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Association of chronic kidney disease with postoperative outcomes: a national surgical quality improvement program (NSQIP) multi-specialty surgical cohort analysis

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Abstract

Background Chronic kidney disease (CKD) is associated with higher incidence of major surgery. No studies have evaluated the association between preoperative kidney function and postoperative outcomes across a wide spectrum of procedures. We aimed to evaluate the association between CKD and 30-day postoperative outcomes across surgical specialties.

Methods We selected adult patients undergoing surgery across eight specialties. The primary study endpoint was major complications, defined as death, unplanned reoperation, cardiac complication, or stroke within 30 days following surgery. Secondary outcomes included Clavien-Dindo high-grade complications, as well as cardiac, pulmonary, infectious, and thromboembolic complications. Multivariable regression was performed to evaluate the association between CKD and 30-day postoperative complications, adjusted for baseline characteristics, surgical specialty, and operative time.

Results In total, 1,912,682 patients were included. The odds of major complications (adjusted odds ratio [aOR] 2.14 [95% confidence interval (CI): 2.07, 2.21]), death (aOR 3.03 [95% CI: 2.88, 3.19]), unplanned reoperation (aOR 1.57 [95% CI: 1.51, 1.64]), cardiac complication (aOR 3.51 [95% CI: 3.25, 3.80]), and stroke (aOR 1.89 [95% CI: 1.64, 2.17]) were greater for patients with CKD stage 5 vs. stage 1. A similar pattern was observed for the secondary endpoints.

Conclusion This population-based study demonstrates the negative impact of CKD on operative outcomes across a diverse range of procedures and patients.

Keywords Chronic kidney disease, Postoperative outcomes, Quality improvement

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Background

Glomerular filtration rate (GFR), whether estimated or indirectly measured, is a widely accepted marker of overall renal function [1]. Decreased kidney function for at least 3 months, as indicated by GFR < 60 ml/min/1.73m^2 and/or the presence of kidney damage markers, characterizes chronic kidney disease (CKD) [2]. The prevalence of CKD is almost 11% in high-income nations and is the fourteenth leading cause of death worldwide, hence posing a public health challenge [3]. Further, CKD is a well-recognized independent predictor of cardiovascular events, hospitalizations, and all-cause mortality [4, 5].

Chronic kidney disease has been previously demonstrated to influence surgical outcomes, with patients experiencing increased length of stay and requiring intensive postoperative management [6–9]. Harrison et al. previously reported that CKD is not only associated with a higher incidence of major surgery [10], but also greater odds of death and myocardial infarction following ambulatory non-cardiac operations [11]. However, no studies have evaluated the association between preoperative kidney function and postoperative outcomes across a wide spectrum of common surgical procedures. We postulated that CKD may be independently associated with worse 30-day outcomes following surgery, and that there would be significant variation among specialties. To test this hypothesis, we performed a population-based retrospective cohort study of surgical patients, evaluating the association between CKD and 30-day postoperative outcomes across various specialties.

Materials and methods

Study design and population

This retrospective study utilized data from the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP). Briefly, the ACS-NSQIP is a validated database of prospectively collected 30-day perioperative data from over 600 participating community and academic institutions [12]. This study was deemed exempt by our institutional review board as the ACS-NSQIP contains de-identified data. This study was reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline and the Reporting of Studies Conducted Using Observational Routinely-Collected Health Data (RECORD) statement [13, 14].

Cohort selection

We selected patients aged ≥ 18 years undergoing elective surgery across any of the following eight specialties: gynecology, orthopedics, urology, thoracic, cardiac, general, vascular, and neurosurgery between 2005 and 2021. Using Common Procedural Terminology (CPT) codes (Supplementary Table 1), we identified a representative multiprocedural cohort. Patients with missing age, sex, race, height, weight, preoperative laboratory values, American Society of Anesthesiologists (ASA) physical status class, functional health status, or operative time were excluded.

Outcomes

The primary study endpoint was major complication, defined as death, unplanned reoperation, cardiac complication (myocardial infarction, cardiac arrest requiring cardiopulmonary resuscitation), and stroke within 30 days following surgery [15]. Secondary outcomes included Clavien-Dindo high-grade complication (defined as death, unplanned reoperation, septic shock, pulmonary embolism, cardiac complication, stroke, reintubation, prolonged intubation, coma, or acute renal failure), as well as cardiac, pulmonary (reintubation or prolonged intubation), infectious (pneumonia, urinary tract infection, wound infection, or sepsis), and thromboembolic (deep venous thrombosis or pulmonary embolism) complications.

Exposure and covariates

We calculated estimated GFR, using serum creatinine adjusted for age and sex, with the recommended race-agnostic CKD-EPI Eqs [16, 17]. Estimated GFR was categorized according to the Kidney Disease Improving Global Outcomes CKD 2012 Guidelines, with stage 1: ≥90 mL/min/1.73m^2; 2: 60–89 mL/min/1.73m^2; 3a: 45–59 mL/min/1.73m^2; 3b: 30–44 mL/min/1.73m^2; 4: 15–29 mL/min/1.73m^2; and 5: <15 mL/min/1.73m^2 [2]. The upper bound of age at surgery was capped at 90 years. Body mass index (BMI) was calculated using height and weight, and patients were categorized into underweight, normal, overweight, or obese according to the Centers for Disease Control classification [18].

American Society of Anesthesiologists status, smoking history (within 1 year prior to surgery), steroid use for chronic conditions, functional health status, chronic obstructive pulmonary disease (COPD), diabetes mellitus requiring therapy (oral or insulin), as well as cardiac (congestive heart failure in 30 days before surgery, history of myocardial infarction 6 months prior to surgery, previous cardiac surgery, history of angina 1 month before surgery, or arterial hypertension requiring medication), and neurologic history (transient ischemic attack, stroke, hemiplegia, or quadriplegia) were reported. We reported surgical specialty, preoperative hematocrit and platelet count, as well as operative time and perioperative transfusion of ≥ 1 unit of packed or whole red blood cells.

