

## Original Article

## Risk factors for wound complications following spine surgery

Keaton F. Piper, Samuel B. Tomlinson, Gabrielle Santangelo, Joseph Van Galen, Ian DeAndrea-Lazarus, James Towner, Kristopher T. Kimmell, Howard Silberstein, George Edward Vates

Department of Neurosurgery, University of Rochester Medical Center, Rochester, New York, United States

E-mail: \*Keaton F. Piper - [Keaton\\_Piper@urmc.rochester.edu](mailto:Keaton_Piper@urmc.rochester.edu); Samuel B. Tomlinson - [Samuel\\_Tomlinson@urmc.rochester.edu](mailto:Samuel_Tomlinson@urmc.rochester.edu); Gabrielle Santangelo - [Gabrielle\\_Santangelo@urmc.rochester.edu](mailto:Gabrielle_Santangelo@urmc.rochester.edu); Joseph Van Galen - [Joseph\\_VanGalen@urmc.rochester.edu](mailto:Joseph_VanGalen@urmc.rochester.edu); Ian DeAndrea-Lazarus - [Ian\\_DeandreaLazarus@urmc.rochester.edu](mailto:Ian_DeandreaLazarus@urmc.rochester.edu); James Towner - [James\\_Towner@urmc.rochester.edu](mailto:James_Towner@urmc.rochester.edu); Kristopher T. Kimmell - [Kkimmell@gmail.com](mailto:Kkimmell@gmail.com); Howard Silberstein - [Howard\\_Silberstein@urmc.rochester.edu](mailto:Howard_Silberstein@urmc.rochester.edu); George Edward Vates - [Edward\\_Vates@urmc.rochester.edu](mailto:Edward_Vates@urmc.rochester.edu)

\*Corresponding author

Received: 13 August 17 Accepted: 22 August 17 Published: 01 November 17

### Abstract

**Background:** Wound complications, including surgical site infections (SSIs) and wound dehiscence, are among the most common complications following spine surgery often leading to readmission. The authors sought to identify preoperative characteristics predictive of wound complications after spine surgery.

**Methods:** The American College of Surgeons National Surgical Quality Improvement Program database for years 2012–2014 was reviewed for patients undergoing spine surgery, defined by the Current Procedural Terminology codes. Forty-four preoperative and surgical characteristics were analyzed for associations with wound complications.

**Results:** Of the 99,152 patients included in this study, 2.2% experienced at least one wound complication (superficial SSI: 0.9%, deep SSI: 0.8%, organ space SSI: 0.4%, and dehiscence: 0.3%). Multivariate binary logistic regression testing found 10 preoperative characteristics associated with wound complications: body mass index  $\geq 30$ , smoker, female, chronic steroid use, hematocrit  $< 38\%$ , infected wound, inpatient status, emergency case, and operation time  $> 3$  hours. A risk score for each patient was created from the number of characteristics present. Receiver operating characteristic curves of the unweighted and weighted risk scores generated areas under the curve of 0.701 (95% CI: 0.690–0.713) and 0.715 (95% CI: 0.704–0.726), respectively. Patients with unweighted risk scores  $> 7$  were 25-fold more likely to develop a wound complication compared to patients with scores of 0. In addition, mortality rate, reoperation rate, and total length of stay each increased nearly 10-fold with increasing risk score.

**Conclusion:** This study introduces a novel risk score for the development of wound dehiscence and SSIs in patients undergoing spine surgery, using new risk factors identified here.

#### Access this article online

**Website:**

[www.surgicalneurologyint.com](http://www.surgicalneurologyint.com)

**DOI:**

10.4103/sni.sni\_306\_17

**Quick Response Code:**

This is an open access article distributed under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike 3.0 License, which allows others to remix, tweak, and build upon the work non-commercially, as long as the author is credited and the new creations are licensed under the identical terms.

**For reprints contact:** [reprints@medknow.com](mailto:reprints@medknow.com)

**How to cite this article:** Piper KF, Tomlinson SB, Santangelo G, Van Galen J, DeAndrea-Lazarus I, Towner J, et al. Risk factors for wound complications following spine surgery. *Surg Neurol Int* 2017;8:269.

<http://surgicalneurologyint.com/Risk-factors-for-wound-complications-following-spine-surgery/>

**Key Words:** Spine surgery, surgical site infection, wound dehiscence, wound complication, risk factors

## INTRODUCTION

The increasing cost associated with spine surgery is a well-known problem affecting the United States (US) healthcare system; this is becoming more important with the increasing prevalence of spine surgeries. From 2002 to 2007, the rate of complex spine surgery increased almost 15-fold in the Medicare population.<sup>[10]</sup> During the first decade of the 21<sup>st</sup> century, an estimated 3.6 million spine fusions occurred in the US, responsible for \$287 billion in healthcare expenses.<sup>[16]</sup> Addressing the reducible costs of spine surgery (e.g., preventable complications and readmissions) is critical for promoting healthcare efficiency and improving surgical outcomes.<sup>[22,25,43]</sup>

