The Impact of CKD on Perioperative Risk and Mortality after Bariatric Surgery

Flavia Carvalho Silveira,1 William P. Martin,2 Gabrielle Maranga,1 Carel W. le Roux,2 and Christine J. Ren-Fielding

Abstract

Background Twenty percent of patients with CKD in the United States have a body mass index (BMI) $\geq 35$ kg/m$^2$. Bariatric surgery reduces progression of CKD to ESKD, but the risk of perioperative complications remains a concern.

Methods The 24-month data spanning 2017–2018 were obtained from the Metabolic and Bariatric Surgery Quality Improvement Program (MBSAQIP) database and analyzed. Surgical complications were assessed on the basis of the length of hospital stay, mortality, reoperation, readmission, surgical site infection (SSI), and worsening of kidney function during the first 30 days after surgery.

Results The 277,948 patients who had primary bariatric procedures were 44.6 ± 11.9 (mean ± SD) years old, 79.6% were women, and 71.2% were White. Mean BMI was 45.7 ± 7.6 kg/m$^2$. Compared with patients with an eGFR $\geq 90$ ml/min per BSA, those with stage 5 CKD/ESKD were 1.91 times more likely to be readmitted within 30 days of a bariatric procedure (95% CI, 1.37 to 2.67; $P < 0.001$). Similarly, length of hospital stay beyond 2 days was 2.05-fold (95% CI, 1.64 to 2.56; $P < 0.001$) higher and risk of deep incisional SSI was 6.92-fold (95% CI, 1.62 to 29.52; $P = 0.009$) higher for those with stage 5 CKD/ESKD. Risk of early postoperative mortality increased with declining preoperative eGFR, such that patients with stage 3b CKD were 3.27 (95% CI, 1.82 to 5.89; $P < 0.001$) times more likely to die compared with those with normal kidney function. However, absolute mortality rates remained relatively low at 0.53% in those with stage 3b CKD. Furthermore, absolute mortality rates were <0.5% in those with stages 4 and 5 CKD, and these advanced CKD stages were not independently associated with an increased risk of early postoperative mortality.

Conclusions Increased severity of kidney disease was associated with increased complications after bariatric surgery. However, even for the population with advanced CKD, the absolute rates of postoperative complications were low. The mounting evidence for bariatric surgery as a renoprotective intervention in people with and without established kidney disease suggests that bariatric surgery should be considered a safe and effective option for patients with CKD.

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Introduction

According to the Centers for Disease Control and Prevention, the prevalence of CKD among Americans is 14% (1). Over one-fifth of these patients have a body mass index (BMI) $>35$ kg/m$^2$ (2). Similarly, over 35% of people attending outpatient nephrology services were found to have a BMI $>30$ kg/m$^2$, and an increasing BMI was associated with greater antihypertensive usage and proteinuria among those with CKD (3). Obesity is a contributor to declining kidney function (4), but Weisinger et al. (5) showed in 1974 that kidney function can improve with weight loss and that kidney function deteriorates with weight regain (4).

More recently, the MOMS randomized controlled study suggested that early stages of CKD can be placed in remission with bariatric surgery (6,7).

The mechanism by which obesity promotes glomerular injury is centered around glomerular hyperfiltration, an alteration postulated to represent an early stage in the development of CKD (8). Beyond altering renal hemodynamics, obesity also increases the incidence of type 2 diabetes and hypertension, conditions responsible for two-thirds of all cases of CKD (9). Modifications in adipocytokine signaling and changes in renal tubular sodium handling further contribute to CKD among people with obesity, which may be reversed by bariatric surgery (10,11).

Weight loss improves GFR and decreases the risk of adverse kidney disease outcomes (11). In 2018, Shulman et al. (12) reported that bariatric surgery is associated with long-term protection against ESKD. They followed 4047 patients with obesity for 18 years, and when comparing subjects who underwent bariatric surgery...
surgery with a control group, surgery reduced the risk of progressing to ESKD by 73% (adjusted hazard ratio, 0.27; 95% confidence interval [95% CI], 0.12 to 0.60; \( P=0.001 \)). Because of a higher risk of kidney allograft complications with increasing BMI, obesity prevents many people with ESKD from being considered for kidney transplants (13). BMI \( \geq 40 \) kg/m\(^2\) is often considered an absolute contraindication to kidney transplantation, whereas most consider class 2 obesity (BMI \( \geq 35 \) kg/m\(^2\)) a relative contraindication (14).

Bariatric surgery in people with obesity and ESKD has the potential to improve access to kidney transplantation and consequently, lower mortality attributable to kidney failure (15).

