Predictors of Deterioration in Sagittal Balance Following Long Fusion Arthrodesis to L5 in Patients with Adult Scoliosis

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Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: The aim of this study was to identify the predictors of deterioration in sagittal balance in patients with adult scoliosis following long fusion arthrodesis to L5.

Material/Methods: A retrospective clinical study included 63 patients with adult scoliosis who underwent long fusion arthrodesis to L5, between February 2005 and May 2015. Radiological imaging values included the angle of lumbar lordosis (LL), and the angle of pelvic incidence (PI). The patients were divided into two cohorts, according to the threshold of average loss of sagittal vertical axis (SVA): a cohort with stable sagittal balance (SSB) and a cohort with deteriorated sagittal balance (DSB). Multivariate logistic regression analysis and the receiver operating characteristic (ROC) curve were used to identify the predictors of clinical outcome.

Results: There were significant differences between the SSB and DSB cohorts in age (p<0.001), preoperative SVA (p<0.001), last follow-up SVA (p<0.001), preoperative LL (p=0.001), last follow-up LL (p<0.001), subsequent L5–S1 disc degeneration (p<0.001) and PI (p=0.028). Patient age >61.5 years (OR=1.251, 95% CI, 1.055–1.484) (P=0.010), preoperative SVA >3.54 cm (OR=1.844, 95% CI, 1.249–2.732) (P=0.002) and preoperative LL <19.0 degrees (OR=0.922, 95% CI, 0.869–0.979) (P=0.008) were identified as predictors of deterioration in sagittal balance.

Conclusions: Deterioration in sagittal balance following long fusion arthrodesis to L5 in patients with adult scoliosis was associated with subsequent L5–S1 disc degeneration and loss of LL, age >61.5 years, preoperative SVA >3.54 cm, and preoperative LL <19.0 degrees.

MeSH Keywords: Adult • Postoperative Complications • Postoperative Period • Scoliosis • Spinal Fusion

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Background

Adult scoliosis is defined as spinal deformity that has a Cobb angle of more than 10° that occurs after skeletal maturity and is of two types, idiopathic adolescent scoliosis in adult life, and *de novo* scoliosis or adult degenerative lumbar scoliosis [1]. With an increasingly aging population worldwide, more people are suffered from syndromes of adult scoliosis. Adult scoliosis is often accompanied by spinal stenosis and results in intractable low back pain, radicular pain, claudication and may also include neurological deficit. Long fusion arthrodesis is proven to be an important surgical strategy for patients with adult scoliosis resulting in good clinical outcome [2–7].

However, whether the caudal extent of long fusion arthrodesis is chosen to be L5 or S1 remains controversial [2,5,8–12]. Fusion to L5 not only preserves lumbosacral motion, but also reduces pseudarthrosis, or movement due to inadequate healing, and arthrodesis screw-related complications [3,8–10,13,14]. The most concerning problems of the fusion to L5 are two major clinical complications, subsequent degeneration in L5–S1 disc and sagittal imbalance [3,5,8–12,15,16]. Subsequent L5–S1 disc degeneration is commonly observed in patients after long fusion arthrodesis with some cases requiring further intervention. Instead, postoperative sagittal imbalance is a more serious complication, which is associated with and adverse postoperative prognosis, including low back pain and a high revision rate.

Sagittal imbalance that occurs after surgery is also an indication for further surgical revision. Therefore, preserving postoperative sagittal balance is an important consideration when planning surgical arthrodesis for adult scoliosis. There have been several studies to evaluate the incidence rate, risk factors, surgical outcome, and requirements for revision surgery resulting from postoperative sagittal imbalance [5,10,17]. However, few studies have identified the predictors of postoperative deterioration in sagittal balance, which could be effective preoperative indicators and improve surgical decision making.

Therefore, the aim of this study was to identify the predictors of deterioration in sagittal balance in patients with adult scoliosis following long fusion arthrodesis to L5 and to contribute to the evidence required for the choice of surgical treatment.

