Surgery for Obesity and Related Diseases 15 (2019) 2075–2086

SURGERY FOR OBESITY AND RELATED DISEASES

Original article

The impact of chronic kidney disease on bariatric perioperative outcome: a MBSAQIP matched analysis

Michael Mazzei, M.D.[a], Huaqing Zhao, Ph.D.[b], Michael A. Edwards, M.D., F.A.C.S.[c,*]

[a]Department of Surgery, Division of Bariatric and Minimally Invasive Surgery, Temple University Hospital, Philadelphia, Pennsylvania
[b]Department of Clinical Sciences, Lewis Katz School of Medicine at Temple University, Philadelphia, Pennsylvania
[c]Department of Surgery, Division of General, Mayo Clinic, Jacksonville, Florida

Received 19 November 2018; accepted 16 July 2019

Abstract

Background: Morbid obesity is considered a strong independent risk factor for chronic kidney disease (CKD), and bariatric surgery remains the most effective treatment for obesity-related co-morbidities. Previous large database analyses have suggested that CKD does not independently increase the risk of adverse outcomes after bariatric surgery. The safety of elective bariatric surgery in this patient population remains unclear. To this end, we compared 30-day outcomes in this patient population after laparoscopic sleeve gastrectomy or Roux-en-Y gastric bypass.
Objectives: To compare 30-day outcomes in CKD patients after laparoscopic sleeve gastrectomy or gastric bypass.
Setting: University Hospital, United States.
Methods: Using the Metabolic and Bariatric Surgery Accreditation Quality Improvement Program database, we identified patients with CKD who underwent laparoscopic sleeve gastrectomy or Roux-en-Y gastric bypass in 2015 or 2016. An unmatched cohort analysis, a propensity-matched analysis, and a case-control, matched-cohort analysis was performed of patients with and without CKD.
Results: Of the 302,092 patients included in this study, 2362 (.7%) had CKD, of whom 837 (35.4%) required dialysis. CKD patients were older with significantly higher rates of co-morbid conditions. Hospital length of stay, intensive care unit admission, reoperation, readmission, bleeding, cardiopulmonary, infectious complications, and total morbidity were significantly higher in CKD patients. In propensity-matched and case-control matched analyses of 4006 patients and 2264 patients, respectively, poorer outcomes in CKD patients highlight it an independent risk factor for morbidity.
Conclusions: In contrast to previously reported large database analysis, CKD and dependence on dialysis independently increases the risk of 30-day adverse outcomes after primary bariatric surgery. The benefits conferred by bariatric surgery should be carefully weighed against the increased risk of complications in this challenging population. (Surg Obes Relat Dis 2019;15:2075–2086.)

Key words: Bariatric surgery outcomes; Sleeve gastrectomy; Gastric bypass; Chronic kidney disease; Propensity-score matching; Case-control matching

*Correspondence: Michael A. Edwards, M.D., F.A.C.S., Senior Associate Consultant, Mayo Clinic, 4500 San Pablo Rd S, Jacksonville, FL 32224.

E-mail addresses: edwards.michael@mayo.edu or maeedw@gmail.com (M.A. Edwards).

https://doi.org/10.1016/j.soard.2019.07.013
1550-7289/

The link between high body mass index (BMI) and the development and progression of renal disease is well established. The pathophysiology of this relationship is likely multimodal. Obesity often contributes to the presence of concomitant known risk factors, such as diabetes, hypertension, and the metabolic syndrome; even in the absence of these risk factors, obesity itself is recognized as an independent contributor [1]. Obesity is implicated in the development of glomerulopathy [2] due to an inflammatory response to ectopic lipid accumulation in the kidney [3]. Numerous studies, including randomized controlled trials (e.g., LOOK-AHEAD) [4], have documented that weight loss can help to arrest the glomerular functional decline in patients with obesity at risk for chronic kidney disease (CKD) [5–7] or halt the progression of established renal impairment to an end-stage renal disease state [8–10]. Bariatric surgery has been proven as an effective method for sustained weight loss and could serve as a useful adjunct in this regard [11].

As the potential benefits of bariatric surgery for patients with obesity and CKD become clearer, it is increasingly important to likewise understand the potential risks associated with operating on this complex population. To that end, in the present study we compare the 30-day outcomes in the bariatric patient population with CKD compared with those without kidney disease using the Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program (MBSAQIP) Participant User Files (PUF). To our knowledge, this is the largest study to date specifically looking at the effects of CKD on perioperative outcomes after bariatric surgery.

Methods

The MBSAQIP participant user file

We retrospectively analyzed data from the MBSAQIP PUF database to compare bariatric surgical outcomes between individuals who had underlying CKD and those who did not, from January 1, 2015 to December 31, 2016. The MBSAQIP accredits bariatric surgical facilities in the United States. As a requirement for accreditation, facilities are required to report bariatric surgical outcomes to the MBSAQIP PUF. The PUF is a Health Insurance Portability and Accountability Act–compliant data file registry containing prospective, risk-adjusted, clinically rich data based on standardized definitions for preoperative, intraoperative, and postoperative variables that are specific for metabolic and bariatric surgery. Data points are abstracted at participating institutions by certified reviewers who are audited for accuracy of performance.

Inclusion criteria

For this study, inclusion criteria were limited to patients who underwent either a laparoscopic sleeve gastrectomy or a laparoscopic Roux-en-Y gastric bypass (primary or secondary Current Procedural Terminology codes 43644, 43645, or 43775) as these procedures represent the preponderance of weight loss procedures offered in the United States at this time, accounting for 85.2% of all procedures offered in the MBSAQIP database in 2015 to 2016 and for 93.6% of all primary weight loss procedures offered during that time. This cohort was further selected to exclude patients <18 years of age and those undergoing revisional or conversional procedures. Cases in the resulting cohort (n = 301,678) were stratified by the preoperative diagnosis of CKD, with further subset stratification of those patients requiring dialysis. A flow diagram of inclusion criteria is depicted in Fig. 1.

Data collection

Descriptive statistics were collected and compared between groups, including demographic factors such as age, race, sex, preoperative BMI, and weight, and health summary status variables such as the American Society of Anesthesiologists' classification and preoperative comorbidities. These included a history of myocardial infarction, hypertension requiring medication, hyperlipidemia, vein thrombosis requiring therapy, history of pulmonary embolism, diabetes, smoking history, immunosuppressant use, obstructive sleep apnea, history of chronic obstructive pulmonary disease, and oxygen dependence. Operative choice was also noted.

The MBSAQIP database contains 2 binary variables related to the presence of CKD. These are "preoperative renal insufficiency," defined as "the reduced capacity of the kidney to perform its function as evidenced by a creatinine of greater than 2 mg/dL but with no requirement for dialysis;" or "preoperative currently requiring or on dialysis," defined as "a clinical condition associated with the decline of kidney function severe enough requiring dialysis." For the purposes of this analysis, patients meeting either of the 2 criteria were defined as having CKD. Creatinine and glomerular filtration rate were not available in the MBSAQIP database for this analysis, and therefore further subset analysis based on CKD stage could not be performed.

