Preoperative thoracic curve magnitude and L4 end vertebra were risk factors for subjacent disc wedging after selective thoracolumbar/lumbar fusion with L3 as the lowest instrumented vertebra in Lenke type 5 curve patients.

Title: Preoperative thoracic curve magnitude and L4 end vertebra were risk factors for subjacent disc wedging after selective thoracolumbar/lumbar fusion with L3 as the lowest instrumented vertebra in Lenke type 5 curve patients.

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IRB approval

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Abstract

Study Design: Retrospective multicenter study

Objective: This study aimed to investigate the incidence and risk factors of subjacent disc wedging (SDW) in adolescent idiopathic scoliosis (AIS) patients with Lenke type 5 curve.

Summary of Background Data: SDW is frequently observed after surgery; however, data about its mechanism and relations with outcome are limited.

Methods: Data of 59 AIS patients with Lenke type 5 curves who underwent posterior spinal fusion to L3 as the lowest instrumented vertebra (LIV) were retrospectively analyzed. The subjacent disc angle (SDA) was defined as the angle between L3 (LIV) and L4. SDW was defined as the absolute value of SDA ≥10° at 2-year post-operation. The incidence of SDW was investigated between non-selective and selective thoracolumbar/lumbar (TL/L) fusion group. In the selective group, patients with and without SDW were compared.

Results: Among 59 patients, 11 had nonselective and 48 had selective fusion. No patients in the non-selective group showed SDW vs 13 patients in the selective group (27%) showed SDW. In the selective group, patients with SDW showed significantly greater main thoracic (MT) curve, apical vertebral translation of the MT curve, upper instrumented vertebra tilt, LIV tilt, and SDA at 2 years post-operation, while no differences were found in the coronal balance nor clinical outcome. Multivariate analysis revealed preoperative T curve and SDA as predictors of SDW occurrence. T

curve >30° and SDA >0° were calculated as cutoff values based on the receiver operating characteristic curve.

Conclusions: SDW is sometimes seen in Lenke type 5 AIS patients who underwent selective TL/L fusion. SDW seemed to occur as a compensation mechanism for progressing deformity of unfused segments (thoracic curve and residual lumbar curve) to maintain coronal alignment. Preoperative T curve > 30° and SDA > 0° (LEV as L4) were determined as risk factors for SDW occurrence.

Keywords: adolescent idiopathic scoliosis, Lenke type 5 curves, subjacent disc wedging, coronal balance, main thoracic curve, lower instrumented vertebra, L3 vertebra

Level of Evidence: Level III

Introduction

Adolescent idiopathic scoliosis (AIS) is a complex three-dimensional spinal deformity of the coronal, sagittal, and transverse planes. The principles of surgical treatment for scoliosis are to achieve deformity correction, maintain global alignment, prevent curve progression, and save mobile segments with minimal fusion area. AIS patients with Lenke type 5 curve are characterized by a major thoracolumbar/lumbar (TL/L) curve with a non-structural main thoracic (MT) curve.[1] The typical surgical treatment for the Lenke type 5 curve is selective TL/L curve fusion.[1,2] Spontaneous MT curve correction is usually accompanied by TL/L curve correction.[3-6] Moreover, postoperative coronal imbalance was corrected spontaneously.[7] Most cases with Lenke type 5 curve had end vertebra of L3 or L4; thus, those vertebrae were commonly selected as the lower instrumented vertebra (LIV).[8-10]

Some reports revealed that progressing low-back pain and loss of lumbar motion were observed when the fusion segment reached L4[11-13]; thus, many surgeons preferred to select L3 as the LIV to conserve mobile spinal segments.[14,15] However, stopping fusion at L3 sometimes causes insufficient deformity correction and progression of subjacent disc wedging (SDW).[10,16] Lonner et al.[17] observed that disc wedging subjacent to the LIV after corrective fusion surgery was one of the risk factors for the progression of disc degeneration. Therefore, postoperative SDW might be indicative of early disc degeneration or an adding-on phenomenon.[10] Preoperative

L3 and L4 translation, subjacent disc angle, and short fusion, excluding the lower end vertebra (LEV), were reported as risk factors for SDW after selective TL/L fusion surgery in AIS patients with Lenke type 5 curve.[16,18] However, these reports neither revealed the relations with thoracic curve progression nor compared non-selective TL/L fusion surgery.

Thus, this study aimed to clarify the incidence and related factors of SDW after posterior fusion surgery with the LIV at L3 and estimate the effect of SDW on spinal alignment and clinical outcomes in AIS patients with Lenke type 5 curve.

Materials and methods

This retrospective study was approved by the Institutional Review Board of our institution (IRB No.19-305). The medical records of eligible patients with major TL/L curve (Lenke type 5 curve) AIS who underwent posterior corrective surgery to L3 as the LIV between July 2007 and August 2017 at one of the three university hospitals, with a minimum of 2 years of postoperative follow-up, were reviewed retrospectively.

This Lenke classification defined a major TL/L curve with non-structural thoracic curves (Cobb angle <25° on side bending film).[1] Patients with congenital scoliosis, syndromic scoliosis, and anterior surgery or who required revision surgery within 2 years after the initial operation were excluded. Posterior corrective surgeries were performed using all pedicle screw constructs. For the

determination of the upper instrumented vertebrae (UIV), in case of selective TL/L fusion, UIV was selected as the upper-end vertebra (UEV) or UEV-1. The decision regarding the inclusion of the MT curve in the fusion range was determined by every institution; however, relatively rigid MT, such as bending thoracic curve >20°, tended to be included in the fusion area.

