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ORIGINAL CONTRIBUTIONS

Acute Kidney Injury Following Bariatric Surgery

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Abstract
Background Postoperative acute kidney injury (AKI) following bariatric surgery has not been well studied. The aim of this study is to identify factors associated with risk of AKI.
Methods The medical records of adult patients who underwent bariatric surgery between March 1, 2005 and March 31, 2011 at the Mayo Clinic were reviewed to identify patients who experienced AKI, defined as postoperative increase in serum creatinine (sCr) by 0.3 mg/dL within 72 h. For each AKI case, two controls were matched for surgical approach (laparotomy vs. laparoscopic). A chart review was conducted and conditional logistic regression analyses were performed to identify risk factors for AKI.
Results There were 1,227 patients who underwent bariatric surgery, and of these, 71 developed AKI (5.8 %). The median sCr increase was 0.4 (interquartile range 0.3–0.6) mg/dL. Independent patient factors associated with increased risk included higher body mass index [odds ratio (OR) 1.24, 95 % CI 1.06–1.46 per 5 unit increase, $P=0.01$] and medically treated diabetes mellitus (OR 2.77, 1.36–5.65, $P=0.01$). Patients experiencing AKI had higher rates of blood transfusions ($P<0.01$), postsurgical complications ($P<0.01$), and longer hospital stays ($P<0.01$). Another 30 patients developed kidney injury after 72 postoperative hours, usually in the setting of dehydration.
Conclusions Kidney injury following bariatric surgery is not uncommon and is associated with higher body mass index and diabetes. Further, there should be a high risk of suspicion for kidney injury in postoperative patients developing volume depletion.

Keywords Acute kidney injury · Risk factors · Bariatric surgery · General anesthesia

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Introduction

Development and progression of chronic kidney disease is among the many adverse effects associated with obesity [1]. Independent of hypertension or diabetes, obesity causes increased glomerular capillary pressure and glomerular hyperfiltration, which are early precursors of chronic kidney disease [2]. The microalbuminuria, hyperfiltration, and proteinuria observed in obesity-related renal disease can ultimately lead to glomerular hemodynamic and ultrastructural changes resulting in a decline in glomerular filtration rate (GFR), accompanied by eventual renal failure unless abated [3]. Further, hypertension and diabetes mellitus, two conditions commonly associated with obesity [4], are the leading causes of chronic kidney disease in the USA. The weight loss achieved with bariatric surgery has been shown to reverse

microalbuminuria and proteinuria and result in a decrease in hyperfiltration-related excess creatinine clearance [5].

We previously reported that between 6.2 and 8.6 % bariatric surgical patients may develop postoperative acute kidney injury (AKI) [6, 7], which is higher than 1 % following general and orthopedic operations [8, 9]. However, our previous studies were not designed to examine the risk factors associated with AKI. This complication following bariatric surgery is not well understood, and to our knowledge, only one study examined clinical factors associated with AKI following gastric bypass surgery [10]. Postoperative AKI is a serious complication, and identification of modifiable associated factors could assist in perioperative management. The primary aim of this present study is to explore clinical factors associated with postoperative AKI in patients undergoing bariatric surgery.

Methods and Materials

This retrospective 2:1 matched case–control study was approved by the Mayo Clinic Institutional Review Board, and all patients provided prior written consent to participate in minimal risk retrospective studies. We obtained from electronic medical records preoperative serum creatinine (sCr) (baseline value, within 2 years antecedent to surgery) and postoperative sCr (postoperative value within the first 30 days following surgery) concentrations for all patients who underwent bariatric surgery for medically complicated obesity (banding procedures and gastric sleeve resections were excluded) at the Mayo Clinic between March 1, 2005 and March 31, 2011. All patients without baseline and postoperative sCr were excluded. Patients undergoing revision of bariatric surgery were included only if surgery was indicated for the treatment of obesity and not for a complication of the initial procedure (i.e., recurrent bowel obstructions, malabsorption).

