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Analysis of tranexamic acid usage in adult spinal deformity patients with relative contraindications: does it increase the risk of complications?

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OBJECTIVE Complex spinal deformity surgeries may involve significant blood loss. The use of antifibrinolytic agents such as tranexamic acid (TXA) has been proven to reduce perioperative blood loss. However, for patients with a history of thromboembolic events, there is concern of increased risk when TXA is used during these surgeries. This study aimed to assess whether TXA use in patients undergoing complex spinal deformity correction surgeries increases the risk of thromboembolic complications based on preexisting thromboembolic risk factors.

METHODS Data were analyzed for adult patients who received TXA during surgical correction for spinal deformity at 21 North American centers between August 2018 and October 2022. Patients with preexisting thromboembolic events and other risk factors (history of deep venous thrombosis [DVT], pulmonary embolism [PE], myocardial infarction [MI], stroke, peripheral vascular disease, or cancer) were identified. Thromboembolic complication rates were assessed during the postoperative 90 days. Univariate and multivariate analyses were performed to assess thromboembolic outcomes in high-risk and low-risk patients who received intravenous TXA.

RESULTS Among 411 consecutive patients who underwent complex spinal deformity surgery and received TXA intraoperatively, 130 (31.6%) were considered high-risk patients. There was no significant difference in thromboembolic

ABBREVIATIONS AFib = atrial fibrillation; ASD = adult spinal deformity; CHF = congestive heart failure; DVT = deep venous thrombosis; EBL = estimated blood loss; MI = myocardial infarction; PE = pulmonary embolism; PVD = peripheral vascular disease; TXA = tranexamic acid.

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complications between patients with and those without preexisting thromboembolic risk factors in univariate analysis (high-risk group vs low-risk group: 8.5% vs 2.8%, p = 0.45). Specifically, there were no significant differences between groups regarding the 90-day postoperative rates of DVT (high-risk group vs low-risk group: 1.5% vs 1.4%, p = 0.98), PE (2.3% vs 1.8%, p = 0.71), acute MI (1.5% vs 0%, p = 0.19), or stroke (0.8% vs 1.1%, p > 0.99). On multivariate analysis, high-risk status was not a significant independent predictor for any of the thromboembolic complications.

CONCLUSIONS Administration of intravenous TXA during the correction procedure did not change rates of thromboembolic events, acute MI, or stroke in this cohort of adult spinal deformity surgery patients.

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KEYWORDS adult spinal deformity surgery; antifibrinolytic therapy; high-risk; thromboembolic complications; tranexamic acid

Adult spinal deformity (ASD) surgery has markedly increased in frequency in the past decade (3.4-fold).[1,2] Despite advancements in surgical technique, ASD surgery remains a substantial burden for patients, with a greater than 55% risk of developing minor complications, a 44% risk of developing major complications, and a death rate of nearly 1%.[3–5] One of the major concerns of ASD surgeries is that the estimated blood loss (EBL) can range from 1200 to 11,000 mL, leading to blood transfusion rates ranging from 50% to 81%.[6–8] Although blood transfusion is effective in the replacement of blood loss during deformity surgery, it has an increased risk of transfusion reaction, viral or bacterial transmission, and morbidity, as well as increased hospital costs.[9,10]

Tranexamic acid (TXA) utilization during ASD surgery has significantly reduced volumes of intraoperative and postoperative blood loss as well as the need for blood transfusions despite its not being in broad use for these procedures.[11–22] Theoretically, TXA can increase the risk of thrombotic complications because of its antifibrinolytic mechanism of action;[23] however, previous studies have not shown a significant increase in thromboembolic complications in patients administered TXA during ASD surgery.[18–21] These studies were not clear on the indication for using TXA in high-risk patients, such as those having a history of arterial thromboembolic complications. This clinical question is very important, as the incidence of high-risk patients undergoing ASD surgery continues to increase and the use of TXA in these high-risk patients is still controversial among surgeons and anesthesiologists worldwide.[1] Also, many of these high-risk patients are on anticoagulation regimens, which increases the risk of bleeding during surgery if such therapy is not well optimized.[24]

In the current study, we aimed to compare the risk of postoperative thromboembolic complications in high-risk versus low-risk patients who received intravenous TXA during ASD surgery.

