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Acute Kidney Injury, Renal Function, and the Elderly Obese Surgical Patient: A Matched Case-Control Study

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Abstract

Objective—To investigate the association between obesity and perioperative acute kidney injury (AKI), controlling for preoperative kidney dysfunction.

Summary Background Data—More than 30% of patients over the age of 60 are obese, and therefore at risk for kidney disease. Post-operative AKI is a significant problem.

Methods—We performed a matched case control study of patients enrolled in the Obesity and Surgical Outcomes Study (OBSOS), using Medicare claims data enriched with detailed chart review. Each AKI patient was matched to a non-AKI control similar in procedure type, age, sex, race, emergency status, transfer status, baseline eGFR, admission APACHE score, and the risk of death score with fine balance on hospitals.

Results—We identified 514 AKI cases and 694 control patients. Of the cases, 180 (35%) followed orthopedic procedures and 334 (65%) followed colon or thoracic surgery. After matching, obese patients undergoing a surgical procedure demonstrated a 65% increase in odds of AKI within 30 days from admission (OR=1.65, $p<0.005$) when compared to the non-obese patients. After adjustment for potential confounders, the odds of post-operative AKI remained elevated in the elderly obese (OR=1.68, $p=0.01$.)

Conclusions—Obesity is an independent risk factor for post-operative AKI in patients over 65 years of age. Efforts to optimize kidney function pre-operatively should be employed in this at risk population along with keen monitoring and maintenance of intra-operative hemodynamics. When

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subtle reductions in urine output or a rising creatinine are observed post-operatively, timely clinical investigation is warranted to maximize renal recovery.

Introduction

In 2000, 30.5% percent of patients living in the United States were obese, with more than 15% of patients over the age of 70 being obese.[1] As recently as 2008, more than 30% of patients over the age of 60 are obese.[2] Obesity has been shown to be an independent risk factor for chronic kidney disease.[3, 4] The relationship between obesity and post-operative acute kidney injury (AKI) is less well defined. A rise in creatinine of as little as 0.3 mg/dl following hospital admission or surgical intervention has been associated with a 4.5-fold increase in the odds of in-patient death.[5]

Post-operative AKI accounts for 18% to 47% of all hospital-acquired AKI[6] and is often multifactorial. The majority of post-operative AKI is thought to result from renal hypoperfusion or acute tubular necrosis.[7, 8] Obese surgical patients are at an increased risk for hypoperfusion as the intra-operative volume resuscitation required to minimize the risk of AKI is often underestimated in the obese patient.[9] Similarly, obesity is associated with multiple independent risk factors for post-operative AKI including chronic kidney disease (CKD), diabetes and heart failure.

Current literature investigating the effect of obesity on post-operative AKI is conflicting. Some studies have shown that post-operative renal impairment following cardiac and noncardiac surgery is more common in the obese than the non obese.[10–12] Others have found no difference in AKI in the obese when controlling for pre-operative renal function.[13] While comorbidities associated with obesity can make peri-operative management of the obese patient more complex, it is not clear if obesity is independently associated with AKI in patients undergoing non-bariatric, non-cardiac surgery. Using the unique OBSOS dataset, we evaluate the association between obesity and acute kidney injury in the post-operative period to identify a potential target for quality improvement initiatives when caring for obese surgical patients.

Methods

We performed a matched case-control study of patients enrolled in the Obesity and Surgical Outcomes Study (OBSOS). OBSOS, which has been previously described,[14, 15] was designed to compare very obese (body mass index (BMI) > 35 kg/m^2) and non-obese (20 $kg/m^2 \leq BMI < 30\ kg/m^2$) elderly surgical patients with respect to outcomes, such as survival, complications, length of stay, and readmission rates.[15] Following approval from The Children's Hospital of Philadelphia IRB (the IRB associated with the PI of the study), as well as hospital-specific IRBs when requested, the study examined surgical outcomes for patients enrolled in Medicare in three states: Illinois, New York and Texas. Patients between the ages of 65 and 80 were enrolled if they underwent hip or knee replacement, thoracotomy or colon resection. Administrative claims data were collected for all patients for at least 6 months prior to the index surgical procedure and a minimum of 30 days following the surgical intervention. In addition to the claims data, baseline laboratory studies (including serum creatinine), vital signs and body mass index were obtained from direct review of the medical charts for all subjects enrolled in OBSOS.

In this study, we excluded patients with a pre-operative history of dialysis dependence as defined by International Classification of Diseases, Ninth Revision (ICD-9) diagnosis and procedure codes and Current Procedural Terminology (CPT) codes (Appendix A). Procedure codes for patient exclusion were identified in the Inpatient file (Part A) (ICD-9 procedure codes) and Outpatient and Carrier files (Part B) (CPT procedure codes.)

Diagnosis codes for patient exclusion were identified in all three sources using ICD-9 diagnosis codes.

Cases of acute kidney injury (AKI) were identified using specific International Classification of Diseases, Ninth Revision (ICD-9) diagnosis codes (see Appendix B). Patients were assigned a diagnosis of AKI if it was coded upon discharge from the index admission or coded at any subsequent inpatient or outpatient follow-up encounter within 30 days of admission from the index surgical procedure. Five hundred and fourteen AKI cases were available for inclusion in this study.