However, the perioperative complications after bariatric surgery remain to be assessed for patients at each progressive stage of CKD. Patients with CKD are postulated to be at a higher risk for mortality and adverse outcomes in the perioperative setting (16). Although surgical procedures in patients with CKD are commonly performed, data regarding the adequate evaluation and minimization of perioperative risk are scarce. Most studies report on the surgical risk of conditions that are associated with CKD, such as diabetes, anemia, or heart disease. Others discuss the association between CKD and postoperative complications while failing to signal at what stage CKD starts to affect surgical risk.

Turgeon et al. (17) evaluated the effect of kidney function on bariatric surgery outcomes for 27,736 patients treated during 2006–2008. Although more advanced CKD stages increased risk of postoperative complications, absolute complication rates remained low at \(<10\%\).

However, \(<2000\) patients in the study cohort had an eGFR \(<60\) ml/min per BSA, and \(<200\) patients had stages 4 and 5 CKD. Larger numbers of patients with established and advanced CKD are required to generate robust estimates of postoperative complication rates after bariatric surgery among patients with kidney disease.

In a study published by Cohen et al. (18) in 2019, bariatric surgery complications stratified by CKD status were reported. A key limitation of this report that we aim to address in this study is that Cohen et al. (18) defined CKD as a preoperative serum creatinine \( \geq 2 \) mg/dl rather than staging CKD according to Kidney Disease Improving Global Outcomes (KDIGO) criteria on the basis of eGFR. The former is not an accepted definition of CKD, underestimated the true prevalence of CKD in their study cohort, and prevented them from investigating risks of bariatric surgery across KDIGO categorical CKD classes (18).

Therefore, the objective of this analysis is to investigate the effect of different stages of CKD on the occurrence of perioperative complications following bariatric surgery. In this study, we interrogate and extend previous observations by including a larger sample of patients with confirmed CKD across KDIGO-defined CKD categories in a study cohort reflective of contemporary bariatric surgery practice.

Materials and Methods

Data prospectively collected between 2017 and 2018 were extracted from the Metabolic and Bariatric Surgery Quality Improvement Program (MBSAQIP) database. The MBSAQIP accredits inpatient and outpatient bariatric surgery centers in the United States and Canada that have undergone a rigorous peer evaluation in accordance with nationally recognized bariatric surgical standards. This database contains prospectively collected patient-level aggregate data submitted from 854 MBSAQIP-participating centers.

The primary bariatric operations registered in the MBSAQIP database from 2017 to 2018 consisted of sleeve gastrectomy, Roux-en-Y gastric bypass, adjustable gastric band, and duodenal switch. Prior to 2017, the MBSAQIP database did not collect creatinine values from which eGFR could be calculated; thus, this study commenced from 2017 onward.

Statistical analysis was performed to determine whether there was an association between preoperative renal function and bariatric surgery complications. Exclusion criteria included unknown age, age \(<18\) or \(\geq80\) years, unknown sex, unknown BMI, BMI \(\geq35\) kg/m\(^2\), revisional surgery, and missing preoperative creatinine value.

Renal function was assessed by calculating eGFR from serum creatinine accounting for age, sex, and race using the Chronic Kidney Disease Epidemiology Collaboration (CKD-EPI) creatinine equation (19). The CKD-EPI equation is currently the recommended method for estimating GFR in adults. The equation was reported to perform better and with less bias than other equations, such as the Modification of Diet in Renal Disease equation, particularly in patients with higher GFR, resulting in reduced misclassification of CKD stages.

Logistic regression determined if preoperative renal function, classified according to KDIGO CKD stages, was associated with various bariatric surgical outcomes, including the length of hospital stay (\(>2\) days was considered abnormal), rates of reoperation, readmission, mortality, surgical site infection (SSI), and progressive renal insufficiency (reduced kidney function in comparison with the preoperative state).

Surgical complications were only included in the analysis when reported within 30 days of a bariatric procedure.

Definitions of postoperative decline in kidney function included (1) a rise in creatinine \(\geq2\) mg/dl with no requirement for dialysis or (2) AKI requiring dialysis in a patient with no preoperative dialysis requirement. For analyses of progressive renal insufficiency postoperatively, patients with stage 5 CKD and patients recorded as being on dialysis preoperatively were excluded. Preoperative dialysis was recorded in the database for individuals treated with peritoneal dialysis, hemodialysis, hemofiltration, hemodiafiltration, or ultrafiltration within 2 weeks prior to the principal operative procedure; 101 individuals recorded as being on dialysis but with an eGFR in the stage 1–4 CKD range (eGFR \(\geq15\) ml/min per BSA) were excluded from the dataset due to concerns regarding misclassification.

