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# The impact of chronic kidney disease on perioperative risk and mortality after bariatric surgery

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Abstract:

Background

20% of patients with chronic kidney disease (CKD) in the United States have a body-mass index (BMI) ≥35 kg/$m^2$. Bariatric surgery reduces progression of CKD to end-stage kidney disease (ESKD), but the risk of perioperative complications remains a concern.

Methods

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 based on 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±11.9 (mean±SD) years old, 79.6% female, and 71.2% Caucasian. Mean BMI was 45.7±7.6 kg/$m^2$. Compared with patients with an eGFR ≥90 mL/min/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, 1.37-2.67; p<0.001). Similarly, length of hospital stay beyond 2 days was 2.05-fold (95% CI, 1.64-2.56; p<0.001) higher and risk of deep incisional surgical site infection was 6.92-fold (95% CI, 1.62-29.52; 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 CKD stage 3b were 3.27 (95% CI, 1.82-5.89; 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 CKD stage 3b. Furthermore, absolute mortality rates were less than 0.5% in those with CKD stages 4 and 5, and these advanced CKD stages were not independently associated with an increased risk of early postoperative mortality.

Conclusion

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.

*Introduction*

According to the Centers for Disease Control and Prevention, the prevalence of chronic kidney disease (CKD) among Americans is 14% [1]. Over one-fifth of these patients have a 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 associated with greater antihypertensive usage and proteinuria amongst those with CKD [3]. Obesity is a contributor to declining kidney function [4] but Weisinger et al. showed in 1974 that kidney function can improve with weight loss and that kidney function deteriorates with weight regain [4,5]. 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 amongst 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. reported that bariatric surgery is associated with long-term protection against ESKD [12]. They followed 4,047 patients with obesity for 18 years and when comparing subjects that underwent bariatric surgery to a control group, surgery reduced the risk of progressing to ESKD by 73% (adjusted hazard ratio (HR) = 0.27; 95% CI 0.12–0.60; $p$ = 0.001). Due to a higher risk of kidney allograft complications with increasing BMI, obesity prevents many people with ESKD from being considered for kidney transplants [13]. BMI ≥40 kg/m$^2$ is often considered an absolute contraindication to kidney transplantation, while most consider class II obesity (BMI ≥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 CKD patients are commonly performed, data regarding the adequate evaluation and minimization of perioperative risk is 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 impact surgical risk.

Turgeon et al. evaluated the impact of kidney function on bariatric surgery outcomes for 27,736 patients treated during 2006-2008 [17]. While increasing CKD stage increased risk of postoperative complications, absolute complication rates remained low at less than 10%. However, less than 2,000 patients in the study cohort had an eGFR <60 mL/min/BSA and less than 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 amongst patients with kidney disease.

In a study published by Cohen et al. in 2019, bariatric surgery complications stratified by CKD status were reported. A key limitation of this report that we aim to address in the present study is that Cohen et al. defined CKD as a preoperative serum creatinine >2mg/dL rather than staging CKD according to KDIGO criteria based on 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 impact of different stages of CKD on the occurrence of perioperative complications following bariatric surgery. In the present 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.

*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 (SG), Roux-en-Y gastric bypass (RYGB), adjustable gastric band (AGB), and duodenal switch (DS). Prior to 2017, the MBSAQIP database did not collect creatinine values from which eGFR could be calculated; thus, the present study commenced from 2017 onwards.

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 ≥80 years, unknown gender, unknown BMI, BMI <35kg/m$^2$, revisional surgery, and missing preoperative creatinine value.

Renal function was assessed by calculating estimated GFR from serum creatinine accounting for age, gender, 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 (MDRD) equation, particularly in patients with higher GFR resulting in reduced misclassification of CKD stages.

