Factors and Predictive Model Associated With Perioperative Complications After Long Fusion in the Treatment of Adult Non-Degenerative Scoliosis

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Abstract

Introduction

Adult non-degenerative scoliosis accounts for 90% of spinal deformities in young adults. However, perioperative complications and related risk factors of long posterior instrumentation and fusion for the treatment of adult non-degenerative scoliosis have not been adequately studied.

Methods

We evaluated clinical and radiographical results from 180 patients with adult non-degenerative scoliosis who underwent long posterior instrumentation and fusion. Preoperative clinical data, intraoperative variables, and perioperative radiographic parameters were collected to analyze the risk factors for perioperative complications. Potential and independent risk factors for perioperative complications were evaluated by univariate analysis and logistic regression analysis.

Results

180 adult non-degenerative scoliosis patients were included in our study. There were 31 perioperative complications for 25 (13.9%) patients, 11 of which were cardiopulmonary-related complications, five of which were infection, six of which were neurological-related complications, three of which were gastrointestinal-related complications, and six of which were incision-related problems. The independent risk factors for development of perioperative complications included change in Cobb angle (odds ratio [OR]=1.058, 95% CI=1.011~1.108, *P*=0.015), change in central vertical axis (CVA) (OR=1.066, 95% CI=1.019-1.116, *P*=0.006) and red blood cell (RBC) transfusion (OR=5.631, 95% CI=1.676~18.924, *P*=0.005). The area under the receiver operating characteristic (ROC) curve based on predicted probability of the logistic regression was 0.746.

Conclusions

Blood transfusion, Cobb change, and CVA change were independent risk factors for perioperative complications after long-segment posterior instrumentation and fusion in adult non-degenerative scoliosis patients.

Introduction

Adult spinal deformities (ASD) can be classified into two subtypes: progression of childhood scoliosis (non-degenerative scoliosis) and degenerative scoliosis [1]. Because conservative treatment is often insufficient to effectively improve the diverse symptoms, surgical treatment is usually recommended. When a spinal surgery is advocated, determining the extent of the fusion is important. Long-segment instrumentation and fusion have been proven to be able to correct severe deformities and rotatory subluxations [2]. However, long fusions are also associated with excessive intraoperative blood loss, which contributes to the development of perioperative complications [3].

As life expectancy increases, adult degenerative scoliosis (ADS), or de novo scoliosis, is gaining more attention in the field. Patients with ADS suffer from pain, disability, and neurological symptoms [4]. The estimated incidence of postoperative complications has been reported to range from 16.4% to as high as 80% [5, 6]. Many risk factors for these complications have been reported, including massive intraoperative blood loss (>2 or 4 L), age, the extent and approach of the surgery, and the presence of more than three comorbidities [7-9].

In contrast to ADS, adult non-degenerative scoliosis remains poorly studied. Non-degenerative factors are presumed to account for as high as 90% of the spinal deformities in young adults [10]. Although surgical correction of ASD is cost-effective and improves the quality-of-life and clinical outcomes for scoliosis patients when compared to the non-operative conservative treatment, it is not risk-free. In addition to being associated with worse clinical outcomes and further difficulties in treatment, perioperative complications can impose a substantial clinical and financial burden on state healthcare [11]. In this study, we aim to retrospectively evaluate the risk factors for potential perioperative complications stemming from the use of long-segment posterior-only instrumentation and fusion in the treatment of adult non-degenerative scoliosis.

Materials And Methods

Patients

A single center-based, retrospective cohort study was performed on adult patients who had undergone long spinal fusions at the Department of Orthopedic Surgery, Peking Union Medical College Hospital. A total of 180 consecutive patients, who were diagnosed with adult non-degenerative scoliosis and who had undergone long-segment internal fixation and fusion by the conventional midline open posterior approach from January 2012 to July 2018, were selected and reviewed (Figure 1). The experimental protocol was reviewed and approved by the Ethics Committee of Peking Union Medical College Hospital (agreement number: JS-908). Our study was performed in accordance with experimental protocol and the Declaration of Helsinki, and informed consent was obtained from all participants.

Inclusion criteria for this study were operatively treated adult spinal deformity patients with the following conditions: (1) age > 18 years by the time of the surgery, (2) major Cobb angle ≥ 40°, (3) posterior long-segment internal fixation and fusion (≥ 4 vertebrae), (4) follow-up ≥ 1 year (5) complete preoperative and postoperative radiographic data and clinical evaluations, and (6) complete medical history. Exclusion criteria were (1) degenerative scoliosis and other kinds of secondary spinal deformities (e.g., ankylosing spondylitis, or spinal tumor); (2) previous history of lumbar surgery; and (3) anterior instrumentation or non-fusion surgery.

Medical history and operative data

Baseline characteristics, including age, sex, body mass index (BMI), presenting symptoms, any history of smoking, medication use, previous surgeries, comorbidities, etiology of scoliosis, preoperative hemoglobin (Hgb) level, and the length of hospital stay were collected. American Society of Anesthesiologists (ASA) grades were evaluated by anesthetists. Fusion levels, distal fusion levels, estimated blood loss, duration of the operation, and the volume of blood transfusions were charted. Perioperative complications were defined as previously described by Carreon et al. [12]

Radiographic measurements

For all patients, both anterior-posterior and lateral whole-spine X-rays were included to measure parameters. The following parameters, including clavicle angle (CA), sacral obliquity (SO), T1 tilt angle (T1TA), L5 tilt angle (L5TA), T1 pelvic angle (T1PA), coronal vertical axis (CVA), sagittal vertical axis (SVA), thoracic kyphosis (TK), pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), pelvic incidence (PI) and pelvic incidence minus lumbar lordosis (PI-LL), were recorded to assess the degree of spinal deformities in the coronal and sagittal plane. These data were measured on both the preoperative and the immediate postoperative radiographs. All measurements were performed independently by two spinal surgeons to decrease subjective bias.

