Review Article

Perioperative Blood Management in Pediatric Spine Surgery

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Abstract

Blood management strategies are integral to successful outcomes in many types of orthopaedic surgery. These strategies minimize blood loss and transfusion requirements, ultimately decreasing complications, improving outcomes, and potentially eliminating risks associated with allogeneic transfusion. Practices to achieve these goals include preoperative evaluation and optimization of hemoglobin, the use of pharmacologic agents or anesthetic methods, intraoperative techniques to improve hemostasis and cell salvage, and the use of predonated autologous blood. Guidelines can also help manage allogeneic transfusions in the perioperative period. Although the literature on blood management has focused primarily on arthroplasty and adult spine surgery, pediatric spinal fusion for scoliosis involves a large group of patients with a specific set of risk factors for transfusion and distinct perioperative considerations. A thorough understanding of blood management techniques will improve surgical planning, limit transfusion-associated risks, maintain hemostasis, and optimize outcomes in this pediatric population.

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Dr. Oetgen or an immediate family member serves as a board member, owner, officer, or committee member of the American Academy of Orthopaedic Surgeons, the Pediatric Orthopaedic Society of North America, and the Scoliosis Research Society. Neither Dr. Litrenta nor any immediate family member has received anything of value from or has stock or stock options held in a commercial company or institution related directly or indirectly to the subject of this article.

J Am Acad Orthop Surg 2017;25: 480-488

DOI: 10.5435/JAAOS-D-16-00035

Improved blood management is a focus in many areas of orthopaedics. Arthroplasty and adult spine surgery in particular have benefitted from blood conservation techniques.[1] Pediatric spinal fusion for scoliosis is associated with substantial blood loss because of the extensive soft-tissue dissection and instrumentation of the vertebrae, as well as specific risk factors (eg, long surgery, osteotomy requirements) in patients who undergo the procedure. As a result, this large cohort would also benefit from a well-planned blood conservation strategy.

Optimization of blood management in the surgical management of scoliosis involves techniques that span the preoperative, intraoperative, and postoperative periods. These techniques include early identification of patients who may need blood management; institution of preoperative interventions when necessary; the use of a combination of intraoperative anesthetic, pharmacologic, and surgical techniques; and postoperative monitoring of patients for transfusion needs. In general, the goals of these blood management strategies are to minimize blood loss or prevent allogeneic transfusion (Table 1).

Preoperative Assessment

In pediatric patients undergoing spinal fusion for scoliosis, a complete history and physical examination are necessary to assess physical status and relevant comorbidities, as well as to adequately prepare the patients and their families for the procedure. Patients at risk for substantial blood loss should be identified early so that appropriate planning can be initiated.

Substantial research has been done on the risk factors for transfusion in adolescent spine surgery. Some factors, such as laboratory abnormalities or the use of certain medications, are modifiable. Other factors cannot be modified but can help determine when special attention is required intraoperatively or postoperatively. Although published results vary, in general, risk factors for transfusion in this patient population include a long surgical time, a large number of levels fused (>6), the need for Ponte osteotomies, a Cobb angle >50°, a neuromuscular etiology, and lower body weight[2-8] (Table 2).

In a series of 107 patients who underwent posterior fusion surgery, Meert et al[3] identified neuromuscular etiology as the most significant independent predictor of allogeneic transfusion; compared with idiopathic scoliosis, neuromuscular etiology was associated with a 7.8-fold increased risk for allogeneic transfusion. In combination, neuromuscular etiology, a greater number of levels fused, and lower body weight contributed to 53% of the variability in allogeneic transfusion. Other factors, such as sex, age, and the magnitude of the Cobb angle, were not predictors of allogeneic and autologous red cell transfusion in this study.

In contrast, Cristante et al[4] evaluated a series of 94 patients with idiopathic, neuromuscular, or congenital scoliosis and found that they required an average blood transfusion of <2 units during surgery, with no statistically significant difference on the basis of diagnosis. In this study, regression analysis identified only the number of levels fused as a significant risk factor for transfusion. Scoliosis etiology, preoperative Cobb angle, sex, and the duration of surgery were not predictors of transfusion.

In a larger series, Vitale et al[5] retrospectively reviewed 290 pediatric patients, 63 of whom received transfusion during spine surgery. The authors proposed an algorithm to predict blood loss based on three factors: the presence of neurogenic scoliosis, the use of lumbosacral fusion, and the degree of curvature. The authors called it a "rule of twos" algorithm because the presence of any one of these risk factors doubled the risk of transfusion. A curve >50° doubled the transfusion risk, with a 1.015 incremental increase in the transfusion risk per degree of curvature.

