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SURGERY

Does a Kaolin-Impregnated Hemostatic Dressing Reduce Intraoperative Blood Loss and Blood Transfusions in Pediatric Spinal Deformity Surgery?

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Study Design. Retrospective case-control study.

Objective. To evaluate the hemostatic benefits of using a kaolin-impregnated dressing during pediatric spinal deformity correction surgery.

Summary of Background Data. Minimizing blood loss and transfusions are clear benefits for patient safety. A technique common in both severe trauma and combat medicine that has not been reported in the spine literature is wound packing with a kaolin-impregnated hemostatic dressing.

Methods. Estimated blood loss and transfusion amounts were analyzed in a total of 117 retrospectively identified cases. The control group included 65 patients (46 females, 19 males, 12.7 ± 4.5 yr, 10.2 ± 4.8 levels fused) who received standard operative care with gauze packing between June 2007 and March 2010. The treatment group included 52 patients (33 females, 19 males, 13.9 ± 3.2 yr, 10.4 ± 4.3 levels fused) who underwent intraoperative packing with QuikClot Trauma Pads (QCTP, Z-Medica Corporation) for all surgical procedures from July 2010 to August 2011. No other major changes in the use of antifibrinolytics or perioperative, surgical, or anesthesia technique were noted. Statistical differences were analyzed using analysis of covariance in R with P value of less than 0.05. The statistical model included sex, age, weight, scoliosis type, the number of vertebral levels fused, and surgery duration as covariates.

Results. The treatment group had 40% less intraoperative estimated blood loss than the control group (974 mL *vs*. 1620 mL) ($P < 0.001$). Patients who received the QCTP treatment also had 42% less total perioperative transfusion volume (499 mL *vs*. 862 mL) ($P < 0.01$).

Conclusion. The use of a kaolin-impregnated intraoperative trauma pad seems to be an effective and inexpensive method to reduce intraoperative blood loss and transfusion volume in pediatric spinal deformity surgery.

Key words: kaolin, hemostatic dressing, scoliosis surgery, blood loss.

Level of Evidence: 3

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For patients with severe scoliosis, surgeons may perform spinal arthrodesis, or spinal fusion, to prevent further progression of scoliosis and create a more normal alignment of the spine. Surgeons utilize 3 approaches for spinal fusion: posterior, anterior, or a circumferential anterior/posterior combination. Regardless of the surgical approach, deformity correction warrants extensive soft tissue and bony dissection. Therefore, spinal fusion may potentiate significant blood loss because of large incisions and prolonged procedural times.

Posterior spinal fusion with rigid transpedicular screw fixation is used to correct severe pediatric spinal deformity. In posterior spinal fusion, pediatric patients may experience blood loss of up to 4 L or 60% of estimated blood volume because of the extensive dissection through the highly vascular paraspinal muscles.[1] This considerable blood loss often requires blood transfusion therapy,[2] which may pose a variety of deleterious effects, including blood-borne infections, development of immune reactions, and acute lung injury.[3–5] Consequently, these risks may increase morbidities, hospital stay, and cost.[6,7]

Many innovations in surgical technique and anesthesia have optimized blood conservation such as bipolar cautery, systemic administration of antifibrinolytics (tranexamic acid and aminocaproic acid), autologous blood donation, blood salvage, normovolemic hemodilution, hypotensive anesthesia, and patient positioning.[8–10] Despite these improvements, transfusion therapy is often required. Therefore, it is important for researchers to investigate new methods in hemostasis.

A relatively unexplored hemostatic product in the surgical setting is the advanced hemostatic dressing. Since the Iraq and Afghanistan military operations, hemostatic agents have developed rapidly to address local hemorrhage control.[11,12]

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Early generations of these advanced dressings elicited complications, including difficulty of administration due to a granular product design[13] and exothermic reaction of the active ingredient zeolite.[14–17] However, a widely used hemostatic dressing, a kaolin-impregnated gauze, has no known contraindications to date[18] and has been found to be safe and effective in testing performed by the US Military.[19]

