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Predicting massive transfusion in adolescent idiopathic scoliosis patients undergoing corrective surgery

Association of preoperative radiographic findings

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Abstract

Corrective surgery with a posterior approach for adolescent idiopathic scoliosis (AIS) is often accompanied by considerable bleeding. Massive transfusion after excessive hemorrhage is associated with complications such as hypothermia, coagulopathy, and acid–base imbalance. Therefore, prediction and prevention of massive transfusion are necessary to improve the clinical outcome of AIS patients. We aimed to identify the factors associated with massive transfusion in AIS patients undergoing corrective surgery. We also evaluated the clinical outcomes after massive transfusion.

We included and analyzed AIS patients who underwent corrective surgery with a posterior approach from January 2008 to February 2015. We retrospectively reviewed the electronic medical records of 765 consecutive patients. We performed multivariable logistic regression analysis to assess the factors related to massive transfusion. Furthermore, we compared the effects of massive transfusion on clinical outcomes, including postoperative morbidity and hospital stay.

Of 765 patients, 74 (9.7%) received massive transfusion. Body mass index (odds ratio [OR] 0.782, 95% confidence interval [CI] 0.691–0.885, $P<.001$) and the number of fused vertebrae (OR 1.322, 95% CI 1.027–1.703, $P=.03$) were associated with massive transfusion. In the comparison among the different Lenke curve types, Lenke type 4 showed the highest prevalence of massive transfusion. Patients in the massive transfusion group showed a higher incidence rate of postoperative morbidity and prolonged hospital stay.

Massive transfusion was required in 9.7% of AIS patients who underwent corrective surgery with a posterior approach. A lower body mass index and higher number of fused vertebrae were associated with massive transfusion. Massive transfusion is related to poor clinical outcomes in AIS patients.

Abbreviations: AIS = adolescent idiopathic scoliosis, BMD = bone mineral density, BMI = body mass index, CI = confidence interval, Cobb angle = maximal Cobb angle in standing position, CSVL = central sacral vertical line, ICU = intensive care unit, OR = odds ratio, RSH = radiographic shoulder height.

Keywords: adolescent idiopathic scoliosis, massive transfusion, posterior fusion, radiographic findings

1. Introduction

Adolescent idiopathic scoliosis (AIS) is defined as a lateral deviation of the spine associated with vertebral rotation in an otherwise healthy person.[1] The main treatment options for AIS are observation, bracing, and operation.[2] Operation is usually indicated for patients with relatively greater curve angles or those with rapid progression.[3] A previous study has shown that corrective surgeries for AIS patients are relatively safe with a very low incidence of major complications.[4]

Spinal surgeons correct deformities through various approaches, including anterior, posterior, and combined anterior and posterior approaches.[5] Several recent studies have demonstrated that the posterior approach is an effective method for the correction of AIS. In addition, posterior spinal fusion is known to be more advantageous than the other 2 approaches in terms of postoperative pulmonary function.[6] However, posterior spinal fusion entails a higher risk of excessive hemorrhage than the anterior approach.[7,8]

Massive bleeding may result in the development of the lethal triad of acidosis, hypothermia, and coagulopathy, which is associated with higher mortality and morbidity.[9,10] In case of massive bleeding, massive transfusion could be a life-saving treatment. However, massive transfusion per se not only exacerbates the lethal triad but also increases the risk of electrolyte abnormalities, postoperative bacterial infection, transfusion-related acute lung injury, and transfusion-associated circulatory overload.[9,10] Thus, predicting and preventing

Editor: Johannes Mayr.

Information on Institutional Review Board Approval: The Institutional Review Board of Asan Medical Center (2016-0070) approved this study.

The authors have no conflicts of interest to disclose.

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Medicine (2018) 97:22(e10972)

Received: 27 December 2017 / Accepted: 9 May 2018

http://dx.doi.org/10.1097/MD.0000000000010972

massive transfusion are important and may help improve the clinical outcomes of patients. Several previous studies have commonly suggested that the maximal Cobb angle and the levels of fused vertebrae are the main predictors of massive transfusion in AIS patients.[11–13] However, those previous reports were relatively small retrospective studies and the results were inconsistent. In addition, little is known about the association of preoperative radiographic measurements with massive transfusion. Therefore, in this study, we aimed to assess the factors associated with massive transfusion in AIS patients undergoing deformity correction and posterior fusion. We also evaluated the effect of massive transfusion on the clinical outcomes.