Methods

This is a retrospective review of a prospective multicenter ASD database and was approved by the University at Buffalo Institutional Review Board. The database includes consecutive patients at 21 centers in the United States and Canada who were operated on between August 2018 and October 2022. At the time of hospital admission, informed consent for patient data to be published was provided by each patient or a legally authorized representative. We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[25]

Patient Selection

This study included adults ≥ 18 years of age who received TXA during complex ASD surgery for thoracolumbar ASD, defined as having ≥ 1 of the following characteristics: 1) > 12 levels fused or at least one three-column osteotomy or anterior column release; 2) geriatric deformity surgery, defined as age > 65 years and at least 7 levels fused; and 3) severe radiographic deformity, defined as at least one of the following: pelvic incidence minus lumbar lordosis ≥ 25°, T1 pelvic angle ≥ 30°, sagittal vertical axis ≥ 15 cm, thoracic Cobb angle ≥ 70°, or thoracolumbar Cobb angle ≥ 50°. Patients were excluded if they had an inflammatory or autoimmune disease, a neuromuscular disorder (e.g., Parkinson's disease), neoplasm, infection, syndromic scoliosis, or posttraumatic deformities.

Data Extraction and Definition of Variables

The demographic data collected included the patient's age, sex, BMI, comorbidities (history of atrial fibrillation [AFib], blood clots, cancer, metastasis, congestive heart failure [CHF], stroke, myocardial infarction [MI], and peripheral vascular disease [PVD]), smoking status, and history of previous lumbar surgery. The perioperative data (within 90 days), which included EBL, total thromboembolic complications, cardiac arrest, deep venous thrombosis (DVT), pulmonary embolism (PE), and stroke, were also recorded. Patients were classified as high-risk if they had a history of one of the following conditions before surgery: AFib, PE, DVT, cancer, metastasis, CHF, stroke, MI, or PVD. Any patient who did not meet the high-risk patient criteria was considered low-risk. The thromboembolic complications were recorded at hospital admission and within 90 days from the date of surgery.

Statistical Analysis

All statistical analyses were performed using RStudio (https://posit.co/). First, univariate analysis was performed, with the continuous variables presented as mean and standard deviation and differences between high- and low-risk patient groups compared using the Student t-test. The categorical variables are presented as frequency and percentages, and both groups were compared using the chi-square

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TABLE 1. Univariate analysis comparing baseline data between patients who did and did not receive TXA when undergoing ASD surgery

Variable	TXA (n = 411)	No TXA (n = 59)	p Value
Age, yrs, mean (SD)	59.5 (16.1)	66.8 (10.1)	**<0.001**
Male sex	124 (30.2)	21 (35.6)	0.4
AFib	28 (6.8)	4 (6.8)	0.99
Blood clots	13 (3.2)	13 (22.0)	**<0.001**
Cancer	59 (14.4)	12 (20.3)	0.23
Metastasis	11 (2.7)	0	0.2
CHF	4 (1.0)	3 (5.1)	**0.01**
Stroke	5 (1.2)	1 (1.7)	0.8
MI	12 (2.9)	2 (3.4)	0.8
PVD	2 (0.5)	0	0.6
Current smoker	21 (5.1)	5 (8.5)	0.3
BMI, mean (SD)	26.9 (5.7)	29.1 (4.9)	**0.002**
Revision surgery	171 (41.6)	23 (39.0)	0.7

Values are presented as number of patients (%) unless indicated otherwise. Boldface type indicates statistical significance.

test. This analysis was followed by several multivariate logistic regression models, with the dependent variables being thromboembolic complications, cardiac arrest, DVT, PE, and stroke. Furthermore, we performed a multivariate linear regression model to identify significant predictors of increased blood loss. The independent variables that were included in all multivariate analysis regression models were high-risk patients; age; sex; smoking status; previous revision surgery; and history of AFib, blood clots, cancer, metastasis, CHF, stroke, MI, and PVD. The results of the multivariate analyses are presented as odds ratios, 95% confidence intervals, and p values. Furthermore, we performed a multivariate linear regression model to find independent predictors of increased blood loss. A p value < 0.05 was considered statistically significant.

