Blood management in pediatric spinal deformity surgery: review of a 2-year experience

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BACKGROUND: Pediatric scoliosis surgery is associated with considerable blood loss and allogenic transfusions. Transfusions contribute to morbidities and cost. A perioperative pediatric blood management program was implemented at our institution. Patients received preoperative evaluation, cell salvage, topical hemostasis, antifibrinolytics, and hypotensive anesthesia.

STUDY DESIGN AND METHODS: The study was a 2-year retrospective cohort review of the program’s population from September 2007 through August 2009.

RESULTS: A total of 110 scoliosis surgeries were performed with only 34 and 12% of the patients requiring preoperative oral iron and erythropoietin, respectively. Neuromuscular scoliosis patients had more repaired segments and a larger transfusion rate than idiopathic scoliosis patients (36% vs. 1.7%, p = 0.001). Transfused patients had more blood loss relative to their blood volume (p = 0.001) and blood loss was associated with higher Cobb angles (p = 0.04). Logistic regression revealed that blood loss (p = 0.001), number of segments fused (p = 0.004), and lower patient weight (p = 0.007) are associated with increased odds for transfusion. Twelve patients (10.9%) were identified with low von Willebrand activity with a trend toward higher blood losses (p = 0.07) with lower activity levels.

CONCLUSION: Transfusion requirements in scoliosis patients are dependent on blood loss as determined by Cobb angles and number of segments fused relative to the patients’ blood volume as determined by weight. Implementation of a blood management protocol resulted in a low transfusion rate and unexpectedly led to the preoperative diagnosis of a number of patients with low levels of von Willebrand activity.

ABBREVIATIONS: ICU = intensive care unit; IS = idiopathic scoliosis; NMS = neuromuscular scoliosis; O = other (group).

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supports the observations that transfused patients under several clinical settings have increased resource utilization, longer hospital stay, and higher mortality. Multiple interventions have been used to minimize blood losses during scoliosis surgery including positioning on a spinal table to decrease abdominal pressure, hypotensive anesthesia, hemodilution, cell salvage, use of antifibrinolytics (aminocaproic acid and tranexamic acid), surgical techniques like subperiosteal dissection, electrocautery, and topical hemostatic agents.

**PEDIATRIC SCOLIOSIS PROGRAM AT HELEN DEVOS CHILDREN’S HOSPITAL**

In September 2007, a pediatric scoliosis program was launched at Helen DeVos Children’s Hospital led by two specialized spine surgeons. One of its goals was to provide comprehensive care that incorporates blood conservation measures in collaboration with pediatric anesthesia and the pediatric blood management program. A protocol was adopted that includes the following elements to produce a maximum cumulative effect: 1) preoperative evaluation—screening for anemia, screening for bleeding or clotting disorders, and hematins supplementation as needed; 2) two fellowship-trained spine surgeons operating simultaneously to decrease operative time; 3) intraoperative—moderate hypotensive anesthesia, the utilization of topical hemostatics, cell salvage, and antifibrinolytic therapy with aminocaproic acid or tranexamic acid; and 4) postoperative—hematinics if needed (see Appendix, available as supporting information in the online version of this paper). We report here a 2-year review of the program’s outcome results with regard to blood loss and allogeneic RBC transfusion requirements.

**STUDY DESIGN**

A retrospective review of prospectively collected data of a cohort of scoliosis patients treated by the pediatric scoliosis program at Helen DeVos Children’s Hospital over a period of 24 months (September 2007-August 2009) was performed.

Data were prospectively collected after obtaining institutional review board approval in advance of initiating the program. Data were collected by two coordinators assigned to the blood management program on a dedicated database. A second institutional review board approval was obtained to conduct a retrospective review of such a cohort of patients, with regard to bleeding and transfusion data.

Data collected included:

A. Patients demographics, any bleeding or clotting abnormalities, medications given, and any comorbidities. The comorbidities were defined as any of the following regardless of the type of scoliosis:

- Severe airway obstruction or restrictive lung disease;
- Pulmonary or systemic hypertension;
- Cardiomyopathy or renal or hepatic dysfunction;
- Severe dysphagia or gastroesophageal reflux.

B. Intraoperative data with regard to extent of repair, duration of surgery, blood loss, transfusion requirements, hemoglobin (Hb), and coagulation test results.