2. Materials and methods

2.1. Study population

The medical records of patients who underwent deformity correction and posterior fusion between January 2008 and February 2015 were retrospectively reviewed. The institutional review board of Asan Medical Center approved this study after an expedited review, and waived the requirement for informed consent owing to the retrospective nature of this study.

All surgeries were performed at a tertiary center in Seoul, South Korea. The surgical technique was relatively similar for every patient undergoing deformity correction; each patient underwent the rod derotation method with pedicle screw fixation using the posterior approach with a midline incision. We identified a total of 1028 patients through our electronic medical records system. Among them, we excluded 263 patients for the following reasons: no diagnosis of AIS (n = 175), age < 12 years or >30 years (n = 64), presence of mental retardation (n = 13), concomitant growing rod insertion (n = 7), revision operation (n = 2), presence of chronic kidney disease or liver disease (n = 1), and abnormal finding in the preoperative coagulation laboratory test (n = 1). None of the patients had a history of previous bleeding or previous spine surgery. Finally, we included a total of 765 AIS patients in this study.

2.2. Anesthetic management

All patients were operated on under general anesthesia; 745 patients received total intravenous anesthesia with propofol and remifentanil as the main anesthetics, and 20 patients received inhalation anesthesia with desflurane or sevoflurane combined with nitrous oxide. Arterial blood pressure and central venous pressure were continuously monitored through arterial and central line catheterizations. Somatosensory evoked potentials and motor evoked potentials were examined during the operation except in patients who were anesthetized with inhalation agents. Balanced salt solution as crystalloid and hetastarch as colloid were used. During surgery, systolic blood pressure was targeted at 80 to 90 mm Hg for blood conservation, and ephedrine or phenylephrine was administered if sudden hypotension occurred. Packed red blood cell transfusion was decided based on the rate of bleeding and carried out when the hematocrit level decreased to < 25% to 30%. Fresh frozen plasma and/or platelet concentrate was administered as required, according to the discretion of the attending anesthesiologist or depending on the result of rotational thromboelastometry, which was performed when massive bleeding occurred and dilution coagulopathy was suspected.

2.3. Clinical data

We investigated the demographic, laboratory, and perioperative variables of the included patients through a review of electronic medical records. We also analyzed preoperative radiographic findings associated with the severity of scoliosis. We collected demographic data including age, sex, body mass index (BMI), bone mineral density (BMD), and underlying diseases. The collected laboratory data were hemoglobin, platelet count, activated partial thromboplastin time, prothrombin time, and serum creatinine. Perioperative data included the amount of transfusion, estimated blood loss during surgery and the postoperative period, place of admission after surgery, and postoperative complications. Maximal Cobb angle in standing position (Cobb angle), Lenke classification, number of fused vertebrae, radiographic shoulder height (RSH), and coronal-plane trunk shift (C7-central sacral vertical line [CSVL]) were included in the preoperative radiographic variables.

2.4. Definition of outcomes

Massive transfusion is generally defined as transfusion of ≥10 red blood cell units. However, this definition is suitable only for adult patients. As almost all patients included in this study were pediatric patients, we applied the following definition for massive transfusion: transfusion of >100% total blood volume within 24 hours.[14] We estimated the total blood volume based on body weight, as follows: young child (10–24 kg), 75 mL/kg body weight; older child (25–49 kg), 70 mL/kg body weight; young adult (≥50 kg), 70 mL/kg body weight for male and 65 mL/kg body weight for female.[15] The other outcome variables we attempted to assess were the length of postoperative hospital stay, postoperative complications, and requirement for intensive care unit (ICU) admission. We divided postoperative complications according to body system, as follows: cardiovascular complications including hypotension and arrhythmia; pulmonary complications including pneumonia, pleural effusion, and pneumothorax; gastrointestinal complications including moderate to severe ileus and acute gastritis; neurologic complications including sensory or motor change; wound complications including infection or dehiscence; and renal complications including acute kidney injury. Postoperative fever was defined as body temperature >38°C during the 7 postoperative days. Complications requiring a surgical, endoscopic, or radiologic intervention or those that were life threatening (Clavien–Dindo classification ≥3) were considered major complications. We extracted all data from the electronic medical records system.