Results

Study Population

Of the 470 patients who had ASD surgery during the study time frame, 411 patients received TXA. The baseline data for patients who did and did not receive TXA are summarized in Table 1. Of these 411 patients, 130 (31.6%) were considered high-risk patients. On univariate analysis, there was no significant difference between the groups in terms of total TXA dosage ($p = 0.88$). Table 2 summarizes the univariate analysis of baseline, intraoperative, and postoperative data between the low-risk and high-risk patients. Blood loss was significantly greater in the high-risk group on univariate analysis ($p < 0.001$); however, this was not significant on multivariate analysis ($p = 0.35$).

TABLE 2. Univariate analysis comparing the baseline, intraoperative, and postoperative data between low-risk and high-risk patients who underwent ASD surgery

Variable	Low Risk (n = 281)	High Risk (n = 130)	p Value
Preop data			
Age, yrs, mean (SD)	57.1 (16.9)	64.7 (12.7)	**<0.001**
Male sex	82 (29.2)	42 (32.3)	0.61
AFib	0	28 (21.5)	**<0.001**
Blood clots	0	13 (10.0)	**<0.001**
Cancer	0	59 (45.4)	**<0.001**
Metastasis	0	11 (8.5)	**<0.001**
CHF	0	4 (3.1)	**0.02**
Stroke	0	5 (3.8)	**0.01**
MI	0	12 (9.2)	**<0.001**
PVD	0	2 (1.5)	0.19
Current smoker	0	21 (16.2)	**<0.001**
BMI, mean (SD)	26.5 (5.6)	27.9 (5.8)	**0.02**
Revision	112 (39.9)	59 (45.4)	0.34
Intraop & postop data			
Total TXA dosage, mg, mean (SD)	4172.8 (2225.4)	4207.7 (2279.4)	0.88
EBL, mL, mean (SD)	1455.4 (1154.4)	1642.7 (1263.5)	**<0.001**
Thromboembolic complications	8 (2.8)	11 (8.5)	0.45
Cardiac arrest	0	2 (1.5)	0.19
DVT	4 (1.4)	2 (1.5)	0.98
PE	5 (1.8)	3 (2.3)	0.71
Stroke	3 (1.1)	1 (0.8)	>0.99

Values are presented as number of patients (%) unless indicated otherwise. Boldface type indicates statistical significance.

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TABLE 3. Multivariate model analyzing the predictors of postoperative thromboembolic complications

Variable	OR	95% CI		p Value
		Lower Bound	Upper Bound	
High risk	0.985	0.871	1.114	0.81
Age	1.002	1.000	1.003	**0.02**
Male sex	0.974	0.931	1.020	0.27
AFib	0.966	0.861	1.084	0.56
Blood clots	1.018	0.879	1.179	0.81
Cancer	0.999	0.892	1.118	0.98
Metastasis	0.967	0.819	1.142	0.69
CHF	1.087	0.862	1.371	0.48
Stroke	1.153	0.953	1.395	0.14
MI	1.020	0.874	1.191	0.80
PVD	1.567	1.143	2.149	**0.01**
Current smoker	1.072	0.936	1.228	0.32
BMI	1.005	1.001	1.008	**0.02**
Revision	1.001	0.960	1.044	0.95

Boldface type indicates statistical significance.

TABLE 5. Multivariate model analyzing the predictors of postoperative DVT

Variable	OR	95% CI		p Value
		Lower Bound	Upper Bound	
High risk	0.944	0.879	1.013	0.11
Age	1.001	1.000	1.001	0.15
Male sex	0.977	0.952	1.003	0.08
AFib	1.027	0.961	1.098	0.43
Blood clots	1.027	0.944	1.118	0.53
Cancer	1.022	0.958	1.090	0.52
Metastasis	1.041	0.946	1.145	0.41
CHF	0.957	0.837	1.093	0.52
Stroke	0.995	0.891	1.110	0.92
MI	1.130	1.033	1.235	**0.01**
PVD	1.057	0.881	1.268	0.55
Current smoker	1.144	1.058	1.237	**<0.001**
BMI	1.001	0.999	1.003	0.24
Revision	0.996	0.972	1.020	0.74

Boldface type indicates statistical significance.

Postoperative Thromboembolic Complications

There was no significant difference between the high-risk and low-risk groups in terms of postoperative thromboembolic complications on univariate (p = 0.45) and multivariate (p = 0.81) analyses. Furthermore, we stratified the patients who had one risk factor (6 thromboembolic complications in 106 patients) versus multiple risk factors (2 thromboembolic complications in 24 patients) and did not find a significant difference in postoperative thromboembolic complications between the groups (p = 0.62). On multivariate analysis, older age (OR 1.002, 95% CI 1–1.003; p = 0.02), PVD (OR 1.567, 95% CI 1.143–2.149; p = 0.01), and increased BMI (OR 1.005, 95% CI 1.001–1.008; p = 0.02) were independent predictors of postoperative thromboembolic complications. The results of the multivariate analysis are summarized in Table 3.