Statistical analysis

We presented the preoperative characteristics and 30-day postoperative complication rates of all patients, stratified by CKD stage. All data were presented as mean ± standard deviation (SD) for continuous variables, and number (%) for categorical variables. To account for the ordinal nature of CKD stages, we analyzed the trend of each preoperative characteristics and outcomes across CKD stages using the Cochran-Armitage test and ordinal logistic regression analysis for binary and ordinal categorical variables, respectively, and linear regression analysis for continuous variables. We characterized the preoperative profile of patients who experienced 30-day complications, stratified by CKD stage. Multivariable logistic regression analysis was performed for the primary endpoint and its components, as well as the secondary endpoints. Chronic kidney disease stage 1 was used as the reference category. We evaluated the association between CKD and 30-day postoperative complications, adjusted for age, race, BMI, ASA category, cardiac and neurologic history, COPD, diabetes, 12-month smoking status, steroid use for chronic conditions, functional health status, preoperative hematocrit and platelet counts, perioperative transfusion, operative time, and surgical specialty. The models' predictive margins of CKD stages were estimated and visualized with forest plots. Stratified modeling further examined the association of CKD stages with our primary endpoint, by specialty subgroups. Further, we performed a post-hoc sensitivity analysis by excluding urologic procedures that inherently impact postoperative renal function (i.e. nephrectomy). All tests were two-tailed and $p \leq 0.05$ was deemed significant. All analyses were performed with STATA 16.1 (StataCorp. 2019. Stata Statistical Software: Release 16. College Station, TX: StataCorp LLC). Figures were graphed using GraphPad Prism (GraphPad Software LLC, version 9.0, San Diego, CA, USA).

Results

Variation in baseline characteristics by CKD stage

In total, 1,912,682 patients were included in this analysis (Fig. 1). This cohort was stratified by CKD stage, with 861,721 patients with CKD Stage 1, 752,508 with Stage 2, 167,902 with Stage 3a, 73,616 with Stage 3b, 30,649 with Stage 4, and 26,286 with Stage 5 (Table 1). In terms of demographics, patients with advanced stage CKD tended to be older and underweight (both p for trend < 0.001). These patients demonstrated increased rates of various comorbidities, including a poorer ASA status and increased history of cardiac and neurologic events, COPD, diabetes, tobacco use, and chronic steroid utilization (all p for trend < 0.001). Preoperative platelet counts and hematocrit decreased with advanced CKD stage (both p for trend < 0.001) as well. Overall, functional status was markedly lower in those with worse CKD staging (p for trend < 0.001). Surgery type, as measured by surgical specialty, was markedly different based on CKD staging. Most notably, patients of advanced CKD stage were less likely to undergo gynecologic and orthopedic procedures, but significantly more likely to undergo urologic and vascular operations (p for trend < 0.001).

Association between postoperative complication rates and CKD stage

Unadjusted postoperative complication rates were significantly increased across patients with advanced CKD staging. Major complications, namely death, unplanned reoperation, cardiac complication and stroke were all significantly more frequent among patients with advanced stage CKD (all $p < 0.001$). Most notably, while only 1.8% of the total cohort died within 30 days, 12.2% of patients with end stage renal disease (CKD 5) died within the same period. Similarly, reoperations occurred in 13% of patients with CKD 5, compared to 4.2% among the general cohort (Table 2). Regarding secondary endpoints, rates were significantly higher in patients with advanced CKD (4 & 5). Specifically, Clavien-Dindo high-grade complications, bleeding, pulmonary, infectious, and thromboembolic complications were all more common as CKD stage increased (p for trend < 0.001).

Predictive value of CKD for postoperative outcomes

After multivariable logistic regression, the odds of most complications were associated with increasing CKD stage (Figs. 2 and 3). In general, the odds of each complication type increased proportionally with CKD staging. Specifically, the odds of major complications were more than double for CKD stage 5 patients (adjusted odds ratio [aOR] 2.14 [95% confidence interval (CI): 2.07, 2.21]), while odds of death were tripled (aOR 3.03 [95% CI: 2.88, 3.19]), when compared to patients with CKD stage 1. Reoperations were 57% more likely among patients with CKD stage 5 (aOR 1.57 [95% CI :1.51, 1.64]) compared to stage 1. Within the components of the primary outcome, the magnitude of odds was greatest for cardiac complications (CKD stage 5: aOR 3.51 [95% CI: 3.25, 3.80]). Chronic kidney disease stage 4 and 5 were both associated with greater odds of stroke (aOR 1.96 [95% CI: 1.72, 2.23] and aOR 1.89 [95% CI: 1.64, 2.17], respectively), compared to CKD stage 1.

The odds of secondary outcomes for patients with CKD stage 5 were each substantially increased as well. Increasing CKD stage was associated with greater odds of bleeding requiring transfusion (CKD stage 4: aOR 1.81 [95% CI: 1.76, 1.87] and CKD stage 5: aOR 1.19 [95% CI: 1.15, 1.23]). Of note, the risk of a VTE was significantly increased with CKD stages 3a, 3b, and 4, but not stage 5. Subgroup analysis of major complications revealed consistency of results for most specialties, namely cardiac and general surgery, neurosurgery, orthopedics, and urology (Fig. 4). There were notable differences for