C. Postoperative course, Hb, and coagulation studies

Primary end points included blood loss and allogeneic RBC transfusion requirements.

**Statistical analysis**

Data are presented as means and standard deviations and quantitative data were compared using the Mann-Whitney and Kruskal-Wallis tests while incidence data were compared using the Fisher’s Exact test or chi-square test. Logistic regression analysis was performed to examine correlation of variables to transfusion requirement.

**RESULTS**

From September 2007 to August 2009, a total of 110 scoliosis surgeries were performed. Those who underwent VEPTR procedures were excluded from the analysis due to the different nature of the procedure and expected lesser blood losses. Those who underwent posterior spinal fusions were classified as idiopathic scoliosis (IS, n = 60), neuromuscular scoliosis (NMS, n = 28), and others (O, n = 18). The latter group included other types that did not fall under either of the other two groups and required generally a shorter segment fusion. Two patients with IS did not undergo a preoperative visit for blood management consultation due to travel constraints. These two patients still underwent a phone history screening, blood testing, and evaluation of laboratory findings by the blood management team. All the remaining patients received an actual outpatient preoperative evaluation. Thirty-seven patients (34%) received preoperative oral iron and folate supplementation but only 13 patients (12%) received preoperative weekly erythropoietin (EPO) injections for 2 to 4 weeks before surgery to optimize their Hb (Fig. 1). Two patients were placed on oral contraceptives at the end of their menstruation before surgery due to menorrhagia and went on to receive intraoperative antifibrinolytic infusion without any complications. A third patient was previously placed on oral contraceptives to advance bone growth. This patient was not given antifibrinolytics therapy intraoperatively and developed a postoperative upper body deep venous thrombosis related to a central line.

Patients with NMS (n = 28) compared to IS (n = 60) were smaller (46 ± 18 kg vs. 58 ± 18 kg; p = 0.004) despite
Transfused patients (n = 15) compared to the nontransfused patients (n = 95) were smaller (38 ± 15 kg vs. 54 ± 21 kg; p = 0.006), had greater incidence of comorbidities (80% vs. 45%; p = 0.012), and were more likely of the neuromuscular type (67% vs. 19%; Fisher’s p value < 0.001). Transfused patients had similar preoperative Hb, clotting studies, and number of osteotomies, but more levels fused (13.6 ± 4.7 segments vs. 10.5 ± 3.6 segments; p = 0.003) and higher blood losses (80 ± 51 mL/kg vs. 21 ± 14 mL/kg; p = 0.001; Table 2 and Fig. 4). Transfused patients had a longer pediatric ICU stay (2.8 ± 1.1 days vs. 1.8 ± 0.74 days; p = 0.001), but similar hospital stay (4.93 ± 1.16 days vs. 5.12 ± 1.56 days). The volumes of transfused allogeneic blood were 225 mL (n = 1) in the IS group, 590 ± 420 mL (n = 10) in the NMS group, and 317 ± 126 mL (n = 4) in the O group (p = 0.142 comparing the later two groups).

Univariate logistic regression showed that higher blood loss and number of segments fused increased the odds for requiring transfusion, while higher weight lowered those odds (Fig. 5). Multivariate logistic regression revealed that older age was associated with lower odds for transfusion (odds ratio [OR], 0.973; 95% confidence interval [CI], 0.951-0.996; p = 0.023), and higher blood loss was associated with increased odds for transfusion (OR, 1.129; 95% CI, 1.06-1.2; p = 0.001; Fig. 6). Other variables (scoliosis type, Cobb angle, operating room time, segments fused, osteotomies, and clotting studies) did not reach significance.

