Risk Factors for and Prediction of Early Thromboembolic Disease Following Adult Spinal Deformity Surgery

An Analysis of >7,400 Patients with Spinal Deformity

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Background: The aim of this study was to determine the risk factors associated with deep vein thrombosis (DVT) or pulmonary embolism (PE) within 30 days after multilevel adult spinal deformity (ASD) surgery and to develop risk prediction models.

Methods: A retrospective observational study was conducted using the American College of Surgeons National Surgical Quality Improvement Program database from 2010 to 2019. Current Procedural Terminology (CPT) codes 22843 and 22844 were used to query the database and to identify patients who underwent surgical correction of ASD with ≥7 levels of posterior instrumentation. The primary outcomes were the incidences of, and risk factors for, postoperative DVT and PE. Multiple logistic regression was utilized to identify variables associated with an elevated risk of DVT or PE within 30 days after surgery and to develop prediction models for assessing risk.

Results: A total of 7,445 patients (56% female; 73% Caucasian; mean age, 61 years) met the inclusion criteria. Postoperatively, the rate of any venous thromboembolism (VTE; i.e., DVT or PE) was 3.4% (254 patients), the rate of DVT was 2.0% (151 patients), and the rate of PE was 1.7% (127 patients). The following independent predictors of any VTE were identified: weight (odds ratio [OR], 1.054; 95% confidence interval [CI]: 1.027 to 1.081), age per decade of life (OR, 1.106; 95% CI: 1.012 to 1.209), body mass index (BMI; OR, 1.032; 95% CI: 1.015 to 1.049), medicated hypertension (OR, 1.523; 95% CI: 1.168 to 1.987), chronic corticosteroid use (OR, 2.654; 95% CI: 1.848 to 3.812), American Society of Anesthesiologists (ASA) class (OR, 1.768; 95% CI: 1.426 to 2.192), and total operative time (OR, 1.002; 95% CI: 1.002 to 1.003) ($p < 0.05$ for all). When incorporated into a single model, total operative time, BMI, ASA class, and chronic corticosteroid use were associated with VTE risk.

Conclusions: Four major risk factors were identified as being associated with postoperative VTE risk in patients undergoing surgery for ASD. Corticosteroid use for a chronic medical condition was the strongest predictor of VTE risk, followed by ASA class, BMI, and operative time. Knowledge of these risk factors can aid in preoperative risk assessment, informed consent, and medical decision-making, such as in determining the clinical thresholds for VTE testing and chemoprophylaxis.

Level of Evidence: Prognostic Level III. See Instructions for Authors for a complete description of levels of evidence.

Deep vein thrombosis (DVT) and pulmonary embolism (PE), collectively known as venous thromboembolism (VTE), are major postoperative complications, with >500,000 cases of VTE resulting in 100,000 VTE-related deaths reported annually in the U.S.[1-3]. The adoption of a standardized protocol for VTE management following spine surgery is

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challenging because of an incomplete understanding of patient-specific risk factors for postoperative VTE and the delicate balance between hypercoagulability and bleeding complications such as epidural hematomas[4-8].

Advancements in spinal instrumentation, alignment objectives, and patient counseling have improved clinical outcomes for patients with adult spinal deformity (ASD)[9]. However, fusion and revision surgeries involving ≥9 vertebral levels have increased 141% from 2004 to 2014, with a 460% increase among patients 65 to 84 years old[10]. These surgeries have been associated with higher rates of complications, including VTE[10-15].

The factors that are associated with, and predictive of, VTE risk in patients undergoing multilevel surgery for ASD remain understudied. Given the paucity of available data on VTE risk after multilevel ASD surgery, and the clinical necessity of such information, we aimed to identify the risk factors associated with VTE and to develop a prediction model utilizing those risk factors.

Materials and Methods

Data Source

The American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) collects >150 variables from >600 hospitals in the U.S., with preoperative to 30-day postoperative data extracted by trained clinical reviewers. The NSQIP has developed processes to ensure data accuracy, including interrater reliability audits of selected sites[16]. The mean time to VTE following spinal surgery has been reported to be within 10 days after surgery[17]. Therefore, the NSQIP 30-day follow-up period is adequate for identifying postoperative VTEs, and those occurring >30 days postoperatively are unlikely to be attributable to surgery.

