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CASE SERIES

The incidence and risk factors for perioperative allogeneic blood transfusion in primary idiopathic scoliosis surgery

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Abstract

Study design Case–control study.

Objectives Evaluate the rate and risk factors for perioperative allogeneic blood transfusion (ABT) in primary idiopathic scoliosis surgery at a single institution.

Summary of background data Avoiding perioperative ABT is ideal as transfusions are associated with adverse reactions, increased rates of infection, prolonged hospitalization, additional laboratory testing, and increased cost. Risk factors identified in other studies have differed, and to our knowledge, few studies have identified clinical strategies to predict patients at high risk for ABT.

Methods We reviewed 402 idiopathic scoliosis patients who underwent primary posterior spinal fusion and instrumentation (PSFI) at a single institution from 2015 to 2017. Medical records and radiographs were reviewed for all patients. Transfused patients were compared to the remaining cohort to find significant differences and identify predictors of higher ABT risk.

Results ABT occurred in 73 patients (18.2%), with the majority of transfusions occurring intraoperatively (41%) or postoperatively on the day of surgery (25%). The seven surgeons involved varied significantly in incidence of ABT (2.4–35.8%, $p = 0.002$). Patients who had ABT were younger (13.3 vs. 14.1 years, $p < 0.01$), had lower BMI (48th vs. 61st percentile, $p < 0.001$), and lower preoperative hemoglobin (13.1 vs. 13.7 g/dL, $p < 0.01$). Greater preoperative major Cobb angle (69° vs. 61.5°, $p < 0.001$), number of fusion levels (11.8 vs. 10.3, $p < 0.001$), and estimated blood loss (770 vs. 448 mL, $p < 0.001$) also predicted ABT.

Conclusions ABT was associated with several risk factors, five of which are known preoperatively. Surgeons can use knowledge of these risk factors to assess transfusion risk preoperatively and plan surgery, blood management, and laboratory testing accordingly. The development of best practices for ordering ABT is possible given the variation amongst providers.

Level of evidence Level III.

Keywords Adolescent idiopathic scoliosis · Transfusions · Curve magnitude · Variation

Introduction

Surgical intervention in adolescent idiopathic scoliosis (AIS) has historically resulted in significant blood loss, often requiring transfusion of allogeneic blood [1–4]. More recently, however, the rate of allogeneic blood transfusion (ABT) has appeared to decline with the advent of blood-conserving techniques including hypotensive anesthesia, topical hemostatic agents, systemic antifibrinolytics, and intraoperative blood salvage [4–8].

Despite the decreased rate of perioperative (defined as the intraoperative and/or postoperative periods) ABT in modern AIS surgery, it remains common practice for surgeons to request one or more units of packed red blood cells (pRBC) before surgery, and this can lead to inefficient use of resources [9]. Few studies have identified clinically applicable strategies to predict which patients have a high likelihood of requiring ABT. Authors have reported factors such as surgical time, length of fusion construct, major Cobb angle, thoracic kyphosis, use of Ponte osteotomies, and preoperative hemoglobin level as predictors of blood transfusion

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requirement, but conclusions have been inconsistent between studies [1, 2, 4–6, 10–13].

The ability to accurately stratify patients based on their likelihood of transfusion requirement could lead to fewer unnecessary blood bank requests and laboratory tests such as type and cross, hemoglobin, and hematocrit. In addition, an improved understanding of ABT risk factors could potentially help guide surgical planning to reduce the likelihood of a transfusion, thereby minimizing transfusion reactions, associated increased rates of infection, and prolongation of hospitalization [2, 11, 13–16]. Such improvements could help lower overall patient morbidity and the financial burden of idiopathic scoliosis surgery. The purpose of this study was to evaluate the frequency of ABT, identify risk factors, and develop clinically useful recommendations regarding when allogeneic blood products will likely be needed based on patient variables.

Materials and methods

This was an Institutional Review Board-approved, retrospective review of a consecutive series of idiopathic scoliosis patients who underwent primary posterior spinal fusion and instrumentation (PSFI) from January 2015 to December 2017 at a single institution. Patients with juvenile idiopathic scoliosis were included on the basis of similarity to AIS and were only included when they had their primary surgery between the ages of 10 and 18 years of age. Patients with intrathecal abnormalities (e.g. syringomyelia), connective tissue diseases (e.g. Marfan's disease), religious objections to blood transfusion, and those that required concomitant anterior surgery, preoperative halo traction, or early reoperation within 3 days following PSFI were excluded.

