Predictors of Complication Severity Following Adult Spinal Deformity Surgery: Smoking Rate, Diabetes, and Osteotomy Increase Risk of Severe Adverse Events

Cole A. Bortz, Katherine E. Pierce, Oscar Krol, Nicholas Kummer, Lara Passfall, Max Egers, Cheongeun Oh, Samantha R. Horn, Frank A. Segreto, Dennis Vasquez-Montes, Nicholas J. Frangella, John A. Buza III, Tina Raman, Tomas Kuprys, Renaud Lafage, Pawel P. Jankowski, Hamid Hassanzadeh, Shaleen N. Vira, Bassel G. Diebo, Michael C. Gerling and Peter G. Passias

Int J Spine Surg published online 7 February 2023
http://ijssurgery.com/content/early/2023/02/03/8393

The International Journal of Spine Surgery
2397 Waterbury Circle, Suite 1,
Aurora, IL 60504, Phone: +1-630-375-1432

International Journal of Spine Surgery, Vol. 00, No. 0, 2023, pp. 1–9
https://doi.org/10.14444/8393

Predictors of Complication Severity Following Adult Spinal Deformity Surgery: Smoking Rate, Diabetes, and Osteotomy Increase Risk of Severe Adverse Events

COLE A. BORTZ, BA[1]; KATHERINE E. PIERCE, BS[1]; OSCAR KROL, BA[1]; NICHOLAS KUMMER, BS[1]; LARA PASSFALL, BS[1]; MAX EGERS, BS[2]; CHEONGEUN OH, PHD[2]; SAMANTHA R. HORN, BA[1]; FRANK A. SEGRETO, BS[1]; DENNIS VASQUEZ-MONTES, MS[2]; NICHOLAS J. FRANGELLA, BS[2]; JOHN A. BUZA III, MD, MS[2]; TINA RAMAN, MD[2]; TOMAS KUPRYS, MD[2]; RENAUD LAFAGE, MS[3]; PAWEL P. JANKOWSKI, MD[2]; HAMID HASSANZADEH, MD[4]; SHALEEN N. VIRA, MD[2]; BASSEL G. DIEBO, MD[5]; MICHAEL C. GERLING, MD[2]; AND PETER G. PASSIAS, MD[1]

[1]Division of Spinal Surgery/Departments of Orthopaedic and Neurosurgery, NYU Medical Center, NY Spine Institute, New York, NY, USA; [2]Department of Orthopaedic Surgery, NYU Langone Orthopaedic Hospital, New York, NY, USA; [3]Department of Orthopaedics, Hospital for Special Surgery, New York, NY, USA; [4]Department of Orthopaedic Surgery, University of Virginia, Charlottesville, VA, USA; [5]Department of Orthopaedic Surgery, SUNY Downstate Medical Center, Brooklyn, NY, USA

ABSTRACT

Background: Given the physical and economic burden of complications in spine surgery, reducing the prevalence of perioperative adverse events is a primary concern of both patients and health care professionals. This study aims to identify specific perioperative factors predictive of developing varying grades of postoperative complications in adult spinal deformity (ASD) patients, as assessed by the Clavien-Dindo complication classification (Cc) system.

Methods: Surgical ASD patients ≥18 years were identified in the American College of Surgeons' National Surgical Quality Improvement Program from 2005 to 2015. Postoperative complications were stratified by Cc grade severity: minor (I, II, and III) and severe (IV and V). Stepwise regression models generated dataset-specific predictive models for Cc groups. Model internal validation was achieved by bootstrapping and calculating the area under the curve (AUC) of the model. Significance was set at $P < 0.05$.

Results: Included were 3936 patients (59 ± 16 years, 63% women, 29 ± 7 kg/m^2) undergoing surgery for ASD (4.4 ± 4.7 levels, 71% posterior approach, 11% anterior, and 18% combined). Overall, 1% of cases were revisions, 39% of procedures involved decompression, 27% osteotomy, and 15% iliac fixation. Additionally, 66% of patients experienced at least 1 complication, 0% of which were Cc grade I, 51% II, 5% III, 43% IV, and 1% V. The final model predicting severe Cc (IV–V) complications yielded an AUC of 75.6% and included male sex, diabetes, increased operative time, central nervous system tumor, osteotomy, cigarette pack-years, anterior decompression, and anterior lumbar interbody fusion. Final models predicting specific Cc grades were created.

Conclusions: Specific predictors of adverse events following ASD-corrective surgery varied for complications of different severities. Multivariate modeling showed smoking rate, osteotomy, diabetes, anterior lumbar interbody fusion, and higher operative time, among other factors, as predictive of severe complications, as classified by the Clavien-Dindo Cc system. These factors can help in the identification of high-risk patients and, consequently, improve preoperative patient counseling.

Clinical Relevance: The findings of this study provide a foundation for identifying ASD patients at high risk of postoperative complications .

Level of Evidence: 4.