Cohort Selection

This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines[18]. This study focused on procedures involving greater levels of deformities, which require more instrumentation and a generally longer operative time, resulting in a higher likelihood of VTE, as shown in the literature[19]. Because cases of spinal deformity are billed according to the number of levels involved (i.e., <3, 3 to 6, 7 to 12, or >12), patients ≥18 years old who underwent surgical correction of ASD with ≥7 levels of correction from 2010 to 2019 were identified using Current Procedural Terminology (CPT) codes 22843 (posterior segmental instrumentation for 7 to 12 vertebral segments) and 22844 (posterior segmental instrumentation for ≥13 vertebral segments). Patients who had an American Society of Anesthesiologists (ASA) class of 6, disseminated cancer, or a history of transplant surgery or who underwent procedures involving intraperitoneal chemotherapy or procedures for acute trauma were excluded as per the NSQIP user file.

Data Collection

Patient demographics, comorbidities, preoperative laboratory values, functional status, surgical variables, and postoperative complications were extracted using the NSQIP Participant Use Data File (Table I). The selection of variables was made in accordance with the NSQIP data dictionary and a prior publication on the risk factors for perioperative complications and mortality in patients undergoing ASD surgery[20].

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics (version 26). Patient demographics, comorbidities, operative indications, and preoperative and postoperative data were analyzed using descriptive statistics and univariate analysis. Next, a Spearman correlation analysis was performed to determine which demographic, comorbidity, or surgical variables were correlated with the incidence of DVT, PE, or any VTE. Variables that were observed to be significantly correlated with each outcome were evaluated using univariate logistic regression in order to determine and characterize the risk ratios and odds ratios. An independent-samples t test was used to compare parametric continuous variables, and a Mann-Whitney test was used to compare nonparametric variables between patients with a VTE and those without a VTE. Chi-square analysis was used similarly to compare the frequency of VTE occurrence for binary variables. Multiple logistic regression with forward entry was then used to develop a final model based on the variables that were identified to be independently associated with VTE risk. Final model selection was based on the best model fit (i.e., the model with the highest accuracy and lowest error). This model was developed using an 80/20 split strategy whereby 80% of the VTE cases were randomly selected and matched to the same number of cases randomly selected from patients without a VTE (the training data set)[21-23]. During each successive step of model development, variables were excluded if they did not significantly contribute to improved model accuracy as a result of a lack of significance in the model or if they increased model error. Next, a receiver operating characteristic (ROC) curve was created to test the ability of the model to predict VTE occurrence via the calculation of the area under the curve (AUC). AUC metrics were interpreted as negligible (0.5 to 0.59), poor (0.6 to 0.69), fair (0.7 to 0.79), good (0.8 to 0.89), or excellent (0.9 to 1.0)[21,22]. The AUC metrics were utilized to test the full model and to evaluate the individual prediction variables selected for the model. To further test the model, the remaining 20% of the VTE cases that were not selected for the initial model were matched to 3 separate, randomly selected test groups of patients from the population without a VTE to confirm whether the model yielded statistically similar AUC metrics (the validation data sets). Significance was set at $p < 0.05$ for all analyses.

Results

Demographics and Risk Factor Prevalence (Table I)

The inclusion criteria were met by 7,445 patients. The mean age was 61 years. The mean operative time (and standard deviation) was 350 ± 150 minutes. The most prevalent preoperative risk factors were a history of medicated hypertension (57.25%), diabetes (24.04%), tobacco use within 1 year prior to