Demographic data collected included age, gender, height, weight, body-mass index (BMI) with corresponding percentile (calculated using CDC growth charts), ethnicity, and menarchal status [17]. Pre- and postoperative radiographs were examined to determine major coronal Cobb angle, thoracic kyphosis (T5-T12), postoperative Cobb angle and kyphosis, and percent changes in Cobb angle and kyphosis. Radiographic measurements were determined independently by multiple researchers, and an intraclass correlation coefficient (ICC) was calculated to assess agreement. Preoperative laboratory results included hemoglobin, hematocrit, and number of pRBC units requested. Patients who had a family history of coagulation disorders or who themselves had a history of easy bruisability, etc. were sent for prothrombin time (PT), partial thromboplastin time (PTT). There were 39 patients who met these criteria and no one had an abnormal value for PT or PTT.

Surgical information collected included physician and anesthesiologist experience (years of practice), presence and experience of assisting trainee(s), type of fusion construct, vertebral levels fused, total implants used, use of osteotomy, topical hemostatic use, occurrence of intraoperative neuromonitoring changes, and drain placement. Detailed anesthesia logs were reviewed to record estimated blood loss (EBL), tranexamic acid (TXA) dosage, volume of crystalloid and colloid given, cell saver blood salvage volume re-administered, surgical time, and anesthesia time. Length of stay, daily and total drain output, and post-operative hemoglobin and hematocrit measurements were also recorded for each patient. All patients in this study had a drain postoperatively and these were placed superficial to the fascia.

The primary outcome was defined as the administration of ABT on the day of surgery or during the subsequent post-operative hospitalization. For patients requiring one or more ABT, the time of transfusion(s), number of units of pRBC, EBL before each transfusion, and pre- and post-transfusion hemoglobin and hematocrit were recorded along with the reason for each ABT.

Continuous variables were described using means ± standard deviations and range, while categorical variables were described as counts and percentages. A two-sample *t* test was used to compare continuous variables and for categorical variables, Chi-square or Fisher's exact test was used to compare cohorts and subgroups as appropriate. In addition, multivariate logistic regression analysis was performed to identify risk factors. Receiver operating characteristic (ROC) curves were used to determine the optimal cutoff values by utilizing sensitivity and specificity. A p value < 0.05 was considered statistically significant for all comparisons. All statistical analyses were performed using SAS (version 9.4, SAS Institute Inc., Cary, NC, USA) and SPSS software (version 24, IBM, Inc., Chicago, IL, USA).

Results

Four hundred and thirty-one patients with idiopathic scoliosis underwent PSFI during the study period. Twenty-nine were excluded, leaving 402 patients in the analyzed cohort (Table 1). The diagnosis was AIS in 360 (90%) and juvenile or infantile IS in the remaining 62. All the patients had their primary surgery performed during the 10–18 years of age. The average age was 14 (range 10–20), 330 patients were female (82%), and ethnicities included Caucasian (61%), Hispanic (15%), African American (19%), and other (5%). Average BMI was 21.7 kg/m^2 (range 14.7–41.8), corresponding to the 59th percentile. Mean preoperative major coronal Cobb angle was 62.9° (range 42–117°), and mean coronal plane correction was 70% (range 22–100%). The average PSFI involved 10.6 levels of fusion with an implant density of 1.4 implants per level. Mean TXA loading dose was 38 mg/kg. Surgical time was 243 min on average with