Odds ratios were adjusted for age, sex, race-ethnicity, BMI, surgery type, year of surgery, smoking status, diabetes, hyperlipidemia, number of antihypertensives, sleep apnea, history of myocardial infarction, previous cardiac surgery, history of deep venous thrombosis, venous stasis, dialysis treatment, functional dependence, history of chronic obstructive pulmonary disease, history of oxygen dependence, and history of pulmonary embolism.

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and...
with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Results

From January 1, 2017 to December 31, 2018, a total of 277,948 primary bariatric operations that fit our inclusion criteria were registered in the MBSAQIP database. The demographic characteristics of this cohort were as follows: age was 44±11.9 years (mean ± SD), 79.6% were women, and 71.2% were White. Mean BMI was 45.7±7.6 kg/m²; 72.5% of patients underwent sleeve gastrectomy, 25.5% had Roux-en-Y gastric bypass, 1% had duodenal switch, and <1% underwent adjustable gastric band. The distribution of KDIGO CKD staging categories on the basis of CKD-EPI eGFR is presented in Table 1. The study cohort consisted of 185,904 (66.9%) people with stage 1 CKD, 76,975 (27.7%) people with stage 2 CKD, 9403 (3.4%) people with stage 3a CKD, 3230 (1.2%) people with stage 3b CKD, 1029 (0.4%) people with stage 4 CKD, and 1407 (0.5%) people with stage 5 CKD/ESKD.

Compared with patients with normal kidney function (eGFR≥90 ml/min per BSA), those with stage 5 CKD/ESKD were older (48.0±10.9 versus 40.6±10.7 years, P<0.001), more likely to be men (36% versus 19.6%, P<0.001), and more likely to undergo sleeve gastrectomy (80.2% versus 73.2%, P<0.001) despite having a higher prevalence of diabetes. Mean ± SD BMIs were similar between those with stage 5 CKD/ESKD and stage 1 CKD at 45.8±7.4 and 46.1±7.7 kg/m², respectively. Compared with patients with normal kidney function (eGFR≥90 ml/min per BSA), those with stage 5 CKD/ESKD also had a greater burden of cardiovascular risk factors and established cardiovascular disease. For example, those with stage 5 CKD were more likely to have diabetes (51.5% versus 23%, P<0.001), have hyperlipidemia (44.1% versus 16.8%, P<0.001), be treated with three or more antihypertensives (26.7% versus 6.9%, P<0.001), have sleep apnea (46.2% versus 35.0%, P<0.001), and have a history of prior PCI or PTCA (8% versus 1%, P<0.001).

Rates of most 30-day surgical complications trended to be higher for the population with the lowest preoperative eGFR. For the group with stage 5 CKD/ESKD, rates of mortality, reoperation, readmission, and SSI within 30 days were 0.43%, 2.49%, 8.60%, and 0.05%, respectively. This is in comparison with patients with normal kidney function (eGFR≥90 ml/min per BSA), whose rates of mortality, reoperation, readmission, and SSI were 0.06%, 1.09%, 3.31%, and 0.05%, respectively (Table 2).

The odds of postoperative progressive renal insufficiency were higher with increasing severity of baseline CKD. In the population with normal kidney function (eGFR≥90 ml/min per BSA), 0.03% had progressive renal insufficiency within 30 days of surgery, whereas 1.36% of patients with stage 4 CKD (eGFR=15–29 ml/min per BSA) suffered from the same complication. This resulted in a 9.51-fold (95% CI, 4.20 to 21.56; P<0.001) increase in the risk of progressive renal insufficiency postoperatively among those with stage 4 CKD compared with those with normal kidney function. The group with stage 5 CKD/ESKD were excluded from analysis of this outcome as dialysis was an outcome of interest, and 58.7% of the stage 5 CKD/ESKD group were recorded as being on dialysis preoperatively.

The likelihood of postoperative mortality trended to increase with advancing CKD. However, stages 4 and 5 CKD were not independently associated with an increased risk of early postoperative mortality. Absolute mortality rates were <0.5% in both of these groups. When compared with those with normal kidney function (eGFR≥90 ml/min per BSA) who experienced a 0.06% 30-day postoperative mortality rate, those with stage 3b CKD (eGFR=30–44 ml/min per BSA) were 3.27 times more likely to die within 30 days (95% CI, 1.82 to 5.89; P<0.001) and experienced a 0.53% absolute mortality rate.