Kaolin is an aluminum phyllosilicate clay mineral that enhances the formation of hemostatic clots. Kaolin assists clot formation because of its negatively charged surface,[20] which interacts with Factor XII[21] and platelet-associated Factor XI,[22,23] both of which independently activate the intrinsic coagulation cascade. These interactions facilitate clot formation by decreasing the initial time of blood clot activation as demonstrated by thromboelastogram studies.[24] Thus, kaolin's clot activating function establishes it as an effective hemostatic control. Furthermore, kaolin-impregnated gauze has been reported as a safe and effective hemostatic control in combat trauma,[25] porcine hemorrhage trials,[19,24,26–30] and the interventional cardiology setting.[31,32] Although kaolin-impregnated gauze gains recognition in the operating room, it has not yet been studied in pediatric spinal fusion surgery. The objective of this research is to determine whether packing with kaolin-impregnated gauze during posterior scoliosis surgery reduces blood loss and transfusion amount. We hypothesize that patients who receive treatment with the kaolin-impregnated gauze during posterior spinal fusion will experience less blood loss and consequently require less transfusion.

MATERIALS AND METHODS

This retrospective study was approved by the institutional review board and was conducted at a tertiary pediatric center. In the senior author's practice, many hemostatic methods were already established to minimize blood loss. Before surgery, caregivers assessed the patient's nutrition, coagulation parameters, and platelet count. Also, patients with neuromuscular scoliosis received preoperative vitamin K. Intraoperatively, the patient was kept warm to prevent coagulopathy. Surgeons achieved intraoperative hemostasis with tranexamic acid (Pfizer, New York, NY), Gelfoam (Pfizer, New York, NY), thrombin packing, Surgiflo (Ethcon, Somervile, NJ), and bonewax. The mean arterial pressure was maintained normotensive, approximately 60 mm Hg.

We selected patients who underwent a posterior spinal deformity correction surgery by the senior attending pediatric spine surgeon from June 2007 to August 2011. Selection parameters excluded patients who had received prior spine surgery. Clinical data obtained from medical files included age, sex, scoliosis type, weight, surgery duration, number of vertebrae fused, amount of estimated blood loss (EBL), transfusion amount, and blood chemistry results. Transfusion amount was calculated as the total volume of transfusions a patient received during surgery until discharge. Transfusion volumes included intraoperative blood salvage from Cell Saver, packed red blood cells, fresh frozen plasma, and platelets. Within our selection parameters, we included both hemivertebra resections and posterior osteotomies to include a wide range of posterior spinal fusion levels. By including a broad range of fusion levels, one of the independent variables for blood loss, we strengthened the statistical power of the regression analysis.

Patients in this study were assigned to 1 of 2 groups. The control group consisted of cases between June 2007 and March 2010. These patients received intraoperative surgical wound packing with standard gauze and towel clamps whenever possible. In June 2010, the standard operating procedure for scoliosis was modified to include a kaolin-impregnated gauze, QuikClot Trauma Pads (QCTP, Z-Medica Corporation, Wallingford, CT), for intraoperative packing. A typical case used 3 QuikClot Trauma Pads, which measure 1 ft^2, or 30.48 cm^2. Cases from July 2010 to August 2011 were identified for the treatment group. There was no difference between the 2 groups in the use of the antifibrinolytic, tranexamic acid, or perioperative, surgical, or anesthesia technique.

Data were analyzed in R, a statistical and graphical computing freeware. Prior to data analysis, we identified outliers with the Bonferroni outlier test. We used the Bonferroni outlier test to lower the probability of making a type 1 error, falsely concluding that there is a significant effect of our treatment. From this statistical test, we excluded patients who had EBL or transfusion amounts that were extreme for their respective linear models ($P < 0.05$). Specifically, there were 4 outliers in the control group who lost more than their expected EBL. In addition, there was 1 outlier in the control group who had more than his or her expected transfusion amount. Because we hypothesized that the control group should have higher EBL and transfusion amounts than the treatment group, excluding these outliers resulted in a more conservative test of our hypothesis.

Demographic data between the two groups were compared using a Student *t* test ($\alpha = 0.05$). Hemostatic effects were evaluated using 2 analysis of covariance (ANCOVA) statistical models that accommodated both continuous and categorical variables. In these ANCOVAs, the variable of interest (EBL or transfusion amount) was modeled as a function of treatment (control, QCTP), sex (male, female), scoliosis type (idiopathic, neuromuscular, congenital, syndromic), age, weight, number of vertebrae fused, and surgery duration. When creating these models, we found that surgery duration and the number of vertebrae fused were correlated. However, we decided to keep both factors in the statistical models, because the correlation was not strong (Pearson correlation coefficient, $R = 0.491$). During data analysis, significance was defined as P value of less than 0.05. Estimated marginal means, which are the mean response for each variable adjusted for covariates in the model, and 95% confidence intervals were also calculated in R.