Lumbar Spine

Keywords: Adult Spinal Deformity, ASD, Clavien, NSQIP, predictor, complication, surgery

INTRODUCTION

Adult spinal deformity (ASD) refers to a multitude of conditions that disrupts appropriate curvature and orientation of the spine in the adult. Diagnoses encompassed in the category of ASD include scoliosis, kyphosis, sagittal malalignment, axial plane deformity, and rotary subluxation. Spinal deformity can arise de novo—as in adult idiopathic scoliosis—as well as secondary to progressive asymmetric degeneration of spinal elements such as intervertebral discs and facet joints.[1,2] Spinal alignment is critical in the maintenance of upright posture, stability of the axial skeleton, and protection of neural elements; when this is compromised, many deleterious sequelae present including deformity, axial pain, and neurologic symptoms, significantly affecting health-related quality of life as well as physical function.[3–5] While there is no current consensus on

the prevalence of adult scoliosis in the general population, with estimates ranging from 1.4% to 36%, a 2005 prospective study by Schwab et al found the prevalence in the elderly population to be 68%. These estimates put the number of patients in the United States with ASD conservatively at 27.5 million and, given the rapid growth of the elderly US population, this number is expected to reach 60 million by 2050.[6,7]

Surgical intervention is the recommended treatment for certain ASD patients whose symptoms progress despite nonoperative treatment. With advancements in technology, medical understanding, and surgical technique, adult deformity surgery outcomes and morbidity have improved in the past few decades, leading to corrective procedures becoming a more utilized treatment option.[3,8] McCarty et al recently illustrated this in a study, revealing a 4-fold increase in the number of ASD surgeries for Medicare patients from 2000 to 2010.[9] Despite these advances, postoperative complications remain significant, affecting both outcomes and cost of care, with some studies reporting complication rates as high as 86%.[8] A 2011 systematic review concluded that elderly deformity surgery has a complication rate of 38%, and a 2007 study on 51 spinal deformity patients undergoing surgical treatment demonstrated 37% had perioperative complications with 20% of them classified as major complications, including myocardial infarction, pulmonary embolism, neurologic defect, pneumonia, and deep wound infection.[10,11]

Given the frequency, effect on outcome, and cost of complications in ASD surgery, greater understanding of factors predictive of complications is necessary to facilitate more effective care from a patient counseling, operative patient selection, surgical, and medical standpoint. Using the Clavien-Dindo grading system, validated for general surgery to classify perioperative complications, this study investigates the use of patient factors, comorbidities, and surgical variables in predicting complications and complication severity. It is our hope that by connecting factors with not just complication predictability but the severity of said complications, we are providing more clinical relevance to the data.

METHODS

Data Source

The American College of Surgeons' National Surgical Quality Improvement Program (ACS-NSQIP) database was used for analysis of perioperative factors in patients undergoing ASD-corrective surgery. NSQIP was developed by the US Department of Veterans Affairs with use of information from hospitals across the United States to track the outcome of risk-adjusted surgical interventions. The NSQIP tracks 135 clinical metrics, including preoperative risk factors, intraoperative variables, 30-day postoperative outcomes, current procedural terminology (CPT) coding, and International Classification of Disease 9th Edition (ICD-9) coding. Data are collected and audited by training surgical clinical reviewers from randomly assigned patients, which ensure the database's standardization and reliability. Additional information regarding the ACS-NSQIP program can be found at https://www.facs.org/quality-programs/acs-nsqip/about.

Study Design

This is a retrospective analysis of ACS-NSQIP data from the years 2005 to 2015. The inclusion criteria were patients older than 18 years undergoing elective ASD-corrective surgery. An ASD population undergoing corrective surgery was isolated, as previously published.[12] Patients with dyspnea, esophageal varices, do-not-resuscitate status, or a history of angina within 1 month before surgery; patients in a coma 24 hours prior to surgery, and patients who were pregnant were excluded. The CPT and ICD-9 codes used for inclusion and exclusion criteria are listed in Appendix A.

Statistical Analysis

Primary analysis tracked postoperative complications stratified through the Clavien-Dindo complication classification system by severity. This classification was established as an objective, reliable, and reproducible system to define and grade postoperative complications. Through this system, complications are categorized into 5 grades. This study grouped patients by minor Clavien complications (groups I, II, and III) and severe (groups IV and V). An individual is categorized as a grade I complication when they deviate from the normal postoperative course. Grade II classification is assigned when the patient requires pharmacological treatment, and grade III entails surgical, endoscopic, or radiological intervention. Clavien grade IV involves life-threatening complications with intensive care/intensive care unit management, and Clavien V classification is used when the complication results in the death of the patient.[13]

Univariate analysis was performed using χ^2 tests for categorical variables and unpaired Student t tests for continuous variables. Multivariate analysis was performed using stepwise regression models to generate

Table 1. Patient demographic characteristics between minor Clavien complications and severe Clavien complications.

Demographic	Minor Clavien	Severe Clavien	*P* Value for Minor vs Severe	Underwent Adult Spinal Deformity Surgery (*N* = 3936)
Age, y, mean (SD)	60.36 (15.67)	58.82 (16.28)	0.43	58.7 (16.36)
Female sex, %	60.50	65	**<0.001**	63
Body mass index, mean (SD)	28.65 (6.67)	29.06 (6.91)	**0.011**	28.7 (6.61)

Note: Boldface indicates statistical significance at $P < 0.05$.

dataset-specific predictive models for Clavein-Dindo complication groups. Secondary analysis of model internal validation was achieved by bootstrapping and calculating the area under the curve (AUC) of the model. All statistical analysis was performed using SPSS version 23.0 (Armonk, NY, USA). A *P* value of less than 0.05 was considered statistically significant.

