Intervertebral Disc Degeneration in Long-Term Postoperative Patients with Adolescent Idiopathic Scoliosis: MRI Evaluation 34-51 Years after Surgery and its Changes during Middle and Older Age for an Average of 6.9 Years

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Abstract:

Introduction: This study aimed to identify factors associated with intervertebral disc degeneration (DD) in adolescent idiopathic scoliosis (AIS) patients who reached middle and older age after surgery.

Methods: A total of 252 AIS patients who underwent spinal fusion surgery between 1968 and 1988 were included in this survey-based study. Patients with a mean follow-up period of 40.9 years were evaluated through lumbar spine magnetic resonance imaging (MRI), radiographic assessments, and patient-reported outcome measures (PROMs). DD was evaluated using the Pfirrmann grading system. Various factors, such as surgical levels, sagittal alignment, and PROMs, were analyzed for their association with DD.

Results: Among the 21 participants who underwent both previous (conducted from 2014 to 2016) and latest surveys (conducted in 2022), the prevalence of DD increased from 66.7% in the previous survey to 76.9% in the latest survey. The overall Pfirrmann disc score significantly increased from 3.2 to 3.5. Sagittal alignment parameters, such as sagittal vertical axis (SVA), pelvic incidence minus lumbar lordosis (PI-LL), and pelvic tilt (PT), worsened over time. Scores in the Scoliosis Research Society-22 Questionnaire pain, Roland-Morris Disability Questionnaire, and Oswestry Disability Index were significantly worse in the latest survey than in the previous one. Comparison between patients with the lower instrumented vertebra (LIV) at L4 or lower and L3 or higher revealed significantly higher disc scores and 100% prevalence of DD in the L4 or lower group. Factors associated with DD included LIV at L4 or lower, smaller LL, larger thoracolumbar kyphosis, and increased SVA, PI-LL, and PT.

Conclusions: This study suggests that maintaining the LIV at L3 or higher, achieving good sagittal alignment, and maintaining LL may help prevent long-term DD in AIS patients.

Keywords:

adolescent idiopathic scoliosis, disc degeneration, spinal fusion, middle age, long-term

Spine Surg Relat Res 2025; 9(1): 61-70
dx.doi.org/10.22603/ssrr.2024-0043

Introduction

Intervertebral disc degeneration (DD) is a pathological condition caused by changes and damage to the intervertebral disc tissue, and its prevalence increases with age[1-3)]. It is one of the causes of lower back pain, particularly in the lumbar region[2)]. As age progresses, the flexibility and water content of the intervertebral discs decrease, resulting in a

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Received: February 15, 2024, Accepted: April 18, 2024, Advance Publication: June 10, 2024

decline in function. Magnetic resonance imaging (MRI) is used to evaluate this condition. It is an important tool for noninvasively assessing the state and degree of degeneration of the intervertebral discs. Degenerative disc disease is evaluated based on low signal changes in T2-weighted MRI images, indicating degradation and dehydration of the disc tissue. The Pfirrmann grading system[4] is widely used for the evaluation of DD on MRI.

Adolescent idiopathic scoliosis (AIS) patients undergo surgery in their teenage years, and various studies have investigated the long-term outcomes after surgery. It has been reported that the long-term health-related quality of life in AIS patients after surgery is good[5-7]; however, there are reports of worsening back pain in the middle and older age groups[8]. Therefore, evaluation of the unfused intervertebral discs using lumbar spine MRI is performed in postoperative AIS patients. These studies have reported the prevalence of DD, a relationship between DD and back pain, and other factors associated with DD[9-24]. However, there have been no reports of DD in AIS patients who have undergone surgery and reached middle and older age, with a follow-up of 40 years.

This study aims to identify factors associated with DD in AIS patients who have undergone long-term postoperative follow-up and reached middle and older age. We hypothesized that with advancing age into middle and older adulthood, DD and spinal alignment deterioration would accelerate. Furthermore, we conducted a literature review of DD using MRI in postoperative AIS patients and discussed preventive measures for long-term DD in AIS patients undergoing surgery.

Materials and Methods

1. Study subjects

The institutional review board of our institution approved this study. The study included 252 patients aged 10-19 years who underwent spinal fusion for AIS at a university hospital between 1968 and 1988. The inclusion criteria were as follows: (1) AIS, (2) spinal fusion with implants, and (3) age <20 years at the time of surgery. The exclusion criteria were as follows: (1) neuromuscular disease, (2) congenital scoliosis, or (3) syndromic scoliosis. The mean age at the time of surgery was 14.8 years, the mean preoperative Cobb angle was 68.3°, and the mean Cobb angle at 2 years postoperatively was 39.4°. In the previous survey conducted from 2014 to 2016[23,24], there were 62 who were nonresponders, 134 who had unknown addresses, 8 who died, and 13 who refused examination, leaving 35 patients who participated in the survey. In the latest survey conducted in 2022 of these 35 patients, 13 did not provide consent and one patient with extended fusion was excluded, resulting in 21 patients who took the survey. Written informed consents were obtained from all participants.