Logistic regression determined if baseline eGFR 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 to 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: a) a rise in creatinine ≥2 mg/dl with no requirement for dialysis, or b) acute kidney injury 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 two weeks prior to the principal operative procedure. 101 individuals recorded as being on dialysis but with an eGFR in the CKD stage 1-4 range (eGFR ≥15 mL/min/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 through 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 female, and 71.2% were Caucasian. Mean BMI was 45.7±7.6 $kg/m^2$. 72.5% of patients underwent sleeve gastrectomy (SG), 25.5% had Roux-en-Y gastric bypass (RYGB), 1% had duodenal switch (DS), and less than 1% underwent adjustable gastric band (AGB). The distribution of KDIGO CKD staging categories based on 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%) with stage 2 CKD, 9,403 (3.4%) with stage 3a CKD, 3,230 (1.2%) with stage 3b CKD, 1,029 (0.4%) with stage 4 CKD, and 1,407 (0.5%) with stage 5

CKD/ESKD.

Compared with patients with normal kidney function (eGFR ≥90 mL/min/BSA), those with stage 5 CKD/ESKD were older (48.0±10.9 vs 40.6±10.7 years, p<0.0001), more likely to be male (36% vs 19.6%, p<0.0001), and more likely to undergo LSG (80.2% vs 73.2%, p<0.0001) 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/m$^2$, respectively. Compared with patients with normal kidney function (eGFR ≥90 mL/min/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% vs 23%, p<0.0001), hyperlipidaemia (44.1% vs 16.8%, p<0.0001), be treated with ≥3 antihypertensives (26.7% vs 6.9%, p<0.0001), have sleep apnea (46.2% vs 35.0%, p<0.0001), and have a history of prior PCI or PTCA (8% vs 1%, p<0.0001).

Rates of most 30-day surgical complications trended to be higher for the population with the lowest 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 0.14% respectively. This is in comparison to patients with normal kidney function (eGFR ≥90 mL/min/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 was higher with increasing severity of baseline CKD. In the population with normal kidney function (eGFR ≥90 mL/min/BSA), 0.03% had progressive renal insufficiency within 30 days of surgery, whereas 1.36% of stage 4 CKD (eGFR 15-29 mL/min/BSA) patients suffered from the same complication. This resulted in a 9.51-fold (95% CI, 4.20-21.56; p<0.001) increase in the risk of progressive renal insufficiency postoperatively amongst those with CKD stage 4 compared with those with normal kidney function. The group with stage 5/ESKD were excluded from analysis of this outcome as dialysis was an outcome of interest, and 58.7% of the stage 5/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 less than 0.5% in both of these groups. When compared to those with normal kidney function (eGFR ≥90 mL/min/BSA), who experienced a 0.06% 30-day postoperative mortality rate, those with stage 3b CKD (eGFR 30-44 mL/min/BSA) were 3.27 times more likely to die within 30 days (95% CI, 1.82-5.89; $p<0.001$) and experienced a 0.53% absolute mortality rate.

Patients with stage 5 CKD were 6.92 (95% CI, 1.62-29.52; $p=0.009$) times more likely to have a SSI compared with those with normal kidney function. The odds of 30-day readmission was progressively higher with each stage of CKD as compared to those with normal kidney function, although absolute 30-day readmission rates were still not very high even amongst 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, 1.37-2.67; $p<0.001$) 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 was 2.05-fold higher in those with stage 5 CKD/ESKD, as compared to those with normal eGFR (95% CI, 1.64-2.56; $p<0.001$).