RESULTS

Overall Cohort Characteristics

This study analyzed 3936 patients (mean age 59 ± 16 years, 63% women, mean body mass index [BMI] 29 ± 7 kg/m^2) who underwent ASD-corrective surgery from 2005 to 2015 (Table 1). Overall, operations averaged 4.4 ± 4.7 levels fused, 0.49 ± 1.31 anterior fusion, and 3.87 ± 4.74 posterior fusion. Of the included operations, 31.22% involved insertion of an interbody device, 27.11% osteotomy, 3.91% anterior decompression, 35.82% posterior decompression, 15.65% iliac fixation, and 6.68% 3-column osteotomy. By approach, 12.40% of procedures were anterior only, 66.67% posterior only, and 13.59% combined (Table 2). Prior to surgery, 94.2% had an independent functional status, indicating no reliance on others for daily living, 4.70% were partially dependent, and 0.70% were totally dependent.

Clavien Grades and Demographics

A total of 2581 patients from the cohort suffered at least 1 complication, 0% of which were classified as a grade I Clavien complication. Also, 1304 (50.52%) experienced a grade II complication, 139 (5.39%) grade III, 1111 (43.04%) grade IV, and 27 (1.05%) grade V (Table 3). Across the Clavien groups, there was no significant difference in age, yet those who had complications categorized as severe Clavien were significantly more likely to be women ($P < 0.001$) and have a larger BMI ($P = 0.011$) compared with minor Clavien grades. Tables 4 and 5 show differences in demographics and preoperational blood protein levels. There was an increase in patients with a history of diabetes mellitus ($P < 0.001$), hemiplegia/paraplegia/quadriplegia ($P < 0.05$), a tumor involving the central nervous system (*P*

Table 2. Patient procedural characteristics between severe and minor Clavien grades.

Patient Procedural Characteristics	Clavien Grade		Total	*P* Value
	Minor	Severe		
Anterior approach	9.08%	13.27%	12.4%	**0.036**
Posterior approach	72.42%	65.82%	66.67%	0.156
Combined approach	11.37%	14.32%	13.59%	**0.09**
Anterior decompression	3.33%	5.62%	3.91%	**<0.001**
Posterior decompression	39.43%	35.59%	35.82%	0.694
Iliac fixation	20.17%	19.68%	15.65%	**<0.001**
Osteotomy	33.96%	30.84%	27.11%	**<0.001**
3-Column osteotomy	10.05%	7.29%	6.68%	0.051
Interbody device placement	28.00%	33.74%	31.22%	**<0.001**
Anterior fusion (0.49 [1.31])				
1 Level	10.05%	7.12%	8.50%	**<0.001**
2–3 Levels	4.78%	6.24%	7.10%	**0.005**
4–7 Levels	3.74%	2.64%	3.40%	**0.001**
8+ levels	0.69%	0.35%	0.60%	**0.026**
Posterior fusion (3.87 [4.74])				
1 Level	40.68%	45.43%	32.70%	**<0.001**
2–6 Levels	12.68%	14.59%	15.50%	**0.048**
7–12 Levels	21.28%	15.38%	16.80%	**0.001**
13+ Levels	14.35%	11.60%	10.20%	**<0.001**
Anterior lumbar interbody fusion	8.87%	16.61%	13.87%	**<0.001**
Posterior lumbar interbody fusion	79.49%	71.53%	70.81%	0.200
Operative time, min, mean (SD)	387.1 (148.6)	346.6 (159.3)	336.1 (153.9)	0.169

Note: Boldface indicates statistically significant findings at $P < 0.05$ across complication levels.

Table 3. Clavien complications from the total patient population.

Clavien Grades	*n*	% of Patient Population	% of Clavien Complications
Suffered at least 1 complication	2581	65.57%	100%
Grade I	0	0%	0%
Grade II	1304	33.13%	50.52%
Grade III	139	3.50%	5.39%
Grade IV	1111	28.20%	43.04%
Grade V	27	0.70%	1.05%

< 0.001), and amputation for peripheral vascular disease ($P < 0.001$), with an increase in severity of Clavien grade. Also, there statistically significant findings for the severely classified groups for patients with a history of disseminated cancer ($P = 0.016$), those with an open wound/wound infection ($P = 0.016$), patients with a history of a percutaneous coronary intervention ($P = 0.001$), individuals with bleeding disorders ($P < 0.001$), and patients who underwent chemotherapy treatment for malignancy less than 30 days prior to surgery ($P = 0.001$). Patients categorized as severe Clavien had more cigarette pack-years ($P < 0.001$) and were found to consume alcohol more frequently ($P = 0.027$) than those with minor grades. Those patients categorized as a minor Clavien grade had a greater history of transient ischemic attacks ($P = 0.003$) and had undergone more blood transfusions less than 72 hours prior to the operation ($P = 0.002$). When comparing the blood protein levels preoperatively between each Clavien classification, prothrombin time ($P = 0.021$), serum albumin ($P < 0.001$), alkaline phosphatase ($P = 0.009$), blood urea nitrogen ($P = 0.046$), hematocrit ($P < 0.001$), and white blood cell count ($P = 0.036$) were all significant. The American Society of Anesthesiologists (ASA) classification across Clavien grades was significant ($P < 0.001$),

Table 4. Patient comorbidity characteristics across Clavien grades.