Among the most common postoperative complications associated with readmissions are wound complications, including surgical site infections (SSIs) and dehiscence.<sup>[2,28]</sup> Neurosurgical SSIs have been reported as the highest costs of all specialty-based SSIs, on average contributing to a \$23,755 per case increase in cost compared to those cases without SSIs.<sup>[36]</sup> Expectedly, SSIs in spine surgery have been associated with increased mortality rates, readmission rates, and hospital length of stay (LOS).<sup>[23,42]</sup> Similar to SSIs, wound dehiscence is a costly complication reported as the second most common postoperative complication in spinal fusion procedures.<sup>[16]</sup>

Given the relatively low percentage of wound infections and dehiscence in spine surgery, it is difficult to develop a cost-effective intervention for reducing these rates. One approach to this problem is to identify patients who are at an increased risk of wound complications and may benefit from more intensive preventative wound care. There have been various effective interventions aimed at reducing wound complications.<sup>[1,6,9,11,12]</sup> However, implementation on a wide-scale manner can be costly and time-consuming. At present, the field lacks a robust bedside tool for stratifying wound complication risk at the individual-patient level.

In the present study, we sought to determine preoperative characteristics independently associated with wound complications in patients undergoing spine surgery. Using these factors, we developed a novel risk score for this cohort that may be used to calculate a patient's risk of developing a wound complication including organ-space SSI, deep incisional SSI, superficial SSI, or dehiscence. Further validation of this methodology may allow clinicians to anticipate high-risk cases and adjust perioperative management with the goal of reducing occurrences of wound complications.

## MATERIALS AND METHODS

### Data acquisition

Data were collected from the National Surgical Quality Improvement Project (NSQIP) dataset during the years 2012–2014. Organized by the American College of Surgeons (ACS), the NSQIP database is a collection of perioperative data sourced from deidentified surgical cases at over 700 hospitals in the US. Data allocation at each participating site is performed by an ACS-trained Surgical Clinician Reviewer (SCR), who collects information in a standardized manner, maintains a degree of separation from the hospital's physicians, and undergoes regular audits.<sup>[18]</sup> Over 300 perioperative characteristics are reported for each case and postoperative follow-up is documented for 30 days. The full training and auditing process of the SCRs is detailed at the ACS NSQIP website: <https://www.facs.org/quality-programs/acs-nsqip>.<sup>[17,20]</sup>

### Univariate and multivariate analyses

All patients who underwent spine surgery between 2012 and 2014 were identified by the Current Procedural Terminology (CPT) codes [Supplemental Table S1]. Thirty-nine preoperative characteristics from the NSQIP dataset of interest were defined *a priori* based on potential associations with wound complications [Table 1]. Patients with incomplete datasets in respect to these characteristics were excluded, resulting in 99,152 patients analyzed [Figure 1]. Categorical variables were converted to binary variables prior to analysis using the following criteria: [American Society of Anesthesiologists (ASA) classification score  $\geq 3$ ; Age <45; 45  $\leq$  Age <55; 55  $\leq$  Age <65; Age  $\geq 65$  years; operation time >3 hours; BMI <18.5, 18.5–25, 25–30, >30; WBC  $\geq 10,000/\mu\text{L}$ ; hematocrit <38%; platelet count <150,000/ $\mu\text{L}$ ; dependent functional status; wound classification].<sup>[4,8,21,33]</sup> Cases were subdivided by procedure (osteotomies, arthrodesis, instrumentation, use of graft, or procedure for fractures) to analyze for utility of a risk score encompassing all spine surgeries.

Four specific wound complications tracked by NSQIP were examined in this study: dehiscence, superficial SSI, deep SSI, and organ-space SSI. To construct a generalizable risk score, a composite binary outcome representing the occurrence of any wound complication was defined. Preoperative characteristics underwent univariate analysis for association with the composite wound complication outcome measure using Chi-square tests and Fischer's exact tests where appropriate.