Primary outcomes of interest were identified as 30-day overall mortality, 30-day reoperation rate, 30-day reintervention rate, and 30-day readmission rate, as well as hospital length of stay, intensive care unit days, and ventilator days. Secondary outcomes included the rates of certain aggregate complications (leak, bleeding, cardiovascular, pulmonary, and infections, defined in Appendix 1). In addition, worsening of renal failure was a secondary outcome among those patients not already on dialysis. Univariate analyses were performed using Pearson χ^2 test for categorical variables, independent sample t tests for normally distributed continuous

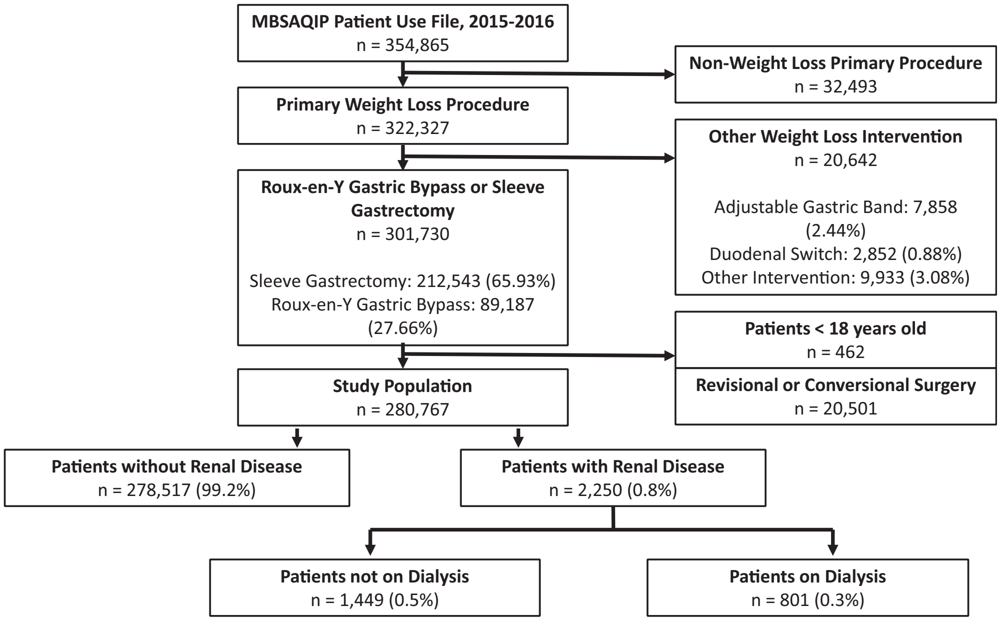

Fig. 1. Flow diagram of inclusion and exclusion criteria. MBSAQIP = Metabolic and Bariatric Surgery Accreditation and Quality Improvement Program.

variables, and Mann–Whitney *U* tests for skewed continuous variables.

Subset analysis

To determine if the risk associated with CKD was disproportionately carried by individuals who were dialysis dependent compared with those who were non–dialysis dependent, we performed a subset analysis of dialysis-independent and dialysis-dependent cohorts compared with patients without CKD. To determine if the risk associated with CKD was disproportionately carried by individuals who received a particular operation type, we performed a subset analysis of outcomes in patients who received a sleeve gastrectomy and in those who underwent Roux-en-Y gastric bypass.

Matched analysis

To determine the independent risk of CKD on bariatric outcomes while controlling for potentially confounding co-morbidities, 1:1 matching was performed on the CKD and non–renal disease cohorts using both a propensity-score matching technique and a case-control matching technique. For propensity-score matching, a logistic regression model was generated in which renal disease status was regressed on baseline characteristics that were thought to serve as potential confounders; from this, a propensity score was assigned to each subject based on the probability of CKD given other covariates. One-to-one matching of case and control patients with similar propensity scores was then used to generate new cohorts hypothesized to be balanced on important potentially confounding baseline characteristics. For propensity score calculation, candidate variables for regression consisted of all available demographic characteristics and preoperative co-morbidities, as well as operation choice.

In tandem with this, case control-matching was also used in which 1:1 matching by a number of physician-selected clinically relevant baseline variables was used to generate new cohorts perfectly matched between those variables. Successful matches between patients with CKD and without renal disease consisted of perfect conformity on all categorical data points and proximity to within a specified caliper distance for each continuous data point. The continuous variables used to match in this analysis included age, which was matched to within 1 year, and both highest BMI and BMI closest to surgery, which were matched to within 1 point of BMI. The univariate analysis was then repeated in this matched cohort in a manner identical to the unmatched cohorts. Candidate variables included the aforementioned demographic factors, health summary status variables, and co-morbidities; the advantage of this is a hypothesized tighter match of baseline characteristics at the expense of a smaller sample size. All statistical analysis was performed with SPSS version 25 (IBM Corporation, Armonk, NY, USA) or SAS version 9.4 (SAS Institute, Cary, NC, USA). A P value $< .05$ was considered statistically significant.

Table 1
Patient demographic characteristics comparing those with chronic kidney disease and dialysis-dependent chronic kidney disease

	CKD (−) versus CKD (+), ± Dialysis (n = 280,767)				Dialysis (−) versus Dialysis (+) (n = 280,767)			
	(−) CKD (n = 278,517)	(+) CKD (n = 2250)	RR/ROM (95% CI)	*P* value	(−) Dialysis (n = 279,966)	(+) Dialysis (n = 801)	RR/ROM (95% CI)	*P* value
Demographic Data								
Age, yr	44.62	52.92	1.19 (1.18–1.20)	<.001	44.68	48.54	1.09 (1.08–1.10)	<.001
Sex (male)	20.60%	44.53%	2.16 (2.15–2.17)	<.001	20.72%	44.57%	2.15 (2.10–2.20)	<.001
Race (white)	64.56%	52.40%	.81 (.78–.84)	<.001	64.54%	39.08%	.61 (.56–.66)	<.001
Race (black)	16.69%	32.53%	1.95 (1.84–2.07)	<.001	16.74%	42.57%	2.54 (2.35–2.76)	<.001
Race (Hispanic)	12.33%	9.38%	.76 (.67–.87)	<.001	12.30%	12.48%	1.01 (.84–1.22)	.877
Race (Asian)	.44%	.84%	1.92 (1.22–3.01)	.005	.45%	.62%	1.39 (.58–3.33)	.454
Patient data								
BMI (highest)	47.34	48.41	1.02 (1.01–1.03)	<.001	47.34	47.64	1.01 (.98–1.04)	.336
BMI (OR)	45.49	46.33	1.02 (1.01–1.03)	<.001	45.50	45.83	1.01 (.99–1.03)	.259
ASA class	2.80	3.24	1.16 (1.14–1.18)	<.001	2.80	3.41	1.22 (1.18–1.26)	<.001
Sleeve gastrectromy	71.23%	73.38%	1.03 (1.00–1.06)	.025	71.21%	83.02%	1.17 (1.13–1.20)	< .001
Albumin	4.06	3.87	.95 (.93–.97)	<.001	4.05	3.90	.96 (.93–.99)	<.001
Hematocrit	40.94	37.24	.91 (.90–.92)	< .001	40.93	35.51	.87 (.84–.90)	<.001
Co-morbid conditions								
GERD	31.20%	41.02%	1.31 (1.25–1.38)	<.001	31.25%	39.33%	1.26 (1.15–1.37)	<.001
History of MI	1.29%	8.13%	6.30 (5.47–7.27)	<.001	1.33%	5.87%	4.41 (3.34–5.83)	<.001
History of PCI	2.06%	13.07%	6.34 (5.68–7.08)	<.001	2.13%	9.74%	4.57 (3.70–5.65)	<.001
Cardiac surgery	1.10%	8.93%	8.12 (7.08–9.31)	.001	1.15%	6.49%	5.64 (4.33–7.36)	<.001
HTN	48.69%	87.60%	1.80 (1.77–1.83)	<.001	48.91%	80.15%	1.64 (1.58–1.70)	<.001
HLD	24.41%	59.33%	2.43 (2.35–2.52)	<.001	24.61%	51.69%	2.10 (1.96–2.25)	<.001
VTE	1.57%	5.78%	3.68 (3.11–4.36)	<.001	1.59%	5.62%	3.53 (2.66–4.70)	<.001
Venous stasis	1.03%	4.40%	4.27 (3.51–5.20)	<.001	1.06%	1.87%	1.77 (1.07–2.92)	.025
Anticoagulation	2.36%	12.27%	5.20 (4.64–5.82)	<.001	2.42%	11.49%	4.75 (3.91–5.76)	<.001
T2D	26.38%	63.33%	2.40 (2.33–2.48)	<.001	26.6%	55.68%	2.09 (1.97–2.23)	<.001
Insulin	8.55%	48.40%	5.66 (5.42–5.92)	<.001	8.77%	45.44%	5.18 (4.80–5.60)	<.001
Current Smoker	8.77%	6.36%	.72 (.62–.85)	<.001	8.76%	5.37%	.61 (.46–.82)	.001
COPD	1.75%	6.58%	3.76 (3.21–4.40)	<.001	1.79%	3.62%	2.02 (1.41–2.89)	<.001
Home O_2	0.69%	3.47%	5.02 (4.02–6.28)	<.001	.71%	2.37%	3.34 (2.14–5.22)	<.001
History of PE	1.12%	3.29%	2.94 (2.34–3.68)	<.001	1.13%	2.5%	2.21 (1.43–3.41)	<.001
OSA	37.76%	58.09%	1.54 (1.48–1.59)	<.001	37.88%	52.56%	1.39 (1.30–1.48)	<.001
Steroids	1.57%	8.44%	5.38 (4.68–6.18)	<.001	1.61%	6.12%	3.80 (2.89–4.99)	<.001
IVC Filter	.85%	2.89%	3.40 (2.67–4.33)	<.001	.86%	2.75%	3.19 (2.11–4.83)	<.001