Table 1 Summary of study population

Variable	Mean ± SD	Range
Age	13.9 ± 2.1	10–20
Gender		
Female	330 (82.1%)	
Male	72 (17.9%)	
Ethnicity		
Caucasian	246 (61.2%)	
African American	76 (18.9%)	
Hispanic	59 (14.7%)	
Other	21 (5.2%)	
BMI (kg/m^2)	21.7 ± 4.8	14.7–41.8
BMI percentile	58.6 ± 30.2	1–99
Preoperative hemoglobin (g/dL)	13.6 ± 1.1	10.0–16.9
Preoperative hematocrit (%)	39.6 ± 2.5	32.9–47.9
Major Cobb angle (degrees)	62.9 ± 11.6	42–117
Thoracic kyphosis T5–T12 (degrees)	21.1 ± 12.3	− 5 to 78
Surgeon experience (years)	19.2 ± 9.1	3.5–35.2
Anesthesiologist experience (years)	21.1 ± 8.7	0.04–32.54
Total levels of fusion	10.6 ± 2	4–15
Implant density	1.4 ± 0.2	0.9–2
Osteotomy		
Yes	27 (6.7%)	
No	375 (93.3%)	
Postoperative Cobb angle (°)	19.1 ± 10	0–80
Coronal plane correction (%)	70 ± 13.4	21.6–100
Postoperative thoracic kyphosis (°)	21.5 ± 7.5	− 3 to 59
Estimated blood loss, EBL (mL)	505.5 ± 292.9	100–1800
Cell saver returned (mL)	227.9 ± 130	79–900
Net blood loss (mL)	301.3 ± 195.1	0—1105
Surgical time (min)	242.5 ± 60.9	112–528
Anesthesia time (min)	318.6 ± 66.1	175–623
Total drain output (mL)	236.8 ± 249.7	0–1325
Length of hospitalization (days)	3.3 ± 0.8	1–7

506 mL of blood loss and 228 mL of Cell Saver returned (net blood loss of 301 mL). Ponte osteotomies were performed in 27 patients (6.7%), and critical intraoperative neuromonitoring changes occurred in 7 patients (1.7%) without any permanent neurological deficits.

The average preoperative hemoglobin level was 13.6 g/dL, with a decrease to an average of 9.8 g/dL on postoperative day one (POD1). ABT occurred in a total of 73 patients (18.2%) with most transfusion events occurring intraoperatively ($n = 33$, 42%) or postoperatively on the day of surgery (POD0, $n = 19$, 24%). The timing and volume of ABT for each patient are represented in Fig. 1. Notable non-modifiable risk factors for ABT were younger age (13.3 vs. 14.1 years), female gender (20.9 vs. 5.6% ABT rate), non-Caucasian ethnicity (25.6 vs. 13.4% ABT rate), lower BMI percentile (48.2 vs. 61.0), larger Cobb angle (69.0 vs 61.5°), more levels of fusion (11.8 vs. 10.3), and lower preoperative hemoglobin (13.1 vs. 13.7 g/dL, $p < 0.001$). Modifiable risk factors included greater net blood loss (480 vs. 262 mL), larger TXA loading dose (43.3 vs. 36.8 mg/kg), longer surgical times (270 vs. 237 min), higher volume of colloid given (464 vs. 330 mL), use of posterior osteotomies (44.4 vs. 16.3% ABT rate), and occurrence of critical neuromonitoring changes intraoperatively (71.4 vs. 17.3% ABT rate, $p < 0.01$). The comparison of the ABT and non-ABT groups is summarized in Table 2. Surgeons also varied in rates of ABT from 2.4 to 35.8% (Table 3), but anesthesiologists did not (11.9–22.8% ABT rate). Physician years of experience did not differ between the groups.

Multivariate regression modelling showed age, BMI percentile, gender, preoperative hemoglobin, levels of fusion, and EBL as independent predictors of ABT (Table 4). We also sought to develop a tool to predict the risk of transfusion based only on variables known before surgery. Multivariate regression using only those variables showed age, BMI percentile, Cobb angle, levels fused, and preoperative hemoglobin to be independent predictors of ABT. Using those five variables, we developed ROC curves to determine cutoff values that could be used to predict a higher likelihood of transfusion. Figure 2 illustrates an example curve. Area under the curve (AUC) ranged from 0.605 to 0.723 for these five curves. This analysis revealed cutoffs of: BMI percentile less than 52, preoperative hemoglobin below 13.6 g/dL, age under 14, major Cobb angle greater than 65°, and 12 or more levels of fusion. The number of risk cutoffs met correlated positively with rate of transfusion (Fig. 3).

Subgroup analyses

We compared patients who received ABT to those not receiving ABT on the day of surgery. Fifty-two patients received a transfusion on the day of surgery. Multivariate analysis of this cohort showed age, gender, BMI percentile, Cobb angle, preoperative hemoglobin, total levels fused, and EBL to be independent predictors of ABT.

