The Impact of Renal Function on Outcomes of Bariatric Surgery

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ABSTRACT

The effect of CKD on the risks of bariatric surgery is not well understood. Using the American College of Surgeons National Surgical Quality Improvement Program Participant Use File, we analyzed 27,736 patients who underwent bariatric surgery from 2006 through 2008. Before surgery, 34 (0.12%) patients were undergoing long-term dialysis. Among those not undergoing dialysis, 20,806 patients (75.0%) had a normal estimated GFR or stage 1 CKD, 5011 (18.07%) had stage 2 CKD, 1734 (6.25%) had stage 3 CKD, 94 (0.34%) had stage 4 CKD, and 91 (0.33%) had stage 5 CKD. In an unadjusted analysis, CKD stage was directly associated with complication rate, ranging from 4.6% for those with stage 1 CKD or normal estimated GFR to 9.9% for those with stage 5 CKD (test for trend, \( P < 0.001 \)). Multivariable logistic regression demonstrated that CKD stage predicts higher complication rates (odds ratio for each higher CKD stage, 1.30) after adjustment for diabetes and hypertension. Although patients with higher CKD stage had higher complication rates, the absolute incidence of complications remained <10%. In conclusion, these data demonstrate higher risks of bariatric surgery among patients with worse renal function, but whether the potential benefits outweigh the risks in this population requires further study.


Morbid obesity has reached epidemic proportions across the United States. It has been described as a national health threat and public health challenge—approximately 72.5 million adults in the United States are obese (Centers for Disease Control and Prevention, unpublished data 2010). Obesity is associated with the development of multiple medical conditions and comorbid illnesses, including coronary artery disease, stroke, type II diabetes, CKD leading to ESRD, increased surgical risk, and premature death; reduced quality of life; social stigmatization; and discrimination. As a result, obesity is one of the leading causes of death in the United States, leading to approximately 300,000 deaths per year. In 2006, medical costs associated with obesity were estimated to be as high as $147 billion (2008 dollars) among all payers, $1429 per patient higher than costs for patients of normal weight.6,7 An array of weight loss options exists for the treatment of obesity. The nonoperative options, including diet, exercise, behavior modification, and appetite-suppressant medications, have historically been associated with high failure rates.8 Bariatric surgery is an acceptable alternative for long-term weight loss in patients with morbid obesity; it results in improvement in obesity-related comorbid conditions, enhanced quality of life, and a reduction in obesity-related mortality.9–12

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Many obesity-related comorbid conditions, including diabetes mellitus, hypertension, and dyslipidemia, are also risk factors for CKD.\textsuperscript{13–17} In addition, obesity itself is an independent risk factor for CKD.\textsuperscript{14,15,18–20} Trends in increasing obesity in the ESRD population overall have mirrored trends in the adult population in the United States.\textsuperscript{21} To our knowledge, no large, prospective, longitudinal studies of patients with CKD who underwent bariatric surgery have evaluated safety, efficacy, and improvement in comorbid conditions.

This analysis was performed with the American College of Surgeons: National Surgical Quality Improvement Program (ACS/NSQIP) Participant Use Files (PUFs) from 2006 through 2008 to evaluate the effect of impaired renal function on perioperative outcomes in patients undergoing bariatric surgery. The ACS/NSQIP collects data on 135 variables, including preoperative risk factors, intraoperative variables, and follow-up data on 30-day postoperative morbidity and mortality for patients undergoing major surgical procedures in patient and outpatient settings at NSQIP-participating hospitals. Using these data, the ACS/NSQIP has developed predictive models that apply to a broad range of surgical procedures.\textsuperscript{22} We hypothesized that perioperative morbidity and mortality in patients with impaired renal function who underwent bariatric surgery would increase compared with patients with normal renal function.

RESULTS

Patient Demographic Characteristics

A total of 33,519 patients undergoing bariatric surgery were identified in the PUFs from 2006 to 2008. Of these, 31,560 met the study inclusion criteria. However, 3824 patients (12%) were missing serum creatinine values and were therefore excluded from the analysis. Only 34 (0.12%) of the final 27,736 patients were undergoing long-term dialysis before surgery. There were 20,806 (75.0%) patients with CKD stage 1, including those with normal estimated GFR (eGFR); 5011 (18.07%) with CKD stage 2; 1734 (6.25%) with CKD stage 3; 94 (0.34%) with CKD stage 4; and 91 (0.33%) with CKD stage 5. All patients undergoing dialysis were included in the CKD stage 5 group.