TABLE I Patient Demographics*

Demographics	
Total no. of patients	7445
Sex	
Male	3276 (44.00%)
Female	4169 (56.00%)
Age *(yr)*	61.19 ± 15.31
Height *(cm)*	165.79 ± 11.15
Weight *(kg)*	80.99 ± 21.86
BMI *(kg/m²)*	29.42 ± 6.91
Race	
Caucasian	5469 (73.46%)
African American	657 (8.82%)
Hispanic	349 (4.69%)
Native American	34 (0.46%)
Asian	135 (1.81%)
Other/not reported†	801 (10.76%)
Comorbidities and functional status	
Bleeding disorder	205 (2.75%)
Smoking‡	1346 (18.08%)
Diabetes	1790 (24.04%)
Dialysis	68 (0.91%)
Dyspnea	524 (7.04%)
COPD	453 (6.08%)
Congestive heart failure	68 (0.91%)
Medicated hypertension	4262 (57.25%)
Preoperative sepsis	248 (3.33%)
Chronic steroid use	473 (6.35%)
Rapid weight loss	82 (1.10%)
Functional status	
Dependent	606 (8.14%)
Independent	6839 (91.86%)
ASA class	
1	134 (1.80%)
2	2173 (29.19%)
3	4584 (61.57%)
4	543 (7.29%)
Not reported	11 (0.15%)
Discharge destination	
Home	3676 (49.38%)
Rehabilitation or care facility	3769 (50.62%)
Surgical variables and laboratory values	
Total operative time *(min)*	349.66 ± 150.01
Total LOS *(days)*	7.79 ± 6.87
Case type	
Elective	6131 (82.35%)
Emergency	243 (3.26%)
Other/not reported	1071 (14.39%)
Preoperative laboratory values	
BUN *(mg/dL)*	15.77 ± 9.67
Sodium *(mEq/L)*	138.74 ± 3.28
Creatinine *(mg/dL)*	0.95 ± 0.63
Hematocrit *(%)*	35.29 ± 11.87
WBC count *(thousand/mm³)*	7.05 ± 3.04
Postoperative complications	
Blood transfusion	110 (1.48%)
Urinary tract infection	310 (4.16%)
Pneumonia	281 (3.77%)
Sepsis	248 (3.33%)
Ventilator-assisted respiration at >48 hours postop.	229 (3.07%)
DVT	151 (2.03%)
PE	127 (1.65%)
Any VTE	254 (3.40%)

*Data are presented as the mean ± standard deviation or as the number of patients, with the percentage in parentheses. BUN = blood urea nitrogen, WBC = white blood cell. †Pacific Islander, "Other," or not reported to the NSQIP Database. ‡Tobacco use within 1 year preoperatively.

surgery (18.08%), dyspnea (7.04%), chronic corticosteroid use (6.35%), and chronic obstructive pulmonary disease (COPD; 6.08%). The procedure was elective in 82.35% of the patients and emergency in 3.26%. Most (91.86%) of the patients had independent functional status, and 68.87% had an ASA class of ≥3.

Factors Associated with the Risk of DVT (Table II)

The incidence of DVT was 2.03%. Variables that were identified to be associated with the risk of DVT are summarized in Table II with odds ratios (ORs) and means or percentages of occurrence. Significant factors associated with an increased risk of DVT were older age, greater height, greater weight, greater BMI, medicated hypertension, chronic corticosteroid use, higher ASA class, longer length of stay (LOS), and longer total operative time ($p < 0.05$ for all; Table II).

Factors Associated with the Risk of PE (Table III)

The incidence of PE was 1.65%. Variables that were identified to be associated with the risk of PE are summarized in Table III with ORs and means or percentages of occurrence. Significant factors associated with an increased risk of PE were longer LOS, longer total operative time, chronic corticosteroid use, higher BMI, and higher ASA class ($p < 0.05$ for all; Table III).

Factors Associated with the Risk of Any VTE (Table IV)

The incidence of any VTE was 3.40%. Variables that were identified to be associated with the risk of any VTE are summarized in Table IV with ORs and means or frequencies of