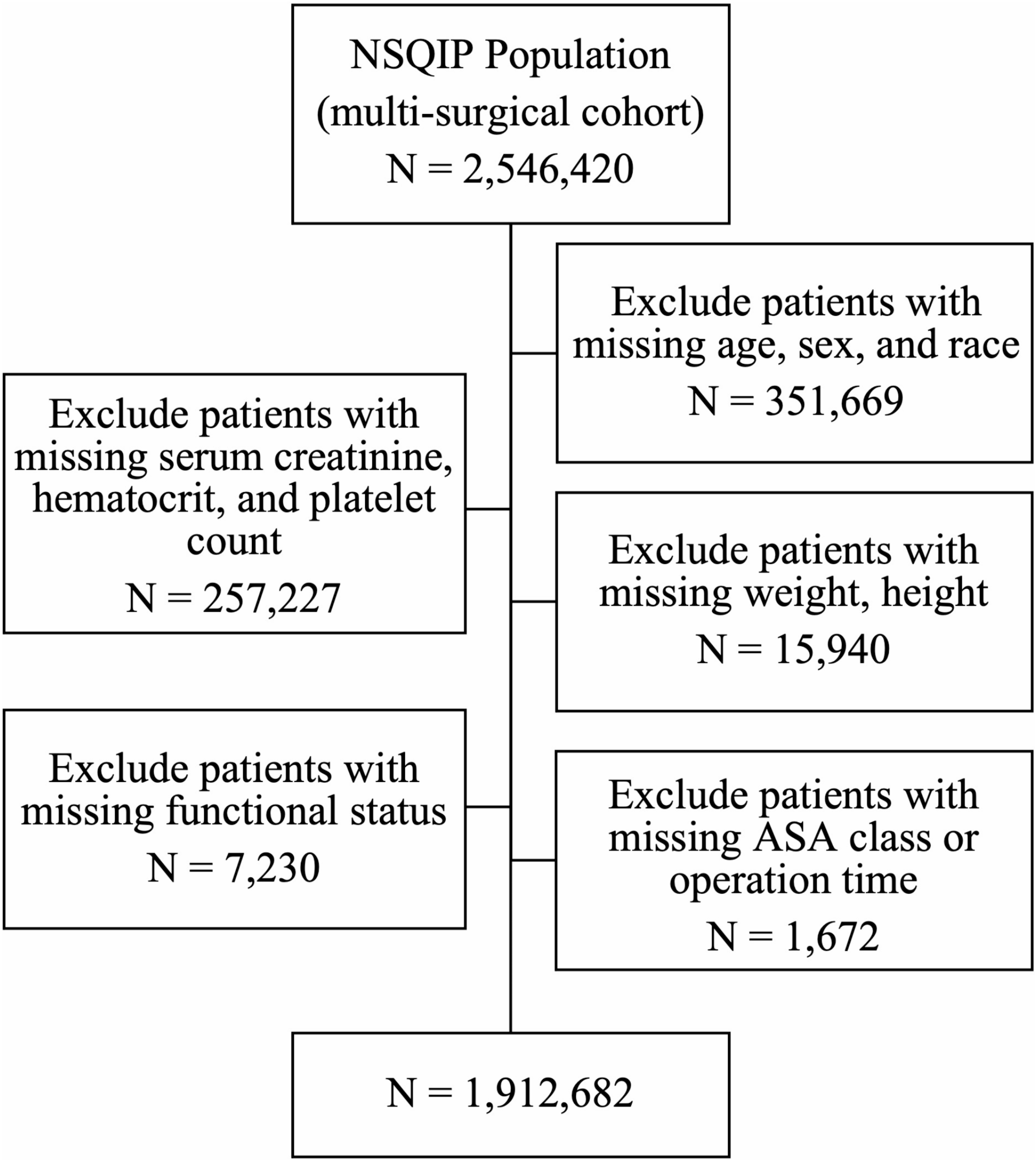

Fig. 1 Patient selection flow diagram

gynecology, thoracic, and vascular surgery. There was no association between CKD stage 5 and major complications for gynecology. For thoracic and vascular surgery, there was no association between CKD stage 3 and major complications. In sensitivity analysis, overall results remained unchanged for primary and secondary endpoints, after exclusion of CPT codes for nephrectomy (Supplementary Fig. 1). In further subgroup analysis, there was a decrease in the magnitude of the associations between increasing CKD stages and major complications (Supplementary Fig. 2). The only exception was urology,