We also compared patients receiving ABT on postoperative day 1 or later with those that did not. Twenty-five patients received a transfusion after the day of surgery, with four having previously been transfused. Multivariate analysis identified preoperative hemoglobin, estimated blood loss, and POD1 hemoglobin as independent predictors of ABT on POD1 or later. Patients receiving ABT after POD0 also had a longer hospitalization than those that did not (3.6 vs. 3.2 days). ROC analysis using POD1 hemoglobin levels showed a protective cutoff value of 9.1 g/dL. The sensitivity and specificity of this test were 0.78 and 0.75, respectively, and AUC was 0.834. The rate of transfusion in patients with a POD1 hemoglobin greater than or equal to 9.1 g/dL was 2.2% (negative predictive value of 97.8%) while the rate

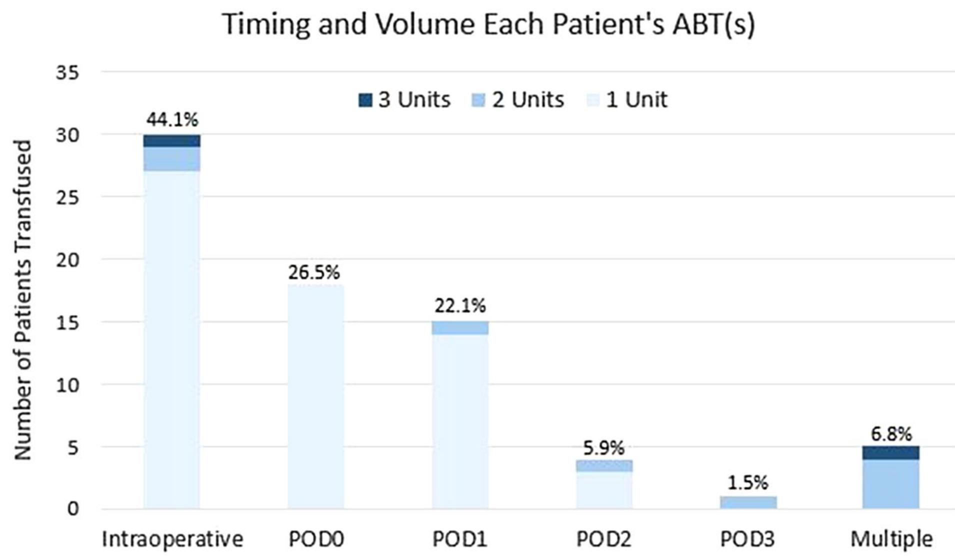

Fig. 1 Number of patients transfused on each day of hospitalization and quantity of blood received

Table 2 Comparison of transfused and non-transfused patients

Variable	No ABT ($n = 329$)	ABT ($n = 73$)	p value*
Age	14.1 ± 2.1	13.3 ± 1.8	0.004
Gender			0.001
Female	261 (79%)	69 (21%)	
Male	68 (94%)	4 (6%)	
Ethnicity			0.010
White	213 (86.6%)	33 (13.4%)	
African-American	42 (71.2%)	17 (28.8%)	
Hispanic	60 (78.9%)	16 (21.1%)	
Other	14 (66.7%)	7 (33.3%)	
BMI percentile	61.0 ± 30.2	48.2 ± 27.9	< 0.001
Preoperative hemoglobin (g/dL)	13.7 ± 1	13.1 ± 1	< 0.001
Preoperative hematocrit (g/dL)	41.0 ± 22.3	38.4 ± 2.5	< 0.001
Major Cobb angle (°)	61.5 ± 10	69.0 ± 15.6	< 0.001
Thoracic kyphosis T5–T12 (°)	20.7 ± 12	23.3 ± 13	0.191
Surgeon experience (years)	19.6 ± 8.8	17.4 ± 10.4	0.217
Anesthesiologist experience (years)	21.1 ± 8.6	20.9 ± 9.3	0.861
Total levels of fusion	10.3 ± 2.0	11.8 ± 1.5	< 0.001
Implant density	1.4 ± 0.2	1.4 ± 0.2	0.123
Osteotomy			< 0.001
Yes	15 (55.6%)	12 (44.4%)	
No	314 (83.7%)	61 (16.3%)	
EBL (mL)	447.5 ± 250.4	769.8 ± 327.3	< 0.001
Cell saver returned (mL)	210.9 ± 125.2	297 ± 127	< 0.001
Net blood loss (mL)	262 ± 155.4	479.9 ± 251.2	< 0.001
Neuromonitoring change			0.003
Yes	2 (28.6%)	5 (71.4%)	
No	326 (82.7%)	68 (17.3%)	
Total drain output (mL)	218 ± 218.4	320.7 ± 347.4	0.114
Length of hospitalization (days)	3.2 ± 0.8	3.4 ± 0.7	0.071