Analysis was performed on the 21 patients who participated in both surveys. The mean age at the time of the latest survey was 56.0±5.2 years (ranging from 47 to 67 years), and the mean duration since surgery was 40.9±4.6 years (ranging from 34 to 51 years). The interval between the previous and latest surveys was 6.9±0.5 years (ranging from 6 to 8 years). There were 18 females and 3 males among the participants. The mean body mass index at the latest survey was 21.4±3.4 (ranging from 17.0 to 32.0). The surgical procedures used were as follows: Harrington instrumentation in nine patients; Harrington instrumentation with wiring in seven; Luque wiring, multiple hooks, or the Dwyer method in one each; and Zielke instrumentation in two. The upper instrumented vertebra was T2 in two patients; T3 in six; T4 in eight; T5, T6, or T9 in one each; and T11 in two. The lower instrumented vertebra (LIV) was T12 in one patient, L 1 in three, L2 in eight, L3 in five, L4 in three, and L5 in one.

Lumbar spine MRI, whole spine standing X-ray radiographs, and patient-reported outcome measures (PROMs) were conducted on the 21 patients in both the previous and latest surveys.

2. MRI evaluation

Lumbar spine MRI was performed to assess DD in the unfused segments. MRI included T1-weighted sagittal, T2-weighted sagittal, and T2-weighted coronal images. Three blinded examiners independently interpreted the images. DD was evaluated using the Pfirrmann grading system[4], assessing the unfused discs from L1-2 to L5-S1. Pfirrmann grade 4 or 5 was considered as DD, and the prevalence was investigated. For grading, consensus among two or more of the three examiners was required. In cases where agreement could not be reached, the median value was used.

3. Radiographic evaluation

Plain radiographs were taken in an upright position, including frontal and lateral views of the entire spine. In the frontal view, measurements were taken for Cobb angles of the upper thoracic curve (UT), main thoracic curve (MT), and thoracolumbar/lumbar curve (L). In the lateral view, measurements were taken for thoracic kyphosis (TK: T5-T12 angle), thoracolumbar kyphosis (TLK: T10-L2 angle), lumbar lordosis (LL: L1-S1 angle), pelvic incidence (PI), pelvic tilt (PT), and sagittal vertical axis (SVA: distance between a vertical line from C7 and the posterior corner of S1).

4. PROMs

PROMs included the Scoliosis Research Society-22 Questionnaire (SRS-22), Roland-Morris Disability Questionnaire (RDQ), and Oswestry Disability Index (ODI).

5. Definitions and comparisons

DD was defined as Pfirrmann grade 4 or 5.

The mean disc score was calculated by summing the Pfirrmann grades for each unfused lumbar disc and dividing

it by the total number of unfused lumbar discs.

The previous (2014-2016) and latest surveys (2022) were compared. Comparisons were also made between the L3 or higher group (patients with the LIV at L3 or higher) and the L4 or lower group (patients with the LIV at L4 or lower) and between the DD [+] group (patients with DD in at least one disc at the latest survey) and the DD [−] group (patients with no DD in any of the unfused discs at the latest survey).

6. Statistical analysis

Variables were expressed as mean±standard deviation. Paired t-tests and Fisher's exact tests were used to compare the previous and latest surveys. Unpaired t-tests and Fisher's exact tests were used to compare LIV level and DD. A P value of <0.05 was considered statistically significant.

Results

1. Comparison between the previous survey and the latest survey (Table 1)

Disc score: The overall disc score significantly increased from 3.2±0.7 in the previous survey to 3.5±1.0 in the latest survey, indicating a progression of disc degeneration. Statistically significant progression of degeneration was observed at the L3-4, L4-5, and L5-S1 levels. The highest disc score was not consistently found at the L5-S1 disc.

DD prevalence: The prevalence of DD increased, although there was no significant difference.

Radiographic parameters: There were no significant differences between the previous and latest surveys in UT, MT, L, TK, LL, and TLK. However, the SVA, the pelvic incidence minus lumbar lordosis (PI-LL), and PT significantly increased (Fig. 1).

PROMs: On the SRS-22 questionnaire, the scores in the pain and mental health subdomains were significantly worse in the latest survey than in the previous one. The RDQ and ODI scores also significantly worsened.

Table 1. Comparison between the Previous and Latest Surveys.

	Previous survey	Latest survey	p
Age at the survey, years	49.0±4.8	56.0±5.2	
Follow-up period, years	34.0±4.0	40.9±4.6	
BMI	21.0±4.2	21.4±3.4	
MRI evaluation			
Disc score			
L1-2 (n=4)	2.3±0.5	2.8±1.0	0.826
L2-3 (n=12)	3.0±0.7	3.5±1.1	0.055
L3-4 (n=17)	3.1±0.8	3.5±1.1	<0.001*
L4-5 (n=20)	3.2±0.9	3.5±1.1	0.004*
L5-S1 (n=21)	3.0±0.9	3.2±1.3	<0.001*
Overall (n=21)	3.2±0.7	3.5±1.0	<0.001*
Prevalence of DD	66.7%	76.9%	0.520
Radiographic evaluation			
UT	31.4±10.9	33.0±11.4	0.074
MT	44.6±16.9	45.3±15.3	0.483
L	24.3±12.3	25.5±13.7	0.205
TK	28.4±15.5	28.5±15.0	0.928
LL	44.7±11.6	41.1±16.1	0.116
TLK	10.1±8.4	11.4±9.5	0.131
SVA (mm)	21.9±45.1	46.3±49.0	<0.001*
PI-LL	0.4±21.0	6.7±24.1	0.010*
PT	17.2±13.3	19.8±14.6	0.043*
PROMs			
SRS-22			
Function	4.4±0.5	4.2±0.6	0.115
Pain	4.5±0.4	3.9±0.8	0.003*
Self-image	3.0±0.8	3.0±0.7	0.803
Mental health	4.3±0.7	3.7±0.9	0.016*
Satisfaction	3.6±0.7	3.5±0.8	0.297
RDQ	0.5±0.9	2.1±2.8	0.015*
ODI	7.6±8.1	13.8±10.2	0.005*

Variables were expressed as mean±standard deviation. * means statistical significance.

