J Chin Med Assoc

ORIGINAL ARTICLE

Incidence and predictors of acute kidney injury after elective surgery for lumbar degenerative disease: A 13-year analysis of the US Nationwide Inpatient Sample

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Abstract

Background: Acute kidney injury (AKI) is a severe postoperative complication associated with poor clinical outcomes, including the development of chronic kidney disease (CKD) and death. This study aimed to investigate the incidence and determinants of AKI following elective surgeries for degenerative lumbar spine disease.

Methods: All patient data were extracted from the US Nationwide Inpatient Sample database. After surgery, AKI's incidence and risk factors were identified for lumbar degenerative disease. ICD-9 and ICD-10 codes defined lumbar spine degenerative disease, fusion, decompression, and AKI. The study cohort was categorized by type of surgery, that is, decompression alone or spinal fusion. Regression analysis was used to identify associations between AKI and risk factors organized by surgery type.

Results: The incidence of AKI after decompression or fusion was 1.1% and 1.8%, respectively. However, the incidence of AKI in the United States is rising. The strongest predictor of AKI was underlying CKD, which was associated with an 9.0- to 12.9-fold more significant risk of AKI than in subjects without comorbid CKD. In this setting, older age, congestive heart failure, anemia, obesity, coagulopathy and hospital-acquired infections were also strong predictors of AKI. In contrast, long-term aspirin/anticoagulant usage was associated with lowered AKI risk.

Conclusion: Findings of this study inform risk stratification for AKI and may help to optimize treatment decisions and care planning after elective surgery for lumbar degenerative disease.

Keywords: Acute kidney injury; Complication; Degenerative spine surgery; Lumbar spine; National inpatient sample

1. INTRODUCTION

Acute kidney injury (AKI) is a serious postoperative complication and is associated with poor clinical outcomes, including the development of chronic kidney disease (CKD) and death. AKI occurs in approximately 12% of patients undergoing surgery,[1] affecting one in five people during postoperative hospitalization and associated with a significant increase in morbidity and mortality.[2] AKI is also associated with longer hospital stays.[3] In particular, AKI occurs in 7% to 11% of patients undergoing elective total hip and knee arthroplasty.[4] Important risk factors for AKI after lower extremity arthroplasty are CKD, postoperative sepsis, acute myocardial infarction, and blood transfusion. A previous study has shown that even transient AKI increases the risk of mortality, hospital costs, and length of stay.[5]

Degenerative spine disease is a leading cause of the loss of functional health status. Degenerative spine disease arises from a combination of micro- and macromechanical injuries, metabolic processes and risk factors such as age, sex, work environment, and genetics.[6] Spinal surgery is always elective, meaning that patients' make the decision whether or not to undergo surgery.[7] The joints and ligamentous elements are part of the functional spinal unit underlying all degenerative morphological and structural changes. These changes involve the disc structure of one spinal segment, the joint-ligament at the same level, and the adjacent functional spinal unit.[8] These factors affect various structures, including intervertebral discs, articular surfaces, ligaments, and spinal muscles. Degenerative spine disease accounts for extensive aspects of healthcare and may lead to substantial healthcare costs, as well as to loss of quality-adjusted life years—on top of the fact that disease incidence is increasing.[9] One standard surgical treatment for lumbar degenerative disc disease is spinal fusion surgery, a surgical procedure in which two vertebrae are grafted together. The goal of fusion surgery is to reduce pain by reducing movement of the spinal segment.[10] The other commonly performed surgery is lumbar decompression, which is performed to treat nerves compressed by degenerating discs in

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Conflicts of interest: The authors declare that they have no conflicts of interest related to the subject matter or materials discussed in this article.

Journal of Chinese Medical Association. (2024) 87: 400-409.

Received March 27, 2023; accepted November 13, 2023.

doi: 10.1097/JCMA.0000000000001065

the spine; it is only performed when nonsurgical treatments have not relieved pain and nerve symptoms.[10]

As a result of increases in life expectancy and the widespread use of noninvasive imaging methods, clinicians, surgeons, and institutions are increasingly faced with the possibility of spinal lesions and surgical treatment of older adults.[11] Surgery for most degenerative diseases is elective, and the risk-benefit of the intended surgery must be fully estimated before an individual patient undergoes surgery. Understanding the risks and benefits of surgery will help patients and physicians make clinical decisions. Spine surgery has several risk factors for the development of AKI, including increased intra-abdominal pressure due to being in a prone position, hemodynamic changes, surgical inflammation, embolic events, use of intraoperative vasoactive drugs, blood loss, and hemodilution.[12,13] Although patients may develop AKI in various clinical conditions, the incidence of AKI associated with major surgery is particularly high.[14] Preoperative identification of high-risk patients will enable early intervention and optimal perioperative management, leading to improved patient outcomes.

As mentioned earlier, recent studies have shown an increase in the incidence of AKI and its impact on morbidity and mortality.[1,9,15,16] However, although potential risk factors for AKI have been examined in studies of orthopedic patients, only limited evidence is available to guide targeted intervention strategies aimed at reducing the risk of AKI.[15,17,18] Few studies have investigated AKI after spinal surgery, especially surgery for degenerative spinal disease. The true incidence and predictors for AKI following degenerative spine surgery have yet to be evaluated. Data from administrative health records may be useful for stratifying patients at risk of perioperative AKI. This study aimed to investigate the incidence and determinants of AKI following elective surgeries for degenerative lumbar spine disease, using data from a large, nationally representative cohort.

2. METHODS

2.1. Study design and data source

This population-based, retrospective observational study extracted all data from the US Nationwide Inpatient Sample (NIS) database, the largest all-payer, continuous inpatient care database, including about 8 million hospital stays each year.[19] Patient data include primary and secondary diagnoses, primary and secondary procedures, admission and discharge status, patient demographics, expected payment source, duration of hospital stay, and hospital characteristics (i.e., bed size/location/teaching status/hospital region). All patients are initially considered for inclusion. Data from the most recent NIS database are derived from about 1050 hospitals from 44 States in the United States, sampled to represent a 20% stratified sample of US community hospitals as defined by the American Hospital Association.