Incidence of thrombophilia and bleeding disorders
One patient was diagnosed with homozygous factor V Leiden while two others were heterozygous. None received antifibrinolytics and all did well. No patients were diagnosed with hemophilia, but two had prolonged prothrombin time/partial thromboplastin time presumably due to anticoagulant antibodies. One patient was deferred due to significant medical risks while the other spontaneously improved and was operated on 3 months later. Based on von Willebrand activity level and significant bleeding history, 12 patients were identified to be at high risk for hemorrhage. One patient met activity diagnostic criteria for von Willebrand’s disease (29%). Ten

**Fig. 1. Study population group assignment. Four patients underwent VEPTR procedures and were excluded from the analysis.**
patients had levels between 30 and 70% but had significant bleeding history. One patient had a von Willebrand activity level of 90% but had an abnormal PF100 screening test with clinically significant bleeding history. Significant bleeding history was defined as any frequent and prolonged epistaxis, excessive or prolonged mucosal bleeding, menorrhagia, history of intraoperative excessive bleeding, or similar family history in parents and siblings, including significant postpartum bleeding. Of the 12 patients, four had NMS, six had, and two were categorized as others (O; Table 3). Six of these (including two in the O group) received von Willebrand replacement factor intraoperatively per hematology consult and one (IS) required a transfusion. Those who received von Willebrand factor (VWF) replacement were judged clinically to be at a higher risk for bleeding than the rest who simply had borderline low VWF activity levels. The overall incidence of von Willebrand’s disease among NMS, IS, and O patients was 14.3, 10, and 9.1%, respectively (p = 0.074) with an overall incidence of 10.9%. Despite giving four of 10 NMS and IS patients perioperative VWF replacement...

### TABLE 1. Type of scoliosis and outcome*

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Idiopathic (n = 60)</th>
<th>Neuromuscular (n = 28)</th>
<th>p value (Mann-Whitney)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (female)</td>
<td>45 (75)</td>
<td>14 (50)</td>
<td>0.02†</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>58 ± 18</td>
<td>46 ± 18</td>
<td>0.004</td>
</tr>
<tr>
<td>Age (months)</td>
<td>162 ± 39</td>
<td>157 ± 51</td>
<td>0.869</td>
</tr>
<tr>
<td>Comorbidities</td>
<td>18 (30)</td>
<td>27 (96)</td>
<td>0.001†</td>
</tr>
<tr>
<td>Cobb angle</td>
<td>61° ± 18</td>
<td>66° ± 21°</td>
<td>0.188</td>
</tr>
<tr>
<td>Number of segments fused</td>
<td>10 ± 3</td>
<td>15 ± 2</td>
<td>0.001</td>
</tr>
<tr>
<td>Number of osteotomies</td>
<td>6 ± 3</td>
<td>8 ± 5</td>
<td>0.27</td>
</tr>
<tr>
<td>Operating room time (min)</td>
<td>301 ± 90</td>
<td>348 ± 79</td>
<td>0.025</td>
</tr>
<tr>
<td>EBL Intraoperative</td>
<td>833 ± 462</td>
<td>1523 ± 1144</td>
<td>0.004</td>
</tr>
<tr>
<td>EBL Intraoperative/kg</td>
<td>16 ± 9</td>
<td>39 ± 39</td>
<td>0.001</td>
</tr>
<tr>
<td>EBL Total</td>
<td>1080 ± 686</td>
<td>1930 ± 1250</td>
<td>0.001</td>
</tr>
<tr>
<td>EBL/segment fused</td>
<td>93 ± 41</td>
<td>101 ± 82</td>
<td>0.377</td>
</tr>
<tr>
<td>EBL as % of total blood volume</td>
<td>23 ± 13%</td>
<td>55 ± 55%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Preoperative Hb</td>
<td>13.6 ± 1.2</td>
<td>13.9 ± 1.1</td>
<td>0.34</td>
</tr>
<tr>
<td>Lowest</td>
<td>9.3 ± 1.4</td>
<td>8.4 ± 1.7</td>
<td>0.006</td>
</tr>
<tr>
<td>Postoperative Hb</td>
<td>10.59 ± 2.11</td>
<td>10.83 ± 1.44</td>
<td></td>
</tr>
<tr>
<td>Change</td>
<td>4.4 ± 1.5</td>
<td>5.5 ± 1.9</td>
<td>0.002</td>
</tr>
<tr>
<td>Pediatric ICU stay (days)</td>
<td>1.7 ± 0.6</td>
<td>2.3 ± 1</td>
<td>0.012</td>
</tr>
<tr>
<td>Hospital stay (days)</td>
<td>5 ± 1.7</td>
<td>5.2 ± 1.2</td>
<td>0.333</td>
</tr>
<tr>
<td>Received allogeneic transfusion</td>
<td>1 (1.7)</td>
<td>10 (36)</td>
<td>0.001†</td>
</tr>
<tr>
<td>Allogeneic blood volume transfused</td>
<td>225</td>
<td>590 ± 420</td>
<td></td>
</tr>
</tbody>
</table>

* Data are reported as number (%) or mean ± SD. No difference in preoperative coagulation studies or hematinsics use.
† Chi-square.
‡ Fisher’s exact test.