Material and Methods

Ethical considerations

This study was approved by the Institutional Ethics Board of the Third Hospital of Hebei Medical University, China. Patient informed consent to participate in the study, and to use clinical and radiologic data were given by all study participants. The diagnostic and surgical methods used in the study were carried out in accordance with the approved clinical guidelines.

Patient inclusion and exclusion criteria

There were 63 patients with adult scoliosis included in the study, from a retrospective analysis of clinical records from February 2005 to May 2015 at the Department of Spinal Surgery, the Third Hospital of Hebei Medical University, China.

All patients in the study had undergone long fusion arthrodesis with the caudal extent to L5. The patient inclusion criteria included: patients with scoliosis with a Cobb angle >10°; a posterior surgical procedure with the caudal extent to L5; a posterior surgical procedure that used pedicle screws only; segment surgery that included the use of four or more pedicle screws; and a minimum two-year follow-up.

The patient exclusion criteria included: the presence of a spinal tumor or inflammatory condition; a history of previous surgery involving the spine; and incomplete or unclear imaging data.

Surgical procedures

The surgical management of the 63 patients included in the retrospective study was made according to the preoperative symptoms, and imaging data. The duration of patient symptoms was recorded from symptom onset to the time of surgery. The surgical procedure included decompression and inter-body fusion with autogenous bone. A non-absorbable biopolymer polyetheretherketone (PEEK) cage was used with surgery performed at levels where there was nerve compression.

Patient follow-up

The patients were followed up for an average of 3.88±1.57 years (range, 2–8 years). Patient data were collected and included age, gender, body mass index (BMI), follow-up period, preoperative lumbar lordosis (LL), preoperative Cobb angle, preoperative coronal vertical axis (CVA), preoperative sagittal vertical axis (SVA), pelvic incidence (PI), L5 oblique angle, the degree of preoperative L5–S1 disc degeneration, number of instrumented vertebrae, the presence or absence of inter-body fusion, patient smoking history, and duration of symptoms. These data were analyzed as potential predictors of postoperative deterioration in sagittal balance.

Radiologic evaluation: definition of sagittal imbalance

The sagittal balance was determined using the sagittal vertical axis (SVA), which was defined on lateral standing full-length films, as the vertical line (plumb line) from the middle of the

body of the C7 vertebral body, passing through the superior endplate of S1, with the position of this line being termed positive, negative, or neutral. In this study, a line passing within >5 cm of the posterosuperior corner of the S1 vertebral body was used to define sagittal imbalance (Figure 1) [15,17].

Patient cohorts: stable sagittal balance (SSB) and deteriorated sagittal balance (DSB)

Standing long posterior-anterior and lateral X-rays included the entire spine, and images were taken preoperatively and at the last follow-up visit. Postoperative long posterior-anterior and lateral X-rays without brace were taken 7–10 days after surgery, as appropriate, when patients were able to stand. According to the average loss of SVA from the surgery to last follow-up visit, the patients were divided into two cohorts: a cohort with stable sagittal balance (SSB) with loss of SVA below the average, and a cohort with deteriorated sagittal balance (DSB) with a loss of SVA that was above the average.

Coronal vertical axis (CVA), coronal imbalance, and lumbar lordosis (LL)

The coronal vertical axis (CVA), which was defined as the horizontal distance from C7, and central sacral vertical line on posterior-anterior X-ray >3 cm was regarded as coronal imbalance (Figure 1) [15,17]. On long posterior-anterior X-ray, the angle between the two vertebrae with the greatest inclination (upper and lower end vertebrae) was defined as the Cobb angle (Figure 1). The angle between the upper endplate of L1 and the upper endplate of S1 was defined as the lumbar lordosis (LL) (Figure 1).

The pelvic incidence (PI)

The pelvic incidence (PI) was defined as the angle between the perpendicular line from the endplate of S1 and a connecting line from the center of the femoral heads, if the femoral heads were non-overlapping (Figure 1). Following skeletal maturation, the PI value remained relatively fixed [18], and so PI was measured only on the preoperative radiologic films. The L5 oblique angle was measured between the upper endplate of L5 and the connecting line of two highest points of iliac crests (Figure 1).