Statistical analysis

Data analysis was performed with SPSS version 25.0 (SPSS, Inc., Chicago, IL, USA). Continuous variables are reported as mean ± standard deviations (SD). Categorical variables are presented as a number or ratio. In the univariate testing, continuous variables were examined by the Student t-test. Categorical variables were tested by the Pearson chi-square test or Fisher's exact test, depending on which was appropriate. Predictors with a P value < 0.2 on univariate analysis were included in the multivariate analysis.

The selection of variables in the final model was not only driven by statistical power but also by clinical judgement, collinearity, and previously reported risk factors. These variables were analyzed using a binary logistic regression model. The selection method was the forward stepwise selection model. The resulting multivariable regression model served as the basis for the nomogram.

A nomogram was constructed based on the results of the binary logistic analysis, with the use of the rms package in R version 3.6.1. The performance of nomogram was evaluated by the concordance index (C-index, a natural extension of the receiver operating characteristic curve area to measure the model discrimination). Discrimination, as a measure of how well the score can differentiate between patients with and without complications, was quantified by the concordance index (C-index) and calculated using the pROC package [13], which was equal to the area under the receiver-operating characteristic curve (AUC-ROC) and reflected the sensitivity and specificity.

Calibration was visually assessed by plotting the nomogram predicted probability against the observed incidence of complications, using the calibrated package [14]. A poor calibration was defined as the discrepancy between observed and expected incidence of complications. A bootstrap with 1000 re-samples was used for this analysis. In the internal validation, the total points of each patient in the same patient population were calculated based on the established nomogram. A *P* value of < 0.05 was considered statistically significant.

Results

Baseline Characteristics

A total of 180 patients were included in our study. Our patients had an average age of 29.8±9.8 years, a higher proportion (83.3%) of females, and an average BMI of 20.8±3.2 kg/m^2. A majority of these patients' conditions was a direct progression from adolescent idiopathic scoliosis (146 patients, 81.1%). The rest were affected with congenital scoliosis (24 patients, 13.3%), neuromuscular scoliosis (9 patients, 5.0%), or marfanoid scoliosis (1 patient, 0.6%). The onset of symptoms lasted for an average of 15.7 months before being clinically diagnosed. Clinical presentation varied, including back pain (120 patients, 66.7%), neurological symptoms (10 patients, 5.6%) and dyspnea (18 patients, 10.0%). In addition to scoliosis, other observed deformities included spinal stenosis (6 patients, 3.3%), vertebral rotation (19 patients, 10.6%), herniated disk (19 patients, 10.6%), syringomyelia (22 patients, 12.2%) and kyphosis (19 patients, 10.6%). In terms of patients' medical histories, incidence of smoking (7 patients, 3.9%), heart disease (6 patients, 3.3%), respiratory disease (23 patients, 12.8%), hypertension (3 patients, 1.7%), and anemia (11 patients, 6.1%) were all present. A summary of baseline characteristics is shown in Table 1.

Surgical characteristics

The preoperative assessment showed that 39.6% of the patients in our sample had mild or severe systemic disease (ASA 2-3). The average levels of plasma Hgb and albumin were 131.6±14.4 and 43.1±3.5 g/L, respectively. For correction of deformity, distal fusions of most cases were at L4 or higher (144 patients, 81.4%), with some extending to L5 (27 patients, 15.3%), S1 (3 patients, 1.7%) or S2 (3 patients, 1.7%), with an average of 11.6±2.8 fused vertebrae. Fusion levels, ranging from 3 to 16, could be subdivided into three groups: 3 to 7 (19 patients, 10.7%), 8 to 12 (79 patients, 44.6%) and 13 to 16 (79 patients, 44.6%). Decompression and osteotomy were performed in 6.1% (11 of 180) and 20.6% (37 of 180) of our patients, respectively. The mean operative time was 259.7±81.1 minutes, and the mean length of stay (LOS) was 14.6±4.6 days. With an average estimated blood loss of 755.8±483.1 ml, 162 cases (90.0 %) used an autologous blood transfusion system, 73 cases (40.6%) accepted allogeneic RBC transfusion with 3.0 ± 1.4 U, and 70 cases (38.9%) received pure plasma transfusion, averaging out to 414.1± 134.1 ml. The radiographic parameters were based on anterior-posterior and lateral whole-spine X-rays. Prior to surgery, the average Cobb angle, clavicle angle (CA), sacral obliquity (SO), T1 tilt angle (T1TA), L5 tilt angle (L5TA), T1 pelvic angle (T1PA), coronal vertical axis (CVA), sagittal vertical axis (SVA), thoracic kyphosis (TK), pelvic tilt (PT), sacral slope (SS), lumbar lordosis (LL), pelvic incidence (PI), and pelvic incidence minus lumbar lordosis (PI -LL) were as follows: 66.6±24.1°, 2.3±2.9°, 2.3±2.6°, 7.2±7.4°, 12.4±8.9°, 8.2±6.7°, 15.1±12.4 mm, 22.8±17.0 mm, 33.9±18.2°, 9.1±8.6°, 33.2±10.9°, 49.3±16.1°, 42.3±13.1°, 15.9±14.5°; the respective postoperative data were the following: 30.0±21.9°, 3.2±2.6°, 2.0±2.1°, 6.5±7.3°, 7.0±6.2°, 9.0±6.9°, 15.2±11.7 mm, 20.5±16.7 mm, 33.5±13.3°, 10.5±8.8°, 32.7±7.6°, 47.3±11.6°, 43.2±10.5°, 10.5±9.3°. A summary of surgical characteristics is shown in Table 2.