**Table 1: Summary of univariate analysis results for all wound complications**

Variable	Number of patients (%)	Wound comp (%)	Odds ratio (95% CI)
Female sex	48,386 (48.8)	2.4	1.2 (1.1-1.3)*
White ethnicity	80,945 (81.6)	2.1	0.8 (0.7-0.8)*
Black ethnicity	8,364 (8.4)	3.2	1.5 (1.3-1.7)*
Inpatient procedure	74769 (75.4)	2.5	2.1 (1.8-2.3)*
Age <45	19,386 (19.6)	2.3	1.0 (0.9-1.2)
45 ≤ Age <55	21,274 (21.5)	2.2	1.0 (0.9-1.1)
55 ≤ Age <65	24,260 (24.5)	2.2	1.0 (0.9-1.1)
Age ≥65	34,232 (34.5)	2.2	1.0 (0.9-1.1)
Performed by neurosurgeon	63,450 (64.0)	1.9	0.7 (0.7-0.8)*
BMI <18.5	1,121 (1.1)	2.2	1.0 (0.7-1.5)
18.5 ≤ BMI <25	20,298 (20.5)	1.9	0.8 (0.7-0.9)*
25 ≤ BMI <30	33,159 (33.4)	1.8	0.7 (0.7-0.8)*
BMI ≥30	44,574 (45.0)	2.7	1.5 (1.4-1.6)*
Diabetes	17,456 (17.6)	3.2	1.6 (1.5-1.8)*
Current smoker	23,256 (23.5)	2.7	1.3 (1.2-1.4)*
Dyspnea	5,525 (5.6)	2.8	1.3 (1.1-1.5)*
Dependent functional status	4,237 (4.3)	4.9	2.4 (2.1-2.8)*
Ventilator dependent	208 (0.2)	6.7	3.2 (1.9-5.5)*
History of COPD	4,671 (4.7)	3.1	1.5 (1.2-1.7)*
Ascites	51 (0.1)	9.8	4.8 (1.9-12.1)*
History of CHF	516 (0.5)	6.8	3.2 (2.3-4.6)*
Anti-HTN medication use	50102 (50.5)	2.5	1.3 (1.2-1.4)*
Renal failure	200 (0.2)	8.5	4.1 (2.5-6.8)*
Dialysis	717 (0.7)	6.1	2.9 (2.1-4.0)*
Disseminated cancer	1,448 (1.5)	3.7	1.7 (1.3-2.3)*
Wound infection	3,560 (3.6)	9.2	5.1 (4.5-5.8)*
Steroid use	4,466 (4.5)	3.8	1.8 (1.5-2.1)*
Weight loss	533 (0.5)	5.6	2.7 (1.8-3.8)*
Bleeding disorder	2,510 (2.5)	4.8	2.3 (1.9-2.8)*
Transfusion	536 (0.5)	6.5	3.1 (2.2-4.4)*
Preoperative sepsis	2,528 (2.5)	8.9	4.7 (4.1-5.4)*
WBC count <4	2,369 (2.4)	2.4	1.1 (0.8-1.4)
WBC count ≥10	15,617 (15.8)	3.5	1.8 (1.6-2.0)*
Hematocrit <38%	24,709 (24.9)	3.8	2.3 (2.1-2.5)*
Platelet <150	5,409 (5.5)	2.9	1.4 (1.1-1.6)*
Emergency case	3,228 (3.3)	7.3	3.8 (3.3-4.3)*
Wound Class ≥II	6,322 (6.4)	9.4	5.9 (5.3-6.5)*
ASA Class ≥III	47,050 (47.5)	3.0	2.1 (1.9-2.3)*
Operative time ≥3 h	25,388 (25.6)	2.9	1.5 (1.3-1.6)*

BMI: Body Mass Index, COPD: Chronic Obstructive Pulmonary Disease, HTN: Hypertension, CHF: Congestive Heart Failure, WBC: White Blood Cell, ASA: American Society of Anesthesiologists, CI: Confidence Interval. \*Significant variables by a  $P < 0.01$

Variables were gated for entry into multivariate modeling using a  $P$  value threshold of  $P = 0.01$ . These factors were then submitted into a multivariate binary logistical regression model for association with the “any wound complication” composite outcome (entry level = 0.01, exit = 0.05). Statistical significance was determined by using an adjusted  $\alpha$  from a Holm-Bonferroni correction.

### Query NSQIP database

111,892 spinal neurosurgery cases identified between the years of 2012 - 2014



### Curate study dataset

99,152 cases preserved after list-wise exclusion of patients with incomplete datasets



### Univariate testing

Thirty three significant factors identified for inclusion in multivariate analyses



### Multivariate testing and risk score development

Ten independent predictors identified for risk score development

**Figure 1: Flow chart of data allocation**

For each factor, odds ratios were calculated. Statistical analysis was performed with a combination of Statistical Analysis Software (SAS Institute Inc., Cary, NC) and Statistical Package for the Social Science (SPSS) software (version 24.0 IBM).

### Risk score computation

Ten preoperative characteristics deemed statistically significant by multivariate analysis were used in generating weighted and unweighted risk scores. For the unweighted risk score, each independent risk factor was given a value of 1 when present. The factors were summed to create each individual patient's risk score, ranging from 0 to 10. A weighted risk score was created using adjusted multivariate odds ratios, consistent with previous risk score computations.<sup>[15]</sup> Patients were stratified by the unweighted risk score into groups. Those groups with fewer than 100 cases were considered together as a single

group which applied to unweighted scores of  $\geq 8$ . The risk scores and associated wound complications were used to generate a receiver operating characteristic (ROC) curve, and an area under the curve (AUC) was used to assess the predictability of the scoring system. ROC analysis was conducted using MATLAB 2016a scripts and SPSS software (version 24.0 IBM).

## RESULTS

In total, 99,152 spine surgery cases with complete datasets were analyzed [Table 2]. The overall wound complication rate in this cohort was 2.2%. Individual wound complication rates were as follows: superficial SSI: 0.9%, deep SSI: 0.8%, organ space SSI: 0.4%, and dehiscence: 0.3%. Of the 292 patients who experienced wound dehiscence, 135 (46%) also had concomitant SSI. The presence of at least one wound complication was associated with an increased 30-day mortality from 0.5% to 0.8%, an increased average postoperative stay from 3 to 6 days, and an increased rate of reoperation from 2.3% to 42%. For all wound complications, the