T2-weighted magnetic resonance imaging (MRI)

T2-weighted magnetic resonance imaging (MRI) scans were used to define the degree of L5–S1 disc status according to Pfirrmann classification (Table 1) [19]. Each image was evaluated in triplicate by the same radiologist, and the average value was recorded for analysis.

Statistical analysis

The SPSS program version 22.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. A P-value <0.05 was considered to be statistically significant. Quantitative data were analyzed using Student's t-test or Mann–Whitney U test, as appropriate, while qualitative data were analyzed using the chi-squared test. The significance level was corrected to 0.0167 in multiple comparisons, according to the Bonferroni correction, to reduce the type 1 error rate. Multivariate logistic regression analysis was used to identify the predictors of deterioration in sagittal balance, with an adjusted odds ratio (OR) and 95% confidence intervals (CIs). The factors in a univariate analysis showing p<0.05 were selected for the multivariate logistic model. The receiver operating characteristic (ROC) curve analysis was applied to determine the cutoff value of each predictor. The cutoff value was selected at maximum Youden index, with the best compromise between sensitivity and specificity. Logistic regression analysis was used to identify the association between deterioration in sagittal balance and patients with none, one, or more than two predictors.

Results

Patient characteristics and symptoms

This retrospective clinical study included 63 patients with adult scoliosis who underwent long fusion arthrodesis to L5, between February 2005 and May 2015. Adult degenerative lumbar scoliosis was present in 51 patients (80.95%); a history of idiopathic adolescent scoliosis was present in 12 adult patients (19.05%) who had no history of previous surgery. The patients complained of the following syndromes: radicular pain in 49 patients (77.78%), claudication in 29 patients (46.03%), and intractable low back pain in all patients (100.00%). The mean duration of symptoms was 9.19±4.20 years. There were 52 women and 11 men in the study with an average age at surgery of 59.78±5.19 years.

Surgical treatment, pre-operative, and postoperative findings

The upper instrumented vertebrae ranged from T6 to L2, including T6 in two patients, T7 in three patients, T8 in seven patients, T9 in ten patients, T10 in 12 patients, T11 in five patients, T12 in six patients, L1 in 14 patients, and L2 in four patients. Decompression and inter-body fusion were performed in 43 patients (68.25%), and the average fused level number was 1.91±0.75.