Table 3 Surgeon ABT rate comparison

Surgeon	No ABT	ABT	Rate (%)	*p* value
1	12	5	29.4	0.002
2	41	1	2.4	
3	34	19	35.8	
4	50	13	20.6	
5	51	13	20.3	
6	79	18	18.6	
7	62	4	6.1	

Table 4 Multivariate regression using preoperative variables

Variable	Odds ratio	95% Confidence interval	*p* value
Age	0.771	0.655–0.907	0.018
BMI percentile	0.981	0.971–0.991	0.002
Major Cobb angle	1.039	1.013–1.065	< 0.001
Total fusion levels	1.524	1.263–1.840	< 0.001
Preoperative hemoglobin	0.465	0.337–0.641	< 0.001

of transfusion in patients with hemoglobin below 9.1 g/dL was 19.1%.

Patients receiving multiple units of blood

Eleven patients required multiple ABTs during hospitalization. This group could not be analyzed with statistical significance. It consisted of all females with an average age of 13.2, BMI percentile of 47, major Cobb angle of 71°, and preoperative hemoglobin of 12.6 g/dL. PSFI in this group involved an average of 12.4 vertebral levels and EBL of 895 mL. These patients were mostly transfused due to signs and symptoms of anemia (hypotension, tachycardia, dizziness, neuromonitoring changes, etc.) and less often for a known low hemoglobin level.

Discussion

The primary objective of this study was to identify the risk factors which lead to an ABT in a consecutive series of patients with AIS to allow surgical teams to better plan preoperatively and to better manage patients while in the hospital to minimize ABT and to move towards standardizing care. The risk factors identified for ABT are primarily those which cannot be modified, however, the surgeons can use the factors to modify their management of the patients and to better plan for intraoperatively and postoperative management of the patient. ABT occurred in 18.2% of patients in this study. This falls within the widely varying rates of 13–47% reported in previous studies [1, 5, 6, 11, 14, 18]. ABT in the overall study cohort was predicted by age, BMI percentile, gender, total vertebral levels of fusion,

