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Determinants of perioperative transfusion risk in patients with adult spinal deformity

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OBJECTIVE To determine predictors of perioperative allogeneic packed red blood cell (pRBC) transfusion requirement (total units transfused) in patients with adult spinal deformity (ASD).

METHODS The authors retrospectively analyzed records of patients aged 18 years or older who underwent surgical correction of ASD that involved 4 or more spinal levels by the same spine surgeon between 2010 and 2016. Data regarding patient characteristics, comorbidities, surgical factors, and perioperative transfusions (up to 10 days after surgery) were analyzed using a linear regression model. Significance was set at $p < 0.05$.

RESULTS The authors analyzed 165 patients (118 women) with a mean (± SD) age of 61 ± 12 years. Three-column osteotomies were associated with a mean intraoperative transfusion volume of 1.74 additional units of pRBCs. Each unit of intraoperatively salvaged blood used was associated with a mean 0.39-U increase in postoperative transfusion volume ($p = 0.031$). Every unit of allogeneic blood transfused intraoperatively was associated with a mean 0.23-U decrease in postoperative transfusion volume ($p = 0.001$). A preoperative hemoglobin concentration of 11.5 g/dl or more was associated with significantly fewer units transfused intraoperatively; a preoperative hemoglobin concentration of 14.0 g/dl or more was associated with fewer units transfused postoperatively. A history of smoking and intraoperative antifibrinolytic use were associated with increased and decreased numbers of units transfused postoperatively, respectively.

CONCLUSIONS Effective blood management is key to perioperative care of patients with ASD. Three-column osteotomies were associated with a greater number of units of blood transfused. When considering postoperative transfusion requirements, surgeons should note that intraoperative blood salvage might be inferior to intraoperative allogeneic blood transfusion. Using antifibrinolytics and increasing the preoperative hemoglobin concentration to 11.5 g/dl or more are strategies for decreasing the need for perioperative transfusion. A history of smoking is a risk factor for postoperative transfusion requirement (total units transfused).

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KEY WORDS adult spinal deformity; bleeding; blood management; blood salvage; CellSaver; complications; perioperative transfusion; smoking; 3-column osteotomy; tranexamic acid

Surgery for adult spinal deformity (ASD) is associated with substantial blood loss because of the extensive soft-tissue dissection and osteotomies required.[17] This increased risk of blood loss leads to a greater need for intravascular volume replacement. From 2000 to 2009, the number of allogeneic blood transfusions performed during spinal arthrodesis increased.[34] However, allogeneic transfusions in surgical patients are associated with increased rates of wound complications, postoperative infections, and pulmonary complications, although the causal relationships are unclear.[14] This risk must be weighed against the risk of spinal hypoperfusion, which can lead to neurological deficits after major blood loss.[5,32] Other intravascular resuscitative options include using other colloids and intraoperative blood salvage.

Perioperative blood management in patients with ASD

ABBREVIATIONS ASD = adult spinal deformity; EBL = estimated blood loss; pRBC = packed red blood cell.

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remains poorly studied. Many factors, including modifiable preoperative risk factors and the use of specific intraoperative techniques, including blood salvage, must be studied to better understand risk factors for perioperative transfusion requirement during and after major spine surgery. The goal of our study was to identify factors associated with intraoperative and postoperative transfusion requirement (total units transfused) in patients treated with posterior spinal arthrodesis for ASD and to provide evidence to support appropriate strategies for perioperative blood management.

Methods

Institutional review board approval was obtained for this study. We retrospectively reviewed records of consecutive patients (n = 192) treated with posterior spinal arthrodesis for ASD by the same experienced spine surgeon between 2010 and 2016. We included patients who underwent thoracolumbosacral fusion at 4 or more vertebral levels (spanning 5 or more vertebrae) and who had a diagnosis of scoliosis, kyphosis, or kyphoscoliosis. We excluded patients with polio or spina bifida; those with a spinal tumor, infection, or acute trauma; and those for whom preoperative hemoglobin values were not retrievable. A total of 165 (86%) patients were included in the study.