2.2. Ethical statement

HCUP-NIS is a deidentified database, and the Institutional Review Board of Johns Hopkins Medical Institutions deemed that the study using HCUP-NIS database does not require institutional review board.

2.3. Study population

In the present study, patient data were identified in the NIS database through codes of the International Classification of Diseases, Ninth and Tenth Revision (ICD-9 and ICD-10). Data of adults ≥40 years old admitted to US hospitals between 2005 and 2018 who were diagnosed with degenerative disease of the lumbar spine and were undergoing elective spinal fusion or decompression were included. Emergent admissions were excluded. Patients with missing information on age, gender, and other main study variables were also excluded. The study cohort was categorized by type of surgery, that is, decompression alone or spinal fusion.

2.4. Study endpoints

The primary study endpoint was the occurrence of AKI after elective surgical procedures for degenerative lumbar spine disease. Secondary endpoints were determinants of AKI following these elective spinal surgeries. The ICD-9 and ICD-10 codes for defining lumbar spine degenerative disease, fusion, decompression, and AKI are listed in Supplementary Table 1, http://links.lww.com/JCMA/A233. The usage of these ICD codes to identify AKI has been previously validated.[20,21] (Supplementary Table 1, http://links.lww.com/JCMA/A233).

2.5. Study variables

Patients' characteristics included age (grouped by range: 40–49, 50–59, 60–69, 70–79, and ≥80 years), gender, household income level (in quartiles), insurance status (primary payer), smoking status, major comorbidities (ischemic heart disease, congestive heart failure, atrial fibrillation, diabetes, anemia, hypertension, dyslipidemia, chronic obstructive pulmonary disease, cerebrovascular disease, peripheral vascular disease, overweight and obesity, drug abuse, alcohol abuse, autoimmune rheumatic disease, CKD, coagulopathy, or any malignancy), surgical approach for fusion (anterior, posterior, combined), ≥2 level of fusion, and whether or not having hospital-acquired infections. Long-term use of NSAIDs and aspirin/anticoagulants, identified through ICD codes, were also included as study covariates. Weekend admission, hospital-related characteristics (bed size/location/teaching status/hospital region), and hospital caseload (i.e., annual caseload of spinal metastasis) were extracted from the database as part of the comprehensive data available for all patients.

2.6. Statistical analysis

Given the complex sampling design of the HCUP-NIS data, all analyses were performed using SAS survey analysis statements (SAS Institute Inc., Cary, NC, USA). Continuous data are presented as weighted mean ± standard error. Categorical data are presented as unweighted counts (weighted percentage). Distribution of continuous and categorical data between patient groups were compared using SURVEYREG, while the Rao-Scott chi-square test was performed to examine differences in the proportions between groups using SURVEYFREQ statement for categorical variables. Univariate and multivariate logistic regression analysis was conducted using SURVEYLOGISTIC to evaluate associations between variables and AKI. To explore the potential predictors of AKI, covariates that were significantly associated with AKI in univariate analysis model were entered into the multivariate models. A two-sided p value of <0.05 was regarded as statistical significance.

3. RESULTS

3.1. Patient selection

During 2005 to 2018 in the HCUP-NIS database, data of 1,369,502 hospital admissions with diagnoses of lumbar degenerative disease were identified. Among these hospitalized patients, the data of 467,862 patients aged ≥40 years who had undergone or who were scheduled to undergo elective lumbar spinal surgeries for lumbar degenerative disease were included.

After excluding patients who had undergone emergent surgery and those with missing information on age, gender, or main study variables, the remainder of 424,569 admissions were included for analysis. Applying the sample weights provided by the NIS, this sample size could be extrapolated back to a population of 2,099,145 hospitalized patients in the whole United States. The flow diagram of the study cohort selection process is presented in Fig. 1.

3.2. Characteristics of patients undergoing surgery for degenerative lumbar spine disease

Table 1 shows the baseline demographic, clinical, and hospital characteristics of the study population. Patients' mean age was 61.7 ± 0.04 years. Most patients were female (56.2%) and nonsmokers (70.6%). Hypertension (56.2%), dyslipidemia (34.1%), and diabetes (19.4%) were the most common comorbidities in the study cohort. Among the study population, 55,495 (13.1%) patients received decompression alone, among whom 608 (1.1%) developed AKI. In addition, 369,074 patients (87.9%) had spinal fusion, among whom 6500 (1.8%) patients developed AKI. Age, gender, insurance status, certain comorbidities, status of weekend admission, long-term use of aspirin/anticoagulant, hospital-acquired infections, and hospital bed size were significantly different between patients with or without AKI during hospitalization among patients receiving decompression alone or fusion. Patients with AKI were older with a higher proportion of males. Most comorbidities were more frequent among patients with AKI (**Table 1**).

3.3. Annual incidence of AKI from 2005 to 2018 in the United States

Overall, an increasing trend was observed in AKI incidence, which had grown from 0.006% in 2005 to 0.023% in 2018, accompanied by an increase in lumbar spinal surgeries. In addition, the incidence of AKI was higher among the patients receiving spinal fusion than in those receiving decompression only, with a mean difference of about 0.006% (**Fig. 2**).