BMI, body mass index; DD, disc degeneration; UT, upper thoracic curve; MT, main thoracic curve; L, lumbar curve; TK, thoracic kyphosis; LL, lumbar lordosis; TLK, thoracolumbar kyphosis; SVA, sagittal vertical axis; PI, pelvic incidence; PT, pelvic tilt; PROMs, patient-reported outcome measures; SRS-22, Scoliosis Research Society-22 Questionnaire; RDQ, Roland-Morris Disability Questionnaire; ODI, Oswestry Disability Index

2. Comparison between L3 or higher and L4 or lower groups (Table 2)

The mean disc score was significantly higher in the L4 or lower group than in the L3 or higher group. There was no significant difference in the changes in disc score from the previous survey to the latest survey. The prevalence of DD did not show significant differences, but the prevalence of DD was 100% in the L4 or lower group (Fig. 2).

Radiographically, the LL was significantly smaller in the L4 or lower group. The PI-LL and PT were not significantly different.

On the SRS-22 questionnaire, the satisfaction score was significantly worse in the L4 or lower group (Table S1).

3. Comparison between DD[+] and DD[−] group (Table 3)

Age at follow-up was not significantly different between the two groups. The number of unfused lumbar segments was also not significantly different.

Radiographically, the DD[+] group had significantly smaller LL, larger TLK, larger SVA, larger PI-LL, and larger PT.

On the PROMs, the SRS-22 subdomain, RDQ, and ODI scores were not significantly different.

In addition, the patients whose disc score had progressed to 1 or more from the previous survey to the latest survey (DD progress [+] group) and the patients whose disc score had progressed to less than 1 (DD progress [−] group) were compared. In the previous survey, SRS-22 Pain was significantly lower in the DD progress [+] group. In the latest survey, the DD progress [+] group had significantly smaller LL and larger PT (Table S2).