Data Collection

We retrospectively studied the medical records of these patients to review patient characteristics (age, sex, weight, race, and American Society of Anesthesiologists score),[11] comorbidities, surgical factors, and total number of perioperative transfusions. We recorded their hemoglobin concentrations (in grams per deciliter) before surgery (within 1 month of the index procedure) and throughout the hospital stay for up to 10 days after surgery. The comorbidities recorded were cardiovascular disease, diabetes mellitus, hypertension, and history of smoking. Intraoperative details we assessed included whether the surgery was a primary or revision procedure, operative time, estimated blood loss (EBL), number of spinal levels fused, intraoperative use of an antifibrinolytic agent, number of osteotomies performed, and amount of intraoperatively salvaged blood used. Osteotomies were classified using the Schwab classification.[26]

The number of transfused units each patient received was recorded. Transfusions were recorded in units of allogeneic packed red blood cells (pRBCs) and were classified as intraoperative or postoperative. Transfusions were given according to results of the assessment of various clinical parameters and judgment of the attending surgeon (the same surgeon for all patients), the attending anesthesiologist present for the case, and the intensivist who attended to the patients during postoperative intensive care unit stays.

Instances of transfusion reactions and infections of any type within the 30-day postoperative period were analyzed and recorded also.

Statistical Analysis

We analyzed intraoperative and postoperative transfusion quantities. Linear regression analysis was performed using Stata 11.0 software (StataCorp LP). For this analysis, Schwab grade 1 osteotomies were not quantified. Patients were dichotomized as having fewer than 3 or 3 or more grade 2 osteotomies. Schwab grade 3 and 4 osteotomies were grouped together, as were Schwab grade 5 and 6 osteotomies. These variables were characterized in a binary fashion. Preoperative hemoglobin values were tiered according to approximate quartiles; the lowest quartile included patients with a preoperative level of less than 11.5 g/dl, and the highest quartile included patients with a preoperative hemoglobin level of 14.0 g/dl or greater. Our analysis of factors predictive of intraoperative transfusions required (total units transfused) included the aforementioned characteristics and comorbidities, operative time, number of levels fused, the use of osteotomies, and all modifiable preoperative risk factors. The postoperative transfusion analysis included the same factors and the EBL assessed at the end of each procedure, total number of units of intraoperatively salvaged blood used, and total number of units of allogeneic pRBCs transfused intraoperatively. Last, we performed univariate and multivariate regression analyses to determine whether a greater number of units of pRBCs transfused was associated with an increased infection rate in the 30-day postoperative period. In the multivariate analysis, we adjusted for comorbidities, demographic characteristics, American Society of Anesthesiologists score, operative time, number of levels fused, whether the surgery was a primary arthrodesis, and number of units of intraoperatively salvaged blood. Significance was established at $p < 0.05$.

Results

Patient Characteristics

The mean patient age was 61 years (range 22–86 years) (Table 1), and 118 (72%) were women. Most of the patients (94 [57%]) had an American Society of Anesthesiologists score of 3, and most of them (146 [88%]) were Caucasian. The mean preoperative hemoglobin concentration was 12.8 g/dl (range 8.5–15.9 g/dl). Hypertension was the most prevalent comorbidity assessed and was found to be present in 47% of the patients.

Surgical Factors

Fifty percent of the surgeries performed were primary fusions. The mean operative time was 403 minutes (range 231–606 minutes). The mean (± SD) number of levels fused was 9 ± 4. Three-column osteotomies were used in 71 (43%) patients. The mean EBL was 2220 ± 1708 ml. An antifibrinolytic agent was used in 58 (35%) patients (Table 1). Of the patients treated with an antifibrinolytic agent, 2 were treated with aminocaproic acid and all others were treated with tranexamic acid.