Perioperative Complications

Twenty-five (13.9%) patients had at least one perioperative complication, while a total of 31 perioperative complications were observed. The majority (21 patients, 84%) experienced a perioperative complication only once, 11 of which were cardiopulmonary-related (35.5%), including seven pleural effusions, one arrhythmia, one congestive heart failure, one pneumothorax, and one atelectasis. Outside of systemic complications, there were also six incision-related surgical complications. Four patients (14%) suffered two or more complications: one case with pleural effusion and ileus; one case with pleural effusion and cerebrospinal fluid leakage; one with pleural effusion, pneumothorax, and arrhythmia; and the last one with pleural effusion, atelectasis, and pulmonary infection. Two patients were readmitted into the hospital during the perioperative period: one for severe pulmonary infection, one was suffering from radiating pain as a result of malposition of a pedicle screw (Table 3).

Different strategies were employed to deal with perioperative complications (Table 4). Closed thoracic drainage proved beneficial for patients with pleural effusion, pneumothorax and atelectasis. To treat congestive heart failure, the patient's fluid status was closely monitored, and drugs were given to promote diuresis. Infection was treated with antibiotics effective against the strain of bacteria cultured from the site of infection. When presenting with symptoms suggestive of septic shock, patients were sent to the intensive care unit. Acute neurological problems could be rapidly corrected by dehydration and steroid treatment, while chronic neurological symptoms required patience and a nerve-nurturing treatment. If a patient suffered from unbearable pain due to malposition of the implants, a revision surgery was deployed as soon as possible. Generally, all symptoms tended to improve in the follow-up period.

Univariate analysis

Patients were divided into two groups based on whether they had any perioperative complications: a complication-free group (155) and a group with complications (25). The results of univariate analysis investigating the relationships between baseline/surgical characteristics and perioperative complications are shown in Tables 1 and 2. Factors that were found to carry a statistically significant weight in risk prediction were ASA classification (P=0.043), RBC transfusion (P=0.028), total length of stay (LOS) (P=0.004), total EBL (P=0.020), levels of fusion (P=0.038), osteotomy (P=0.003), anatomical grades of resection (P=0.045), preoperative Cobb angle (P=0.015), change in Cobb angle (P=0.003) and CVA change (P=0.005). Predictors with P values < 0.2 were also considered eligible to be factored into risk calculations. Therefore, factors that can affect the incidence of perioperative complications further encompass the duration of symptoms (P=0.071), preoperative L5TA (P=0.088), change in L5TA (P=0.103), postoperative T1PA (P=0.160), change in T1PA (P=0.056), preoperative CVA (P=0.106), postoperative CVA (P=0.143), preoperative TK (P=0.136), change in TK (P=0.113), postoperative PT (P=0.117), change in PT (P=0.171), postoperative SS (P=0.144), postoperative LL (P=0.052) and change in LL (P=0.128).

Multivariate analysis

Factors whose *P* value < 0.2 in the univariate analysis were selected for multivariate analysis. Observations from clinical experience and previously published research were considered while trying to find the suitable predictors for complications. A binary logistic regression model was used to eliminate influences of confounding factors, and determine the independent predictors of perioperative complications. Finally, we proposed a triple risk factor model: change in Cobb angle (*P*=0.015, OR=1.058, 95% CI=1.011~1.108), change in CVA (*P*=0.006, OR=1.066, 95% CI=1.019-1.116) and RBC transfusion (*P*=0.005, OR=5.631, 95% CI=1.676~18.924) were the three independent risk factors for perioperative complications (Table 5).

Nomogram construction and validation

A prognostic nomogram that integrated the two independent risk factors from the multivariate analysis in the cohort was constructed (Figure 2A). The predictive accuracy for perioperative complication as evaluated by C-index was 0.746, with a 95% CI of 0.639-0.853 (*P*<0.001) (Figure 2B). Calibration curves for the probability of perioperative complications showed a good correlation between the nomogram-predicted and observed values (Figure 2C).

Discussion

Non-degenerative factors are presumed to account for as high as 90% of spinal deformities in young adults [10]. ASD patients often undergo long-segment thoracolumbar arthrodesis that extends to the lower lumbar spine or the sacral region, and this procedure is associated with more perioperative complications [6]. The treatment for adult non-degenerative scoliosis aims not only to prevent further progression but also seeks to improve the existing manifestations [15]. In this study, we collected a cohort of data on the perioperative complications after surgical treatment of adult non-degenerative scoliosis. The statistical analysis reviewed that the changes in Cobb angle and CVA, as well as RBC transfusion are the three primary independent risk factors for the incidence of perioperative complications.

Degenerative and non-degenerative scoliosis are conditions that manifest differently. Take adult idiopathic scoliosis, accounting for about 81.1% of our cohort, as an example. A previous study showed that the average age of patients with adult degenerative scoliosis (ADS) was higher compared to that of those with idiopathic scoliosis [4]. The average age was as young as 29.8 years old in our study. Gender distribution is relatively equal in ADS, with a typical onset after 50 years of age and an average age of 70.5 years [16]. Pain, disability, and neurological complaints are more commonly reported in ADS than exacerbation of the deformity [5]. Our retrospective study confirmed that some adult non-degenerative scoliosis patients (49 patients, 27.2%) came to surgery with no discomfort, which was not observed in ADS patients. Instead, adult non-degenerative scoliosis patients primarily elected for spinal surgery due to cosmetic reasons, and concerns that further progression of the curvature may occur. Pulmonary function impairment, defined as a reduction in total lung capacity and functional residual capacity, decreasing oxygen saturation, was demonstrated in some studies [17]. Dyspnea was seen in 18 out of 180 patients.

The incidence of perioperative complications in our study (13.4%) was less than what was reported in a previous study (19.5%) [18]. Additionally, coronal and sagittal imbalance is more common in degenerative scoliosis than in non-degenerative adult scoliosis [4]. These lines of evidence reflect the difference between the clinical courses of these two subtypes of scoliosis. However, in terms of the pattern of spinal deformity, adult idiopathic scoliosis often mimics adolescent idiopathic scoliosis (AIS) [19]. Our data is consistent with the previous study, in which the female to male ratio is nearly 3:1 in idiopathic scoliosis, which can be contrasted against that of ADS [16]. Indeed, the ratio of female to male patients in our study was even higher, at 5:1 (female: male).