RESULTS

A total of 117 children were identified as eligible for this study: 65 patients for the control group and 52 patients for the treatment group. Demographically, the control and treatment patient groups were similar. There was no difference in mean age, weight, surgery duration, and number of vertebrae fused between the 2 groups (Table 1) ($P > 0.05$).

TABLE 1. Comparison of Kaolin Sponge Treatment and Standard Gauze Control Groups

Characteristic	Treatment Group (n = 52)	Control Group (n = 65)	*P* (α = 0.05)	Total Population (n = 117)
Sex (female:male)	33:19	46:19	…	79:38
Scoliosis type (C:I:N:S)	6:23:17:6	8:30:24:3	…	14:53:41:9
Mean patient age (yr) ± SD (minimum-maximum)	13.91 ± 3.20 (4.0–19.33)	12.70 ± 4.54 (1.5–20.5)	0.093	13.24 ± 4.03
Mean patient weight (kg) ± SD (minimum-maximum)	47.24 ± 19.79 (15.5–104.1)	50.87 ± 30.13 (8.0–124.0)	0.436	49.26 ± 26.01
Mean surgery duration (hr) ± SD (minimum-maximum)	7.00 ± 1.99 (3.28–11.50)	6.34 ± 2.20 (0.95–12.67)	0.094	6.63 ± 2.13
Mean number of vertebrae fused ± SD (minimum-maximum)	10.40 ± 4.35 (3–17)	10.20 ± 4.82 (2–17)	0.811	10.29 ± 4.60

C:I:N:S indicates congenital:idiopathic:neuromuscular:syndromic.

According to the first ANCOVA statistical model, EBL was significantly affected by 3 factors: treatment, number of vertebrae fused, and surgery duration (Table 2). Figure 1 illustrates all factors that significantly affected EBL. Patients packed with QCTP lost 40% less blood than those who received standard gauze (974 mL *vs*. 1620 mL [marginal means]) ($P < 0.001$) (Figure 1A). Blood loss was also positively correlated with surgical duration (Figure 1B) and the number of vertebrae fused (Figure 1C).

Similar results were observed for transfusion amounts. The second ANCOVA model determined that treatment, number of vertebrae fused, and surgery duration significantly affected transfusion amount (Table 3). Surgical cases with QCTP received 42% less transfusion volume than the control group (499 mL *vs*. 862 mL [marginal means]) ($P < 0.01$) (Figure 2A). Transfusion amount was also affected by increased surgical duration (Figure 2B) and the number of vertebrae fused (Figure 2C).

TABLE 2. Estimated Blood Loss Analysis of Covariance Model

	Sum of Squares	*df*	*F*	*P* (α = 0.05)
Treatment*	10,830,606	1	26.9861	9.862e-07*
Sex	845,306	1	2.1062	0.149628
Scoliosis type	419,121	3	0.3481	0.790589
Age	1,163,025	1	2.8979	0.091601
Weight	550,984	1	1.3729	0.243924
Number of vertebrae fused*	2,430,010	1	6.0547	0.015469*
Surgery duration*	14,401,511	1	35.8835	2.855e-08*
Residuals	42,943,443	107		

**Significant.*

DISCUSSION

Massive blood loss, defined as more than 30% estimated blood volume, can occur in nearly 60% of patients undergoing posterior spinal fusion procedures.[33] This intraoperative blood loss may have extensive clinical and financial implications for patients. Previous studies have correlated substantial intraoperative blood loss with a longer procedural time, the administration of blood products, the use of systemic and topical hemostats, and a prolonged hospitalization.[34] When considerable blood loss occurs, transfusions are required, which can carry the risk of hypersensitivity reaction, transfusion-related acute lung injury, and transfusion-associated circulatory overload.[10]

Large financial impacts are also concomitant with blood loss and transfusions. Blood products can cost $1650/unit for packed red blood cells,[35] $81/unit for fresh frozen plasma, and $742/unit for platelets (adjusted for inflation according to U.S. Bureau of Labor Statistics, http://www.bls.gov/data/inflation_calculator.htm, accessed March 4, 2014).[36] In addition, uncontrolled bleeding may lead to a longer operative time, which is charged as $214/min (Susan Mecklenburg, RN, Children's Mercy Hospital, written communication, April 1, 2014). Thus, limiting intraoperative blood loss offers both clinical and financial benefits.