The diagnosis of AKI was made by a comparison between baseline and highest postoperative sCr to determine the presence of predefined significant change. The development of AKI was defined, using the modified Acute Kidney Injury Network (AKIN) criteria [11], as an increase in sCr of 0.3 mg/dL within a 48-h period. Generally, this time period was defined at the end of surgery. However, if the *first* postoperative sCr was obtained between 49 and 72 postoperative hours, we assumed that this represented the postoperative value which qualifies for determining if AKI occurred. This timeframe was selected to limit analysis of causative factors to the immediate perioperative period. Decline in urine output was not used because of inaccuracies of hourly measurements on postoperative wards. AKI severity was characterized using the AKIN staging system [11] into three grades: stage I = increase sCr ≥0.3 mg/dL or increase ≥150 to 200 % from baseline value; stage II = increase sCr ≥200 %; and stage II = increase sCr ≥300 % or need for dialysis. GFR was calculated from sCr using the Modification of Diet in Renal Disease Study equation [12]. Patients who developed a kidney injury within 30 days, but after 72 postoperative hours, were not included in the case-controlled analysis. The characteristics of those patients are presented separately.

To assess for factors associated with AKI following bariatric surgery, we utilized a retrospective 2:1 matched case–control study design. For each case, two controls were randomly matched according to the surgical approach (laparotomy vs. laparoscopic) and year of surgery (within 2 years and in the study timeframe). Electronic medical records were abstracted for demographics, comorbid conditions, and intraoperative variables with the potential for association with postoperative AKI including age, gender, body mass index, presence of cardiovascular disease, medically treated hypertension, obstructive sleep apnea, respiratory disease, medically treated diabetes, medically treated hyperlipidemia, preoperative GFR, and surgical duration. Cardiovascular disease was defined as coronary artery disease (myocardial infarction, coronary stent placement, or cardiac bypass surgery), congestive heart failure/cardiomyopathy (or ejection fraction <40 %), or cardiac dysrhythmia (atrial fibrillation or flutter, implanted pacemaker and/or automated defibrillator), and respiratory disease was defined as asthma treated with daily use of inhalers, moderate to severe chronic obstructive pulmonary disease, moderate to severe pulmonary hypertension (mean pulmonary pressure ≥35 mmHg), or home use of oxygen. Additionally, overall physical status was assessed from the American Society of Anesthesiologists Physical Status Score (ASA-PS). The medical record was also reviewed for perioperative blood transfusion; fluid administration; urine output; use of nonsteroidal anti-inflammatory agents (NSAID); and perioperative complications: hypotension (systolic blood pressure <90 mmHg for ≥6 min or the use of phenylephrine infusion as surrogate for recalcitrant hypotension), need for cardioversion, respiratory events, or other severe perioperative complication. Postoperative complications and mortality that occurred within 30 postoperative days were reported. Surgical complications were defined as wound dehiscence, anastomotic leak, wound infection, or need for reoperation. All data were abstracted from the electronic medical records and entered manually into the web-based Research Electronic Data Capture (REDCap®) system (Version 3.6.7, Vanderbilt University, Nashville, TN, USA) [13].

Data Analysis

Potential factors associated with AKI were assessed using conditional logistic regression, making use of the 1:2

matched case–control study design. Characteristics found to have some evidence of association with AKI ($P<0.10$) were included in a multivariable logistic regression analysis. Findings from the logistic regression analyses are summarized by presenting the odds ratios (OR) and corresponding 95 % confidence intervals (CI). Two-sided tests were used. P values≤.05 denoted statistical significance. Descriptive statistics were employed to summarize patients who developed kidney injury after 72 h. Statistical analyses were performed using SAS Version 9.2 (SAS Institute Inc., Cary, NC, USA).

Results

During the study period, 1,619 patients underwent bariatric surgeries, of which 161 were surgeries to correct complications resulting from a previous bariatric surgery and 231 either gastric banding or sleeve procedures and were excluded per protocol. Of the remaining 1,227 patients, 1,191 had preoperative and postoperative sCr and were included in the study. Two hundred thirty cases were performed via laparotomy. Revision surgeries to treat obesity accounted for 65 cases. General anesthesia was used for all cases. Epidural catheter for postoperative pain was used in 59 % of laparotomy surgeries. There were 101 patients who experienced postoperative rise in sCr by ≥0.3 mg/dL, with 71 occurring within 72 h of surgery (5.8 % cases). Twenty-eight AKI cases occurred following laparotomy including 1 revision surgery (12.2 % cases) and 43 AKI cases occurred following laparoscopic surgeries (3.9 % cases). The median sCr increase was 0.4 (interquartile range 0.3–0.6) mg/dL. All cases that occurred within 72 h of surgery were AKIN stage I injuries except for three patients who had stage II and two stage III injuries. All cases were matched 2:1 with control patients by surgical approach. The majority of the cohort were Caucasian [68 (95.8 %) of cases and 137 (96.5 %) controls, $P=0.80$].