Standing whole spine posterior–anterior (PA) and lateral standing radiographs were reviewed at pre-operation, just after operation, and at 2 years after the operation. The side-bending films at the supine position were taken before surgery to evaluate curve flexibility. The magnitudes of the MT and TL/L curves were measured based on the Cobb method for the curve parameters. Additionally, the apical vertebral translation (AVT) of the MT and TL/L curves, L4 tilt, UIV tilt, LIV tilt, lumbosacral takeoff angle (LSTOA), and coronal balance (CB) measurements were obtained. LSTOA was defined as the angle between the center sacral vertical line (CSVL) and a line through the midpoints of L4, L5, and S1.[19] L4, UIV, and LIV tilt values were defined as positive when they were “left side up.” The CB was measured as the horizontal distance between the C7 plumb line and the CSVL and was defined as positive when the C7 plumb line was located to the right of the CSVL. From whole spine lateral standing radiographs, thoracic kyphosis (T5-T12 kyphosis), thoracolumbar kyphosis (T10-L2 kyphosis), and lumbar lordosis (LL; L1-S1 lordosis) were measured. Moreover, on radiographs in which patients were instructed to bend to the side at the supine position, bending Cobb angles were measured to calculate the flexibility of

the curves using the equation below:

(Standing Cobb angle - bending Cobb angle) / Standing Cobb angle × 100

The subjacent disc angle (SDA), defined as the angle between the LIV (L3) and the vertebra just below the LIV (L4), was measured on standing PA radiographs. It was defined as positive and negative when it opens to the convex and concave sides of the TL/L curve, respectively, and these parameters were evaluated by three spine surgeons.

The Scoliosis Research Society (version 22) questionnaire (SRS-22) was administered preoperatively and 2 years postoperatively. Surgical outcomes were evaluated in terms of the SDW. The patients were classified according to an absolute value of the SDA at 2-year follow-up, that is, SDW (-) as SDA <10° and SDW (+) as SDA ≥10° (Figs. 1, 2). First, we compared demographic data and radiographic parameters, including the incidence of SDW, between patients who underwent non-selective and selective fusion surgery. Moreover, in patients with selective TL/L fusion, factors related to SDW were evaluated by comparing SDW (+) and SDW (-) groups.

Student's t-test, Mann–Whitney U test, chi-squared test, and Fisher's exact test were used to evaluate differences between these groups. Univariate logistic regression analysis was performed to identify risk factors for SDW. Subsequent multivariate analysis was conducted with stepwise model selection. The sensitivity, specificity, and receiver operating characteristic (ROC) curve were measured to identify valuable indexes for predicting SDW. All statistical analyses were

138 performed using SPSS version 23.0 (SPSS Inc., Chicago, IL, USA). A p-value <0.05 was
139 considered statistically significant.
140

141 ## Results

142 In total, 59 patients (54 women and 5 men; mean age 15.3 ± 2.2 years, range 12–22 years)
143 were included in this study. Eleven (19%) of those patients underwent non-selective surgery,
144 whereas 48 patients (81%) underwent selective fusion surgery. No inter-group differences were
145 observed in the demographic data except for the fusion length (Table 1). Regarding preoperative
146 radiographic parameters, the non-selective group showed greater MT curve, bending MT curve,
147 AVT-T, and sagittal LL than the selective group ($p<0.05$) (Table 1). At 2 years post-operation, the
148 MT curve, TL/L curve, and AVT-T were significantly smaller in the non-selective group than the
149 selective group (Table 2). SDA was not different between groups at pre-operation; however, it was
150 significantly greater at 2 years post-operation in the selective group than in the non-selective group.
151 No patient in the non-selective group developed SDW, whereas 13 patients (27%) in the selective
152 group developed SDW ($p<0.05$) (Table 2). As for the SRS-22 score, no inter-group differences
153 were observed at pre-operation and 2 years post-operation (Table 2).
154 Among 48 patients who underwent selective TL/L fusion, we categorized patients into
155 two groups according to the incidence of SDW. Compared with the SDW (-) group, the SDW (+)

group showed a high rate of LEV at L4, short fusion length, significant MT curve, bending MT curve, AVT-T, LIV tilt, LSTOA, and SDA at pre-operation ($p<0.05$) (Table 3). At 2 years post-operation, the SDW (+) group showed greater MT curve, AVT-T, UIV tilt, LIV tilt, and SDA than the SDW (-) group ($p<0.05$) (Table 4). Regarding the SRS-22 score, no inter-group differences were observed at pre-operation and 2 years post-operation (Table 4). The T curve, AVT-T, LSTOA, and SDA significantly deteriorated between just after operation and 2 years post-operation in the SDW (+) group compared with the SDW (-) group. While the LIV tilt was corrected after surgery in both groups, the SDW (+) group showed a positive value, whereas the SDW (-) group showed a negative value. On the contrary, CB improved spontaneously during the postoperative period, and no inter-group difference was observed (Fig. 3).

Multivariate analysis identified MT curve (odds ratio [OR]: 1.140, 95% confidence interval [CI] 1.025–1.266, p=0.015) and SDA (OR 1.305, 95%CI 1.036–1.644, p=0.024) as independent risk factors for the occurrence of SDW.

Based on the ROC analysis, the cutoff value of the preoperative T curve was determined to be 30°, with sensitivity and specificity of 62% and 83%, respectively. The area under the ROC curve (AUC) was 0.78 (95%CI 0.637–0.919, p=0.003). In addition, the cutoff SDA value was 0° with sensitivity and specificity of 62% and 77%, respectively (AUC 0.78, 95%CI 0.639–0.915, p=0.003) (Fig. 4).

174 In the selective TL/L fusion group, 8 (62%) patients in the SDW (+) group and 6 (17%)
175 in the SDW (-) group had MT curve >30° (OR=7.8). Similarly, 8 patients (62%) in the SDW (+)
176 group and 7 (20%) in the SDW (-) group had SDA >0° (OR=6.4). Moreover, while 6 patients
177 (46%) in the SDW (+) group had both MT curve >30° and SDA >0°, none had this in the SDW (-)
178 group. In contrast, three patients (27%) in the non-selective TL/L fusion group with both T curve
179 >30° and SDA >0° did not show SDW (Table 5).
180