The kaolin-impregnated gauze is currently considered a leading hemostatic agent because of (1) its easy application and removal, (2) its topical action at the site of bleeding, and (3) for its excellent hemostatic ability. First, QCTP is a single radiopaque sponge, which makes it amenable to surgical

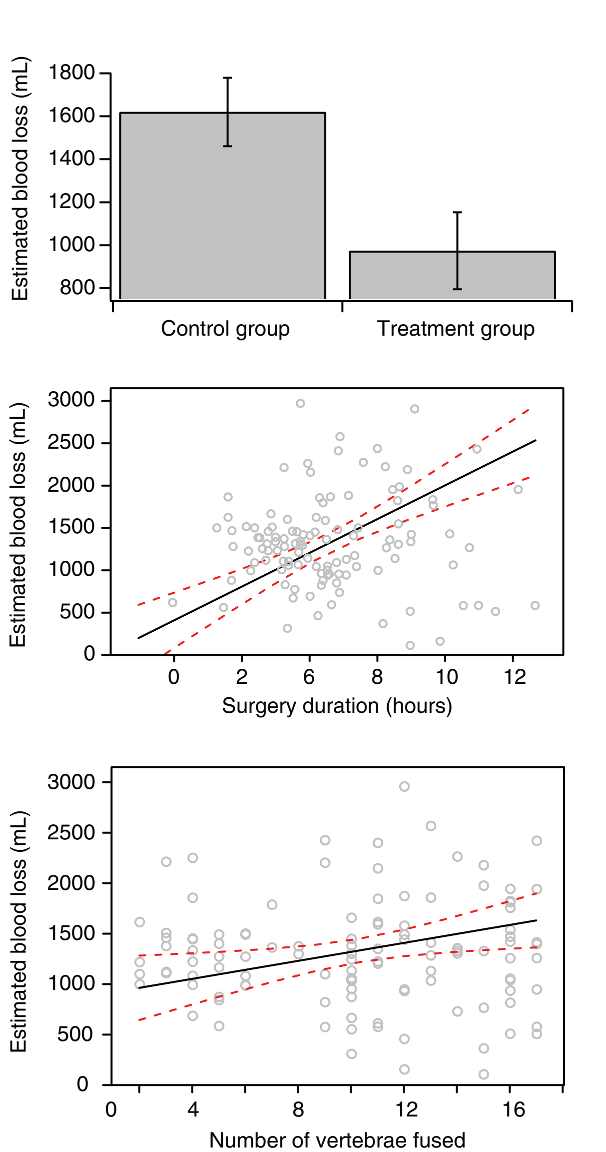

Figure 1. A, Patients with scoliosis treated with the kaolin-impregnated gauze lost significantly less blood than control patients ($P < 0.001$). Gray bars represent estimated marginal means, which characterize estimated blood loss adjusted for all other covariates in the analysis of covariance model. Error bars represent 95% confidence intervals. **B**, Estimated blood loss increased with increased surgical duration for all patients. Dashed lines represent 95% confidence intervals. **C**, Estimated blood loss also increased with the number of vertebrae fused.

TABLE 3. Blood Transfusion Amount Analysis of Covariance Model

	Sum of Squares	*df*	*F*	*P* ($\alpha = 0.05$)
Treatment*	3,441,142	1	8.9354	0.00347*
Sex	1579	1	0.0041	0.94906
Scoliosis type	1,863,186	3	1.6127	0.19074
Age	1923	1	0.0050	0.94380
Weight	1,201,840	1	3.1208	0.08015
Number of vertebrae fused*	1,859,754	1	4.8291	0.03014*
Surgery duration*	2,506,107	1	6.5075	0.01216*
Residuals	41,206,949	107		