Using the unique hybrid OBSOS dataset, containing administrative claims and chart abstracted data, we were able to calculate the pre-operative estimated glomerular filtration rate (eGFR) using the 1999 Modification of Diet in Renal Disease (MDRD4) formula.[16] For those observations with missing creatinine, we estimated the missing values of eGFR using a robust regression with the other non-missing variables in the MDRD4 formula and the matching variables. An additional determinant of pre-operative kidney dysfunction and end stage kidney function was defined using the claims data as a secondary control for pre-operative kidney function. (Appendix C)

Known surgical complications associated with hemodynamic instability, and therefore risk factors for AKI, were considered potential confounders. Bleeding, sepsis, cardiac emergency, cardiac events and hypotension were defined for all study patients using the administrative claims data as previously described.[11] Using claims data as defined in Appendix D, each variable was uniquely assigned using ICD – 9 CM diagnosis and procedure codes to satisfy described inclusion and exclusion criteria.

Matching Methods

We matched (i) exactly on procedure subcategory (ii) with both fine balance and near-exact matching for the hospitals (described below) [17], (iii) explicitly minimizing the differences in the means of important patient covariates, and (iv) also minimizing the Kolmogorov-Smirnov test for eGFR to balance its whole empirical distribution across cases (with AKI) and matched controls (those without AKI). Each AKI patient was matched to a control non-AKI patient with similar age, sex, race, emergency status, transfer status, and baseline eGFR. Cases were also matched to controls that were similar on the modified APACHE score calculated using chart the abstracted data, a risk-of-death score using claims data, and preoperative kidney dysfunction and end-stage kidney disease as defined using claims data[18, 19]. (Appendix C) The risk-of-death score was created from a model which takes into account patient comorbidities as estimated from Medicare claims from all hospitals in Illinois, Texas and New York excluding the 47 hospitals that performed chart abstractions for this study.[14]

As there were 47 hospitals in the study, we also wanted to account for potential differences in practice styles and systems issues that may lead to differences in outcomes. Hence we matched on the hospital using “fine balancing.”[20–22] Fine balancing assures that for each study hospital the number of patients with AKI and the number of patients without AKI utilized in the final matches were the same. We enhanced this fine balancing for hospitals with near-exact matching to not only balance the cases and matched controls in aggregate across hospitals but also to increase the number of matched pairs from the same hospitals.[17]

Thoracic and colorectal cases were matched with a 1:1 matching ratio, whereas orthopedic cases were matched with 1:2 ratio due to the larger pool of available controls.

Statistical Tests

Balance on match characteristics was examined using the Wilcoxon rank-sum test for continuous variables[23] and the Fisher exact test for categorical variables.[24] Conditional logistic regression was used to control for complications that are known to be associated with AKI.[25] In an attempt to isolate the risk of AKI attributable to obesity, we adjusted for bleeding, sepsis, cardiac events and cardiac emergencies in the regression models, both with and without hypotension. As hypotension in the obese surgical patient may be related to management of the hemodynamic profile of the obese patient, we ran the models with and without an interaction term for obesity and hypotension and tested for the significance of the additional parameters using the fit of the models.[25]

The analysis was performed with and without patients with missing creatinine (n=98 cases and 145 controls). As results were similar with and without patients missing creatinine, results including the imputed values are displayed, using all patients. We also provide regression results after excluding patients with missing creatinine in Appendix E.

Results

We identified 514 AKI patients and matched 694 controls from a pool of 15338 controls that met study criteria. Of the cases, 180 (35.02%) followed orthopedic procedures and 334 (64.98%) followed colon or thoracic surgery. After matching, there was no significant difference between the cases and matched controls in age, sex, race, procedure, transfer status, emergency status, pre-operative eGFR, preoperative kidney dysfunction defined by claims data, APACHE, or risk of death score. See Table 1 for results of colectomy and thoracotomy matches and Table 2 for orthopedic matches.

Obese patients undergoing a surgical procedure demonstrated a 65% increase in odds of AKI within 30 days from admission (OR=1.65, p-value < 0.005) after matching. (Table 3) After adjustment for complications known to be associated with an increased risk of AKI, obese patients remained at increased risk of AKI when compared to the non-obese patients. (OR=1.74, p-value < 0.005, Table 3). After adjustment for the effect of hypotension on the likelihood of post-operative AKI, the obese remained at increased risk of AKI (OR=1.68, p-value=0.01.) Sepsis, cardiac emergency/event and hypotension remained significantly associated with an increased likelihood of AKI. The addition of interaction terms between obesity and hypotension did not have a significant effect on the predictive value of the model (p-value=0.68.)

Discussion

We conducted this study to further investigate the observed relationship between postoperative AKI and obesity[14] after incorporating additional information regarding pre-operative kidney function. In this study, unlike studies using only administrative data, we were able to estimate pre-operative kidney function utilizing the availability of chart abstracted data including: BMI and baseline laboratory studies, including creatinine. In so doing, we were able to control for the contribution of pre-operative kidney dysfunction associated with an elevated BMI when evaluating the relationship between obesity and the likelihood of post-operative AKI in a large cohort of elderly surgical patients. Notably, pre-existing renal impairment has been previously shown to be the most consistent risk factor for post-operative AKI. Additionally, we sought to understand the effects of potential causes of renal hypoperfusion that result in AKI, such as sepsis, hypotension, bleeding and cardiac events or emergencies, on the relationship between AKI and obesity in a more focused analysis than we performed in the original study.