Characteristics Associated with AKI

Patients who developed AKI had a higher comorbidity burden as reflected by a greater proportion having ASA-PS score ≥3 (94.3 vs. 78.2 %, $P<0.01$) (Table 1). Older age, male gender, and greater body mass index (BMI) were associated with developing AKI. Specific comorbidities associated with developing AKI by univariate analysis included diabetes, hyperlipidemia, arterial hypertension, and cardiovascular disease (Table 2). Longer surgical durations were also associated with AKI. A multivariable model of potential patient and procedural factors found that greater BMI and diabetes were independently associated with the development of postsurgical AKI (Table 2). Figure 1 shows the distribution of BMI between cases (top panel) and controls (bottom panel). The weight in patients who developed AKI patients was shifted towards higher BMI values. The multivariable analysis was repeated with BMI dichotomized using a cut-point of 50 kg/m^2. From this post hoc multivariable analysis, BMI ≥50 kg/m^2 was associated with an increased risk for AKI (OR=2.44, 95 % CI 1.28 to 4.63; $P<0.01$). Urine output during surgery did not vary between patients who developed AKI compared to controls (0.59± 0.38 vs. 0.63±0.55 mL/kg/h, $P=0.69$). Intraoperative ketorolac was used in 40.8 % of cases and 40.1 % of controls ($P=0.92$) for a median dose of 30 mg [interquartile range (IQR) 15–30 mg] ($P=0.90$).

Postoperative Course and Outcomes of AKI Patients Compared to Controls

Blood transfusions [13 (18.3 %) vs. 3 (2.1 %), $P<0.01$] and surgical complications [12 (16.9 %) vs. 8 (5.6 %), $P<0.01$] were more frequent and hospital length of stay was longer [median 5 (IQR 3–7) vs. 3 (IQR 2–5) days, $P<0.01$] among patients that developed a kidney injury. Only two cases and three controls required reoperation within the first 30 days ($P=0.329$). Readmission rates did not significantly differ [12 (16.9 %) vs. 13 (9.9 %), $P=0.10$]. Only one patient died within the first 30 days, a 49-year-old woman who underwent revision gastric bypass laparotomy surgery for obesity. She developed sepsis and acute respiratory distress syndrome 2 days after surgery and became oliguric, requiring hemodialysis. She was the only patient who experienced an early kidney injury that required dialysis. She died 18 days after surgery from multiorgan failure. Another patient experienced an early stage I kidney injury following a laparotomy gastric bypass surgery. The injury subsequently resolved; however, the patient became septic 20 days later. Sepsis was complicated by shock and multiorgan failure including a stage III kidney injury and need for hemodialysis. He died 41 days after the initial surgery. The remainder of the patients, except for four, had a return of sCr to baseline values. Postoperative ketorolac was administered to 69 % of cases and 75.4 % of controls ($P=0.52$) for a median dose of 90 mg (60–150 mg) vs. 180 mg (90–240 mg), respectively ($P<0.01$).

Characteristics of Patients Who Developed a Late Kidney Injury

Thirty patients (12 men, 18 women, mean age 50±13 years) developed a kidney injury after 72 h of surgery, but within 30 days of surgery, and all of these were AKIN stage I injuries except for one stage II and three stage III injuries. Sixteen of these patients were readmitted to the hospital. The median number of days between surgery and the first

Table 1 Clinical characteristics of patients undergoing bariatric surgery

Variable	AKI cases (*N*=71)	Controls (*N*=142)	*P* values
Age (years)	51.6±12.7	48.0±11.5	0.02
Body mass index (kg/m^2)	50.6±10.8	46.8±9.0	<0.01
Male	29 (40.9)	36 (25.4)	0.02
Cardiovascular disease	12 (16.9)	11 (7.8)	0.04
Hypertension	58 (81.7)	81 (57.0)	<0.01
Obstructive sleep apnea	54 (76.1)	103 (72.5)	0.58
Respiratory disease	20 (28.2)	44 (31.0)	0.67
Diabetes	42 (59.2)	40 (28.2)	<0.01
Hyperlipidemia	38 (53.5)	51 (35.9)	0.01
Preoperative GFR (mL/min)	78.1±25.4	83.3±25.6	0.04
Surgical duration (h)	5.2±1.9	4.82±1.8	0.10