Surgical treatment is recommended when conservative treatment proves unsatisfactory, and decompression surgery is essential for alleviating symptoms. Most surgeons recommend fusion and instrumentation techniques for decompression [20]. Thus, choosing the proper extent of the fusion is key to a successful surgery. Long fusion and instrumentation proved successful in correcting scoliotic curvature and coronal imbalance. For patients with a large Cobb angle and rotatory subluxation, long fusion should be carried out to minimize adjacent segment disease[6]. All the patients selected for our study had long fusions, and their levels of distal fusions were different. Stopping a fusion at L5 can lead to subsequent degeneration at L5-S1. If the fusion extends to the sacrum, the procedure would be more complex, and there is a higher likelihood of pseudarthrosis at the lumbosacral junction. However, studies have found that long fusions terminating at L5 or the sacrum was similar in overall complication rate and improvement in pain and disability [21, 22]. In our study, we found no association between the incidence of perioperative complications and the level at which the fusion stopped ($p=0.640$). There is a new instrument method, the S2AI iliac screw, which is designed to fix drawbacks such as screw site prominence and wound complication, that can successfully avoid the complications associated with conventional iliac screws[23]. However, this presumed reduction in perioperative complications in the S2AI group was not detected by our study, which might be due to our limited sample size.

Focused on adult non-degenerative scoliosis patients who underwent long fusion surgeries, we collected and analyzed all the parameters deemed relevant according to our clinical expertise and previous research, which involved collecting the patients' medical history, radiographic data, and clinical evaluations. Owing to the fact that most of our patients were fairly young, there was relatively little data on history of lumbar operation, previous medication use, or whether there were any age-associated comorbidities such as diabetes and osteoporosis, some of which could be potential risk factors for ADS. Several studies have reported a direct correlation between parameters such as the ASA grade, Cobb angle, total operation time, PT, level of fusion, length of hospital stay, staging, multiple surgeries and the incidence of perioperative complications in ADS [9, 18, 24-26]. However, further research is needed to identify the risk factors for perioperative complications in adult non-degenerative scoliosis.

With respect to the current literature, our analysis provided further evidence of the correlation between perioperative complications and RBC transfusions. More than 4U of intraoperative RBC transfusion is significantly correlated with higher occurrence of perioperative complications in our cohort ($p=0.005$, $OR=5.631$, 95% $CI=1.676\sim18.924$). Previous studies have found that the factors including number of levels fused, age, gender, operative time, and preoperative Hb were associated with blood transfusions [27, 28]. However, the multivariate regression results in the current study showed that blood transfusion is an independent predictor of perioperative complications, indicating that blood transfusion is directly associated with the incidence of perioperative complications, including infection and cardiopulmonary-related complications. These findings are consistent with previous report. Abduljabbar et al. found that more blood transfusions associated with increased incidences of complications, including surgical site infections, sepsis, pulmonary embolism, and re-operation [29].

In our cohort, change in the main Cobb angle (P=0.015, OR=1.058, 95%CI=1.011~1.108) and that in the coronal imbalance (P=0.006, OR=1.066, 95%CI=1.019-1.116) were significantly associated with the risk of complications. We included changes of all parameters in our analysis, which have rarely been reported in previous studies. Previous studies have shown that preoperative magnitude of the spinal curvature and coronal imbalance was associated with the likelihood of complications. In our data, larger preoperative Cobb (P=0.015) and coronal imbalance (P=0.106) is associated with a higher risk. It was reported that an increased Cobb angle is associated with impaired pulmonary function due to airway blockage [30]. A higher risk of postoperative non-neurological complications, pulmonary compromise in particular, could be caused by a larger Cobb angle in adults and juvenile scoliosis patients [31]. An increased Cobb angle causes abnormal chest and lung development and results in less reserved space for ventilation. Our data also indicated that the change in CVA was another risk factor. CVA and SVA are two important parameters in assessing the deformity at coronal and sagittal planes. It is understood that a pathologically elevated SVA is the result of failure in recruiting physiological compensatory mechanisms to maintain an upright posture. Increased SVA correlated with a worse health-related quality of life (HRQOL) [32]. However, for patients in our cohort, degenerative changes had not yet occurred, and coronal deformities were far more severe. Correcting coronal imbalance is one of the primary goals of surgery. Elevated CVA determines a more serious coronal deformity. In patients with coronal imbalance alone, it is a significant criterion in outcome evaluation [33]. It is, however, unclear whether this finding can be of a true clinical relevance in adult non-degenerative scoliosis, despite being statistically significant.

There are some limitations to our study, the most significant being its retrospective nature. Another weakness is that all of the data was obtained from single medical center, and results were not validated by other centers. Finally, due to the relatively young age of many of our patients, the effect of comorbidities that are more prevalent in elderly populations could not be adequately investigated.

In conclusion, we conducted a study on the perioperative complications of patients with adult non-degenerative scoliosis and identified a three-risk-factor nomogram which could be used for predicting perioperative complications. The identified risk factors were blood transfusion, Cobb change, and CVA change.

Abbreviations

OR: odds ratio; CVA: central vertical axis; RBC: red blood cell; ROC: receiver operating characteristic; ASD: adult spinal deformities; ADS: adult degenerative scoliosis; BMI: body mass index; Hgb: hemoglobin; ASA: American Society of Anesthesiologists; CA: clavicle angle; SO: sacral obliquity; T1TA: T1 tilt angle; L5TA: L5 tilt angle; T1PA: T1 pelvic angle; SVA: sagittal vertical axis; TK: thoracic kyphosis; PT: pelvic tilt; SS: sacral slope; LL: lumbar lordosis; PI: pelvic incidence; PI-LL: pelvic incidence minus lumbar lordosis; LOS: length of stay; AIS: adolescent idiopathic scoliosis.