*Discussion*

Despite preoperative medical optimization, patients with CKD are perceived to have a significantly higher risk of morbidity and mortality after surgery [20,21]. The present study shows that while 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/BSA) undergoing bariatric surgery appear to have a less than 1/200 chance of early postoperative mortality. These findings are reassuring and will help to guide informed counselling of prospective patients with advanced CKD and ESKD undergoing bariatric surgery in clinical practice. The low absolute event rates of postoperative complications even amongst those with the most advanced preoperative CKD stages suggests 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 suggests that eGFR is not a good independent predictor of adverse outcomes following bariatric surgery. Taking into consideration the potential benefits of bariatric surgery amongst people with CKD such as reduced long-term incidence of kidney failure, the modest increases in risk of postoperative complications observed in this study do not appear to out-weigh 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 1,000 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/BSA enrolled in the current 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 post-operative kidney function decline, which is defined as a rise in creatinine ≥2 mg/dL or acute kidney injury requiring dialysis in patients with no preoperative dialysis requirement. A more standardized definition of progressive renal functional decline would include, for example, KDIGO suggested endpoints for randomized studies in nephrology, such as slope of eGFR, decline in CKD-EPI eGFR ≥40%, doubling of serum creatinine, as well as new requirement for dialysis [20,22].

Nevertheless, the definition of postoperative decline in kidney function used in the current 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/BSA.

Confirmation of our findings with another large cohort of patients with severely impaired kidney function which 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 so 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 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 amongst those with CKD should be a priority. A meta-analysis by Mishra et al. showed that bariatric surgery increased the risk of nephrolithiasis due to enteric hyperoxaluria [23]. The absolute risks of clinically meaningful outcomes relating to enteric hyperoxaluria post-bariatric surgery amongst 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 chronic kidney disease.

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*Author contributions:* F. Carvalho Silveira: Formal analysis; Writing - original draft; Writing - review and editing

W. P. Martin: Writing - original draft; Writing - review and editing

G. Maranga: Formal analysis; Writing - review and editing

C. W. le Roux: Conceptualization; Writing - review and editing

C. J. Ren-Fielding: Conceptualization; Writing - review and editing

All authors revised and approved the final version of the manuscript.

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Table 1. Univariate and Bivariate Analysis of 277,948 MBSAQIP Participants with eGFR values (2017 & 2018)

| | Total | Outcome | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Stage 1 | Stage 2 | Stage 3a | Stage 3b | Stage 4 | Stage 5/ESKD | p-value[1] |
| | 277,948 | 185,904 (66.9%) | 76,975 (27.7%) | 9,403 (3.4%) | 3,230 (1.2%) | 1,029 (0.4%) | 1,407 (0.5%) | |
| Mean age (SD, range) | 44.30 (11.93, 18 - 78.96) | 40.55 (10.65, 18 - 78.64) | 50.80 (10.47, 18.11 - 78.96) | 58.41 (9.21, 20.15 - 78.95) | 59.36 (9.58, 18.4 - 78.73) | 55.22 (11.75, 18.22 - 78.61) | 48.00 (10.91, 18.97 - 75.23) | P<0.0001[2] |
| Sex | | | | | | | | |
| Female | 221,273 (79.61) | 149,454 (67.54) | 60,704 (27.43) | 7,185 (3.25) | 2,358 (1.07) | 672 (0.30) | 900 (0.41) | P<0.0001 |
| Male | 56,675 (20.39) | 36,450 (64.31) | 16,271 (28.71) | 2,218 (3.91) | 872 (1.54) | 357 (0.63) | 507 (0.89) | |
| Race | | | | | | | | P<0.0001 |
| American Indian | 1,201 (0.43) | 840 (69.94) | 308 (25.65) | 35 (2.91) | 7 (0.58) | 4 (0.33) | 7 (0.58) | |
| Asian | 1,491 (0.54) | 1,160 (77.80) | 261 (17.51) | 37 (2.48) | 18 (1.21) | 7 (0.47) | 8 (0.54) | |
| Black or African American | 51,285 (18.45) | 38,332 (74.74) | 10,420 (20.32) | 1,241 (2.42) | 526 (1.03) | 267 (0.52) | 499 (0.97) | |
| Native Hawaiian or Other Pacific Islander | 817 (0.29) | 581 (71.11) | 194 (23.75) | 20 (2.45) | 9 (1.10) | 7 (0.86) | 6 (0.73) | |
| Unknown/Not Reported | 25,239 (9.08) | 18,469 (73.18) | 5,855 (23.20) | 555 (2.20) | 199 (0.79) | 52 (0.21) | 109 (0.43) | |
| White | 197,915 (71.21) | 126,522 (63.93) | 59,937 (30.28) | 7,515 (3.80) | 2,471 (1.25) | 692 (0.35) | 778 (0.39) | |
| Mean BMI (SD, range) | 45.71 (7.61, 35 - 143.02) | 46.08 (7.72, 35 - 143.02) | 44.80 (7.21, 35 - 140.82) | 45.51 (7.70, 35 - 102.66) | 46.35 (7.94, 35.02 - 89.08) | 46.61 (7.92, 35 - 93.6) | 45.78 (7.44, 35.13 - 96.89) | P<0.0001[2] |