2.5. Statistical analysis

We tested the associations between massive transfusion and characteristic variables of participants by using univariable and multivariable logistic regression analyses. We analyzed only the recorded data without any special processing, considering that the portion of missing data was insignificant. Only BMD was excluded from the multivariable analysis, as missing data accounted for 46%. We calculated the estimated odds ratios (ORs) and 95% confidence intervals (CIs). Moreover, we confirmed the linearity assumption for continuous variables in the logistic regression model by using the Box–Tidwell test, and found no relevant violations.

We divided the patients into 2 groups according to the occurrence of massive transfusion: massive transfusion group and nonmassive transfusion group. We compared the 2 groups in

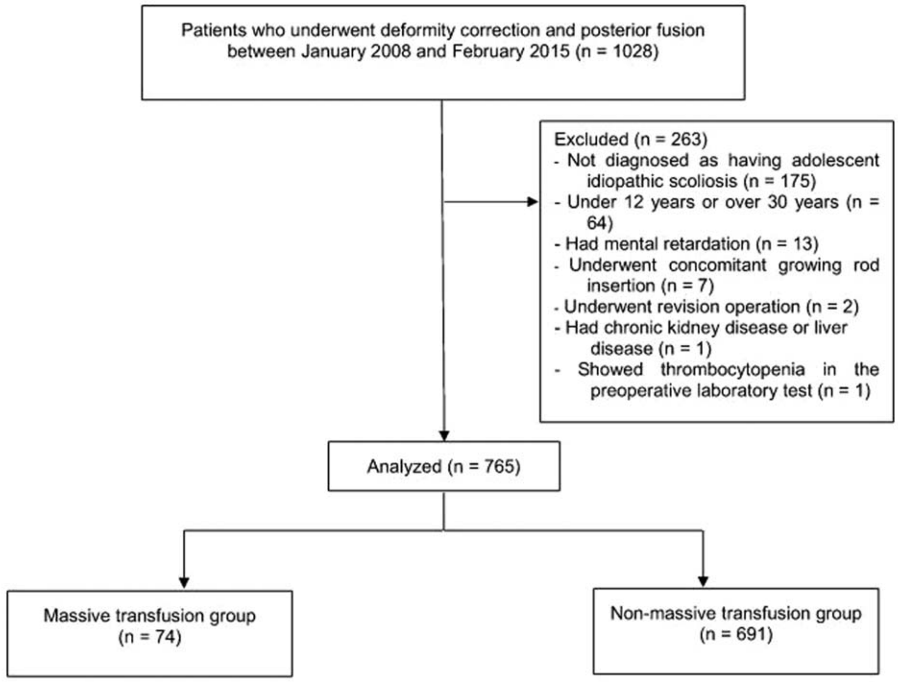

Figure 1. Flow diagram of patient inclusion and allocation.

terms of postoperative morbidities categorized as cardiovascular, gastrointestinal, pulmonary, neurologic, wound, and renal complications. We also compared major complications, ICU admission, and postoperative hospital stay. We calculated the ORs by using the logistic regression model for the complication rate and estimated the beta values by using the linear regression model for hospital stay.

All reported P values were 2-sided, and $P < .05$ was considered significant. We conducted all statistical analyses with IBM SPSS Statistics (version 21; SPSS Inc, Chicago, IL).

3. Results

We analyzed a total of 765 patients in this study (Fig. 1). The baseline demographic, laboratory, and perioperative variables are shown in Table 1, and radiographic variables are shown in Table 2. Categorical variables are presented as frequencies and percentages, and continuous variables as mean ± standard deviation or median [interquartile range]. Among the 765 patients, 74 patients (9.7%) required massive transfusion. The results of univariable logistic regression analysis revealed that, among the preoperative factors, BMI, Cobb angle, Lenke curve type, and number of fused vertebrae were relevant to massive transfusion (Table 3). After multivariable logistic regression analysis with a full-fitting model, BMI and the number of fused vertebrae remained significant factors for massive transfusion (Table 3). When we further included intraoperative variables, multivariable logistic regression analysis demonstrated that a lower BMI, and volume of crystalloid and colloid solution were related to massive transfusion.

Although Cobb angle and Lenke curve type did not demonstrate statistical significance after multivariable analysis ($P = .08$ and .10, respectively), they demonstrated trends toward a positive correlation. The greater the Cobb angle, the higher the risk of massive transfusion. Comparisons among the different

Table 1

Baseline characteristics of adolescent idiopathic scoliosis patients undergoing corrective surgery.