181 ## Discussion

182 After selective TL/L fusion surgery for AIS patients with Lenke type 5 scoliosis, SDW
183 sometimes occurs along with spontaneous coronal alignment correction. This study revealed that
184 the incidence of SDW (defined as SDA ≥10° at 2 years post-operation) was 27% after selective
185 TL/L fusion, whereas no SDW was observed after non-selective TL/L fusion (Table 2). In the
186 selective TL/L fusion group, although no inter-group differences were observed in the correction
187 rate, CB, or SRS-22, patients with SDW had significantly greater MT curve, AVT-T, UIV tilt, LIV
188 tilt, and SDA at 2 years post-operation than patients without SDW (Table 4). Although
189 postoperative disc wedging could be caused by compressive forces directly applied to the convex
190 side during scoliosis correction that pulls the LIV,[18] the mechanism of SDW was unclear. In this
191 study, SDA improved immediatly after the operation in both groups. However, the SDW (+) group

showed significant deterioration of the SDA during post-operative time course along with the MT curve and LSTOA deterioration despite spontaneous CB correction (Fig. 3). These results suggested that the SDW phenomenon seemed to occur by a compensatory mechanism for the progressing deformity of the unfused segments (MT curve and residual lumbar curve) to maintain coronal alignment (Fig 5). Moreover, the SDW (+) group showed a positive value in LIV tilt, whereas the SDW (-) group showed a negative value just after the operation (Fig. 3). Thus, LIV tilt should not be overcorrected during operation to prevent SDW. In our series, only one patient required reoperation due to thoracic curve progression with SDW after selective TL/L fusion for the Lenke type 5C curve. The reported revision rate of AIS surgery is 4.6-7.5%. [20,21] In these reports, the proportion of revision cases due to curve progression is only 0.6-2.0%. We could not conclude whether SDW is a serious complication leading to revision surgery exclusively from this study; however it suggested a compensatory mechanism for coronal alignment caused by thoracic curve progression or residual lumbar curve progression. Although the long-term result of SDW was unclear, postoperative SDW could indicate coronal malalignment and poor clinical outcome caused by chronic back pain due to the progression of disc degeneration[17,22].

To identify the risk factors for SDW, we compared the demographic and radiographic data of patients with and without SDW. Patients with SDW had a significantly higher rate of LEV at L4, shorter fusion length, greater preoperative MT curve, bending MT curve, AVT-T, LIV tilt,

LSTOA, and SDA than patients without SDW (Table 3). Previous reports revealed that preoperative SDA, LIV translation, and shorter LIV selection correlated with postoperative SDW.[16,18] Consistent with these reports, we similarly demonstrated that the MT curve was related to the occurrence of SDW. These results indicated that the preoperative deformity of the thoracic and lower lumbar curve could be key factors for the occurrence of SDW after selective TL/L fusion.

The typical surgical treatment for the Lenke type 5 curve is TL/L fusion alone because the non-structural thoracic curve should be corrected spontaneously.[3-6] However, Zhang et al.[23] reported that approximately half of the patients with Lenke type 5 curve demonstrated MT curve progression after selective TL/L fusion. The degree of preoperative thoracic curvature, flexibility, and improper fusion area were reported as related factors for thoracic cure progression.[3,15,23] Our results demonstrated that preventing MT curve progression was crucial to suppress the occurrence of SDW after selective TL/L fusion. Actually, in the non-selective TL/L fusion group, no patient developed SDW despite the more significant preoperative MT curve (Table 1).

In this study, after the multivariate analysis, the preoperative MT curve and SDA were detected as independent risk factors. Moreover, based on the ROC curve, cutoff values for preoperative MT curve and SDA were determined to be 30° (OR=7.8) and 0° (OR=6.4), respectively. In other words, pre-operative large thoracic curve and LEV as L4 were risk factors for the occurrence of SDW after selective TL/L fusion surgery. In the selective group, all six

patients who had both MT curve >30° and SDA >0° preoperatively showed SDW. Interestingly, three patients (27%) in the non-selective group who had an MT curve >30° and an SDA >0° did not show SDW (Table 5).

Two possible strategies could be considered to prevent postoperative SDW. The first is to include the thoracic curve into the fusion area that could prevent MT curve progression. The thoracic spine has a relatively small range of motion compared with the lumbar spine; thus, including the thoracic curve into the fusion area may be of less concern for surgeons. Lark et al.[6] showed that nearly 27% of AIS patients with Lenke type 5 curve were treated with non-selective fusion by experienced AIS surgeons. Moreover, they showed that compared with selective fusion, non-selective fusion demonstrated a significant correction rate of the thoracic and lumbar curve, but less thoracic kyphosis and trunk flexibility. However, it is unclear whether the immobility of a longer spinal segment will increase the risk of disc degeneration and low back pain; thus, long-term studies are needed. The second option is to extend the fusion area down to L4. In the same time period, we treated 6 patients with AIS type 5C who underwent posterior fusion surgery to L4 as the LIV, and none of them showed SDW. In contrast, the incidence of SDW was 27% in the case with L3 as the LIV; the sample size was small for comparative analysis, and the incidence of SDW was relatively high in this case. Especially in the case of LEV at L4, extending the fusion level down to L4 might prevent SDW. In the case of a rigid curve, the LIV should be extended to

L4 to prevent correction loss.[24] Wang et al.[9] recommended that a translation of less than 28 mm and a tilt of less than 25° may be used as general criteria for selecting the LIV. However, many studies reported that low back pain increases if L4 was selected as the LIV[11-13]; thus, determining the appropriate LIV remains controversial.[10,24-27] Improper selection of the LIV may result in excessive loss of lumbar motion segments, loss of deformity correction, and spinal imbalance.[9] Similarly, our results demonstrated that proper LIV selection was crucial to suppress the occurrence of SDW.

Our study has several limitations. First, the sample size was relatively small. Simplified whole spine biomechanical analysis comparing different fusion levels was crucial to reveal the optimal fusion level for AIS type 5C patients. Second, we only assessed the short-term outcome of SDW defined as SDA ≥10°, which did not affect the global alignment or SRS-22. Hence, a long-term study is needed to determine the effect of SDW on the global alignment and clinical outcomes, such as disc degeneration and low back pain, and to evaluate the clinically important cutoff value of SDA.

In conclusion, among Lenke type 5 AIS patients with posterior spinal fusion to L3 as the LIV, SDW was sometimes observed after selective TL/L fusion, although the majority of patients attained coronal balance at 2 years. SDW seemed to occur as a compensatory mechanism for progressing deformity of unfused segments (thoracic curve and residual lumbar curve) to maintain

coronal alignment. Preoperative MT curve >30° and SDA >0° (LEV as L4) were determined as risk factors for the occurrence of SDW.

