A novel index for quantifying the risk of early complications for patients undergoing cervical spine surgeries

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OBJECTIVE It is becoming increasingly necessary for surgeons to provide evidence supporting cost-effectiveness of surgical treatment for cervical spine pathology. Anticipating surgical risk is critical in accurately evaluating the risk/benefit balance of such treatment. Determining the risk and cost-effectiveness of surgery, complications, revision procedures, and mortality rates are the most significant limitations. The purpose of this study was to determine independent risk factors for medical complications (MCs), surgical complications (SCs), revisions, and mortality rates following surgery for patients with cervical spine pathology. The most relevant risk factors were used to structure an index that will help quantify risk and anticipate failure for such procedures.

METHODS The authors of this study performed a retrospective review of the National Inpatient Sample (NIS) database for patients treated surgically for cervical spine pathology between 2001 and 2010. Multivariate models were performed to calculate the odds ratio (OR) of the independent risk factors that led to MCs and repeated for SCs, revisions, and mortality. The models controlled for age (< and > 65 years old), sex, race, revision status (except for revision analysis), surgical approach, number of levels fused/re-fused (2–3, 4–8, ≥ 9), and osteotomy utilization. ORs were weighted based on their predictive category: 2 times for revision surgery predictors and 4 times for mortality predictors. Fifty points were distributed among the predictors based on their cumulative OR to establish a risk index.

RESULTS Discharges for 362,989 patients with cervical spine pathology were identified. The mean age was 52.65 years, and 49.47% of patients were women. Independent risk factors included medical comorbidities, surgical parameters, and demographic factors. Medical comorbidities included the following: pulmonary circulation disorder, coagulopathy, metastatic cancer, renal failure, congestive heart failure, alcohol abuse, neurological disorder, nonmetastatic cancer, liver disease, rheumatoid arthritis/collagen vascular diseases, and chronic blood loss/anemia. Surgical parameters included posterior approach to fusion/re-fusion, ≥ 9 levels fused/re-fused, corpectomy, 4–8 levels fused/re-fused, and osteotomy; demographic variables included age ≥ 65 years. These factors increased the risk of at least 1 of MC, SC, revision, or mortality (risk of death). A total of 50 points were distributed among the factors based on the cumulative risk ratio of every factor in proportion to the total risk ratios.

CONCLUSIONS This study proposed an index to quantify the potential risk of morbidity and mortality prior to surgical intervention for patients with cervical spine pathology. This index may be useful for surgeons in patient counseling efforts as well as for health insurance companies and future socioeconomics studies in assessing surgical risks and benefits for patients undergoing surgical treatment of the cervical spine.

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KEY WORDS risk index; surgical risk; cervical; spine surgery

ABBREVIATIONS ARDS = adult respiratory distress syndrome; CHF = congestive heart failure; CI = confidence interval; MC = medical complication; NIS = National Inpatient Sample; NSQIP = National Surgical Quality Improvement Program; OR = odds ratio; SC = surgical complication.

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DEGENERATIVE changes in the cervical spine are a near-universal feature of aging^{9,18} and are at the root of a wide spectrum of clinical presentations and sequelae. Cervical spine pathologies might include cervical radiculopathy and/or cervical myelopathy and can manifest variably, with common symptoms including neck and/or arm pain. The incidence of cervical spine pathologies has varied, depending on the specific diagnosis; cervical radiculopathy has been estimated annually at an incidence rate of 83 per 100,000 persons and cervical myelopathy rates are reported to have dramatically increased in patients over the age of 55 years.^{10,24}

While many cervical pathologies can be managed conservatively, surgical intervention is often required for persistent and progressive symptoms.^{10,14,17,20} Despite established clinical and functional benefits of surgical interventions, complications associated with cervical spine surgery persist. In addition, there is a steady increase in the average national age in the US, which necessitates measures to evaluate the efficacy of treatment for cervical spine pathologies. From a clinical and cost-effectiveness standpoint, these measures retain increased value.²⁶ Useful metrics for evaluating such features of cervical surgery remain largely unexplored, however.