[1] Pearson's $\chi^2$ unless otherwise indicated
[2] P-value calculated using ANOVA

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Primary Surgery | | | | | | | | P<0.0001 |
| RYGB | 70,056 (25.49) | 45,551 (65.02) | 20,213 (28.85) | 2,731 (3.90) | 996 (1.42) | 309 (0.44) | 256 (0.37) | |
| LSG | 199,187 (72.46) | 134,716 (67.63) | 54,250 (27.24) | 6,309 (3.17) | 2,116 (1.06) | 671 (0.34) | 1,125 (0.56) | |
| LAGB | 2,475 (0.90) | 1,607 (64.93) | 733 (29.62) | 89 (3.60) | 27 (1.09) | 10 (0.40) | 9 (0.36) | |
| BPD/DS | 3,157 (1.15) | 2,179 (69.02) | 783 (24.80) | 123 (3.90) | 45 (1.43) | 15 (0.48) | 12 (0.38) | |
| Operative Year | | | | | | | | P=0.088 |
| 2017 | 136,175 (48.99) | 90,722 (66.62) | 38,003 (27.91) | 4,631 (3.40) | 1,597 (1.17) | 508 (0.37) | 714 (0.52) | |
| 2018 | 141,773 (51.01) | 95,182 (67.14) | 38,972 (27.49) | 4,772 (3.37) | 1,633 (1.15) | 521 (0.37) | 693 (0.49) | |
| Smoker | | | | | | | | P<0.0001 |
| No | 254,124 (91.43) | 168,971 (66.49) | 71,054 (27.96) | 8,783 (3.46) | 3,036 (1.19) | 970 (0.38) | 1,310 (0.52) | |
| Yes | 23,824 (8.57) | 16,933 (71.08) | 5,921 (24.85) | 620 (2.60) | 194 (0.81) | 59 (0.25) | 97 (0.41) | |
| Diabetes (and use of Insulin) | | | | | | | | P<0.0001 |
| No | 205,244 (73.84) | 143,145 (69.74) | 54,971 (26.78) | 4,911 (2.39) | 1,205 (0.59) | 330 (0.16) | 682 (0.33) | |
| Insulin | 23,119 (8.32) | 11,302 (48.89) | 7,221 (31.23) | 2,233 (9.66) | 1,303 (5.64) | 507 (2.19) | 553 (2.39) | |
| Non-Insulin | 49,585 (17.84) | 31,457 (63.44) | 14,783 (29.81) | 2,259 (4.56) | 722 (1.46) | 192 (0.39) | 172 (0.35) | |
| Hyperlipidemia | | | | | | | | P<0.0001 |
| No | 213,902 (76.96) | 154,662 (72.31) | 52,458 (24.52) | 4,406 (2.06) | 1,228 (0.57) | 361 (0.17) | 787 (0.37) | |
| Yes | 64,046 (23.04) | 31,242 (48.78) | 24,517 (38.28) | 4,997 (7.80) | 2,002 (3.13) | 668 (1.04) | 620 (0.97) | |
| Hypertension Medications | | | | | | | | P<0.0001 |
| 0 | 145,322 (52.28) | 111,972 (77.05) | 31,117 (21.41) | 1,536 (1.06) | 252 (0.17) | 90 (0.06) | 355 (0.24) | |
| 1 | 58,488 (21.04) | 36,417 (62.26) | 18,555 (31.72) | 2,292 (3.92) | 691 (1.18) | 179 (0.31) | 354 (0.61) | |
| 2 | 45,216 | 24,761 (54.76) | 16,100 (35.61) | 2,796 (6.18) | 956 (2.11) | 280 (0.62) | 323 (0.71) | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | (16.27) | | | | | | | |
| 3+ | 28,922 (10.41) | 12,754 (44.10) | 11,203 (38.74) | 2,779 (9.61) | 1,331 (4.60) | 480 (1.66) | 375 (1.30) | |
| Sleep Apnea | | | | | | | | P<0.0001 |
| No | 169,626 (61.03) | 120,864 (71.25) | 41,956 (24.73) | 4,251 (2.51) | 1,346 (0.79) | 452 (0.27) | 757 (0.45) | |
| Yes | 108,322 (38.97) | 65,040 (60.04) | 35,019 (32.33) | 5,152 (4.76) | 1,884 (1.74) | 577 (0.53) | 650 (0.60) | |
| MI All History | | | | | | | | P<0.0001 |