Patient demographic characteristics are detailed in Table 1. The most common operation performed in all groups was laparoscopic gastric bypass. The mean age of the patients undergoing bariatric surgery in the groups with higher CKD stage (particularly stage 3) was significantly higher than the age of patients with lower CKD stage. Most patients in all CKD categories were white, and there was a significantly higher percentage of white patients in the CKD stage 3 group. The mean body mass index (BMI) was similar between groups (although the difference proved statistically significant because of the sample sizes).

In general, patients with higher CKD stages had a significantly higher incidence of obesity-related comorbid conditions. Patients with CKD stages 3, 4, and 5 had a significantly higher prevalence of diabetes mellitus, hypertension, and peripheral vascular disease. Patients with higher CKD stages also trended significantly toward a higher American Society of Anesthesiology classification. The prevalence of tobacco use was higher in patients with lower CKD stage.

Perioperative Outcomes

Table 2 documents the perioperative outcomes for patients undergoing bariatric surgery. Mean operating time was slightly longer in the CKD stage 3 group. Patients had significantly longer hospital length of stay and significantly higher risk for return to the operating room with increasing CKD stage. Although the CKD stage 3 group had a higher risk for death, this risk was not significantly different from that in the other CKD groups. The total mortality rate was 0.12% (n=32) in the entire study population.

Postoperative Occurrences

Table 3 reports the postoperative complications for the study population. In general, the incidence of complications was low in all groups. However, there was an increasing trend in the rate of surgical site infections (deep and organ space) in higher CKD stage groups. In addition, patients with higher CKD stages had a higher incidence of postoperative pulmonary complications, including pneumonia, unplanned reintubation, and prolonged postoperative ventilation. They also had a higher incidence of postoperative renal complications, including renal failure and urinary tract infection. Finally, patients with stage 3 CKD had a significantly higher incidence of septic shock.

Univariate analysis demonstrated a positive trend between CKD stage and risk for complications: 4.6% in patients with CKD stage 1, 6.1% in stage 2, 7.7% in stage 3, 7.5% in stage 4, and 9.9% in stage 5 (P<0.001 for trend). An increased risk for complications was also observed in patients with an elevated creatinine level (>1.2 mg/dl) or those undergoing dialysis (Table 4).

Results of the multivariable logistic regression on CKD stage and complications appear in Tables 5 to 6. CKD was tested as both a categorical variable (Table 5) and a continuous variable (Table 6). The log likelihood for both models was very similar (−2 log likelihood, 11,077 versus 11,078), demonstrating that the risk for complication probably increases as a linear function of CKD stage. In categorical models, patients with CKD stage 4 had odds ratios similar to those with CKD stage 3 (crude odds ratios, 1.68 for CKD 4 and 1.75 for CKD 3), and the odds ratio for CKD 4 was not statistically significant (95% confidence interval for CKD stage 4, 0.776–3.638). Of all the variables tested (shown in Table 1), only diabetes and hypertension fit the criteria of being confounders of the relationship between CKD and complications (i.e., they had >10% influence on the crude odds ratio), and adjusted odds ratios are shown. It is difficult to determine whether diabetes and hypertension are truly confounders or are factors in the causal pathway. As a result, both crude and adjusted odds ratios are
reported. In both cases, adjustment for these confounders attenuated the effect of CKD stage on complications, but the overall conclusion—that complications increase as a result of higher CKD stages—remains the same.

After adjustment for age, BMI, American Society of Anesthesiology class, and bypass surgery, the effect of CKD on complications was slightly attenuated but still remained significant. Patient race and gender were not significant. We did not detect effect modification between CKD stages and any other demographic or clinical covariate.

**DISCUSSION**

This study is the largest of its kind to focus on the effect of renal function on the early outcomes of bariatric surgery. The analysis demonstrates that operative time is on average 4 minutes longer for patients with CKD stage 3 than for patients with CKD stage 1 or 2. Although this small difference is statistically significant because of the large sample size, the clinical impact is questionable. More significant is the trend toward a higher incidence of return to the operating room.