TABLE 4. Multivariate model analyzing the predictors of postoperative cardiac arrest or acute MI

Variable	OR	95% CI		p Value
		Lower Bound	Upper Bound	
High risk	0.970	0.937	1.005	0.1
Age	1.000	1.000	1.000	0.62
Male sex	1.003	0.989	1.016	0.70
AFib	1.031	0.997	1.066	0.07
Blood clots	1.021	0.978	1.065	0.34
Cancer	1.041	1.008	1.075	**0.02**
Metastasis	1.028	0.980	1.078	0.26
CHF	1.183	1.106	1.264	**<0.001**
Stroke	1.005	0.952	1.062	0.85
MI	0.990	0.947	1.035	0.66
PVD	1.537	1.404	1.683	**<0.001**
Current smoker	1.025	0.986	1.065	0.22
BMI	1.000	0.999	1.001	0.64
Revision	1.001	0.989	1.013	0.83

Boldface type indicates statistical significance.

Postoperative Cardiac Arrest or Acute MI

There was no significant difference between the high-risk and low-risk groups in terms of postoperative cardiac arrest or acute MI on univariate (p = 0.19) and multivariate (p = 0.1) analyses. On multivariate analysis, history of cancer (OR 1.041, 95% CI 1.008–1.075; p = 0.02), CHF (OR 1.183, 95% CI 1.106–1.264; p < 0.001), and PVD (OR 1.537, 95% CI 1.404–1.683; p < 0.001) were independent predictors of postoperative cardiac arrest or acute MI. The results of the multivariate analysis are summarized in Table 4.

Postoperative DVT

There was no significant difference between the high-risk and low-risk groups in terms of postoperative DVT on univariate (p = 0.98) and multivariate (p = 0.11) analyses. On multivariate analysis, current smokers (OR 1.144, 95% CI 1.058–1.237; p < 0.001) and history of MI (OR 1.130, 95% CI 1.033–1.235; p = 0.01) were independent predictors of postoperative DVT. The results of the multivariate analysis are summarized in Table 5.

Postoperative PE

There was no significant difference between the high-risk and low-risk groups in terms of postoperative PE in univariate (p = 0.71) and multivariate (p = 0.12) analyses. On multivariate analysis, higher BMI (OR 1.003, 95% CI 1–1.005; p = 0.02) and history of stroke (OR 1.171, 95% CI 1.033–1.328; p = 0.01) were independent predictors of postoperative PE. The results of the multivariate analysis are summarized in Table 6.

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TABLE 6. Multivariate model analyzing the predictors of postoperative PE

Variable	OR	95% CI		p Value
		Lower Bound	Upper Bound	
High risk	1.067	0.984	1.157	0.12
Age	1.001	1.000	1.002	0.13
Male sex	0.992	0.963	1.023	0.62
AFib	0.929	0.861	1.003	0.06
Blood clots	0.983	0.892	1.083	0.73
Cancer	0.936	0.869	1.008	0.08
Metastasis	0.919	0.824	1.025	0.13
CHF	0.968	0.830	1.128	0.67
Stroke	1.171	1.033	1.328	**0.01**
MI	0.928	0.837	1.028	0.15
PVD	0.967	0.786	1.191	0.75
Current smoker	0.923	0.844	1.010	0.08
BMI	1.003	1.000	1.005	**0.02**
Revision	1.018	0.991	1.047	0.20

Boldface type indicates statistical significance.