Transfusion Rates

One hundred forty-eight (90%) patients received at least 1 U of allogeneic pRBCs intraoperatively. Similarly, 144 (87%) patients received a postoperative transfusion. A mean (± SD) of 4.8 ± 3.7 allogeneic pRBC units were transfused intraoperatively, and 2.4 ± 1.5 allogeneic pRBC

TABLE 1. Characteristics of 165 patients who underwent ASD surgery by the same surgeon between 2010 and 2016

Parameter	Value
Patient characteristics	
Age in yrs	61 ± 12
Female sex	118 (72)
Weight in kg	76 ± 18
Race	
Caucasian	146 (88)
African American	11 (6.7)
Other	8 (4.8)
ASA score	
1	2 (1.2)
2	66 (40)
3	94 (57)
4	3 (1.8)
Preop hemoglobin concentration in g/dl	12.8 ± 1.7
Comorbidities	
Cardiovascular disease	12 (7.3)
Diabetes mellitus	15 (9.1)
Hypertension	78 (47)
Smoking history	72 (44)
Surgical factors	
Revision arthrodesis	82 (50)
Op time in mins	403 ± 79
EBL in ml	2220 ± 1708
No. of levels fused	9 ± 4
Antifibrinolytic use	58 (35)
Osteotomies	
Schwab grade 2*	64 (39)
Schwab grade 3 or 4	51 (31)
Schwab grade 5 or 6	21 (13)
Periop transfusions	
Intraop blood salvage units	0.8 ± 0.9
Intraop allogeneic pRBC units	4.8 ± 3.7
Postop allogeneic pRBC units	2.4 ± 1.5

ASA = American Society of Anesthesiologists.
Values are number (%) or mean ± SD.
* Patients treated with ≥ 3 Schwab grade 2 osteotomies.

TABLE 2. Determinants of the number of units of allogeneic pRBCs transfused intraoperatively

Variable	β Coefficient (95% CI)	p Value
Patient characteristics		
Age	0.04 (0.00 to 0.09)	0.074
Male sex	−0.10 (−1.56 to 1.36)	0.889
Weight	0.00 (−0.04 to 0.04)	0.959
Race		
Caucasian	Index	
African American	−1.34 (−3.52 to 0.83)	0.224
Other	−0.03 (−2.38 to 2.45)	0.978
ASA score		
1	Index	
2	0.30 (−4.53 to 5.14)	0.902
3	0.08 (−4.82 to 4.98)	0.974
4	3.85 (−2.46 to 10.16)	0.230
Preop hemoglobin concentration		
<11.5 g/dl	Index	
11.5–13.9 g/dl	−1.52 (−2.92 to −0.12)	0.034
≥14.0 g/dl	−2.09 (−3.64 to −0.54)	0.008
Comorbidities		
Cardiovascular disease	0.45 (−1.89 to 2.77)	0.700
Diabetes mellitus	−0.25 (−2.28 to 1.78)	0.809
Hypertension	−0.99 (−2.18 to 0.19)	0.099
Smoking history	−0.18 (−1.27 to 0.91)	0.744
Surgical factors		
Revision arthrodesis	−0.35 (−1.59 to 0.90)	0.581
Op time	0.02 (0.01 to 0.02)	<0.001
No. of levels fused	−0.05 (−0.23 to 0.12)	0.558
Antifibrinolytic use	−0.17 (−1.31 to 0.98)	0.775
Osteotomies		
Schwab grade 2 (≥3)	1.57 (0.14 to 3.00)	0.032
Schwab grade 3 or 4	1.74 (0.42 to 3.05)	0.010
Schwab grade 5 or 6	1.81 (0.04 to 3.58)	0.046

units were transfused postoperatively. Intraoperatively salvaged blood was used in 121 (73%) patients (Table 1).

Determinants of the Number of Allogeneic pRBC Units Transfused Intraoperatively

Operative time was significantly associated with an increase in the number of units transfused intraoperatively (Table 2). The performance of 3 or more Schwab grade 2 osteotomies was associated with a mean of 1.57 additional units of pRBCs transfused intraoperatively ($p = 0.032$), Schwab grade 3 or 4 osteotomies were associated with a mean of 1.74 additional units ($p = 0.010$), and Schwab grade 5 or 6 osteotomies were associated with a mean of 1.81 additional units ($p = 0.046$). A preoperative hemoglobin concentration of 14.0 g/dl or greater was associated with a mean of 2.09 fewer units transfused intraoperatively compared with a preoperative hemoglobin concentration of less than 11.5 g/dl ($p = 0.008$). Similarly, preoperative hemoglobin concentrations of 11.5–13.9 g/dl were associated with a mean of 1.52 fewer units transfused intraoperatively ($p = 0.034$).