Complication rates range widely based on patient characteristics and the extent of the surgical intervention; rates have been estimated from 18.5% to 51.7%. Significant complications, including neurological functional changes and infections, demonstrate significant postoperative clinical impact and diminish the value of such interventions.^{5–7,15} The need for revision surgery is also a well-documented occurrence for cervical pathologies and has been shown to be influenced by surgical approach, diagnosis, and baseline factors.^{19,25} The value, then, in anticipating adverse events associated with the surgical management of cervical pathology is critical in balancing the risk/benefit ratio of such a treatment course. More importantly, studies investigating predictors for poor outcomes following cervical surgery are surprisingly varied in their findings: older age, sex, diabetes, hypertension, and smoking status, for instance, have all been implicated as factors contributing to worse postoperative results.^{12,23,27} One risk index for the application of any surgical procedure is the National Surgical Quality Improvement Program (NSQIP) Surgical Risk Calculator. Using similarly aggregated data as the National Inpatient Sample (NIS), NSQIP uses logistic regression to divide comorbidities and demographic factors into a variety of outcome categories. Examples of these categories are “serious complication,” “any complication,” and “return to OR.” Although these categories are not cervical specific and thus have their limitations, they serve as the basis for the model described in this paper, which is an adaptation of the same model the authors previously created for adult spinal deformity using the NIS.

This study sought to determine independent risk factors for perioperative medical complications (MCs), surgical complications (SCs), revisions, and mortality following operative treatment for cervical spine pathologies, and subsequently combine these independent risk factors to determine the collective risk of surgical intervention. We queried a nationwide database (the NIS) from 2001 to

2010 to structure relevant risk factors into a novel index to quantify the risk of cervical spine surgical procedures.

Methods

Data Source

The NIS (<https://www.hcup-us.ahrq.gov/nisoverview.jsp>) is the largest all-payer database in the US. It contains data for approximately 8 million annual discharges from approximately 1000 hospitals in 45 states, representing an approximate 20% stratified sample of community hospitals. The NIS contains 100 clinical and demographic data elements, with diagnoses and procedures presented in ICD-9-CM format. National estimates are derived from discharge weighted files. More information on the NIS design is available at http://hcup-us.ahrq.gov/db/nation/nis/NIS_Introduction_2012.jsp.

Inclusion Criteria

Annual data files from 2001 to 2010 were collected. Included discharges were those patients 25 years of age and older with the following ICD-9-CM coding for cervical spine pathology: patients included based on procedure code were those undergoing anterior or posterior fusion of the spine (81.01–81.03, 81.31–81.33), cervical discectomy (80.51), and decompression of the spinal canal including laminoplasty (03.09). Also, by diagnosis code, patients with an open or closed cervical fracture (805.0x, 805.1, 806.1x, 839.0x, 839.0x, 839.1x), cervical spondylosis with or without myelopathy (721.0, 721.1), and cervical stenosis or disc degeneration (723.0, 722.4) were included. Cervical fusion or re-fusion lengths were categorized as 2–3, 4–8 or ≥ 9 levels (81.62–81.64). An anterior fusion (81.02 and 81.32) and posterior fusion (81.03 and 81.33) approach was stratified. Exclusion criteria included patients with any metastatic or nonmetastatic cancer, lymphoma, or leukemia (140.x–172.x, 174.x–195.8x, 200.x–208.x, 196.x–199.1). The laminoplasty cohort excluded any fusions, re-fusions, bone morphogenetic protein usage, fusion devices, or corpectomies (81.00–81.09, 81.30–81.39, 84.52, or 80.99). The combined anterior and posterior cohort excluded lumbar fusions or re-fusions (81.06, 81.08, 81.36, 81.38). Additionally, the anterior cervical discectomy and fusion cohort excluded posterior and lumbar fusions or re-fusions (81.03, 81.33, 81.06–81.08, and 81.36–81.38). The posterior fusion cohort excluded anterior and lumbar fusions or re-fusions (81.06–81.08 and 81.36–81.38).