TABLE 7. Multivariate model analyzing the predictors of postoperative stroke

Variable	OR	95% CI		p Value
		Lower Bound	Upper Bound	
High risk	1.003	0.945	1.064	0.91
Age	1.001	1.000	1.001	0.11
Male sex	0.999	0.977	1.021	0.93
AFib	0.981	0.928	1.037	0.50
Blood clots	0.988	0.921	1.061	0.74
Cancer	1.002	0.949	1.058	0.94
Metastasis	0.985	0.909	1.067	0.71
CHF	0.991	0.887	1.109	0.88
Stroke	0.982	0.896	1.076	0.69
MI	0.985	0.914	1.062	0.70
PVD	1.001	0.860	1.165	0.99
Current smoker	0.994	0.931	1.061	0.86
BMI	1.000	0.998	1.002	0.89
Revision	0.982	0.962	1.002	0.07

Postoperative Stroke

There was no significant difference between the high-risk and low-risk groups in terms of postoperative stroke in univariate ($p > 0.99$) and multivariate ($p = 0.9$) analyses. On multivariate analysis, there were no independent predictors of postoperative stroke. The results of the multivariate analysis are summarized in Table 7.

Discussion

In this large multicenter cohort of ASD surgery patients, intravenous TXA administration in high-risk patients (e.g., history of AFib, venous thromboembolism, or stroke) did not increase the risk of postoperative thromboembolic events compared with that for low-risk patients.

The effectiveness of TXA administration in the reduction of intraoperative bleeding and blood transfusion during ASD surgeries is well established in the literature.[11–22] Although TXA safety in ASD surgery has been studied in multiple retrospective studies and prospective randomized controlled trials, these studies included small sample sizes (32–132 patients) and did not focus on high-risk patients.[11,14] Furthermore, to our knowledge, all the randomized controlled trials on this topic specifically excluded patients with risk factors for venous thromboembolism (high-risk patients).[14,17–19] Additionally, several meta-analyses were published on this topic, none of which detected an increased risk of thromboembolic complications in patients who had ASD surgery with TXA; again, none of these studies focused on high-risk patients.[12,13,15]

TXA in ASD Surgery and Blood Loss

Many studies showed that the administration of TXA is associated with a reduction of intraoperative and postoperative blood loss.[11–22] However, to our knowledge, no previous study has compared blood loss in high-risk versus low-risk patients who have undergone ASD surgery with TXA administration. In this study, on univariate analysis, there was significantly more blood loss in high-risk patients than in low-risk patients ($p < 0.001$); however, on multivariate analysis, patients having a high risk of a thromboembolic event was not an independent significant predictor of increased blood loss ($p = 0.35$). Furthermore, blood loss became insignificant in multivariate analysis because of the effect of the confounding factors.

TXA in ASD Surgery and Thromboembolic Complications

Some studies reporting on the use of TXA in ASD did not focus on postoperative thromboembolic complications, or these complications were one of the secondary outcomes evaluated.[12,15] In the randomized controlled trial conducted by Carabini et al., no significant difference was noted in thromboembolic complications between patients administered TXA versus the placebo group (no TXA).[14] In another randomized controlled trial on the use of TXA in ASD surgeries, Peters et al. also did not find significant differences in thromboembolic complications between groups, although 1 patient developed PE in the TXA group versus none in the placebo group.[17] Furthermore, the same results were replicated in the randomized controlled trial conducted by Colomina et al.[18] These randomized controlled trials had small sample sizes and excluded high-risk patients.[14,17,18] In a multicenter retrospective analysis of prospective data collected by Soroceanu et al., no significant difference in thromboembolic complications was reported between the TXA group and the control group.[21] In another retrospective study, Pernik et al. showed similar results.[20] In the meta-analyses performed by Li et al. and Lu et al., no significant differences in terms of thromboembolic complications after adult spine surgery were found between patients who received antifibrinolytics and those who did not.[13,22] Again, none of these studies focused on patients who had a high risk of developing thromboembolic complications.[13,20–22] In the current study of 411 pa-

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tients who received TXA during ASD surgery, we did not find a significant difference in total thromboembolic complications or rates of stroke, cardiac arrest or MI, DVT, and PE between high-risk and low-risk patients on multivariate analysis.

Implications for Practice

The current study shows that TXA administration in high-risk patients undergoing ASD surgery is not associated with an increased risk of the thromboembolic complications mentioned above. Still, there are serious concerns in the healthcare system for patients with increased blood loss and, consequently, an increased need for blood transfusion.[9] "Blood loss prophylaxis," a term that has recently been used among surgeons,[26] is as important as infection prophylaxis. Perioperative antibiotics are used for infection prophylaxis,[27] and our study shows that it is time to use antifibrinolytic therapy, such as TXA, for blood loss prophylaxis. It is well established that the use of TXA significantly reduces blood loss and blood transfusion;[11–22] however, its utilization in high-risk patients undergoing ASD surgery is still controversial among spine surgeons and anesthesiologists. These high-risk patients are at risk of increased blood loss compared with low-risk patients because they are commonly taking anticoagulants for their underlying conditions.[28] The findings of this study should be recognized by spine surgeons, anesthesiologists, internists, and cardiologists for optimal management of high-risk patients undergoing ASD surgeries.