Yu et al[6] also found that a Cobb angle >50° was predictive of massive blood loss, which they defined as combined intraoperative and postoperative blood loss totaling >30% of the patient's estimated blood volume. Other predictive factors were fusion of more than six spinal levels and posterior osteotomies.[6] In this study and others, osteotomies were associated with both greater blood loss and transfusion without improving curve correction.[6,7]

Ponte osteotomies can produce good radiographic results,[9] but they

Table 1

Blood Conservation Strategies for Surgical Management of Scoliosis

Strategy	Minimizing Blood Loss	Preventing Allogeneic Transfusion
Preoperative interventions	—	Iron supplementation, erythropoietin, autologous predonation
Anesthetic practices	Controlled hypotension, epidural blockade, acute normovolemic hemodilution	—
Pharmacologic agents	Antifibrinolytic agents, desmopressin	—
Surgical techniques	Hemostatic products, Aquamantys System (Medtronic)	Intraoperative cell salvage
Postoperative interventions	—	Physiologic transfusion triggers, autologous transfusion

Table 2

Risk Factors for Transfusion During Adolescent Spine Surgery

Study	Risk Factors
Ialenti et al[2]	Sex, surgical time, preoperative kyphosis
Meert et al[3]	Lower weight, neuromuscular scoliosis, number of levels fused
Cristante et al[4]	Number of levels fused (>10)
Vitale et al[5]	Neuromuscular scoliosis, Cobb angle >50°, lumbosacral fusion
Yu et al[6]	Number of levels fused (>6), Cobb angle >50°, the use of posterior osteotomies
Koerner et al[7]	The use of Ponte osteotomies, low preoperative hemoglobin level
Halanski and Cassidy[8]	The use of Ponte osteotomies

are not always necessary to achieve good outcomes. One study compared the use of Ponte osteotomies at >75% of the included levels versus facetectomies alone in patients with adolescent idiopathic scoliosis (AIS).[8] No difference was found in coronal or sagittal alignment, but comparison of Ponte osteotomy with facetectomy alone demonstrated significantly increased average blood loss per level fused (97 ± 42 mL and 66 ± 25 mL, respectively; $P = 0.01$) and surgical time per level fused (31 ± 5 min/level and 23 ± 3 min/level, respectively; $P < 0.001$) with Ponte osteotomy. In a series of pediatric patients with severe deformity, vertebral column resection demonstrated excellent radiographic results; however, the average blood loss was 65% of total volume.[10] These studies support the judicious use of osteotomies for challenging cases in which the benefit outweighs the risk of additional blood loss.

Although identification of neuromuscular etiology, large curves, curves requiring many fusion levels, and low body weight help to predict blood loss and facilitate blood management, these factors are largely nonmodifiable. Modifiable risk factors, such as anemia, coagulopathy, and certain medications with potential adverse effects, can be identified preoperatively.

Anemia based on a low preoperative hemoglobin level has correlated well with transfusion needs.[7] In a study of 86 patients who underwent instrumented fusion for AIS, van Popta et al[11] found that preoperative hemoglobin level was predictive of transfusion need, whereas the magnitude of the preoperative curve and the number of levels fused were not. The authors recommended targeting a preoperative hemoglobin level 5 g/dL higher than the surgeon's preferred transfusion trigger.

Anemia can be addressed with iron supplementation, or adjunctive erythropoietin can be used to boost preoperative hemoglobin levels. Of note, although Vitale et al[5] found that certain factors in their algorithm doubled the risk for transfusion, they also demonstrated that preoperative erythropoietin decreased the need for transfusion by half. Erythropoietin has allowed patients with a low hematocrit level to donate autologous units preoperatively. In another study, patients receiving erythropoietin had higher hematocrit levels at the time of surgery and greater avoidance of allogeneic transfusion than patients not receiving erythropoietin.[12]

Preoperative laboratory evaluations should include prothrombin time (PT), activated partial thromboplastin time (aPTT), and the international normalized ratio. However, these commonly used screening tests identify only a small number of patients with a true coagulopathy. In a review of 792 medical records of pediatric patients with an abnormal coagulation panel, <5% had a serious underlying condition.[13]

Patients with a coagulopathy should be referred to a hematology consultant for workup and management of underlying blood dyscrasia. One example is von Willebrand disease, the most common hereditary coagulopathy, which is often diagnosed during preoperative evaluation. Although many patients with a coagulopathy are asymptomatic, they are at risk for increased bleeding, and blood management strategies (eg, antifibrinolytic agents, desmopressin) have been successful.