Table 1 Preoperative characteristics

	Total	CKD Categories						P for trend[4]
		1	2	3a	3b	4	5	
	N = 1,912,682	**N = 861,721**	**N = 752,508**	**N = 167,902**	**N = 73,616**	**N = 30,649**	**N = 26,286**	
Age[1]	61.8 ± 13.9	55.3 ± 13.3	65.6 ± 12.0	71.3 ± 10.4	72.8 ± 10.9	70.2 ± 12.4	63.8 ± 12.7	< 0.001
18–50	365,135 (19.1)	280,595 (32.6)	71,711 (9.5)	5,089 (3.0)	2,307 (3.1)	1,925 (6.3)	3,508 (13.3)	
50–70	949,769 (49.7)	455,522 (52.9)	385,578 (51.2)	60,598 (36.1)	22,904 (31.1)	11,413 (37.2)	13,754 (52.3)	
70+	597,778 (31.3)	125,604 (14.6)	295,219 (39.2)	102,215 (60.9)	48,405 (65.8)	17,311 (56.5)	9,024 (34.3)	
Female Sex	1,131,724 (59.2)	517,262 (60.0)	444,849 (59.1)	98,960 (58.9)	42,932 (58.3)	16,001 (52.2)	11,720 (44.6)	< 0.001
Race/Ethnicity[2]								< 0.001
White	1,483,893 (77.6)	654,337 (75.9)	605,432 (80.5)	133,143 (79.3)	56,810 (77.2)	21,436 (69.9)	12,735 (48.4)	< 0.001
Black	215,302 (11.3)	81,611 (9.5)	84,831 (11.3)	22,297 (13.3)	11,089 (15.1)	6,001 (19.6)	9,473 (36.0)	< 0.001
Hispanic	139,182 (7.3)	85,135 (9.9)	38,282 (5.1)	7,450 (4.4)	3,512 (4.8)	2,134 (7.0)	2,669 (10.2)	< 0.001
Other	74,305 (3.9)	40,638 (4.7)	23,963 (3.2)	5,012 (3.0)	2,205 (3.0)	1,078 (3.5)	1,409 (5.4)	< 0.001
BMI[3]	31.0 ± 8.1	31.2 ± 8.6	31.0 ± 7.6	30.8 ± 7.5	30.4 ± 7.7	29.7 ± 8.1	29.3 ± 7.9	< 0.001
Underweight	33,992 (1.8)	18,365 (2.1)	9,546 (1.3)	2,687 (1.6)	1,541 (2.1)	1,020 (3.3)	833 (3.2)	
Normal	407,445 (21.3)	193,205 (22.4)	148,843 (19.8)	33,317 (19.8)	16,395 (22.3)	8,277 (27.0)	7,408 (28.2)	
Overweight	557,646 (29.2)	236,415 (27.4)	230,780 (30.7)	51,720 (30.8)	22,141 (30.1)	8,786 (28.7)	7,804 (29.7)	
Obese	913,599 (47.8)	413,736 (48.0)	363,339 (48.3)	80,178 (47.8)	33,539 (45.6)	12,566 (41.0)	10,241 (39.0)	
ASA Classification								< 0.001
1-No Disturbance	39,803 (2.1)	26,430 (3.1)	12,592 (1.7)	604 (0.4)	110 (0.1)	32 (0.1)	35 (0.1)	
2-Mild Disturbance	748,915 (39.2)	398,615 (46.3)	299,378 (39.8)	39,292 (23.4)	9,461 (12.9)	1,434 (4.7)	735 (2.8)	
3-Severe Disturbance	960,671 (50.2)	393,143 (45.6)	389,198 (51.7)	105,581 (62.9)	46,945 (63.8)	15,224 (49.7)	10,580 (40.2)	
4-Life Threatening Disturbance	156,240 (8.2)	42,316 (4.9)	49,826 (6.6)	21,422 (12.8)	15,930 (21.6)	12,544 (40.9)	14,202 (54.0)	
5-Moribund	7,053 (0.4)	1,217 (0.1)	1,514 (0.2)	1,003 (0.6)	1,170 (1.6)	1,415 (4.6)	734 (2.8)	
Cardiac History	66,974 (3.5)	15,042 (1.7)	23,923 (3.2)	10,874 (6.5)	7,580 (10.3)	5,079 (16.6)	4,476 (17.0)	< 0.001
Neurologic History	23,582 (1.2)	5,973 (0.7)	8,499 (1.1)	3,773 (2.2)	2,429 (3.3)	1,465 (4.8)	1,443 (5.5)	< 0.001
History of Severe COPD	104,182 (5.4)	35,181 (4.1)	40,965 (5.4)	13,799 (8.2)	7,625 (10.4)	3,833 (12.5)	2,779 (10.6)	< 0.001
Diabetes Mellitus Requiring Therapy	369,051 (19.3)	135,383 (15.7)	134,742 (17.9)	46,896 (27.9)	26,184 (35.6)	13,070 (42.6)	12,776 (48.6)	< 0.001
Current Smoker within One Year	315,955 (16.5)	173,421 (20.1)	101,288 (13.5)	21,545 (12.8)	9,969 (13.5)	5,130 (16.7)	4,602 (17.5)	< 0.001
Steroid Use for a Chronic Condition	90,840 (4.7)	40,397 (4.7)	30,344 (4.0)	9,395 (5.6)	5,454 (7.4)	3,190 (10.4)	2,060 (7.8)	< 0.001
Functional Health Status								< 0.001
Independent	1,838,161 (96.1)	839,839 (97.5)	729,761 (97.0)	158,220 (94.2)	65,951 (89.6)	24,384 (79.6)	20,006 (76.1)	
Partially Dependent	58,887 (3.1)	16,946 (2.0)	19,012 (2.5)	7,950 (4.7)	5,873 (8.0)	4,282 (14.0)	4,824 (18.4)	
Totally Dependent	15,634 (0.8)	4,936 (0.6)	3,735 (0.5)	1,732 (1.0)	1,792 (2.4)	1,983 (6.5)	1,456 (5.5)	
Surgical Specialty								
Cardiac Surgery	29,565 (1.5)	9,745 (1.1)	12,844 (1.7)	3,859 (2.3)	1,714 (2.3)	657 (2.1)	746 (2.8)	< 0.001
General Surgery	704,115 (36.8)	354,797 (41.2)	245,371 (32.6)	53,863 (32.1)	27,364 (37.2)	14,411 (47.0)	8,309 (31.6)	< 0.001
Gynecology	237,840 (12.4)	145,363 (16.9)	79,183 (10.5)	9,295 (5.5)	2,756 (3.7)	684 (2.2)	559 (2.1)	< 0.001
Neurosurgery	9,516 (0.5)	4,522 (0.5)	3,222 (0.4)	852 (0.5)	437 (0.6)	228 (0.7)	255 (1.0)	< 0.001
Orthopedic Surgery	677,404 (35.4)	267,391 (31.0)	317,375 (42.2)	65,276 (38.9)	21,492 (29.2)	4,182 (13.6)	1,688 (6.4)	< 0.001
Thoracic Surgery	35,228 (1.8)	14,189 (1.6)	15,746 (2.1)	3,569 (2.1)	1,253 (1.7)	302 (1.0)	169 (0.6)	< 0.001
Urology	62,545 (3.3)	17,859 (2.1)	25,496 (3.4)	9,634 (5.7)	4,793 (6.5)	1,756 (5.7)	3,007 (11.4)	< 0.001
Vascular Surgery	156,469 (8.2)	47,855 (5.6)	53,271 (7.1)	21,554 (12.8)	13,807 (18.8)	8,429 (27.5)	11,553 (44.0)	< 0.001
Preoperative Hematocrit	39.3 ± 5.4	39.6 ± 5.1	40.0 ± 5.1	38.2 ± 5.6	36.2 ± 6.0	33.7 ± 6.5	32.5 ± 6.0	< 0.001

Table 1 (continued)

	Total	CKD Categories						P for trend[4]
		1	2	3a	3b	4	5	
	N = 1,912,682	N = 861,721	N = 752,508	N = 167,902	N = 73,616	N = 30,649	N = 26,286	
Preoperative Platelet Count	260.4 ± 87.7	269.2 ± 90.0	254.6 ± 80.9	250.8 ± 87.5	251.1 ± 97.3	248.0 ± 111.3	241.7 ± 107.3	< 0.001
Transfusion of ≥ 1 Unit of RBCs	25,919 (1.4)	9,058 (1.1)	6,771 (0.9)	2,991 (1.8)	2,503 (3.4)	2,453 (8.0)	2,143 (8.2)	< 0.001