**Table 2: Summary of clinical characteristics**

Variable	Number of patients (% of total)
Gender	
Male	50,766 (51.2)
Female	48,386 (48.8)
Age (years)	
Age <45	19,386 (19.6)
45 $\leq$ Age <55	21,274 (21.5)
55 $\leq$ Age <65	24,260 (24.5)
Age $\geq$ 65	34,232 (34.5)
BMI	
BMI <18.5	1,121 (1.1)
18.5 $\leq$ BMI <25	20,298 (20.5)
25 $\leq$ BMI <30	33,159 (33.4)
30 $\leq$ BMI <35	24,557 (24.8)
BMI $\geq$ 35	20,017 (20.2)
Race	
White	80,945 (81.6)
Black	8,364 (8.4)
Other	9,843 (9.9)
Medical co-morbidities	
Current smoker	23,256 (23.5)
Diabetes	17,456 (17.6)
Anti-HTN medication use	50,102 (50.5)
Adverse wound outcome	
Superficial SSI	906 (0.9)
Deep SSI	793 (0.8)
Organ space SSI	356 (0.4)
Dehiscence	292 (0.3)
Any wound complication	2,196 (2.2)

BMI: Body Mass Index, HTN: Hypertension, SSI: Surgical Site Infection

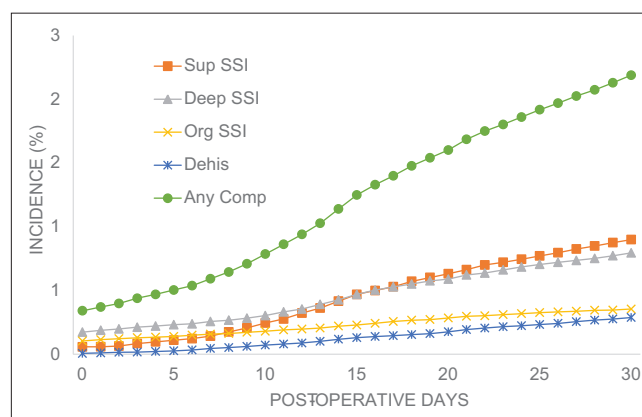
average postoperative day of occurrence was 14 days with a standard deviation (SD) of 9 days (superficial SSI:  $16 \pm 8$ ; deep SSI:  $13 \pm 10$ ; organ space SSI:  $11 \pm 10$ ; dehiscence:  $17 \pm 8$ ) [Figure 2].

Univariate analysis identified 33 characteristics significantly related to an increased risk of developing a postoperative wound complication [Table 1]. Of those univariate-significant factors, subsequent multivariate analysis using the composite wound complication outcome identified 10 significant independent predictors [Table 3]. No associations were found with spine procedure type when analyzing CPT codes. Weighted and unweighted risk scores created using the 10 predictors exhibited similar performance for classifying patients by the presence of at least one wound complication. Unweighted and weighted risk scores generated ROC AUCs of 0.701 (95% CI: 0.690–0.713) and 0.715 (95% CI: 0.704–0.726), respectively. The unweighted risk score was considered for further analyses due to intuitive clinical applicability and similar performance to the weighted model. When the unweighted risk score was further analyzed (median score = 3, mean = 2.6), we found wound complication

**Table 3: Summary of multivariate analysis results for all wound complications**

Predictor	Odds ratio (95% CI)	Score ( $\chi^2$ )
Wound Class $\geq$ II	4.0 (3.5-4.6)	1600.7
Operative time $\geq$ 3 h	1.6 (1.5-1.8)	170.0
ASA Class $\geq$ III	1.4 (1.3-1.5)	118.4
BMI $\geq$ 30	1.3 (1.3-1.5)	54.0
Hematocrit <38%	1.4 (1.3-1.5)	50.7
Inpatient procedure	1.4 (1.3-1.6)	38.6
Emergency case	1.6 (1.3-1.8)	30.3
Current smoker	1.3 (1.2-1.4)	26.4
Steroid use	1.5 (1.3-1.7)	22.3
Wound infection	1.3 (1.1-1.5)	8.7

ASA: American Society of Anesthesiologists, BMI: Body Mass Index, CI: Confidence Interval. All  $P < 0.001$



**Figure 2: Postoperative occurrence of wound complication**

rates of 0.7% in those with a risk score of 0 compared to 17.5% in those with a risk score  $\geq 8$  [Table 4; Figure 3]. An increase in risk score was also associated with increasing rates of mortality, length of stay, and return to the operating room [Table 5]. Among patients with a score of  $\geq 5$  (“high risk” group), there was a 4-fold increased rate of wound complication compared to those with a  $< 5$  (“low risk” group) [Table 4].

## DISCUSSION

In this study, we examined preoperative factors associated with postoperative wound complications following spine surgery. Using a sample encompassing nearly 100,000 cases from a national surgical database, we characterized wound complication rates and identified independent predictors associated with the development of at least one wound complication. Further, we implemented a novel scoring system for stratifying preoperative risk and demonstrated its performance among our sample. This study provides the largest to-date analysis of SSIs and dehiscence in spine surgery. Patient characteristics and wound complication rates [Table 2] were similar to other spine surgery cohorts with wound complication rates of 0.2–4.2%.<sup>[19,23,31,38,41]</sup>

Several of the characteristics have previously been reported as potential risk factors for SSI or dehiscence in specific spine surgeries. For example, a recent study of posterior cervical spine surgery identified BMI  $> 35$  kg/m<sup>2</sup>, chronic steroid use, prolonged operation time, hematocrit  $< 33\%$ , and ASA class  $> 2$  as independent risk factors for postoperative SSI.<sup>[37]</sup> Other studies have found smoking to be correlated with superficial, deep, and organ space SSI.<sup>[23,29,32]</sup> Interestingly, some factors previously found to be associated with SSI in spine surgery including chronic hypertension and diabetes mellitus were not significant here.<sup>[29]</sup> This discrepancy may be due to differing definitions of these variables, the larger sample size used in this study, or changes in population characteristics over time.