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**Table 1. Patient demographic and clinical characteristics**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Normal GFR or CKD Stage 1 (n=20,806)</th>
<th>CKD Stage 2 (n=5011)</th>
<th>CKD Stage 3 (n=1734)</th>
<th>CKD Stage 4 or 5 (n=183)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Procedure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bypass</td>
<td>14,765 (71.0)</td>
<td>3380 (67.5)</td>
<td>1227 (70.8)</td>
<td>130 (71.0)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>band</td>
<td>6041 (29.0)</td>
<td>1631 (32.6)</td>
<td>507 (29.2)</td>
<td>53 (29.0)</td>
<td></td>
</tr>
<tr>
<td>Laparoscopic method</td>
<td>18,678 (89.8)</td>
<td>4406 (87.9)</td>
<td>1487 (85.8)</td>
<td>159 (86.9)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Men</td>
<td>3295 (15.8)</td>
<td>1848 (36.9)</td>
<td>418 (24.1)</td>
<td>47 (25.7)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean age ± SD (yr)</td>
<td>42.4±10.40</td>
<td>52.0±10.78</td>
<td>57.2±8.41</td>
<td>50.8±11.31</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>White race</td>
<td>15,595 (80.6)</td>
<td>4004 (85.7)</td>
<td>1466 (89.9)</td>
<td>126 (75.0)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>ASA classa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>143 (0.7)</td>
<td>24 (0.5)</td>
<td>2 (0.1)</td>
<td>0 (0.0)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>2</td>
<td>7462 (35.9)</td>
<td>1243 (24.8)</td>
<td>266 (15.3)</td>
<td>30 (16.4)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>12,845 (61.8)</td>
<td>3598 (71.8)</td>
<td>1366 (78.8)</td>
<td>130 (71.0)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>338 (1.6)</td>
<td>142 (2.8)</td>
<td>100 (5.8)</td>
<td>23 (12.6)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>6 (0.0)</td>
<td>1 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td></td>
</tr>
<tr>
<td>Mean BMI ± SD (kg/m²)</td>
<td>47.2±8.19</td>
<td>46.5±7.93</td>
<td>47.2±6.83</td>
<td>47.7±7.70</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Type I diabetes</td>
<td>1418 (6.8)</td>
<td>577 (11.5)</td>
<td>449 (25.9)</td>
<td>66 (36.1)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Smoker</td>
<td>2898 (13.9)</td>
<td>482 (9.6)</td>
<td>144 (8.3)</td>
<td>14 (7.7)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Hypertension</td>
<td>9977 (48.0)</td>
<td>3531 (70.5)</td>
<td>1490 (85.9)</td>
<td>153 (83.6)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Taking steroids</td>
<td>189 (0.9)</td>
<td>56 (1.1)</td>
<td>40 (2.3)</td>
<td>4 (2.2)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Previous CVA</td>
<td>123 (0.6)</td>
<td>69 (1.4)</td>
<td>43 (2.5)</td>
<td>6 (3.3)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Previous PCI</td>
<td>265 (1.3)</td>
<td>215 (4.3)</td>
<td>149 (8.6)</td>
<td>16 (8.7)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Previous PVD</td>
<td>39 (0.2)</td>
<td>13 (0.3)</td>
<td>20 (1.2)</td>
<td>2 (1.1)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>History of COPD</td>
<td>310 (1.5)</td>
<td>123 (2.5)</td>
<td>61 (3.5)</td>
<td>8 (4.4)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Previous cardiac surgery</td>
<td>156 (0.8)</td>
<td>130 (2.6)</td>
<td>87 (5.0)</td>
<td>11 (6.0)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>History of CHF</td>
<td>15 (0.1)</td>
<td>12 (0.2)</td>
<td>7 (0.4)</td>
<td>0 (0.0)</td>
<td>0.003</td>
</tr>
<tr>
<td>History of myocardial infarction</td>
<td>1 (0.0)</td>
<td>2 (0.0)</td>
<td>3 (0.2)</td>
<td>0 (0.0)</td>
<td>0.002</td>
</tr>
<tr>
<td>Bleeding disorders</td>
<td>334 (1.6)</td>
<td>151 (3.0)</td>
<td>71 (4.1)</td>
<td>7 (3.8)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Alcohol abuse</td>
<td>50 (0.2)</td>
<td>19 (0.4)</td>
<td>5 (0.3)</td>
<td>0 (0.0)</td>
<td>0.35</td>
</tr>
<tr>
<td>History of TIA</td>
<td>97 (0.5)</td>
<td>52 (1.0)</td>
<td>28 (1.6)</td>
<td>4 (2.2)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>History of angina</td>
<td>26 (0.1)</td>
<td>14 (0.3)</td>
<td>5 (0.3)</td>
<td>2 (1.1)</td>
<td>0.003</td>
</tr>
<tr>
<td>SIRS</td>
<td>137 (0.7)</td>
<td>33 (0.7)</td>
<td>12 (0.7)</td>
<td>3 (1.6)</td>
<td>0.27</td>
</tr>
</tbody>
</table>