Although not commonly measured in standard coagulation laboratory testing, the preoperative fibrinogen level can be used to identify patients at risk for intraoperative bleeding and transfusion.[14] In a series of 82 patients with AIS, blood loss and transfusion requirements correlated significantly with lower preoperative fibrinogen concentrations ($P = 0.005$).[14] Patients in the highest quartile for blood loss and those requiring transfusion of >2 units had preoperative fibrinogen concentrations of 2.6 and 2.5 g/L, respectively, compared with a concentration of 3.1 g/L in patients with less blood loss (ie, those not in the highest quartile for blood loss) and receiving <2 units of blood transfusion. The platelet count, aPTT, and PT were not correlated with total blood loss or need for transfusion. These findings suggest that preoperative fibrinogen level may predict increased blood loss and transfusion needs in AIS surgery.

Nutritional status can also help the clinician to identify patients with an increased risk of bleeding. Achieving adequate nutritional status preoperatively can benefit wound healing and decrease the risk of infection. In one study of patients with neuromuscular disease who underwent spinal fusion surgery for scoliosis, an albumin level <35 g/L and a total lymphocyte count <1,500 mm^3 were found to be risk factors for postoperative infection in these patients.[15]

The preoperative visit is an ideal time to carefully review and identify current medications that may increase blood loss. For example, valproic acid, an antiseizure medication commonly used to treat patients with neuromuscular diseases, has been associated with platelet-mediated adverse effects. In a retrospective analysis of patients with cerebral palsy who were undergoing posterior spinal fusion, patients taking valproic acid had increased blood loss.[16] None of the preoperative laboratory tests, including platelet count, aPTT, and PT, could have been used to identify these patients (who had a risk of increased blood loss) because these test results were within normal limits. The use of antidepressants is

associated with a similar increase in blood loss. Although not evaluated specifically in the setting of adolescent scoliosis, the use of selective serotonin and norepinephrine reuptake inhibitors, bupropion, and other antidepressants was associated with increased blood loss in an adult cohort undergoing posterior lumbar spinal fusion.[17] Therefore, surgeons should consider advising patients to discontinue these medications before surgery when possible or should discuss the anticipated blood loss with the patient and his or her family.

Another important intervention in the preoperative period is the collection of autologous blood, which can be predonated, thereby decreasing the need for future allogeneic transfusion. Preoperative donation can include red blood cells, whole blood, or fresh-frozen plasma; however, red blood cells are most commonly collected because they are easily stored and are most likely to require replacement in the perioperative period. Collection practices vary, but donations generally are done within 1 month before surgery, with 1 week between donations to allow repletion of red blood cells.[18] With iron supplementation, most healthy patients can tolerate this donation schedule. In some cases, patients most at risk for blood loss intraoperatively, such as those with low weight or hemoglobin level, are restricted from donating.[18]

Autologous blood donation initially gained support because it substantially decreased the need for allogeneic transfusion.[19-21] In a series of 243 patients with idiopathic and neuromuscular scoliosis, >90% of 164 autologous donors did not require additional allogeneic transfusion during posterior spinal fusion.[20] In a study of patients with low body weight (<45.5 kg) who donated partial units of blood before undergoing spine surgery, the need for allogeneic transfusion was greatly reduced.[21] The drawback is that collection of autologous blood is costly and time-consuming, and many units are either wasted or transfused inappropriately. In a series of 680 patients who predeposited blood before spine surgery, 18% to 42% of predeposited units were unused.[19] Bess et al[22] reviewed the medical records of 123 patients with AIS who underwent spine surgery; 104 patients participated in preoperative autologous blood donation. The authors found that 51% of patients "wasted at least one unit" of autologous blood or underwent a blood transfusion for a hematocrit level >30.