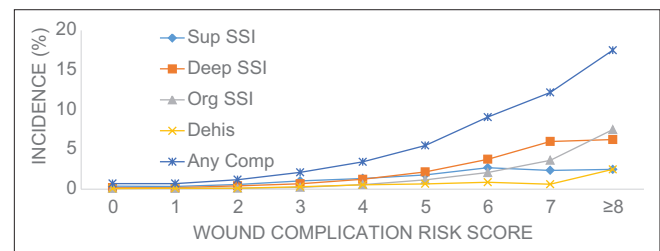


Figure 3: Wound complication incidence by risk score

Table 4: Increasing risk score and associated rates of wound complications

Risk score	Number of patients (n, % of total)	Superficial SSI (n, %)	Deep SSI (n, %)	OS SSI (n, %)	Dehiscence (n, %)	Any wound complication (n, %)
0	5,716 (5.8)	22 (0.4)	11 (0.2)	6 (0.1)	5 (0.1)	41 (0.7)
1	17,571 (17.7)	63 (0.4)	35 (0.2)	18 (0.1)	20 (0.1)	126 (0.7)
2	26,177 (26.4)	156 (0.6)	112 (0.4)	32 (0.1)	34 (0.1)	316 (1.2)
3	24,504 (24.7)	258 (1.1)	170 (0.7)	57 (0.2)	76 (0.3)	522 (2.1)
4	15,690 (15.8)	213 (1.4)	196 (1.2)	91 (0.6)	87 (0.6)	540 (3.4)
5	6,634 (6.7)	119 (1.8)	145 (2.2)	78 (1.2)	45 (0.7)	365 (5.5)
6	2,148 (2.2)	58 (2.7)	81 (3.8)	45 (2.1)	19 (0.9)	195 (9.1)
7	632 (0.6)	15 (2.4)	38 (6)	23 (3.6)	4 (0.6)	77 (12.2)
$\geq 8$	80 (0.1)	2 (2.5)	5 (6.3)	6 (7.5)	2 (2.5)	14 (17.5)
Overall	99,152	906 (0.9)	793 (0.8)	356 (0.4)	292 (0.3)	2,196 (2.2)

SSI: Surgical Site Infection, OS: Organ Space

Table 5: Complications associated with increasing risk score

Risk score	Number of patients (% of total)	Mortality (%)	Return to OR (%)	Post-operative LOS (median)	Days to 1 <sup>st</sup> wound complication (median)
0	5,716 (5.8)	0.1	1.1	0	16
1	17,571 (17.7)	0.2	1.5	1	16
2	26,177 (26.4)	0.4	2.1	1	15
3	24,504 (24.7)	0.6	3.2	2	15
4	15,690 (15.8)	0.8	4.6	3	15
5	6,634 (6.7)	1.3	7.1	4	13
6	2,148 (2.2)	1.4	9.8	5	2
7	632 (0.6)	0.3	11.1	7	0
$\geq 8$	80 (0.1)	0	12.5	8	2
Overall	99,152	0.5	3.2	2	14

OR: Operating Room, LOS: Length of Stay

Our study is the first to identify risk factors for all wound complications including dehiscence and SSIs in patients undergoing spine surgery. For wound complications, specific factors such as inpatient status and emergent case classification are first reported here. Although some risk factors associated with dehiscence have been published previously in relation to other types of surgery, they have not been associated with wound complications specifically after spine surgery.<sup>[3,5,34]</sup> While our study does not include postoperative characteristics that may be associated with wound complications, we choose to limit our analysis to preoperative and surgical characteristics to have a scoring system that can be utilized without missing variables prior to surgery.<sup>[29]</sup>

Existing NSQIP-derived risk scores have shown promise in predicting outcomes within other surgical fields.<sup>[7,13]</sup> In the present study, our risk score could classify patients based on the occurrence of  $\geq 1$  wound complication with relatively strong performance (AUC unweighted risk score = 0.701, weighted risk score = 0.715). The patients in this study with a risk score of  $\geq 5$  encompassed less than 10% of the total number of patients undergoing spine surgery but contained 30% of the wound complications that occurred. This risk score threshold is of clinical importance as those with a score of  $\geq 5$  have a mortality rate of 1.2%, average postoperative length of stay of 5 days, and 8% rate of returning to the operating room within 30 days compared to mortality rate of 0.5%, average postoperative length of stay of 3 days, and 3% rate of returning to the operating room within 30 days in those with a score of  $< 5$ . These findings highlight that a small subset of patients account for a disproportionate amount of surgical complications and are a “high risk” group that may be used for future validation studies.

Although NSQIP-based risk scores have been introduced within many different specialties,<sup>[26,30,40]</sup> the field of spine surgery currently lacks a robust scoring system for SSIs or dehiscence. While wound dehiscence and surgical site infections are separate entities, upon multivariate analysis of each individual wound complication we found nearly all associations with preoperative characteristics were overlapping, and previous studies showed similarities in preventative therapies. For example, there is extensive literature on the use of negative pressure wound vacuum-assisted closures (VACs) to prevent infection and dehiscence, including studies on spine surgery.<sup>[1,24]</sup> In addition, our results showed no significant associations of CPT codes with wound complications, highlighting the clinical utility of an overall spine surgery risk score applicable to many different spine surgeries. Spine procedures often involve similar surgical approaches, operative spaces, and closures that play an important role in the development of wound complications. Similarly, other studies on specific spine surgeries have identified overlapping perioperative characteristics associated with

SSIs and dehiscence.<sup>[19,26,29,31,35]</sup> Thus, a risk score for all wound complication has merit in that the preoperative characteristics and potential interventions significantly overlap.