TABLE II Variables Independently Associated with the Incidence of DVT *

Variable	OR	95% CI		Patient DVT Status Postoperatively		P Value
		Lower Bound	Upper Bound	DVT = No	DVT = Yes	
Total LOS in days	1.054	1.043	1.066	7.65 ± 0.15	14.60 ± 1.93	<0.001
ASA class (1-4)	2.054	1.555	2.713	2.73 ± 0.01	3.00 ± 0.09	<0.001
Weight (per 5 kg)	1.082	1.049	1.117	80.99 ± 0.05	89.47 ± 4.17	<0.001
On corticosteroid medication	2.588	1.63	4.107	6.18%	14.57%	0.003
Total operative time in min	1.002	1.001	1.003	348.79 ± 3.44	397.81 ± 25.81	0.005
Height in centimeters	1.011	1.000	1.022	165.71 ± 0.25	168.83 ± 1.83	0.001
BMI in kg/m^2	1.033	1.012	1.056	29.36 ± 0.16	31.10 ± 1.16	0.002
Medicated hypertension	1.618	1.145	2.285	57.02%	68.21%	0.006
Age (decade of life/per 10 yr)	1.148	1.020	1.292	61.13 ± 0.35	64.02 ± 1.78	0.022

*Data are presented as odds ratios (OR) for variables that were significantly ($p < 0.05$) associated with DVT risk. Data are also provided as absolute means ± standard deviations for each variable included in the model, with the exception of the binary variables "on corticosteroid medication" and "medicated hypertension," which are presented as percentages. CI = confidence interval.

occurrence. Significant factors associated with an increased risk of DVT or PE were longer LOS, longer operative time, chronic corticosteroid use, higher ASA class, higher body weight or BMI, medicated hypertension, older age, and bleeding disorders ($p < 0.05$ for all; Table IV). Similar to the results of the independent analyses of DVT and PE, chronic corticosteroid use was the greatest extrinsic binary risk factor for VTE, with an OR of 2.654 ($p < 0.001$).

Final Predictive Model for Any VTE (Fig. 1)

Multiple logistic regression was conducted with the variables that were significantly associated with VTE in order to determine the most suitable VTE prediction model. LOS was excluded during model development because it represents postoperative information that would not be available for preoperative decision-making. The forward entry approach revealed that total operative time, chronic corticosteroid use, ASA class, and BMI were the best variables for predicting VTE risk; the remaining variables did not significantly add to the model with regard to the AUC (Fig. 1-A). The selected final model was observed to be "fair" (AUC, 0.711) with regard to predicting VTE occurrence, although it was skewed toward greater sensitivity and lower specificity. An example of the use of the risk equation is presented in Figure 1-A. Significant risk cutoffs were also generated for each of the independent predictor variables (Fig. 1-B), which may potentially be useful for setting criteria for general risk guidelines. When testing this model against the 3 internal validation groups, the AUC values for all groups (0.703, 0.707, and 0.728) were statistically similar to that of the training data set (0.711).

Discussion

VTE is a major type of complication after ASD surgery, especially after prolonged and invasive surgeries[19,24-27]. Anticoagulants are used to reduce VTE incidence but may increase the risks of spinal epidural hematomas and perioperative bleeding[7,8,28]. Identifying the patients who are at a high risk for VTE among those undergoing ASD surgery is crucial for initiating prophylactic measures and targeted diagnostic tests. In the present study, we were able to identify several independent risk factors for DVT, PE, and VTE that can be assessed from preoperative and intraoperative variables, which may assist physicians and patients in making preoperative decisions regarding surgery or postoperative management. One of the key findings of this investigation was that, across all analyses, chronic corticosteroid use was the greatest extrinsic binary risk factor for VTE. Whether used as part of a risk model or as a single risk indicator, these findings indicate that patients taking such medications prior to surgery are at a 2 to 3-times higher risk for VTE.

VTE Incidence

This study demonstrated a 3.40% postoperative VTE rate, including a 2.03% DVT rate and a 1.65% PE rate, that is comparable with other studies. Earlier studies examining risk factors for VTE in patients undergoing ASD surgery had limitations regarding preoperative risk factors or sample size[25,29,30]. In a retrospective cohort study involving 737 patients, Kim et al. found a 4.3% VTE rate, with 1.9% of patients experiencing DVT and 2.4% experiencing PE[31]. Patients with VTE had significantly higher rates of liver disease and osteoporosis than those without VTE, whereas there were no significant differences in VTE rates associated with smoking, cancer, or clotting disorders, which was attributed to the limited sample size[31].