Characteristics	n (%) or mean ± SD or median [IQR]
Demographic	
Sex, female	648 (84.7)
Age (y)	15.6 ± 3.3
Body mass index (kg/m^2)	19.6 ± 3.0
ASA grade 1/2	330 (43.1)/435 (56.9)
Cardiac disease	12 (1.6)
Pulmonary disease	13 (1.7)
Other disease	21 (2.8)
Abnormal pulmonary function test	6 (0.8)
Bone mineral density	−1.15 ± 1.07
Laboratory	
Preoperative anemia	69 (9.0)
Hemoglobin (g/dL)	13.4 ± 1.2
Platelet (×10^3/μL)	257.2 ± 51.5
PT (INR)	1.03 ± 0.06
aPTT (s)	29.67 ± 2.35
Creatinine (g/dL)	0.63 ± 0.13
Albumin (g/dL)	4.34 ± 0.34
Perioperative	
Crystalloid (mL)	2550 [1650]
Colloid (mL)	800 [500]
Anesthetic time (min)	269.2 ± 49.1
Operation time (min)	200.4 ± 43.1
Fused level (number)	11.15 ± 1.49
24-h bleeding (mL)	2900 [1300]
Intraoperative transfusion (mL)	1400 [1100]
24-h transfusion (mL)	1400 [1050]

aPTT = activated partial thromboplastin time, ASA = American Society of Anesthesiologists, IQR = interquartile range, n = number, PT (INR) = prothrombin time (international normalized ratio), SD = standard deviation.

Table 2

Radiographic characteristics.

Characteristics	n (%) or mean ± SD
Maximal Cobb angle in standing position (°)	56.83 ± 10.35
Radiographic shoulder height (mm)	11.45 ± 8.87
Coronal-plane trunk shift (mm)	11.09 ± 8.79
Lenke classification, curve type	
1	272 (36.8)
2	108 (14.6)
3	171 (23.1)
4	28 (3.8)
5	102 (13.8)
6	58 (7.9)

n = number, SD = standard deviation.

Lenke curve types revealed that Lenke type 4 had a higher risk of massive transfusion than the other curve types.

The postoperative clinical outcomes of patients who received massive transfusion compared with those of patients without massive transfusion are presented in Table 4. There were significant differences in the occurrence of postoperative pulmonary and gastrointestinal complications between the massive transfusion group and the nonmassive transfusion group. The massive transfusion group also demonstrated significantly higher incidence of any major complications and higher ICU admission rates. Furthermore, the postoperative hospital stay was significantly prolonged (0.701 days) in the massive transfusion group.

4. Discussion

The study results demonstrated that massive transfusion occurred in 9.7% of AIS patients who underwent scoliosis corrective surgery with a posterior approach. The factors associated with massive transfusion were lower BMI and larger numbers of fused vertebrae. We identified Lenke type 4 to involve the highest incidence of massive transfusion among all Lenke curve types. Massive transfusion was related to poor clinical outcomes including more frequent occurrence of postoperative pulmonary and gastrointestinal complications, higher rate of ICU admission, and prolonged postoperative hospital stay.

Massive transfusion after massive blood loss could result in poor clinical outcomes by increasing perioperative morbidity. However, there is a wide variation in the incidence of massive transfusion in scoliosis patients who underwent corrective surgery across different studies. In the study by Yu et al,[12] 59.7% patients had massive bleeding. Cristante et al[16] described that most of the scoliosis patients in their study required transfusion, but none received a massive transfusion. In this study, most patients received transfusion of >1 unit and the proportion of patients requiring massive transfusion was 9.7%. Considering that there exists a study in which none of the patients required blood transfusion, the incidence of massive transfusion in our study was higher.[17] The disparity in the definition of the term "massive" might partly explain the inconsistent results. The differences in surgical procedure and anesthetic management at our center also contributed to the result. Pedicle screw instrumentation, one of the methods for deformity correction, has been reported to offer better curve correction and higher patient satisfaction than hook or hybrid instrumentation.[18,19] However, blood loss was significantly higher in the pedicle screw instrumentation group.[18] In the anesthetic aspect, we did not administer blood-conserving strategies including administration of antifibrinolytic agents, intraoperative blood salvage, and acute normovolemic hemodilution.[20–22] In addition, the use of colloid solution might have caused the higher incidence of massive transfusion by diluting red blood cells, platelets, and coagulation factors, although the volume of colloid solution administered was small (<10–20 mL/kg). Therefore, it might be difficult to generalize the conclusion drawn from our research to all AIS patients. However, even considering these limitations, the preoperative factors that were identified to be associated with massive transfusion in this study would be valuable, as we believe

Table 3

Risk factors for massive transfusion of adolescent idiopathic scoliosis patients undergoing corrective surgery.