| No | 274,550 (98.78) | 184,636 (67.25) | 75,563 (27.52) | 8,993 (3.28) | 3,047 (1.11) | 959 (0.35) | 1,352 (0.49) | |
| Yes | 3,398 (1.22) | 1,268 (37.32) | 1,412 (41.55) | 410 (12.07) | 183 (5.39) | 70 (2.06) | 55 (1.62) | |
| Previous PCI/PTCA | | | | | | | | P<0.0001 |
| No | 272,910 (98.19) | 184,123 (67.47) | 74,845 (27.42) | 8,789 (3.22) | 2,929 (1.07) | 929 (0.34) | 1,295 (0.47) | |
| Yes | 5,038 (1.81) | 1,781 (35.35) | 2,130 (42.28) | 614 (12.19) | 301 (5.97) | 100 (1.98) | 112 (2.22) | |
| Previous Cardiac Surgery | | | | | | | | P<0.0001 |
| No | 275,138 (98.99) | 184,901 (67.20) | 75,820 (27.56) | 9,048 (3.29) | 3,059 (1.11) | 967 (0.35) | 1,352 (0.49) | |
| Yes | 2,810 (1.01) | 1,003 (35.69) | 1,155 (41.10) | 355 (12.63) | 180 (6.41) | 62 (2.21) | 55 (1.96) | |
| History of DVT | | | | | | | | P<0.0001 |
| No | 273,240 (98.31) | 183,537 (67.17) | 75,274 (27.55) | 9,004 (3.30) | 3,088 (1.13) | 979 (0.36) | 1,358 (0.50) | |
| Yes | 4,708 (1.69) | 2,367 (50.28) | 1,701 (36.13) | 399 (8.47) | 142 (3.02) | 50 (1.06) | 49 (1.04) | |
| Venous Stasis | | | | | | | | P<0.0001 |
| No | 275,094 (98.97) | 184,396 (67.03) | 75,973 (27.62) | 9,201 (3.34) | 3,136 (1.14) | 1,000 (0.36) | 1,388 (0.50) | |
| Yes | 2,854 (1.03) | 1,508 (52.84) | 1,002 (35.11) | 202 (7.08) | 94 (3.29) | 29 (1.02) | 19 (0.67) | |
| Dialysis | | | | | | | | P<0.0001 |
| No | 277,122 (99.70) | 185,904 (67.08) | 76,975 (27.78) | 9,403 (3.39) | 3,230 (1.17) | 1,029 (0.37) | 581 (0.21) | |
| Yes | 826 (0.30) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 826 (100) | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Functional Dependence | | | | | | | | P<0.0001 |
| Independent | 275,139 (98.99) | 184,397 (67.02) | 76,090 (27.66) | 9,168 (3.33) | 3,133 (1.14) | 989 (0.36) | 1,362 (0.50) | |
| Partially Dependent | 1,705 (0.61) | 807 (47.33) | 562 (32.96) | 190 (11.14) | 81 (4.75) | 33 (1.94) | 32 (1.88) | |
| Totally Dependent | 1,104 (0.40) | 700 (63.41) | 323 (29.26) | 45 (4.08) | 16 (1.45) | 7 (0.63) | 13 (1.18) | |
| COPD | | | | | | | | P<0.0001 |
| No | 273,558 (98.42) | 184,086 (67.29) | 75,167 (27.48) | 8,909 (3.26) | 3,043 (1.11) | 981 (0.36) | 1,372 (0.50) | |
| Yes | 4,390 (1.58) | 1,818 (41.41) | 1,808 (41.18) | 494 (11.25) | 187 (4.26) | 48 (1.09) | 35 (0.80) | |
| O2 Dependent | | | | | | | | P<0.0001 |
| No | 275,896 (99.26) | 185,095 (67.09) | 76,155 (27.60) | 9,164 (3.32) | 3,111 (1.13) | 996 (0.36) | 1,375 (0.50) | |
| Yes | 2,052 (0.74) | 809 (39.42) | 820 (39.96) | 239 (11.65) | 119 (5.80) | 33 (1.61) | 32 (1.56) | |
| History of PE | | | | | | | | P<0.0001 |
| No | 274,481 (98.75) | 184,156 (67.09) | 75,687 (27.57) | 9,134 (3.33) | 3,137 (1.14) | 994 (0.36) | 1,373 (0.50) | |
| Yes | 3,467 (1.25) | 1,748 (50.42) | 1,288 (37.15) | 269 (7.76) | 93 (2.68) | 35 (1.01) | 34 (0.98) | |