Data Collection

Demographic data for patient age, sex, race, mortality, comorbidity status, expected primary payer, total charges, length of hospital stay, and discharge/admission type were collected. Surgical factors collected included approach, number of levels fused/re-fused, osteotomy usage (77.39, 77.29), and revision status. Procedure-related complications resulting from surgical and medical care were determined using ICD-9-CM codes specific for individual complications. SCs included postoperative shock, hematoma/seroma formation, puncture laceration of a nerve or vessel, wound dehiscence, postoperative infection, hemorrhagic anemia, and dural tear complications; MCs includ-

TABLE 1. Patient- and hospital-related characteristics for all patients undergoing cervical spine surgery (2001–2010)

Variable	Value (%)
Age	
Overall mean yrs	52.65
18–44 yrs	99,988 (27.55)
45–64 yrs	194,723 (53.64)
65–74 yrs	45,476 (12.53)
75+ yrs	22,802 (6.28)
Sex	
Male	183,186 (50.53)
Female	179,324 (49.47)
Race	
White	221,071 (81.73)
Black	24,976 (9.23)
Hispanic	13,598 (5.03)
Asian/Pacific Islander	3368 (1.25)
Native American	1170 (0.43)
Other	6304 (2.33)
Primary payer	
Medicare	86,513 (23.89)
Medicaid	20,472 (5.65)
Private insurance	206,257 (56.97)
Self-pay	
No charge	
Other	
Admission type	
Routine	25,373 (7.72)
Urgent	24,046 (7.32)
Elective	276,967 (84.31)
Trauma center	2081 (0.63)
Other	27 (0.01)
Discharge type	
Routine	309,765 (85.41)
Short-term hospital	1723 (0.48)
Other transfers	31,149 (8.59)
HHC	18,196 (5.02)
AMA	270 (0.07)
Death	1501 (0.41)
Deyo score*	0.44
Mean total charges in dollars	46,446.03
Mean LOS in days	3.14
Mortality	1501 (0.41)

AMA = against medical advice; HHC = home health care; LOS = length of hospital stay.

* From Schneeweiss S, Wang PS, Avorn J, et al: Consistency of performance ranking of comorbidity adjustment scores in Canadian and U.S. utilization data. *J Gen Intern Med* 19:444–450, 2004.

TABLE 2. Baseline patient comorbidities for all patients undergoing cervical spine surgery (2001–2010)

Comorbidity	No. of Patients	%
Smoking history	67,904	18.71
Chronic pulmonary disease	47,274	13.02
Obesity	22,757	6.27
Anemia (deficiency)	10,306	2.84
Neurological disorders	10,271	2.83
Rheumatoid arthritis/collagen vascular diseases	8382	2.31
Cardiac valvular disorders	8350	2.30
Alcohol abuse	6555	1.81
CHF	5166	1.43
Renal failure	4215	1.16
Peripheral vascular disorders	4139	1.14
Illicit drug usage	3597	0.99
Coagulopathy	2688	0.74
Liver disease	2688	0.74
Tumor	2346	0.65
Metastasis	2163	0.60
Pulmonary circulation disorders	1205	0.33
Chronic blood loss/anemia	669	0.18

models were generated to identify the independent risk factors for experiencing an MC, SC, revision surgery, or death. Each model controlled for age (< and > 65 years old), sex, race, revision status (except for the revision analysis), surgical approach, number of levels fused/re-fused (2–3, 4–8, ≥ 9), and osteotomy utilization. Odds ratios (ORs) for each identified factor were included in the novel index both if they were statistically significant ($p < 0.05$) and clinically relevant ($OR < 1.5$) to ensure clinical impact and to avoid borderline factors.¹¹ Cumulative ORs were weighted based on their predictive category to generate a novel index according to the following equation: $(1 \times MC) + (1 \times SC) + (2 \times revision) + (4 \times mortality)$. Fifty points were then distributed among the identified predictors based on their cumulative ORs and ranked to establish the novel risk index. Three risk thresholds were proposed: mild (0–10), moderate (10–20), and severe (> 20–50 points).