CKD = chronic kidney disease; RR = relative risk; ROM = ratio of means; CI = confidence interval; BMI highest = highest body mass index; BMI (OR) = body mass index closest to operation date; ASA = American Society of Anesthesiologists physical status classification; GERD = gastroesophageal reflux disease; MI = myocardial infarction; PCI = percutaneous coronary intervention; HTN = hypertension; HLD = hyperlipidemia; VTE = venous thromboembolic event; T2D = type 2 diabetes; COPD = chronic obstructive pulmonary disease; O_2 = oxygen; PE = pulmonary emboli, OSA = obstructive sleep apnea; IVC = inferior vena cava.

Results

Baseline characteristics

Of the 354,865 cases in the 2015 and 2016 MBSAQIP PUF, a total of 280,767 were ultimately included in the analysis. Patient demographic characteristics comparing those with CKD to those without, as well as the subset of individuals requiring dialysis to the broader cohort, are listed in Table 1. At baseline, patients in the CKD cohort were older (52.92 ± 11.14 versus 44.62 ± 11.94, ratio of means [ROM] = 1.19, $P < .001$), were more likely to be black (32.53% versus 16.69%, relative risk [RR] = 1.95, $P < .001$), and had a higher perioperative risk based on the American Society of Anesthesiologists physical status classification (3.24 ± .50 versus 2.80 ± .49, ROM = 1.16, $P < .001$). They had a slightly higher BMI at both highest measured level (48.41 ± 8.56 versus 47.34 ± 8.30, ROM = 1.02, $P < .001$) and level closest to surgery (46.33 ± 8.16 versus 45.49 ± 8.07, ROM = 1.02, $P < .001$). They also had a significantly higher preponderance of most co-morbidities, including history of myocardial infarction (8.13% versus 1.29%, RR = 6.33, $P < .001$), diabetes (63.33% versus 26.38%, RR = 2.40, $P < .001$), and chronic obstructive pulmonary disease (6.58% versus 1.75%, RR = 2.03, $P < .001$). They had a significantly higher need for medical intervention for chronic co-morbidities, including the use of home O_2 (3.47% versus .69%, RR = 3.36, $P < .001$), insulin (48.4% versus 8.55%, RR = 5.18, $P < .001$), and systemic anticoagulation (12.27% versus 2.36%, RR = 5.19% $P < .001$) (Table 1).

Table 2
Perioperative outcome in bariatric patients with and without chronic kidney disease, an unmatched cohort analysis

	CKD (−) versus CKD (+), ± dialysis (n = 280,767)				Dialysis (−) versus dialysis (+) (n = 280,767)			
	(−) CKD (n = 278,517)	(+) CKD (n = 2250)	RR/ROM (95% CI)	*P* value	(−) Dialysis (n = 279,966)	(+) Dialysis (n = 801)	RR/ROM (95% CI)	*P* value
Hospital Outcomes								
OR length, min	87.17	100.39	1.15 (1.14–1.16)	<.001	87.23	96.16	1.10 (1.08–1.12)	.001
Postop LOS, d	1.76	2.64	1.50 (1.48–1.52)	<.001	1.77	2.50	1.41 (1.39–1.43)	<.001
Total LOS, d	1.77	2.74	1.55 (1.53–1.57)	<.001	1.78	2.57	1.44 (1.42–1.46)	<.001
ICU Admission	.69%	3.51%	5.09 (4.08–6.35)	<.001	.7%	2.50%	3.57 (2.31–5.51)	<.001
Transfusion Requirment	.66%	1.89%	2.9 (2.15–3.91)	<.001	.67%	1.62%	2.42 (1.41–4.16)	.001
Intubation	.65%	1.08%	1.64 (1.1–2.45)	<.001	.16%	.12%	.78 (.11–5.54)	.807
30-d Outcomes								
Mortality	.09%	.59%	6.41 (3.68–11.18)	<.001	.1%	.87%	8.74 (4.14–18.44)	<.001
Reoperation	1.26%	2.86%	2.26 (1.77–2.88)	<.001	1.26%	3.62%	2.87 (2.01–4.11)	<.001
Readmission	4.01%	9.83%	2.45 (2.16–2.78)	<.001	4.03%	10.49%	2.6 (2.12–3.19)	<.001
Intervention	1.44%	3.89%	2.72 (2.21–3.34)	<.001	1.45%	3.62%	2.5 (1.74–3.57)	<.001
Aggregate complications								
Leak	.27%	.49%	1.81 (1–3.28)	.082	.28%	.12%	.45 (.06–3.17)	.416
Bleed	.43%	1.67%	3.93 (2.85–5.41)	<.001	.44%	.87%	1.99 (.95–4.16)	.062
Cardiac	.08%	.59%	7.22 (4.13–12.6)	<.001	.09%	.25%	2.77 (.69–11.13)	.114
Pulmonary	.48%	2.27%	4.72 (3.58–6.23)	<.001	.49%	1.37%	2.8 (1.55–5.05)	<.001
Renal*	.14%	3.66%	26.26 (19.8–34.82)	<.001				
VTE	.61%	1.08%	1.75 (1.17–2.61)	.011	.62%	1.00%	1.61 (.81–3.21)	.168
Wound infection	.78%	1.08%	1.37 (.92–2.04)	.146	.78%	.75%	.96 (.43–2.13)	.912
Other infection	.77%	1.78%	2.31 (1.69–3.15)	<.001	.78%	2.12%	2.72 (1.70–4.36)	<.001
Total infection	1.39%	2.49%	1.79 (1.38–2.32)	<.001	1.4%	2.62%	1.87 (1.23–2.86)	<.002
Total morbidity								
Morbidity	5.41%	14.1%	2.6 (2.35–2.89)	<.001	5.44%	15.36%	2.82 (2.40–3.32)	<.001

CKD = chronic renal disease; RR = relative risk; ROM = ratio of means; CI = confidence interval; OR = operation; LOS = length of stay; ICU = intensive care unit; VTE = venous thromboembolic events.