The postoperative Cobb angle was significantly corrected to 8.35±4.14, from a preoperative Cobb angle of 35.50±5.99
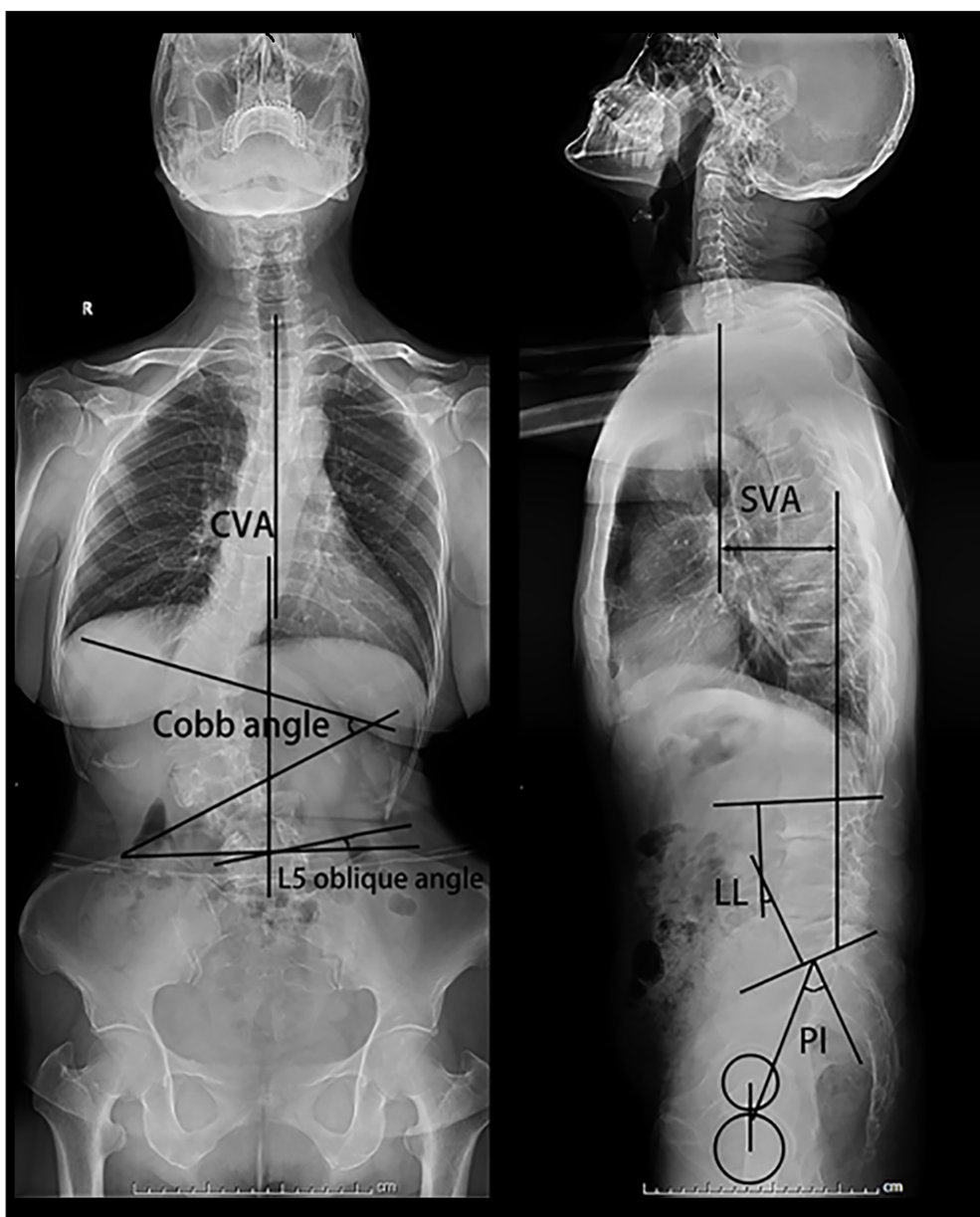
Figure 1. Measurement of sagittal vertical axis (SVA), coronal vertical axis (CVA), lumbar lordosis (LL), Cobb angle, pelvic incidence (PI) and L5 oblique angle.

Table 1. Pfirrmann classification for intervertebral disc degeneration.

Grade	Nucleus signal intensity	Nucleus structure	Distinction of nucleus and annulus	Disc height
I	Hyperintense	Homogenous, white	Clear	Normal
II	Hyperintense	Inhomogenous with horizontal band, white	Clear	Normal
III	Intermediate	Inhomogenous, gray to black	Unclear	Normal to decreased
IV	Hypointense	Inhomogenous, gray to black	Lost	Normal to decreased
V	Hypointense	Inhomogenous, gray to black	Lost	Collapsed

Table 2. Comparison of patient characteristics between Cohort SSB and Cohort DSB.