Limitations

Our retrospective analysis does have limitations. The high-risk patients who received TXA might have included some patients with a minor thromboembolic history, as shown in Table 1, which might indicate self-selection by the surgeons and anesthesiologists and could have introduced selection bias. Another limitation is the thromboembolic risk factor timing before the ASD surgery. For example, the risk for a patient who had a DVT 10 years before the index surgery is not as high as that for a patient who had a DVT a few months prior to surgery. Despite each of the patients having their own clinical scenario, our threshold was very low in defining high-risk patients to capture the largest number of high-risk patients. Specifically, our stratification of high-risk may be too narrow; there may be higher-risk patients in whom TXA should not be used. Furthermore, for some risk factors, the number of patients was insufficient to achieve conclusive results using multivariate regression analysis. Finally, TXA use in spine surgery increased throughout the study period, so this might have introduced some selection bias with increased use of TXA in high-risk patients during the end of the study period.

Conclusions

Our study provides evidence supporting the safety of intravenous TXA administration in high-risk patients undergoing ASD surgery. The results of this study indicate that TXA utilization during ASD surgery was not associated with a significant increase in postoperative thromboembolic events across a large cohort of high-risk patients.

Appendix

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Disclaimer

Although the effectiveness of TXA administration during ASD surgeries in the reduction of intraoperative bleeding and blood transfusion, as discussed in this study, is well established in the literature, this indication has not received approval from the United States Food and Drug Administration.

Disclosures

Dr. Mullin reported consulting fees for SI-Bone and Medtronic. Dr. Smith reported grants from DePuy Synthes during the conduct of the study; and personal fees from ZimVie, NuVasive, SeaSpine, Cerapedics, Carlsmed, and Medtronic; grants from AO Spine, NREF, SeaSpine, and NuVasive; and stock ownership in NuVasive and Alphatec outside the submitted work. Dr. Kelly reported honoraria from Wolters Kluwer and travel expenses from AO Spine. Dr. Diebo reported personal fees from Spineart, Spinevision, and Clariance; and grants from Medtronic and Alphatec outside the submitted work. Dr. Line reported personal fees from ISSG outside the submitted work. Dr. V. Lafage reported consulting fees from Alphatec and Globus Medical; royalties from NuVasive; lecture fees from Johnson & Johnson, Stryker, and Implanet; ethics committee member of ISSG; and committee member of SRS outside the submitted work. Mr. R. Lafage reported personal fees from Carlsmed outside the submitted work. Dr. Klineberg reported consulting fees from DePuy Synthes, Stryker Spine, Medtronic, SeaSpine, SI-Bone, and Agnovos; royalties from Stryker Spine; fellowship support from Medtronic and AONA Spine (paid to previous institution); stock ownership in MMI and Relatable; speaker fees from AONA Spine; and board of directors of AONA Spine, SRS, and IMAST outside the submitted work. Dr. Kim reported grants from ISSGF (paid to institution); royalties and license fees from Zimmer Biomet, K2M/Stryker, and Acuity Surgical; consulting fees from NuVasive; leadership fees from Vivex Biologics and Aspen Medical; and fellowship support from AO Spine (paid to institution) during the conduct of the study. Dr. Passias reported personal fees from AlloSource, Medtronic, Royal Biologics, Spine Wave, Terumo, and Globus Medical; grants from CSRS; and nonfinancial support from Spine and Zimmer outside the submitted work. Dr. Gum reported consulting fees from Acuity, DePuy, Medtronic, NuVasive, Stryker, FYR Medical, and Expanding Innovations; royalties from Acuity, Medtronic, and NuVasive; stock ownership in FYR Medical and Cingulate Therapeutics; honoraria from Pacira Pharmaceuticals, Baxter, NASS, Broadwater, and MIMEDX; speaker fees from Kyana; staff physician for Norton Healthcare; travel funding from Fischer Owen Fund; patent issued for Medtronic; advisory board member for Medtronic, National Spine Health Foundation, and FYR Medical; journal reviewer for *The Spine Journal*, *Spine Deformity*, and *Global Spine Journal*; and research support from Alan L. & Jacqueline B. Stuart Spine Center, Biom'Up, Cerapedics Inc., Empirical Spine Inc., Medtronic, National Spine Health Foundation, Pfizer, SRS, Stryker, and Texas Scottish Rites Hospital. Dr. Kebaish reported personal fees from DePuy Synthes and Ethicon; and royalties from Stryker, Orthofix, and SpineCraft outside the submitted work. Dr. Eastlack reported shareholder for Alphatec; personal fees from Aesculap, NuVasive, SI-Bone, SeaSpine, Neo, Silony, Medtronic, DePuy, Biedermann Motech, and Spinal Elements; and royalties from Globus outside the submitted work. Dr. Daniels reported personal fees from Stryker, Medtronic, and Spineart; and grants from Alphatec and Orthofix outside the submitted work. Dr. Mundis reported consulting fees from NuVasive, SeaSpine, Carlsmed, SI-Bone, and Viseon; royalties from NuVasive, SeaSpine, and Stryker; scientific