Characteristic	Clavien Grade		*P* Value
	Minor	Major	
Diabetes mellitus	14.5%	54.2%	**<0.001**
Smoking status	14.1%	16.8%	0.526
Cigarette pack-years			**<0.001**
Alcohol consumption, >2 drinks/d	2.4%	4.5%	**0.027**
Preoperative functional health status			0.967
Independent	93%	94.1%	
Partially dependent	5.5%	4.7%	
Totally dependent	1%	0.8%	
Ventilator-dependent	0.3%	0.2%	0.625
Chronic obstructive pulmonary disease	4.6%	4.7%	0.645
Ascites	0.1%	0.0%	0.202
Congestive heart failure	0.4%	0.3%	0.546
History of myocardial infarction 6 mo prior	0%	0%	0.55
Previous percutaneous coronary intervention	5.1%	9.0%	**0.001**
Previous cardiac surgery	4.8%	6.0%	0.341
Hypertension	54.7%	49.8%	0.41
Revascularization/amputation for peripheral vascular disease	0.5%	0.3%	**<0.001**
Rest pain/gangrene	0%	0%	0.55
Acute renal failure	0.1%	0.2%	0.063
Preoperative dialysis	0.5%	3.0%	**<0.001**
Impaired sensorium	1%	1.5%	0.131
Hemiplegia	0.5%	3.0%	**<0.001**
Paraplegia	5.3%	9.0%	**0.009**
Quadraplegia	0.7%	3.0%	**0.002**
History of transient ischemic attack	1.9%	0%	**0.003**
Cerebral vascular accident /stroke with neurological deficit	1.7%	1.5%	0.971
Tumor involving central nervous system	1.4%	4.5%	**<0.001**
Disseminated cancer	2.6%	3.0%	**0.016**
Open wound/wound infection	1.2%	1.4%	**0.016**
Steroid use for chronic infection	5.1%	5.7%	0.057
>10% Loss body weight in past 6 mo	1%	0.9%	0.111
Bleeding disorders	2.3%	5.1%	**<0.001**
Transfusion <72 h before surgery	2%	0.8%	**0.002**
Chemotherapy ≤30 d before surgery	1.0%	3.0%	**0.001**
Radiotherapy in past 90 d	0.5%	0%	0.3
Prior operation within 30 d	8.7%	13.6%	**0.002**
American Society of Anesthesiologists classification			0.641
1—No disturbance	1.9%	3.1%	
2—Mild disturbance	36.9%	40.0%	
3—Severe disturbance	57.4%	53.5%	
4—Life-threatening disturbance	3.7%	3.3%	

Note: Boldface indicates statistical significance at $P < 0.05$ across complication levels.

Table 5. Patient blood protein levels across Clavien grades.

Outcome Measure	Grade II	Grade III	Grade IV	Grade V	Total	*P* Value
Total length of stay, d	7.36 (4.84)	10.68 (7.8)	7.9 (8.01)	9.07 (6.56)		**<0.001**
Preoperative						
Prothrombin time, sec	12.03 (1.82)	12.65 (1.59)	12.41 (1.76)	13.64 (1.84)	12.06 (1.97)	**0.021**
Serum albumin, g/dL	3.93 (0.53)	3.82 (0.53)	4.02 (0.53)	3.56 (0.68)	4.00 (0.54)	**<0.001**
Alkaline phosphatase, IU/L	87.15 (51.39)	91.6 (50.2)	81.73 (31.47)	108.9 (35.8)	84.25 (41.35)	**0.009**
Total bilirubin, mg/dL	0.59 (0.72)	0.62 (0.58)	0.52 (0.29)	0.57 (0.27)	0.55 (0.55)	0.274
Blood urea nitrogen, mg/dL	16.46 (7.91)	15.44 (7.93)	16.25 (7.15)	18.06 (10)	16.10 (7.44)	**0.046**
Serum creatinine, mg/dL	0.87 (0.49)	0.88 (0.46)	0.89 (0.49)	0.87 (0.38)	0.88 (0.49)	0.827
Hematocrit, %	38.27 (4.71)	38.45 (4.55)	39.82 (4.85)	36.69 (6.97)	29.31 (4.78)	**<0.001**
International normalized ratio	1.03 (0.31)	1.02 (0.11)	1.02 (0.18)	1.08 (0.12)	1.02 (0.22)	0.54
Partial thromboplastin time, sec	29.5 (5.3)	30.13 (8.58)	29.61 (5.35)	30.17 (4.88)	29.38 (5.24)	0.082
Platelet, $\times 10^3/\mu L$	248.2 (74.4)	252.1 (12)	251.2 (74.0)	218.6 (78.6)	250.1 (73.1)	0.173
Serum glutamic-oxaloacetic transaminase, IU/L	3.75 (4.03)	3.40 (3.42)	1.00 (2.35)	2	2.15 (2.92)	0.065
Serum sodium, mEq/L	26.39 (22.3)	26.14 (12.11)	25.59 (18.35)	32.13 (16.38)	25.72 (18.3)	0.444
White blood cells, %	138.7 (3.2)	138.6 (3.2)	139 (3)	138.74 (4.12)	138.8 (3.0)	0.062
Intraoperative red blood cells given, units	7.08 (2.87)	7 (2.38)	7.18 (2.5)	8.52 (4.5)	7.18 (2.65)	**0.036**

Note: Boldface indicates statistical significance at $P < 0.05$ across complication levels.

where minor categorization coincided with an increased mild systemic disease (II) and those in severe Clavien groups had increased severe (IV) and life-threatening (V) systemic disease. Patients with severe Clavien complications had a higher overall postoperative length of stay in the hospital ($P < 0.001$).