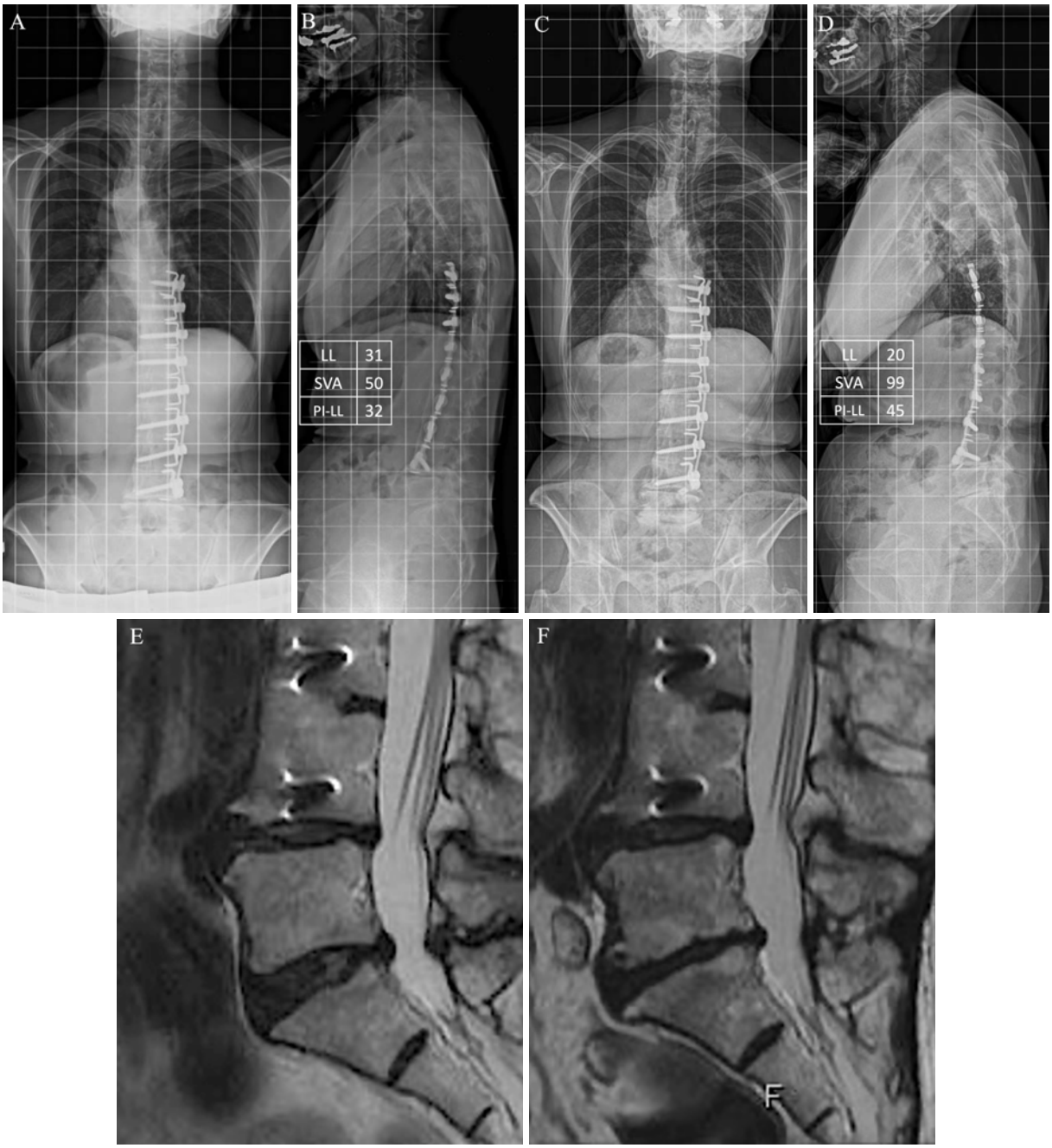

Figure 1. The patient underwent anterior spinal fusion (Dwyer method) from T9 to L4 at the age of 14. Frontal and lateral radiographs (A, B) were taken at the previous (age 51, 37 years postsurgery) and latest surveys (age 58, 44 years postsurgery) (C, D). Sagittal alignment had worsened in the latest survey than in the previous survey. The MRI findings at the previous survey showed a Pfirrmann grade 3 for the L5–S1 disc (E), while at the latest survey, it had progressed to grade 5, indicating advanced intervertebral disc degeneration (F).

4. Comparison between participants and nonparticipants (Table 4)

The demographics of 21 participants were compared to those of 231 nonparticipants, and there were no statistically significant differences in terms of patient age at surgery, preoperative Cobb angle, postoperative Cobb angle 2 years after surgery, or the percentage of females between participants and nonparticipants.

5. Reliability of MRI readings among examiners

Intraclass correlation coefficients (ICCs) were used to assess the reliability among examiners. The ICC for the Pfirrmann classification demonstrated a reliability value of 0.734, indicating substantial agreement.

6. Additional information

Although excluded from the main analysis, we also report a case in which extended fusion was required due to DD in

Table 2. Comparison in the Latest Survey between L3 or Higher and L4 or Lower Group.

	L3 or higher group (n=17)	L4 or lower group (n=4)	p
Age at follow-up, years	56.4±5.6	54.5±3.4	0.535
Follow-up period, years	41.5±4.6	38.5±4.2	0.253
BMI	21.2±3.7	22.3±1.1	0.577
Unfused lumbar segment	4.0±0.9	1.8±0.5	<0.001*
MRI evaluation			
Disc score	3.2±0.9	4.8±0.3	0.004*
Changes in disc score from the previous survey to the latest survey	0.3±0.9	0.6±0.8	0.307
Prevalence of DD	70.6%	100%	0.532
Radiographic evaluation			
UT	33.8±12.5	29.5±4.4	0.511
MT	46.3±15.6	41.0±15.4	0.548
L	24.4±11.8	30.2±21.6	0.456
TK	29.7±14.9	23.8±17.0	0.494
LL	44.5±16.0	26.5±5.1	0.041*
TLK	10.1±9.7	16.5±7.9	0.241
SVA (mm)	40.2±51.3	72.5±29.6	0.246
PI-LL	2.1±22.7	26.5±21.9	0.066
PT	17.1±12.8	31.5±18.2	0.074
PROMs			
SRS-22			
Function	4.2±0.7	4.4±0.4	0.520
Pain	3.8±0.9	4.0±0.6	0.745
Self-image	3.1±0.8	2.9±0.4	0.583
Mental health	3.8±0.8	3.4±1.0	0.331
Satisfaction	3.6±0.7	2.6±0.5	0.013*
RDQ	2.4±3.0	0.8±1.0	0.315
ODI	13.9±11.0	13.2±6.8	0.911

Variables were expressed as mean±standard deviation. * means statistical significance.

BMI, body mass index; DD, disc degeneration; UT, upper thoracic curve; MT, main thoracic curve; L, lumbar curve; TK, thoracic kyphosis; LL, lumbar lordosis; TLK, thoracolumbar kyphosis; SVA, sagittal vertical axis; PI, pelvic incidence; PT, pelvic tilt; PROMs, patient-reported outcome measures; SRS-22, Scoliosis Research Society-22 Questionnaire; RDQ, Roland-Morris Disability Questionnaire; ODI, Oswestry Disability Index

the unfused segments. She underwent T4-L4 spinal fusion with Harrington instrumentation at the age of 14 years. At the time of the previous survey, 37 years had passed since the surgery, and she had low back pain but no complaints of leg pain. MRI evaluation of DD was grades 4 and 5 at L4-5 and L5-S1, respectively, with findings of spinal canal stenosis at L4-5. Forty years after surgery, she underwent L4-5 and L5-S posterior lumbar interbody fusion with posterior fusion extension to the pelvis at another institution due to low back pain.