Unless otherwise noted, values are number (percentage) of patients. ASA, American Society of Anesthesiology; CVA, cerebral vascular accident; PCI, percutaneous coronary intervention; PVD, peripheral vascular disease; COPD, chronic obstructive pulmonary disease; CHF, congestive heart failure; TIA, transient ischemic attack; SIRS, systemic inflammatory response syndrome.

aFifteen patients in the CKD 1 or 2 groups were missing ASA class.

**Table 2. Perioperative outcomes**

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Normal GFR or CKD Stage 1 (n=20,806)</th>
<th>CKD Stage 2 (n=5011)</th>
<th>CKD Stage 3 (n=1734)</th>
<th>CKD Stage 4 or 5 (n=183)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean length of stay ± SD (d)</td>
<td>2.18±2.94</td>
<td>2.25±2.84</td>
<td>2.91±6.12</td>
<td>3.06±5.06</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Mean surgery time ± SD (min)</td>
<td>119.19±58.80</td>
<td>120.82±62.63</td>
<td>123.11±60.03</td>
<td>118.69±58.08</td>
<td>0.03</td>
</tr>
<tr>
<td>Return to operating room, n (%)</td>
<td>469 (2.3)</td>
<td>133 (2.7)</td>
<td>54 (3.1)</td>
<td>9 (4.9)</td>
<td>0.008</td>
</tr>
<tr>
<td>30-day mortality (%)</td>
<td>15 (0.1)</td>
<td>12 (0.2)</td>
<td>5 (0.3)</td>
<td>0 (0.0)</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Table 3. Postoperative complications

<table>
<thead>
<tr>
<th>Postoperative Complication</th>
<th>Normal GFR or CKD Stage 1 (n=20,806)</th>
<th>CKD Stage 2 (n=5011)</th>
<th>CKD Stage 3 (n=1734)</th>
<th>CKD Stage 4 or 5 (n=185)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superficial wound infection</td>
<td>368 (1.8)</td>
<td>111 (2.2)</td>
<td>42 (2.4)</td>
<td>1 (0.5)</td>
<td>0.03</td>
</tr>
<tr>
<td>Deep incisional SSI</td>
<td>69 (0.3)</td>
<td>16 (0.3)</td>
<td>8 (0.5)</td>
<td>3 (1.6)</td>
<td>0.02</td>
</tr>
<tr>
<td>Organ space SSI</td>
<td>113 (0.5)</td>
<td>29 (0.4)</td>
<td>15 (0.9)</td>
<td>3 (1.6)</td>
<td>0.09</td>
</tr>
<tr>
<td>Wound disruption</td>
<td>42 (0.2)</td>
<td>14 (0.3)</td>
<td>0 (0.0)</td>
<td>1 (0.5)</td>
<td>0.05^a</td>
</tr>
<tr>
<td>Pneumonia</td>
<td>93 (0.5)</td>
<td>38 (0.8)</td>
<td>19 (1.1)</td>
<td>2 (1.1)</td>
<td>0.0004</td>
</tr>
<tr>
<td>Unplanned reintubation</td>
<td>56 (0.3)</td>
<td>30 (0.6)</td>
<td>24 (1.4)</td>
<td>1 (0.5)</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Pulmonary embolism</td>
<td>23 (0.1)</td>
<td>18 (0.4)</td>
<td>3 (0.2)</td>
<td>1 (0.5)</td>
<td>0.0011^a</td>
</tr>
<tr>
<td>Ventilator &gt; 48 hr</td>
<td>64 (0.3)</td>
<td>14 (0.3)</td>
<td>16 (0.9)</td>
<td>1 (0.5)</td>
<td>0.0003</td>
</tr>
<tr>
<td>Urinary tract infection</td>
<td>151 (0.7)</td>
<td>41 (0.8)</td>
<td>26 (1.5)</td>
<td>3 (1.6)</td>
<td>0.003</td>
</tr>
<tr>
<td>Stroke/CVA</td>
<td>3 (0.0)</td>
<td>4 (0.1)</td>
<td>1 (0.1)</td>
<td>0 (0.0)</td>
<td>0.06^a</td>
</tr>
<tr>
<td>Coma</td>
<td>5 (0.0)</td>
<td>1 (0.0)</td>
<td>0 (0.0)</td>
<td>0 (0.0)</td>
<td>1.000^a</td>
</tr>
<tr>
<td>Peripheral nerve injury</td>
<td>10 (0.1)</td>
<td>6 (0.1)</td>
<td>1 (0.1)</td>
<td>0 (0.0)</td>
<td>0.25^a</td>
</tr>
<tr>
<td>Cardiac arrest requiring CPR</td>
<td>15 (0.1)</td>
<td>9 (0.2)</td>
<td>9 (0.5)</td>
<td>0 (0.0)</td>
<td>&lt;0.0001^a</td>
</tr>
<tr>
<td>Myocardial infarction</td>
<td>1 (0.0)</td>
<td>1 (0.0)</td>
<td>4 (0.2)</td>
<td>0 (0.0)</td>
<td>0.0004^a</td>
</tr>
<tr>
<td>Bleeding transfusion</td>
<td>60 (0.3)</td>
<td>11 (0.2)</td>
<td>5 (0.3)</td>
<td>1 (0.5)</td>
<td>0.54^a</td>
</tr>
<tr>
<td>Graft/prosthesis failure</td>
<td>8 (0.0)</td>
<td>3 (0.1)</td>
<td>1 (0.1)</td>
<td>0 (0.0)</td>
<td>0.50^a</td>
</tr>
<tr>
<td>DVT/thrombophlebitis</td>
<td>43 (0.2)</td>
<td>22 (0.4)</td>
<td>12 (0.7)</td>
<td>0 (0.0)</td>
<td>0.0007^a</td>
</tr>
<tr>
<td>Sepsis</td>
<td>132 (0.6)</td>
<td>41 (0.8)</td>
<td>18 (1.0)</td>
<td>3 (1.6)</td>
<td>0.06</td>
</tr>
<tr>
<td>Septic shock</td>
<td>57 (0.3)</td>
<td>20 (0.4)</td>
<td>20 (1.2)</td>
<td>1 (0.5)</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