* Dialysis-dependent CKD patients excluded.

A predisposition toward older age (48.54 ± 10.47 versus 44.68 ± 11.96, ROM = 1.09, $P < .001$) and more comorbidities was preserved in the subset of patients requiring dialysis compared with those not requiring dialysis, including myocardial infarction (5.87% versus 1.33%, RR = 4.42, $P < .001$), diabetes (55.68% versus 26.6%, RR = 2.09, $P < .001$), and chronic obstructive pulmonary disease (3.62% versus 1.79%, RR = 2.03, $P < .001$). In this subset, however, there was no statistical significance between groups in terms of highest BMI (47.64 ± 7.63 versus 47.34 ± 8.30, ROM = 1.01, $P = .336$) or BMI closest to surgery (45.83 ± 7.36 versus 45.50 ± 8.07, ROM = 1.01, $P = .259$) (Table 1).

Perioperative outcomes

Perioperative outcomes between unmatched cohorts are described in Table 2. Patients with CKD were found to be at greater risk of nearly all adverse perioperative outcomes. Patients with CKD had longer operating room times (100.39 ± 58.28 versus 87.17 ± 47.53, ROM = 1.15, $P < .001$) despite a higher likelihood of receiving a sleeve gastrectomy (73.38% versus 71.23%, RR = 1.03, $P = .025$), which is in the general database otherwise a significantly shorter procedure compared with a Roux-en-Y gastric bypass (74.12 ± 37.26 versus 119.80 ± 54.39 min, ROM = .62, $P < .001$). Postoperative hospital length was also significantly increased in the CKD cohort, with over 18 extra hours of admission for CKD patients (2.64 ± 4.05 versus 1.76 ± 1.66 d, ROM = 1.5, $P < .001$). These patients were more likely to require intensive care unit transfer (3.51% versus .69%, RR = 5.09, $P < .001$), transfusion (1.08% versus .65%, RR = 1.65, $P < .001$), and reintubation (1.08% versus .65%, RR = 1.65, $P < .001$).

Thirty-day adverse outcomes were likewise increased in CKD patients, including rates of readmission (10.49% versus 4.03%, RR = 2.6, $P < .001$), reintervention (3.62% versus 1.45%, RR = 2.5, $P < .001$), and reoperation (3.62% versus 1.26%, RR = 2.87, $P < .001$). Overall, individuals with CKD had a total morbidity (defined as mortality, readmission, reoperation or reintervention, or unplanned intensive care unit admission) of 14.1% compared with a rate of 5.4% among patients without CKD (14.1% versus 5.41%, RR = 2.61, $P < .001$).

Aggregate complications, representing the rates of certain systems-based complications associated with the bariatric surgery leading to readmission, reintervention, or reoperation, are also listed. While the rates of individual complications were generally low, patients with CKD had higher rates of nearly all categories of aggregate complication.

This included anastomotic leak (.49% versus .27%, RR = 1.78, P = .082), bleeding (1.67% versus .43%, RR = 3.89, $P < .001$), a cardiac or cerebrovascular complication (.59% versus .08%, RR = 7.18, $P < .001$), or a pulmonary complication (2.27% versus .48%, RR = 4.71, $P < .001$). Of particular note, the rate of worsening renal function after surgery was over 20 times higher in patients with preexisting CKD compared with those without (3.03% versus .14%, RR = 21.64, $P < .001$) (Table 2).

These general findings were largely duplicated in the dialysis-dependent cohort compared with those not requiring dialysis; this includes longer length of stay (2.5 versus 1.77, ROM = 1.41, $P < .001$), reoperation (3.62% versus 1.26%, RR = 2.87, $P < .001$), and readmission (10.49% versus 4.03%, RR = 2.6, $P < .001$). While mortality was a rare occurrence, in the dialysis-dependent cohort, surgery was associated with over a 9 times greater risk of death (.87% versus .1%, RR = 9.13, $P < .001$). Dialysis was associated with nearly 3 times the total morbidity after bariatric surgery compared with those not requiring dialysis (15.36% versus 5.72%, RR = 2.82, $P < .001$) (Table 2).

Subset analysis

In subset analysis, the risk of CKD appears to be shared by both dialysis-independent and dialysis-dependent patients. In general, compared with a total morbidity rate of 5.39% among individuals without CKD, those with dialysis-independent CKD had a total morbidity of 14.63% (5.39 versus 14.63, RR = 2.71, $P < .001$), and those with dialysis-dependent CKD had a total morbidity of 15.36% (5.39 versus 15.36, RR = 2.85, $P < .001$) (Appendix 2). In additional subset analysis, the overall morbidity risk of chronic renal disease is conferred across patients undergoing sleeve gastrectomy (13.2% versus 4.2%, RR = 3.2, $P < .001$) and Roux-en-Y gastric bypass (16.3% versus 8.5%, RR = 1.9, $P < .001$). While the RR of total morbidity was less in patients with CKD undergoing Roux-en-Y gastric bypass (RR = 1.9) compared with sleeve gastrectomy (RR = 3.2), this appears to be secondary more to the baseline increased risk of bypass compared with sleeve gastrectomy rather than any risk-reducing effects of Roux-en-Y gastric bypass in this population (Appendix 3).

A subset analysis was performed of renal complications in patients with dialysis-independent CKD. Among these patients, there was an overall renal complication rate of 3.66% compared with .14% in the control cohort, representing an overall RR among CKD patients that is >25 times greater than controls (.14 versus 3.66, RR = 26.26 [19.8–34.82], $P < .001$). Of CKD patients with renal complications, 39% demonstrated a rise in creatinine >2 mg/dL from their preoperative value, but with no requirement for dialysis (.06% versus 1.45%, RR = 23.61 [15.05–37.03], $P < .001$). Fifty-seven percent had worsening of renal dysfunction postoperatively requiring dialysis (.07% versus 2.07%, RR = 30.51 [20.83–44.69], $P < .001$). The remainder were readmitted or received intervention for renal complications other than those listed.

Matched analysis

The extent of the matching success, and the resulting cohort demographic characteristics, for both matching styles are shown in Table 3. Propensity score matching resulted in matched cohorts consisting of 4006 patients (2003 in each group) that had statistically equal distributions of age, sex, race, operation type, preoperative BMI, and comorbid conditions, with the exception of a slightly lower distribution of diabetes (63.11% versus 66.2%, RR = .95, P = .040) and home O_2 use (3.39% versus 4.89%, RR = .69, P = .017) in the cohort with CKD (Table 3). Case-control matching resulted in matched cohorts consisting of 2264 patients (1132 in each group) that had identical distributions of sex, race, operation type, and co-morbidities and were statistically equal in terms of age and preoperative BMI (Table 3).