3.4. Factors associated with AKI in patients receiving decompression alone

Univariate analysis revealed that age, gender, insurance status, certain comorbidities, weekend admission, long-term use of aspirin/anticoagulant, hospital-acquired infections, hospital bed size, and hospital caseload were significantly associated with AKI occurrence during admission. Results of multivariable analysis were similar after adjusting for relevant confounders. Older age was significantly associated with an increased risk for AKI (aOR: 1.78, 95% CI, 1.00-3.16 for ≥80 years; 1.89, 95% CI, 1.10-3.25 for 70–79 years; 1.76, 95% CI, 1.04-2.99 for 60–69 years; 1.79, 95% CI, 1.05-30.5 for 50–59 years) compared with risk in patients aged 40 to 49 years. Men had significantly greater risk for AKI than women (aOR: 1.57, 95% CI, 1.31-1.90). CKD had the strongest impact on AKI risk among all comorbidities (aOR: 12.89, 95% CI, 10.45-15.90). Congestive heart failure, atrial fibrillation, diabetes, anemia, hypertension, overweight/obesity, drug abuse, and coagulopathy also remained significantly associated with AKI occurrence. Moreover, patients admitted on weekends had greater risk for AKI than those

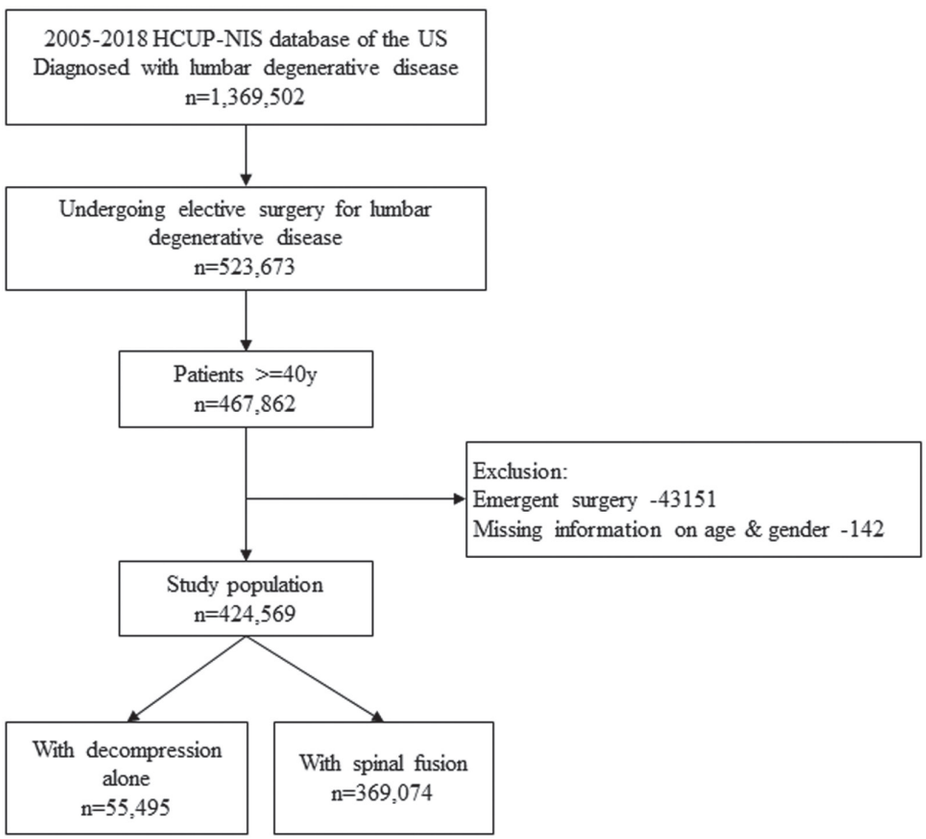

Fig. 1 Flow diagram of study selection.

Table 1

Characteristics of patients undergoing surgery for degenerative lumbar spine disease by surgery type