Declarations

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Ethics approval and consent to participate: The study was approved by the Ethical Review Board of the Peking Union Medical College Hospital (agreement number: JS-908). Written informed consent was provided by each participant.

Consent for publication: Written informed consent for publication of clinical details and/or clinical images was obtained from the all of the participants.

Availability of data and materials: All of the patient’s medical record and images are kept in Peking Union Medical College Hospital. For the review, please refer to the method section.

Conflict of interest/ Competing interests: The authors declare that they have no competing interests.

Authors' contributions: Nan Wu, Zhen Zhang and Jiashen Shao made substantial contributions to the conception and design of the work. Shengru Wang, Ziquan Li, Sen Zhao, Yuanqiang Zhang and Lianlei Wang made contributions to the acquisition and analysis of data. Nan Wu, Zhen Zhang and Jiashen Shao drafted the manuscript. Yu Zhao, Keyi Yu, Hong Zhao, Jianxiong Shen, Guixing Qiu and Zhihong Wu helped to revised manuscript critically for important intellectual content. Yang Yang, Lian Liu, Chenxi Yu, Sen Liu, Zhengye Zhao and You Du helped with data management and statistical analysis. All authors approved the final version to be published.

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Tables

Table 1. Demographics and baseline characteristics of study cohort

Characteristics	Total (n=180)	No perioperative complication group (n=155)	Perioperative complication group (n=25)	P value
Age (y/o)	29.8±9.8	29.5±9.6	31.4±10.5	0.373
Gender (male %)				0.850
Male	30(16.7%)	27(90.0%)	3(10.0%)	
Female	150(83.3%)	128(85.3%)	22(14.7%)	
BMI (kg/m^2)	20.8±3.2	20.6±2.9	21.0±4.7	0.620
Etiology				0.547*
Adolescent idiopathic scoliosis	146(81.1%)	125(85.6%)	21(14.4%)	
Congenital scoliosis	24(13.3%)	22(91.7%)	2(8.3%)	
Neuromuscular scoliosis	9(5.0%)	7(77.8%)	2(22.2%)	
Marfan-like scoliosis	1(0.6%)	1(100.0%)	0(0.0%)	
Symptoms duration (month)	15.7±10.2	14.4±9.3	18.5±10.0	0.071
Back pain				0.230
No	60(33.3%)	55(91.7%)	5(8.3%)	
Yes	120(66.7%)	100(83.3%)	20(16.7%)	
Neurological symptom				0.681
No	170(94.4%)	146(85.9%)	25(14.1%)	
Yes	10(5.6%)	9(90.0%)	1(10.0%)	
Dyspnea				0.777
No	162(90.0%)	140(86.4%)	22(13.6%)	
Yes	18(10.0%)	15(83.3%)	3(16.7%)	
Spinal stenosis				0.209*
No	174(96.7%)	151(86.8%)	24(13.2%)	
Yes	6(3.3%)	4(66.7%)	2(33.3%)	
Vertebral rotation				0.229

No	161(89.4%)	137(85.1%)	25(14.9%)	
Yes	19(10.6%)	18(94.7%)	1(5.3%)	
Herniated disk				0.607
No	161(89.4%)	138(85.7%)	23(14.3%)	
Yes	19(10.6%)	17(89.5%)	2(10.5%)	
Syringomyelia				0.908
No	158(87.8%)	136(86.1%)	22(13.9%)	
Yes	22(12.2%)	19(86.4%)	3(13.6%)	
Kyphosis				0.386
No	161(89.4%)	139(87.0%)	21(13.0%)	
Yes	19(10.6%)	15(78.9%)	4(21.1%)	
Smoking				0.990
No	173(96.1%)	149(86.1%)	24(13.9%)	
Yes	7(3.9%)	6(85.7%)	1(14.3%)	
Heart disease				1*
No	174(96.7%)	150(86.2%)	24(13.8%)	
Yes	6(3.3%)	5(83.3%)	1(16.7%)	
Respiratory disease				0.401
No	157(87.2%)	134(85.4%)	23(14.6%)	
Yes	23(12.8)	21(91.3%)	2(8.7%)	
Hypertension				0.376*
No	177(98.3%)	153(86.4%)	24(13.6%)	
Yes	3(1.7%)	2(66.7%)	1(33.3%)	
Anemia				0.602
No	169(93.9%)	145(85.8%)	24(14.2%)	
Yes	11(6.1%)	10(90.9%)	1(9.1%)	

*Fisher exact test; y/o, years old; BMI, body mass index; Neurological symptoms include radiating pain, intermittent claudication and numbness caused by spinal stenosis.

Table 2. Operative characteristics of study cohort

Characteristics	Total (n=180)	No complication group (n=155)	Complication group (n=25)	*P* value
ASA classification				0.043
1	102(60.4%)	93(91.2%)	9(8.8%)	
2-3	67(39.6%)	53(79.1%)	14(20.9%)	
Distal fusion level				0.640*
L4 or upper	144(81.4%)	125(86.8%)	20(13.2%)	
L5	27(15.3%)	22(81.5%)	5(18.5%)	
S1+2	6(3.4%)	6(100.0%)	0(0.0%)	
RBC transfusion				0.028
<4u	151(83.9%)	134(88.7%)	18(11.3%)	
>=4u	29(16.1%)	21(72.4%)	8(27.6%)	
Total operative time (min)	259.7±81.1	260.0±77.9	242.0±112.0	0.389
Total length of stay (day)	14.6±4.6	14.1±3.8	17.7±5.7	0.004
Total EBL (mL)	755.8±483.1	719.9±455.0	943.7±668.0	0.020
Preoperative Hgb (g/L)	131.6±14.4	132.6±14.7	134.1±9.2	0.584
Preoperative albumin (g/L)	43.1±3.5	43.4±3.7	42.7±2.8	0.498
Levels of fusion (n)				0.038
3-7	19(10.7%)	17(89.5%)	2(10.5%)	
8-12	79(44.6%)	73(92.4%)	6(7.6%)	
13-16	79(44.6%)	62(78.5%)	17(21.5%)	
Decompression				0.212
No	169(93.9%)	146(86.4%)	23(13.6%)	
Yes	11(6.1%)	8(72.7%)	3(27.3%)	
Osteotomy				0.003
No	143(79.4%)	128(89.5%)	15(10.5%)	
Yes	37(20.6%)	26(70.3%)	11(29.7%)	
Anatomic grades of				0.045