Patients with stage 5 CKD were 6.92 (95% CI, 1.62 to 29.52; P=0.009) times more likely to have an SSI compared with those with normal kidney function. The odds of 30-day readmission were progressively higher with each stage of CKD as compared with those with normal kidney function, although absolute 30-day readmission rates were still not very high even among those with stage 5 CKD/ESKD (8.60%). For patients with stage 5 CKD/ESKD, the odds of 30-day readmission were 1.91 times higher (95% CI, 1.37 to 2.67; P<0.001) compared with those with normal kidney function. The odds of an extended length of hospital stay postoperatively (>2 days) also increased across preoperative CKD stages, reaching 21.75% for patients with stage 5 CKD/ESKD. The odds of having an extended length of hospital stay were 2.05-fold higher in those with stage 5 CKD/ESKD as compared with those with normal eGFR (95% CI, 1.64 to 2.56; P<0.001).

Discussion

Despite preoperative medical optimization, patients with CKD are perceived to have a significantly higher risk of morbidity and mortality after surgery (20,21). This study shows that although bariatric surgical risk increased according to preoperative KDIGO CKD stages, absolute mortality and morbidity rates were still low. These results from a large sample in a national database enabled the identification of an increase in 30-day complications occurring in patients with more advanced CKD undergoing bariatric surgery. However, even for the population with stage 5 CKD/ESKD, absolute complication rates were modest. Furthermore, absolute event rates for adverse perioperative outcomes, including readmission, reoperation, and death within 30 days, were comparable between those with stages 4 and 5 CKD.

The absolute event rates of death within 30 postoperative days remained relatively low in those with stages 4 and 5 CKD at 0.49% and 0.43%, respectively. Thus, patients with advanced CKD (eGFR<30 ml/min per BSA) undergoing bariatric surgery appear to have a less than one in 200 chance of early postoperative mortality. These findings are reassuring and will help to guide informed counseling of prospective patients with advanced CKD and ESKD undergoing bariatric surgery in clinical practice. The low absolute event rates of postoperative complications, even among those with the most advanced preoperative CKD stages, suggest that CKD should not be an absolute contraindication to bariatric surgery.

The low absolute event rates of bariatric surgery complications across all preoperative CKD stages suggest that eGFR is not a good independent predictor of adverse outcomes following bariatric surgery. Taking into consideration the potential benefits of bariatric surgery among people with CKD, such as reduced long-term incidence of kidney failure, the modest increases in risk of postoperative complications
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Total, 277,948</th>
<th>Outcome</th>
<th>P Value&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Stage 1, 185,904 (66.9%)</td>
<td></td>
</tr>
<tr>
<td>Mean age (SD, range)</td>
<td>44.30 (11.93, 18–78.96)</td>
<td>40.55 (10.65, 18–78.64)</td>
<td>&lt;0.001&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
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<td>Sex</td>
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<td>Stage 2, 76,975 (27.7%)</td>
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</tr>
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<td>Women</td>
<td>221,273 (79.61)</td>
<td>149,454 (67.54)</td>
<td>&lt;0.001</td>
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<td>Men</td>
<td>56,675 (20.39)</td>
<td>16,271 (84.31)</td>
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<td>Race</td>
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<td>Stage 3a, 9403 (3.4%)</td>
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<tr>
<td>American Indian</td>
<td>1201 (0.43)</td>
<td>304 (25.65)</td>
<td>&lt;0.001</td>
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<td>1491 (0.54)</td>
<td>261 (17.51)</td>
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<td>Black</td>
<td>51,285 (18.45)</td>
<td>10,420 (20.32)</td>
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<td>Native Hawaiian or other</td>
<td>817 (0.29)</td>
<td>194 (23.75)</td>
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<td>Pacific Islander</td>
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<td>Stage 3b, 3230 (1.2%)</td>
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<td>Unknown/not reported</td>
<td>25,239 (9.08)</td>
<td>555 (22.00)</td>
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<tr>
<td>White</td>
<td>197,915 (71.21)</td>
<td>7515 (3.80)</td>
<td></td>
</tr>
<tr>
<td>Mean BMI (SD, range)</td>
<td>45.71 (7.61, 35–143.02)</td>
<td>44.80 (7.21, 35–143.02)</td>
<td>&lt;0.001&lt;sup&gt;b&lt;/sup&gt;</td>
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<td>Primary surgery</td>
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<td>Stage 4, 1029 (0.4%)</td>
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<td>RYGB</td>
<td>70,056 (25.49)</td>
<td>20,213 (28.85)</td>
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<td>LSG</td>
<td>199,187 (72.46)</td>
<td>54,230 (27.24)</td>
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<td>LAGB</td>
<td>2475 (0.90)</td>
<td>733 (29.62)</td>
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<td>783 (24.80)</td>
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<td>Operative year</td>
<td></td>
<td>Stage 5/ESKD, 1407 (0.5%)</td>
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<td>2017</td>
<td>136,175 (48.99)</td>
<td>38,003 (27.91)</td>
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<td>2018</td>
<td>141,773 (51.01)</td>
<td>38,972 (27.49)</td>
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<td>Smoker</td>
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<td>Diabetes (and use of insulin)</td>
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<td>254,124 (91.43)</td>
<td>71,054 (27.96)</td>
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<td>Yes</td>
<td>23,824 (8.57)</td>
<td>5921 (24.85)</td>
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<td>Antihypertensives</td>
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<td>Hyperlipidemia</td>
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<td>No</td>
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<td>52,458 (24.52)</td>
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<td>64,046 (23.04)</td>
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<td>Sleep apnea</td>
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<td>MI (all history)</td>
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<td>No</td>
<td>169,626 (61.03)</td>
<td>41,956 (24.73)</td>
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<td>Yes</td>
<td>108,322 (38.97)</td>
<td>51,564 (32.33)</td>
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<td>MI (all history)</td>
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Table 1. (Continued)