One notable advance of the present study is the rigorous vetting of preoperative data to exclude patients with incomplete datasets and missing variables. The handling of missing data in NSQIP-based studies has come under increased scrutiny and excluding patients with incomplete data entry is expected to address these concerns.<sup>[14]</sup> Limitations of this study primarily concern the retrospective nature of the analysis and the corresponding possibility of selection bias. While the NSQIP database provides strength to the study with a large study population, it is limited in some of the characteristics reported. One limitation is NSQIP does not report on postoperative complications occurring after 30 days. Therefore, this analysis and scoring system is limited to 30 days for wound complication prediction, even though other studies have reported wound complications after 30 days as supported by Figure 2.<sup>[27]</sup> In addition, NSQIP is not a spine database and therefore does not report spine-specific variables. Unreported variables not included in this analysis that would be important in relation to wound complications include antibiotics administered, drains used, and other closure methods. While this risk scoring system is not exhaustive, it does provide a method for predicting wound complications within 30 days using a minimal number of variables that will benefit from further validation studies using prospective surgical cohorts.

Future work will be aimed at extending this risk score to include spine-specific variables and outcomes beyond 30 days for a more comprehensive scoring system. Additionally, further validation of this risk score is important by measuring the clinical response of providing preventative interventions for wound complications among identified “high-risk” patients in attempt to implement targeted cost-effective interventions. Such interventions include systemic antibiotics, local intraoperative antibiotics, multimodal preoperative skin preparation, negative pressure wound therapy, more extensive incisional closure (e.g. muscle flap closure), and more extensive postoperative wound care.<sup>[1,9,12,24]</sup> For example, the use of intraoperative local vancomycin was found to reduce SSI rates from 6.3% to 0.8% and reduce infection duration by over 18 days in patients undergoing instrumented spine surgery.<sup>[9]</sup> Featherall *et al.* proposed a bundle of 9 interventions to reduced SSIs in spine surgery that lead to a 50% reduction in SSIs and savings of nearly \$1000 per patient.<sup>[12]</sup> Adogwa *et al.* showed that negative pressure wound therapy reduced the incidence of wound dehiscence by 50% in thoracolumbar fusions, which is similar to many wounds for other spine surgeries.<sup>[11]</sup> Another study of

235 patients who underwent spine surgery showed the use of 2-octyl-cyanoacrylate (Dermabond, Ethicon Inc., Somerville, NJ, USA) reduced the total infection rate to 0.43% compared to the historical control group of 2.2%.<sup>[39]</sup> Many of these interventions have shown promise in reducing wound complications particularly in spine surgery. While these interventions are costly to provide to all patients, a risk score may help target these interventions to the most vulnerable patients.

## CONCLUSION

This study introduces a novel preoperative risk score for the development of wound dehiscence and SSIs in patients undergoing spinal surgery. The results suggest that a subset of spine surgery patients account for a disproportionate percentage of adverse wound outcomes, suggesting that high-risk patients may be identified before surgery. Further development of this risk score may prove useful for identifying high-risk patients that might benefit from more intensive wound management.

## Financial support and sponsorship

Nil.

## Conflicts of interest

There are no conflicts of interest.