Table 2: Logistic Regression of Bariatric Outcomes of 277,948 MBSAQIP Participants with eGFR values (2017 & 2018)

| | | Stage 1 185,904 (66.9%) | Stage 2 76,975 (27.7%) | Stage 3a 9,403 (3.4%) | Stage 3b 3,230 (1.2%) | Stage 4 1,029 (0.4%) | Stage 5/ESKD 1,407 (0.5%) |
|---|---|---|---|---|---|---|---|
| Death within 30-days | % event | 0.06% | 0.14% | 0.23% | 0.53% | 0.49% | 0.43% |
| | OR | Ref | 2.44 | 4.15 | 9.36 | 8.64 | 7.58 |
| | 95% CI | | (1.86-3.20) | (2.62-6.57) | (5.60-15.65) | (3.52-21.24) | (3.32-17.28) |
| | p-value | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| | Adj OR | Ref | 1.65 | 1.82 | 3.27 | 2.39 | 3.40 |
| | 95% CI | | (1.21-2.24) | (1.09-3.03) | (1.82-5.89) | (0.82-6.93) | (0.79-14.55) |
| | p-value | | 0.001 | 0.02 | <0.0001 | 0.11 | 0.10 |
| Reoperation within 30-days | % event | 1.09% | 1.32% | 1.72% | 1.98% | 2.24% | 2.49% |
| | OR | Ref | 1.21 | 1.58 | 1.83 | 2.07 | 2.30 |
| | 95% CI | | (1.12-1.31) | (1.35-1.86) | (1.42-2.35) | (1.36-3.13) | (1.64-3.23) |
| | p-value | | <0.0001 | <0.0001 | <0.0001 | 0.001 | <0.0001 |
| | Adj OR | Ref | 1.07 | 1.21 | 1.36 | 1.42 | 1.52 |
| | 95% CI | | (0.98-1.16) | (1.02-1.44) | (1.04-1.77) | (0.86-2.33) | (0.81-2.88) |
| | p-value | | 0.12 | 0.03 | 0.025 | 0.17 | 0.20 |
| Readmission within 30-days | % event | 3.31% | 3.71% | 5.63% | 6.78% | 8.16% | 8.60% |
| | OR | Ref | 1.12 | 1.74 | 2.12 | 2.59 | 2.75 |
| | 95% CI | | (1.07-1.18) | (1.59-1.91) | (1.85-2.44) | (2.07-3.25) | (2.27-3.31) |
| | p-value | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| | Adj OR | Ref | 1.14 | 1.52 | 1.65 | 1.69 | 1.91 |
| | 95% CI | | (1.08-1.20) | (1.37-1.68) | (1.42-1.92) | (1.30-2.20) | (1.37-2.67) |
| | p-value | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Intervention within 30-days | % event | 1.05% | 1.15% | 1.43% | 1.21% | 2.53% | 2.56% |
| | OR | Ref | 1.09 | 1.36 | 1.15 | 2.45 | 2.48 |
| | 95% CI | | (1.01-1.19) | (1.14-1.63) | (0.84-1.59) | (1.65-3.62) | (1.77-3.46) |