Procedural Factors as Predictors of Clavien Grade

Patients with severe Clavien complications had more anterior decompressions ($P < 0.001$), interbody device placements ($P < 0.001$), anterior lumbar fusion procedures (16.61% vs 8.87%, $P < 0.001$), 2–3 levels fused anteriorly ($P = 0.005$), as well as ($P < 0.001$) and 6 levels ($P = 0.048$) fused posteriorly. The patients classified with minor Clavien complications underwent more iliac fixations ($P < 0.001$) from 2005 to 2015, as well as osteotomies ($P < 0.001$) and 1 ($P < 0.001$), 4 to 7 ($P = 0.001$), and 8 or more anterior fused levels. Minor Clavien had significantly more 7 to 12 ($P = 0.001$) and 13+ ($P < 0.001$) posterior levels fused. By approach, severe Clavien-grouped patients underwent more anterior and combined approach procedures ($P < 0.05$), and minor Clavien complications had undergone more posterior approach operations, though the difference was not found to be significant ($P = 0.156$) (Table 2).

Predicting Complications

Specific predictors of Clavien grade II complications were increased age (OR, 1.038; 95% CI, 1.018–1.059), ASA score (OR, 0.656; 95% CI, 0.413–1.041), decreased preoperative hematocrit (OR, 0.955; 95% CI, 0.904–1.009), posterior lumbar interbody fusion (OR, 4.245; 95% CI, 2.236–8.060), lumbar fusion (OR, 0.541; 95% CI, 0.293–0.996), and increased operative time (OR, 1.003; 95% CI, 1.002–1.005), all resulting in an AUC of 74.9%. Clavien III classified perioperative complications had preoperative dialysis (OR, 23.966; 95% CI, 1.319–435.406) and increased operative time (OR, 1.003; 95% CI, 1–1.006) as predictors (AUC 70.2%). Multivariate modeling for Clavien grade IV predictors yielded an AUC of 92.8% and included anterior decompression (OR, 5.845; 95% CI, 2.018–16.933), lumbar fusion (OR, 0.006; 95% CI, 0.002–0.020), sepsis (OR, 895.786; 95% CI, 108.551–7392.236), and inpatient length of stay (OR, 1.071; 95% CI, 1.033–1.110). Grade V complications had specific predictors of hemiplegia and paraplegia, significant weight loss prior to surgery (OR, 49.773; 95% CI, 2.229–1111.401), and increased preoperative white blood cell count (OR, 1.505; 95% CI, 1.137–1.992) with an AUC of 77.4%. The final model also predicted severe Clavien complications combined (IV–V), yielding an AUC of 75.6%, and included female sex (OR, 0.029; 95% CI, 0.012–0.071), diabetes (OR, 3.122; 95% CI, 1.364–7.143), increased operative time (OR, 1.001; 95% CI, 1.000–1.003), central nervous system tumor (OR, 6.930; 95% CI, 1.677–28.640), osteotomy (OR, 1.847; 95% CI, 0.954–3.578), cigarette pack-years (OR, 1.015; 95% CI, 1.003–1.027), anterior fusion (OR, 3.508; 95% CI, 1.349–9.123), and anterior lumbar interbody fusion (OR, 2.286; 95% CI, 0.942–5.548) (Table 6).

DISCUSSION

As the number of adult deformity surgeries continues to increase with the growth of an increasingly numerous

Table 6. Predictors of Clavien complications with AUC amounts.

Variable	Final AUC
Clavien grade II complications	0.749
American Society of Anesthesiologists score	
Preoperative hematocrit level	
Operative room time	
Any lumbar fusion	
Posterior lumbar interbody fusion	
Clavien grade III complications	0.702
Dialysis	
Time from incision open to incision close	
Clavien grade IV complications	0.928
Anterior decompression	
Any lumbar fusion	
Preoperative sepsis	
Inpatient length of stay	
Clavien grade V complications	0.744
Increased preoperative white blood cell count	
Hemiplegia and paraplegia	
Preoperative >10% loss body weight in past 6 mo	
Severe Clavien complications	0.756
Female sex	
Diabetes mellitus	
Operative time	
Central nervous system tumor	
Osteotomy	
Cigarette pack-years	
Anterior fusion	
Anterior lumbar interbody fusion	

Abbreviation: AUC, area under the curve.

and active elderly population, more thorough understanding of complications and their predictive factors is needed to ensure satisfactory outcomes as well as economic sustainability.[1] Currently, complications status after corrective ASD surgery is a significant economic burden to both hospitals and patients.[14] A 2016 study in the *Journal of Neurosurgery* demonstrated that ASD surgeries associated with a single complication can increase hospital charges from 1.7 to 4.3 times greater than those of patients without a complication. In the same study, inpatient charges increased by $108,387 to $313,536 for spine surgery cases complicated by deep vein thrombosis and by $127,958 to $246,637 for spine surgery cases complicated by pulmonary embolism.[15] With respect to outcomes, major complications have been shown to have a significant effect on self-reported wellness as measured by the short form-12 general health subscale.[14] Additionally, satisfaction scores have been demonstrated to negatively correlate with complications, further decreasing with increased complication severity.[16]