In 1995, when autologous blood donation was gaining popularity, its cost-effectiveness for four procedures was evaluated at a single academic institution.[23] Although posterior spinal fusion was not represented, this study highlighted the costs associated with autologous blood transfusion. The direct cost difference per unit of autologous and allogeneic blood at that time was $48.24, and autologous units were approximately 30% more expensive than allogeneic units. However, this price difference escalated sharply as the percentage of unused units increased. For example, the fewest units of blood (16%) were wasted during total hip arthroplasty. When this percentage of wasted units was factored into the cost, the difference between autologous and allogeneic blood nearly doubled. With greater numbers of wasted units of blood, the cost difference rose to hundreds of dollars per unit.

Although autologous blood donation is generally safe, the process is associated with some risks. Pediatric patients, particularly girls with low body weight, are more likely to have a vasovagal event while donating. In addition, there are isolated case reports of bacterial contamination of donated units and transfusion errors. These cases are rare, but they do present a potential safety concern.[18]

Although initially popular in the United States, autologous blood transfusion during AIS decreased from 9.7% in 2000 to 2.6% in 2009.[24] During the same time, intraoperative blood salvage increased from 6.0% to 17.3%. Interest in other intraoperative strategies to decrease bleeding and transfusion requirements has also grown.

Intraoperative Management

Intraoperative blood management requires cooperation between the surgical and anesthesia teams. Many strategies exist to accurately monitor and minimize blood loss, prevent allogeneic transfusion by intraoperative collection, and transfuse autologous or allogeneic units appropriately. The most effective strategy involves the simultaneous use of multiple practices.

Monitoring

Intraoperative hemostasis can be quickly monitored with point-of-care testing, which produces immediate results with minimal blood loss. Several point-of-care methods for monitoring hemoglobin level and coagulation have demonstrated accuracy similar to that of laboratory blood draws.[25] Continuous monitoring with spectrophotometry also has been described.[26] Although it is less accurate than point-of-care testing, spectrophotometry has shown promising results and may be useful in some high-risk patients. Thromboelastography (TEG), another measure of blood coagulation, assesses parameters not captured by standard laboratory tests, such as clot strength and platelet function. In one study, TEG showed that patients with neuromuscular disease had weaker blood clot formation intraoperatively than did patients with idiopathic disease.[27]

These data provide interesting insight regarding hemostasis in different patient populations; however, TEG equipment is available in only a few centers, and there are no standardized recommendations for its use.[27]

Anesthesia Strategies

Anesthetic practices contribute substantially to successful blood management in pediatric spinal fusion. These techniques primarily minimize bleeding intraoperatively. Among them, controlled hypotension, epidural blockade, and acute normovolemic hemodilution have a long history in orthopaedic surgery. Each of these techniques contributes a small but measurable effect, and when used together, they can substantially decrease intraoperative blood loss.

Controlled hypotension has been used for decades to decrease blood loss. The basic principle is that lowered blood pressure decreases blood loss during exposure. With this technique, mean arterial pressure is lowered by 30%, usually corresponding to a mean arterial pressure of 50 to 65 mm Hg. In posterior spinal fusion, however, bony bleeding from decortication contributes the most to blood loss. Because this type of bleeding is predominantly venous, lower arterial pressures may not be as effective in minimizing blood loss.[28]

The greatest risk associated with systemic hypotension is poor systemic tissue perfusion, and maintaining the thresholds for perfusion of the spinal cord is crucial. Another complication of hypotension in spinal fusion surgery is ischemic optic neuropathy; however, this complication is rare, with one case report involving a child.[29]

Despite these concerns, the literature supports the use of controlled hypotension without perfusion-related complications. Early research into the use of this technique during placement of Harrington rod instrumentation demonstrated decreased intraoperative blood loss compared with blood loss in patients who remained normotensive.[30] The current anesthesia literature supports the use of hypotensive agents for minimizing intraoperative blood loss during spinal surgery.[31] Although the data support this practice for controlling blood loss, no definitive corresponding decrease in transfusion needs has been shown. Furthermore, hypotensive anesthesia is most appropriate for minimizing blood loss during exposure and should be reversed before deformity correction.

Epidural blockade minimizes bleeding by inducing vasodilation distally and vasoconstriction proximal to the blocked levels. The induced vasoconstriction decreases arterial flow to the surgical field, which is proximal to the blockade. The simultaneous pooling of blood distally decreases venous blood loss at the surgical site. This technique has been used in adults undergoing spine surgery, resulting in decreased blood loss compared with that associated with the use of normotensive anesthesia.[32] During arthroplasty, epidural blockade combined with hypotensive anesthesia has decreased both blood loss and the need for allogeneic transfusions.[33] Although these results are promising, formal evaluation of this technique in the setting of pediatric spinal fusion surgery is lacking.