	Univariate			Multivariable		
	OR	95% CI	*P* value	OR	95% CI	*P* value
Sex, male	0.647	0.302–1.386	.26	0.565	0.233–1.367	.21
Age	1.020	0.950–1.095	.59	1.076	0.994–1.166	.07
Body mass index	0.802	0.720–0.894	<.001	0.782	0.691–0.885	<.001
ASA PS 2	1.450	0.879–2.392	.15	1.223	0.708–2.112	.47
Cardiac disease	0.847	0.108–6.653	.87	0.479	0.055–4.152	.50
Pulmonary disease	1.717	0.373–7.899	.49	1.034	0.189–5.655	.97
Abnormal pulmonary function test	1.879	0.217–16.306	.57	0.361	0.029–4.439	.43
Bone mineral density	0.878	0.588–1.051	.46			
Maximal Cobb angle	1.045	1.024–1.066	<.001	1.023	0.998–1.020	.08
Radiographic shoulder height	0.994	0.966–1.022	.68	0.259	0.096–0.697	.47
Coronal-plane trunk shift	0.985	0.956–1.014	.31	0.994	0.963–1.027	.72
Lenke type			.009			.10
1	0.177	0.071–0.439	<.001	0.259	0.096–0.697	.008
2	0.239	0.087–0.657	.006	0.243	0.080–0.741	.01
3	0.296	0.118–0.738	.009	0.319	0.119–0.854	.02
4	1 (ref)			1 (ref)		
5	0.132	0.042–0.414	.001	0.228	0.062–0.840	.03
6	0.199	0.059–0.669	.009	0.194	0.053–0.707	.01
Fused level	1.484	1.217–1.809	<.001	1.322	1.027–1.703	.03

ASA PS = American Society of Anesthesiologists physical status, CI = confidence interval, OR = odds ratio.

Table 4

Postoperative clinical outcomes of patients receiving massive transfusion compared with those of patients without massive transfusion.

	Massive transfusion group	Nonmassive transfusion group	OR	95% CI	*P* value
Cardiovascular complication	1 (1.4)	2 (0.3)	4.718	0.218–49.824	.21
Pulmonary complication	10 (13.5)	8 (1.2)	13.340	5.089–36.097	<.001
Gastrointestinal complication	11 (14.9)	41 (5.9)	2.768	1.299–5.486	.005
Neurologic complication	1 (1.4)	14 (2.0)	0.662	0.036–3.369	.69
Wound complication	0 (0.0)	3 (0.4)	1.320	0.066–26.268	.86
Miscellaneous complication	2 (2.7)	5 (0.7)	3.811	0.539–18.031	.11
Acute kidney injury	1 (1.4)	9 (1.3)	1.038	0.056–5.641	.97
Postoperative fever	39 (52.7)	295 (42.7)	1.496	0.925–2.427	.10
Major complication*	10 (13.5)	2 (0.3)	53.828	13.818–355.136	<.001
Transfer to ICU	8 (10.8)	6 (0.9)	13.838	4.676–43.181	<.001
			Beta	95% CI	*P* value
Postoperative hospital stay (d)	8.04±1.56	7.34±0.96	0.701	0.453–0.949	<.001

CI=confidence interval, ICU=intensive care unit, OR=odds ratio.
* Major complication: complication requiring a surgical, endoscopic, or radiologic intervention or those that were life threatening (Clavien-Dindo classification 3 or 4).

that our data may provide useful information for predicting the subgroup of AIS patients who are at a risk for more surgical bleeding and transfusion.

In this study, we found that the level of fused vertebrae was a predictor of massive transfusion in AIS correction surgery. This result is consistent with those of previous studies. Thompson et al and Minhas et al identified that excessive hemorrhage can be predicted when 12 or more levels are fused.[7,23] In Yoshihara and Yoneoka's analysis, patients who underwent spinal fusion of 9 or more levels were considered likely to receive more transfusions.[24] These articles commonly identified that bleeding risk increased with the number of fused levels. The length of incision becomes longer and the range of manipulated vertebrae becomes larger as the number of fused levels increases. Thus, we could easily infer that the number of fused vertebrae is associated with the risk of massive bleeding.