EBL = estimated blood loss.

**Fig. 2.** Type of scoliosis and outcome. [Idiopathic; Neuromuscular. *Mann-Whitney; †Fisher’s exact test.**

**Fig. 3.** Cobb angle, blood loss, and transfusion events (all patients). (I) Blood loss (mL/kg), p = 0.04 Kruskal-Wallis test; (I) percent transfused, p = 0.008 Fisher’s exact test.
there was a tendency for more blood loss with low von Willebrand activity (Fig. 7), with NMS patients having a slightly lower activity level (53 ± 19% vs. 36 ± 18%; p = 0.17).

In all our study patients, blood loss did not correlate with VWF activity nor was there a difference between the NMS or IS groups. However, transfused patients tended to have lower preoperative von Willebrand activity (78 ± 34% vs. 95 ± 38%; p = 0.134).

**DISCUSSION**

Blood loss in spinal fusion surgery has been addressed in the literature repeatedly due to its magnitude. However, comparative analysis of outcomes is challenging because blood loss depends on several factors such as the type of scoliosis, severity, surgical approach, operative time, and extent of the repair. Additionally, blood conservation...
strategies may be simultaneously employed in variable combinations and data have been reported in various forms that make it difficult to compare interventions and outcomes precisely. In our population we exclusively performed posterior spinal fusion utilizing two spinal deformity surgeons. We report both patient’s intraoperative and patient’s total blood loss and reference it to patient weight and blood volume. Over the study period 75% of the children underwent routine posterior-basal osteotomies, which are associated with considerably increased blood loss. Despite this our reported blood losses are lesser than other reports. Since May 2009 the routine use of these osteotomies has diminished.

Patients with NMS compared to IS were smaller, had more comorbidities, and had a larger number of segments fused. They had higher blood loss that seems to be related to the extent of the repair because blood loss per segment fused was similar to the IS group. For the same reason, higher blood transfusion requirement could be attributed to the higher blood losses relative to the total blood volume given their smaller size. However, transfusion rates in our population (1.7% in the IS patients, 36% in the NMS patients, 13% overall) were lower than several other reports. In a similar population, Meert and colleagues reported an overall 59% incidence of allogeneic blood exposure with NMS, lower body weight, and higher number of fused vertebrae being predictors of allogeneic transfusion. Autologous donation, hypotensive anesthesia, cell salvage, and normovolemic hemodilution were utilized in some of their patients. We did not utilize preoperative autologous donation; few of our patients underwent hemodilution but all underwent hypotensive anesthesia and cell salvage.

Sethna and coworkers reported a 60 and 71% incidence of allogeneic RBC transfusion in a mixed scoliosis population with and without the use of tranexamic acid infusion, respectively. Preoperative platelet (PLT) count, American Society of Anesthesiologists score, and tranexamic acid use were predictors of allogeneic transfusion requirements. The dose of tranexamic acid used was much lower than what is currently being used and none of our patients had preoperative low PLTs.

More recently Shapiro and coworkers reported a 75% incidence of allogeneic transfusion in a cohort of Duchenne muscular dystrophy scoliosis patients receiving tranexamic acid during surgery. Florentino-Pineda and colleagues reported a zero homologous blood exposure in a smaller group of posterior spinal fusion for IS in an approach similar to ours with some of those patients receiving aminocaproic acid in a blinded trial. In both studies blood losses were lower with antifibrinolytic therapy, but other blood conservation measures were simultaneously implemented. McShane and colleagues reported on the efficacy of a blood conservation program that emphasized preoperative hematinics and autologous blood donation in a cohort of pediatric posterior spinal fusion patients that showed a decline in allogeneic transfusion rates from 63% to 14%. Our data reflect the cumulative effects of various elements of perioperative management without attributing a given outcome to any particular intervention. We are currently examining the