SSI, surgical site infection; CVA, cerebrovascular accident; CPR, cardiopulmonary resuscitation; DVT, deep venous thrombosis.

^aFisher exact test.

(2.3% for stage 1, 2.7% for stage 2, 3.1% for stage 3, and 4.9% for stage 4 or 5) and longer lengths of stay (2.18, 2.25, 2.91, and 3.06 days, respectively) as CKD stage increases. These outcomes are clinically significant because they contribute to increasing costs for patient care delivery. The overall 30-day mortality rate in this study was 0.12%. This is consistent with the 0.3% perioperative mortality recently reported by the Longitudinal Assessment of Bariatric Surgery (LABS) consortium in 2009.23 Although the mortality rate for the stage 3 CKD group was three times that for the patients with CKD stage 1 and 2 (0.3% versus 0.1%), no patients with CKD stage 4 or 5 died and the differences between groups did not reach statistical significance. The risk for death in each separate CKD group was also similar to that reported by the LABS consortium.23

Although the overall incidence of perioperative complications is low, this study does demonstrate an increased risk for complications in patients with higher CKD stages. For example, patients with stage 3, 4, and 5 CKD have a higher incidence of organ space surgical site infection. This finding, coupled with the higher rate of return to the operating room, may have been explained by a higher incidence of anastomotic leaks after gastric bypass surgery in these patients. Unfortunately, ACS/NSQIP does not capture data for anastomotic leaks. Patients with higher CKD stage also had a higher incidence of postoperative pulmonary complications, renal complications, and septic shock.

Univariate analysis showed a significant relationship between elevated creatinine level, dialysis, and higher CKD stage and the risk for complications. Clinicians have long used serum creatinine levels as a measure of renal function. Yet, there is interassay variation in serum creatinine results, and most consider it a poor predictor of GFR by itself across many populations.24 It is unclear as to which formula best approximates GFR in obese patients and whether GFR values should be adjusted for body surface area (BSA).25–27 Verhave et al. demonstrated that neither the Modification of Diet in Renal Disease (MDRD) nor the Cockcroft-Gault formula was reliable in estimating GFR in obese individuals.28 The MDRD may also underestimate GFR in obese patients with type II diabetes.29,30 Others suggest that a formula that does not correct for BSA may lead to overestimation of renal function in obese individuals.28,31,32 Controversy exists as to whether there is a relationship between BSA and GFR and whether BSA should be adjusted because the BSA of
obese individuals is higher than the standard BSA value of 1.73 m². GFR corrected for BSA in obese individuals may lead to underestimation of GFR, and using a nonindexed BSA may be preferable in the obese population. 12,27,32,33 Although differences in BSA may exist, it is unclear whether the accuracy of the equations is improved by correcting for BSA.25 In our analysis we adjusted for BSA and found no change in the conclusions (data not shown).