AKI is a potentially lethal clinical problem. Post-operative AKI is associated with prolonged length of stay,[5] impaired long term survival[26] and has been identified as a cause for readmission.[27] Identification of at risk populations may permit the adoption of pre-operative interventions to mitigate risk. While obesity is known to be associated with kidney impairment, obesity alone has not been well accepted as a risk factor for post-operative AKI. Therefore, efforts to minimize acute kidney injury centered on pre-operative assessment of renal risk may frequently overlook the obese patient. Our findings suggest that obesity should be recognized as an independent risk factor for post-operative AKI in the elderly surgical patient.

This work expands the literature regarding AKI in the elderly. Renal recovery from AKI can be substantially lower in patients over the age of 65 when compared to younger patients.[28] The reasons for this finding are not clearly understood. Additionally, even mild post-operative AKI has been shown to result in chronic kidney disease.[29] We have now demonstrated that obesity independently places the elderly at risk for AKI following surgical intervention even after adjustment for pre-operative kidney function and comorbidities.

In this study, we identified obesity as an independent risk factor for post-operative AKI after controlling for pre-operative renal function. Upon further evaluation, the effects of hypotension, sepsis and cardiac events in the peri-operative period in conjunction with the case-mix of the obese appeared to explain a portion of the increased risk of AKI observed in the obese patients, but did not account for the entire effect. The effects of hypotension and complications on the risk of AKI in the obese surgical patient are consistent with our clinical experience. Monitoring blood pressure in the obese patient can be challenging and detection of deterioration in the obese patient is difficult in part due to impaired sensitivity of physical examination in the obese.

Furthermore, the data suggest that hypotension may be a mediator of the elevated risk of post-operative AKI in the obese patient. Hypotension is a known risk factor for pre-renal azotemia. In a recent meta-analysis, Brienza et al reported that hemodynamic optimization resulted in a decreased risk of peri-operative AKI.[30] Kheterpal et al showed an association between acute renal failure and vasopressor use intra-operatively.[7] Therefore, is not clear if “normal” blood pressure or euvolemia is more important in preserving renal function. Volume resuscitation in the obese patient is often more challenging that in the non-obese. Unfortunately, while under-resuscitation can result in hypotension and oliguria, volume overload can be associated with cardiopulmonary and wound complications[31] which are also more common in obese patients.[32, 33] The inability of practitioners to adequately gauge volume status in the obese patient might contribute to the increased risk of post-operative AKI observed in this study. Typical signs of volume overload, distended neck veins and peripheral edema, may be hard to appreciate in the obese patient due to redundant fatty tissue. Similarly, inadequately sized blood pressure cuffs, may make non-invasive monitoring more difficult in the obese patient. For operations with expected blood loss, volume shifts, or a preference to restrict fluid resuscitation, closer monitoring might be useful for the obese patients to mitigate the occurrence of AKI.

Most of the work on post-operative AKI and obesity has been performed on bariatric, cardiac surgery and transplantation patients. The bariatric outcomes, by definition, make comparisons to the non-obese impossible. Cardiac surgery and transplantation populations make it hard to generalize to our cohort of orthopedic, thoracic and general surgical patients. Despite these limitations, elevated BMI has been associated with AKI following surgery.[34–36] To our knowledge, we are the first to demonstrate the association between obesity and AKI with adjustment for comorbidities, physiologic state at the time of surgery and the admission eGFR.

Strategies for renal preservation should be extended to the obese patient. Pre-operative efforts should be made to minimize exposure to nephrotoxins. Hydration with 0.9% normal saline around exposure to iodinated contrast may be of benefit to the pre-operative obese patient.[37] Intra-operative monitoring and optimization of renal perfusion should be employed in obese patients. A heightened awareness of the possibility of post-operative AKI in the obese should prompt timely evaluation and intervention when suspected fluctuations in urine production or creatinine levels occur. Practitioners should bear this in mind for all follow-up visits as well and consider laboratory testing when concerns arise on the outpatient setting.

Obese patients with subtle changes in kidney function should prompt initiation of a “renal rescue” program. The program should include careful clinical examination including assessment for rhabdomyolysis,[38] assessment of volume status and identification of complications that can result in AKI. Initiatives to minimize ongoing renal damage including administration of intravenous fluids, vasopressors or inotropes as needed, treatment of sepsis and urinary obstruction, if present and consultation with senior colleagues or nephrologists should be employed.[39]

Informed consent is a critical part of surgical care. While certain oncologic surgical procedures are time sensitive, others like total knee arthroplasty maybe less urgent. Patients over the age of 65 should also be made aware of the association between obesity and post-operative kidney injury. The implications of AKI might provide additional incentive for weight reduction efforts in lieu of surgical intervention. Additionally, consideration should be given to discontinuing nephrotoxic drugs prior to surgical intervention. The patient must understand the risks of surgical intervention in order to make an informed decision. While weight reduction has been effective in management of hypertension and diabetes, the effect of weight reduction on kidney function is not well understood. Future studies should be performed to determine if pre-operative weight loss reduces the risk of post-operative kidney injury in the obese patient.