**Significant.*

counting practices. Second, topical action is considered superior in safety to systemic activation of coagulation factors such as lysine analogs and aprotinin.[37] Third, many studies have shown the efficacy of kaolin hemostatic dressings in porcine and human trials. In particular, Kheirabadi *et al*[19] compared the efficacy of QuikClot Combat Gauze, which is another widely studied kaolin-impregnated product, with other hemostatic dressings including HemCon, Celox-D, TraumaStat, and a placebo gauze. In these trials, QuikClot Combat Gauze outperformed the others while securing hemostasis for 135 ± 22 minutes after a femoral artery injury in splenectomized swine models. Moreover, kaolin-impregnated gauze has been shown to be safe and effective in a variety of human clinical and prehospital settings.[25,32,38,39] However, our study is the first analysis of the *in vivo* utilization of a reformulated kaolin-impregnated product in pediatric spinal deformity surgery. In addition to kaolin's safe and effective history, our results suggest that packing with a kaolin-impregnated gauze may improve both the clinical and financial outcomes of blood loss in severe pediatric spinal deformity.

Our results indicate that pediatric patients who received QCTP packing during posterior scoliosis surgery lost significantly less blood and received smaller transfusion amounts than a historical control group. No contraindications of using QCTP were noted. However, there are still some limitations to consider. Because QCTP requires clotting factors to be effective, it may not work in cases of dilutional coagulopathy. In combat, an 8% failure rate of a past-generation advanced hemostatic dressings was attributed to coagulopathic patients and the inability to position the dressings over the hemorrhage site.[16] However, recent studies seem to indicate that the kaolin-based products are effective in promoting clotting even in the presence of hemodilution and hypothermia.[24,40,41] Therefore, although dilutional coagulopathy may rarely develop in scoliosis correction surgery, the use of QCTP as packing should function as a preventative measure. Thus, kaolin-impregnated gauze may be a safe and effective routine hemostatic control for posterior scoliosis surgery.

In addition to limiting blood loss and transfusion amounts, a kaolin-impregnated dressing during posterior scoliosis may also reduce costs. Although we did not demonstrate decreased overall cost of surgery, the additional cost of this treatment seems inconsequential. In this study, the typical posterior spine deformity surgery used about 3 QuikClot Trauma Pads priced at $8.30 each (Julie Crookshank, RN, Children's Mercy Hospital, written communication,