Values are displayed as number (*N*) and percentage, or mean ± standard deviation. Comparisons between continuous variables were made using the Wilcoxon test and categorical variables with the chi-square test

AKI acute kidney injury, *GFR* calculated glomerular filtration rate

noted elevated serum creatinine was 16 days (IQR 9–23 days). The most common cause of kidney injury was poor oral intake and subsequent volume depletion postoperatively (18 patients). Nine of these patients required hospitalization for volume repletion, two with stage III injuries. One patient who required rehospitalization had a history of idiopathic cardiomyopathy with left ventricular assist device as bridge therapy for eventual heart transplant. Two patients with underlying stage III chronic kidney disease experienced transient increases in their sCr several days after surgery that spontaneously returned to baseline. Six patients developed kidney injury in the setting of anastomotic leak or wound infection that required reoperation. Two other patients were readmitted for bleeding requiring blood transfusions, including a patient that experienced a stage II injury. Another patient developed a kidney injury in the setting of a postoperative course complicated by a myocardial infarction and pneumonia requiring reintubation. Lastly, a 40-year-old male developed a scrotal abscess complicated by sepsis that required surgery 7 days postoperatively. He developed a stage III injury from acute tubular necrosis with sCr increasing from 0.8 to 10.2 mg/dL and required hemodialysis. However, after 8 weeks, he no longer required hemodialysis (sCr not obtained at that visit) and was lost to further follow up. The remainder of the patients, except for four patients, had a return of sCr to baseline values.

Discussion

After bariatric surgery, 70 % of patients who developed AKI, sCr increased within 72 h (early AKI), while in 30 %, it occurred after that time (late AKI). Based on onset timing, we believe that early onset of AKI may be related to factors associated with anesthesia and surgery, while late AKI in sCr usually occurred in the setting of transient volume depletion arising from transient intolerance of oral intake and/or other surgical complications. In both groups, the majority of injuries were AKIN stage I; however, any increase in sCr reflects clinically relevant decrement in GFR [14]. Independent factors associated with early injury were higher BMI and medically treated diabetes mellitus.

Table 2 Logistic regression analysis of clinical factors and their association with the development of acute kidney injury within 72 h of bariatric surgery

Variable	Univariate conditional logistic regression			Multivariable conditional logistic regression		
	OR	95 % CI	*P*	OR	95 % CI	*P*
Age, per 10 years	1.29	1.01–1.66	0.04	1.11	0.82–1.5	0.49
BMI, per 5 unit increase	1.22	1.05–1.42	0.01	1.24	1.06–1.46	0.01
Male gender	2.02	1.11–3.69	0.02	1.34	0.69–2.63	0.39
Cardiovascular disease	2.4	1.01–5.74	0.05	1.64	0.63–4.26	0.31
Hypertension	3.35	1.69–6.66	<0.01	1.78	0.78–4.05	0.17
Obstructive sleep apnea	1.2	0.62–2.31	0.58	–		–
Respiratory disease	0.87	0.47–1.63	0.67	–		–
Diabetes	3.77	2.06–6.9	<0.01	2.77	1.36–5.65	0.01
Hyperlipidemia	2.05	1.15–3.65	0.01	0.91	0.43–1.91	0.80
Preoperative GFR, unit increase	0.99	0.98–1	0.18	–		–
Surgical duration, h	1.14	0.96–1.35	0.13	–		–