## REFERENCES

- Adogwa O, Fatemi P, Perez E, Moreno J, Gazcon GC, Gokaslan ZL, et al. Negative pressure wound therapy reduces incidence of postoperative wound infection and dehiscence after long-segment thoracolumbar spinal fusion: A single institutional experience. *Spine J* 2014;14:2911-7.
- Akins PT, Harris J, Alvarez JL, Chen Y, Paxton EV, Bernbeck J, et al. Risk Factors Associated With 30-day Readmissions After Instrumented Spine Surgery in 14,939 Patients: 30-day readmissions after instrumented spine surgery. *Spine (Phila Pa 1976)* 2015;40:1022-32.
- Aksamija G, Mulabdic A, Rasic I, Aksamija L. Evaluation of Risk Factors of Surgical Wound Dehiscence in Adults After Laparotomy. *Med Arch* 2016;70:369-72.
- Alan N, Seicean A, Seicean S, Neuhauser D, Weil RJ. Impact of preoperative anemia on outcomes in patients undergoing elective cranial surgery. *J Neurosurg* 2014;120:764-72.
- Althumairi AA, Canner JK, Gearhart SL, Safar B, Fang SH, Wick EC, et al. Risk factors for wound complications after abdominoperineal excision: Analysis of the ACS NSQIP database. *Color Dis* 2016;18:O260-6.
- Andrew Glennie R, Dea N, Street JT. Dressings and drains in posterior spine surgery and their effect on wound complications. *J Clin Neurosci* 2015;22:1081-7.
- Bekelis K, Desai A, Bakhom SF, Missios S. A predictive model of complications after spine surgery: The National Surgical Quality Improvement Program (NSQIP) 2005-2010. *Spine J* 2014;14:1247-55.
- Dasenbrock HH, Devine CA, Liu KX, Gormley WB, Claus EB, Smith TR, et al. Thrombocytopenia and craniotomy for tumor: A National Surgical Quality Improvement Program analysis. *Cancer* 2016;122:1708-17.
- Dennis HH, Wei DT, Darren KZ, Shantakumar JT, Kumar N, Lau LL, et al. Is Intraoperative Local Vancomycin Powder the Answer to Surgical Site Infections in Spine Surgery? *Spine (Phila Pa 1976)* 2016 [Epub ahead of print].
- Deyo RA, Mirza SK, Martin BI, Kreuter W, Goodman DC, Jarvik JG. Trends, major medical complications, and charges associated with surgery for lumbar spinal stenosis in older adults. *JAMA* 2010;303:1259-65.
- Dumanian GA, Ondra SL, Liu J, Schafer MF, Chao JD. Muscle flap salvage of spine wounds with soft tissue defects or infection. *Spine (Phila Pa 1976)* 2003;28:1203-11.
- Featherall J, Miller JA, Bennett EE, Lubelski D, Wang H, Khalaf T, et al. Implementation of an Infection Prevention Bundle to Reduce Surgical Site Infections and Cost Following Spine Surgery. *JAMA Surg* 2016;151:988-90.
- Fink AS, Campbell Jr. DA, Mentzer Jr. RM, Henderson WG, Daley J, Bannister J, et al. The National Surgical Quality Improvement Program in non-veterans administration hospitals: Initial demonstration of feasibility. *Ann Surg* 2002;236:344.
- Gani F, Canner JK, Pawlik TM. Use of the Modified Frailty Index in the American College of Surgeons National Surgical Improvement Program Database: Highlighting the Problem of Missing Data. *JAMA Surg* 2017;152:205-7.
- Giannopoulos G, Raisakis K, Synetos A, Davlourous P, Hahalis G, Alexopoulos D, et al. A predictive score of radial artery spasm in patients undergoing transradial percutaneous coronary intervention. *Int J Cardiol* 2015;188:76-80.
- Goz V, Weinreb JH, McCarthy I, Schwab F, Lafage V, Errico TJ. Perioperative complications and mortality after spinal fusions: Analysis of trends and risk factors. *Spine (Phila Pa 1976)* 2013;38:1970-6.
- Guillamondegui OD, Gunter OL, Hines L, Martin BJ, Gibson W, Clarke PC, et al. Using the National Surgical Quality Improvement Program and the Tennessee Surgical Quality Collaborative to improve surgical outcomes. *J Am Coll Surg* 2012;214:706-9.
- Hall BL, Hamilton BH, Richards K, Bilimoria KY, Cohen ME, Ko CY. Does surgical quality improve in the American College of Surgeons National Surgical Quality Improvement Program: An evaluation of all participating hospitals. *Ann Surg* 2009;250:363-76.
- Jalai CM, Worley N, Poorman GW, Cruz DL, Vira S, Passias PG. Surgical site infections following operative management of cervical spondylotic myelopathy: Prevalence, predictors of occurrence, and influence on peri-operative outcomes. *Eur Spine J* 2016;25:1891-6.
- Khuri SF, Daley J, Henderson W, Hur K, Demakis J, Aust JB, et al. The Department of Veterans Affairs' NSQIP: The first national, validated, outcome-based, risk-adjusted, and peer-controlled program for the measurement and enhancement of the quality of surgical care. National VA Surgical Quality Improvement Program. *Ann Surg* 1998;228:491-507.
- Kimmell KT, Algattas H, Joynt P, Schmidt T, Jahromi BS, Silberstein HJ, et al. Risk Modeling Predicts Complication Rates for Spinal Surgery. *Spine (Phila Pa 1976)* 2015;40:1836-41.
- Kuhns BD, Lubelski D, Alvin MD, Taub JS, McGirt MJ, Benzel EC, et al. Cost and quality of life outcome analysis of postoperative infections after subaxial dorsal cervical fusions. *J Neurosurg Spine* 2015;22:381-6.
- De la Garza-Ramos R, Abt NB, Kerezoudis P, McCutcheon BA, Bydon A, Gokaslan Z, et al. Deep-wound and organ-space infection after surgery for degenerative spine disease: An analysis from 2006 to 2012. *Neurol Res* 2016;38:117-23.
- Labler L, Keel M, Trentz O, Heinzelmann M. Wound conditioning by vacuum assisted closure (V.A.C.) in postoperative infections after dorsal spine surgery. *Eur Spine J* 2006;15:1388-96.
- Lau D, Chan AK, Theologis AA, Chou D, Mummaneni P V, Burch S, et al. Costs and readmission rates for the resection of primary and metastatic spinal tumors: A comparative analysis of 181 patients. *J Neurosurg Spine* 2016;25:366-78.
- Lee MJ, Cizik AM, Hamilton D, Chapman JR. Predicting medical complications after spine surgery: A validated model using a prospective surgical registry. *Spine J* 2014;14:291-9.
- Lewkonja P, DiPaola C, Street J. Incidence and risk of delayed surgical site infection following instrumented lumbar spine fusion. *J Clin Neurosci* 2016;23:76-80.
- McCormack RA, Hunter T, Ramos N, Michels R, Hutzler L, Bosco JA. An analysis of causes of readmission after spine surgery. *Spine (Phila Pa 1976)* 2012;37:1260-6.
- Meng F, Cao J, Meng X. Risk factors for surgical site infections following spinal surgery. *J Clin Neurosci* 2015;22:1862-6.
- Piper K, Algattas H, DeAndrea-Lazarus IA, Kimmell KT, Li YM, Walter KA, et al. Risk factors associated with venous thromboembolism in patients undergoing spine surgery. *J Neurosurg Spine* 2017;26
- Pull ter Gunne AF, Cohen DB. Incidence, prevalence, and analysis of risk