CKD: chronic kidney disease; BMI: body mass index; COPD: chronic obstructive pulmonary disease; RBCs: red blood cells

1. Age at surgery in years. Patients < 18 years old are not included in dataset; ≥ 90 years old were converted to 90

2. Race and ethnicity were merged into a single variable

3. BMI is categorized using the CDC's classification: underweight, normal, overweight, and obese

4. Linear regression analysis was used to determine the relationship between CKD (eGFR) and continuous variables; the Cochran-Armitage test for trend was used to examine trends across the categories of CKD for categorical variables

Table 2 Postoperative outcomes

	Total	CKD Categories						P for trend
		1	2	3a	3b	4	5	
Outcomes	N = 1,912,682	N = 861,721	N = 752,508	N = 167,902	N = 73,616	N = 30,649	N = 26,286	
Major complication	112,847 (5.9)	39,224 (4.6)	36,174 (4.8)	13,289 (7.9)	9,891 (13.4)	7,801 (25.5)	6,468 (24.6)	< 0.001
Death	33,829 (1.8)	7,038 (0.8)	9,124 (1.2)	4,879 (2.9)	4,793 (6.5)	4,776 (15.6)	3,219 (12.2)	< 0.001
Unplanned reoperation	79,995 (4.2)	32,316 (3.8)	27,069 (3.6)	8,491 (5.1)	5,326 (7.2)	3,374 (11.0)	3,419 (13.0)	< 0.001
Cardiac complication	11,149 (0.6)	2,496 (0.3)	3,257 (0.4)	1,596 (1.0)	1,343 (1.8)	1,232 (4.0)	1,225 (4.7)	< 0.001
Stroke	5,176 (0.3)	1,321 (0.2)	1,845 (0.2)	811 (0.5)	569 (0.8)	353 (1.2)	277 (1.1)	< 0.001
Clavien-Dindo high grade complications	155,591 (8.1)	51,277 (6.0)	48,371 (6.4)	18,581 (11.1)	14,217 (19.3)	12,352 (40.3)	10,793 (41.1)	< 0.001
Pulmonary complication	52,933 (2.8)	14,679 (1.7)	15,064 (2.0)	7,279 (4.3)	6,425 (8.7)	5,752 (18.8)	3,734 (14.2)	< 0.001
Infectious complication	262,642 (13.7)	109,354 (12.7)	84,745 (11.3)	27,444 (16.3)	18,321 (24.9)	12,689 (41.4)	10,089 (38.4)	< 0.001
Sepsis	153,269 (8.0)	59,947 (7.0)	44,789 (6.0)	16,939 (10.1)	12,927 (17.6)	10,287 (33.6)	8,380 (31.9)	< 0.001
Pneumonia	37,921 (2.0)	12,616 (1.5)	12,199 (1.6)	4,940 (2.9)	3,724 (5.1)	2,740 (8.9)	1,702 (6.5)	< 0.001
Urinary tract infection	36,477 (1.9)	14,789 (1.7)	13,608 (1.8)	4,069 (2.4)	2,338 (3.2)	1,139 (3.7)	534 (2.0)	< 0.001
Wound infection	110,437 (5.8)	52,435 (6.1)	37,512 (5.0)	9,725 (5.8)	5,424 (7.4)	2,941 (9.6)	2,400 (9.1)	< 0.001
Venous thromboembolism	27,471 (1.4)	10,861 (1.3)	10,307 (1.4)	3,034 (1.8)	1,756 (2.4)	926 (3.0)	587 (2.2)	< 0.001
Deep venous thrombosis	19,704 (1.0)	7,683 (0.9)	7,135 (0.9)	2,201 (1.3)	1,415 (1.9)	778 (2.5)	492 (1.9)	< 0.001
Pulmonary embolism	10,149 (0.5)	4,131 (0.5)	4,158 (0.6)	1,090 (0.6)	460 (0.6)	185 (0.6)	125 (0.5)	< 0.001
Bleeding	174,796 (9.1)	60,932 (7.1)	59,393 (7.9)	22,740 (13.5)	15,218 (20.7)	9,289 (30.3)	7,224 (27.5)	< 0.001
Acute renal failure	18,703 (1.0)	2,012 (0.2)	2,915 (0.4)	1,865 (1.1)	2,233 (3.0)	4,576 (14.9)	5,102 (19.4)	< 0.001

1. All outcomes are dichotomous. There is no missing data

2. Cochran-Armitage test for trend was used to examine trends across the categories of CKD for all outcome variables

in which there was no longer an association between CKD stage 3 and major complications.

Discussion

This population-based analysis of more than 1.9 million patients provides a comprehensive overview of the effects of CKD on postoperative outcomes, both corroborating previous literature and adding novel insights into the understanding of the importance of CKD. Though it may seem predictable that common patient comorbidities such as CKD can worsen outcomes, this study includes a rigorous statistical analysis, adjusting for numerous confounders, to provide quantifiable risk which can be used to counsel patients on clinical decision-making. Further, this study suggests that CKD is associated with greater odds of nearly all key postoperative adverse outcomes, including cardiovascular events, stroke, pulmonary complications, infectious, and bleeding events. Results remained robust after subgroup and sensitivity analyses.