resection				
1	9(24.3%)	9(100.0%)	0(0.0%)	
2	16(43.2%)	11(68.8%)	5(31.3%)	
3-6	12(32.4%)	6(50.0%)	6(50.0%)	
Levels of osteotomy (n)				0.392
1-6	24(64.9%)	18(75.0%)	6(25.0%)	
7-13	13(35.1%)	8(61.5%)	5(38.5%)	
Cobb (°)				
Preoperative	66.6±24.1	63.7±22.7	78.0±24.7	0.015
Postoperative	30.0±21.9	28.5±20.3	35.1±25.5	0.320
Change	36.7±12.1	35.5±10.3	45.5±17.2	0.003
CA (°)				
Preoperative	2.3±2.9	2.1±2.7	3.4±3.7	0.242
Postoperative	3.2±2.6	3.2±2.7	3.6±2.9	0.518
Change	-0.8±2.9	-1.1±2.9	-0.2±2.7	0.550
SO (°)				
Preoperative	2.3±2.6	2.2±2.4	2.3±2.2	0.946
Postoperative	2.0±2.1	2.0±1.9	1.7±1.5	0.905
Change	0.3±1.8	0.2±1.7	0.6±1.9	0.858
T1TA (°)				
Preoperative	7.2±7.4	7.3±7.4	7.5±8.5	0.974
Postoperative	6.5±7.3	6.8±7.5	6.7±9.6	0.846
Change	0.6±5.2	0.5±5.0	0.6±6.4	0.821
L5TA (°)				
Preoperative	12.4±8.9	11.4±8.2	14.3±9.4	0.088
Postoperative	7.0±6.2	6.4±5.4	7.4±6.3	0.503
Change	5.4±6.7	5.1±6.6	7.7±8.0	0.103
T1PA (°)				
Preoperative	8.2±6.7	7.9±6.6	9.3±8.1	0.551

Postoperative	9.0±6.9	9.4±7.1	7.5±6.1	0.160
Change	-0.8±7.2	-1.4±6.7	1.8±10.1	0.056
CVA (mm)				
Preoperative	15.1±12.4	14.3±10.6	19.5±17.3	0.106
Postoperative	15.2±11.7	15.1±12.4	11.1±7.4	0.143
Change	-0.04±13.48	-1.2±12.1	8.2±16.1	0.005
SVA (mm)				
Preoperative	22.8±17.0	22.7±16.4	22.7±20.9	0.496
Postoperative	20.5±16.7	19.4±15.1	20.6±24.1	0.714
Change	2.4±21.4	3.2±19.5	2.3±31.3	0.777
TK (°)				
Preoperative	33.9±18.2	32.7±16.9	41.8±19.5	0.136
Postoperative	33.5±13.3	33.0±13.1	34.9±13.0	0.608
Change	0.5±15.9	-0.6±14.0	6.1±23.4	0.113
PT (°)				
Preoperative	9.1±8.6	9.2±8.5	7.9±8.9	0.690
Postoperative	10.5±8.8	11.0±8.7	7.6±10.0	0.117
Change	-1.2±6.9	-1.5±6.8	0.7±7.3	0.171
SS (°)				
Preoperative	33.2±10.9	33.9±10.9	34.3±12.0	0.839
Postoperative	32.7±7.6	32.5±7.6	34.8±8.6	0.144
Change	0.9±9.9	1.2±9.6	-0.7±11.7	0.414
LL (°)				
Preoperative	49.3±16.1	49.0±16.4	51.7±14.0	0.915
Postoperative	47.3±11.6	46.6±11.5	51.6±12.0	0.052
Change	1.7±13.5	2.1±13.5	-0.1±12.2	0.128
PI (°)				
Preoperative	42.3±13.1	43.1±13.0	42.3±15.6	0.926
Postoperative	43.2±10.5	43.5±10.4	42.4±12.7	0.794

Change	-0.3±10.3	-0.4±9.9	-0.03±12.60	0.886
PI-LL (°)				
Preoperative	15.9±14.5	14.9±14.4	16.9±14.0	0.286
Postoperative	10.5±9.3	10.5±9.4	13.3±10.3	0.214
Change	4.5±13.5	4.7±13.5	3.7±14.0	0.789

*Fisher exact test; ASA indicates American Society of Anesthesiologists; EBL, estimated blood loss; CA, clavicle angle; SO, sacral obliquity; T1TA, T1 tilt angle; L5TA, L5 tilt angle; T1PA, T1 pelvic angle; CVA, coronal vertical axis; SVA, sagittal vertical axis; TK, thoracic kyphosis; PT, pelvic tilt; SS, sacral slope; LL, lumbar lordosis; PI, pelvic incidence; PI -LL, pelvic incidence minus lumbar lordosis; Anatomic grades of resection: 1 SPO, 2 Ponte, 3 PSO,4 BDBO, 5 VCR, 6 VCRs.