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Table 1 Demographic and baseline characteristics of non-selective and selective fusion groups

	Non-selective (n=11)	Selective (n=48)	p-value
Age (years)	16.5 ± 3.6	15.0 ± 1.7	0.342
Risser grade	4.1 ± 0.7	3.7 ± 0.9	0.194
Female	10 (91%)	44 (92%)	0.713
BMI (kg/m^2)	18.5 ±1.6	19.5 ± 2.1	0.134
DEV (L3/L4)	7 / 4	32 / 16	0.712
UIV	T4: 3, T5: 4, T6: 3, T7: 1	T9: 10, T10: 21, T11: 16, T12: 1	
Fusion length	10.8 ± 1.0	5.8 ± 0.8	<0.001*
Coronal parameters			
MT curve (°)	33.7 ± 6.4	25.6 ± 8.0	0.004*
TL/L curve (°)	45.0 ± 8.9	42.6 ± 7.6	0.539
Bending MT curve (°)	21.4 ± 2.9	13.7 ± 6.7	<0.001*
Bending TL/L curve (°)	18.1 ± 9.0	16.8 ± 7.8	0.777
Flexibility MT curve (%)	35.3 ± 11.4	46.2 ± 21.9	0.119
Flexibility TL/L curve (%)	60.0 ± 16.7	60.6 ± 17.0	0.884
AVT -MT (mm)	16.0 ± 9.2	10.3 ± 7.4	0.040*
AVT -TL/L (mm)	37.8 ± 9.9	42.4 ± 9.6	0.139
LIV tilt (°)	-21.5 ± 5.8	-22.9 ± 4.7	0.324
L4 tilt (°)	-19.1 ± 4.5	-21.1 ± 4.5	0.099
SDA (°)	-2.5 ± 5.3	-1.7 ± 4.2	0.853
LSTOA (°)	13.9 ± 3.2	15.0 ± 4.2	0.412
CB (mm)	-16.1 ± 11.9	-20.7 ± 10.8	0.192
Sagittal parameters			
TK (°)	18.9 ± 6.2	18.1 ± 8.8	0.827
TLK (°)	1.5 ± 5.7	5.8 ± 9.5	0.121
LL (°)	49.8 ± 7.8	43.3 ± 9.8	0.030*

Continuous data are presented as mean ± standard deviation of median. Categorical data are presented as number (%). Abbreviations: BMI, body mass index; DEV, distal end vertebra; UIV, upper instrumented vertebra; AVT, apical vertebral translation; LSTOA, lumbosacral takeoff angle; SDA, subjacent disc angle; CB, coronal balance.

* Statistically significant

345 Table 2 Radiographic parameters at 2 year and SRS-22r scores of non-selective and selective fusion groups.

		Non-selective (n=11)	Selective (n=48)	P-value
Coronal parameters				
MT curve (°)		13.9 ± 4.7	20.7 ± 9.6	0.018*
TL/L curve (°)		14.9 ± 9.2	19.9 ± 8.1	0.015*
MT curve correction (%)		65.2 ± 12.4	25.1 ± 20.3	0.001*
TL/L curve correction (%)		75.7 ± 16.2	69.0 ± 16.3	0.115
AVT -MT (mm)		8.4 ± 7.4	16.1 ± 11.1	0.035*
AVT -TL/L (mm)		14.5 ± 4.8	16.5 ± 10.0	0.539
LIV tilt (°)		-4.3 ± 5.1	-2.3 ± 6.5	0.344
L4 tilt (°)		-8.2 ± 4.7	-8.8 ± 5.1	0.646
SDA (°)		3.9 ± 1.4	6.6 ± 3.3	0.011*
SDW		0	13 (27%)	0.048*
LSTOA (°)		9.1 ± 3.1	9.9 ± 4.6	0.309
CB (mm)		-7.6 ± 6.3	-7.7 ± 10.0	0.992
Sagittal parameters				
TK (°)		27.5 ± 8.0	24.7 ± 10.6	0.436
TLK (°)		-5.1 ± 6.0	-2.7 ± 7.9	0.483
LL (°)		52.4 ± 8.0	46.0 ± 9.8	0.032*
SRS-22 score				
function	pre-op	4.0 ± 1.1	4.4 ± 0.6	0.470
	2y	4.4 ± 0.5	4.7 ± 0.4	0.102
pain	pre-op	4.3 ± 0.9	4.5 ± 0.5	0.908
	2y	4.5 ± 0.5	4.6 ± 0.5	0.657
self-image	pre-op	2.8 ± 0.8	2.8 ± 0.6	0.888
	2y	4.0 ± 0.7	4.0 ± 0.6	0.602
mental	pre-op	3.8 ± 1.2	4.1 ± 0.8	0.582
	2y	4.3 ± 0.6	4.3 ± 0.6	0.948
sub-total	pre-op	3.7 ± 0.9	3.9 ± 0.5	0.771
	2y	4.3 ± 0.5	4.4 ± 0.4	0.517
satisfaction		3.9 ± 0.8	4.0 ± 0.7	0.629

346 Continuous data are presented as mean ± standard deviation of median. Abbreviations: AVT, apical vertebral
347 translation; LIV, lower instrumented vertebra; LSTOA, lumbosacral takeoff angle; SDA, subjacent disc angle;
348 SDW, distal disc wedging; CB, coronal balance; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis; LL,
349 lumbar lordosis. * Statistically significant
350

Table 3 Demographic and baseline characteristics of SDW (+) and SDW (-) groups in patients with selective fusion

	SDW (+) (n=13)	SDW (-) (n=35)	P-value
Age (years)	15.3 ± 2.0	14.9 ± 1.6	0.594
Risser grade	3.9 ± 0.8	3.6 ± 1.0	0.438
Female	12 (92%)	32 (91%)	0.706
BMI (kg/m^2)	19.1 ± 1.5	19.6 ± 2.3	0.378
DEV (L3/L4)	5 / 8	29 / 6	0.005*
UIV	T9: 1, T10: 4, T11: 7, T12: 1	T9: 9, T10: 17, T11: 9	0.069
Fusion length	5.4 ± 0.8	6.0 ± 0.8	0.017*
Coronal parameters			
MT curve (°)	31.3 ± 7.0	23.4 ± 7.3	0.003*
TL/L curve (°)	43.5 ± 6.3	42.3 ± 8.1	0.409
Bending MT curve (°)	17.5 ± 6.4	13.0 ± 7.5	0.035*
Bending TL/L curve (°)	18.2 ± 8.0	16.3 ± 7.8	0.798
Flexibility MT curve (%)	43.0 ± 19.8	45.0 ± 26.2	0.981
Flexibility TL/L curve (%)	58.4 ± 16.7	61.4 ± 17.3	0.826
AVT -MT (mm)	14.5 ± 8.7	8.7 ± 6.2	0.044*
AVT -TL/L (mm)	38.9 ± 8.6	43.7 ± 9.8	0.137
UIV tilt (°)	19.7 ± 5.1	16.6 ± 4.9	0.073
LIV tilt (°)	-20.2 ± 4.5	-23.8 ± 4.5	0.033*
L4 tilt (°)	-21.3 ± 3.4	-21.0 ± 4.8	0.601
SDA (°)	1.1 ± 3.1	-2.8 ± 4.1	0.003*
LSTOA (°)	16.8 ± 2.1	14.3 ± 4.6	0.049*
CB (mm)	-17.5 ± 12.4	-21.9 ± 10.1	0.359
Sagittal parameters			
TK (°)	15.8 ± 11.7	19.0 ± 7.4	0.300
TLK (°)	4.1 ± 11.9	6.5 ± 8.5	0.475
LL (°)	42.2 ± 9.3	43.7 ± 10.0	0.766