Characteristics	Overall (n = 424,569)	Decompression alone (n = 55,495)		p	Fusion (n = 369,074)		p
		No AKI (n = 54,887)	With AKI (n = 608)		No AKI (n = 362,574)	With AKI (n = 6500)	
Age, years	61.7 ± 0.04	66.0 ± 0.1	70.6 ± 0.4	**<0.001**	61.0 ± 0.05	66.6 ± 0.1	**<0.001**
40–49	72780 (17.1)	5382 (9.8)	18 (2.9)	**<0.001**	67,022 (18.5)	358 (5.5)	**<0.001**
50–59	109,813 (25.9)	10,745 (19.6)	78 (12.9)		97,827 (27.0)	1163 (17.9)	
60–69	125,875 (29.7)	15,800 (28.8)	161 (26.5)		107,610 (29.7)	2304 (35.5)	
70–79	92,258 (21.7)	15,971 (29.1)	228 (37.4)		73,954 (20.4)	2105 (32.3)	
80+	23,843 (5.6)	6989 (12.7)	123 (20.3)		16,161 (4.5)	570 (8.8)	
Gender							
Male	186,108 (43.8)	29,257 (53.3)	402 (66.2)	**<0.001**	152,808 (42.2)	3641 (56.0)	**<0.001**
Female	238,441 (56.2)	25,628 (46.7)	206 (33.8)		209,749 (57.8)	2858 (44.0)	
Insurance status/primary payer							
Medicare/medicaid	209,774 (49.5)	32,669 (59.6)	464 (76.5)	**<0.001**	172,364 (47.7)	4277 (65.9)	**<0.001**
Private including HMO	177,541 (41.9)	18,719 (34.1)	130 (21.3)		156,888 (43.3)	1804 (27.8)	
Self-pay/no-charge/other	36,485 (8.6)	3432 (6.3)	13 (2.2)		32,627 (9.0)	413 (6.4)	
Household income							
Q1	89,873 (21.6)	11,107 (20.7)	137 (23.2)	0.232	77,174 (21.7)	1455 (22.8)	0.081
Q2	110,649 (26.6)	13,706 (25.5)	143 (24.1)		95,063 (26.7)	1737 (27.2)	
Q3	112,469 (27.0)	14,406 (26.9)	168 (28.5)		96,231 (27.0)	1664 (26.1)	
Q4	103,436 (24.9)	14,466 (26.9)	144 (24.3)		87,299 (24.6)	1527 (23.9)	
Smoking							
No	299,902 (70.6)	40,285 (73.3)	430 (70.8)	0.165	254,546 (70.1)	4641 (71.4)	**0.046**
Yes	124,667 (29.4)	14,602 (26.7)	178 (29.2)		108,028 (29.9)	1859 (28.6)	
Comorbidities							
Ischemic heart disease	51,897 (12.2)	8733 (15.9)	199 (32.7)	**<0.001**	41,298 (11.4)	1667 (25.7)	**<0.001**
Congestive heart failure	8699 (2.1)	1305 (2.4)	93 (15.4)	**<0.001**	6580 (1.8)	721 (11.1)	**<0.001**
Atrial fibrillation	15,758 (3.7)	2680 (4.9)	86 (14.1)	**<0.001**	12,247 (3.4)	745 (11.5)	**<0.001**
Diabetes	80,086 (19.4)	11,623 (21.2)	284 (46.8)	**<0.001**	67,524 (18.6)	2655 (40.9)	**<0.001**
Anemia	33,563 (7.9)	2486 (4.5)	161 (26.6)	**<0.001**	29,410 (8.1)	1506 (23.1)	**<0.001**
Hypertension	238,716 (56.2)	32,809 (59.8)	453 (74.5)	**<0.001**	200,608 (55.3)	4846 (74.6)	**<0.001**
Dyslipidemia	144,627 (34.1)	19,704 (36.0)	308 (50.6)	**<0.001**	121,290 (33.5)	3325 (51.2)	**<0.001**
COPD	62,768 (14.8)	7393 (13.5)	110 (18.2)	**0.001**	53,905 (14.9)	1360 (20.9)	**<0.001**
Cerebrovascular disease	848 (0.2)	117 (0.2)	6 (0.1)	**<0.001**	676 (0.2)	49 (0.8)	**<0.001**
Peripheral vascular disease	11,836 (2.8)	2196 (4.0)	176 (29.1)	**<0.001**	9185 (2.5)	394 (6.1)	**<0.001**
Overweight and obesity	68,865 (16.3)	8393 (15.4)	29 (4.8)	**<0.001**	58,086 (16.1)	2210 (34.1)	**<0.001**
Drug abuse	15,655 (3.7)	1704 (3.1)	18 (2.9)	**0.019**	13,640 (3.8)	282 (4.3)	**0.022**
Alcohol abuse	6571 (1.6)	739 (1.4)	35 (5.6)	**0.001**	5565 (1.5)	249 (3.8)	**<0.001**
Rheumatic disease	16,526 (3.9)	1882 (3.4)	293 (48.2)	**0.003**	14,311 (4.0)	298 (4.6)	**0.008**
CKD	14,713 (3.5)	2019 (3.7)	46 (7.6)	**<0.001**	10,233 (2.8)	2168 (33.4)	**<0.001**
Coagulopathy	7936 (1.9)	653 (1.2)	71 (11.5)	**<0.001**	6615 (1.8)	622 (9.6)	**<0.001**
Any malignancy	3523 (0.8)	743 (1.4)	20 (3.3)	**<0.001**	2684 (0.7)	77 (1.2)	**<0.001**
Weekend admission							
No	422,075 (99.4)	54,195 (98.7)	588 (96.7)	**<0.001**	360,835 (99.5)	6457 (99.3)	**0.037**
Yes	2494 (0.6)	692 (1.3)	20 (3.3)		1739 (0.5)	43 (0.7)	
Long-term use of NSAIDs							
No	421,356 (99.2)	54,483 (99.3)	607 (99.8)	0.101	359,818 (99.2)	6448 (99.2)	0.718
Yes	3213 (0.76)	404 (0.7)	1 (0.2)		2756 (0.8)	52 (0.8)	
Long-term use of aspirin/anticoagulant							
No	390,489 (91.9)	49,489 (90.1)	528 (86.8)	**0.006**	334,773 (92.3)	5699 (87.6)	**<0.001**
Yes	34,080 (8.1)	5398 (9.9)	80 (13.2)		27,801 (7.7)	801 (12.4)	
Hospital-acquired infections							
No	423,558 (99.8)	54,754 (99.8)	594 (97.7)	**<0.001**	361,797 (99.8)	6413 (98.7)	**<0.001**
Yes	1011 (0.2)	133 (0.2)	14 (2.3)		777 (0.2)	87 (1.3)	
Hospital bed size							
Small	75,999 (17.6)	9202 (16.4)	75 (12.2)	**0.029**	65,765 (17.9)	957 (14.6)	**<0.001**
Medium	101,022 (24.0)	12,518 (23.1)	146 (24.2)		86,611 (24.1)	1747 (27.2)	
Large	246,208 (58.4)	33,063 (60.5)	386 (63.6)		208,996 (58.0)	3763 (58.2)	
Hospital location/teaching status							
Rural	19,581 (4.6)	2555 (4.6)	75 (12.2)	0.095	16,783 (4.6)	220 (3.4)	**<0.001**
Urban nonteaching	166,104 (39.1)	21,656 (39.2)	146 (24.2)		141,841 (39.1)	2392 (36.9)	

(Continued)

Table 1

(Continued.)

Characteristics	Overall (n = 424,569)	Decompression alone (n = 55,495)		p	Fusion (n = 369,074)		p
		No AKI (n = 54,887)	With AKI (n = 608)		No AKI (n = 362,574)	With AKI (n = 6500)	
Urban teaching	237,544 (56.4)	151,695 (56.3)	386 (63.6)		202,749 (56.3)	3855 (59.8)	
Hospital caseload							
High (>46)	363,331 (85.4)	47,221 (85.8)	484 (79.5)	**<0.001**	310,162 (85.4)	5464 (83.9)	**0.007**
Middle (4–46)	60,889 (14.5)	7611 (14.1)	123 (20.3)		52,123 (14.5)	1032 (16.0)	
Low (<4)	349 (0.1)	55 (0.1)	1 (0.2)		289 (0.1)	4 (0.1)	

P-values <0.05 are shown in bold.