Results

Patient Demographics

There were 362,989 cervical pathology discharges identified from 2001 to 2010. Patient- and hospital-related characteristics for the total cohort are summarized in Table 1. The mean patient age was 52.65 years, with most patients in the 45–64 age range (53.64%) and comprising 183,186 males (50.53%). Patients were predominantly white (81.73%) and were insured by private insurance (56.97%) and Medicare (23.89%). The average length of hospital stay was 3.14 days, and the mean cost of hospital charges was \$46,446.03. There were 92,255 patients with cervical myelopathy (25.42%), and 7162 (1.98%) had scoliosis. The most frequent comorbidities (Table 2) among

ed CNS, cardiac, peripheral vascular, respiratory, gastrointestinal, genitourinary, and venous thrombotic events as well as adult respiratory distress syndrome (ARDS).

Statistical Analysis

Statistical analysis was performed using R (R Foundation for Statistical Computing). All calculated and reported statistics were weighted to provide nationwide estimates using the NIS-provided weight files. Four multivariate

the patients with cervical spine pathology were a history of smoking ($n = 67,904$; 18.71%), chronic pulmonary disease ($n = 47,274$; 13.02%), and obesity ($n = 22,757$; 6.27%).

Surgical Summary

Overall, 3.54% of patients underwent corpectomies and 0.08% underwent osteotomies. The overall complication rate for all cervical patients in this study was 8.14%. The most frequently experienced complications were device related (2.67%), ARDS (1.51%), and acute posthemorrhagic anemia (1.38%; Table 3).

Independent Risk Factors

Multivariate analysis of presenting patient comorbidities and procedure-related variables identified the following factors as significant independent risk factors for increasing MC, SC, revision, and/or mortality (Table 4): pulmonary circulation disorders, coagulopathy, posterior fusion/re-fusion, metastatic cancer, renal failure, age ≥ 65 years, congestive heart failure (CHF), ≥ 9 levels fused/re-fused, corpectomy, alcohol abuse, neurological disorder, nonmetastatic cancer, liver disease, rheumatoid arthritis, 4–8 levels fused/re-fused, osteotomy utilization, and chronic blood loss/anemia. Overall, among the identified baseline comorbidities, pulmonary circulation disorders had the greatest impact, increasing MCs (OR 16.14) and mortality (risk of death; OR 8.53). Among the considered surgical factors, ≥ 9 levels fused had the most effect, as it increased the odds of both MCs (OR 3.88) and SCs (OR 5.61) the most.

Medical Complications

The model for MCs revealed that pulmonary circulation disorders had the greatest risk of sustaining an MC (OR 16.14, 95% confidence interval [CI] 14.53–17.93). These odds are far greater than the next two highest risk factors combined: ≥ 9 -level fusion (OR 3.88, 95% CI 3.39–4.45) and blood loss (OR 3.23, 95% CI 2.67–3.90). Nevertheless, the surgical factor that most increased the MC odds was ≥ 9 -level fusion (OR 3.88, 95% CI 3.39–4.45). This is in contrast to 4- to 8-level fusion, which increased the MC odds to a lesser degree (OR 1.76, 95% CI 1.70–1.83). Other surgical variables that increased the risk of MCs were posterior approach (OR 1.74, 95% CI 1.67–1.82) and the utilization of corpectomy (OR 1.68, 95% CI 1.58–1.77). All p values were < 0.05 .

Surgical Complications

The model for SCs showed that patients who had ≥ 9 -level fusion had the greatest risk of sustaining SCs (OR 5.61, 95% CI 4.93–6.39). Consequently, fewer levels of fusion had a smaller impact on the odds of complication, i.e., 4- to 8-level fusion (OR 2.18, 95% CI 2.10–2.27). However, the comorbidity that most increased SC odds was coagulopathy (OR 3.92, 95% CI 3.55–4.33). Unlike what was observed with MCs, pulmonary circulation disorders increased the SC odds to a smaller extent (OR 2.05, 95% CI 1.74–2.30) compared with coagulopathy. Other independent predictors of SCs included revision surgery (OR 1.71, 95% CI 1.58–1.86); metastases (OR 1.58, 95% CI