<table>
<thead>
<tr>
<th>von Willebrand ristocetin cofactor activity (%)</th>
<th>IS</th>
<th>NMS</th>
<th>History</th>
<th>Received VWF replacement</th>
<th>Total blood loss†</th>
<th>Transfused</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1133 ± 19</td>
<td>1</td>
</tr>
<tr>
<td>50-70</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>725 ± 56</td>
<td>0</td>
</tr>
<tr>
<td>&gt;70</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>400</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>6</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>937 ± 539</td>
<td>1</td>
</tr>
</tbody>
</table>

* Mean activity (IS 53 ± 19%, NMS 36 ± 8%; p = 0.17).
† p = 0.074 Kruskal-Wallis test.

Fig. 7. IS and NMS patients with low von Willebrand activity. $r = -0.458$; Spearman’s $\rho = -0.450$; $p = 0.192$. 

TABLE 3. IS and NMS patients diagnosed with mild von Willebrand disease
efficacy of aminocaproic acid compared to tranexamic acid in a prospective blinded trial in both IS and NMS.

Prediction of transfusion requirements has been attempted with various methods with patients’ weight, age, and preoperative Hb identified as risk factors. Lenoir and coworkers have developed a predictive model of transfusion in adult spine surgery with reasonable success. Meert and colleagues utilized multivariate logistic regression to elicit factors associated with transfusion as mentioned earlier. In our population, univariate logistic regression showed that blood loss, number of vertebrae fused, and weight are significant predictors of transfusion while in multivariate analysis age emerged as a significant variable. Preoperative Hb was not a significant factor since all of our patients but one had a Hb level of higher 11 g/dL and any with a Hb of less than 13 g/dL received oral iron with or without EPO. With all of our data considered it is reasonable to conclude that blood loss relative to patient’s blood volume in a preoperatively nonanemic patient is the major determinant of intraoperative allogeneic transfusion, with the number of segments fused and Cobb angle as indirect predictors of blood loss.

Studies have shown that perioperative transfusions are associated with postoperative infection, longer ICU stay, and higher mortality. In our data transfused patients had longer ICU stay. These patients all were the NMS type that is associated with comorbidities requiring longer ICU stay except one. It will be difficult to show the effect of transfusion on outcome without studying a single institutional outcome of a large cohort of NMS patients.

In our cohort, there were no patients diagnosed with hemophilia. There were two patients presumed to have anticoagulant antibodies. One of these patients corrected and underwent uneventful surgery. Given our past experience of occasional unexpected excessive operative bleeding, we have included screening for von Willebrand ristocetin cofactor activity. We identified only one case of an activity level less than 30% which fulfills the more recent and rather stringent diagnostic criteria for diagnosis of von Willebrand disease. This corresponds to the reported 1% incidence of von Willebrand disease in the general population. We have identified several others with borderline low von Willebrand activity (30%-50%) and/or history of a significant bleeding tendency. The findings elicit more questions than answers as to the nature of the von Willebrand (acquired vs. genetic) and its relationship with scoliosis if any (cause and effect vs. genetic association). The von Willebrand gene is located on the short arm of Chromosome 12 and extensive work on the genetic basis of scoliosis is under way that so far does not seem to overlap with the von Willebrand gene. The issue is worthy of future investigations particularly in light of the likely complex genetic nature of both conditions and significant variability in phenotypic expression.

Our report is limited by its retrospective nature and absence of a historical control at our institution. Furthermore, since all patients were managed similarly there is no simultaneous control group. Our data describe the incidence of transfusion in our cohort and attempts to elicit predictors of blood loss and transfusion requirements retrospectively with internal comparisons.

In summary, posterior spinal fusion is associated with significant risk of bleeding and allogeneic transfusions. Blood loss relative to patient’s blood volume is the major predictor of allogeneic transfusion with the former being dependent on the extent of the repair. Collaborative and comprehensive blood management strategies resulted in lower transfusion rates compared to previous reports. Patients with low von Willebrand activities are unexpectedly frequent and may be at increased risk for bleeding.
CONFLICT OF INTEREST

No financial support was attained for this project nor do the authors have any potential conflict of interest.

REFERENCES


SUPPORTING INFORMATION

Additional supporting information may be found in the online version of this article:
Appendix. Summary of blood management protocol.

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