Because our study is retrospective, one limitation is that we can only report an association between AKI and obesity. We also cannot confirm the role of hypotension in this relationship. Additionally, we are not able to explore the role of medication toxicity or medication usage on the extent of AKI observed because that data was not collected as part of OBSOS. It is also important to note that administrative claims are highly specific but insensitive to cases of AKI.[40] There is no reason to believe that this underascertainment of AKI cases would be differential between obese and non-obese patients. Therefore, the results presented should remain valid despite the fact that we may have missed some cases of AKI.

In conclusion, obesity appears to increase the risk of post-operative AKI in older patients undergoing colon, orthopedic and thoracic surgery. Identifying obesity as a risk factor for AKI, as shown in this study, is a critical step in the journey to improving surgical outcomes for the elderly obese surgical patient. Recognition of this risk factor will result in concrete changes to patient care. Attention to mitigating pre-operative risk by minimizing exposure to nephrotoxic agents and medications and careful management of intra-operative blood pressure and volume status are crucial to kidney preservation in this at-risk population. Similarly, practitioners should have a high index of suspicion when subtle signs of post-operative kidney impairment occur in the elderly obese surgical patient and initiate early intervention of renal rescue efforts.

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Table 1

Match Characteristics (COLECTOMY AND THORACOTOMY)

Controls were matched on age, sex, race, procedure type, estimated glomerular filtration rate (eGFR), emergent and transfer status, previous comorbidity risk score, the admission APACHE score, kidney dysfunction and end-stage kidney disease with fine balance on hospitals.

Variable	AKI Cases N=334	Matched Controls N=334	P-value
Creatinine (mG/dL) mean	1.59	1.57	0.18
BMI (kg/m^2)			
BMI < 20	0.05	0.07	0.51
20 ≤ BMI < 30	0.65	0.61	0.34
30 ≤ BMI < 35	0.16	0.23	0.05
BMI ≥ 35	0.13	0.09	0.14
Mean Age (years)	74.07	74.12	0.96
Sex Male (%)	61.08	58.04	0.93
Race:			
White (%)	88.32	89.82	0.62
Black (%)	7.78	6.89	0.77
Other (%)	3.90	2.99	0.67
Colectomy for cancer (%)	40.12	40.12	≈1.00
Left Colectomy	11.08	11.08	≈1.00
Right Colectomy	23.95	23.95	≈1.00
Total/Other colectomy	5.09	5.09	≈1.00
Colectomy not for cancer (%)	23.95	23.95	≈1.00
Left Colectomy	18.26	18.26	≈1.00
Right Colectomy	2.10	2.10	≈1.00
Total/Other Colectomy	3.59	3.59	≈1.00
Thoracotomy (%)	35.93	35.93	≈1.00
Pneumonectomy	1.50	1.50	≈1.00
Lobectomy	25.15	25.15	≈1.00
Wedge Resection	8.98	8.98	≈1.00
Other Thoracotomy	0.03	0.03	≈1.00
Closed Thoracotomy	4.19	5.09	0.71
Thoracotomy with dx of cancer	33.23	32.04	0.80
Transfer-In (%)	2.69	1.80	0.60
Admission from ER (%)	32.04	30.84	0.80
eGFR	57.35	58.05	0.52
APACHE score (mean)	33.26	33.02	1.00
Risk of Death Score	−2.77	−2.84	0.41
Kidney Dysfunction (%)	29.94	27.84	0.61
End-stage kidney disease (%)	29.34	24.85	0.22

Table 2
Match Characteristics (ORTHOPEDIC)

Controls were matched on age, sex, race, procedure type, estimated glomerular filtration rate (eGFR), emergent and transfer status, previous comorbidity risk score, the admission APACHE score, kidney dysfunction and end-stage kidney disease with fine balance on hospitals.

Variable	AKI Cases N=180	Matched Controls N=360	P-value
Creatinine (mG/dL) mean	1.42	1.42	0.82
BMI (kg/m^2)			
BMI < 20	0.03	0.02	0.55
20 ≤ BMI < 30	0.43	0.50	0.17
30 ≤ BMI < 35	0.21	0.28	0.12
BMI ≥ 35	0.33	0.21	<0.005
Mean Age (years)	73.34	73.34	0.96
Sex Male (%)	49.44	49.44	1.00
Race:			
White (%)	94.44	95.00	0.84
Black (%)	2.78	3.89	0.62
Other (%)	2.78	1.11	0.17
Procedure:			
Hip (%)	42.78	42.78	≈1.00
Total hip replacement	34.45	34.45	≈1.00
Partial hip replacement	3.33	3.33	≈1.00
Revision of hip	5.00	5.00	≈1.00
Knee (%)	57.22	57.22	≈1.00
Total Knee Replacement	53.33	53.33	≈1.00
Revision of Knee	3.89	3.89	≈1.00
Transfer-In (%)	1.11	1.39	≈1.00
Admission from ER (%)	5.00	3.89	0.65
eGFR	59.04	59.04	0.97
APACHE score (mean)	27.61	27.61	0.69
Risk of Death Score	−5.28	−5.29	0.83
Kidney Dysfunction (%)	20.56	17.22	0.35
End-stage kidney disease (%)	23.33	21.11	0.58

Table 3

Conditional logistic models to examine the relationship between obesity and postoperative AKI with adjustment for potential confounders.