<table>
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<tr>
<th>Characteristic</th>
<th>Total, 277,948</th>
<th>Outcome</th>
<th>(P) Value*</th>
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<tr>
<td></td>
<td></td>
<td>Stage 1, 185,904 (66.9%)</td>
<td>Stage 2, 76,975 (27.7%)</td>
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<td>Previous PCI/PTCA</td>
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<td>184,123 (67.47)</td>
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<td>5038 (1.81)</td>
<td>1781 (35.35)</td>
<td>2130 (42.28)</td>
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<td>Previous cardiac surgery</td>
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<td>No</td>
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<td>184,901 (67.20)</td>
<td>75,820 (27.56)</td>
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<td>Yes</td>
<td>2810 (1.01)</td>
<td>1003 (35.69)</td>
<td>1155 (41.10)</td>
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<td>History of DVT</td>
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<td>No</td>
<td>273,240 (98.31)</td>
<td>183,537 (67.17)</td>
<td>75,274 (27.55)</td>
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<td>Yes</td>
<td>4708 (1.69)</td>
<td>2367 (50.28)</td>
<td>1701 (36.13)</td>
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<td>Venous stasis</td>
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<td>75,973 (27.62)</td>
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<td>2854 (1.01)</td>
<td>1508 (52.94)</td>
<td>1002 (35.11)</td>
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<td>76,975 (27.78)</td>
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<td>Yes</td>
<td>826 (0.30)</td>
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<td>Functional dependence</td>
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<td>Independent</td>
<td>275,139 (98.99)</td>
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<td>1705 (0.61)</td>
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<td>1104 (0.40)</td>
<td>700 (63.41)</td>
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<td>COPD</td>
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<td>No</td>
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<td>75,167 (27.48)</td>
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<td>Yes</td>
<td>4390 (1.58)</td>
<td>1818 (41.18)</td>
<td>1808 (41.18)</td>
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<td>O2 dependent</td>
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<tr>
<td>No</td>
<td>275,896 (99.26)</td>
<td>185,095 (67.09)</td>
<td>76,155 (27.60)</td>
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<td>Yes</td>
<td>2052 (0.74)</td>
<td>809 (39.42)</td>
<td>820 (39.96)</td>
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<td>History of PE</td>
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<td>No</td>
<td>274,481 (98.75)</td>
<td>184,156 (67.09)</td>
<td>75,687 (27.57)</td>
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<td>Yes</td>
<td>3467 (1.25)</td>
<td>1748 (50.42)</td>
<td>1288 (37.15)</td>
</tr>
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</table>

BMI, body mass index; RYGB, Roux-en-Y gastric bypass; LSG, laparoscopic sleeve gastrectomy; LAGB, laparoscopic adjustable gastric band; BPD/DS, biliopancreatic diversion/duodenal switch; MI, myocardial infarction; PCI/PTCA, percutaneous coronary intervention/percutaneous transluminal coronary angioplasty; DVT, deep venous thrombosis; COPD, chronic obstructive pulmonary disease; O2, oxygen; PE, pulmonary embolism.

*aPearson chi-squared test unless otherwise indicated.