Variable	Cohort SSB (n=34)	Cohort DSB (n=29)	P-value
Age (years)	57.68±5.26	62.24±3.92	<0.001[1]
Gender			0.479[2]
Male	7	4	
Female	27	25	
Body Mass Index	23.56±2.84	24.27±2.62	0.313[1]
Followed up period	4.17±1.86	3.63±1.25	0.346[3]
Sagittal vertical axis			
Preoperative	2.37±1.76	4.74±2.45	<0.001[3]
Postoperative	1.09±1.05*	1.16±0.95*	0.359[3]
Last follow-up	1.62±1.23*	4.72±2.36	<0.001[3]
Postoperative loss	0.53±0.69	3.56±2.02	<0.001[3]
Coronal vertical axis			
Preoperative	2.23±1.95	1.85±1.06	0.863[3]
Postoperative	0.97±0.79*	0.85±0.76*	0.396[3]
Last follow-up	1.09±0.81*	0.98±0.79*	0.629[3]
Cobb angle			
Preoperative	34.85±6.14	36.28±5.84	0.352[1]
Postoperative	8.59±4.34*	8.07±3.95*	0.624[1]
Last follow-up	8.71±4.43*	8.24±3.81*	0.660[1]
Lumbar lordosis			
Preoperative	27.15±13.06	17.07±13.09	0.001[3]
Postoperative	31.24±10.11*	27.10±12.32*	0.149[1]
Last follow-up	29.38±10.21	18.28±11.24	<0.001[1]
Pelvic incidence	56.68±9.28	51.79±8.70	0.028[3]
L5 oblique angle	10.93±3.06	9.62±2.98	0.090[1]
L5–S1 disc degeneration degree			
Preoperative	1.88±0.48	2.07±0.65	0.202[3]
Last follow-up	2.15±0.50*	3.14±0.79*	<0.001[3]
Incidence rate	26.47%	79.31%	<0.001[2]
Instrumented vertebra number			0.476[2]
4–6	15	9	
7–9	14	13	
>9	5	7	
Interbody fusion	22	21	0.512[2]
Smoking	9	8	0.921[2]
Duration of symptoms (years)	8.91±4.38	9.52±4.37	0.415[3]

[1] Independent t-test; [2] Chi-square test; [3] Mann-Whitney U test; * Significantly different from preoperative (p< 0.0167).

Table 3. Predictors for deteriorated sagittal balance: multiple logistic regression analysis.

Variable	Adjusted odds ratio	95% confidence interval	P-value
Age (years)	1.251	1.055–1.484	0.010
Preoperative sagittal vertical axis	1.844	1.249–2.732	0.002
Preoperative lumbar lordosis	0.922	0.869–0.979	0.008
Pelvic incidence	0.929	0.853–1.012	0.091

(p<0.001). At the last follow-up visit, the Cobb angle remained stable at 8.49±4.13, which compared significantly with the preoperative Cobb angle (p<0.001), and compared significantly with the postoperative Cobb angle (p=0.315).

There were significant differences between the preoperative lumbar lordosis (LL) (22.51±13.92) and the postoperative LL (29.22±11.28) (p<0.001), the postoperative LL, and the last follow-up LL (24.27±11.98) (p<0.001). However, a significant difference was not found between the preoperative LL and the last follow-up LL (p=0.103).

The L5 oblique angle and pelvic incidence (PI) of patients were 10.22±3.07 and 54.43±9.27, respectively. The preoperative average degree of the L5–S1 disc was 1.97±0.57; at the last follow-up visit, the average degree of the L5–S1 disc increased to 2.60±0.81 (p<0.001).

The average coronal vertical axis (CVA) before surgery was 2.03±1.53 cm, including a coronal imbalance in eight patients (12.70%). The CVA was corrected to postoperative 0.90±0.77 cm (p<0.001), and at last follow-up visit was 1.03±0.79 cm, compared with the preoperative p<0.001, and compared with postoperative p=0.150. No patients with coronal imbalance were found postoperatively or at the last follow-up visit.

There were statistically significant differences between the preoperative sagittal vertical axis (SVA) (3.46±2.40 cm) and postoperative SVA (1.12±0.99 cm) (p<0.001), postoperative SVA and last follow-up SVA (3.05±2.39 cm) (p<0.001). However, no significant difference was found between the preoperative SVA and the SVA at last follow-up (p=0.084). Sixteen patients, 0 patients, and nine patients with sagittal imbalance were found preoperatively, postoperatively, and at last follow-up visit, respectively.