Table 3. Perioperative complications

Number of perioperative complications per patient	Number of patients (percentage %)
1	21(84)
2	2(8)
3	2(8)
Total	25
Type of perioperative complications	Number of patients
Cardiopulmonary-related	11
Pleural effusion	7
Arrhythmia	1
Congestive heart failure	1
Pneumothorax	1
Atelectasis	1
Infection	5
Urinary infection	2
Pulmonary infection	2
Septic shock	1
Deep infection	1
Neurological-related	6
Radicular edema	3
Sensory deficit	2
Peripheral nerve palsy	1
Total of gastrointestinal	3
Ileus	2
acute pancreatitis	1
Total of incision-related problems	6
Superficial infection/ fat liquefaction	2
Non-aligned edges	1
Dura tear/cerebrospinal fluid leakage	1
Inappropriate screw position	1

Atopic dermatitis	1
Type of complications during long-term follow-up	
Screw-related infection	1
Rod fracture	3

Table 4. Category, management and treatment outcomes of perioperative complications

Category	Symptoms and signs	Management	Results
Cardiopulmonary	Pleural effusion, pneumothorax, atelectasis	Thoracic closed drainage	Recovered in 2w postoperatively
	Congestive heart failure	Consultation with cardiology, myocardium-nurturing, and control fluid infusion	Recovered in 1w postoperatively
	Arrhythmia	Antiarrhythmic drugs	Recovered in 1w postoperatively
Infection	Urinary infection	Urine culture, anti-infection drug	Recovered in 2w postoperatively
	Pulmonary infection	Anti-infection drug, phlegm, turn back and pat on the back	Recovered
	Septic shock	Monitor the temperature and blood pressure, fluid replacement, anti-infection, and vasoactive drugs	Recovered in 2w postoperatively
	Deep infection	Debridement and anti-infection drug	Recovered in 5w postoperatively
Neurological	Radicular edema	Dehydration and steroid treatment	Recovered
	Sensory deficit, peripheral nerve palsy	Dehydration and nerve-nurturing treatment	Recovered in 4w postoperatively
Gastrointestinal	Ileus	Fasting and water deprivation, acid-suppressive drugs, liquid paraffin, and glycerine enema	Recovered in 2w
	Acute pancreatitis	Fluid replacement, monitoring electrolytes and oxygen saturation, anti-infection, and acid-suppressive drugs	Recovered in 2w postoperatively
Incision	Superficial infection/ fat liquefaction	Debridement and suture and anti-infection drugs	Recovered in 1w postoperatively
	Non-aligned edges	Dressing change and anti-infection drugs	Recovered in 1w postoperatively
	Dura tear/cerebrospinal fluid leakage	In supine or lateral position, drainage, elevate head in bed, increased fluid infusion, and dense suture of incision	Recovered in 2w postoperatively
	Inappropriate screw position	Revision surgery	Recovered

	Atopic dermatitis	Maintaining skin hydration and topical anti-inflammatory therapy	Recovered
	Screw-related infection	Debridement and withdrawal of the internal fixation	Recovered
	Rod fracture	Revision and replacement of internal fixation rod	Recovered

Table 5. Multivariate analysis of risk factors

Predictors for perioperative complication	OR	S.E.	z	$P>\lvert z\rvert$*	95% CI
Cobb change	1.058	0.023	5.861	0.015	1.011-1.108
CVA change	1.066	0.023	7.636	0.006	1.019-1.116
RBC transfusion	5.631	0.618	7.81	0.005	1.676-18.924
constant	0.009	1.003	21.195	<0.001	

Performed with forward stepwise selection model building. $P>\lvert z\rvert$*value 0.05 represents statistically significant threshold. CI indicates confidence interval; OR, odds ratio; S.E., standard error; CVA, coronal vertical axis.