	OR	CI	p-value
BMI Only			
<20	0.91	0.49–1.69	0.76
20–30 (reference)	--	--	--
30–35	0.79	0.59–1.06	0.11
≥35	**1.65**	1.16–2.32	<0.005
BMI and complications excluding hypotension			
<20	0.84	0.43–1.67	0.62
20–30 (reference)	--	--	--
30–35	0.87	0.63–1.20	0.40
≥35	**1.74**	1.19–2.53	<0.005
Bleeding	**1.37**	1.03–1.82	0.03
Sepsis	**4.89**	3.08–7.77	<0.005
Cardiac Emergency	**2.55**	1.62–4.03	<0.005
Cardiac Event	**1.89**	1.07–3.36	0.03
BMI and complications including hypotension			
<20	0.90	0.43–1.88	0.78
20–30 (reference)	--	--	--
30–35	0.88	0.63–1.25	0.49
≥35	**1.68**	1.11–2.52	0.01
Bleeding	1.21	0.88–1.65	0.24
Sepsis	**3.50**	2.12–5.79	<0.005
Cardiac Emergency	1.67	1.00–2.81	0.05
Cardiac Event	**1.91**	1.02–3.57	0.04
Hypotension	**5.08**	3.48–7.41	<0.005

Bolded odds ratios denote significant results. Controls were matched on age, sex, race, procedure type, estimated glomerular filtration rate (eGFR), emergent and transfer status, previous comorbidity risk score, the admission APACHE score, kidney dysfunction and end-stage kidney disease with fine balance on hospitals.

Appendix A

Codes for pre-operative (chronic) kidney disease requiring dialysis–excluded from study.

Dialysis ICD-9 Diagnosis/Status Codes	
E870.2	Accidental cut, puncture, perforation or hemorrhage during kidney dialysis or other perfusion
E871.2	Foreign object left in body during kidney dialysis or other perfusion
E872.2	Failure of sterile precautions during kidney dialysis and other perfusion
E874.2	Mechanical failure of instrument or apparatus during kidney dialysis and other perfustion
E879.1	Kidney dialysis as the cause of abnormal reaction of patient, or of later complication, without mention of misadventure at time of procedure
V45.1	Renal dialysis status
V56	Encounter for dialysis and dialysis catheter care
V56.0	Encounter for extracorporeal dialysis
V56.1	Fitting and adjustment of extracorporeal dialysis catheter
V56.2	Fitting and adjustment of peritoneal dialysis catheter
V56.3	Encounter for adequacy testing for dialysis
V56.31	Encounter for adequacy testing for hemodialysis
V56.32	Encounter for adequacy testing for perionteal dialysis
V56.8	Encounter for other dialysis
792.5	Cloudy (hemodialysis) (peritoneal) dialysis affluent
996.68	Infection and inflammatory reaction due to peritoneal dialysis catheter
996.73	Other complications due to renal dialysis device, implant and graft
Dialysis ICD-9 Procedure Codes	
38.95	Venous catheterization for renal dialysis
39.27	Arteriovenostomy for renal dialysis
39.42	Revision of arteriovenous shunt for renal dialysis
39.43	Removal of arteriovenous shunt for renal dialysis
39.95	Hemodialysis
54.93	Creation of cutaneoperiotneal fistula
54.98	Peritoneal dialysis
Dialysis CPT Codes	
36833	Revision open arteriovenous fistula with thrombectomy autogenous or nonautogenous dialysis graft (separate procedure)
90966	ESRD related services for home dialysis per full month, for patients 20 years of age or older
90970	ESRD related services for dialysis less than a full month of service, per day; for patients 20 years of age or older
90989	Dialysis training, patient, including helper where applicable any mode course not completed per training session
90999	Unlisted dialysis procedure, inpatient or outpatient
90935	Hemodialysis procedure with single physician evaluation
90937	Hemodialysis procedure requiring repeated evaluation(s) with or without substantial revision of dialysis prescription
90940	Hemodialysis access flow study to determine blood flow in grafts and arteriovenous fistulae by an indicator method
90945	Dialysis procedure other than hemodialysis with single physician
90947	Dialysis procedure other than hemodialysis requiring repeated physician evaluations, with or without substantial revision of dialysis prescription

99512	Home visit for hemodialysis
99601	Home infusion of peritoneal dialysis (up to 2 hours)
99602	Home infusion of peritoneal dialysis (each additional hour)
4051F	Referred for an arteriovenous (AV) fistula (ESRD, CKD)
4052F	Hemodialysis via functioning arteriovenous (AV) fistula (ESRD)
4053F	Hemodialysis via functioning arteriovenous (AV) graft (ESRD)
4054F	Hemodialysis via catheter (ESRD)
4055F	Patient receiving peritoneal dialysis (ESRD)

Appendix B

[1] Codes used to identify AKI, for identifying cases.