*\(P\) value calculated using ANOVA.
### Table 2. Logistic regression of bariatric outcomes of 277,948 Metabolic and Bariatric Surgery Quality Improvement Program participants with eGFR values (2017 and 2018)

<table>
<thead>
<tr>
<th>Bariatric outcomes</th>
<th>Stage 1, 185,904 (66.9%)</th>
<th>Stage 2, 76,975 (27.7%)</th>
<th>Stage 3a, 9403 (3.4%)</th>
<th>Stage 3b, 3230 (1.2%)</th>
<th>Stage 4, 1029 (0.4%)</th>
<th>Stage 5/ESKD, 1407 (0.5%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Death within 30 d</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Event, %</td>
<td>0.06</td>
<td>0.14</td>
<td>0.23</td>
<td>0.53</td>
<td>0.49</td>
<td>0.43</td>
</tr>
<tr>
<td>OR Reference</td>
<td>2.44</td>
<td>4.15</td>
<td>9.36</td>
<td>8.64</td>
<td>7.58</td>
<td></td>
</tr>
<tr>
<td>95% CI</td>
<td>(1.86 to 3.20)</td>
<td>(2.62 to 6.57)</td>
<td>(5.60 to 15.65)</td>
<td>(3.52 to 21.24)</td>
<td>(3.32 to 17.28)</td>
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</tr>
<tr>
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<td>2.39</td>
<td>3.40</td>
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<td>95% CI</td>
<td>(1.21 to 2.24)</td>
<td>(1.09 to 3.03)</td>
<td>(1.82 to 5.89)</td>
<td>(0.82 to 6.93)</td>
<td>(0.79 to 14.55)</td>
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<td>&lt;0.001</td>
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<tr>
<td><strong>Reoperation within 30 d</strong></td>
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<td></td>
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</tr>
<tr>
<td>Event, %</td>
<td>1.09</td>
<td>1.32</td>
<td>1.72</td>
<td>1.98</td>
<td>2.24</td>
<td>2.49</td>
</tr>
<tr>
<td>OR Reference</td>
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<td>1.58</td>
<td>1.83</td>
<td>2.07</td>
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<td></td>
</tr>
<tr>
<td>95% CI</td>
<td>(1.12 to 1.31)</td>
<td>(1.35 to 1.86)</td>
<td>(1.42 to 2.35)</td>
<td>(1.36 to 3.13)</td>
<td>(1.64 to 3.23)</td>
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</tr>
<tr>
<td>P value</td>
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<td>&lt;0.001</td>
<td>0.001</td>
<td>&lt;0.001</td>
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</tr>
<tr>
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<td>1.07</td>
<td>1.21</td>
<td>1.36</td>
<td>1.42</td>
<td>1.52</td>
<td></td>
</tr>
<tr>
<td>95% CI</td>
<td>(0.98 to 1.16)</td>
<td>(1.02 to 1.44)</td>
<td>(1.04 to 1.77)</td>
<td>(0.86 to 2.33)</td>
<td>(0.81 to 2.88)</td>
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<td>P value</td>
<td>0.12</td>
<td>0.03</td>
<td>0.03</td>
<td>0.17</td>
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<td><strong>Readmission within 30 d</strong></td>
<td></td>
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<td>Event, %</td>
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<td>3.71</td>
<td>5.63</td>
<td>6.78</td>
<td>8.16</td>
<td>8.60</td>
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<td>OR Reference</td>
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<td>2.59</td>
<td>2.75</td>
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<td>95% CI</td>
<td>(1.07 to 1.18)</td>
<td>(1.59 to 1.91)</td>
<td>(1.85 to 2.44)</td>
<td>(2.07 to 3.25)</td>
<td>(2.27 to 3.31)</td>
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</tr>
<tr>
<td>P value</td>
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<td>&lt;0.001</td>
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<td>1.14</td>
<td>1.52</td>
<td>1.65</td>
<td>1.69</td>
<td>1.91</td>
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</tr>
<tr>
<td>95% CI</td>
<td>(0.98 to 1.16)</td>
<td>(1.02 to 1.44)</td>
<td>(1.04 to 1.77)</td>
<td>(0.86 to 2.33)</td>
<td>(0.81 to 2.88)</td>
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<tr>
<td>P value</td>
<td>0.12</td>
<td>0.03</td>
<td>0.03</td>
<td>0.17</td>
<td>0.20</td>
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<tr>
<td><strong>Intervention within 30 d</strong></td>
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</tr>
<tr>
<td>Event, %</td>
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<td>1.15</td>
<td>1.43</td>
<td>1.21</td>
<td>2.53</td>
<td>2.56</td>
</tr>
<tr>
<td>OR Reference</td>
<td>1.09</td>
<td>1.36</td>
<td>1.56</td>
<td>2.15</td>
<td>2.45</td>
<td>2.48</td>
</tr>
<tr>
<td>95% CI</td>
<td>(1.01 to 1.19)</td>
<td>(1.14 to 1.63)</td>
<td>(0.84 to 1.59)</td>
<td>(1.65 to 3.62)</td>
<td>(1.77 to 3.46)</td>
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</tr>
<tr>
<td>P value</td>
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<td>0.001</td>