Pateder et al. conducted a retrospective review of 407 surgeries in 361 patients and found that symptomatic PE occurred after 2.4% of the surgeries[29]. Of the 10 patients who developed a PE, 5 had smoking, hormone replacement, a previous thromboembolism, or a neoplasm as a risk factor, but the

TABLE III Variables Independently Associated with the Incidence of PE*

Variable	OR	95% CI		Patient PE Status Postoperatively		P Value
		Lower Bound	Upper Bound	PE = No	PE = Yes	
Total LOS *(days)*	1.042	1.029	1.055	7.71 ± 0.16	12.39 ± 1.46	<0.001
Total operative time *(min)*	1.003	1.002	1.004	348.28 ± 3.42	432.13 ± 29.15	<0.001
On corticosteroid medication	2.246	1.317	3.831	6.24%	13.01%	0.003
BMI *(kg/m²)*	1.029	1.004	1.054	29.36 ± 0.16	31.00 ± 1.27	0.021
ASA class (1-4)	1.421	1.053	1.919	2.74 ± 0.01	2.87 ± 0.09	0.022

*Data are presented as odds ratios (OR) for variables that were significantly ($p < 0.05$) associated with PE risk. Data are also provided as absolute means ± standard deviations for each variable included in the model, with the exception of the binary variable "on corticosteroid medication," which is presented as a percentage. CI = confidence interval.

study did not assess for diabetes, corticosteroid use, or inherited coagulability disorders. Combined with our findings, these previous reports highlight additional factors that may be considered when assessing high-risk or borderline high-risk patients.

Chronic Corticosteroid Medication Use

In the present study, chronic corticosteroid use was a strong independent predictor of DVT, PE, and any VTE. Chronic preoperative corticosteroid use was observed in 6.35% of patients, a rate that is significantly higher than the reported national average of 1.2%[32-34]. Chouairi et al. found that 3.5% of 5,244,588 patients undergoing surgery were on corticosteroid therapy for chronic medical conditions[35]. White et al. found that 5.3% of 7,936 patients undergoing ASD surgery were on corticosteroid therapy for chronic medical conditions[36]. Chronic corticosteroid therapy is commonly used to treat various diseases, including rheumatoid arthritis, polymyalgia rheumatica, asthma, COPD, and Crohn's disease[37-39]. It has been shown that patients undergoing surgery who are on chronic corticosteroid therapy are more likely to have other comorbidities than the general population[38].

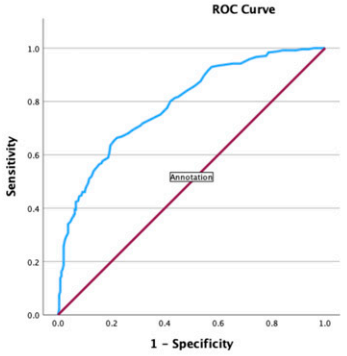
After adjusting for potential confounding factors in the present study, we found that the use of corticosteroids for chronic medical conditions was linked to a 159% higher risk of DVT, a 125% higher risk of PE, and a 165% higher risk of any VTE. These findings are consistent with results from previous studies on orthopaedic and non-orthopaedic surgeries[33,34]. Corticosteroids can increase the levels of procoagulant factors and decrease thrombolytic plasminogen, resulting in a hypercoagulable state[40-42]. Tumor necrosis factor blockers have been associated with postoperative DVT risk in patients with rheumatoid arthritis, and corticosteroids can promote atherosclerotic plaque formation, endothelial damage, and vascular wall dysfunction, further increasing the risk of thrombosis[40]. Therefore, while the additional variables identified herein may be utilized to model VTE risk, it may be advisable to take appropriate precautions when patients are on corticosteroid medications alone and certainly in the presence of additional risk factors.