AKI acute kidney injury, *BMI* body mass index, *GFR* glomerular filtration rate

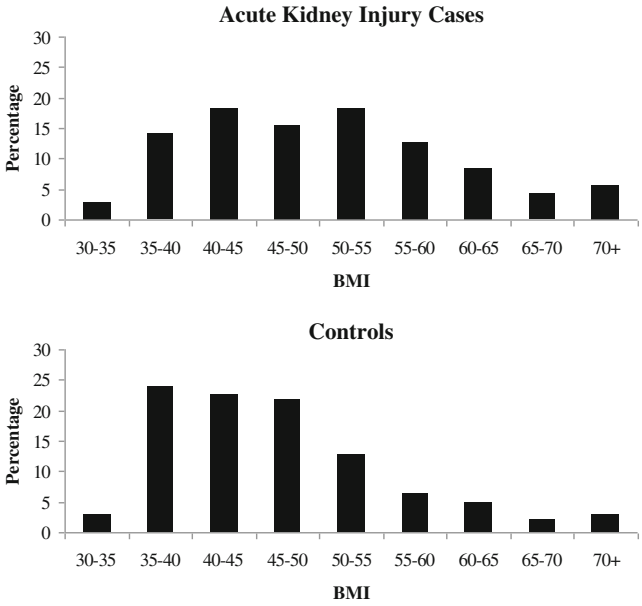

Fig. 1 Comparison of body mass index (BMI) distribution between patients who developed postoperative acute kidney injury within 72 h of bariatric surgery and matched controls

The observed rate of injury following bariatric surgery in our study is approximately sixfold greater than the rate reported by a review more than 75,000 general surgical cases from the American College of Surgeons National Surgical Quality Improvement Program (ACS-NSQIP) [8]. The rates of injury in this study were greater among patients undergoing an open procedure, consistent with our previous observations [6, 7]. As the number of open procedures declines relative to the number of laparoscopic procedures, we expect that there would be a further reduction in the number of cases of injuries. Our overall rate of injury was slightly less than that reported by Thakar et al. [10], despite that we used the slightly more sensitive AKIN criteria [11] while they used the RIFLE criteria [15]. One explanation for this is that their cohort was from an earlier time period (2003–2005) and a greater proportion of their patients may have had open procedures, information not provided in their report. Regardless, it appears that the patients undergoing bariatric surgery experience rates of kidney injury substantially greater than patients undergoing other general surgical procedures.

A plausible explanation for these higher rates of kidney injury is that all patients undergoing this surgery are obese. Another large study using ACS-NSQIP data of over 300,000 patients undergoing noncardiac surgery found that the risk of postoperative AKI was increased by three- to sevenfold in obese patients when compared to normal weight patients [16]. Further, this risk became greater as BMI index increased [16]. Our multivariable analysis suggests that increasing BMI was a risk for AKI, independent of other obesity-associated comorbidities. In post hoc dichotomized analysis, we demonstrated a 2.4-fold greater risk for super-obese patients (BMI≥50 kg/m^2) compared to bariatric patients with lower weight. In this regard, our results are comparable with the finding of others who reported that the higher BMI in bariatric surgery is associated with increased risk of postoperative AKI [10].

Though obesity per se has been linked to higher rates and acceleration of chronic kidney disease [2], it is closely associated with metabolic syndrome [4], a condition also associated with the development of major risk factors for chronic kidney disease [17]. Different components of the metabolic syndrome (hypertension, hyperlipidemia, microalbuminuria, diabetes, or insulin resistance) may act in concert to increase risk, though identifying the relevance of specific individual factors is challenging. On this note, our results differed from Thakar et al. [10] in that we also found diabetes mellitus to be independently associated with AKI while they found hyperlipidemia and the use of an angiotensin-converting enzyme inhibitors (ACE-I) or angiotensin II receptor blockers (ARB) (but not arterial hypertension) to be independently associated.

General surgical patients from the ACS-NSQIP database who were diabetic were 1.3 (for those on oral therapy) to 1.7 (for those on insulin therapy) times more likely to develop AKI [8]. Though our study did not distinguish between types of therapy for diabetes, we found that any patient with diabetes had a risk of AKI 2.7 times greater that the patient without diabetes. Insulin resistance results in widespread endothelial dysfunction with increased levels of endothelin-1 and decreases in nitric oxide through disruption of nitric oxide synthase both of which can which can impair renal vascular autoregulation [18]. In murine models of ischemic AKI, this endothelial dysfunction leads to worsening of injury in diabetic mice [19].