Acute normovolemic hemodilution involves the removal of venous blood before the incision is made to decrease hematocrit level, typically to 30%. Blood volume is replaced with crystalloid, which decreases blood loss via dilution. Additional benefits include improved cardiac output and circulation resulting from decreased viscosity and the ability to return autologous blood postoperatively. Larger decreases in hematocrit level are more effective.[34] Although many healthy pediatric patients can tolerate these decreases in hematocrit level, safety thresholds for red cell mass removal based on individual risks factors have not been established.

Although acute normovolemic hemodilution has been used safely in pediatric spinal fusion surgery, research supporting its efficacy is limited. A case-control series evaluated this technique in two groups of 43 patients each who underwent fusion for AIS; one group was treated with acute normovolemic hemodilution, and the other was not.[35] Hypotensive anesthesia and intraoperative cell salvage were also used in all patients. In this series, the hemodilution group received substantially fewer postoperative transfusions. However, this difference reflected autologous rather than allogeneic units, and the transfusion thresholds were not clearly stated. In addition, patients in the nonhemodilution group predonated blood at a far greater rate than those in the hemodilution group, further complicating the results. Although hemodilution was a safe and possibly effective strategy in this group, a clear benefit from this technique could not be confirmed.

Pharmacologic Intervention

Many pharmacologic strategies exist to decrease bleeding. Antifibrinolytic agents (eg, tranexamic acid, epsilon-aminocaproic acid) are popular blood conservation agents.[36-41] Antifibrinolytic agents decrease bleeding by inhibiting the degradation of fibrin (Figure 1). They have been successfully and safely used in some types of orthopaedic surgery, especially arthroplasty. In a randomized trial of 125 pediatric patients who underwent spinal fusions to manage idiopathic scoliosis, both tranexamic acid and epsilon-aminocaproic acid

Figure 1

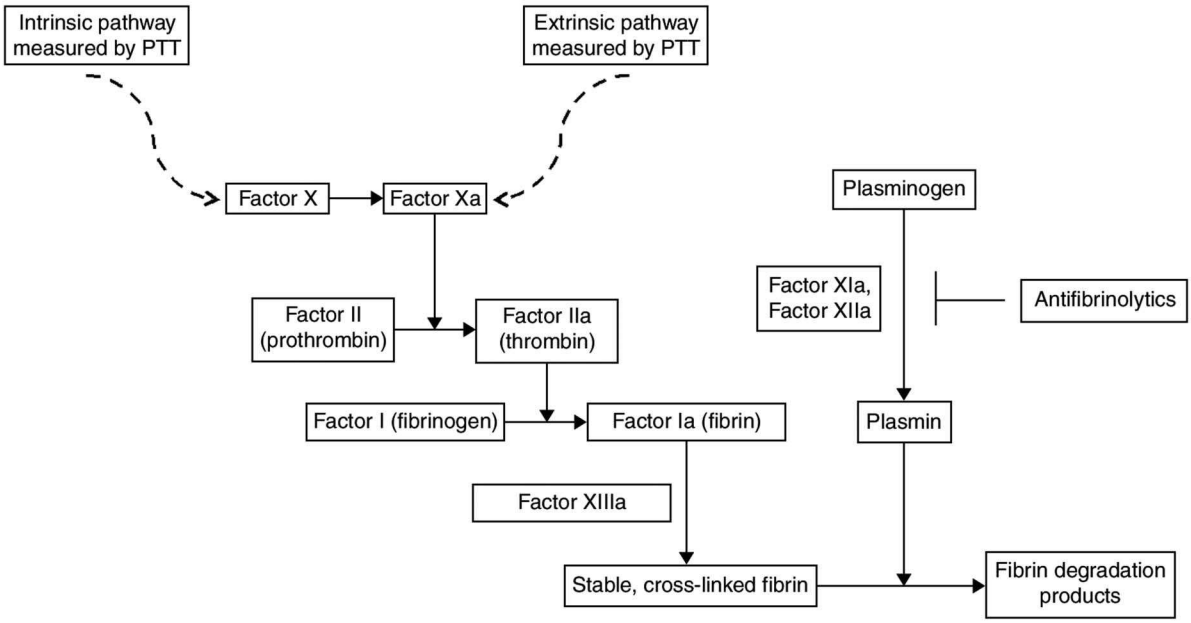

Diagram showing the coagulation cascade, fibrinolysis, and the mechanism of antifibrinolytic agents. The dashed lines represent the activation of the different pathways leading to the activation of a common pathway through factor Xa. The solid lines are the pathway through the common coagulation cascade. These solid lines represent activation of one factor by another. The T-shaped line represents inhibition of Factor XIa and XIIa, which inhibits conversion of plasminogen to plasmin. PTT = partial thromboplastin time