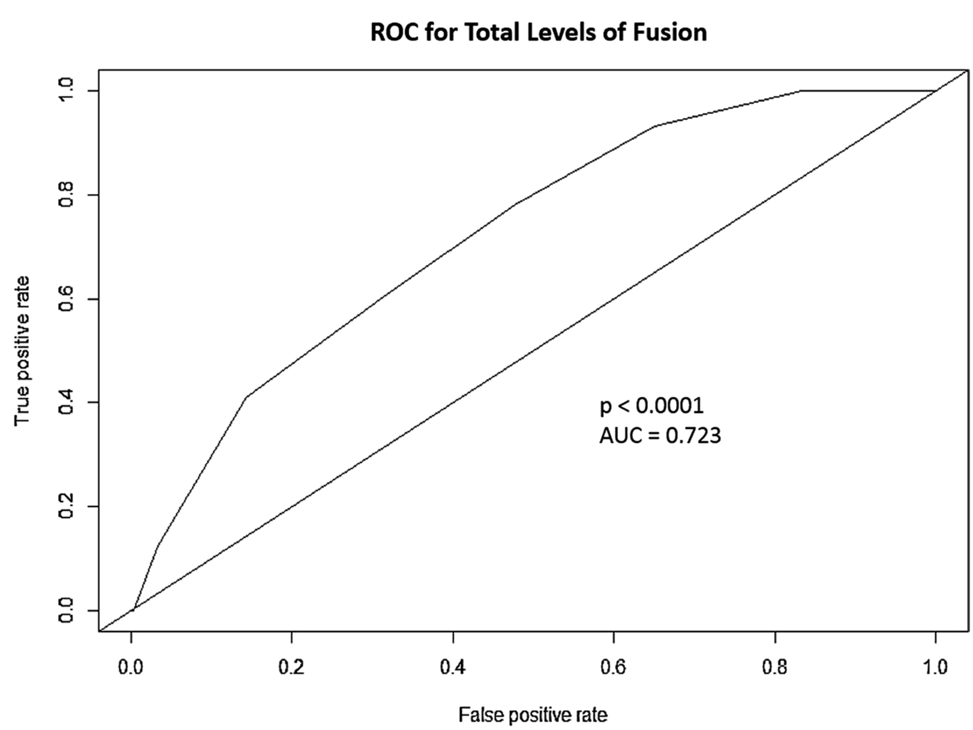

Fig. 2 Example of ROC curves created for all preoperative risk factors

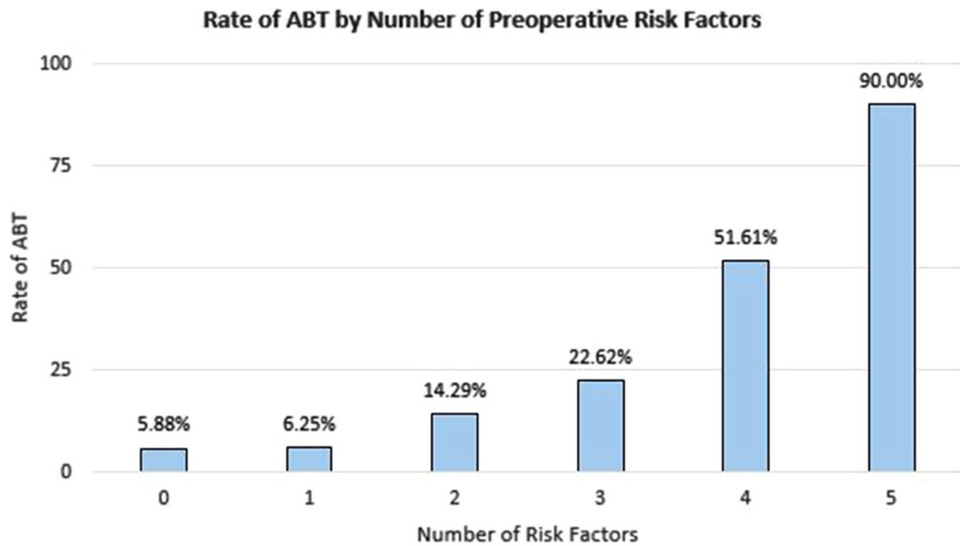

Fig. 3 Rate of ABT increases with each risk factor met (age under 14, BMI percentile less than 52, preoperative hemoglobin less than 13.6 g/dL, Cobb angle greater than 65°, 12 or more levels fused)

preoperative hemoglobin, and blood loss. To preoperatively predict ABT risk, age, BMI percentile, major Cobb angle, preoperative hemoglobin, and total levels of fusion were found to be the appropriate variables. We found useful cut-off values that surgeons can use before surgery to estimate the probability of ABT. When a patient meets four or five of these cutoffs, the chance of transfusion is high, and when a patient meets one or less, the chance of transfusion is low. It was also found that having a hemoglobin level above 9.1 g/dL on POD1 was extremely protective against ABT requirement from that point on. Surgeons can use this knowledge to more efficiently make use of blood products and laboratory testing. If a patient has low preoperative ABT risk, a surgeon may opt to not request any typed and crossed pRBC. If that patient then goes on to have a hemoglobin of 10 g/dL on POD1, the surgeon could then decide not to order further hemoglobin and hematocrit tests, especially if the patient remains normotensive and asymptomatic.

Subgroup analyses

The two subgroup analyses performed demonstrated an interesting phenomenon: ABT occurring on the day of surgery was predicted by similar variables as in the overall transfusion grouping. This is logical given that over two-thirds of transfusions occurred on the day of surgery. In contrast, transfusions occurring on POD1 or later had fewer associated predictive variables in the univariate analysis. Notably, age, BMI percentile, major Cobb angle, and blood loss were not significant in the latter subgroup. This could be due to smaller sample size (only 25 patients received ABT on POD1 or later), but it also suggests that these POD1 or later transfusions were frequently based on subjective clinical judgment—which varies between surgeons—rather than on objective measures like blood pressure and hemoglobin levels that are heavily relied upon during and shortly after surgery when patients are anesthetized. A more standardized transfusion protocol for the postoperative period could help reduce the use of blood product and related testing after surgery. Patients transfused on the days after surgery also had a significantly longer hospitalization, a trend seen in studies evaluating the effects of transfusions [19–21]. Reducing transfusions during the post-operative course might, therefore, lower overall surgical cost as well if length of stay is shortened.