TABLE IV Variables Independently Associated with the Incidence of Any VTE (DVT or PE)*

Variable	OR	95% CI		Patient VTE Status Postoperatively		P Value
		Lower Bound	Upper Bound	VTE = No	VTE = Yes	
Total LOS *(days)*	1.055	1.044	1.066	7.59 ± 0.15	13.54 ± 1.34	<0.001
Total operative time *(min)*	1.002	1.002	1.003	347.68 ± 3.44	406.06 ± 20.00	<0.001
On corticosteroid medication	2.654	1.848	3.812	6.06%	14.62%	<0.001
ASA class (1-4)	1.768	1.426	2.192	2.73 ± 0.01	2.94 ± 0.07	<0.001
Weight (per 5 kg)	1.054	1.027	1.081	80.95 ± 0.50	87.06 ± 3.10	<0.001
BMI *(kg/m²)*	1.032	1.015	1.049	29.34 ± 0.16	31.00 ± 0.88	<0.001
Medicated hypertension	1.523	1.168	1.987	59.91%	66.80%	<0.001
Age (decade of life/per 10 years)	1.106	1.012	1.209	61.11 ± 0.36	63.28 ± 1.48	0.002
Bleeding disorder	1.806	0.994	3.281	2.68%	4.74%	0.027

*Data are presented as correlation coefficients and ORs for variables that were significantly ($p < 0.05$) associated with any VTE risk. Data are also provided as absolute means ± standard deviations for each variable included in the model, with the exception of the binary variables "on corticosteroid medication," "medicated hypertension," and "bleeding disorders," which are presented as percentages. CI = confidence interval.

A) Full Model Statistics

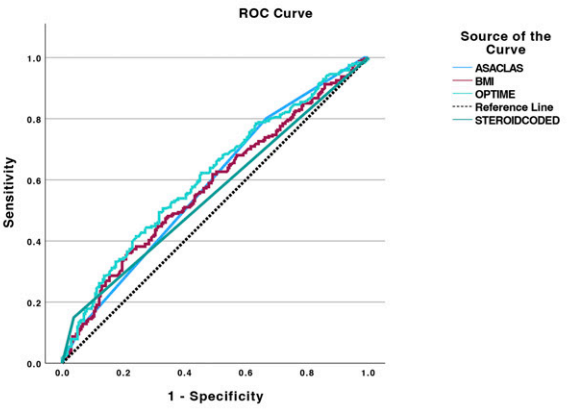


Predictor Variables	Regression Coeff (B)	Standard Error	Model Significance
Total Operative Time (Min.)	0.003	0.001	*P*<0.001
Steroid Medications (1=yes, 0=no)	1.556	0.402	*P*<0.001
BMI (kg/m²)	0.039	0.015	*P*=0.007
ASA Score	0.562	0.173	*P*=0.001
CONSTANT	-3.927	0.601	*P*<0.001

Example Patient Data

Step 1:	(Total Operative Time=200 minutes x 0.003) + (Present steroid medication use=0 x 1.556) + (BMI=35 kg/m² x 0.039) + (ASA Score=2 x 0.562)– 3.927 = Ln (Probability) = -0.838
Step 2:	Exp (-0.838) = 0.43
Step 3:	Probability of PE or DVT = 0.43 / (1+0.43) = 30.20% (±95%CI, 5.60%) (Low-Moderate Risk)

B) Individual Predictor Cutoffs For Significant Increase in VTE Risk



Test Result Variable(s)	Significant Risk Cutoff[b]
Total Operative Time	> 413 Minutes
Steroid Medications	1 (yes)
BMI	> 33 kg/m²
ASA Score	>2

Fig. 1

Final model for combined DVT and PE probability. Data are presented as regression coefficients with standard error (SE) values for variables that were significantly predictive of overall VTE risk ($p < 0.05$). Sig. = significance, ASACLAS = ASA class, OPTIME = operative time, STEROIDCODED = chronic corticosteroid use. **Fig. 1-A** An example prediction calculation utilizing the regression coefficients to calculate risk for a sample patient. **Fig. 1-B** Individual predictor cutoff values for significant increases in VTE risk.

Total Operative Time and Total Hospital LOS

Prolonged operative times have been demonstrated to increase the risk of postoperative VTE across various surgical subspecialties[43]. Our investigation corroborates this finding, as total operative time was found to be an independent risk factor for DVT, PE, and any VTE. The underlying pathophysiology is thought to be multifaceted, predominantly involving Virchow's triad. Extended periods of patient immobility during surgery impede blood circulation, inducing venous stasis and increasing susceptibility to clot formation. The association between increased operative time and heightened vascular trauma also contributes to endothelial damage, activating clotting factors and further increasing the risk of thrombosis[44].