Discussion

1. Summary of research results

Over a 7-year period in middle-aged and elderly AIS patients who underwent spinal fusions as adolescents, there was an increase in disc score and progression of DD. Sagittal alignment parameters, such as SVA, PI-LL, and PT, worsened over time. SRS-22 subscales related to pain and mental health, as well as RDQ and ODI, significantly deteriorated. Patients with LIV at L4 or lower exhibited significantly higher disc scores and a 100% prevalence of DD. Furthermore, patients with LIV at L4 or lower had significantly smaller LL and lower satisfaction scores on the SRS-22 questionnaire. Among patients with DD, there were significant impairments in LL, TLK, SVA, PI-LL, and PT, indicating poor sagittal alignment. The factors associated with DD in this study were LIV at L4 or lower, LL, TLK, SVA, PI-LL, and PT.

2. Postoperative chronological changes in DD using MRI in AIS patients

Table 5 shows long-term intervertebral DD in postoperative AIS patients using MRI.

AIS patients up to 10 years postsurgery

Published papers indicate that the prevalence of Pfirrmann grade 3 or higher ranges from 10.3% to 73.3% and Pfirrmann grade 4 or higher ranges from 2.7% to 7.8%[9-15]. These patients are still in their teens to 20s, so the prevalence of moderate to severe DD is not high. There was no

Figure 2. The patient underwent posterior spinal fusion (Harrington instrumentation) from T4 to L5 at the age of 14. In the latest evaluation (age 54, 39 years postsurgery), the lateral radiograph revealed poor sagittal alignment (A). The remaining solitary intervertebral disc (L5–S1) showed significant degeneration on MRI, with a Pfirrmann grade of 5 (B).

significant difference in DD in healthy individuals of the same age group[13], but there was a lower prevalence of DD in nonsurgical patients with severe scoliosis[15]. Most papers suggest that although DD occurs in AIS patients up to 10 years postsurgery, it is not a significant concern.

AIS patients from 10 to 20 years postsurgery

Published papers indicate that the prevalence of Pfirrmann grade 3 or higher ranges from 45% to 52.1% and Pfirrmann grade 4 or higher is reported at 29.2%[16-21]. These patients are now in their 20s-30s, and the prevalence of moderate to severe DD is higher compared to the previous 10-year postsurgery period. Comparison with healthy individuals of the same age group revealed higher DD grades, except at the L4-5 level[16]. AIS patients from 10 to 20 years postsurgery have a higher prevalence of DD than those from the previous 10-year period, but there is no significant association between DD occurrence and low back pain[17-21].

AIS patients 20 years or more postsurgery

Published papers indicate that the prevalence of Pfirrmann grade 3 or higher ranges from 96.2% to 97.1% and Pfirrmann grade 4 or higher ranges from 61.5% to 68.6%[22-24]. In this study, the prevalence of Pfirrmann grade 3 or higher was 90.4%, and Pfirrmann grade 4 or higher was 76.9%. These patients are in their 40s-50s, and many have degenerative changes in the unfused segments. One report[22] suggests that healthy individuals of the same age group have higher rates of DD and endplate changes, whereas another report[24] suggests similar rates of DD but a higher prevalence of Modic changes[24]. AIS patients 20 years or more postsurgery show a greater incidence of low back pain than healthy individuals[22,24].

Factors associated with DD

Various factors have been reported to be associated with DD in postoperative AIS patients. Reports up to 20 years postsurgery often focus on coronal parameters such as the lumbar curve[12,15,16,19], while reports beyond 20 years postsurgery tend to highlight sagittal parameters such as LL and SVA[22,23]. It has been reported that DD is more prevalent when the LIV level is below L4[22], and it is recommended to stop instrumentation at the L3 level[9,21,23].

3. Our recommendation

In this study, even after a mean of 40.9 years postsurgery, the factors associated with the onset of DD were LIV at L4 or lower, smaller LL, and larger TLK, SVA, PI-LL, and PT. This aligns with previous studies spanning over 20 years postsurgery.

A community-based study reported that sagittal parameters such as SVA and PI-LL tend to worsen with age[25]. In our research, the fact that SVA, PI-LL, and PT have worsened over the past 7 years may suggest a tendency for these parameters to degrade due to general age-related changes. However, LL and TLK have not significantly changed in the past 7 years. Since LL and TLK did not change with age, smaller LL and larger TLK may be the cause that accelerates the progression of DD rather than occurring as the result of DD.

In addition, having the LIV at L4 or lower, or in other words, not preserving at least three mobile intervertebral

discs, also can exacerbate DD. Therefore, our recommendation for preventing DD in the long-term after spinal fusion surgery for AIS is to maintain the LIV at L3 or higher while properly attaining LL and aiming for a good sagittal alignment.