Since transfusions occurring on the day of surgery appear to be the least influenced by surgeon bias and most based on objective signs and symptoms, we consider our subgroup analysis using only patients transfused on the day of surgery to be the most useful. To reiterate, multivariate analysis of this subgroup found only age, gender, BMI percentile, major Cobb angle, preoperative hemoglobin, levels of fusion, and EBL to be independent predictors of transfusion. These appear to be the main risk factors for ABT in idiopathic scoliosis surgery.

Patients receiving multiple units of blood

Though this group included only eleven patients, it complicates the hypothesis that surgeons could limit the amount of blood product set aside for each surgery to one unit or less. This may be especially pertinent for smaller surgical facilities where blood takes longer to obtain. While this concern requires consideration, a few observations should be noted. First, only two patients in this cohort required three units of pRBC during hospitalization: one had an epidural bleed during a Ponte osteotomy requiring all three units intraoperatively, and the other required two units intraoperatively for low blood pressure and one unit on POD1 for borderline hypotension. Second, only 3 of the 16 transfusion events in this group were initiated when measured hemoglobin was below 7 g/dL. Finally, in the five patients who received transfusions at two discrete time points, all the second transfusions were initiated for symptomatic anemia with the lowest pre-transfusion hemoglobin being 8.5 g/dL. These observations suggest that patients rarely ever require multiple transfusions except in extreme situations such as an epidural bleed. Furthermore, second transfusions are typically not as urgent, given that they usually occur postoperatively where ongoing blood loss is smaller. Surgeons can use this information to inform the amount of blood product and related testing ordered, especially in low-risk surgeries.

Considerations

Selection bias was minimized using a consecutive series of AIS patients with minimal exclusion criteria. The effect of information bias is believed to be minimal as data collection was unvarying and all charts were from a single institution with standardized data retention. Bias may have been introduced when choosing variables for the multivariate analyses. Gender was excluded from our preoperative model because females have lower hemoglobin levels and are more likely to progress to higher Cobb angles [22, 23]. Ethnicity was also removed because of the association between minorities and greater burden of disease, especially scoliotic curve magnitude [24, 25]. We also found that minority groups in our cohort had a lower preoperative hemoglobin than the Caucasian patients, and some surgeons treated a different percentage of patients from each ethnic group during this study period, making ethnicity difficult to analyze in isolation.

One important limitation of this study was the variability across time, surgeon, and anesthesiologist in terms of criteria warranting a transfusion. Although some variability exists, the institution has a general consistency amongst the surgeons and the anesthesiologists with respect to the need for transfusion for patients who have a hemoglobin of <7, and when between 7 and 8 transfusion is performed when coincident symptoms are present and when >8 the likelihood of transfusion is low as other means to achieve clinical improvement (heart rate, blood pressure, etc.) are attempted. Reasons for ABT were variable and multifactorial: some were for hemoglobin or hematocrit below a provider's transfusion threshold, some were for symptomatic anemia (low blood pressure, light-headedness, etc.), and still others were ordered for reasons not well understood in a retrospective review of medical records.

Another important consideration is the variability in ABT rate between surgeons, however, this same variability surely occurs between surgical facilities as well. This limits the broad applicability of our predictive risk cutoffs. We also chose not to differentially weight the risk factors or account for any potential interactive affects given our study size. A similar analysis using large, multi-center data could generate a more generalizable and sophisticated predictive model, but regardless, an accurate prediction of ABT probability for any single surgery would need to take into account individual surgeon and facility variables. Our cutoffs give surgeons a way to estimate ABT probability, manage blood product and related testing, and care for patients in a more efficient manner. However, there are certain things which were standardized including the maintenance dose of TXA (10 mg/kg/h) and adjusting the mean arterial pressure (MAP) during spine exposure (60–70 mmHg) with higher MAP (>75 mm) during spine deformity correction.

In conclusion, the rate of allogeneic blood transfusion in idiopathic scoliosis surgery continues to improve over time. We report a rate of 18.2% along with several risk factors that should alert surgeons to an increasing likelihood of ABT. Knowledge of those risk factors, along with the identification of a risk cutoff value for postoperative hemoglobin, should allow for improved blood resource utilization and the avoidance of unnecessary laboratory testing during the postoperative hospitalization. These data can be used to help standardize the management blood products preoperatively, intraoperatively and postoperatively—a process we are currently undergoing at our institution and this process will allow for improved patient care and hospital resource utilization.

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