Previous investigations have elucidated risk factors for the development of complications in ASD surgery. These risk factors include age, extent of surgery, approach, and major intraoperative blood loss.[17–19] A 2016 study specifically investigating risk factors for medical complications in ASD surgery found smoking, hypertension, heart disease, obesity (BMI >30), depression, duration of symptoms, ASA classification, and sex to be significant, with smoking, hypertension, and duration of symptoms identified as independent factors for the development of medical complications. The information on predictors of adverse events is comparatively sparse. A study on predictors of nonhome discharge in ASD surgery patients found the following factors to be significant: total relative value units, female sex, race, age ≥65 years, obesity, partially or totally functionally dependent, osteotomy, pelvis fixation, operation time ≥4 hours, recent weight loss, and ASA class ≥3. Additionally, poor long-term clinical outcomes in ASD surgical patients have been linked to predictors including BMI, severe preoperative disability, frailty, large preoperative sagittal vertical axis, and depression or anxiety.[12,20–22]

Our study utilized the Clavien-Dindo grading system in an effort to provide more clinical relevance to our findings by identifying complications in an evidence-based, standardized system, which grades complications by severity from I to V. By understanding which factors predict which grade of complications, more judicious preoperative counseling, patient selection, as well as surgical and medical treatment can be implemented. To our knowledge, this is the first study that has utilized a validated, standardized complication grading system to identify predictive factors for complications in ASD surgery utilizing data from a multicenter, national database.

With respect to demographic factors, age was found to be predictive of Clavien grade II complications. The fact that age is predictive of complications has been demonstrated consistently in the literature. That age was not found to be predictive of grade III, IV, V, or a combined category termed "severe" including grade IV and V complications, is a significant addition to ASD surgery understanding and is congruent with the growing body of evidence, suggesting that surgical correction of spine deformity in the elderly is more safe and appropriately indicated than was previous understood.[1,3,8] Additionally, our analysis identified female sex as predictive of severe Clavien (IV and V) complications. This finding is echoed in the literature with many studies identifying female sex as a risk factor and salient predictor of complications in spine procedures as well as nonspine procedures, including higher rates of revision surgery and nonhome discharge.[12,23,24]

Clinically based factors were found to be predictive of complications across multiple Clavien complication classes. ASA score and decreased preoperative hematocrit were predictive of grade II complications,

and current dialysis use at the time of surgery was predictive of grade III complications. Preoperative sepsis and inpatient length of stay were predictive of grade IV complications. Clinically based factors predictive of grade V complications included hemiplegia and paraplegia, preoperative weight loss >10% of body weight within 6 months, and elevated preoperative white blood cell count. Diabetes, tumor involving the central nervous system, and cigarette pack-years were significant predictors of developing a "severe" grade IV and/or V complication. Comorbidities are well established as increasing the risk of complications in corrective deformity surgery; our data bring about more complete understanding as specific comorbidities are shown to be predictive of not only the presence but also the severity of anticipated complications: findings that may have substantive impacts on preoperative counseling, patient selection, and overall outcomes.[10,25,26]

Surgical factors were also found to be salient predictors of the severity of complications. Time from incision start to finish, as well as total time in the OR, were significant across multiple Clavien grades. Operative time was predictive of grade II as well severe complications (grade IV and/or V). Time from incision open to close was predictive of grade III complications. Many previous investigations of complications in spine surgery have highlighted increased operative time as a risk factor. This variable is often reflective of surgical complexity and is associated with increased exposure to bacteria, among other deleterious effects.[26–28] Grade IV and/or V complications, termed "severe," were predicted by osteotomy, anterior fusion, anterior lumbar interbody fusion, as well as the aforementioned operative time. Osteotomies, including pedicle subtraction osteotomy and Smith-Peterson osteotomy, are very invasive procedures that involve removing bony segments of the spine in order to achieve correction of marked deformity. These procedures often involve extended procedural time as well as substantial blood loss and have been well described in the literature as associated with high complication rates.[29–31] Interbody instrumentation, while allowing for surgical correction of degenerative discs, can lead to significant complications, each approach with its own constellation of benefits and drawbacks.[30] The anterior vs posterior approach in deformity surgery remains a controversial topic with supportive literature on both sides.[26,32,33] Our finding that anterior fusion and anterior lumbar interbody fusion are predictive of severe postoperative complications adds further information to this debate, and we hope for it to lead to more analysis and understanding.

As the elderly cohort of the US population continues to grow, the prevalence of ASD will follow, leading to an increase in corrective surgery. Advances have allowed for great strides in outcomes of ASD surgical patients, especially in the elderly, but postoperative complications remain significant and costly. This study identifies specific factors that accurately predict the presence and severity of complications in the postoperative period. This understanding provides surgeons with more knowledge to utilize with respect to patient selection, thorough preoperative counseling, and effective follow-up care, leading to higher patient satisfaction and better clinical outcomes.

Our analysis is limited by the fact that the NSQIP database is not designed specifically for spine patients—lacking imaging, procedural data, baseline clinical information, or a complete list of medical comorbidities or complications—rendering our analysis vulnerable to confounding variables we were unable to control for. Other limitations include the use of ICD-9 and CPT codes to isolate our surgical populations, which may diminish the acquisition of unbiased patient populations.

This study allowed us to identify predictors of complications stratified by severity. Multivariate analysis established cigarette pack-years, diabetes, female sex, operative time, tumor involving the central nervous system, osteotomy, anterior fusion, and anterior lumbar interbody fusion as predictive of severe complications (grade IV–V). Significantly, it did not identify age as predictive of grade III IV, or V complications. Neither did it find age to predictive of severe complications (grade IV–V). We believe the insights provided in this study will lead to more effective patient selection, counseling, and overall care.