Hospital LOS was also found to be an independent risk factor for DVT, PE, and any VTE. Despite its predictive value, it was not included in the final predictive model since it is a postoperative variable that would not be available for preoperative clinical decision-making. Previous studies have reported the mean time to VTE to be 9 to 10 days postoperatively, with about half of VTEs occurring after discharge[17,45]. Although our mean LOS (7.79 ± 6.87 days) was shorter than the mean time to VTE reported in the literature, the present study could not definitively establish the temporal relationship between hospital discharge and VTE occurrence and thus could not determine causality.

Functional Status and Comorbidities

Several factors related to functional status and patient comorbidities were identified as independent risk factors. These findings align with previous studies showing that obesity, hypertension, disability, and age are linked to complications, revision rates, rehospitalizations, and VTE in various orthopaedic surgeries[46-48]. These findings add further support for the preoperative implementation of weight management and physical therapy ("prehabilitation") to reduce risk, which has gained substantial interest in recent years among several orthopaedic subspecialties[49].

Additional Risk Factors to Consider

Although not included in the final risk assessment model, the additional variables that were found to be significantly associated with VTE risk in the present study may also warrant consideration, particularly if the patient has been determined to be at a moderate to high risk based on the proposed model. Patients with bleeding disorders were at a higher risk for any postoperative VTE. Although transferrin and ferritin levels were not recorded, low hematocrit may reflect a higher

likelihood of anemia of chronic disease, linked with inflammatory states, which may increase VTE risk. Consistent use of immunosuppressant medications has also been found to be associated with, and a precursor of, chronic disease[50,51].

Patients with medicated hypertension were also found to be at a higher risk for any postoperative VTE in the present study. Hypertension can lead to changes in the blood vessels, including endothelial dysfunction and inflammation, which may promote clot formation. Previous studies have identified hypertension as an independent risk factor for thromboembolism in the general population, as well as after spinal surgery[52,53]. Although our finding regarding hypertension is not new, it can provide an additional consideration for clinicians, especially with regard to patients who were identified to be at a higher risk for VTE based on the model estimates.

The limitations of this study include the broad nature of the NSQIP database, which is not specific to patients with ASD, has voluntary participation, and is limited to 30-day outcomes. The inclusion criteria relied on CPT codes, and postoperative complications that were diagnosed at non-participating hospitals may not have been reported. The study included emergency cases, and, although emergency cases were not observed to be a significant risk factor for VTE, we cannot discount any unforeseen impact on the data set given that emergency cases were provided in a binary (yes/no) manner, which complicates the determination of causal effect.

Future research should investigate anticoagulation strategies for high-risk patients and examine the association between immunomodulator drugs and VTE rates. As previously mentioned, although LOS was observed to be significantly associated with VTE risk, the data set did not allow us to determine whether the VTE occurred during the hospitalization. Additionally, LOS is not available preoperatively and was therefore excluded from the final model. As the determinants of LOS are often multifactorial, future prospective studies are required to determine the conditions under which LOS may or may not influence VTE risk. Lastly, while the model that was developed was tested against 3 separate internal validation sets, further prospective external validation studies are required for full model validation and refinement.

Conclusions

This study identified independent risk factors associated with DVT, PE, and any VTE within 30 days after ASD surgery. When incorporated into a single model, total operative time, chronic corticosteroid use, BMI, and ASA class were observed to be significantly predictive of overall VTE risk. Knowledge of these risk factors can aid in preoperative risk assessment, informed consent, and clinical decision-making, such as in determining the thresholds for VTE testing and chemoprophylaxis. Further research is necessary to determine the clinical implication of interventions that target patients with these specific risk factors. ■

NOTE: Vincent LeMoine (Data Science Manager, Statistical Analyst, LyondellBasell Industries) was consulted to provide guidance on the methodology and statistical analysis.

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