| | p-value | | 0.03 | 0.001 | 0.38 | <0.0001 | <0.0001 |
| | Adj OR | Ref | 1.07 | 1.16 | 0.96 | 1.83 | 1.18 |
| | 95% CI | | (0.97-1.16) | (0.95-1.40) | (0.69-1.34) | (1.13-2.96) | (0.55-2.51) |
| | p-value | | 0.17 | 0.14 | 0.80 | 0.01 | 0.67 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| LOS>2 days | % event | 8.31% | 9.35% | 13.56% | 18.24% | 24.30% | 21.75% |
| | OR | Ref | 1.14 | 1.73 | 2.46 | 3.54 | 3.07 |
| | 95% CI | | (1.11-1.17) | (1.63-1.84) | (2.25-2.69) | (3.07-4.09) | (2.70-3.48) |
| | p-value | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| | Adj OR | Ref | 1.02 | 1.21 | 1.44 | 1.74 | 2.05 |
| | 95% CI | | (0.99-1.06) | (1.13-1.29) | (1.30-1.60) | (1.46-2.07) | (1.64-2.56) |
| | p-value | | 0.15 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Progressive renal insufficiency* | % event | 0.03% | 0.09% | 0.29% | 0.56% | 1.36% | -- |
| | OR | Ref | 3.02 | 9.56 | 18.60 | 45.78 | -- |
| | 95% CI | | (2.13-4.29) | (6.04-15.13) | (10.92-31.67) | (25.40 – 82.49) | |
| | p-value | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | |
| | Adj OR | Ref | 2.10 | 4.02 | 5.25 | 9.51 | -- |
| | 95% CI | | (1.42-3.11) | (2.37-6.81) | (2.80-9.86) | (4.20 – 21.56) | |
| | p-value | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | |
| Any Post-Op Deep Incisional SSI | % event | 0.05% | 0.06% | 0.13% | 0.19% | 0.10% | 0.14% |
| | OR | Ref | 1.26 | 2.70 | 3.93 | 2.05 | 3.01 |
| | 95% CI | | (0.88-1.80) | (1.48-4.93) | (1.72-8.99) | (0.29-14.76) | (0.74-12.22) |
| | p-value | | 0.20 | 0.001 | 0.001 | 0.47 | 0.12 |
| | Adj OR | Ref | 1.01 | 1.44 | 2.02 | 1.42 | 6.92 |
| | 95% CI | | (0.68-1.50) | (0.73-2.87) | (0.83-4.94) | (0.18-11.38) | (1.62-29.52) |
| | p-value | | 0.97 | 0.30 | 0.12 | 0.74 | 0.009 |

*Definitions of postoperative declines in kidney function included a rise in creatinine ≥2 mg/dl with no requirement for dialysis or acute kidney injury 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 were recorded as being on dialysis preoperatively.