Recent evidence suggests that the best overall accuracy of estimation of GFR in obese individuals is the CKD-Epi formula.34–36 We analyzed the data using the CKD-Epi and the MDRD formulas37 (results not shown). In addition to the data being collected retrospectively, the database does not provide information on proteinuria or specify the length of time a given patient had the laboratory values used for GFR calculations; thus, CKD classification was based on eGFR alone. Despite these limitations, multivariable modeling demonstrated that, after adjustment for other variables, CKD stage remained significant and adjusted odds ratios did not change drastically from the crude ratios. The analysis suggests that the risk for complications increases 1.302 times with each increase in the CKD stage (Table 6), such that patients with CKD stage 4 or 5 have two to almost three times (odds ratios, 2.21 for CKD stage 4 and 2.87 for CKD stage 5) higher risk of having a postoperative complication compared with a patient with CKD stage 1. Several studies have demonstrated that impaired renal function (using increased creatinine levels or increased CKD stage as a marker) is associated with worse perioperative morbidity and mortality after elective colon surgery, cardiac surgery, and joint replacement.38–42 Nonetheless, the absolute complication rate in patients with moderate or severe CKD is still low.

Additional limitations of this study include the inability to explore the effects of the program or of surgeon experience because the ACS/NSQIP PUs contain retrospective and deidentified data. Surgeon experience is inversely proportional to complication rates and levels of mortality in bariatric surgery cases.43 Second, data collection in ACS/NSQIP ends at postoperative day 30, so late mortality and morbidity are not accounted for in the analysis. One of the exclusion criteria was a missing preoperative creatinine level. Although the number of excluded patients was small (approximately 12%), the demographic and clinical characteristics of patients excluded were similar to those of the study population. The two exceptions were that patients with missing creatinine values tended to have fewer bypass surgeries (61.9% versus 70.3%) and tended to have less hypertension than patients who had values for creatinine (44.6% versus 54.6%). Another important outcome that cannot be analyzed is the effect of surgically induced weight loss on renal function over time.

The rate of obesity in patients initiating dialysis treatment is similar to the incidence of obesity in the general population,21 44–47 thus resulting in an increase in the number of obese patients who undergo dialysis as well as the number of obese patients being evaluated for kidney transplantation. Obesity is a leading cause of death as a result of the associated comorbid conditions, including coronary artery disease,

Table 5. Effect of CKD stage (as a categorical variable) on complications, with adjustment for diabetes and hypertensiona

Table 6. Effect of CKD (as a continuous variable) on complications, with adjustment for diabetes and hypertensiona

<table>
<thead>
<tr>
<th>Effect</th>
<th>Crude</th>
<th>Controlling for Diabetes</th>
<th>Controlling for Hypertension</th>
<th>Controlling for Diabetes and Hypertension</th>
<th>Full Modelbc</th>
</tr>
</thead>
<tbody>
<tr>
<td>CKD 2 versus 1c</td>
<td>1.353 (1.185–1.545)</td>
<td>1.295 (1.133–1.480)</td>
<td>1.276 (1.115–1.461)</td>
<td>1.256 (1.097–1.437)</td>
<td>1.239 (1.069–1.436)</td>
</tr>
<tr>
<td>CKD 3 versus 1c</td>
<td>1.749 (1.449–2.110)</td>
<td>1.544 (1.275–1.869)</td>
<td>1.587 (1.310–1.923)</td>
<td>1.475 (1.215–1.790)</td>
<td>1.360 (1.102–1.679)</td>
</tr>
<tr>
<td>CKD 4 versus 1c</td>
<td>1.680 (0.776–3.638)</td>
<td>1.399 (0.644–3.037)</td>
<td>1.489 (0.686–3.229)</td>
<td>1.325 (0.610–2.878)</td>
<td>1.023 (0.439–2.385)</td>
</tr>
<tr>
<td>CKD 5 versus 1c</td>
<td>2.292 (1.148–4.576)</td>
<td>2.133 (1.067–4.265)</td>
<td>2.158 (1.080–4.311)</td>
<td>2.073 (1.037–4.147)</td>
<td>2.295 (1.126–4.677)</td>
</tr>
<tr>
<td>Diabetes</td>
<td>—</td>
<td>1.532 (1.368–1.716)</td>
<td>—</td>
<td>1.462 (1.299–1.645)</td>
<td>1.296 (1.144–1.467)</td>
</tr>
<tr>
<td>Hypertension</td>
<td>—</td>
<td>—</td>
<td>1.306 (1.165–1.465)</td>
<td>1.181 (1.048–1.331)</td>
<td>1.019 (0.895–1.160)</td>
</tr>
</tbody>
</table>