<td>0.38</td>
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<td>0.96</td>
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<td>1.18</td>
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<tr>
<td>95% CI</td>
<td>(0.97 to 1.16)</td>
<td>(0.95 to 1.40)</td>
<td>(0.69 to 1.34)</td>
<td>(1.13 to 2.96)</td>
<td>(0.55 to 2.51)</td>
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<tr>
<td>P value</td>
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<td>0.14</td>
<td>0.80</td>
<td>0.01</td>
<td>0.67</td>
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<tr>
<td><strong>LOS &gt;2 d</strong></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Event, %</td>
<td>8.31</td>
<td>9.35</td>
<td>13.56</td>
<td>18.24</td>
<td>24.30</td>
<td>21.75</td>
</tr>
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<td>1.14</td>
<td>1.73</td>
<td>2.46</td>
<td>3.54</td>
<td>4.09</td>
<td>3.07</td>
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<tr>
<td>95% CI</td>
<td>(1.11 to 1.17)</td>
<td>(1.65 to 1.84)</td>
<td>(2.25 to 2.69)</td>
<td>(1.97 to 4.09)</td>
<td>(2.70 to 4.38)</td>
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<tr>
<td>P value</td>
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<td>&lt;0.001</td>
<td>&lt;0.001</td>
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</tr>
<tr>
<td>Adjusted OR Reference</td>
<td>1.02</td>
<td>1.21</td>
<td>1.14</td>
<td>1.44</td>
<td>1.74</td>
<td>2.05</td>
</tr>
<tr>
<td>95% CI</td>
<td>(0.99 to 1.06)</td>
<td>(1.13 to 1.29)</td>
<td>(1.30 to 1.69)</td>
<td>(1.46 to 2.07)</td>
<td>(1.64 to 2.56)</td>
<td></td>
</tr>
<tr>
<td>P value</td>
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<td>0.001</td>
<td>&lt;0.001</td>
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<tr>
<td><strong>Progressive renal insufficiency</strong></td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Event, %</td>
<td>0.03</td>
<td>0.09</td>
<td>0.29</td>
<td>0.56</td>
<td>1.36</td>
<td>—</td>
</tr>
<tr>
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<td>18.60</td>
<td>45.78</td>
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<tr>
<td>95% CI</td>
<td>(2.13 to 4.29)</td>
<td>(6.04 to 15.13)</td>
<td>(10.92 to 31.67)</td>
<td>(25.40 to 82.49)</td>
<td>—</td>
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</tr>
<tr>
<td>P value</td>
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<tr>
<td>Adjusted OR Reference</td>
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<td>4.02</td>
<td>5.25</td>
<td>9.51</td>
<td>—</td>
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<tr>
<td>95% CI</td>
<td>(1.42 to 3.11)</td>
<td>(2.37 to 6.81)</td>
<td>(2.80 to 9.86)</td>
<td>(4.20 to 21.56)</td>
<td>—</td>
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<tr>
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<td>&lt;0.001</td>
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<tr>
<td>Bariatric outcomes</td>
<td>Stage 1, 185,904 (66.9%)</td>
<td>Stage 2, 76,975 (27.7%)</td>
<td>Stage 3a, 9403 (3.4%)</td>
<td>Stage 3b, 3230 (1.2%)</td>
<td>Stage 4, 1029 (0.4%)</td>
<td>Stage 5/ESKD, 1407 (0.5%)</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------------------------</td>
<td>------------------------</td>
<td>-----------------------</td>
<td>------------------------</td>
<td>------------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Any postoperative deep incisional SSI Event, %</td>
<td>0.05</td>
<td>0.06</td>
<td>0.13</td>
<td>0.19</td>
<td>0.10</td>
<td>0.14</td>
</tr>
<tr>
<td>OR Reference</td>
<td>1.26</td>
<td>2.70</td>
<td>3.93</td>
<td>2.05</td>
<td>3.01</td>
<td></td>
</tr>
<tr>
<td>95% CI</td>
<td>(0.88 to 1.80)</td>
<td>(1.48 to 4.93)</td>
<td>(1.72 to 8.99)</td>
<td>(0.29 to 14.76)</td>
<td>(0.74 to 12.22)</td>
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</tr>
<tr>
<td>P value</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.047</td>
<td>0.12</td>
<td>0.009</td>
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<tr>
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<td>1.44</td>
<td>2.02</td>
<td>1.42</td>
<td>6.92</td>
<td></td>
</tr>
<tr>
<td>95% CI</td>
<td>(0.68 to 1.50)</td>
<td>(0.73 to 2.87)</td>
<td>(0.83 to 4.94)</td>
<td>(0.18 to 11.38)</td>
<td>(1.62 to 29.52)</td>
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</tr>
<tr>
<td>P value</td>
<td>0.97</td>
<td>0.30</td>
<td>0.12</td>
<td>0.74</td>
<td>0.009</td>
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</tr>
</tbody>
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OR, odds ratio; 95% CI, 95% confidence interval; LOS, length of stay; —, not applicable; SSI, surgical site infection.