Secondary diagnosis codes	
5845	Renal failure with (acute) tubular necrosis
5846	With lesion of renal cortical necrosis
5847	With lesion of renal medullary (papillary) necrosis
5848	With other specified pathological lesion in kidney
5849	Acute renal failure, unspecified
7885	Oliguria and anuria
7925	Cloudy dialysis effluent
99668	Infection and inflammatory reaction due to peritoneal dialysis catheter (exit site infection or inflammation)
99673	Other complications due to renal dialysis device, implant, and graft
V451	Renal dialysis status
V56	Encounter for dialysis and dialysis catheter care
V560	Encounter for extracorporeal dialysis
V561	Fitting and adjustment of extracorporeal dialysis
V562	Fitting and adjustment of peritoneal dialysis catheter
V563	Encounter for adequacy testing for dialysis
V5631	Encounter for adequacy testing for hemodialysis
V5632	Encounter for adequacy testing for peritoneal dialysis
V568	Encounter other dialysis
E8702	Accidental cut, puncture, perforation or hemorrhage during kidney dialysis or other perfusion
E8712	Foreign object left in body during kidney dialysis or other perfusion
E8722	Failure of sterile precautions during kidney dialysis or other perfusion
E8742	Mechanical failure of instrument or apparatus during kidney dialysis and other perfusion
E8791	Kidney dialysis as the cause of abnormal reaction of patient, or of later complication, without mention of misadventure at time of procedure
Secondary Procedure Codes	
3895	Ven cath renal dialysis
3927	Dialysis arteriovenostom
3995	Hemodialysis
5493	Creation of cutaneoperitoneal fistula
5498	Peritoneal dialysis
CPT Codes	
90935	Hemodialysis procedure with single physician evaluation
90937	Hemodialysis procedure requiring repeated evaluation(s) with or without substantial revision of dialysis prescription
90945	Dialysis procedure other than hemodialysis with single physician evaluation
90947	Dialysis procedure other than hemodialysis requiring repeated physician evaluations, with or without substantial revision of dialysis prescription
90997	Hemoperfusion
90970	ESRD related services for dialysis less than a full month of service, per day; for patients 20 years of age or older

90999	Unlisted dialysis procedure, inpatient or outpatient
4054F	Hemodialysis via catheter (ESRD)
4055F	Patient receiving peritoneal dialysis (ESRD)

[1] Silber JH, Romano PS, Rosen AK, et al. Failure-to-rescue: comparing definitions to measure quality of care. Med Care 2007; 45(10):918–25.

Appendix C

Codes for chronic kidney disease and end-stage kidney failure cormobidities, used in Match 2.

Renal dysfunction codes	
581	Nephrotic syndrome
5810	Nephrotic syndrome, prolifer
5811	Epimembranous nephritis
5812	Membranoprolif nephrosis
5813	Minimal change nephrosis
5818	Nephritic syndrome with other spec pathological lesion in kidney
58181	Nephrotic syndrome in other disorder
58189	Nephrotic syndrome nec
5819	Nephrotic syndrome nos
582	Chronic glomerulonephritis
5820	Chronic proliferative nephritis
5821	Chronic membranous nephritis
5822	Chronic membranoproliferative nephritis
5824	Chronic rapid progr nephrit
5828	Chronic gomerulonephritis with other specific pathologic lesion in kidney
58281	Chronic nephritis in other dis
58289	Chronic nephritis nec
5829	Chronic nephritis nos
583	Nephritis and nephropathy, not spec as acute or chronic
5830	Prolefative nephritis nos
5831	Membranous nephritis nos
5832	Membranoproliferative nephr nos
5834	Rapidly prog nephritis nos
5836	Renal cort necrosis nos
5837	Nephr nos/medull necro
5838	Nephritis and nephropathy, not spec as acute or chronic, with other spec pathological lesion in kidney
58381	Nephritis nos in other dis
58389	Nephritis nec
5839	Nephritis nos
588	Disorders resulting from impaired renal function
5880	Renal osteodystrophy
5881	Nephrogen diabetes insip
5888	Other spec disorder resulting from impaired renal function
58881	Sec hyperparathyrd-renal
58889	Impair ren funct dis nec
5889	Impaired renal funct nos
40300	Mal hy kid w cr kid I–IV

40310	Ben hy kid w cr kid I–IV
40390	Hy kid nos w cr kid I–IV
40400	Mal hy ht/KD I–IV w/o HF
40401	Mal hyp ht/kd I–IV w hf
40410	Ben hy ht/kd I–IV w/o hf
40411	Ben hyp ht/kd I–IV w hf
40490	HY ht/kd nos I–IV w/o HF
40491	Hyp HT/kd nos I–IV w HF
585	Chronic renal failure
5851	Chronic kidney disease stage I
5852	Chronic kidney disease stage II
5853	Chronic kidney disease stage III
5854	Chronic kidney disease stage IV
5859	Chronic kidney disease nos
Renal dysfunction: Current Admission	
584*	Acute renal failure
5845*	Renal failure with (acute) tubular necrosis
5846*	With lesion of renal cortical necrosis
5847*	With lesion of renal medullary (papillary) necrosis
5848*	With other specified pathological lesion in kidney
5849*	Acute renal failure, unspecified
Renal failure codes	
40301	mal hyp kid w cr kid V
40311	Ben hyp kid w cr kid V
40391	Hyp kid nos w cr kid V
40402	Mal hy hy/kd st V w/o HF
40403	Mal hyp ht/kd stg V w HF
40412	Ben hy ht/kd st V w/o HF
40413	Ben hyp ht/kd stg V w HF
40492	Hy ht/kd nos st V w/o HF
40493	Hyp ht/kd nos st V w hf
5855	Chronic kidney disease stage V
5856	End stage renal disease
V420	Kidney transplant status
586	Renal failure nos
V56	Encounter for dialysis and dialysis catheter care
V56.0	Encounter for extracorporeal dialysis
V56.1	Fitting and adjustment of extracorporeal dialysis
V56.2	Fitting an dadjustment of peritoneal dialysis catheter