decreased intraoperative blood loss compared with placebo.[36] Blood loss was quantified by total blood loss as well as per pedicle screw, according to the number of levels, and by the degree of correction. In all patients, antifibrinolytic agents were associated with substantial improvements. Tranexamic acid also decreased postoperative wound drainage as measured by Hemovac output. Despite this decreased blood loss, neither tranexamic acid nor epsilon-aminocaproic acid affected the need for autologous or allogeneic transfusion.[36]

In contrast, a retrospective study found a decreased need for autologous transfusion and intraoperative cell salvage in adolescents with idiopathic scoliosis who received tranexamic acid during posterior spinal fusion compared with a control group.[37] However, the transfusion triggers for autologous blood or intraoperative cell salvage were not clearly described, and only one patient required an allogeneic transfusion. In another retrospective series, tranexamic acid was associated with a 50% reduction in transfusion only when the higher of two doses was used in pediatric patients undergoing posterior spinal instrumentation and fusion.[39] The higher-dose protocol used a loading dose of 20 mg/kg/hr over 15 minutes followed by 10 mg/kg/hr and seemed to be more effective than a loading dose of 10 mg/kg followed by 1 mg/kg/hr. Tranexamic acid is typically administered as a loading dose of 10 mg/kg to 1 g, followed by 1 to 100 mg/kg/hr as a maintenance dosage.[36,37,39] Appropriate dosages to maximize effect and minimize risk have not yet been determined.

Antifibrinolytic agents may be more effective in patients with AIS who are also at high risk for surgical blood loss than in the typical patient with the condition. These agents have been shown to be helpful for reducing blood loss in patients undergoing spine fusion for neuromuscular scoliosis[40] and in patients requiring vertebral column resection.[41] Antifibrinolytic agents also decrease intraoperative cell salvage requirements.

Although antifibrinolytic agents are generally considered safe, a thrombotic event is a possible adverse effect associated with their use. Aprotinin, an antifibrinolytic agent that is no longer on the market, increased risk and mortality as a result of thromboembolic events in cardiac bypass surgery.[42] In the same study, tranexamic and aminocaproic acid did not demonstrate this adverse effect. Although antifibrinolytic agents were safe in a large series of pediatric patients treated with spinal fusion, surgeons should still be cautious

about their use in patients with other thrombotic risk factors.[36-38]

Desmopressin, another agent evaluated for blood conservation, decreases bleeding time in patients with normal coagulation factors by increasing factor VIII and von Willebrand factor. It has been used in many surgical subspecialties. Although limited data support its ability to minimize blood loss in spinal fusion surgery,[43] most research on desmopressin has not demonstrated this efficacy. With the concurrent success and popularity of antifibrinolytic agents, desmopressin is not commonly used; nevertheless, it is still relevant in the treatment of patients with von Willebrand disease who are undergoing surgery.

Intraoperative Cell Salvage

In addition to anesthetic and pharmacologic practices, intraoperative cell salvage is a widely adopted strategy. It involves the collection of blood via intraoperative suction, which is then centrifuged so the red blood cells can be autotransfused. Intraoperative cell salvage does not affect blood loss but does reduce the need for allogeneic transfusion[44-46] and has been beneficial in the setting of lengthy surgery and substantial blood loss.[46] As this technique has gained popularity, the predonation of autologous blood has decreased.[24] Cost is the greatest drawback of intraoperative cell salvage.