AKI=acute kidney injury; CKD=chronic kidney disease; COPD=chronic obstructive pulmonary disease; NSAIDs=nonsteroidal antiinflammatory drugs.

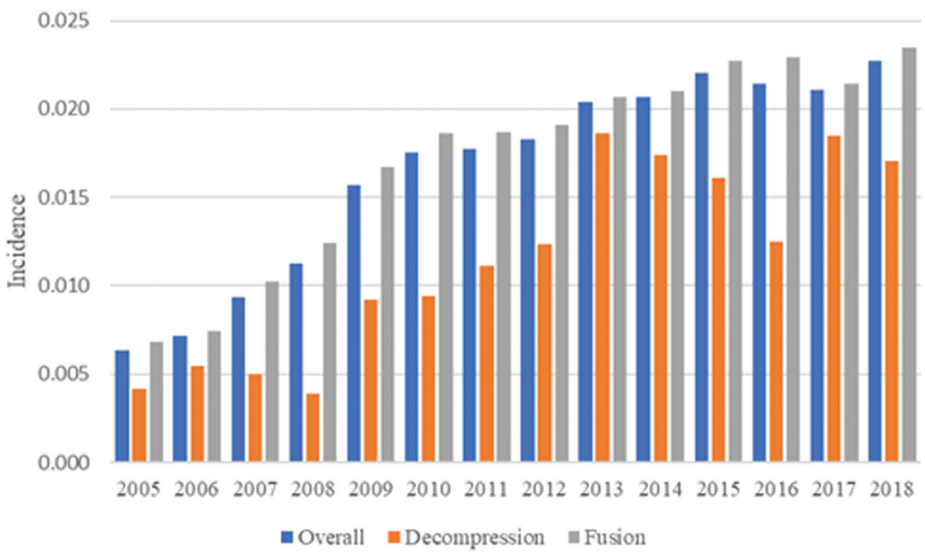

Fig. 2 Annual incidence of AKI after elective surgery for lumbar degenerative disease. AKI=acute kidney injury.

admitted on weekdays (aOR: 2.01, 95% CI, 1.16-3.46). Patients taking long-term aspirin/anticoagulants were at lower risk of AKI (aOR: 0.72, 95% CI, 0.55-0.94). Patients with hospital-acquired infections had significantly a higher risk of AKI (aOR: 9.70, 95% CI, 5.08-18.52). Admission to large hospitals was associated with greater risk of AKI than admission to small hospitals. Admission to hospitals with medium caseloads was associated with higher risk of AKI than admission to those with high caseloads. Regarding insurance status, self-pay/no-charge/other classification was associated with smaller risk of AKI as compared to payment with Medicare/Medicaid (Table 2).

3.5. Factors associated with AKI in patients receiving spinal fusion

Univariate analysis revealed that the surgical approach for fusion, age, gender, insurance status, smoking, having several comorbidities, weekend admission, long-term use of aspirin/anticoagulant, hospital-acquired infections, hospital bed size, hospital location/teaching status, and hospital caseload were significantly associated with AKI risk. Similar results were observed in multivariate analysis after adjusting for covariates. Patients who received the combined approach for fusion had a significantly higher risk for AKI than those receiving the anterior approach (aOR: 1.53, 95% CI, 1.34-1.75). In addition, older patients (≥80 years, aOR: 2.53, 95% CI, 2.14-3.00) and men (aOR: 1.71, 95% CI, 1.61-1.82) had significantly higher risk for developing AKI. Comorbid CKD was also the strongest factor for the occurrence of AKI among all the comorbidities (aOR: 8.95, 95% CI, 8.32-9.62). Patients with congestive heart failure, atrial fibrillation, diabetes, anemia, hypertension, chronic obstructive pulmonary disease, overweight/obesity, alcohol abuse, and coagulopathy also had a significantly greater risk for AKI. Patients taking long-term aspirin/anticoagulants were at lower risk of AKI (aOR: 0.88, 95% CI, 0.80-0.96). Patients with hospital-acquired infections had significantly a higher risk of AKI (aOR: 4.89, 95% CI, 3.67-6.52). Admission to the hospital of medium caseload was associated with higher risk of AKI than high caseload. Admission to medium- and large-sized hospitals were associated with greater risk of AKI than admission to small hospitals (**Table 3**).

3.6. Ten strongest predictors for AKI

Table 4 summarizes the top 10 strongest independent risk factors of AKI during admissions after surgeries for lumbar degenerative disease, as assessed by adjusted odds ratios (aOR). Regardless of the procedures applied, CKD and hospital-acquired infections and coagulopathy were the strongest predictors of AKI occurrence. In addition, older age, congestive heart failure, anemia, and overweight/obesity were also predictive of AKI after spinal procedures (Table 4).