Determinants of the Number of Allogeneic pRBC Units Transfused Postoperatively

Operative time and a history of smoking were significantly associated with a greater number of units transfused postoperatively. In contrast, antifibrinolytic use was associated with fewer units transfused postoperatively (Table 3). Patients with a history of smoking received a mean of 0.58 additional units postoperatively ($p = 0.011$). In contrast, those treated with antifibrinolytics received a mean of 0.87 fewer units postoperatively ($p < 0.001$). Each

TABLE 3. Determinants of the number of units of allogeneic pRBCs transfused postoperatively

Variable	β Coefficient (95% CI)	p Value
Patient characteristics		
Age	0.014 (−0.01 to 0.03)	0.170
Male sex	−0.03 (−0.63 to 0.56)	0.908
Weight	0.01 (0.00 to 0.03)	0.150
Race		
Caucasian	Index	
African American	−0.18 (−1.07 to 0.70)	0.682
Other	0.74 (−0.23 to 1.72)	0.135
ASA score		
1	Index	
2	−0.15 (−2.11 to 1.80)	0.878
3	−0.31 (−2.29 to 1.68)	0.761
4	0.39 (−2.17 to 2.95)	0.762
Preop hemoglobin concentration		
<11.5 g/dl	Index	
11.5–13.9 g/dl	−0.51 (−1.09 to 0.07)	0.085
≥14.0 g/dl	−0.98 (−1.62 to −0.33)	0.003
Comorbidities		
Cardiovascular disease	−0.18 (−1.13 to 0.77)	0.714
Diabetes mellitus	0.01 (−0.81 to 0.84)	0.975
Hypertension	0.01 (−0.47 to 0.50)	0.965
Smoking history	0.58 (0.13 to 1.02)	0.011
Surgical factors		
Revision arthrodesis	0.09 (−0.42 to 0.61)	0.730
Op time	0.004 (0.00 to 0.01)	0.016
EBL	0.00 (0.00 to 0.00)	0.020
No. of levels fused	0.07 (0.00 to 0.14)	0.068
Antifibrinolytic use	−0.87 (−1.35 to −0.39)	<0.001
Osteotomies		
Schwab grade 2 (≥3)	−0.30 (−0.89 to 0.28)	0.310
Schwab grade 3 or 4	−0.48 (−1.03 to −0.06)	0.083
Schwab grade 5 or 6	−0.72 (−1.45 to 0.02)	0.055
Periop transfusions		
Intraop allogeneic pRBCs	−0.23 (−0.35 to −0.10)	0.001
Intraop salvaged blood	0.39 (0.04 to 0.74)	0.031

unit of intraoperatively salvaged blood used was associated with a 0.39-U mean increase in postoperative transfusion volume (p = 0.031); every intraoperative unit of allogeneic blood transfused was associated with a 0.23-U mean decrease in postoperative transfusion volume (p = 0.001). A preoperative hemoglobin concentration of 14 g/dl or greater was associated with a mean of 0.98 fewer units transfused postoperatively (p = 0.003) compared with those with a preoperative hemoglobin concentration of less than 11.5 g/dl.

Complications Associated With Transfusion

No transfusion reactions were noted. We observed 26 (16%) infections during the 30-day postoperative period. Infections included urinary tract infection (12 [7.3%]), surgical site infection (10 [6.1%]), pneumonia (2 [1.2%]), cellulitis of the foot (1 [0.6%]), and bacteremia of unknown cause (1 [0.6%]). On univariate regression analysis, having a greater number of units of pRBCs transfused was associated with a significantly higher rate of infection (p = 0.015), although after we adjusted for pertinent clinical covariates, the association was not significant (p = 0.35).