Continuous data are presented as mean ± standard deviation of median. Categorical data are presented as number (%). Abbreviations: BMI, body mass index; DEV, distal end vertebra; UIV, upper instrumented vertebra; AVT, apical vertebral translation; LIV, lower instrumented vertebra; LSTOA, lumbosacral takeoff angle; SDA, subjacent disc angle; CB, coronal balance; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis; LL, lumbar lordosis. * Statistically significant

359 Table 4 Radiographic parameters at 2-year post-operation and SRS-22r scores of SDW (+) and SDW (-) groups
360 in patients with selective fusion.

		SDW (+) (n=13)	SDW (-) (n=35)	P-value
Coronal parameters				
MT curve (°)		29.5 ± 8.5	17.5 ± 7.8	<0.001*
TL/L curve (°)		21.8 ± 6.3	19.2 ± 8.6	0.140
MT curve correction (%)		16.8 ± 15.2	28.2 ± 21.3	0.082
TL/L curve correction (%)		69.1 ± 15.1	68.6 ± 19.9	0.781
AVT -MT (mm)		26.7 ± 10.2	12.1 ± 8.6	<0.001*
AVT -TL/L (mm)		15.5 ± 7.3	16.9 ± 10.9	0.972
UIV tilt (°)		11.8 ± 5.8	7.8 ± 4.4	0.029*
LIV tilt (°)		2.9 ± 5.1	-4.2 ± 5.9	0.001*
L4 tilt (°)		-7.8 ± 4.5	-9.1 ± 5.3	0.584
SDA (°)		10.8 ± 1.2	5.0 ± 2.3	<0.001*
LSTOA (°)		11.8 ± 3.6	9.1 ± 48.8	0.096
CB (mm)		-7.9 ± 7.1	-7.6 ± 11.0	0.963
Sagittal parameters				
TK (°)		20.3 ± 14.4	26.4 ± 8.5	0.153
TLK (°)		-4.6 ± 9.1	-2.0 ± 7.4	0.125
LL (°)		42.5 ± 9.5	47.2 ± 9.8	0.189
SRS-22 scores				
function	pre-op	4.3 ± 0.7	4.4 ± 0.6	0.821
	2y	4.9 ± 0.4	4.7 ± 0.5	0.052
pain	pre-op	4.6 ± 0.6	4.4 ± 0.4	0.257
	2y	4.7 ± 0.4	4.5 ± 0.5	0.550
self-image	pre-op	2.7 ± 0.7	2.8 ± 0.6	0.933
	2y	4.1 ± 0.7	3.9 ± 0.6	0.338
mental	pre-op	4.4 ± 0.6	4.0 ± 0.8	0.169
	2y	4.5 ± 0.5	4.3 ± 0.6	0.385
sub-total	pre-op	4.0 ± 0.6	3.9 ± 0.4	0.353
	2y	4.5 ± 0.3	4.3 ± 0.4	0.254
SRS-22 satisfaction		4.3 ± 0.4	3.9 ± 0.7	0.069

361 Continuous data are presented as mean ± standard deviation of median. Abbreviations: AVT, apical vertebral
362 translation; UIV, upper instrumented vertebra; LIV, lower instrumented vertebra; LSTOA, lumbosacral takeoff
363 angle; SDA, subjacent disc angle; CB, coronal balance; TK, thoracic kyphosis; TLK, thoracolumbar kyphosis;
364 LL, lumbar lordosis. * Statistically significant

365 Table 5 Rate of the patients according to the cut off value for SDW in each groups

366

	Selective fusion		Non-selective fusion
	SDW (+) (n=13)	SDW (-) (n=35)	(n=11)
MT curve			
>30°	8 (62%)	6 (17%)	9 (82%)
≤30°	5	29	2
SDA			
>0°	8 (62%)	7 (20%)	4 (36%)
≤0°	5	28	7
MT curve>30° and SDA>0°			
+	6 (46%)	0	3 (27%)
-	7	35	8