Previous studies have not evaluated the association between CKD and postoperative outcomes within a diverse multi-specialty surgical cohort and have instead been limited to specific procedures within surgical specialties, thus limiting generalizability. The association of CKD with complications following major abdominal surgery was previously investigated, with a 29% increase in complications and a sevenfold increase in mortality in hemodialysis patients [6]. Infections were found to be the predominant complication. Similarly, patients with stage 5 CKD undergoing bariatric surgery were found to have nearly doubled risk of readmission and increased length of stay, along with infections and mortality. However, the

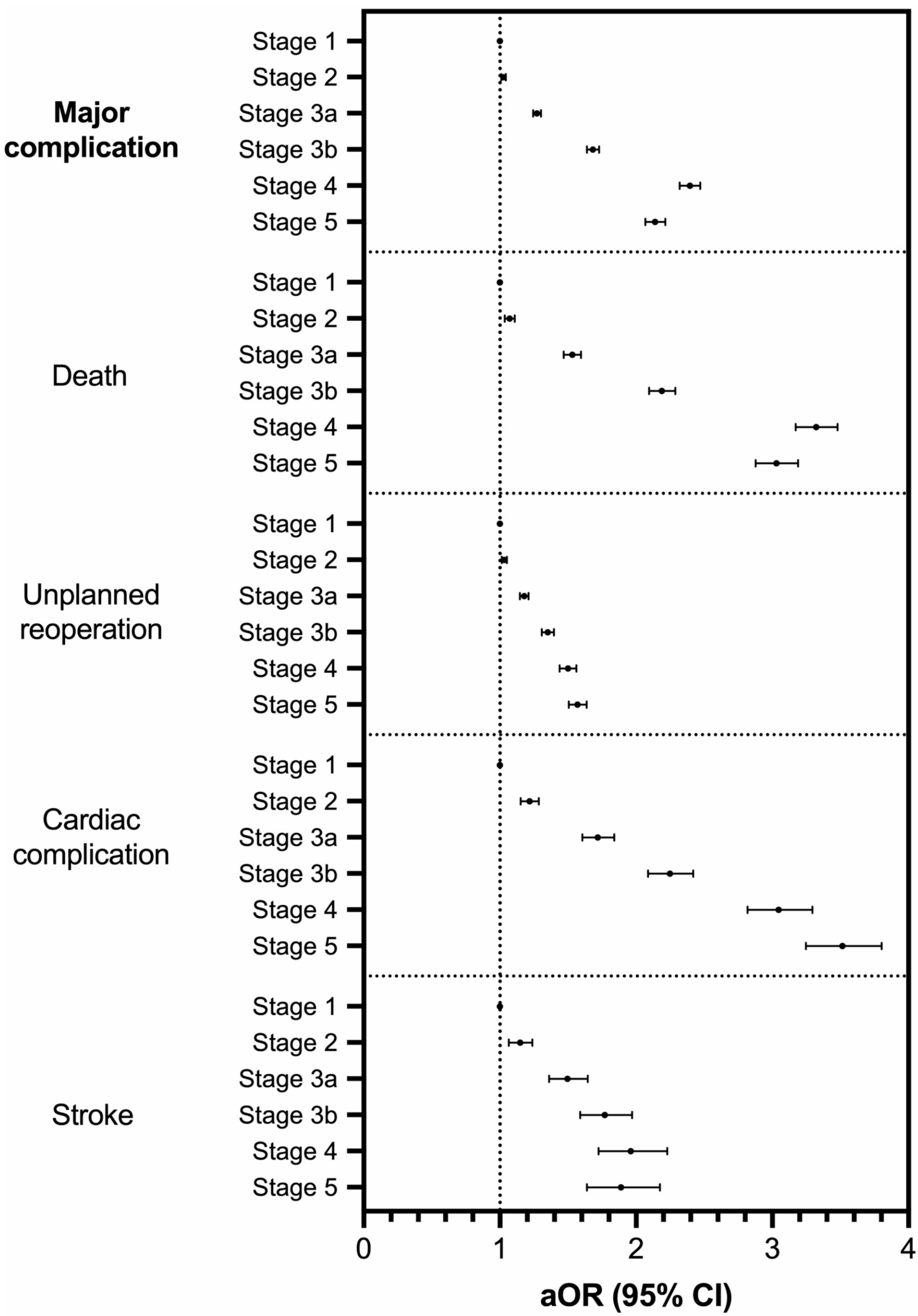

Fig. 2 Association between CKD stage and major complications (along with its components) after multivariable analysis. CKD Stage 1 is the reference category. CKD: chronic kidney disease; aOR: adjusted odds ratio; CI: confidence interval