Surgical Techniques

Additional options exist for improving hemostasis. Many products can control bleeding, such as spray-on collagen-thrombin, fibrin sealant, kaolin-soaked sponges, and local vasoconstrictors.[47-49] Aquamantys (Medtronic), a bipolar tissue sealant, combines radiofrequency energy with saline irrigation to provide hemostatic control for bone and soft tissue. This device has been shown to be more effective than Bovie electrocautery in reducing blood loss, although at greater expense.[50]

Topical hemostatic agents are desirable because they are locally active, act quickly, and improve surgeon visibility. For example, kaolin is an inexpensive clay material developed by the US military as a rapid and locally acting hemostatic agent. Kaolin-soaked sponges, packed intraoperatively, decreased both transfusion and blood loss in a small series of patients who underwent posterior spinal fusion for AIS.[49] Although the application of kaolin in scoliosis surgery is relatively new, this recent study demonstrated promising results.

Transfusion

According to a review of the National (Nationwide) Inpatient Sample database, despite best efforts, allogeneic transfusion was still required in 17.8% of patients undergoing posterior spinal fusion for AIS.[24] Thresholds for transfusion vary, but physiologic-based rather than laboratory-based guidelines are preferred. Historically, an arbitrary hematocrit level of 30% has been used as a threshold for transfusion.[51] However, transfusion thresholds do not take into account the physiologic effect of a given hematocrit level on each patient (ie, based on his or her preoperative cardiopulmonary status or baseline hemoglobin level). Therefore, physiologic transfusion triggers, such as tachycardia, hypotension, urine output <0.5 mL/kg/hr, and acidosis, better indicate potentially poor end-organ perfusion and the need for improved oxygen delivery.

Risks

An effective blood management strategy must balance the risk of the intervention with the risks of blood loss and allogeneic transfusion. Although the dangers associated with allogeneic transfusion have decreased over time because of improved screening and administration practices, the dangers still exist. Transfusion-related complications range from mild reactions, such as fever or hives, to blood-borne infections and acute hemolytic reaction from blood mismatch. In industrialized nations, screening programs have largely eliminated blood-borne infection, and mandatory hospital safety measures have substantially reduced mismatched blood donation; however, these risks are still a concern in parts of the developing world. Transfusion-related acute lung injury also occurs in rare instances after allogeneic transfusion. This immunologically mediated complication can cause acute respiratory problems and is the leading cause of transfusion-related mortality.

The use of a comprehensive blood management strategy during pediatric spinal fusion can largely eliminate allogeneic transfusion and its associated risks. Each strategy has unique considerations. Anesthetic practices, such as controlled hypotension, epidural blockade, and acute normovolemic hemodilution, demonstrate an effect but are clinically limited when used in isolation. Antifibrinolytic agents have the greatest effect in patients at risk for severe blood loss. Other intraoperative tools, such as cell salvage or a bipolar tissue sealant, are effective but expensive. Autologous blood donation still has a role in blood management, but this time-consuming and costly practice should be reserved for patients with a high transfusion risk who can tolerate preoperative donation.

Outcomes

The success of blood conservation strategies is measured in blood loss

and transfusion requirements. Placing a value on blood loss is a subjective exercise, and different methods of determining blood loss can produce statistically different estimates.[52] It is therefore challenging to use estimated blood loss to compare techniques of blood conservation and make treatment recommendations. Furthermore, decreases in blood loss do not always lessen transfusion requirements because the intervention may not produce a large enough effect or the thresholds for transfusion may vary. Although the need for transfusion appears to be an objective end point, it is inherently subjective because of the varying indications.

Summary

Effective blood management involves a complex set of strategies that incorporate preoperative risk stratification; anesthetic, pharmacologic, and surgical techniques; and defined transfusion thresholds. Among contemporary blood conservation strategies, intraoperative cell salvage and antifibrinolytic agents are most widely used. Although data support the use of these strategies in pediatric scoliosis surgery, large randomized controlled trials investigating their utility are limited, and many relevant studies have reported contradictory results. Further research should focus on the preoperative evaluation of the patient and the surgical factors best targeted by specific blood management techniques.

Predicting blood loss and recommending an optimal blood management strategy remain challenging. Using a variety of techniques allows creation of individualized strategies based on a patient's unique needs. These practices are likely to evolve over time, and surgeons should maintain a thorough understanding of these practices and their applications.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, references 36, 38, and 43 are level I studies. References 8, 25-27, 33, 44, 47, and 48 are level II studies. References 2, 6, 12, 15-17, 22, 30, 31, 35, 37, 39-42, 45, 46, 49, 50, and 52 are level III studies. References 3-5, 7, 9-11, 13, 14, 19-21, 23, 24, 28, and 29 are level IV studies. References 1, 18, 34, and 51 are level V expert opinion.

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