CONCLUSION

Specific predictors of adverse events following ASD-corrective surgery varied with regard to the severity of the complication. Multivariate modeling showed smoking rate, osteotomy, diabetes, and higher operative time, among other factors, as predictive of severe complications, as classified by the Clavien-Dindo complication classification system. These factors can help in the identification of high-risk patients, and consequently, improve preoperative patient counseling and surgical patient selection.

REFERENCES

1. Ames CP, Scheer JK, Lafage V, et al. Adult spinal deformity: epidemiology, health impact. *Evaluation, and Management Spine Deform*. 2016;4(4):310–322. doi:10.1016/j.jspd.2015.12.009

2. Grubb SA, Lipscomb HJ, Coonrad RW. Degenerative adult onset scoliosis. *Spine (Phila Pa 1976)*. 1988;13(3):241–245. doi:10.1097/00007632-198803000-00004

3. Good CR, Auerbach JD, O'Leary PT, Schuler TC. Adult spine deformity. *Curr Rev Musculoskelet Med*. 2011;4(4):159–167. doi:10.1007/s12178-011-9101-z

4. Turner JD, Walker CT, Mundis GM, Kakarla UK. Health burden of adult spinal deformity compared with other chronic diseases. *World Neurosurg*. 2015;84(4):876–877. doi:10.1016/j.wneu.2015.08.013

5. Bess S, Line B, Fu K-M, et al. The health impact of symptomatic adult spinal deformity: comparison of deformity types to United States population norms and chronic diseases. *Spine (Phila Pa 1976)*. 2016;41(3):224–233. doi:10.1097/BRS.0000000000001202

6. Kobayashi T, Atsuta Y, Takemitsu M, Matsuno T, Takeda N. A prospective study of de novo scoliosis in a community based cohort. *Spine (Phila Pa 1976)*. 2006;31(2):178–182. doi:10.1097/01.brs.0000194777.87055.1b

7. Schwab F, Dubey A, Gamez L, et al. Adult scoliosis: prevalence, SF-36, and nutritional parameters in an elderly volunteer population. *Spine (Phila Pa 1976)*. 2005;30(9):1082–1085. doi:10.1097/01.brs.0000160842.43482.cd

8. Passias PG, Poorman GW, Jalai CM, et al. Morbidity of adult spinal deformity surgery in elderly has declined over time. *Spine (Phila Pa 1976)*. 2017;42(16):E978–E982. doi:10.1097/BRS.0000000000002009

9. McCarthy I, Hostin R, O'Brien M, Saigal R, Ames CP. Health economic analysis of adult deformity surgery. *Neurosurg Clin N Am*. 2013;24(2):293–304. doi:10.1016/j.nec.2012.12.005

10. Drazin D, Shirzadi A, Rosner J, et al. Complications and outcomes after spinal deformity surgery in the elderly: review of the existing literature and future directions. *Neurosurg Focus*. 2011;31(4):E3. doi:10.3171/2011.7.FOCUS11145

11. Daubs MD, Lenke LG, Cheh G, Stobbs G, Bridwell KH. Adult spinal deformity surgery: complications and outcomes in patients over age 60. *Spine (Phila Pa 1976)*. 2007;32(20):2238–2244. doi:10.1097/BRS.0b013e31814cf24a

12. Passias PG, Poorman GW, Bortz CA, et al. Predictors of adverse discharge disposition in adult spinal deformity and associated costs. *Spine J*. 2018;18(10):1845–1852. doi:10.1016/j.spinee.2018.03.022

13. Dindo D, Demartines N, Clavien P-A. Classification of surgical complications: a new proposal with evaluation in a cohort of 6336 patients and results of a survey. *Ann Surg*. 2004;240(2):205–213. doi:10.1097/01.sla.0000133083.54934.ae

14. Glassman SD, Hamill CL, Bridwell KH, Schwab FJ, Dimar JR, Lowe TG. The impact of perioperative complications on clinical outcome in adult deformity surgery. *Spine (Phila Pa 1976)*. 2007;32(24):2764–2770. doi:10.1097/BRS.0b013e31815a7644

15. Daniels AH, Kawaguchi S, Contag AG, et al. Hospital charges associated with " never events ": comparison of anterior cervical discectomy and fusion, posterior lumbar interbody fusion, and lumbar laminectomy to total joint arthroplasty. *J Neurosurg Spine*. 2016;25(2):165–169. doi:10.3171/2015.11.SPINE15776

16. Auerbach JD, Lenke LG, Bridwell KH, et al. Major complications and comparison between 3-column osteotomy techniques in 105 consecutive spinal deformity procedures. *Spine (Phila Pa 1976)*. 2012;37(14):1198–1210. doi:10.1097/BRS.0b013e31824fffde

17. Cho K-J, Suk S-I, Park S-R, et al. Complications in posterior fusion and instrumentation for degenerative lumbar scoliosis. *Spine (Phila Pa 1976)*. 2007;32(20):2232–2237. doi:10.1097/BRS.0b013e31814b2d3c

18. Bianco K, Norton R, Schwab F, et al. Complications and intercenter variability of three-column osteotomies for spinal deformity surgery: a retrospective review of 423 patients. *Neurosurg Focus*. 2014;36(5):E18. doi:10.3171/2014.2.FOCUS1422

19. Schwab FJ, Hawkinson N, Lafage V, et al. Risk factors for major peri-operative complications in adult spinal deformity surgery: a multi-center review of 953 consecutive patients. *Eur Spine J*. 2012;21(12):2603–2610. doi:10.1007/s00586-012-2370-4