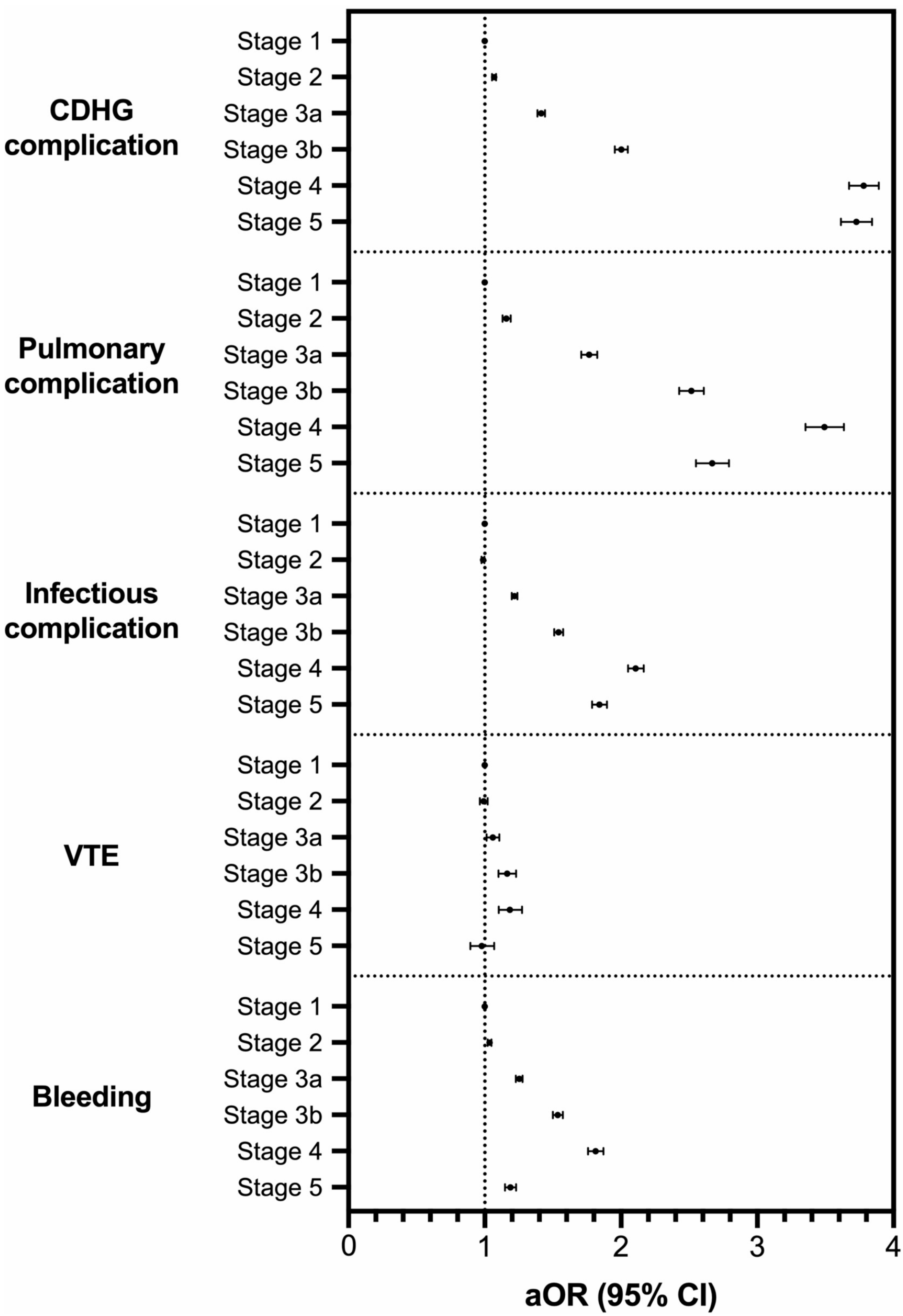

Fig. 3 Association between CKD stage and secondary endpoints after multivariable analysis. CKD Stage 1 is the reference category. CKD: chronic kidney disease; CDHG: Clavien-Dindo high-grade; VTE: venous thromboembolism; aOR: adjusted odds ratio; CI: confidence interval

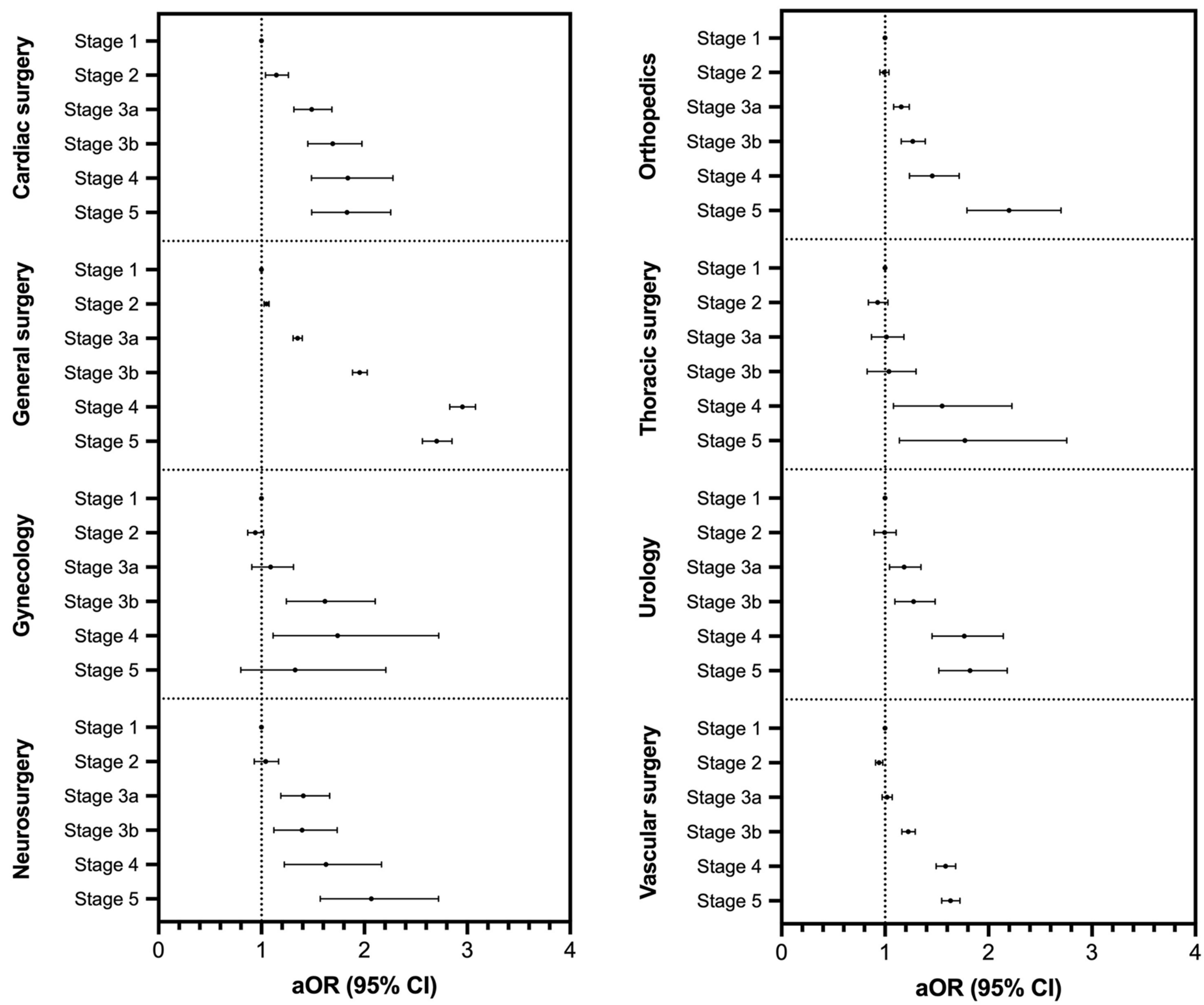

Fig. 4 Association between CKD stage and major complications, subgrouped by surgical specialty. CKD Stage 1 is the reference category. aOR: adjusted odds ratio; CI: confidence interval

authors suggest that bariatric surgery could be renoprotective overall, and the absolute rates of complications, while relatively higher, remained low in terms of absolute values [19]. Similarly, with regard to cardiac surgery, CKD has been shown as an independent risk factor of major complications and mortality following aortic repair [20]. Studies have gone as far as finding that simultaneous kidney transplantation may benefit heart transplant outcomes in patients with baseline CKD [21]. CKD in vascular surgery patients has been shown to increase mortality, cardiovascular and cerebrovascular events, bleeds, and AKI along with reduced chances of procedural success [22–24].