Table 2

Factors associated with AKI after decompression for lumbar degenerative disease (n = 55,495)

	Univariate	Multivariate
Variables	**OR (95% CI)**	**aOR (95% CI)**
Age, years		
40–49	ref	ref
50–59	**2.22 (1.33-3.69)**	**1.79 (1.05-3.05)**
60–69	**3.11 (1.91-5.06)**	**1.76 (1.04-2.99)**
70–79	**4.35 (2.69-7.03)**	**1.89 (1.10-3.25)**
80+	**5.37 (3.27-8.84)**	**1.78 (1.00-3.16)**
Gender		
Female	ref	ref
Male	**1.71 (1.45-2.03)**	**1.57 (1.31-1.90)**
Insurance status/primary payer		
Medicare/Medicaid	ref	ref
Private including HMO	**0.49 (0.40-0.59)**	0.81 (0.65-1.03)
Self-pay/no-charge/other	**0.27 (0.16-0.46)**	**0.50 (0.28-0.88)**
Household income		
Q1	ref	
Q2	0.84 (0.67-1.07)	
Q3	0.95 (0.75-1.19)	
Q4	0.81 (0.63-1.03)	
Smoking		
No	ref	
Yes	1.13 (0.95-1.35)	
Comorbidities		
Ischemic heart disease	**2.57 (2.16-3.05)**	1.15 (0.93-1.42)
Congestive heart failure	**7.40 (5.89-9.30)**	**2.16 (1.57-2.96)**
Atrial fibrillation	**3.20 (2.54-4.03)**	**1.48 (1.10-1.98)**
Diabetes	**3.26 (2.78-3.83)**	**1.54 (1.26-1.87)**
Anemia	**7.63 (6.33-9.20)**	**2.77 (2.20-3.48)**
Hypertension	**1.96 (1.62-2.37)**	**1.51 (1.22-1.86)**
Dyslipidemia	**1.82 (1.54-2.14)**	0.92 (0.77-1.12)
COPD	**1.43 (1.16-1.76)**	1.05 (0.83-1.33)
Cerebrovascular disease	**4.63 (2.03-10.56)**	1.56 (0.59-4.15)
Peripheral vascular disease	**2.64 (2.03-3.45)**	1.01 (0.73-1.41)
Overweight and obesity	**2.26 (1.90-2.69)**	**1.66 (1.35-2.04)**
Drug abuse	**1.55 (1.07-2.24)**	**1.63 (1.03-2.57)**
Alcohol abuse	**2.19 (1.36-3.50)**	1.54 (0.87-2.72)
Rheumatic disease	**1.67 (1.19-2.34)**	1.19 (0.81-1.76)
CKD	**24.17 (20.40-28.64)**	**12.89 (10.45-15.90)**
Coagulopathy	**6.79 (5.00-9.21)**	**2.96 (1.98-4.44)**
Any malignancy	**2.36 (1.49-3.75)**	1.32 (0.79-2.21)
Weekend admission		
No	ref	ref
Yes	**2.67 (1.69-4.20)**	**2.01 (1.16-3.46)**
Long-term use of NSAIDs		
No	ref	
Yes	0.22 (0.03-1.59)	
Long-term use of aspirin/ anticoagulant		
No	ref	ref
Yes	**1.39 (1.10-1.76)**	**0.72 (0.55-0.94)**
Hospital-acquired infections		
No	ref	ref
Yes	**9.62 (5.34-17.35)**	**9.70 (5.08-18.52)**
Hospital bed size		
Small	ref	ref
Medium	**1.41 (1.05-1.90)**	1.31 (0.96-1.79)
Large	**1.42 (1.09-1.84)**	**1.53 (1.16-2.03)**
Hospital location/teaching status		
Rural	ref	
urban nonteaching	1.11 (0.72-1.70)	
urban teaching	1.32 (0.86-2.00)	

(Continued)

Table 2

(Continued.)

Variables	Univariate OR (95% CI)	Multivariate aOR (95% CI)
Hospital caseload		
High	ref	ref
Medium	**1.56 (1.28-1.91)**	**1.80 (1.43-2.27)**
Low	1.75 (0.24-12.59)	3.26 (0.39-27.40)

P-values <0.05 are shown in bold.

AKI=acute kidney injury; aOR=adjusted OR; CKD=chronic kidney disease; COPD=chronic obstructive pulmonary disease; NSAIDs=nonsteroidal antiinflammatory drugs; OR=odds ratio.

4. DISCUSSION

The present study investigated the incidence and determinants of AKI after elective surgery for degenerative lumbar spine disease, extracting patient data from a large, nationally representative cohort. To the best of our knowledge, this is the first population-based study to investigate the incidence and risk factors of postoperative AKI. The incidence of AKI after decompression alone or with fusion was 1.1% and 1.8%, respectively, which is not significantly high. However, from 2005 to 2018, the incidence of AKI in the United States had increased. The strongest predictor of AKI was underlying CKD, which was associated with an 9.0- to 12.9-fold greater risk of AKI compared with cases without CKD. Most comorbidities were more common in patients who developed AKI. Univariate analysis first showed that age, gender, insurance status, some comorbidities, weekend admissions, long-term use of aspirin/anticoagulant, hospital-acquired infections, bed size, and hospital admissions were significantly associated with the occurrence of AKI on admission. Results of multivariate analysis also supported these predictors if AKI after adjusting for relevant confounders.

A previous study noted that spinal surgery is associated with significant intraoperative hemostasis and hemodynamics, potentially increasing the risk of postoperative AKI.[22] Also, advanced age is shown to be associated with increased comorbidities, so changes in the risk profile and different clinical outcomes may be expected in the older adult patient population.[23] In the present study, older age was significantly associated with increased risk of AKI compared to risk in patients aged 40 to 49. Overall, patients who developed AKI were older and more were male.

Another previous study indicated that the treatment of intraoperative hypotension during prone spine surgery included vasopressors.[24] However, avoiding the use of vasopressors administered at typical vasopressor doses in order to prevent renal injury is regarded as a poor strategy. Another study reported a case that demonstrated the importance of monitoring patients for potential complications, and noted especially that allogeneic blood increases the risk of postoperative infection.[25] A high incidence of AKI was also noted after spinal instrumentation surgery in children, which may be associated with frequent use of nephrotoxic medications and fluctuations in perioperative fluid volume.[26] Most cases of AKI are reported to be associated with secondary injury, including sepsis and nephrotoxicity. An orthopedic study showed that perioperative dehydration, nonsteroidal antiinflammatory drug use, and use of nephrotoxic antibiotics were independently associated with postoperative renal dysfunction.[27] In the present study, the annual incidence of AKI after surgery for lumbar degenerative disease was increasing, which may be directly associated with aging of the US population.