We identified that low BMI was related to the risk of massive transfusion. Some articles reported similar results to those of our study concerning BMI. Thompson et al[7] showed that AIS patients with lower BMI tended to bleed more during posterior fusion. Dupuis et al[25] also indicated that a weight less than the third percentile was one of the risk factors for homologous transfusion during pediatric scoliosis surgery. The reason for this result could not be clearly explained.

Many studies have identified Cobb angle, representing scoliosis severity, as a strong risk factor.[26] Nugent et al, Tarrant et al, and Yu et al clarified that a larger Cobb angle was associated with excessive intraoperative bleeding.[12,27,28] In this study, we observed that blood loss tended to be greater when Cobb angle was larger. This can be explained by the relationship between Cobb angle and surgical complexity. Tarrant et al[28] verified that a greater curve magnitude increases the surgical complexity.

Traditionally, physicians have used the King classification to categorize the disease according to the type of curve on coronal radiographs. However, the King classification had a limitation in describing all types of spinal curve. To compensate for this limitation, the Lenke classification was proposed in 2001.[29] The Lenke classification, which consists of the curve type, lumbar modifier, and sagittal thoracic modifier, has been shown to be more comprehensive and reliable than the King classification.[29,30] In this study, we noted that patients suffering from Lenke type 4 scoliosis more frequently required massive transfusion. A plausible explanation seems to involve the relationship between the Lenke curve type and maximal Cobb angle. Sponseller et al[31] described that Lenke type 4 scoliosis, having triple major curves, showed a tendency to have the largest mean magnitude of curvature. We supposed that patients with Lenke type 4 scoliosis have a greater chance of having a larger Cobb angle and a higher number of fused vertebrae, thus representing the high-risk group for massive transfusion.

Besides Cobb angle and the Lenke classification, RSH and coronal-plane trunk shift are also preoperative radiographic variables. RSH, the difference between the horizontal lines passing the superolateral tips of the right and left clavicles, refers to the degree of shoulder imbalance.[32,33] Coronal-plane trunk shift, the distance between the midpoint of C7 and the CSVL, quantify the coronal balance.[34] Although we did not find any association between massive bleeding and these 2 variables, Cobb angle and Lenke curve classification showed a trend of having relevance to massive transfusion. Thus, it is necessary to consider the preoperative radiologic findings in planning a safer management for AIS patients during the perioperative period.

Previous studies have shown massive transfusion to be associated with poor clinical outcomes. Turan et al[35] demonstrated that massive transfusion was associated with increased respiratory and infectious complications and 30-day mortality. A recent retrospective study also showed that massive transfusion increased the risk for postoperative morbidities such as infection, thromboembolic events, and mortality.[36] The result of our study is consistent with those of previous studies, although there were some differences. This disparity might have been caused by the fact that our study patients were previously healthy and young without significant medical histories, thus potentially having a lower risk of overall morbidity than other patient groups.

This study has some limitations. First, there are inevitable flaws owing to the retrospective observational design. We could not prove the causality between the associated factors presumed with logistic regression and the occurrence of massive transfusion, as all data were retrospectively analyzed. Second, some factors related to massive transfusion might have been excluded in this study. Nevertheless, we attempted to include all possible confounding variables. Third, we only evaluated the effect of curve type among the 3 factors of the Lenke classification. The precise Lenke type is classified according to the combination of the 3 factors of curve type, lumbar modifier, and sagittal thoracic modifier.[29] However, as an analysis considering every combination is too complex, we evaluated only the effect of curve type. Fourth, we did not calculate sample size. Since previous reports showed wide variation in incidence of massive transfusion in AIS patients, we included all the patients whose data were accessible through electronic medical records in our hospital.[12,16]

In conclusion, massive transfusion was required in 9.7% of AIS patients who underwent corrective surgery with a posterior approach. BMI and the number of fused vertebrae were associated with the occurrence of massive transfusion. Radiographic findings including Cobb angle and Lenke type also showed relevance to massive transfusion. The occurrence of massive transfusion was related to a higher incidence of postoperative complications and prolonged hospital stay. Our study results provide useful information for predicting and preventing massive transfusion, and thus may help improve the clinical outcomes of AIS patients undergoing corrective surgery.

Author contributions

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Supervision: Won Uk Koh.
Validation: Won Uk Koh.
Writing – original draft: Ha-Jung Kim.
Writing – review & editing: Ha-Jung Kim, Hee-Sun Park, Won Uk Koh, Min-Jung Jang, Jun-Gol Song, Hong-Seuk Yang, Young-Jin Ro.

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