Perioperative and 30-day outcomes of the matched cohorts are listed in Table 4. After propensity matching, CKD remained significantly associated with higher rates of reoperation (3.34% versus 1.8%, RR = 1.86, P = .002), readmission (10.23% versus 5.89%, RR = 1.74, $P < .001$), and intervention (3.94% versus 2.3%, RR = 1.72, P = .003), although mortality no longer showed a significant difference between groups. Hospital lengths of stay were longer for the cohort with CKD (2.71 versus 2.36 d, ROM = 1.15, P = .001). The rates of unexpected intensive care unit admission were also elevated (3.49% versus 1.7%, RR = 2.06, $P < .001$), as were rates of transfusion (1.9% versus .9%, RR = 2.11, P = .007) and intubation (.95% versus .35%, RR = 2.71, P = .018). Overall, the rates of total morbidity for patients with CKD were over 1.75 times that of patients without (15.03% versus 8.49%, RR = 1.77, $P < .001$) (Table 4). This corresponds to an absolute risk increase (based on total morbidity) of 6.54% and a number needed to harm of 15.3 patients for CKD as an independent perioperative risk factor.

Findings were largely preserved in the case-control matched groups, with underlying CKD being associated with longer lengths of stay (2.33 versus 1.94 d, ROM = 1.2, P = .001) and higher rates of reoperation (3.34% versus 1.8%, RR = 1.86, P = .002), readmission (10.23% versus 5.89%, RR = 1.74, $P < .001$), reintervention (3.94% versus 2.3%, RR = 1.72, P = .003), and unexpected intensive care unit admission (2.65% versus .62%, RR = 4.29, P = .036). These factors coalesce into a rate of total morbidity that nearly doubled that of patients without CKD (11.57% versus 6.18%, RR = 1.87, $P < .001$) (Table 4). This corresponds to

Table 3
Propensity-score and case-control matching covariates

	1:1 Propensity matched (n = 4006)				1:1 Case-control matched (n = 2264)			
	(−) CKD	(+) CKD	RR/ROM (95% CI)	*P* value	(−) CKD	(+) CKD	RR/ROM (95% CI)	*P* value
Demographic data								
Age, yr	53.03	52.78	1.00 (.98–1.02)	.473	53.16	53.33	1.00 (.98–1.02)	.701†
Sex (male)	41.54%	43.93%	1.06 (.98–1.14)	.125	41.61%	41.61%	1.00 (.91–1.10)	>.999†
Race (white)	53.07%	53.22%	1.00 (0.95–1.06)	.924	58.04%	58.04%	1.00 (.93–1.07)	>.999†
Race (black)	33.6%	31.45%	0.94 (.86–1.02)	.147	27.74%	27.74%	1.00 (.88–1.14)	>.999†
Race (Hispanic)	8.49%	9.69%	1.14 (.94–1.39)	.187	9.54%	9.54%	1.00 (.78–1.29)	>.999†
Race (Asian)	1.1%	.9%	.82 (.44–1.52)	.525	.35%	.35%	1.00 (.25–3.99)	>.999†
Patient data								
BMI (highest)	48.53	48.48	1.00 (.99–1.01)	.875	47.47	48.1	1.01 (.99–1.03)	.155*
BMI (OR close)	46.51	46.47	1.00 (1.98–1.01)	.891	45.67	45.87	1.00 (.99–1.01)	.500*
ASA class	3.18	3.22	1.01 (1.00–1.02)	.016	2.91	3.17	1.09 (1.07–1.11)	<.001
Sleeve gastrectomy	43.78%	40.94%	.94 (0.87–1.01)	.068	37.28%	37.28%	1.00 (.90–1.11)	>.999†
Albumin	4.10	3.87	.94 (.93–.95)	<.001	4.08	3.89	.95 (.94–.96)	<.001
Hematocrit	40.61	37.25	.92 (.91–.93)	<.001	40.98	37.56	.92 (.91–.93)	<.001
Co-morbid conditions								
GERD	43.78%	40.94%	.94 (.87–1.01)	.068	37.28%	37.28%	1.00 (.90–1.11)	>.999†
History of MI	6.99%	7.69%	1.10 (.88–1.37)	.396	1.86%	1.86%	1.00 (.55–1.82)	>.999†
History of PCI	11.38%	12.38%	1.09 (.92–1.29)	.320	4.42%	4.42%	1.00 (.68–1.47)	>.999†
Cardiac surgery	7.49%	8.24%	1.10 (.89–1.36)	.379	1.5%	1.5%	1.00 (.51–1.95)	>.999†
HTN	88.02%	87.52%	.99 (.97–1.02)	.630	88.87%	88.87%	1.00 (.97–1.03)	>.999†
HLD	61.96%	59.56%	.96 (.91–1.01)	.120	59.01%	59.01%	1.00 (.93–1.07)	>.999†
VTE	6.69%	5.59%	.84 (.66–1.07)	.148	.8%	.8%	1.00 (.40–2.51)	>.999†
Venous stasis	4.49%	4.54%	1.01 (.76–1.34)	.939	1.41%	1.41%	1.00 (.50–1.99)	>.999†
Anticoagulation	12.13%	11.68%	.96 (.81–1.14)	.661	2.74%	2.74%	1.00 (.61–1.63)	>.999†
T2D	66.2%	63.11%	.95 (.91–1.00)	.040	61.04%	61.04%	1.00 (.94–1.07)	>.999†
Insulin	49.48%	48.08%	.97 (.91–1.04)	.376	45.67%	45.67%	1.00 (.91–1.09)	>.999†
Current smoker	5.24%	6.24%	1.19 (.93–1.53)	.174	4.06%	4.06%	1.00 (.67–1.49)	>.999†
COPD	6.24%	6.19%	.99 (.78–1.26)	.948	2.21%	2.21%	1.00 (.58–1.73)	>.999†
Home O_2	4.89%	3.39%	.69 (.51–0.94)	.017	.27%	.27%	1.00 (.20–4.94)	>.999†
History of PE	3.89%	3.39%	.87 (.63–1.20)	.352	.18%	.18%	1.00 (.14–7.09)	>.999†
OSA	62.11%	58.86%	.95 (.90–1.00)	.036	53.36%	53.36%	1.00 (.93–1.08)	>.999†
Steroids	9.79%	8.04%	.82 (.67–1.00)	.052	3.18%	3.18%	1.00 (.63–1.58)	>.999†
IVC filter	2.2%	2.9%	1.32 (.90–1.94)	.160	.27%	.27%	1.00 (.20–4.94)	>.999†

CKD = chronic kidney disease; RR = relative risk; ROM = ratio of means; CO = confidence interval; BMI (highest) = highest body mass index; BMI (close) = body mass index closest to operation; LSG = sleeve gastrectomy; GERD = gastroesophageal reflux; MI = myocardial infarction; PCI = percutaneous coronary intervention; HTN = hypertension; HLD = hyperlipidemia; VTE = venous thromboembolic event; T2D = Type 2 diabetes; COPD = chronic obstructive pulmonary disease; O_2 = oxygen; PE = pulmonary emboli; OSA = obstructive sleep apnea; IVC = inferior vena cava.

* Continuous variables used in propensity and case-control matching.

† Binary variables used in propensity and case-control matching.

an absolute risk increase (based on total morbidity) of 5.39% and a number needed to harm of 18.6 patients for CKD as an independent perioperative risk factor.