Discussion

We found that a greater preoperative hemoglobin concentration lessened the need for perioperative transfusion in patients undergoing posterior spinal arthrodesis of 4 or more levels. The use of blood salvage was found to be inferior to intraoperative transfusion of allogeneic pRBCs in terms of the number of postoperative transfusion units required. Increases in the number of osteotomies performed according to Schwab grading were correlated with increased numbers of units transfused intraoperatively, although this relation was not observed postoperatively. Also, a history of smoking was significantly associated with an increased number of units transfused postoperatively. In contrast, antifibrinolytic use was associated with fewer units transfused postoperatively.

Transfusions can result in several complications that can worsen a patient's outcome. Such complications include infection,[7] transfusion-related acute lung injury,[18] and other transfusion reactions.[31] Although the risk of these complications is low, there has been a trend toward forgoing allogeneic blood transfusion in favor of other techniques that pose less risk. One such technique is the use of intraoperative blood salvage, a technique whereby blood lost during surgery is "recycled" and filtered so that it can be reintroduced into the patient's vascular system. The use of intraoperative blood salvage is indicated if anticipated blood loss is at least one-fifth of the patient's total estimated blood volume, if more than 10% of patients who undergo the procedure require transfusion, or if the mean transfusion volume required for a procedure is greater than 1 U.[1] The results of previous studies were not definitive regarding the efficacy or cost-effectiveness of using intraoperative blood salvage. In the context of lumbar spine arthrodesis, the use of intraoperative blood salvage was not shown to decrease the need for perioperative allogeneic transfusion.[8,22] In reference to intraoperative blood salvage, Elgafy et al. suggested that "there is little to support its cost or effective use during routine elective spinal surgery."[12] Canan et al.[8] also found that the use of intraoperative blood salvage was not cost-effective when used in cases of adult single-level posterior lumbar decompression and arthrodesis. In patients who underwent surgery for adolescent idiopathic scoliosis, study results have not been definitive, showing a decreased[6,13] or no change in[10,20,29,33] need for perioperative allogeneic transfusion.

Our study results, from an exclusive population of patients with ASD, suggest that the use of intraoperative blood salvage can result in an increased requirement for postoperative transfusion of allogeneic pRBC units, even

when we controlled for procedural EBL, which was one of the covariates in our multivariate analysis. In contrast, the use of intraoperative allogeneic blood transfusions resulted in a 0.23-U mean decrease in the volume transfused after surgery. Our data suggest that the quality of salvaged intraoperative blood might be inferior to that of allogeneic blood, although it has not been established in previous studies. In fact, red blood cell membrane deformability might be higher in autologously salvaged red blood cells than in those from stored allogeneic units,[25] although washing of intraoperatively salvaged blood might contribute to postoperative coagulopathies.[23,28] We were unable to assess the potential effects of intraoperative blood salvage on postoperative complications, which might have altered our conclusions. Further biochemical and clinical studies are needed to elucidate how intraoperative blood salvage compares with intraoperative allogeneic blood transfusion.

Other operative factors were significantly associated with perioperative transfusions. A greater mean number of units were transfused intraoperatively in patients undergoing osteotomies, and the number of units was correlated positively with Schwab grade. Greater blood loss with more extensive spinal osteotomy has been found; 3 levels of Smith-Petersen osteotomies (Schwab grade 2) resulted in less blood loss than a single-level pedicle subtraction osteotomy (Schwab grade 3 or 4, depending on extension).[9] Operative time was also significantly associated with increased numbers of units transfused intraoperatively and postoperatively, which supports the findings of Zou et al.,[36] who correlated operative time with blood loss in patients who underwent surgery for lumbar disc herniation. However, in our study, the number of levels fused was not significantly associated with transfusion volume, which contradicts the results of a study by Zheng et al.,[35] who showed that the number of levels fused was a significant predictor of the number of perioperative units transfused. However, in their analysis of predictors of transfused units, they did not adjust for operative time.[35] Last, antifibrinolytic use was associated with fewer units transfused postoperatively, which resulted in a mean 0.87-U decrease in postoperative transfusion volume, which is similar to previous findings.[4]