Among the 10 strongest independent risk factors for AKI during hospital admission after the included patients underwent surgery for lumbar degenerative disease, CKD and coagulopathy were the strongest predictors of AKI regardless of the surgical procedure used. A previous study also found that underlying CKD was the strongest predictor of postoperative AKI. Underlying CKD has been recognized as a definite risk factor for AKI, as decreased glomerular filtration rate and increased proteinuria have been shown to be strongly associated with AKI.[28] Another study indicated that patients with AKI who required dialysis initially and then recovered had a particularly high risk of developing CKD, suggesting that severity of AKI is a strong predictor of progression to CKD.[29] In addition, proteinuria is also a risk factor for AKI.[30] Underlying CKD is more prone to the development of acute and chronic renal failure. Therefore, by quantifying proteinuria closer to the scheduled time of the surgery that induced AKI, proteinuria may be quantified more accurately.

The present study also found that older age, male sex, congestive heart failure, anemia, obesity, and hospital-acquired infection were also predictive of AKI after spinal surgery. Anemia is more common in this surgical population due to various causes such as iron deficiency, blood loss, chronic disease, malignancy, and CKD. Previous studies have indicated that AKI risk was higher in an anemic group than in a nonanemic group, and this trend remained significant regardless of either early or late onset of AKI.[31] Another study also highlighted the deleterious effects of postoperative anemia on different clinical outcomes, including AKI.[32] In general, obesity is associated with an increased risk of multiple metabolic diseases and higher mortality, including risk of AKI, which is increased in obese patients compared with risk in normal-weight patients.[33] In particular, obesity is associated with an increased risk of postoperative AKI in patients undergoing certain surgeries.[34] Another previous study also indicated that obese patients had a higher risk of perioperative surgical complications during hospitalization, including infection, bleeding, anemia, coagulation disorders, the need for mechanical ventilation, and thromboembolic complications, any of which may contribute to AKI.[35] Hospital-acquired infections can increase AKI risk by triggering inflammation, lowering blood pressure, introducing toxins and nephrotoxic medications, causing hemodynamic instability, compromising immune function, and potential medication interactions. Timely infection management and kidney monitoring are critical to mitigate AKI risk in these patients.[36]

The present study found that patients with insurance status of "self-pay/no-charge/other" had a lower risk of AKI following decompression for lumbar degenerative disease. "Self-pay/no-charge/other" typically refers to patients who cover their healthcare expenses directly, without relying on health insurance or third-party payers. One possible explanation is that self-pay patients, often with the financial means, can choose healthcare providers known for higher quality care and specialized expertise, potentially improving outcomes. Additionally, their freedom from insurance approval processes grants them faster access to vital care, which is crucial in emergency situations. The increased risk of AKI in males according to our findings may be attributed to the higher severity of baseline comorbidities, as concluded in a previous study.[37] Weekend admission was associated with increased risk of AKI in the present study. As documented in a previous report,

Table 3

Factors associated with AKI after fusion for lumbar degenerative disease (n = 369074)

	Univariate	Multivariate
Variables	**OR (95% CI)**	**aOR (95% CI)**
Surgical approach for fusion		
Anterior	ref	ref
Posterior	**1.33 (1.19-1.48)**	0.99 (0.88-1.11)
Combined anterior and posterior	**1.83 (1.61-2.08)**	**1.53 (1.34-1.75)**
Level of fusion ≥2	1.08 (0.99-1.17)	
Age		
40–49	ref	ref
50–59	**2.23 (1.98-2.52)**	**1.71 (1.51-1.94)**
60–69	**4.03 (3.60-4.51)**	**2.21 (1.95-2.51)**
70–79	**5.33 (4.75-5.99)**	**2.32 (2.02-2.68)**
80+	**6.62 (5.78-7.59)**	**2.53 (2.14-3.00)**
Gender		
Female	ref	ref
Male	**1.75 (1.66-1.84)**	**1.71 (1.61-1.82)**
Insurance status/primary payer		
Medicare/medicaid	ref	ref
Private including HMO	**0.46 (0.44-0.49)**	**0.88 (0.81-0.94)**
Self-pay/no-charge/other	**0.51 (0.46-0.57)**	1.06 (0.93-1.20)
Household income		
Q1	ref	
Q2	0.97 (0.90-1.04)	
Q3	**0.92 (0.85-0.99)**	
Q4	0.92 (0.85-1.001)	
Smoking		
No	ref	ref
Yes	**0.94 (0.89-0.99)**	**0.87 (0.82-0.93)**
Comorbidities		
Ischemic heart disease	**2.69 (2.54-2.86)**	1.06 (0.98-1.14)
Congestive heart failure	**6.71 (6.18-7.29)**	**2.18 (1.95-2.44)**
Atrial fibrillation	**3.70 (3.42-4.01)**	**1.56 (1.41-1.74)**
Diabetes	**3.02 (2.87-3.18)**	**1.50 (1.41-1.60)**
Anemia	**3.42 (3.19-3.65)**	**2.10 (1.95-2.27)**
Hypertension	**2.36 (2.23-2.51)**	**1.66 (1.56-1.78)**
Dyslipidemia	**2.08 (1.98-2.19)**	1.05 (0.99-1.12)
COPD	**1.52 (1.43-1.61)**	**1.23 (1.14-1.32)**
Cerebrovascular disease	**4.05 (2.99-5.49)**	1.47 (0.95-2.28)
Peripheral vascular disease	**2.48 (2.23-2.76)**	1.02 (0.90-1.16)
Overweight and obesity	**2.70 (2.56-2.86)**	**2.09 (1.96-2.23)**
Drug abuse	**1.15 (1.02-1.30)**	1.14 (0.99-1.32)
Alcohol abuse	**2.54 (2.23-2.88)**	**1.84 (1.57-2.15)**
Rheumatic disease	**1.17 (1.04-1.32)**	0.99 (0.87-1.13)
CKD	**17.18 (16.19-18.24)**	**8.95 (8.32-9.62)**
Coagulopathy	**5.68 (5.19-6.22)**	**3.39 (3.02-3.80)**
Any malignancy	**1.60 (1.27-2.02)**	0.87 (0.66-1.14)
Weekend admission		
No	ref	ref
Yes	**1.37 (1.02-1.84)**	1.04 (0.76-1.43)
Long-term use of NSAIDs		
No	ref	
Yes	1.06 (0.79-1.41)	
Long-term use of aspirin/ anticoagulant		
No	ref	ref
Yes	**1.70 (1.57-1.83)**	**0.88 (0.80-0.96)**
Hospital-acquired infections		
No	ref	ref
Yes	**6.29 (5.02-7.89)**	**4.89 (3.67-6.52)**
Hospital bed size		
Small	ref	ref
Medium	**1.38 (1.23-1.54)**	**1.32 (1.17-1.49)**
Large	**1.22 (1.10-1.36)**	**1.23 (1.10-1.38)**