Discussion

This study, to our knowledge, represents the first matched analyses of the MBSAQIP PUF database specifically looking at outcomes related to the presence of CKD. We conclude that while patients with CKD stand to benefit from the weight loss and concomitant improvement in co-morbid conditions that bariatric surgery offers, the decision to pursue a weight loss procedure in these patients must take into account their statistically and clinically significant higher risk of morbidity, mortality, and complications. A portion of this increased risk is due to the higher prevalence of associated co-morbid conditions in this patient population; however, we also demonstrate that even when accounting for differences in co-morbidities between groups, the presence of CKD represents an independent risk factor for adverse outcomes.

These findings are in contrast to some extent with previous large database studies that have highlighted either no independent risk conferred by CKD among bariatric patients or a statistically but not necessarily clinically significant difference in outcomes conferred by renal disease. For example, a recent analysis of patients in the American College of Surgeons National Surgical Quality Improvement Program did not identify dependence on dialysis to

Table 4
Perioperative outcomes chronic kidney disease bariatric patients after propensity-score and case-control matched analysis

	1:1 Propensity matched (n = 4006)				1:1 Case-control matched (n = 2264)			
	(−) CKD	(+) CKD	RR/ROM (95% CI)	*P* value	(−) CKD	(+) CKD	RR/ROM (95% CI)	*P* value
Hospital outcomes								
OR length, min	114.88	101.41	.88 (.85–.91)	<.001	100.81	97.5	.97 (.93–1.01)	.125
Postop LOS, d	2.32	2.63	1.13 (1.11–1.15)	.001	1.93	2.28	1.18 (1.15–1.21)	<.001
Total LOS, d	2.36	2.71	1.15 (1.13–1.17)	.001	1.94	2.33	1.20 (1.17–1.23)	<.001
ICU admission	1.70%	3.49%	2.05 (1.37–3.08)	<.001	.62%	2.65%	4.27 (1.89–9.68)	.036
Transfusion requirement	.90%	1.90%	2.11 (1.21–3.68)	.007	.97%	1.5%	1.55 (.73–3.29)	.061
Intubation	.35%	.95%	2.71 (1.14–6.44)	.018	.18%	.71%	3.94 (.85–18.31)	.186
30-d outcomes								
Mortality	.15%	.35%	2.33 (.60–9.00)	.279	.18%	.44%	2.44 (.48–12.45)	.276
Reoperation	1.80%	3.34%	1.86 (1.24–2.77)	.002	1.06%	2.21%	2.08 (1.05–4.13)	.001
Readmission	5.89%	10.23%	1.74 (1.40–2.16)	<.001	4.68%	8.39%	1.79 (1.29–2.48)	<.001
Intervention	2.30%	3.94%	1.71 (1.20–2.45)	.003	1.5%	2.65%	1.77 (.98–3.19)	.064
Aggregate complications								
Leak	.30%	.45%	1.50 (.54–4.20)	.438	.09%	.35%	3.89 (.44–34.25)	.267
Bleed	.75%	1.5%	2.00 (1.08–3.70)	.025	.35%	1.06%	3.03 (1.01–9.40)	.049
Cardiac	.15%	.65%	4.33 (1.24–15.17)	.012	.18%	.18%	1.00 (.14–6.96)	>.999
Pulmonary	.95%	2.15%	2.26 (1.32–3.87)	.002	.71%	2.03%	2.86 (1.29–6.36)	.008
Renal	.90%	2.80%	3.11 (1.84–5.27)	<.001	.90%	2.56%	2.84 (1.4–5.78)	<.001
VTE	1.00%	1.00%	1.00 (.54–1.85)	>.999	.35%	.88%	2.51 (.79–8.03)	.116
Wound infection	2.50%	1.25%	.50 (.31–.80)	.004	1.06%	1.24%	1.17 (.54–2.52)	.886
Other infection	1.70%	1.90%	1.12 (0.71–1.77)	.643	1.15%	1.33%	1.16 (.55–2.42)	.742
Total infection	3.69%	2.70%	.73 (0.52–1.03)	.072	2.21%	2.21%	1.00 (.58–1.73)	>.999
Total morbidity								
Morbidity	8.49%	15.03%	1.77 (1.48–2.11)	< .001	6.18%	11.57%	1.87 (1.42–2.47)	< .001

CKD = chronic kidney disease; RR = relative risk; ROM = ratio of means; CI = confidence interval; OR = operation; LOS = length of stay; ICU = intensive care unit; VTE = venous thromboembolic events.

be an independent predictor of total morbidity [12]. Other previous studies evaluating the perioperative outcomes of bariatric patients with CKD have suggested that while patients with obesity are at slightly higher risk of complications, in general, laparoscopic bariatric procedures carry low absolute perioperative risk for morbidity and mortality, even among those patients requiring dialysis [13]. While an association between increased complication rates and stage of CKD was noted, the absolute risk for complication in patients with renal dysfunction undergoing obesity surgery was thought to be acceptably low [14], and the literature suggests that even in those patients with the highest severity of CKD, bariatric procedures may be safely performed.

Somewhat contrary to this, we have shown that CKD independently increases the rate of serious morbidities, with a number needed to harm of between 15 and 18. This is consistent with a number of other reports that present evidence that suggests that CKD may carry a higher burden of risk than is currently appreciated. For example, in other elective surgical circumstances, patients with CKD (especially those requiring dialysis) often carry a less acceptable risk profile than has been noted in the bariatric population. In elective colon surgery, for example, several studies point to an 8% to 10% mortality rate and an overall complication rate of 30% to 50% [15,16]. Prior case studies have similarly identified a high rate of acute kidney injury after gastric bypass [17]. Bariatric surgical patients are also at additional risk for certain unique adverse renal sequelae. Surgery may disturb calcium metabolism, and development of hyperparathyroidism has been noted in 15% of postoperative bariatric patients with underlying renal dysfunction [18]. The bariatric patient is also at significantly increased risk of infrequent complications, such as oxalate nephropathy [19]. Another point that could potential give the bariatric surgeon pause before operating is the “obesity paradox” of CKD. It has been consistently demonstrated that obesity ranges of BMI are paradoxically associated with greater survival in advanced and dialysis-dependent CKD patients [20]. This suggests that once CKD has occurred, a consistent association between obesity and better outcomes may be seen, which adds further complexity to the decision to pursue weight loss surgery in this cohort.

Ultimately, however, it is important to couch these findings in terms of the significant potential benefits that weight loss surgery could bring for renal patients. A 2013 meta-analysis of weight loss in CKD highlighted that weight loss, and in particular weight loss secondary to bariatric surgery, produces a normalization or significant increase in GFR in patients with CKD, suggesting a beneficial effect of weight loss on renal function [8]. Surgical weight loss interventions have also been shown to reduce blood pressure and resolve albuminuria in patients with obesity and chronic renal insufficiency [21]. Additionally, there is increasing evidence to suggest that bariatric surgery has the long-term functional outcome of halting renal decline in some individuals [22].

The National Institutes of Health Consensus guidelines highlight BMI $\geq$40 or BMI $\geq$35 kg/m^2 with obesity-related co-morbidity as approved clinical indications for bariatric surgery [23]; this weight cutoff also coincides with a severely elevated risk of CKD progression. For example, patients with a BMI >35 have been identified as having >3 times the risk of renal functional decline to end stage renal disease compared with patients with nonelevated BMI, and patients with a BMI >40 carry a relative risk of >7 times that of individuals with normal BMI [24]. Furthermore, in many renal transplant centers, BMI thresholds are often present over which patients are restricted from listing for renal transplant. In the population with obesity and end stage renal disease, bariatric surgery has been recognized as a potential bridge to transplantation [25,26] and may improve transplant candidacy in patients with morbid obesity [27].