V56.3	Encounter for adequacy testing for dialysis
V56.31	Encounter for adequacy testing for hemodialysis
V56.32	Encounter for adequacy testing for peritoneal dialysis
V56.8	Enounter other dialysis
7925	Cloudy dialysis effluent
996.68	Infection and inflammatory reaction due to peritoneal dialysis catheter (exit site infection or inflammation)
996.73	Other complications due to renal dialysis device, implant, and graft
996.76	Other complications due to genitourinary device, implant and graft
V45.1	Renal dialysis status
792.5	Cloudy (hemodialysis) (peritoneal) dialysis affluent
E870.2	Accidental cut, puncture, perforation or hemorrhage during kidney dialysis or other perfusion
E871.2	Foreign object left in body during kidney dialysis or other perfusion
E872.2	Failure of sterile precautions during kidney dialysis or other perfusion
E874.2	Mechanical failure of instrument or apparatus during kidney dialysis and other perfusion
E879.1	Kidney dialysis as the cause of abnormal reaction of patient, or of later complication, without mention of misadventure at time of procedure
ICD9 Procedure Codes	
3895	Ven cath renal dialysis
3927	Dialysis arteriovenostom
3942	Revision of arteriovenous shunt for renal dialysis
3943	Removal renal dialysis shunt
3995	Hemodialysis
5498	Peritoneal dialysis
CPT Codes	
36833	Revision open arteriovenous fistula with thrombectomy autogenous or nonautogenous dialysis graft (separate procedure)
90966	ESRD related services for home dialysis per full month, for patients 20 years of age and older
90970	ESRD related services for dialysis less than a full month of service, per day; for patients 20 years of age or older
90989	Dialysis training, patient, including helper where applicable any mode course not completed per training session
90999	Unlisted dialysis procedure, inpatient or outpatient
90935	Hemodialysis procedure with single physician evaluation
90937	Hemodialysis procedure requiring repeated evaluation(s) with or without substantial revision of dialysis prescription
90940	Hemodialysis access flow study to determine blood flow in grafts and arteriovenous fistulae by an indicator dilution method, hook-up; measurement and disconnection
90945	Dialysis procedure other than hemodialysis with single physician evaluation
90947	Dialysis procedure other than hemodialysis requiring repeated physician evaluations, with or without substantial revision of dialysis prescription
99512	Home visit for hemodialysis
99601	Home infusion of peritoneal dialysis (up to 2 hours)
99602	Home infusion of peritoneal dialysis (each additional hour)
4051F	Referred for an arteriovenous (AV) fistula (ESRD, CKD)
4052F	Hemodialysis via functioning arteriovenous (AV) fistula (ESRD)
4053F	Hemodialysis via functioning arteriovenous (AV) graft (ESRD)

4054F	Hemodialysis via catheter (ESRD)
4055F	Patient receiving peritoneal dialysis (ESRD)

*all codes identified only in look-back period except those marked with *

Appendix D

Data used to Determine Post-operative Diagnosis of Bleeding, Sepsis, Cardiac Emergency, Cardiac Event, and Hypotension (numbers indicated International Diagnosis Codes, Ninth Edition included in definition or explicitly excluded in definition unless otherwise specified)