Figures

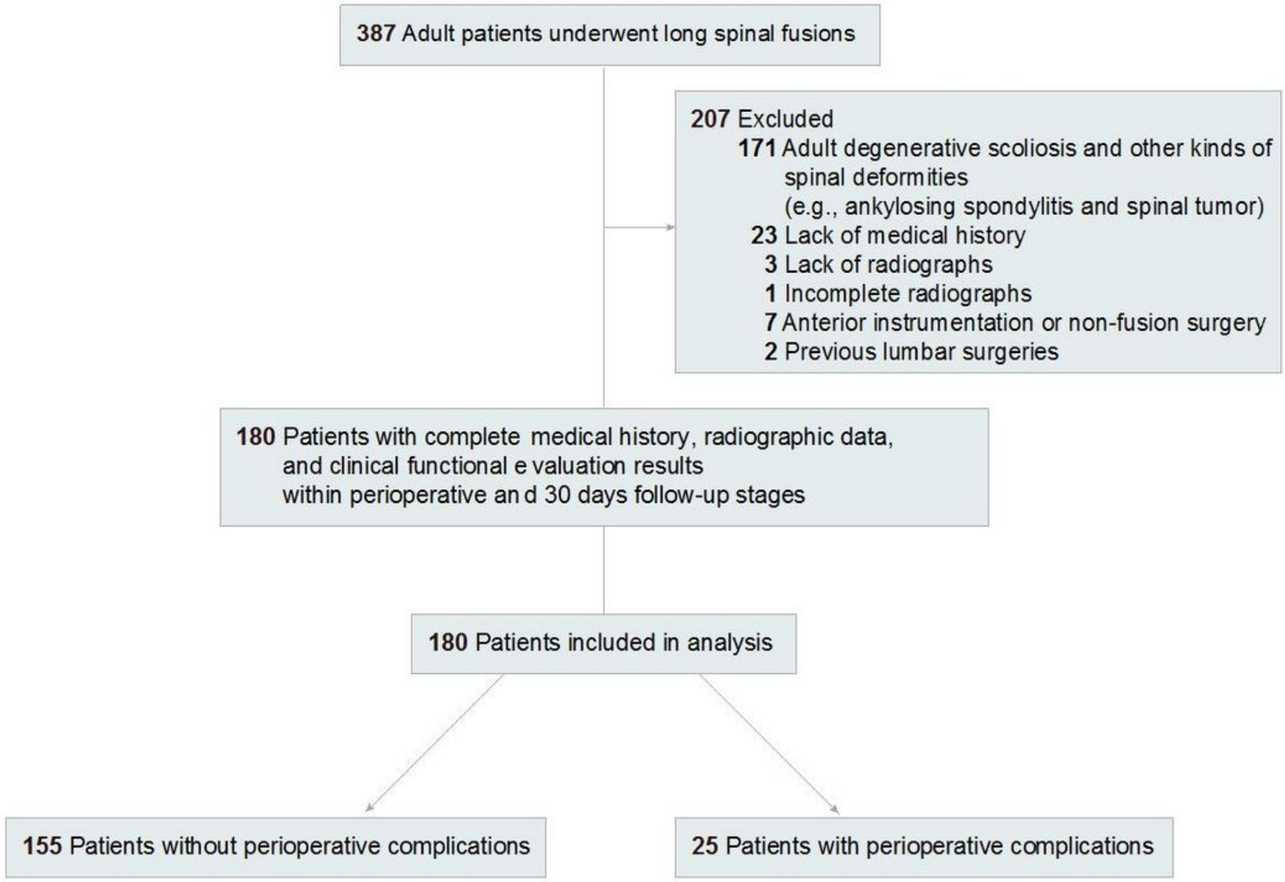

Figure 1

Flowchart showing the patient inclusion process.

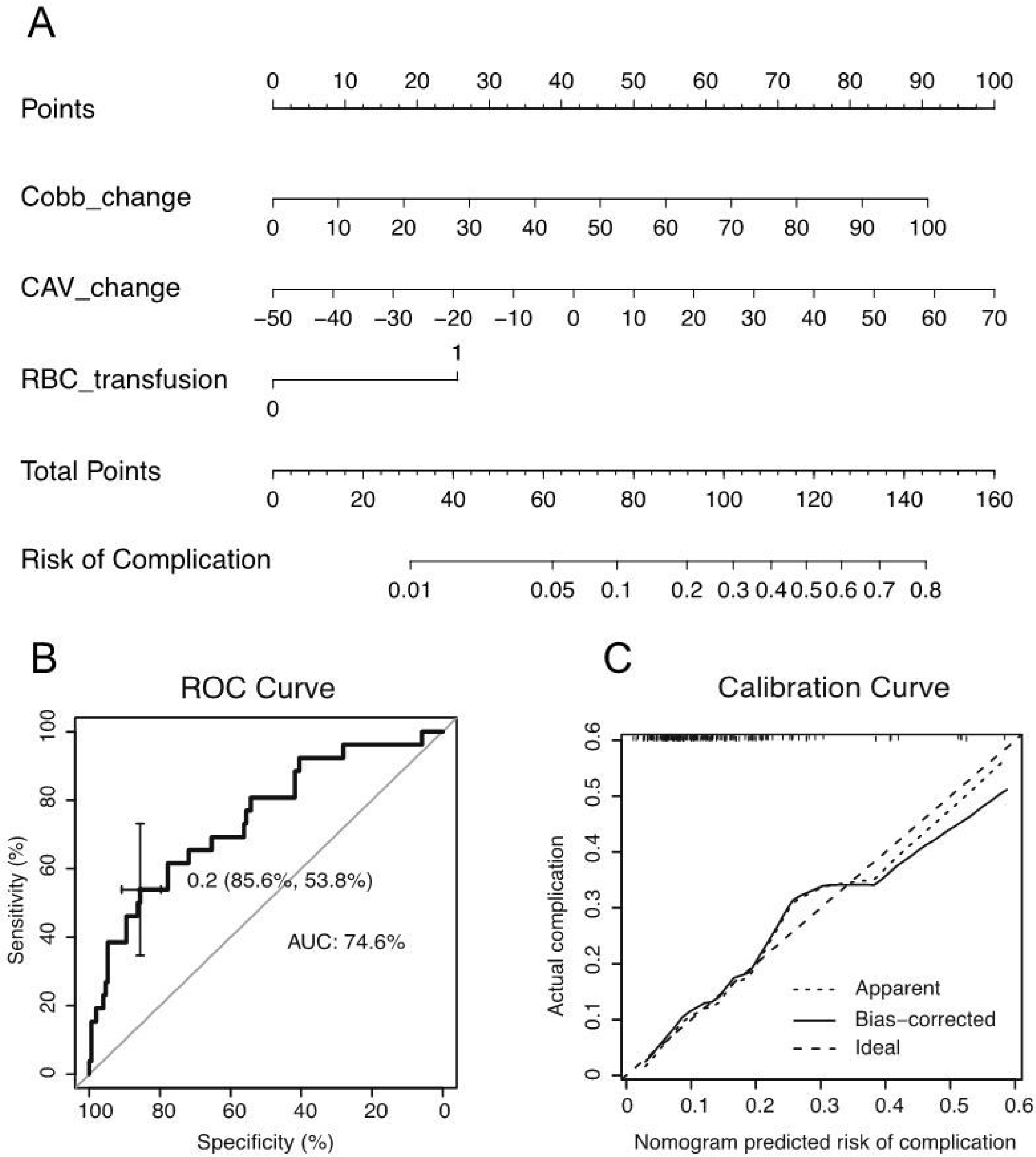

Figure 2

Nomogram predicting perioperative complications of long fusion surgery. A. The nomogram, as a simple graphic representation of a statistical predictive model, could generate a numerical probability of a certain clinical event. To use it, an individual's value is located on each variable axis, and a line is drawn upward to determine the points received for each variable (corresponding points for each variable: Cobb change=100°, 90; CVA change=70mm, 60; RBC transfusion, 25). The sum of these points is located on the total point axis, and a line is drawn downward to the axe of the risk of complication to determine the likelihood of perioperative complication. Inner data analysis of ROC and calibration were shown in B and C.