TABLE 3. Organ-specific and other complication rates for all patients undergoing cervical spine surgery (2001–2010)

Variable	No. of Patients	%
Organ-specific complications		
Respiratory	1915	0.53
Urinary	1723	0.47
Cardiac	1582	0.44
Nervous system	1346	0.37
Digestive system	1158	0.32
Peripheral vascular	114	0.03
Other complications of procedures		
Device-related	9676	2.67
ARDS	5467	1.51
Acute posthemorrhagic anemia	4992	1.38
Hematoma/seroma	1967	0.54
Puncture vessel/nerve	1699	0.47
Venous thrombotic events	1293	0.36
Postop infection	811	0.22
Pulmonary embolism	572	0.16
Dural tear	519	0.14
Wound dehiscence	302	0.08
Postop shock	76	0.02

1.35–1.85) and ≥ 65 years of age (OR 1.58, 95% CI 1.52–1.65) had the smallest impact. All p values were < 0.05 .

Revision Model

The model for revision risk included only surgical factors. Of these surgical factors, a posterior approach elevated the revision odds the most (OR 4.33, 95% CI 4.18–4.48). In contrast, corpectomy had the smallest impact of the considered factors (OR 1.61, 95% CI 1.52–1.71). Additionally, fusion of ≥ 9 levels also had a significant effect on revision risk (OR 2.63, 95% CI 2.27–3.04). Fusion of 4–8 levels also had an effect, although smaller than ≥ 9 levels (OR 1.66, 95% CI 1.60–1.72). Of note, diagnosis of cervical myelopathy was a significant predictor of decreased revision rate (OR 0.41, 95% CI 0.39–0.42). All p values were < 0.05 .

Mortality Model

Pulmonary circulation disorders increased the risk of death the most (OR 8.53, 95% CI 6.96–10.44; Table 4). Among the considered factors, black race had the least impact on mortality odds (OR 1.56, 95% CI 1.36–1.79). The surgical factor that most increased the risk of death was a posterior approach (OR 2.10, 95% CI 1.87–2.05). Although fusions of ≥ 9 levels had a significant impact on surgical complications, it did not have a significant effect on the mortality model (OR 1.14, 95% CI 0.76–1.71). Interestingly, fusions of 4–8 levels had a greater increase in risk of death (OR 1.38, 95% CI 1.24–1.54) compared with ≥ 9 levels. However, the increased odds from 4- to 8-level fusions was not included because the OR was < 1.5 . All p values were < 0.05 .

TABLE 4. Scoring method of the risk index for surgical treatment of patients with cervical spine pathology

Risk Factor	Individual OR				Cumulative OR*
	MC	SC	Revision	Mortality	
Pulmonary circulation disorder	16.14	2.05	NS	8.53	52.29
Coagulopathy	3.12	3.92	NS	5.34	28.40
Posterior approach to fusion/re-fusion	1.74	2.23	4.33	2.10	21.03
Metastatic cancer	1.50	1.58	NS	3.92	18.76
Renal failure	NS	1.86	NS	4.12	18.34
Age ≥65 yrs	1.67	1.58	NS	3.44	17.02
CHF	2.62	NS	NS	3.27	15.69
≥9 levels fused/re-fused	3.88	5.61	2.63	NS	14.75
Corpectomy	1.68	2.07	1.61	1.75	13.97
Alcohol abuse	2.20	1.94	NS	2.18	12.87
Neurological disorder	NS	NS	NS	2.30	9.20
Nonmetastatic cancer	NS	NS	NS	1.91	7.64
Liver disease	NS	NS	NS	1.85	7.40
Rheumatoid arthritis	NS	NS	NS	1.82	7.30
4–8 levels fused/re-fused	1.76	2.18	1.66	NS	7.27
Osteotomy	NS	2.77	1.83	NS	6.43
Chronic blood loss/anemia	3.23	NS	NS	NS	3.23
Total					261.59

NS = nonsignificant, or OR < 1.5.