Before attempting weight loss surgery on patients with renal disease, potential benefits should be carefully weighed against the increased risks on a case-by-case basis. Once the decision is made to perform a bariatric surgery procedure on a CKD patient, special attention should be placed on the preoperative amelioration of modifiable risk factors. These surgeries should be preferentially conducted in high-volume bariatric centers with experience in dealing with high-risk renal patients. Clinical pathways may be put in place to facilitate multidisciplinary coordination of care. The patient with end-stage renal disease on dialysis must in particular be viewed as a high-risk surgical patient, and a team approach will be necessary to provide appropriate perioperative care for this challenging population.

There are several limitations to our study. First, CKD in this data set is extrapolated from the following 2 binary variables, the first capturing all patients with a creatinine of >2 mg/dL but with no requirement for dialysis and the second encompassing those patients on dialysis. While these represent CKD, the database does not allow for a more focused evaluation of risks associated with CKD stage. Without a creatinine or GFR, the extent of renal disease cannot be estimated beyond “renal disease with dialysis” versus “renal disease without dialysis.” Similarly, the data set does not include information such as complete blood count data or other laboratory values, that could provide further information about the clinical status of the cohorts in the preoperative period. Second, this study was limited to perioperative outcomes data only, with the intention of determining the general risk that CKD confers upon bariatric patients. As a result, outcomes related to long-term complications, and the impact of the surgeries on potential weight loss and potential improvement in CKD and other co-morbid conditions, could not be assessed. Third, this data set is a retrospective cohort, and while it is inclusive of all bariatric surgeries performed at accredited centers over 2 years, it provides an incomplete look at surgical decision-making in the perioperative period. For example, the database provides no insight into patient selection and the characteristics of those patients who were deemed to be too high risk for bariatric surgery. It does not take into account differences in surgeon experience or case volume, which has been shown to have a considerable effect on outcomes. It also does not provide insight into perioperative technical decision-making, such as choice of operation. Patient care decisions are likewise not captured in the database. For example, in the case of dialysis-dependent patients, the timing of dialysis to surgery is not known. The increased hospital length of stay in patients with CKD may be related to the need for dialysis and the likelihood of these patients staying later to receive dialysis as in-patients. Thus, increased length of stay among CKD patients should not be considered a worse outcome unless it is clear that this was an unplanned occurrence. Furthermore, the study is subject to the potential biases that are associated with any retrospective analysis of a multi-institutional clinical database. For most variables, missingness is low in this data set and did not appear to be a major issue; however, as with all database studies results are limited by the timeliness and completeness of data entry by Bariatric Clinical Nurse Reviewers. While the MBSAQIP program offers training and oversight, including auditing to ensure accuracy, variations in coding between institutions cannot be fully excluded as a source of bias.

Conclusion

While this study is not without limitations, through unmatched and matched analyses of the MBSAQIP PUF, we demonstrate that CKD potentially increases the risk of perioperative complications during or after bariatric surgery. It appears that even after controlling for co-morbidities between groups, the presence of CKD represents an independent risk factor for poorer outcomes after metabolic and bariatric surgery. While benefits may be construed from weight loss surgery in patients with CKD, these benefits must be weighed against the clinically and statistically significant risks of serious perioperative and 30-day morbidities conferred upon bariatric surgical candidates with CKD. Further research should be conducted to develop strategies for the reduction of perioperative risk in this challenging patient population.

Disclosures

The authors have no commercial associations that might be a conflict of interest in relation to this article.

Appendix 1

Aggregate Variable	Composite Variables
Leak	Reoperation with Suspected Reason: Leak
	Readmission with Suspected Reason: Leak
	Intervention with Suspected Reason: Leak
	Drain present over 30 days
	Complication: Organ space SSI
Bleeding	Reoperation with Suspected Reason: Bleeding
	Readmission with Suspected Reason: Bleeding
	Intervention with Suspected Reason: Bleeding
Cardiac/CVA	Reoperation with Suspected Reason: Cardiac NOS, CVA, or MI
	Readmission with Suspected Reason: Cardiac NOS, CVA, or MI
	Intervention with Suspected Reason: Cardiac NOS, CVA, or MI
	Complication of CVA
	Complication of MI
Pulmonary	Reoperation with Suspected Reason: Shortness of Breath, Pneumonia, or Other Respiratory Failure
	Readmission with Suspected Reason: Shortness of Breath, Pneumonia, or Other Respiratory Failure
	Intervention with Suspected Reason: Shortness of Breath, Pneumonia, or Other Respiratory Failure
	Complication: On Ventilator > 48 hours
	Complication: Unplanned Intubation
	Complication: Pneumonia
Renal	Reoperation with Suspected Reason: Renal Insufficiency
	Readmission with Suspected Reason: Renal Insufficiency
	Intervention with Suspected Reason: Renal Insufficiency
	Complication: Progressive Renal Insufficiency
	Complication: Acute Renal Failure
DVT or PE	Reoperation with Suspected Reason: Vein Thrombosis Requiring Therapy or Pulmonary Embolism
	Readmission with Suspected Reason: Vein Thrombosis Requiring Therapy or Pulmonary Embolism
	Intervention with Suspected Reason: Vein Thrombosis Requiring Therapy or Pulmonary Embolism
	Complication: Vein Thrombosis Requiring Therapy
	Complication: Pulmonary Embolism
	Complication: Anticoagulation initiated of presumed/confirmed vein thrombosis/PE
Wound infection	Reoperation with Suspected Reason: Wound Infection or Other Abdominal Sepsis
	Readmission with Suspected Reason: Wound Infection or Other Abdominal Sepsis
	Intervention with Suspected Reason: Wound Infection or Other Abdominal Sepsis
	Complication: Post-Op Superficial Incisional SSI occurrence
	Complication: Post-Op Deep Incisional SSI occurrence
Other Infection	Reoperation with Suspected Reason: Infection / Fever
	Readmission with Suspected Reason: Infection / Fever,
	Intervention with Suspected Reason: Infection / Fever
	Complication: Post-Op Sepsis Occurrence
	Complication: Post-Op Septic Shock Occurrence
	Complication: Post-Op Pneumonia occurrence
	Complication: Post-Op Urinary Tract Infection occurrence
Total Infection	Wound Infection, as above
	Other Infection, as above
Total Morbidity	Mortality within 30 Days
	Need for Intervention within 30 Days
	Need for Readmission within 30 Days
	Need for Reoperation within 30 Days
	Unplanned ICU Transfer within 30 Days

Appendix 2. Outcomes in dialysis-independent versus dialysis-dependent metabolic and bariatric surgery patients: subgroup analysis