It is somewhat surprising that hypertension was not found to be an associated factor in either study. Arterial hypertension has been associated with postoperative AKI in major noncardiac [8, 20] surgery and in patients undergoing orthopedic surgical procedures [9]. The use of ACE-I or ARB within 10 h of surgery is associated with increased intraoperative hypotension [21]. In addition, ACE-I and ARB alter glomerular hemodynamics (afferent and efferent arteriolar autoregulation) and glomerular filtration fraction which can increase the risk for renal hypoperfusion in susceptible patients [22]. To evaluate this mechanism as a potential risk factor, we performed a post hoc analysis of antihypertensive medications and were unable to identify specific drug class effects. In addition, we did not find any statistically significant association between the number of antihypertensive medications used and acute kidney injury. Many clinicians also counsel their patients not to take ACE-I or ARBs on the day of surgery; however, we do not have data indicating if patients took their usual antihypertensive therapy on the day of surgery.

The rate and dose of perioperative ketorolac and/or other NSAID administration did not differ between patients that developed AKI compared to controls. Though the percentage of patients administered ketorolac postoperatively was similar between cases and controls, the total ketorolac dose was less among AKI cases. The reason for this is unclear, but the surgical team may have discontinued the administration of ketorolac once evidence of acute renal injury was noted. The current study was not designed to determine if an association between ketorolac and/or other NSAID administration and kidney injury exists in this cohort of surgical patients. Nonsteroidal anti-inflammatory drugs have well-known effects on renal autoregulation from impaired synthesis of renal prostaglandins which reduces renal plasma flow and GFR [23, 24]. In surgical patients with normal renal function, a transient decrement in renal function may be observed but is usually not significant clinically [25]; however, in the setting of kidney disease and intrarenal microvascular dysfunction, continued NSAID administration should be avoided [23, 26].

This study was not designed to identify factors associated with injuries that occurred after 72 h. However, the series of patients in this cohort who did develop a later injury frequently did so in the setting of volume depletion. This suggests that there should be a high level of suspicion for kidney injury in patients who cannot maintain adequate oral intake or are suffering from a major postsurgical complication. An analysis of the Bariatric Outcomes Longitudinal Database of readmissions found that nausea, vomiting, and volume depletion were the most common complications at the time of readmission [27]. In our cohort, half of the patients suffering from volume depletion from poor oral intake required rehospitalization.

Outcomes of Patients with AKI

AKI patients were more likely to receive blood transfusions, have postoperative complications, and required longer hospital stays. It is unclear if these observations were a result of AKI or other factors (more complicated surgery or patients with greater disease burden). Most patients had eventual return of kidney function. However, studies suggest that the risk for development of chronic kidney disease is much greater in patients who have experienced prior AKI [28] and the long-term consequence of these injuries is not well known.

Limitations

This study suffers from limitations inherent to retrospective studies. Our timeframe for observation and analysis of events was 72 h postoperatively to limit analysis to preoperative and perioperative factors associated with AKI. This may have resulted in missing some cases because sCr may have a delayed rise in response to the punitive renal insult. In addition, our data on antihypertensive medications lack specific information regarding when these medications were taken in relation to timing of surgery. Our findings reflect a practice at a single center tertiary care institution of a relatively homogenous surgical population which limits the wide generalizability to other populations.

Conclusions

The incidence of postoperative AKI following bariatric surgery is approximately 6 %, which is much greater than observed rates following other general surgical procedures; however, most injuries were transient stage I injuries. Increased BMI and diabetes were independently related with increased risk of acute kidney injury. Another subset of patients developed kidney injury later in the postoperative period, usually in the setting of volume depletion. Appreciation of risk factors for postoperative AKI may help to identify high risk surgical populations.

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Conflict of interest None of the authors have conflicts of interest to report.

References

1. Wang Y, Chen X, Song Y, et al. Association between obesity and kidney disease: a systematic review and meta-analysis. Kidney Int. 2008;73:19–33.
2. Tomaszewski M, Charchar FJ, Maric C, et al. Glomerular hyperfiltration: a new marker of metabolic risk. Kidney Int. 2007;71:816–21.
3. de Jong PE, Verhave JC, Pinto-Sietsma SJ, et al. Obesity and target organ damage: the kidney. Int J Obes Relat Metab Disord. 2002;26 Suppl 4:S21–4.
4. Grundy SM, Brewer Jr HB, Cleeman JI, et al. Definition of metabolic syndrome: report of the National Heart, Lung, and Blood Institute/American Heart Association conference on scientific issues related to definition. Circulation. 2004;109:433–8.
5. Afshinnia F, Wilt TJ, Duval S, et al. Weight loss and proteinuria: systematic review of clinical trials and comparative cohorts. Nephrol Dial Transplant. 2010;25:1173–83.
6. Weingarten TN, Flores AS, McKenzie JA, et al. Obstructive sleep apnoea and perioperative complications in bariatric patients. Br J Anaesth. 2011;106:131–9.
7. Weingarten TN, Swain JM, Kendrick ML, et al. Nonalcoholic steatohepatitis (NASH) does not increase complications after laparoscopic bariatric surgery. Obes Surg. 2011;21:1714–20.
8. Kheterpal S, Tremper KK, Heung M, et al. Development and validation of an acute kidney injury risk index for patients