*Definitions of postoperative declines in kidney function included a rise in creatinine ≥2 mg/dl with no requirement for dialysis or AKI requiring dialysis in a patient with no preoperative dialysis requirement. For analyses of progressive renal insufficiency postoperatively, those with stage 5 CKD/ESKD at baseline were excluded as dialysis was an outcome of interest, and 58.7% of the stage 5 CKD/ESKD group was recorded as being on dialysis preoperatively.
observed in this study do not appear to outweigh the renoprotective benefits conferred by the procedure (22).

Limitations of this study include the fact that most patients in this cohort had normal or mildly impaired kidney function. The overall dataset was, however, very large, and significant numbers at each CKD stage could be analyzed, including over 1000 patients each with stages 4 and 5 CKD and over 12,500 patients with stage 3 CKD. Therefore, the absolute number of patients with an eGFR <60 ml/min per BSA enrolled in this study is significantly larger than prior studies in the field.

Another limitation of this study are the parameters used by the MBSAQIP database to define postoperative kidney function decline, which is defined as a rise in creatinine ≥2 mg/dl or AKI requiring dialysis in patients with no preoperative eGFR. The contributions of postoperative renal functional decline would include, for example, KDIGO-suggested end points for randomized studies in nephrology, such as slope of eGFR, decline in CKD-EPI eGFR ≥40%, and doubling of serum creatinine, as well as new requirement for dialysis (20,22).

Nevertheless, the definition of postoperative decline in kidney function used in this study identified patients with substantial and clinically meaningful changes in kidney function, as demonstrated by the 9.5-fold increase in risk of early postoperative renal functional decline in those with stage 4 CKD compared with those with a preoperative eGFR ≥90 ml/min per BSA.

Confirmation of our findings with another large cohort of patients with severely impaired kidney function that also has longer-term follow-up after bariatric surgery, permitting evaluation of the KDIGO-suggested interim renal outcomes highlighted above, would be advisable. The MBSAQIP database started to record preoperative creatinine values in 2017, and therefore, we cannot provide insights into trends in bariatric surgery across CKD stages over a longer time period. We were not able to test whether proteinuria was a predictor of increased postoperative mortality. Future studies should evaluate the safety of bariatric surgery in populations stratified by the severity of baseline proteinuria.

Our study only focused on short-term complications after surgery. Evaluating risk of longer-term postoperative complications among those with CKD should be a priority. A meta-analysis by Mishra et al. (23) showed that bariatric surgery increased the risk of nephrolithiasis due to enteric hyperoxaluria. The absolute risks of clinically meaningful outcomes relating to enteric hyperoxaluria post-bariatric surgery among people with CKD should be better defined, including new-onset nephrolithiasis and oxalate nephropathy.

The benefits of bariatric surgery in patients with CKD are likely to outweigh the risks associated with the procedures (24), but intervening earlier in the natural history of the disease is recommended (25). CKD does not appear to play a major role in short-term complications after bariatric surgery. Therefore, bariatric surgery should continue to be investigated as a treatment strategy to lower cardiovascular and renal risk in patients with obesity and CKD.

Disclosures

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Acknowledgments

The MBSAQIP and the hospitals participating in the MBSAQIP 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.

Author Contributions

C.W. le Roux and C.J. Ren-Fielding conceptualized the study; F. Carvalho Silveira and G. Maranga were responsible for formal analysis; F. Carvalho Silveira and W.P. Martin wrote the original draft; and F. Carvalho Silveira, C.W. le Roux, G. Maranga, W.P. Martin, and C.J. Ren-Fielding reviewed and edited the manuscript and revised and approved the final version of the manuscript.

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