Fig. 1

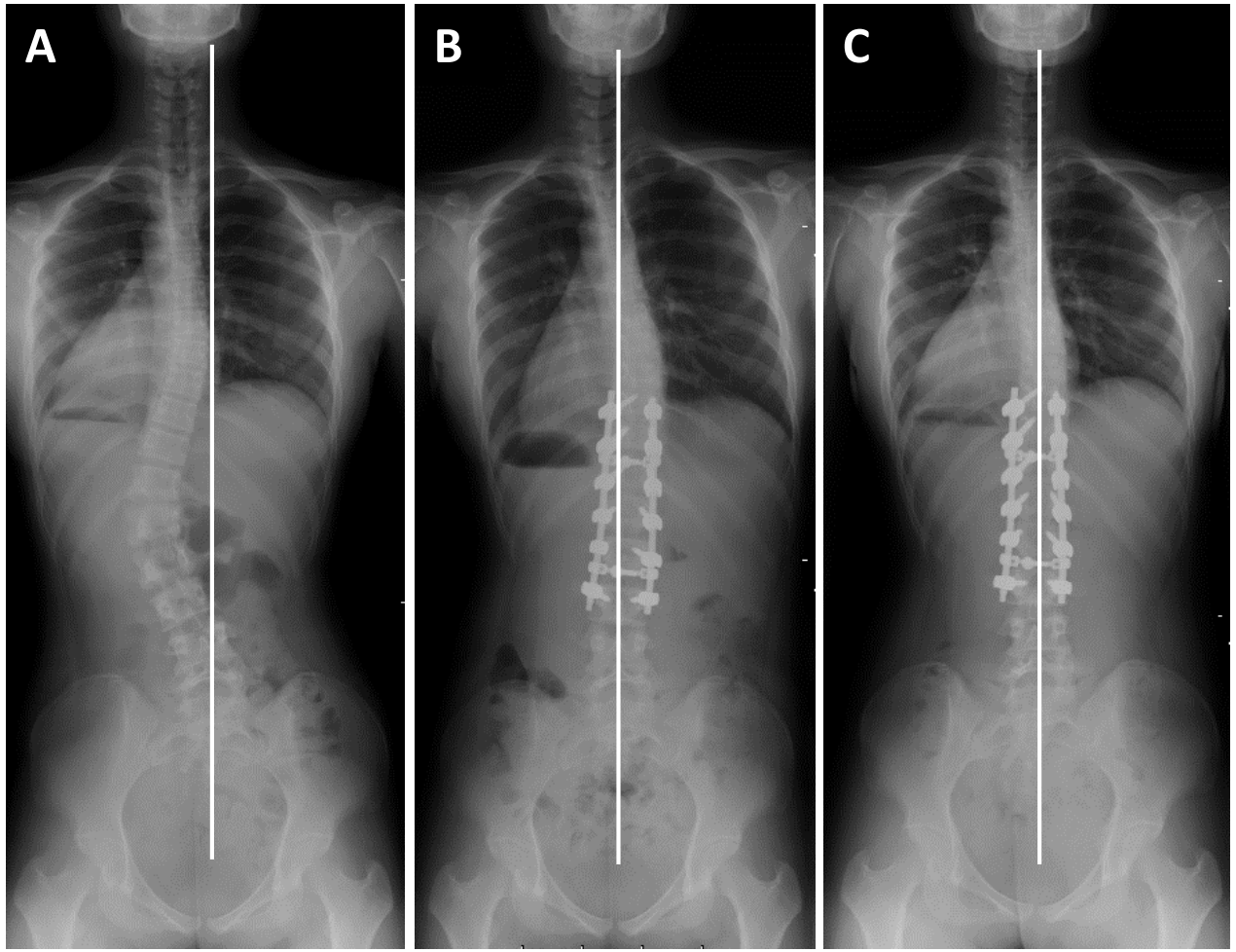


Fig. 2

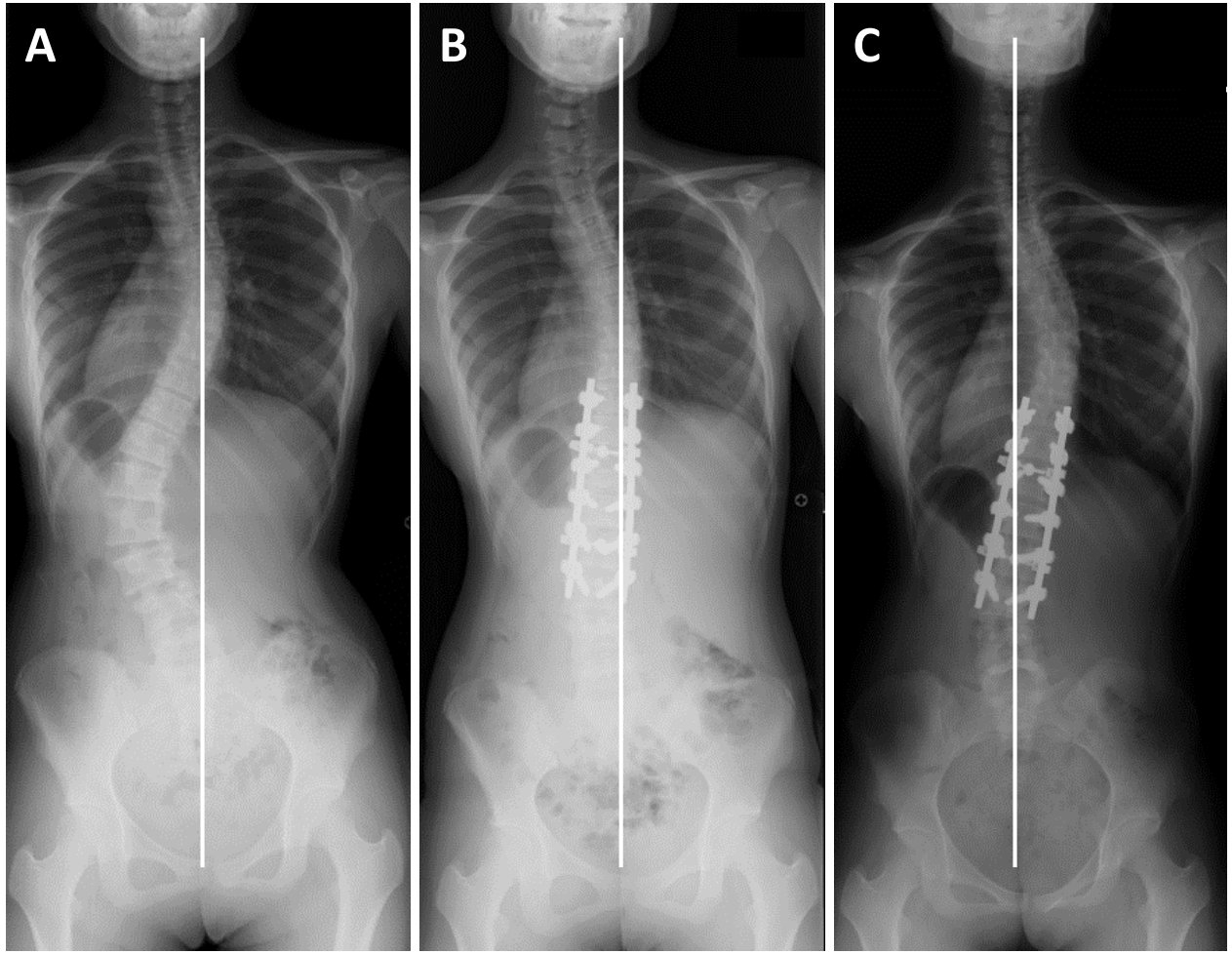


Fig. 3

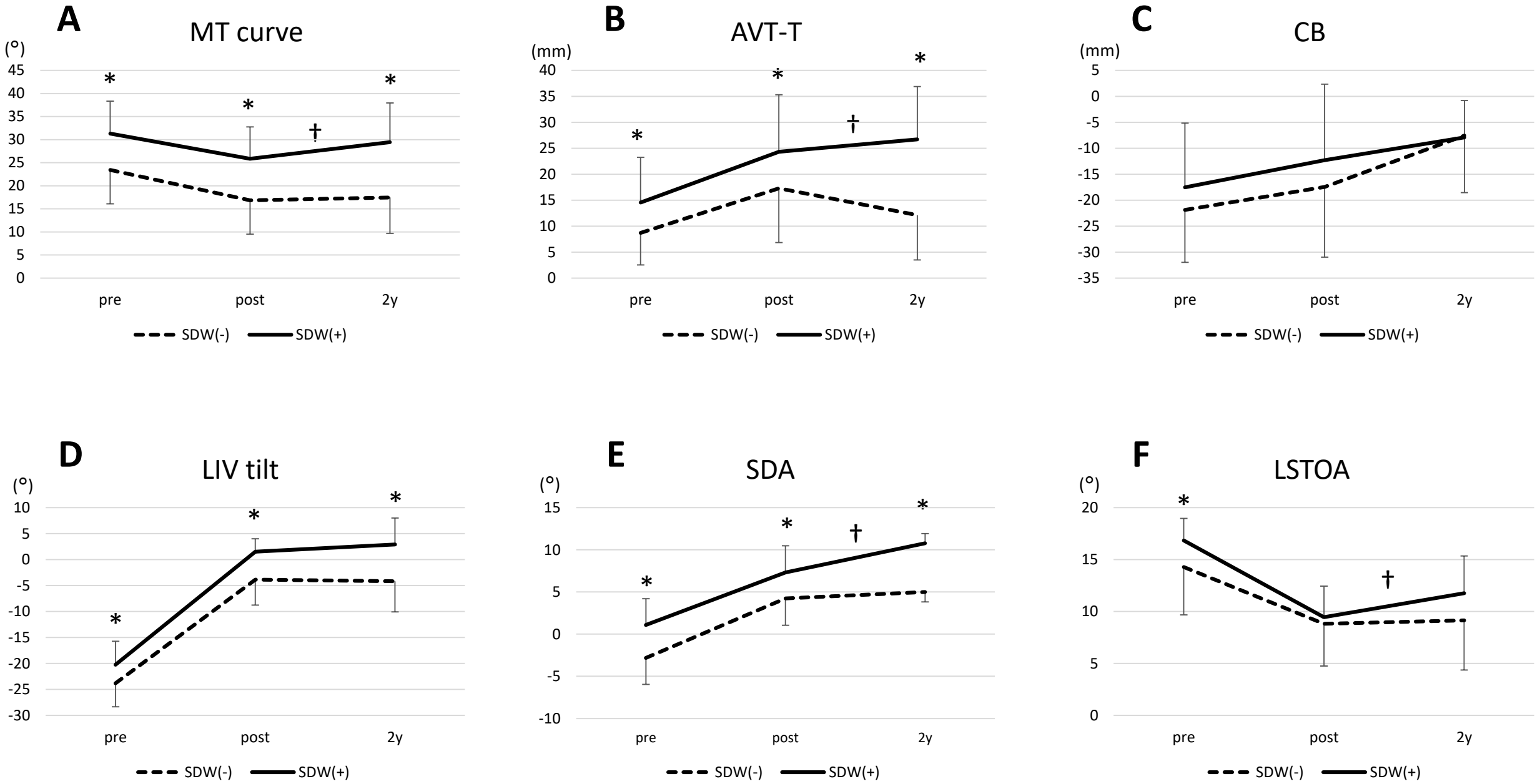

A
MT curve
(°)
45
40
35
30
25
20
15
10
5
0
*
*
†
*
pre
post
2y
SDW(-)
SDW(+)
B
AVT-T
(mm)
40
35
30
25
20
15
10
5
0
*
*
†
*
pre
post
2y
SDW(-)
SDW(+)
C
CB
(mm)
5
0
-5
-10
-15
-20
-25
-30
-35
pre
post
2y
SDW(-)
SDW(+)
D
LIV tilt
(°)
10
5
0
-5
-10
-15
-20
-25
-30
*
*
*
pre
post
2y
SDW(-)
SDW(+)
E
SDA
(°)
15
10
5
0
-5
-10
*
*
†
*
pre
post
2y
SDW(-)
SDW(+)
F
LSTOA
(°)
20
15
10
5
0
*
†
pre
post
2y
SDW(-)
SDW(+)