20. Smith JS, Shaffrey CI, Glassman SD, et al. Clinical and radiographic parameters that distinguish between the best and worst outcomes of scoliosis surgery for adults. *Eur Spine J*. 2013;22(2):402–410. doi:10.1007/s00586-012-2547-x

21. Passias PG, Soroceanu A, Yang S, et al. Predictors of revision surgical procedure excluding wound complications in adult spinal deformity and impact on patient-reported outcomes and satisfaction: a two-year follow-up. *J Bone Joint Surg Am*. 2016;98(7):536–543. doi:10.2106/JBJS.14.01126

22. Leven DM, Lee NJ, Kothari P, et al. Frailty index is a significant predictor of complications and mortality after surgery for adult spinal deformity. *Spine (Phila Pa 1976)*. 2016;41(23):E1394–E1401. doi:10.1097/BRS.0000000000001886

23. Rissman CM, Keeney BJ, Ercolano EM, Koenig KM. Predictors of facility discharge, range of motion, and patient-reported physical function improvement after primary total knee arthroplasty: a prospective cohort analysis. *J Arthroplasty*. 2016;31(1):36–41. doi:10.1016/j.arth.2015.09.002

24. Di Capua J, Somani S, Lugo-Fagundo N, et al. Predictors for non-home patient discharge following elective adult spinal deformity surgery. *Global Spine J*. 2018;8(3):266–272. doi:10.1177/2192568217717971

25. Yagi M, Fujita N, Okada E, et al. Impact of frailty and comorbidities on surgical outcomes and complications in adult spinal disorders. *Spine (Phila Pa 1976)*. 2018;43(18):1259–1267. doi:10.1097/BRS.0000000000002596

26. Lee NJ, Kothari P, Kim JS, et al. Early complications and outcomes in adult spinal deformity surgery: an NSQIP study based on 5803 patients. *Global Spine J*. 2017;7(5):432–440. doi:10.1177/2192568217699384

27. Carreon LY, Puno RM, Dimar JR, Glassman SD, Johnson JR. Perioperative complications of posterior lumbar decompression and arthrodesis in older adults. *J Bone Joint Surg Am*. 2003;85(11):2089–2092. doi:10.2106/00004623-200311000-00004

28. Tang H, Zhu J, Ji F, Wang S, Xie Y, Fei H. Risk factors for postoperative complication after spinal fusion and instrumentation in degenerative lumbar scoliosis patients. *J Orthop Surg Res*. 2014;9(1):15. doi:10.1186/1749-799X-9-15

29. Buchowski JM, Bridwell KH, Lenke LG, et al. Neurologic complications of lumbar pedicle subtraction osteotomy: a 10-year assessment. *Spine (Phila Pa 1976)*. 2007;32(20):2245–2252. doi:10.1097/BRS.0b013e31814b2d52

30. Ikenaga M, Shikata J, Takemoto M, Tanaka C. Clinical outcomes and complications after pedicle subtraction osteotomy for correction of thoracolumbar kyphosis. *J Neurosurg Spine*. 2007;6(4):330–336. doi:10.3171/spi.2007.6.4.8

31. Berjano P, Aebi M. Pedicle subtraction osteotomies (PSO) in the lumbar spine for sagittal deformities. *Eur Spine J*. 2015;24 Suppl 1:S49–57. doi:10.1007/s00586-014-3670-7

32. Pradhan BB, Nassar JA, Delamarter RB, Wang JC. Single-level lumbar spine fusion: a comparison of anterior and posterior approaches. *J Spinal Disord Tech*. 2002;15(5):355–361. doi:10.1097/00024720-200210000-00003

33. Geck MJ, Rinella A, Hawthorne D, et al. Comparison of surgical treatment in lenke 5C adolescent idiopathic scoliosis: anterior dual rod versus posterior pedicle fixation surgery: a comparison of two practices. *Spine (Phila Pa 1976)*. 2009;34(18):1942–1951. doi:10.1097/BRS.0b013e3181a3c777

Funding: The authors received no financial support for the research, authorship, and/or publication of this article.

Declaration of Conflicting Interests: The authors report no conflicts of interest in this work.

Disclosures: Michael Gerling reports royalties from Integrity Implants; consulting fees from Integrity Implants, RTI Surgical, and Wolf Endoscopic; and a leadership role for AAOS and the Cervical Spine Research Society. Hamid Hassanzadeh reports consulting fees from DePuy, Medtronic, and Nuvasive; a leadership role with the Scoliosis Research Society; stock/stock options from 4Web and Nuvasive; research support from Medtronic, Orthofix Inc, and Pfizer; and paid presenter/speaker for Medtronic, Nuvasive, and Orthofix Inc. Peter G. Passias reports personal consulting fees for Medtronic, Royal Biologics, Spinewave, Zimmer Biomet, DePuy Synthes, Terumo, and Medicrea; paid presenter/speaker for Globus Medical; research support from the Cervical Scoliosis Research Society; leadership role for Spine, and other financial or material support from Cerabedics and Spinevision. The remaining authors have nothing to disclose.

Ethical Review Committee Statement: Each institution obtained approval from their local Institutional Review Board to enroll patients in the prospective database and informed consent was obtained from each patient.

Corresponding Author: Peter G. Passias, Division of Spinal Surgery/Departments of Orthopaedics and Neurosurgery, NYU Medical Center, NY Spine Institute, 301 E 17th St, New York, NY 10003, USA; peter.passias@nyulangone.org