- factors for surgical site infection following adult spinal surgery. *Spine (Phila Pa 1976)* 2009;34:1422-8.
32. Radcliff KE, Neusner AD, Millhouse PW, Harrop JD, Kepler CK, Rasouli MR, et al. What is new in the diagnosis and prevention of spine surgical site infections. *Spine J* 2015;15:336-47.
  33. Saleh A, Thirukumaran C, Mesfin A, Molinari RW. Complications and readmission after lumbar spine surgery in elderly patients: An analysis of 2,320 patients. *Spine J* 2017 [Epub ahead of print].
  34. Sandy-Hodgetts K, Carville K, Leslie GD. Determining risk factors for surgical wound dehiscence: A literature review. *Int Wound J* 2015;12:265-75.
  35. Schimmel JJ, Horsting PP, de Kleuver M, Wonders G, van Limbeek J. Risk factors for deep surgical site infections after spinal fusion. *Eur Spine J* 2010;19:1711-9.
  36. Schweizer ML, Cullen JJ, Perencevich EN, Vaughan Sarrazin MS. Costs Associated With Surgical Site Infections in Veterans Affairs Hospitals. *JAMA Surg* 2014;149:575-81.
  37. Sebastian AS, Polites SF, Glasgow AE, Habermann EB, Cima RR, Kakar S. Current Quality Measurement Tools Are Insufficient to Assess Complications in Orthopedic Surgery. *J Hand Surg Am* 2017;42:10-15.e1.
  38. Sielatycki JA, Parker SL, Godil SS, McGirt MJ, Devin CJ. Do Patient Demographics and Patient-Reported Outcomes Predict 12-Month Loss to Follow-Up After Spine Surgery? *Spine (Phila Pa 1976)* 2015;40:1934-40.
  39. Wachter D, Bruckel A, Stein M, Oertel MF, Christophis P, Boker DK. 2-Octyl-cyanoacrylate for wound closure in cervical and lumbar spinal surgery. *Neurosurg Rev* 2010;33:483-9.
  40. van Walraven C, Musselman R. The Surgical Site Infection Risk Score (SSIRS): A Model to Predict the Risk of Surgical Site Infections. *PLoS One* 2013;8:e67167.
  41. Wang T, Wang H, Yang DL, Jiang LQ, Zhang LJ, Ding WY. Factors predicting surgical site infection after posterior lumbar surgery: A multicenter retrospective study. *Med* 2017;96:e6042.
  42. Webb ML, Nelson SJ, Save A, Cui J, Lukaszewicz AM, Samuel AM, et al. Of 20,376 Lumbar Discectomies, 2.6% of Patients Readmitted within 30 Days: Surgical Site Infection, Pain, and Thromboembolic Events are the Most Common Reasons for Readmission. *Spine (Phila Pa 1976)* 2016 [Epub ahead of print].
  43. Yeramaneni S, Robinson C, Hostin R. Impact of spine surgery complications on costs associated with management of adult spinal deformity. *Curr Rev Musculoskelet Med* 2016;9:327-32.



**Supplemental Table S1: Current Procedural Terminology  
Codes for spine surgery analyzed**

22010, 22015, 22100, 22101, 22102, 22210, 22212, 22214, 22220,  
22222, 22224, 22318, 22319, 22325, 22326, 22327, 22328, 22523,  
22524, 22532, 22533, 22534, 22548, 22554, 22556, 22558, 22585,  
22590, 22595, 22600, 22610, 22612, 22614, 22630, 22632, 22800,  
22802, 22804, 22808, 22810, 22812, 22818, 22819, 22830, 22840,  
22841, 22842, 22843, 22844, 22845, 22846, 22847, 22848, 22849,  
22850, 22851, 22852, 22855, 22899, 27080, 63001, 63003, 63005,  
63011, 63012, 63015, 63016, 63017, 63020, 63030, 63035, 63042,  
53043, 63044, 63045, 63046, 63047, 63048, 63050, 63051, 63055,  
63056, 63057, 63064, 63075, 63076, 63077, 63078, 63080, 63081,  
63082, 63085, 63087, 63090, 63101, 63102, 63103, 63170, 63172,  
63173, 63180, 63185, 63191, 63196, 63200, 63250, 63251, 63252,  
62265, 63266, 63267, 63268, 63270, 63271, 63272, 63273, 63275,  
63276, 63277, 63278, 63280, 63281, 63282, 63285, 63286, 63287,  
63290, 63295, 63300, 63301, 63302, 63303, 63304, 63305, 63307,  
63308, 63685, 63700, 63704, 63707, 63709, 63710, 63740, 63741, 69990