undergoing general surgery: results from a national data set. Anesthesiology. 2009;110:505–15.
9. Jafari SM, Huang R, Joshi A, et al. Renal impairment following total joint arthroplasty: who is at risk? J Arthroplasty 2010; 25: 49-53, 53 e41-42.
10. Thakar CV, Kharat V, Blanck S, et al. Acute kidney injury after gastric bypass surgery. Clin J Am Soc Nephrol. 2007;2:426–30.
11. Mehta RL, Kellum JA, Shah SV, et al. Acute Kidney Injury Network: report of an initiative to improve outcomes in acute kidney injury. Crit Care. 2007;11:R31.
12. Levey AS, Coresh J, Greene T, et al. Using standardized serum creatinine values in the modification of diet in renal disease study equation for estimating glomerular filtration rate. Ann Intern Med. 2006;145:247–54.
13. Harris PA, Taylor R, Thielke R, et al. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. J Biomed Inform. 2009;42:377–81.
14. Murugan R, Kellum JA. Acute kidney injury: what's the prognosis? Nat Rev Nephrol. 2011;7:209–17.
15. Uchino S, Bellomo R, Goldsmith D, et al. An assessment of the RIFLE criteria for acute renal failure in hospitalized patients. Crit Care Med. 2006;34:1913–7.
16. Glance LG, Wissler R, Mukamel DB, et al. Perioperative outcomes among patients with the modified metabolic syndrome who are undergoing noncardiac surgery. Anesthesiology. 2010;113:859–72.
17. Chen J, Muntner P, Hamm LL, et al. The metabolic syndrome and chronic kidney disease in U.S. adults. Ann Intern Med. 2004;140:167–74.
18. Anfossi G, Russo I, Doronzo G, et al. Relevance of the vascular effects of insulin in the rationale of its therapeutical use. Cardiovasc Hematol Disord Drug Targets. 2007;7:228–49.
19. Abu-Saleh N, Ovcharenko E, Awad H, et al. (2012) Involvement of the endothelin and nitric oxide systems in the pathogenesis of renal ischemic damage in an experimental diabetic model. Life Sci (in press)
20. Bihorac A, Yavas S, Subbiah S, et al. Long-term risk of mortality and acute kidney injury during hospitalization after major surgery. Ann Surg. 2009;249:851–8.
21. Comfere T, Sprung J, Kumar MM, et al. Angiotensin system inhibitors in a general surgical population. Anesth Analg. 2005;100:636–44.
22. Braam B, Koomans HA. Renal responses to antagonism of the renin–angiotensin system. Curr Opin Nephrol Hypertens. 1996;5:89–96.
23. Murray MD, Brater DC. Renal toxicity of the nonsteroidal anti-inflammatory drugs. Annu Rev Pharmacol Toxicol. 1993;33:435–65.
24. Toto RD, Anderson SA, Brown-Cartwright D. Effects of acute and chronic dosing of NSAIDs in patients with renal insufficiency. Kidney Int. 1986;30:760–8.
25. Lee A, Cooper MG, Craig JC, et al. Effects of nonsteroidal anti-inflammatory drugs on postoperative renal function in adults with normal renal function. Cochrane Database Syst Rev 2007: CD002765.
26. Carmichael J, Shankel SW. Effects of nonsteroidal anti-inflammatory drugs on prostaglandins and renal function. Am J Med. 1985;78:992–1000.
27. Dorman RB, Miller CJ, Leslie DB, et al. Risk for hospital readmission following bariatric surgery. PLoS One. 2012;7:e32506.
28. Chawla LS. Acute kidney injury leading to chronic kidney disease and long-term outcomes of acute kidney injury: the best opportunity to mitigate acute kidney injury? Contrib Nephrol. 2011;174:182–90.