal imbalance 35 years after the surgery. Spine Surg Relat Res. 2017;1(2):1-20.
3. King HA, Moe JH, Bradford DS, et al. The selection of fusion levels in thoracic idiopathic scoliosis. J Bone Joint Surg Am. 1983;65(9):1302-13.
4. Ishikawa M, Nishiyama M, Kamata M. Selective thoracic fusion for King-Moe type II/Lenke 1C curve in adolescent idiopathic scoliosis: a comprehensive review of major concerns. Spine Surg Relat Res. 2019;3(2):113-25.
5. Lonstein JE. Selective thoracic fusion for adolescent idiopathic scoliosis: long-term radiographic and functional outcomes. Spine Deform. 2018;6(6):669-75.
6. Chang MS, Bridwell KH, Lenke LG, et al. Predicting the outcome of selective thoracic fusion in false double major lumbar "C" cases with five- to twenty-four-year follow-up. Spine (Phila Pa 1976). 2010;35(24):2128-33.
7. Pfirrmann CW, Metzdorf A, Zanetti M, et al. Magnetic resonance classification of lumbar intervertebral disc degeneration. Spine (Phila Pa 1976). 2001;26(17):1873-8.
8. Nohara A, Kawakami N, Seki K, et al. The effects of spinal fusion on lumbar disc degeneration in patients with adolescent idiopathic scoliosis: a minimum 10-year follow-up. Spine Deform. 2015;3(5):462-8.
9. Lonner BS, Ren Y, Upasani VV, et al. Disc degeneration in unfused caudal motion segments ten years following surgery for adolescent idiopathic scoliosis. Spine Deform. 2018;6(6):684-90.
10. Ohashi M, Watanabe K, Hirano T, et al. Predicting factors at skeletal maturity for curve progression and low back pain in adult patients treated nonoperatively for adolescent idiopathic scoliosis with thoracolumbar/lumbar curves: a mean 25-year follow-up. Spine (Phila Pa 1976). 2018;43(23):E1403-11.
11. Akazawa T, Watanabe K, Matsumoto M, et al. Modic changes and disc degeneration in adolescent idiopathic scoliosis patients who reach middle age without surgery: can residual deformity cause lumbar spine degeneration? J Orthop Sci. 2018;23(6):884-8.
12. Bernstein P, Hentschel S, Platzek I, et al. Thoracal flat back is a risk factor for lumbar disc degeneration after scoliosis surgery. Spine J. 2014;14(9):925-32.
13. Rose PS, Bridwell KH, Lenke LG, et al. Role of pelvic incidence, thoracic kyphosis, and patient factors on sagittal plane correction following pedicle subtraction osteotomy. Spine (Phila Pa 1976). 2009;34(8):785-91.
14. Schwab F, Ungar B, Blondel B, et al. Scoliosis Research Society-Schwab adult spinal deformity classification: a validation study. Spine (Phila Pa 1976). 2012;37(12):1077-82.