Average loss of SVA in cohorts with stable sagittal balance (SSB) and deterioration of sagittal balance (DSB)

According to the average loss of SVA (1.93 cm), two cohorts included 34 patients with stable sagittal balance (SSB), and 29 patients with deterioration of sagittal balance (DSB). The average loss of SVA in the SSB cohort was 0.53±0.69 cm, while

in the SSB cohort, the average loss of SVA was 3.56±2.02 cm (p<0.001). The comparative data of patient characteristics between the two cohorts are shown in Table 2. Preoperative (p<0.001) and last follow-up SVA (p<0.001) in the DSB cohort were significantly greater than those in the SSB cohort, while there was no significant difference in postoperative SVA (p=0.359).

Pre-operative and postoperative LL in cohorts with stable sagittal balance (SSB) and deterioration of sagittal balance (DSB)

Similar results were found in the comparison of preoperative LL between the two cohorts, SSB and DSB (p=0.001), and the LL at last follow-up (p<0.001), which showed statistically significant differences, while the postoperative LL did not (p=0.149).

Factors associated with the prediction of deterioration in sagittal balance

There was no significant difference in the degree of preoperative L5–S1 disc degeneration (p=0.202). However, at the last follow-up visit, the degree of L5–S1 disc degeneration in the DSB cohort was significantly greater than that in the SSB cohort (p<0.001) and the subsequent rate of degeneration was significantly greater (p<0.001). Patient age at the time of surgery (p<0.001) and PI (p=0.028) also showed statistically significant differences between the two cohorts.

Four factors in univariate analysis were selected into the multivariate logistics model as predictors of deterioration in sagittal balance: age (p=0.001), preoperative SVA (p<0.001), preoperative LL (p=0.007) and preoperative PI (p=0.042). Three factors in multivariate logistic regression analysis were selected as predictors of deterioration in sagittal balance: age (OR=1.251, 95% CI, 1.055–1.484, P=0.010), preoperative SVA (OR=1.844, 95% CI, 1.249–2.732, P=0.002) and preoperative LL (OR=0.922, 95% CI, 0.869–0.979, P=0.008); PI was not included (OR=0.929, 95% CI, 0.853–1.012, P=0.091) (Table 3).

Area under the curve (AUC) analysis showed that age (AUC: 0.752, P=0.001), preoperative SVA (AUC: 0.778, P<0.001) and preoperative LL (AUC: 0.745, P=0.001) showed good predictive
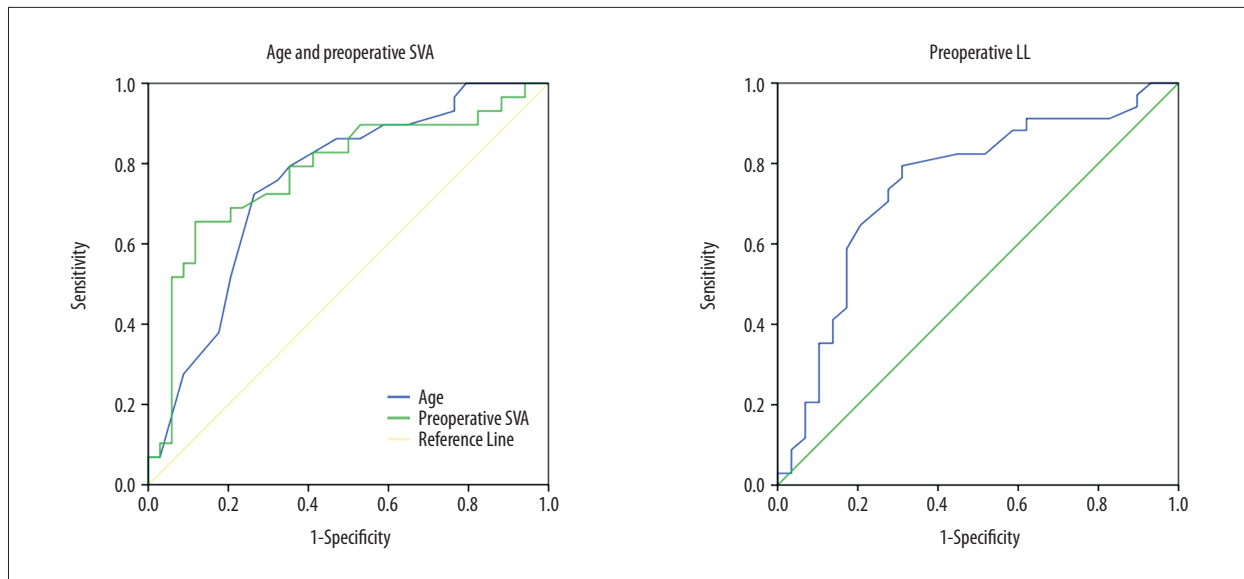
Figure 2. The receiver operating characteristic (ROC) curve of age, sagittal vertical axis (SVA), and lumbar lordosis (LL).