CI, confidence interval.

* A complication is defined as having at least one of the postoperative events listed in Table 3.

* Full model also adjusts for BMI, age, American Society of Anesthesiology class 4 or 5, and whether the surgery was a bypass procedure.

* Reference category for CKD is normal GFR and CKD stage 1.
stroke, type II diabetes, ESRD, and increased surgical risk. Maintaining weight loss is challenging for patients who are undergoing dialysis as a result of decreased exercise capacity. Nonsurgical interventions fail in most patients. However, it is unclear whether weight loss is beneficial in this population.

“Reverse epidemiology” is the term used to describe the paradoxical inverse association between mortality and BMI. Observational and retrospective analyses suggest that greater BMI is considered to be protective in the dialysis population and is associated with lower mortality and decreased hospitalization rates compared with the general population of obese patients. It is uncertain whether this paradox is a true association or is due to the inaccuracy of current clinical methods to assess obesity. In addition, some researchers have reported worse outcomes in obese patients undergoing dialysis.

BMI is commonly used to diagnose obesity and does not provide information about body composition. As a result, its ability to help diagnose obesity can vary considerably by predictors of muscle mass, such as age, gender, and race. Waist-to-hip ratio is better than BMI at predicting future cardiovascular events and mortality in patients with CKD, as well as in transplant recipients, and it is superior for the detection of GFR loss in obese individuals.

Obesity is also known to limit access to transplantation and may be the most important modifiable factor that can influence overall survival. Many centers impose BMI restrictions secondary to increased morbidity around the time of transplantation and decreased patient and graft survival rates. However, overall survival is substantially and significantly improved in dialysis-dependent obese patients compared with their counterparts remaining on the wait list. Whether weight loss is beneficial and results in better outcomes in transplant recipients and whether the paradoxical association of BMI and mortality applies in transplant recipients are unknown. The safety of intentional weight loss in transplant recipients, and it is superior for the detection of GFR loss in obese individuals.

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Bariatric surgery has been shown to result in a significant decrease in morbidity and mortality in obese individuals as a result of improvement of several metabolic effects, including BP, lipid profile, insulin sensitivity and glucose tolerance, and measures of renal function. Substantial weight loss also improves GFR and albuminuria and stabilizes creatinine. Navarro-Díaz et al. demonstrated improved GFR and decreased proteinuria in 61 patients at 12 months after bariatric surgery. Navaneethan et al. reported significantly improved GFR in 25 patients with CKD stage 3 at 6 and 12 months after bariatric surgery. However, renal risks are associated with bariatric surgery. Specifically, acute kidney injury, nephrolithiasis, hyperoxaluria, hyperphosphatemia, oxalate nephropathy, and rhabdomyolysis have been reported and may negatively affect renal function after bariatric surgery.

In conclusion, this study demonstrates that patients with higher stages of CKD undergoing bariatric surgery had higher complication rates than patients with lower stages of CKD or with normal renal function. Although the relative risk is higher, the absolute risk for complications after bariatric surgery remains low in this patient population. Management of obesity requires identification of patients who will benefit from weight loss. Clinicians must weigh the increased risks against the substantial benefits of surgically induced weight loss when counseling patients with renal disease about bariatric surgery. A properly designed prospective trial with longer follow-up of patients with moderate or severe CKD is needed to examine these issues.