	CKD (+) versus CKD (-), Dialysis Excluded (n = 279,966)				Dialysis (+) versus CKD (-), dialysis-independent CKD excluded (n = 279,318)			
	(-) CKD (n 278,517)	(+) CKD (n 1,449)	RR / RoM (95% CI)	p-value	(-) CKD (n 278,517)	(+) Dialysis (n 801)	RR / RoM (95% CI)	p-value
Hospital Outcomes								
OR Length (m)	87.15	101.78	1.16 (1.14-1.18)	< **0.001**	87.15	96.16	1.10 (1.08-1.12)	< **0.001**
Post-op LOS (d)	1.76	2.65	1.51 (1.49-1.53)	< **0.001**	1.76	2.5	1.42 (1.41-1.44)	< **0.001**
Total LOS (d)	1.77	2.76	1.56 (1.54-1.58)	< **0.001**	1.77	2.57	1.45 (1.43-1.47)	< **0.001**
ICU Admission	87.15	96.16	1.10 (1.08-1.12)	< **0.001**	0.69%	2.5%	3.63 (2.35-5.61)	< 0.001
Transfusion Req.	0.66%	2.14%	3.25 (2.29-4.62)	< **0.001**	0.66%	1.62%	2.46 (1.43-4.23)	0.001
Intubation	0.15%	1.38%	9.02 (5.78-14.09)	< **0.001**	0.15%	0.12%	0.82 (0.11-5.8)	0.839
30-Day Outcomes								
Mortality	0.09%	0.48%	5.16 (2.44-10.9)	< **0.001**	0.09%	0.87%	9.33 (4.42-19.69)	< 0.001
Reoperation	1.25%	3.04%	2.43 (1.81-3.25)	< **0.001**	1.25%	3.62%	2.9 (2.02-4.14)	< 0.001
Readmission	4%	10.14%	2.53 (2.17-2.96)	< **0.001**	4.00%	10.49%	2.62 (2.14-3.21)	< 0.001
Intervention	1.43%	4.14%	2.89 (2.25-3.71)	< **0.001**	1.43%	3.62%	2.53 (1.77-3.62)	< 0.001
Aggregate Complications								
Leak	0.67%	0.97%	1.44 (0.85-2.43)	0.169	0.67%	0.5%	0.74 (0.28-1.98)	0.544
Bleed	0.43%	1.86%	4.34 (2.97-6.33)	< **0.001**	0.43%	0.87%	2.03 (0.97-4.26)	0.055
Cardiac	0.07%	1.17%	15.86 (9.7-25.94)	< **0.001**	0.07%	0.12%	1.69 (0.24-12.03)	0.597
Pulmonary	0.48%	2.62%	5.47 (3.98-7.52)	< **0.001**	0.48%	1.37%	2.86 (1.59-5.16)	< 0.001
Renal	0.14%	3.66%	26.26 (19.8-34.82)	< **0.001**				
VTE	0.61%	0.97%	1.57 (0.93-2.65)	0.088	0.61%	1%	1.62 (0.81-3.24)	0.165
Wound Infection	0.67%	1.1%	1.64 (1.01-2.68)	**0.045**	0.67%	1.25%	1.86 (1-3.44)	0.047
Other Infection	0.76%	1.45%	1.91 (1.24-2.92)	**0.003**	0.76%	1.5%	1.97 (1.12-3.46)	0.016
Total Infection	1.35%	2.48%	1.84 (1.33-2.55)	< **0.001**	1.35%	2.75%	2.04 (1.35-3.08)	0.001
Total Morbidity								
Morbidity	5.39%	14.63%	2.71 (2.39-3.08)	< **0.001**	5.39%	15.36%	2.85 (2.42-3.35)	0.001

CKD = chronic renal disease, RR = relative risk, RoM = ratio of means, OR = operation, d = days, LOS = length of stay, d = days, ICU = intensive care unit, Req = requirement, VTE = venous thromboembolic events.

Appendix 3. Bariatric procedure-specific outcomes in patients with and without chronic kidney disease

	Sleeve Gastrectomy (n = 200,027)				Roux-en-Y Gastric Bypass (n = 80,740)			
	(-) CKD (n 198,697)	(+) CKD (n 1,330)	RR / RoM (95% CI)	P value	(-) CKD (n 80,219)	(+) CKD (n 521)	RR / RoM (95% CI)	P value
Hospital Outcomes:								
OR Length (m)	74.04	85.25	1.15 (1.14-1.16)	< **0.001**	119.67	139.04	1.16 (1.14-1.18)	< **0.001**
Post-op LOS (d)	1.65	2.45	1.48 (1.45-1.51)	< **0.001**	2.08	3.14	1.51 (1.49-1.52)	< **0.001**
Total LOS (d)	1.65	2.57	1.56 (1.54-1.56)	< **0.001**	2.09	3.16	1.51 (1.49-1.52)	< **0.001**
ICU Admission	0.50%	3.16%	6.29 (4.64-8.53)	< **0.001**	1.16	4.41	3.81 (2.54-5.71)	< **0.001**
Transfusion Req.	0.48%	1.80%	3.75 (2.51-5.6)	< **0.001**	1.10	2.11	1.91 (1.06-3.44)	**0.029**
Intubation	0.11%	0.90%	8.26 (4.63-14.74)	< **0.001**	0.26	1.54	5.87 (2.91-11.82)	< **0.001**
30-Day Outcomes:								
Mortality	0.07%	0.60%	8.24 (4.05-16.76)	< **0.001**	0.15	0.58	3.88 (1.24-12.17)	**0.012**
Reoperation	0.85%	2.41%	2.85 (2.02-4.02)	< **0.001**	2.27	4.03	1.77 (1.16-2.7)	**0.007**
Readmission	3.18%	9.17%	2.88 (2.43-3.42)	< **0.001**	6.08	11.52	1.9 (1.49-2.41)	< **0.001**
Intervention	0.98%	2.93%	2.99 (2.19-4.08)	< **0.001**	2.56	6.33	2.47 (1.77-3.45)	< **0.001**
Aggregate Complications								
Leak	0.48%	0.75%	1.56 (0.84-2.89)	0.160	1.13	1.34	1.19 (0.57-2.48)	0.649
Bleed	0.26%	1.13%	4.31 (2.59-7.18)	< **0.001**	0.85	3.07	3.62 (2.22-5.9)	< **0.001**
Cardiac	0.07%	0.98%	14.07 (7.99-24.79)	< **0.001**	0.09	0.77	8.93 (3.27-24.37)	< **0.001**
Pulmonary	0.34%	1.88%	5.56 (3.74-8.25)	< **0.001**	0.84	3.26	3.90 (2.43-6.26)	< **0.001**
Renal	0.11%	2.11%	19.55 (13.23-28.88)	< **0.001**	0.22	5.37	24.50 (16.6-36.16)	< **0.001**
VTE	0.61%	1.05%	1.74 (1.03-2.93)	**0.037**	0.63	1.15	1.81 (0.82-4.04)	0.139
Wound Infection	0.39%	0.83%	2.10 (1.16-3.80)	**0.012**	1.37	1.73	1.26 (0.66-2.42)	0.479
Other Infection	0.54%	1.50%	2.77 (1.79-4.30)	< **0.001**	1.30	1.54	1.18 (0.59-2.36)	0.637
Total Infection	0.89%	2.33%	2.61 (1.84-3.71)	< **0.001**	2.48	3.07	1.24 (0.76-2.01)	0.338

(*continued on next page*)

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	Sleeve Gastrectomy (n = 200,027)				Roux-en-Y Gastric Bypass (n = 80,740)			
	(-) CKD (n 198,697)	(+) CKD (n 1,330)	RR / RoM (95% CI)	P value	(-) CKD (n 80,219)	(+) CKD (n 521)	RR / RoM (95% CI)	P value
Total Morbidity								
Morbidity	4.15%	13.23%	3.19 (2.78-3.67)	< **0.001**	8.54	16.31	1.91 (1.57-2.32)	< **0.001**

CKD = chronic renal disease, RR = relative risk, RoM = ratio of means, OR = operation, d = days, LOS = length of stay, d = days, ICU = intensive care unit, Req = requirement, VTE = venous thromboembolic events.

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