* Cumulative OR calculated as: (1 × MC) + (1 × SC) + (2 × revision) + (4 × mortality).

Structured Risk Index

Table 5 presents the cumulative ORs for the significant identified risk factors in the structured index. Based on the weighted OR, 50 points were distributed across the index. Notably, pulmonary circulation disorders, such as primary pulmonary hypertension or pulmonary embolism, received the highest rank with 10 points. Pulmonary circulation disorders were followed by coagulopathy, which includes diseases such as hemophilia and von Willebrand's disease (5 points). The surgical factor with the highest rank was the posterior approach with 4 points. Metastases also received a ranking of 4 points. The other risk factors were given lower ratings up to 1 point. Overall, surgeons can use this model by adding points for each risk factor and the additive model will place a patient into a surgical risk category.

Case Vignette

As an example of how to use the index, a 75-year-old male patient with a history of rheumatoid arthritis is scheduled to undergo 5-level, posterior cervical fusion. To quantify the risk associated with this surgery, the patient can be scored based on our proposed structured index as follows: 3 points for > 65 years of age, 1 point for history of rheumatoid arthritis, 1 point for > 4-level fusion, and

TABLE 5. Structured index for cervical spine surgical risk, based on cumulative ORs

Comorbidity	Cumulative OR	Index Score
Pulmonary circulation disorder	52.29	10
Coagulopathy	28.40	5
Posterior approach to fusion/re-fusion	21.03	4
Metastatic cancer	18.76	4
Renal failure	18.34	4
Age ≥65 yrs	17.02	3
CHF	15.69	3
≥9 levels fused/re-fused	14.75	3
Corpectomy	13.97	3
Alcohol abuse	12.87	2
Neurological disorder	9.20	2
Nonmetastatic cancer	7.64	2
Liver disease	7.40	1
Rheumatoid arthritis	7.30	1
4–8 levels fused/re-fused	7.27	1
Osteotomy	6.43	1
Chronic blood loss/anemia	3.23	1
Total	261.59	50

4 points for the posterior approach. The total number of points is 9 of 50, which is a mild risk.

Discussion

Quantification of surgical risk for cervical spine surgeries is important for the betterment of patient care. While risk assessment is a commonly studied subject, according to the literature, no indices have been developed for the unique surgical considerations associated with cervical spine pathologies. Most literature describes the impact of individual complications on spine surgeries. Comprehensive risk indices, which use patient demographics, surgical procedures, and patient comorbidities, allow for the ascertainment of the probability of adverse events as well as their impact on patients. This helps clinicians to clearly predict the relative impact of patient-specific characteristics and surgical variables on perioperative patient outcomes while allowing them to better gauge benefits and risks for individual patients. This study aimed to develop a comprehensive risk index specific to surgical interventions in the cervical spine.

Overall, pulmonary circulation disorders had the highest associated risk-impact score of any other input variable. This finding is consistent with other studies evaluating the surgical management of spinal disorders. For example, Worley et al. found that pulmonary disorders were associated with the highest OR for increasing morbidity and mortality following surgical correction of adult spinal deformities.²⁷ Following pulmonary disorders, coagulopathy had the next highest risk score. This high risk-impact score may stem from the fact that perioperative hemostatic dysfunction can be multifactorial in nature, resulting from a variety of physiological imbalances.¹³ Our findings agree

with previous studies that have also shown coagulopathy to be an independent risk factor for perioperative mortality.¹⁶ Another particularly at-risk group of patients were those undergoing cervical fusion by a posterior approach. These patients commonly undergo longer and more aggressive surgeries due to revision constructs. These revision constructs are performed to support the increased degeneration and instability that may have resulted from the previous fusion or laminectomy.⁴ Literature can be found showing the deleterious effect of revision status on spine surgery outcomes. For instance, Diebo et al. found that the frequency of procedure-related complications was increased for patients who underwent revision compared with those who did not.³

Smoking, contrary to expectations, did not reach the threshold of inclusion in the final model and thus was not included. This may indicate that the well-established negative impact of smoking on orthopedic outcomes may be limited to longer-term outcomes, as this study focused on inpatient outcomes. Likewise, anemia is a relatively common finding before elective spine surgery, and is usually treated with perioperative blood transfusions.² Our findings indicate that deficiency-related anemia was also not associated with an OR > 1.5 in the incidence of complications, while chronic anemia is. This may, in part, be due to an underlying pathology for those with anemia of chronic disease. The relationship between these comorbidities and elective spine surgery remains unclear and calls for further investigation.