Table 4. Sensitivity, specificity, AUC and cutoff of predictors.

Variable	Sensitivity	Specificity	AUC*	Cutoff	P-value
Age (years)	72.41%	73.53%	0.752	61.5	0.001
Preoperative sagittal vertical axis	65.52%	88.24%	0.778	3.54	<0.001
Preoperative lumbar lordosis	68.79%	82.35%	0.745	19.0	0.001

* Area under the curve.

Table 5. Differences in the incidence of deteriorated sagittal balance: in patients with 0, 1 or ≥2 predictors.

Predictor	Odds radio	95% confidence interval	P-value
0 predictor	1		
1 predictor	0.421	0.136–1.310	0.135
≥2 predictors	50.286	9.537–265.151	<0.001

accuracy for detecting deterioration in sagittal balance in the receiver operating characteristic (ROC) curve analysis (Figure 2, Table 4). The cutoff values of age, preoperative SVA, and preoperative LL were 61.5 years, 3.54 cm, and 19.0 degrees, respectively (Table 4). The presence of two out of three factors (age >61.5 years; preoperative SVA >3.54 cm; and preoperative LL <19.0 degrees), were significantly associated with postoperative deterioration in sagittal balance (OR=50.286, 95% CI, 9.537–265.151, P<0.001) (Table 5).

Discussion

Because of the continuing controversy regarding the choice of distal extent for spinal surgery (L5 or S1) in long fusion arthrodesis for patients with adult scoliosis, the aim of this study was to identify the predictors of deterioration in sagittal balance in patients with adult scoliosis following long fusion arthrodesis to L5. The findings of this study showed that deterioration in sagittal balance following long fusion arthrodesis to L5 in patients with adult scoliosis was associated with subsequent L5–S1 disc degeneration and loss of lumbar lordosis (LL) in patients older than 61.5 years, with the preoperative sagittal vertical axis (SVA) greater than 3.54 cm, and preoperative LL of less than 19.0 degrees.

Fusion to L5 has some advantages, but also has two main complications, subsequent disc degeneration and sagittal imbalance, which became the reasons why some surgeons do not choose this approach, and subsequent disc degeneration has been shown to occur more frequently, with the incidence rate ranging from 15.91–69% [3,10–12,15,16]. Because of the high revision rate, sagittal imbalance is a surgical complication that should attract more attention, as sagittal imbalance has been shown to be associated with poor surgical outcome, including the pain and disability [20,21]. Even mild sagittal imbalance can cause some detrimental symptoms, and the severity of symptoms has been shown to increase linearly with progressive sagittal imbalance [20]. Identifying the predictors of deterioration in sagittal balance could help to choose an optimal surgical approach to surgical correction.

In this study, although sagittal balance was restored immediately after surgery, it deteriorated over time in some patients. These findings are supported by those of previously published studies, as similar results were also reported in two previously published studies by Edwards et al. [3,16], and two studies by Cho et al. [5,17]. In the most recent study by Cho et al. in 2010 [17], in 45 patients, 42% developed sagittal imbalance with preoperative risk factors for that included high pelvic incidence (PI) and distal complications. Several previous studies have shown that subsequent sagittal imbalance was found to be associated with L5–S1 disc degeneration in many patients in which the risk factors were unknown [5,10–12,16,22,23].