4. Limitations

This study has some limitations. First, due to the long duration since surgery, participation rate in the survey was low. However, since there were no differences in background factors between participants and nonparticipants, it is believed that the participants accurately represent the entire patient cohort. In addition, this study primarily includes first-generation instrumentation like the Harrington rod; thus, the results may differ with the pedicle screw fixation commonly used today. Moreover, due to the unavailability of X-ray films from the time of surgery, it was not possible to verify the preoperative condition of patients for comparative analysis. Currently, imaging data is no longer preserved in physical film format, as it has transitioned to digital data. Digital storage provides ease of retention and significantly reduces the risk of data loss. Furthermore, the interval between the previous and latest surveys in this study might have appeared somewhat short in numerical terms. We hypothesized that with advancing age into middle and older adulthood, DD and spinal alignment deterioration would accelerate. Indeed, in this study, the disc scores at L3-4, L4-5, and L5-S1 deteriorated over this interval, and measures such as the SVA, PI-LL, and PT significantly increased. These findings indicate that the interval of our surveys was not excessively short. Nonetheless, it will be necessary to space out the comparisons more in the future. Finally, this study could not completely explain the causes of DD progression in AIS patients. It is difficult to distinguish whether the progression of DD is simply due to age-related changes, the influence of AIS itself, or the impact of spinal fusion surgery. In the future, advances in genetic analysis of AIS are needed to clarify the relationship with DD-related genes. In addition, the status of DD compared to scoliosis patients who did not undergo surgery or normal subjects within the same age group is of interest to surgeons. It has been reported that postoperative 10-year AIS patients experienced a 20% decrease in the rate of DD when compared to the natural progression of nonsurgically treated idiopathic scoliosis[15]. In a study comparing AIS patients who underwent surgery over 27 years ago with healthy controls, there was no significant difference in the proportion of subjects with DD[24]. However, in this study, our AIS patients and those with natural progression of scoliosis or healthy individuals within the same age group were not compared. This is considered one of the future research topics.

Table 3. Comparison between DD [+] and DD [−] Groups.

	DD [+] group (n=16)	DD [−] group (n=5)	p
Age at follow-up, years	57.1±5.0	52.6±4.7	0.094
Follow-up period, years	41.2±4.6	40.0±5.0	0.625
BMI	21.5±3.5	21.2±3.4	0.863
Unfused lumbar segment	3.4±1.1	4.2±1.3	0.189
Radiographic evaluation			
UT	31.4±10.9	39.0±13.0	0.274
MT	44.4±15.6	48.0±15.8	0.662
L	26.6±14.8	22.2±9.7	0.547
TK	28.3±14.7	29.2±17.9	0.912
LL	36.2±14.7	56.4±10.0	0.011*
TLK	14.1±8.0	2.8±9.7	0.017*
SVA (mm)	58.3±48.5	8.2±28.8	0.043*
PI-LL	13.6±23.4	−15.2±7.7	0.015*
PT	24.4±13.6	5.0±4.1	0.006*
PROMs			
SRS-22			
Function	4.2±0.7	4.2±0.6	0.906
Pain	4.0±0.7	3.6±1.2	0.471
Self-image	3.1±0.8	3.0±0.5	0.899
Mental health	3.7±0.9	3.8±0.8	0.784
Satisfaction	3.3±0.7	4.0±0.9	0.068
RDQ	1.8±2.4	3.0±4.1	0.398
ODI	14.6±10.2	11.2±10.9	0.528

Variables were expressed as mean±standard deviation. * means statistical significance.

DD, disc degeneration; BMI, body mass index; UT, upper thoracic curve; MT, main thoracic curve; L, lumbar curve; TK, thoracic kyphosis; LL, lumbar lordosis; TLK, thoracolumbar kyphosis; SVA, sagittal vertical axis; PI, pelvic incidence; PT, pelvic tilt; PROMs, patient-reported outcome measures; SRS-22, Scoliosis Research Society-22 Questionnaire; RDQ, Roland-Morris Disability Questionnaire; ODI, Oswestry Disability Index

5. Conclusions

We identified factors associated with DD in AIS patients who reached middle and older age after spinal fusion. The results suggest that maintaining the LIV at L3 or higher, achieving good sagittal alignment, and maintaining LL may be beneficial in preventing long-term DD in AIS patients.

The cases in this study involved the use of earlier genera-

Table 4. Comparison between Participants and Nonparticipants.

	Participants (n=21)	Nonparticipants (n=231)	p
Age at surgery, years	15.1±2.4	14.7±2.0	0.480
Preoperative Cobb angle	63.5±18.4	68.7±20.2	0.261
Postoperative Cobb angle 2 years after surgery	35.7±14.6	39.7±16.3	0.281
Percentage of females	85.7%	91.3%	0.420

Variables were expressed as mean±standard deviation.

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Table 5. Report on Intervertebral Disc Degeneration in Postoperative AIS Patients Using MRI.