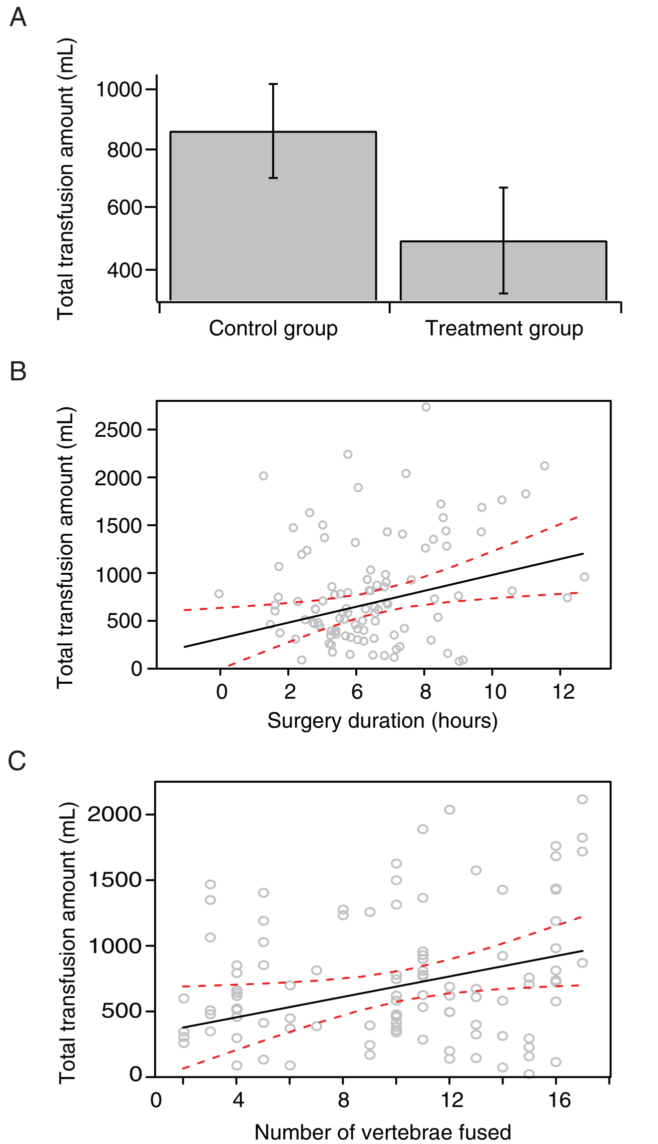

Figure 2. A, Patients with scoliosis treated with the kaolin-impregnated gauze received significantly less total transfusion volume than control patients ($P < 0.01$). Gray bars represent estimated marginal means, which characterize estimated transfusion volume adjusted for all other covariates in the analysis of covariance model. Error bars represent 95% confidence intervals. **B**, Transfusion volume increased with increased surgical duration for all patients. Dashed lines represent 95% confidence intervals. **C**, Total transfusion volume also increased with the number of vertebrae fused.

February 14, 2014). This summates to about $25 total additional cost, which is very negligible compared with overall cost of surgery. Therefore, any reduction of transfusion amount by a kaolin dressing should result in reduced surgical costs.

Regardless of treatment with QCTP, other factors also significantly affected blood loss and transfusion amounts. Previous studies have identified the number of segments fused and surgical duration as predictors for the amount of blood loss.[6,42] These predictions agree with our results. Meert *et al*[2] also identified neuromuscular syndrome to have a higher likelihood of blood loss and blood transfusions. This may be explained by the observation that patients with neuromuscular syndrome generally have more spinal segments repaired.[2,6] Our statistical model controlled for the effects of other covariates, such as the number of spinal segments fused. Therefore, the increased number of vertebrae fused for neuromuscular syndrome–type scoliosis would be taken into account when determining whether scoliosis type affected blood loss and transfusion. Thus, with our statistical model, we found no evidence of type of scoliosis affecting either blood loss or transfusion amount per level fused.

When deciding to use any advanced hemostatic dressing, a number of clinical parameters including the severity of bleeding, the size of the surgical wound, and the possible side effects of the hemostat must be considered prior to its widespread acceptance. For example, a study on blepharoplasty did not find improved hemostasis after using kaolin-impregnated gauze.[43] Oculoplastic surgery may not involve enough bleeding to justify the use of a hemostatic gauze developed for hemorrhage control. On the contrary, some researchers found kaolin-impregnated gauze to be effective for minimally bleeding procedures. Politi *et al*[44] observed less radial artery occlusion, when using kaolin-impregnated gauze after cardiac percutaneous procedures. In spite of these contrasting results for minimal blood loss procedures, we think that posterior scoliosis surgery is an appropriate procedure for using topical hemostatic dressings due to the long time of exposure of vascular tissue and bone.

There are several limitations in this study. First, the retrospective nature of our research required a use of a historical control group. Further research with an adequately powered, randomized trial comparing QCTP *versus* standard gauze packing would unequivocally determine whether QCTP minimizes blood loss. Clinical trials could also determine whether exposure time to QCTP affects blood loss and transfusion volumes, because use of QCTP on the surgical wound was not timed. Second, the study was limited in the type of data available and collected. This study assessed only the inpatient transfusion amounts during and after surgery, so any blood transfusions past the patient's discharge were not captured. Also, blood chemistry data were not consistently reported postoperatively. Therefore, it is inconclusive whether QCTP affects blood chemistry although swine studies have reported that it does not.[24] Finally, the threshold hemoglobin/hematocrit parameters for transfusion were not standardized in this study.

Even with the best of care, posterior scoliosis correction surgery is associated with the risk of excessive bleeding and allogenic transfusions. To mitigate these potential risks, hemostatic controls must be utilized and improvements should be investigated. Our results demonstrate that treatment with the kaolin-impregnated hemostatic dressing may significantly minimize blood loss and transfusion volume in pediatric posterior scoliosis surgery and may be a cost-effective and simple intervention to achieve hemostasis.

➢ Key Points

- This retrospective study on posterior spinal fusion compared 65 patients with pediatric scoliosis who received standard intraoperative wound packing gauze, with 52 patients who received kaolin-impregnated hemostatic dressing (QCTP) for packing.
- Patients who received the kaolin dressing lost significantly less blood and had less total blood transfusion volumes than the control group ($P < 0.01$).
- Blood loss and transfusion volume were approximately 40% less with the use of the hemostatic dressing.
- Our data suggest that the use of this hemostatic dressing during pediatric scoliosis correction surgery may increase safety for the patient without increasing overall cost of surgery.

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