Fig. 4

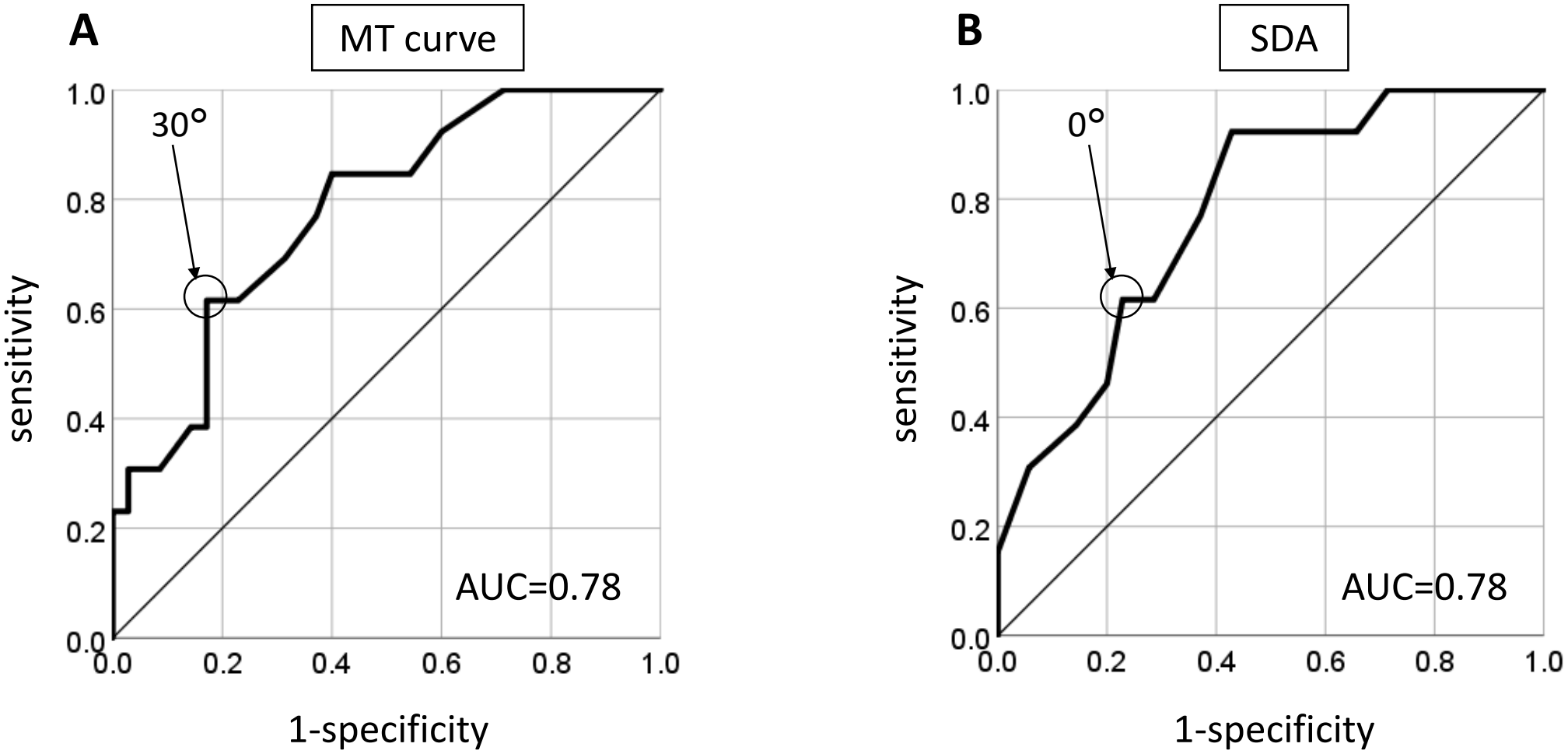
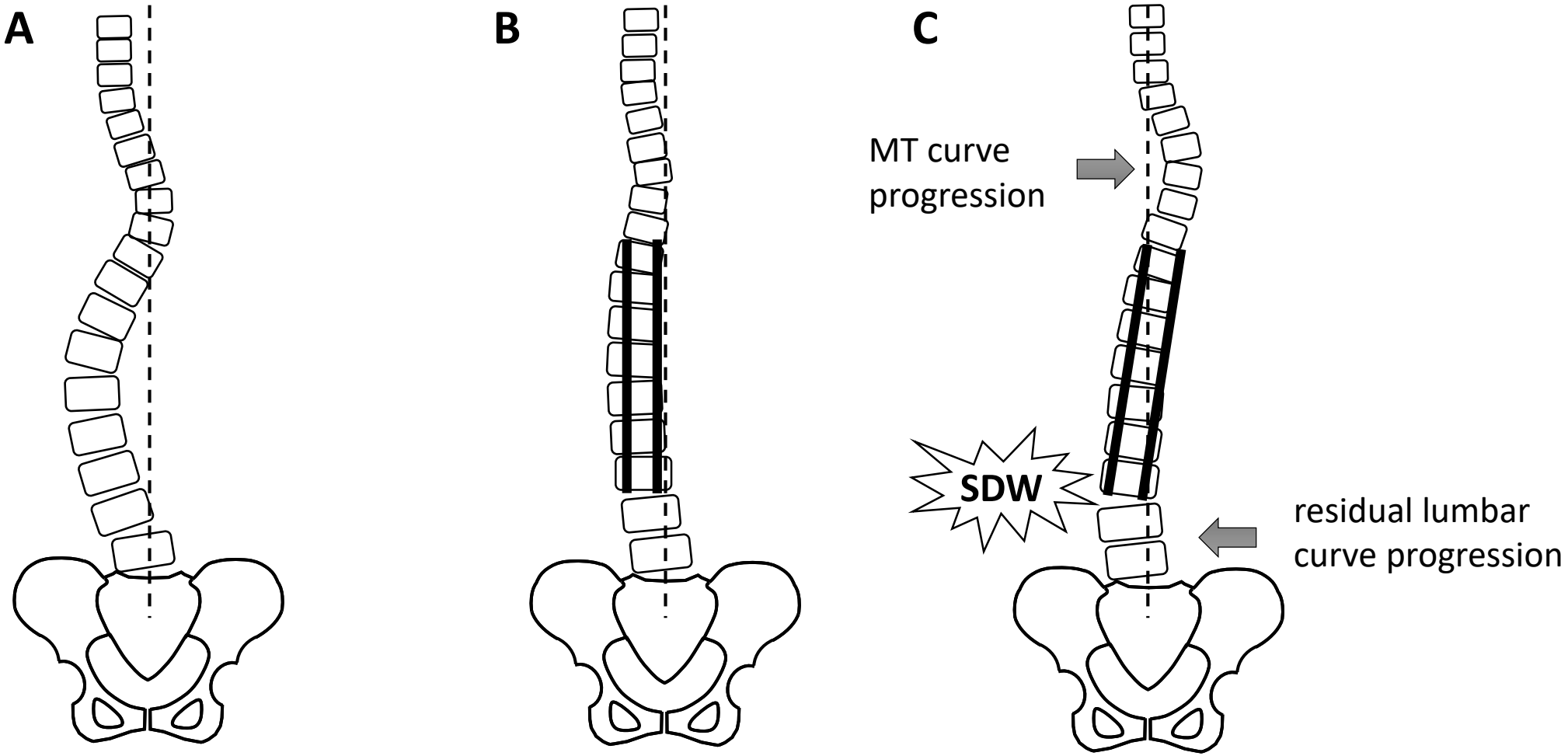

A
MT curve
30°
AUC=0.78
sensitivity
1-specificity
0.0
0.2
0.4
0.6
0.8
1.0
B
SDA
0°
AUC=0.78
sensitivity
1-specificity

Fig. 5


A
B
C
MT curve
progression
SDW
residual lumbar
curve progression