Although surgical factors are important in determining transfusion requirements, other preoperative considerations should be weighed. Preoperative hemoglobin concentration was indirectly related to perioperative transfusion volume. Similar results were found in studies that examined patients undergoing revision posterior lumbar spine decompression and instrumented arthrodesis[35] and multilevel instrumented arthrodeses.[21] Zheng et al.[35] found that preoperative anemia (hemoglobin concentration < 12 g/dl in men and < 11 g/dl in women) seemed to result in an increased number of perioperative units transfused. These data suggest that preoperative hemoglobin concentration might provide a more global measure of perioperative outcomes in patients undergoing spine surgery. For example, Seicean et al.[27] found that in more than 20,000 patients who underwent elective spine surgery, a preoperative hematocrit level of 26%–37% was associated with an overall postoperative complication rate higher than that in patients with a higher hematocrit level, independent of the number of perioperative units transfused. These findings suggest that a minimum preoperative hemoglobin concentration, such as 11.5 g/dl, might decrease the number of units needed in perioperative transfusions.

Another factor that might influence perioperative transfusion requirements is a history of smoking. Cigarette smoke produces vascular derangements, including increased erythrocyte membrane fragility[15] and increased thromboembolism risk,[2] and it is associated with an increased risk of atherosclerosis.[3] Despite these vascular effects, smokers paradoxically have an elevated hemoglobin concentration,[24,30] which might be caused by chronic carbon monoxide exposure, which leads to decreased molecular oxygen delivery per hemoglobin and subsequent compensatory increases in the hemoglobin level.[16,30] However, McCunniff et al.[19] found that patients with a history of smoking are at increased risk of requiring postoperative transfusion, which agrees with the findings from our study. These data suggest that despite their higher preoperative hemoglobin level, patients with a history of smoking might not have an adequate hematological reserve. Such patients might need a higher preoperative hemoglobin concentration before surgery to avoid additional transfusions. We were unable to assess this possibility within the framework of our study.

Many factors influence perioperative transfusion requirements in patients undergoing surgery for ASD. Modifiable risk factors, such as preoperative hemoglobin concentration, should be considered when planning surgery. History of smoking might fall within this category, although we were unable to assess whether smoking cessation changed transfusion requirements (total number of units). However, patients with a history of smoking might require a higher preoperative hemoglobin concentration to withstand the hematological insult of major spine surgery. Furthermore, the use of intraoperative blood salvage should be weighed against traditional intraoperative allogeneic blood transfusion, because it might not be as effective in decreasing postoperative transfusion requirements. The use of antifibrinolytic agents should be considered to lessen the number of postoperative units transfused.

By selecting a large homogeneous cohort of patients with ASD treated for similar indications by the same surgeon, we attempted to eliminate many potential confounders. However, data limitations must be considered. Retrospective analysis limits the determination of factors that can influence transfusion trends. However, we chose cases that occurred during 8 consecutive years of a single attending surgeon's practice to ensure less case-by-case variability in how transfusions were given. Another limitation is that we did not assess a single comorbidity or frailty index, which would have allowed for more effective linear regression adjustment to control for patient health status as a potential confounder. Instead, we chose several assessed comorbidities and the American Society of Anesthesiologists score for data normalization.

Conclusions

Effective blood management is a key element of peri-

operative care of patients with ASD. If 3-column osteotomies are anticipated, increased intraoperative transfusions (total number of units required) can be expected. Although intraoperative blood salvage can effectively reduce the amount of allogeneic blood transfused intraoperatively, the use of salvaged blood might be inferior to intraoperative allogeneic blood transfusion in regard to postoperative transfusion requirements. However, definitive conclusions regarding this inferiority could not be established by this study, and intraoperative blood salvage remains a trusted option in many patients with ASD. Increasing the preoperative hemoglobin concentration to 11.5 g/dl or more might reduce the need for perioperative transfusion. Patients with a history of smoking might require additional hematological reserves. The use of antifibrinolytic agents might be effective in decreasing the rate and volume of postoperative transfusions.

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Disclosures

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Author Contributions

Conception and design: all authors. Analysis and interpretation of data: Puvanesarajah, Rao. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Kebaish. Study supervision: Kebaish.

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