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advisory board of NuVasive, SeaSpine, and Carlsmed; and stock/stock options in NuVasive, Alphatec Spine, and Orthofix during the conduct of the study; CEO of Global Spine Outreach; president of San Diego Spine Foundation; and board member of San Diego Orthopaedic Society. Dr. Protopsaltis reported consulting fees from Globus, NuVasive, Medtronic, and Stryker K2M; royalties from Altus; and stock ownership in OnPoint Surgical outside the submitted work. Dr. Gupta reported personal fees from Innomed, DePuy, Globus, and Medtronic; nonfinancial support from DePuy, Globus, Zimmer, and SRS (board of directors, travel to meetings); honoraria from Wright State (grand rounds), AO Spine (travel to meetings), and LSU (grand rounds); and stock ownership in J&J outside the submitted work. Dr. Lewis reported personal fees from Stryker, Medtronic, DePuy Synthes, and AO Spine; and program/fellowship support from Stryker, Medtronic, and DePuy Synthes outside the submitted work. Dr. Schwab reported consulting fees from Zimmer Biomet, Mainstay Medical, and MSD; royalties from Zimmer Biomet, MSD, and Stryker; executive committee of ISSG; and shareholder in VFT Solutions and SeaSpine outside the submitted work. Dr. Lenke reported consulting fees from Medtronic and Acuity Surgical outside the submitted work; patents for Medtronic and Acuity Surgical with royalties paid; grants from Setting Scoliosis Straight Foundation, ISSGF, and AO Spine; board appointments in National Spine Health Foundation, Global Spine Outreach, and Setting Scoliosis Straight Foundation; philanthropic/society research funding from Fox Family (Prospective Pediatric Spinal Deformity study), AO Spine, and SRS; and travel/accommodations support from AO Spine, BroadWater, and SRS. Dr. Shaffrey reported grants from ISSGF to Duke University during the conduct of the study; and personal fees from NuVasive, Medtronic, SI-Bone, and Proprio outside the submitted work. Dr. Bess reported grants from DePuy Synthes, Stryker, NuVasive, and ISSGF during the conduct of the study; and grants from Medtronic, Globus, Carlsmed, SeaSpine, SI-Bone, and ISSGF outside the submitted work. Dr. Ames reported royalties from Zimmer Biomet Spine, DePuy Synthes, K2M, Medicrea, Next Orthosurgical, NuVasive, and Stryker; consulting fees from DePuy Synthes, Medtronic, Medicrea, K2M, Agada Medical, and Carlsmed; research fees from DePuy Synthes, ISSG, and Titan Spine; grants from SRS; editorial board of *Operative Neurosurgery* and *Neurospine*; executive committee of ISSG; director of Global Spinal Analytics; and chair of SRS Safety and Value Committee outside the submitted work. Dr. Burton reported personal fees from DePuy Spine, Globus, and Blue Ocean Spine; stock options in Progenerative Medical; and board of directors of SRS and ISSG outside the submitted work.

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Supplemental Information

Previous Presentations

Portions of this work were previously presented in abstract form at the Scoliosis Research Society Annual Meeting, Seattle, Washington, September 6–9, 2023.

Data Availability

Data that support the study findings are available from the corresponding author upon reasonable request.

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