### CONCISE METHODS

#### ACS/NSQIP PUFs

The ACS/NSQIP general approach to data collection has been described elsewhere. The program focuses on 30-day outcomes (whether a patient has been discharged from the initial admission) via direct ascertainment of the 30-day time point by a chart review performed by a trained clinical nurse reviewer. Postoperative occurrences assessed include 21 rigorously defined conditions (including the following categories: wound, respiratory, urinary tract, central nervous system, cardiac, and five others), as well as mortality. Data abstraction is coordinated by a dedicated full-time nurse or trained health information expert. Several key features make ACS/NSQIP data extremely robust and reliable. First, the clinical nurse reviewer is specifically trained in NSQIP methods and data definitions. Second, each participating site’s data are regularly audited to ensure accuracy and compliance with the ACS/NSQIP data definitions. Third, the clinical reviewers maintain a degree of separation from individual surgeons in order to avoid any influence on their data abstraction. As a result of these reinforcing approaches, data integrity within the program has been excellent. For example, interrater reliability audits revealed that in 2005, total disagreements across the program were at 3.15% (for nearly 40,000 audited fields), and by 2008 total disagreements were at 1.60% (140,000 audited fields).

The ACS/NSQIP PUFs contain de-identified patient data for surgical cases performed at the more than 250 hospitals that currently participate in ACS/NSQIP.

#### Study Population

We conducted a retrospective study of patients in the United States undergoing major surgical procedures in both inpatient and outpatient settings using the ACS/NSQIP PUFs for 2005 through 2008. Patients were selected using the Current Procedural Terminology codes for Open (43846) and Laparoscopic (43644) Gastric Bypass, (43770) Laparoscopic Lap Band and (43848) Gastric Bypass Revision. Patients were excluded from the study if they had an emergency surgery, were pregnant, had a BMI <30 kg/m², had a history of chemotherapy, had an initial wound infection at the time of surgery, or were designated as having cancer. We also excluded patients who underwent any major concurrent procedures at the time of their...
index bariatric procedure. Finally, patients who were missing values for serum creatinine were omitted from analysis.

**Study Variables**
The primary exposure of interest was CKD stage. Serum creatinine levels measured before surgery were used along with the CKD-Epi creatinine formula to obtain an eGFR for each patient. The eGFR was used to stratify patients into five groups corresponding to CKD stages. The dataset did not include data on proteinuria, so all patients with normal eGFR (>90 ml/min per 1.73 m²) were categorized into CKD stage 1. Any patient undergoing dialysis before surgery was included in the CKD stage 5 group, and eGFR was not used to stratify dialysis patients. Comorbid factors were obtained before surgery, and outcome data were ascertained at 30-day follow-up as described elsewhere. To maintain consistency among ACS/NSQIP participating hospitals, criteria for postoperative complications are strictly defined.

**Statistical Analyses**
Demographic characteristics between groups were compared using chi-squared tests for categorical variables (or Fisher exact tests if needed) and ANOVA tests for continuous variables. In addition to CKD stages, we examined the association between postoperative complications and other renal variables found in the database, namely high creatinine values (>1.2 mg/dl), dialysis status before surgery, and renal failure status. The association between these variables and the probability of morbidity was assessed using chi-squared tests.

To evaluate whether there was a relationship between CKD stage and postoperative complications while accounting for other patient characteristics and comorbid conditions, multivariable logistic models were used to calculate odds ratios and 95% confidence intervals. Models were run with CKD stage as a categorical variable and as a continuous predictor. All demographic and comorbidity variables that were associated with complications and CKD stage were introduced into logistic models along with CKD stage to see whether they had a more than 10% influence on any of the CKD stage crude odds ratios for the categorical models or a 5% influence on the crude odds ratio of the continuous CKD model. Only variables that met these criteria were presented in the final logistic regression models as confounders. Because peripertative and postoperative outcomes were rare (incidence <10%), we interpreted odds ratios as risk ratios.

Finally, eGFR was recalculated using the MDRD formula (results not shown) to see how this would have affected the results. BSA for each patient was also calculated using the Du Bois formula, and GFR was further adjusted for this to determine whether the results were affected (results not shown).

All statistical analyses were performed using SAS software, version 9.2 (SAS Institute, Inc., Cary, NC), and SPSS software, version 17 (SPSS, Chicago, IL), and P values less than 0.05 were considered to represent a statistically significant difference.

**ACKNOWLEDGMENTS**
We thank Dr. William McClellan, Dr. Stephen Pastan, and Dr. Rachel Patzer for expert advice.

The ACS NSQIP and the hospitals participating in the ACS NSQIP are the source of the data used herein; they have not verified and are not responsible for the statistical validity of the data analysis or the conclusions derived by the authors.

**DISCLOSURES**
None.

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