Post- Operative Diagnosis	Data Elements
Bleeding	
Included	**Secondary diagnosis codes:** [2851 or (5780, 5781, 5789 and principal procedure exclusion), or (5307 and DRG exclusion 1) or any of (4560, 45620, 53082, 53100, 53101, 53120, 53121, 53130, 53131, 53190, 53191, 53200, 53201, 53210, 53211, 53220, 53221, 53230, 53231, 53290, 53291, 53300, 53301, 53310, 53311, 53320, 53321, 53330, 53331, 53390, 53391, 53400, 53401, 53410, 53411, 53420, 53421, 53430, 53431, 53490, 53491, 53501, 53511, 53540, 53541, 53551, 53561, 53784, 56212, 56213, 5693, 56985, 5789 and DRG exclusion 2)] and exclusion of Trauma defined by DRG or by principal diagnosis or History of alcoholism
	CPT procedure codes: (75726, 43227, 43255, 44366, 44391, 45317, 45334 and principal procedure exclusion)
Excluded	Trauma defined by DRG or principal diagnosis or History of alcoholism
	*Trauma as defined by principal diagnoses (**include all fourth and fifth digit subclassifications for the following codes**)*
	800, 801, 802, 803, 804, 805, 806, 807, 808, 809, 810, 811, 812, 813, 814, 815, 817, 818, 819, 820, 821, 822, 823, 824, 825, 827, 828, 829, 830, 831, 832, 833, 834, 835, 836, 837, 838, 839, 850, 851, 852, 853, 854, 860, 861, 862, 863, 864, 865, 866, 867, 868, 869, 870, 871, 872, 873, 874, 875, 876, 877, 878, 879, 880, 881, 882, 884, 887, 890, 891, 892, 894, 896, 897, 900, 901, 902, 903, 904, 925, 926, 927, 928, 929, 940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 952, 953, 958
	Trauma DRGs
	002, 027, 028, 029, 031, 032, 072, 083, 084, 235, 236, 237, 440, 441, 442, 443, 444, 445, 446, 456, 457, 458, 459, 460, 484, 485, 486, 487, 491, 504, 505, 506, 507, 508, 509, 510, 511(2004–2007)
	027, 082, 083, 084, 085, 086, 087, 088, 089, 090, 154, 155, 156, 183,184,185, 483, 484, 533, 534, 535, 536, 537, 538, 901, 902, 903, 906, 907, 908, 909, 913, 914, 927, 928, 929, 933, 934, 935, 955, 956, 957, 958, 959, 963, 964, 965(2008–2009)
	History of alcoholism in look back period defined as secondary diagnosis
	2910, 2911, 2912, 2913, 2914, 2915, 29181, 29182, 29189, 2919, 30300, 30301, 30302, 30303, 30390, 30391, 30392, 30500, 30501, 30502, 30503
	Principal procedure codes: 444, 4440, 4441, 4442 if secondary diagnoses 5780, 5781, 9
	DRG
	1) *DRG* = 146–171(2004–2007)
	332–358(2008–2009) if secondary diagnosis = 5307
	2) *DRG* = 146–167, 170–184, 188–208(2004–2007)
	326–358, 374–395, 405–446(2008–2009) if any of the secondary diagnoses in the inclusion are in the set of diagnoses 4560–5789
Sepsis	
Included	**Secondary diagnosis codes:** 0380, 0381, 0382, 0383, 0384, 03810, 03811, 03840, 03841, 03842, 03843, 03844, 03849, 03819, 0388, 0381, 0382, 0383, 0384, 0385, 0386, 0387, 0388, 0389, 78552, 7907
Excluded	**None**
Cardiac Emergency	
Included	**Secondary diagnosis codes:** 4100, 41001, 4101, 41011, 4102, 41021, 4103, 41031, 4104, 41041, 4105, 41051, 4106, 41061, 4107, 41071, 4108, 41081, 4109, 41091, 4271, 4275, 42741, 7855, 78550, 78551
	Secondary procedure codes: (3761, 3791, 9960, 9961, 9962, 9963, 9964, 9969, 996 and exclusion)

Post- Operative Diagnosis	Data Elements
Excluded	**CPT procedure codes:** (92960, 92950, 92950, 92970, 92971, 92980, 92981, 92982, 92984, 92995, 92996, 92997, 92998 and exclusion) **Principal diagnosis codes:** 4275, 7855, 78550, 78551, 78559, 7991 **Principal procedure codes:** 9393, 996, 9963
Cardiac Event	
Included	**Secondary diagnosis codes:** 41189, 99601 or (9971 and any of (7943, 79431, 42612, 42613, 42682, 42689, 42731, 42781, 42789)) **Secondary procedure codes:** 3778, 3780, 3781, 3782, 3783, 3606, 3607, 3609 **CPT procedure codes**: 92953, 33200, 33213, 33201, 33206, 33207, 33208, 33210, 33211, 33212, 33214, 33216, 33217, 33240, 33245, 33246, 33249, 93501, 93510, 93511, 93514, 93524, 93526, 93527, 93529
Excluded	**None**
Hypotension	
Included	**Secondary diagnosis codes:** 2765, 27650, 27651, 27652, 4589, 78550, 78551, 78552, 78559, 7963, 9950, 9954, 9980
Excluded	**None**

Appendix E

Conditional logistic models to examine the relationship between obesity and post-operative AKI with adjustment for potential confounders, excluding the patients with missing creatinine.

	Complete Match		
	OR	**CI**	**p-value**
BMI Only			
<20	0.95	0.48–1.89	0.89
20–30 (reference)	--	--	--
30–35	0.81	0.58–1.13	0.21
≥35	**1.62**	1.09–2.39	0.02
BMI and complications excluding hypotension			
<20	0.86	0.40–1.83	0.69
20–30 (reference)	--	--	--
30–35	0.96	0.67–1.37	0.82
≥35	**1.73**	1.12–2.66	0.01
Bleeding	1.22	0.89–1.69	0.22
Sepsis	**4.55**	2.77–7.48	<0.005
Cardiac Emergency	**2.29**	1.41–3.71	<0.005
Cardiac Event	1.75	0.94–3.25	0.08
BMI and complications including hypotension			
<20	0.88	0.39–2.01	0.77
20–30 (reference)	--	--	--
30–35	0.95	0.65–1.39	0.78
≥35	1.56	0.99–2.47	0.06
Bleeding	1.14	0.81–1.62	0.46
Sepsis	**3.41**	2.00–5.82	<0.005
Cardiac Emergency	1.59	0.92–2.73	0.10
Cardiac Event	1.78	0.92–3.44	0.09
Hypotension	**4.46**	2.95–6.73	<0.005

Bolded odds ratios denote significant results. Basic match on age, sex, race, emergency status, transfer status, baseline eGFR and procedure type with fine balance on hospitals. Complete match on age, sex, race, emergency status, transfer status, baseline eGFR, procedure type, admission APACHE score, the risk of death score and pre-operative kidney dysfunction and end-stage kidney disease with fine balance on hospitals.