Authors, published year	Mean F/U period, years (range)	Diagnosis	Surgical procedure	Number of patients who underwent MRI (gender)	Mean age at F/U, years (range)	Definition of DD on MRI	Prevalence of Pfirrmann grade 3 or higher	Prevalence of Pfirrmann grade 4 or higher	Factors associated with DD
Duramaz A, 2022[9]	4.2 (4–5.2)	AIS, Lenke 3C	PSF (PS)	90 (61F, 29M)	18.8 (N/A)	Pfirrmann grades 4, 5	N/A	7.8%	No factors (not related to LIV level)
Dehnokhalaji M, 2018[10]	4.9 (2.7–6.1)	AIS	Spinal fusion	15 (11F, 4M)	18.9 (13–25)	Pfirrmann	73.3%	6.6%	Smaller number of free discs below LIV
Bernstein P, 2014[11]	7.5 (5–10)	AIS	ASF, combined AP (Zielke, CD with PS)	28 (N/A)	23.1 (N/A)	Pfirrmann grades 3, 4, 5	32.1%	N/A	Thoracal flat back
Akazawa T, 2019[12]	7.7 (5–11)	AIS, Lenke 1AB, 2AB	PSF (hybrid)	19 (17F, 2M)	23.4 (19–28)	Pfirrmann grades 3, 4, 5	47.4%	5.3%	Larger lumbar curve Larger SVA
Enercan M, 2016[13]	8.1 (5–17)	AIS	PSF (PS with LIV at L3, L4)	37 (30F, 7M)	22.0 (18–30)	Pfirrmann	43.2%	2.7%	No factors (not related to LIV level [L3 vs. L4])
Jakkepally S, 2022[14]	9.1 (6.5–N/A)	AIS	PSF (PS)	58 (52F, 6M)	25.2 (18–29)	Pfirrmann	10.3%	6.9%	No factors (not related to LIV level, pre- or postoperative X-ray)
Nohara A, 2018[15]	10 (10–10)	AIS	Spinal fusion	51 (51F)	28.2 (24–35)	Pfirrmann grades 3, 4, 5	62.7%	N/A	Larger lumbar curve, larger L4 tilt, larger main thoracic curve
Enercan M, 2015[16]	11.4 (10–18)	AIS, Lenke 1B, 1C	PSF (PS with STF)	25 (24F, 1M)	23.8 (21–30)	Pfirrmann	N/A	N/A	Nonfused lumbar curves more than 10 degrees
Green DW, 2011[17]	11.8 (9.4–15.1)	AIS	PSF (MH, hybrid)	20 (17F, 3M)	26 (19–32)	Pfirrmann grades 3, 4, 5	45%	N/A	L5-S1 disc
Perez-Grueso FS, 2000[18]	12 (10–N/A)	AIS	PSF (CD with LIV at L3, L4, L5)	33 (*33F, 2M)	27 (21–37)	Original	N/A	N/A	No factors (not related to LIV level, radiographic results)
Nohara A, 2015[19]	12.8 (10–17.9)	AIS	PSF, combined AP	93 (90F, 3M)	28 (N/A)	Pfirrmann grades 3, 4, 5	48%	N/A	L5-S1 disc, larger L4 tilt, fewer mobile segments
Kelly DM, 2010[20]	16.97 (12–22)	AIS, TL/L curve	ASF (Dwyer, TSRH, Zielke)	6 (*16F, 2M)	32.9 (N/A)	Original	N/A	N/A	N/A
Chiu CK, 2021[21]	17.7 (SD 6.3)	AIS	PSF (PS, hook, wire)	48 (45F, 3M)	33.3 (SD 8.7)	Pfirrmann grades 4, 5	52.1%	29.2%	Older age, longer follow-up
Danielsson AJ, 2001[22]	24.6 (22.1–28)	AIS	PSF (Harrington with LIV at L4, L5, L6)	32 (29F, 3M)	39.7 (35–45)	Original	N/A	N/A	Smaller LL
Akazawa T, 2017[23]	35.1 (27–45)	AIS	PSF, ASF (Harrington, Zielke, Dwyer, MH)	35 (30F, 5M)	49.8 (40–64)	Pfirrmann grades 4, 5	97.1%	68.6%	LIV at L4 or lower, smaller LL, larger SVA
Akazawa T, 2018[24]	36.1 (27–45)	AIS	PSF (Harrington)	26 (22F, 4M)	50.8 (40–64)	Pfirrmann grades 4, 5	96.2%	61.5%	N/A
The current study	40.9 (34–51)	AIS	PSF, ASF (Harrington, Zielke, Dwyer, MH)	21 (18F, 3M)	56.0 (47–67)	Pfirrmann grades 4, 5	90.4%	76.9%	LIV at L4 or lower, smaller LL, larger TLK, larger SVA, larger PI-LL, larger PT

* including patients who did not undergo MRI.

F/U, follow-up; DD, disc degeneration; AIS, adolescent idiopathic scoliosis; PSF, posterior spinal fusion; PS, pedicle screw; F, female; M, male; N/A, not available; LIV, lower instrumented vertebra; ASF, anterior spinal fusion; AP, anterior-posterior; CD, Cotrel-Dubousset; SVA, sagittal vertical axis; STF, selective thoracic fusion; MH, multiple hooks; TL/L, thoracolumbar or lumbar; TSRH, Texas Scottish Rite Hospital; SD, standard deviation; LL, lumbar lordosis; TLK, thoracolumbar kyphosis; PI, pelvic incidence; PT, pelvic tilt

dx.doi.org/10.22603/ssrr.2024-0043

tion instrumentation, which may have different outcomes compared to the current mainstream and more advanced segmental pedicle screw fixation. However, there remains much to learn from past cases, and it is essential to leverage that knowledge when using current treatment approaches.

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 the existence of a financial/nonfinancial competing interest from Medtronic and Stryker. Tsutomu Akazawa has received research grants from Medtronic and Stryker. The other authors declare no conflicts of interest.

Sources of Funding: This work was supported by the Grants-in-Aid for Scientific Research of Japan Society for the Promotion of Science.

Acknowledgement: This work was supported by the Grants-in-Aid for Scientific Research of Japan Society for the Promotion of Science, grant number JP21K09311. The authors thank Mr. Hideo Ishikawa, Mr. Takehide Katogi, Ms. Yuri Ichikawa, and Ms. Nana Kondo for their assistance with data collection.

Author Contributions: Tsutomu Akazawa, Toshiaki Kotani, Tsuyoshi Sakuma, Yasushi Iijima, and Shohei Minami collected the data. Tsutomu Akazawa wrote and prepared the manuscript. All authors participated in the study design. All authors have read, reviewed, and approved the article.