(Continued)

Table 3

(Continued.)

Variables	Univariate OR (95% CI)	Multivariate aOR (95% CI)
Hospital location/teaching status		
Rural	ref	ref
Urban nonteaching	**1.29 (1.10-1.52)**	**1.36 (1.15-1.62)**
Urban teaching	**1.45 (1.24-1.70)**	**1.50 (1.15-1.78)**
Hospital caseload		
High	ref	ref
Medium	**1.12 (1.04-1.21)**	**1.17 (1.07-1.28)**
Low	0.78 (0.23-2.10)	0.75 (0.18-3.10)

P-values <0.05 are shown in bold.

AKI=acute kidney injury; aOR=adjusted OR; CKD=chronic kidney disease; COPD=chronic obstructive pulmonary disease; NSAIDs=nonsteroidal antiinflammatory drugs; OR=odds ratio.

Table 4

Top 10 factors associated with AKI after surgery for lumbar degenerative disease, categorized by decompression alone and fusion

	Decompression alone	Fusion
1	CKD	CKD
2	Hospital-acquired infections	Hospital-acquired infections
3	Coagulopathy	Coagulopathy
4	Anemia	Older age
5	Congestive heart failure	Congestive heart failure
6	Weekend admission	Anemia
7	Older age	Overweight and obesity
8	Hospital caseload	Alcohol abuse
9	Overweight and obesity	Male gender
10	Drug abuse	Hypertension

AKI=acute kidney injury; CKD=chronic kidney disease.

the association between weekend admissions and elevated risks of readmissions and poorer short-term outcomes following spinal surgery can likely be attributed to factors such as reduced staffing, limited operating room availability, and variations in clinical decision-making during weekends.[38] Large hospital size is linked to a higher AKI risk according to our results, likely because more severe patients are often referred to larger hospitals. Additionally, there is a trend of higher AKI risk in median to lower caseload hospitals compared with high-caseload hospitals, possibly due to the extensive experience and expertise of surgical teams and support staff in high-caseload hospitals.

In patients undergoing fusion for lumbar degenerative disease, smoking and private insurance were associated with lower AKI risk. The ICD codes only identifies active smoker but not former smokers, potentially leading to a biased observation. Private insurance holders often have enhanced healthcare access, encompassing timely preoperative assessments, vigilant monitoring, and postoperative care, potentially fostering healthier lifestyles, improved nutrition, and a reduced risk profile for AKI. Conversely, the combined anterior and posterior fusion approaches are associated with extended operative durations, which can explain its association with increased AKI risk. Medium/large hospital bed size, urban hospital location, and medium hospital caseload are significantly associated with AKI for similar reasons mentioned in the settings of decompression alone. Generally, we did not observe significant disparities in the risk factors associated with AKI between patients undergoing fusion or decompression alone.

The reduced risk of AKI after lumbar spinal surgery associated with long-term aspirin or anticoagulant usage may stem from their antiinflammatory effects, platelet inhibition, and ability to prevent thromboembolic events. These mechanisms collectively contribute to improved kidney blood flow, microcirculation, and protection against the development of AKI.[39,40] While the present study was strengthened by the use of a large, nationally representative population, retrospective data were used, which inherently lack follow-up data after discharge, precluding the evaluation of late AKI. The retrospective nature of the study may also limit generalization of the data to other populations. ICD code systems were utilized to identify the diagnoses and procedures, and coding errors may exist and hinder accuracy of the analyses. Although previously validated, using ICD codes to identify AKI had a sensitivity of approximately 42% to 60%, and a specificity of 86% to 92%, respectively,[20,21] indicating potential underdiagnoses and misclassifications. The severity of individual comorbidity or performance status before surgery could not be defined via the coding system. Regrettably, detailed information of patients' medication profile, intraoperative factors such as operative duration, blood loss, laboratory parameters, or exposure to contrast medium were not provided by the NIS database thus could not be included in the analysis. The potential impact of the anesthesia protocol or use of medications on the development of AKI were also not evaluated because this information was not included in the NIS data.

In conclusion, the incidence of AKI is increasing in patients undergoing surgery for lumbar spine degenerative disease. Comorbid CKD strongly predicts the occurrence of AKI in these patients, followed by hospital-acquired infection and coagulopathy, whereas long-term aspirin/anticoagulants usage is associated with lowered AKI risk. These findings provide useful information for risk stratification and may help clinicians optimize treatment decisions and care plans following elective surgical procedures for lumbar spine degenerative disease.

APPENDIX A. SUPPLEMENTARY DATA

Supplementary data related to this article can be found at http://links.lww.com/JCMA/A233.

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