Orthopedic surgery has similarly shown increased general morbidity, as a single institution study of lumbar arthrodesis patients found increase rates of intensive care unit transfer, delirium, urinary tract infection, and deep vein thrombosis in CKD patients, along with an increase in readmissions although this was not statistically significant [25]. Total hip arthroplasty has also been shown to yield poorer outcomes with hemodialysis, with threefold increased mortality, 50% increased emergency room visits, and 2.7 times increased readmissions, although infection or revision rates were not increased [26]. Overall, the authors remarked that CKD may not increase orthopedic implant-related complications, but general medical morbidity was significantly poorer. In a separate study of diabetic patients receiving humerus fracture fixation surgery, CKD patients were shown to have increased revision, infection, readmission, and mortality risk [27]. Finally, transmetatarsal amputation failure is 100% more likely in CKD patients, while conferring a 182% increased mortality risk [28]. Otolaryngology has paralleled these findings, demonstrating that readmissions occur at fivefold increased rates following parathyroidectomy in CKD patients [29]. Similarly, urology has demonstrated the effects of CKD on nephrectomy outcomes, with one study demonstrating the value of incorporating baseline CKD into a metric predicting postoperative outcomes [30]. There does not appear to be any previous study of the effects of CKD on gynecologic surgery outcomes.

Interestingly, the predictivity of CKD staging for several complications categories, including pulmonary, infectious, thromboembolic, and bleeding events, appeared to slightly decrease between CKD stage 4 to 5, although it still remained significantly greater than that for lower stage CKD patients. One study limited to bariatric surgery patients interestingly found that although increasing CKD stage was associated with postoperative mortality, this effect appeared to be mitigated with stage 4 and 5 CKD [19]. CKD has been classically associated with an increased risk of bleeding, but also a paradoxical thrombotic potential. This is thought to be secondary to delayed clot formation yet increased clot strength and decreased breakdown [31]. Although we found advanced CKD to be associated with an increased risk of bleeding across all stages of CKD, we did not find a similar uniform association for VTE. We believe this finding is due to the higher rates of DVT but not PE among patients with CKD. Large population-based observational studies have found that patients with advanced CKD have greater odds of VTE at 1 year (HR 1.83, 95% CI 1.03–3.25) but not at 30-days (HR 1.64 [95% CI: 0.59, 4.54]) [32]. This could also explain why we failed to show a consistent association between 30-day postoperative VTE and all stages of CKD.

Although NSQIP is a validated database with strict quality control measures, this study has limitations. Namely, data cannot be verified for accuracy and may have inherent biases due to its retrospective nature. Additionally, NSQIP focuses on 30-day outcomes, limiting the ability to study the effects of CKD on long-term postoperative experiences or sequelae of chronically reduced renal function. Nonetheless, this study utilizes a substantially large, diverse cohort, allowing for generalizability to the larger population. Moreover, a wide range of outcomes were studied across surgical specialties, allowing for a comprehensive understanding of the effects of CKD on surgery. Additionally, we do not have information on perioperative anticoagulation or general DVT prophylaxis. Finally, there could still be unmeasured confounding that we failed to adjust, such as preoperative dialysis.

The findings of this study may be utilized to better approximate fitness for surgery and hence inform shared decision-making amongst providers and their patients. Namely, this study can inform the incorporation of CKD within novel risk stratification tools which predict the likelihood of specific adverse events following an operation. Identification of CKD in a patient undergoing surgery may also permit improved intraoperative and postoperative surveillance or prophylactic techniques to mitigate risk of specific complications.

Conclusions

In summary, this population-based study indicates the negative impacts of CKD on operative outcomes across a diverse range of procedures and patients. As CKD increases in prevalence, further research is necessary to better elucidate the effects of reduced renal function on surgical safety and patient experiences. An improved understanding of the multifactorial effects of CKD can facilitate shared decision-making and improve patient-centered outcomes across surgical specialties.

Abbreviations

GFR	Glomerular filtration rate
CKD	Chronic Kidney Disease
ACS-NSQIP	American College of Surgeons National Surgical Quality Improvement Program
RECORD	Reporting of Studies Conducted Using Observational Routinely Collected Health Data
CPT	Common Procedural Terminology
ASA	American Society of Anesthesiologists
BMI	Body mass index
COPD	Chronic obstructive pulmonary disease
SD	Standard deviation
VTE	Venous Thromboembolism
CI	Confidence interval
DVT	Deep venous thrombosis

Supplementary Information

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Supplementary Material 1

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Author contributions

Conceptualization, C.R. and R.S.; Methodology, C.R.; Software, E.H. AND J.X.; Validation, E.H.; Formal analysis, M.G.; Writing—original draft preparation, C.R. and Y.B.S.; Writing—review and editing, Z.M., S.H., B.J.M, N.E., Z.K., A.J., C.J.D.W., and R.S.; Supervision, R.S. All authors have read and agreed to the published version of the manuscript.

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Data availability

The datasets generated and/or analysed during the current study are available in the American College of Surgeons National Surgical Quality Improvement Program repository. The American College of Surgeons National Surgical Quality Improvement Program and the hospitals participating in the ACS NSQIP are the source of the data used herein; they have not verified and are not responsible for the statistical validity of the data analysis or the conclusions derived by the authors.

Declarations

Ethics approval and consent to participate
This study was deemed exempt by our institutional review board as the database used contains de-identified data.

Clinical trial number
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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