Ethical Approval: The institutional review board of Seirei Sakura Citizen Hospital approved this study (approval no. 2021020).

Informed Consent: Informed consent for publication was obtained from all participants in this study.

References

1. Jensen MC, Brant-Zawadzki MN, Obuchowski N, et al. Magnetic resonance imaging of the lumbar spine in people without back pain. N Engl J Med. 1994;331(2):69-73.
2. Teraguchi M, Yoshimura N, Hashizume H, et al. Prevalence and distribution of intervertebral disc degeneration over the entire spine in a population-based cohort: the Wakayama spine study. Osteoarthritis Cartilage. 2014;22(1):104-10.
3. Fujita N, Ishihara S, Michikawa T, et al. Potential association of metabolic and musculoskeletal disorders with lumbar intervertebral disc degeneration: cross-sectional study using medical checkup data. J Orthop Sci. 2020;25(3):384-8.
4. Pfirrmann CW, Metzdorf A, Zanetti M, et al. Magnetic resonance classification of lumbar intervertebral disc degeneration. Spine. 2001;26(17):1873-8.
5. Danielsson AJ, Nachemson AL. Back pain and function 23 years after fusion for adolescent idiopathic scoliosis: a case-control study-part II. Spine. 2003;28(18):E373-83.
6. Akazawa T, Minami S, Kotani T, et al. Long-term clinical outcomes of surgery for adolescent idiopathic scoliosis 21 to 41 years later. Spine. 2012;37(5):402-5.
7. Farshad M, Kutschke L, Laux CJ, et al. Extreme long-term outcome of operatively versus conservatively treated patients with adolescent idiopathic scoliosis. Eur Spine J. 2020;29(8):2084-90.
8. Akazawa T, Kotani T, Sakuma T, et al. Health-related quality of life of patients with adolescent idiopathic scoliosis at least 40 years after surgery. Spine. 2023;48(7):501-6.
9. Duramaz A, Karaali E, Öztürk V, et al. Importance of lowest instrumented vertebra on clinical and radiological outcomes in patients with Lenke type 3C adolescent idiopathic scoliosis: a minimum 4-year follow-up. J Pediatr Orthop B. 2020;29(6):580-9.
10. Dehnokhalaji M, Golbakhsh MR, Siavashi B, et al. Evaluation of the degenerative changes of the distal intervertebral discs after internal fixation surgery in adolescent idiopathic scoliosis. Asian Spine J. 2018;12(6):1060-8.
11. 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(6):925-32.
12. Akazawa T, Umehara T, Iinuma M, et al. 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. Spine Surg Relat Res. 2020;4(1):50-6.
13. Enercan M, Kahraman S, Yilar S, et al. Does it make a difference to stop fusion at L3 versus L4 in terms of disc and facet joint degeneration: an MRI study with minimum 5 years follow-up. Spine Deform. 2016;4(3):237-44.
14. Jakkepally S, Viswanathan VK, Shetty AP, et al. The analysis of progression of disc degeneration in distal unfused segments and evaluation of long-term functional outcome in adolescent idiopathic scoliosis patients undergoing long-segment instrumented fusion. Spine Deform. 2022;10(2):343-50.
15. Nohara A, Kawakami N, Tsuji T, et al. Intervertebral disc degeneration during postoperative follow-up more than 10 years after corrective surgery in idiopathic scoliosis: comparison between patients with and without surgery. Spine. 2018;43(4):255-61.
16. Enercan M, Kahraman S, Cobanoglu M, et al. Selective thoracic fusion provides similar health-related quality of life but can cause more lumbar disc and facet joint degeneration: a comparison of adolescent idiopathic scoliosis patients with normal population 10 years after surgery. Spine Deform. 2015;3(5):469-75.
17. Green DW, Lawhorne TW 3rd, Widmann RF, et al. Long-term magnetic resonance imaging follow-up demonstrates minimal transitional level lumbar disc degeneration after posterior spine fusion for adolescent idiopathic scoliosis. Spine. 2011;36(23):1948-54.
18. Pérez-Grueso FS, Fernández-Baíllo N, Arauz de Robles S, et al. The low lumbar spine below Cotrel-Dubousset instrumentation: long-term findings. Spine. 2000;25(18):2333-41.
19. 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.
20. Kelly DM, McCarthy RE, McCullough FL, et al. Long-term outcomes of anterior spinal fusion with instrumentation for thoracolumbar and lumbar curves in adolescent idiopathic scoliosis. Spine. 2010;35(2):194-8.
21. Chiu CK, Tan CS, Chung WH, et al. Mid-long-term outcome and degeneration of the remaining unfused lumbar intervertebral disc in adolescent idiopathic scoliosis patients who had posterior spinal

fusion surgery. Eur Spine J. 2021;30(7):1978-87.
22. 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.
23. 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 surgery. Spine Surg Relat Res. 2017;1(2):72-7.
24. Akazawa T, Kotani T, Sakuma T, et al. Modic changes and disc degeneration of nonfused segments 27 to 45 years after Harrington instrumentation for adolescent idiopathic scoliosis: comparison to healthy controls. Spine. 2018;43(8):556-61.
25. Asai Y, Tsutsui S, Oka H, et al. Sagittal spino-pelvic alignment in adults: the Wakayama spine study. PLOS ONE. 2017;12(6): e0178697.