Chronic obstructive pulmonary disease was defined as chronic bronchitis (ICD-9 codes 490–491), emphysema (492), asthma (493), bronchiectasis (494), hypersensitivity pneumonitis (495), or chronic airway obstruction (496). With an incidence of 13.02% in our cohort of 8 million, this patient population most likely consisted of many patients with milder conditions such as asthma, which has contributed an estimated 7.4%–10.8% to the incidence in the population.¹ Controlled asthma is not associated with increased risk for intra- or perioperative complications, but airway-associated complications are associated with the most deaths in spine surgeries.²² Other inputs including obesity, peripheral vascular disease, cardiac valvular disease, and illicit drug use were not associated with an OR of 1.5 or greater and were excluded from the risk index; their adverse effects on outcomes were to a lesser degree than those factors included.

This paper attempts to characterize how the presence of comorbidities interacts with surgical conditions to increase the relative risk of cervical procedures. For example, surgical metrics of osteotomy and fusions of 4–8 levels ranked low in the index, only contributing 1 point each. This indicates that, after controlling for all other comorbidities and surgical indications, these advanced surgeries are being completed with minimal additional risk and no additional mortality. Similarly, fusions of more than 9 levels contributed significantly to the risk index with 3 points, which by itself is a mild risk. However, if these fusions were performed in an elderly patient (age ≥ 65 years) with renal failure, the risk index would increase to 11 points, a high-risk procedure.

To our knowledge this study is unique in its combi-

nation of such an expansive representation of patient comorbidities and their impact on an equally wide scope of complications. Our risk index is externally consistent with complication and comorbidity rates found in other population-based studies and randomized controlled trials. Risks of complications in dedicated studies also report similar results to our outcomes. For example, Skolasky et al. found a mortality rate of 0.42%, as well as a complication rate of 4.09%, compared with our respective rates of 0.42% for both.²¹ This allows caregivers to analyze comorbidities in combination where the impact of multiple comorbidities may be obscure.

Risk indices commonly assess a scalar representation of the minimum to maximum possible impact of an occurrence of a risk. Next, a composite risk index assesses how likely this event is to happen. The current model thoroughly develops the likelihood of complication events occurring through use of a database containing 8 million patients per year. However, the impact of each risk was assigned depending on expert opinion, based on the impact on hospital costs and patient outcomes. Expert surgical opinion has been shown to not always align with patient and payer perspectives.⁸

We acknowledge there are inherent limitations to our cumulative index, and that further evaluation is necessary. The next step in validating this risk index would be to compare outcome measures to patient-reported outcomes and costs. Also, to complete this risk index, it is necessary to consider alleviating effects of healthy patients and less invasive procedures with shorter operative times. Another limit of this study is the usage of a national database such as the NIS, which may not be as precise and focused on our measured outcome variables. Additionally, there are no sustained follow-up or patient-reported outcomes, which limits the scope of our index to comorbidities and intraoperative and perioperative outcomes. The NIS also does not have information on the magnitude of a patient's morbidity.

Conclusions

This study developed an index to score surgeries based on patient and surgical characteristics. Using a database of more than 8 million patients per year, a weighted score was determined based on preoperative considerations and their impact on perioperative outcome measures: MCs, SCs, revisions, and mortality. This index represents an initial step in the clarification of anticipated risk that is intrinsic to surgical interventions in the cervical spine, and may eventually help quantify the relative risk in relation to expected benefits for patients undergoing these various treatments.

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