In the present study, patients with deterioration in sagittal balance had a greater degree of L5–S1 disc degeneration and a reduced degree of LL. The rate of L5–S1 disc degeneration was also significantly greater in the patient groups with deterioration in sagittal balance at the final follow-up visit. LL at the last follow-up visit in the stable sagittal balance (SSB) cohort was smaller, although a similar correction occurred with the other cohort studied, the deteriorated sagittal balance (DSB) cohort, immediately after surgery. The change in the state of sagittal balance was closely related to subsequent L5–S1 disc degeneration and loss of LL.

In this study, the pelvic incidence (PI) showed significant differences between the two cohorts, SSB and DSB. However, PI was not identified as one of the predictors of deterioration sagittal balance in multiple logistic regression analysis. The reason for this finding might be attributed to minor differences in the value of the PI between the two cohorts in the study. The reason that the L5 oblique angle failed to be identified as a factor was that an L5 oblique angle <15° was one of the considerations for ending at L5 when surgical decision-making was undertaken.

The correlation between age and sagittal imbalance remains controversial. Hammerberg et al. studied 50 asymptomatic volunteers with ages ranging from 70–85 years (average, 76 years) and found that age was positively correlated with the progressive anterior positioning of C7 [24]. However, the study of Gelb et al. showed that the loss of LL instead of age was most associated with risk of sagittal imbalance, although the loss of LL might have occurred with the older age group of their study population [25]. In our current study, patient age above 61.5 years at surgery was identified as one of the predictors of deterioration in sagittal balance. As older patients are more likely to suffer from a higher rate of complications after surgery many surgeons recommend that age should be taken into account when making a treatment decision [26].

In the present study, there were 16 patients with preoperative sagittal imbalance and the sagittal alignment were corrected to normal by long fusion arthrodesis surgery. However sagittal imbalance occurred in nine patients at the last follow-up visit, and seven of them suffered postoperative sagittal imbalance. Even though postoperative SVA decreased significantly compared with preoperative SVA, there was no significant difference between preoperative SVA and last follow-up SVA, which may indicate that SVA tended to revert to its original state, and a similar result was found in LL. In DSB cohort in this study, the average loss of SVA was 3.56±2.02 cm, while in the SSB cohort, the sagittal balance remained stable, and the average loss of SVA was 0.53±0.69 cm. In the DSB cohort, postoperative loss of LL was also present postoperatively at 27.10±12.32 degrees, but at the last follow-up, it was 18.28±11.24 degrees. Lee et al. suggested that overcorrection of LL was an effective method to maintain sagittal alignment in patients with adult spinal deformity, which should also be considered in preoperative treatment decision-making [27].

The present study identified three predictors of the surgical outcome by multivariate logistic regression analysis and showed cutoff values. Patients with age >61.5 years, preoperative SVA >3.54 cm and preoperative LL <19.0° were more likely to suffer deteriorated sagittal balance after long fusions arthrodesis surgery to L5. When two or more of these risk factors are present, the rate of postoperative deterioration in sagittal balance would be expected to be increased. Therefore, from the findings of this study, attention should be paid to reduce the outcome of postoperative sagittal balance by careful patient selection with regard to these predictive factors, especially if more than two predictors are present.

This study had several limitations, most importantly, this was a retrospective clinical study. This study was performed at a single center, and the number of patients studied was relatively small. Also, the objective of this study was investigated only using radiographic measurement data, and clinical outcome

analysis was not included. Therefore, large-scale, multicenter and more detailed clinical studies should be performed in the future to verify these results.

Conclusions

The findings of this study add to the evidence to support the choice of surgery for patients with adult scoliosis as they showed that deterioration in sagittal balance following long fusion arthrodesis to L5 was associated with subsequent L5–S1 disc degeneration and loss of lumbar lordosis (LL) in patients older than 61.5 years, with preoperative sagittal vertical axis (SVA) greater than 3.54 cm, and preoperative lumbar lordosis (LL) of less than 19.0 degrees. Although further studies are recommended to support these findings, on the basis of this study, pre-operative patient evaluation is recommended with attention to predictors of outcome, especially if more than two predictors are present.

Conflict of interest

None.

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