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Original contribution

Mortality and costs associated with acute kidney injury following major elective, non-cardiac surgery

W. Brenton French, MD [a], Pranav R. Shah, MD [b], Yahya I. Fatani, MD [c], Megan M. Rashid, MD [b], Spencer T. Liebman, MD [b], Brian J. Cocchiola, MD [b], Kenneth F. Potter, MD [b], Salem Rustom, BS [d], Michael J. Scott, MBChB [b,e,*]

[a] Department of Surgery, Virginia Commonwealth University Health System, Richmond, VA, USA
[b] Department of Anesthesiology, Virginia Commonwealth University Health System, Richmond, VA, USA
[c] Division of Nephrology, Department of Medicine, Virginia Commonwealth University Health System, Richmond, VA, USA
[d] Department of Biostatistics, Virginia Commonwealth University, Richmond, VA, USA
[e] Department of Anesthesiology and Critical Care Medicine, University of Pennsylvania, Philadelphia, PA, USA

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ABSTRACT

Objective: This study evaluated postoperative AKI severity and its relation to short- and long-term patient outcomes.
Design: A retrospective, single-center cohort study of patients undergoing surgery from January 2015 to May 2020.
Setting: An urban, academic medical center.
Patients: Adult patients undergoing elective, non-cardiac surgery at our institution with a postoperative length of stay (LOS) of at least 24 h were included. Patients were included in 1-year mortality analysis if their procedure occurred prior to June 2019.
Interventions: None.
Measurements: Postoperative AKI was identified and staged using the Kidney Disease Improving Global Outcomes definitions. The outcomes analyzed were in-hospital mortality, LOS, total cost of the surgical hospitalization, and 1-year mortality.
Main results: Of the 8887 patients studied, 648 (7.3%) had postoperative AKI. AKI was associated with severity-dependent increases in all outcomes studied. Patients with AKI had rates of in-hospital mortality of 2.0%, 3.8%, and 12.5% for stage 1, 2, and 3 AKI compared to 0.3% for patients without AKI. Mean total costs of the surgical hospitalization were $23,896 (SD $23,736) for patients without AKI compared to $33,042 (SD $27,115), $39,133 (SD $34,006), and $73,216 ($82,290) for patients with stage 1, 2, and 3 AKI, respectively. In the 6729 patients who met inclusion for 1-year mortality analysis, AKI was also associated with 1-year mortality rates of 13.9%, 19.4%, and 22.7% compared to 5.2% for patients without AKI. In multivariate models, stage 1 AKI patients still had a higher probability of 1-year mortality (OR 1.9, 95% CI 1.3–2.6, $p < 0.001$) in addition to $4391 of additional costs when compared to patients without AKI (95% CI $2498–$6285, $p < 0.001$).
Conclusions: All stages of postoperative AKI were associated with increased LOS, surgical hospitalization costs, in-hospital mortality, and 1-year mortality. These findings suggest that patients with even a low-grade or stage 1 AKI are at higher risk for short- and long-term complications.

1. Introduction

Acute kidney injury (AKI) is a common and serious postoperative complication [1]. It occurs in approximately 2–18% of all hospitalized patients, with 30–40% of all AKI cases occurring in surgical patients [2–4]. AKI following surgery is associated with an increased risk of in-hospital mortality and increased hospitalization costs [5,6]. Studies have also shown worse short- and long-term outcomes following

* Corresponding author at: Division Chief Surgical & Neuroscience Critical Care Medicine, University of Pennsylvania, 3400 Spruce St., Philadelphia, PA 19104, USA.
E-mail address: Michael.Scott@Pennmedicine.Upenn.edu (M.J. Scott).

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postoperative AKI in non-cardiac surgery [7–12]. However the specific consequences of AKI, particularly of the stages representing smaller changes in renal function, have yet to be fully elucidated in elective surgery. Key limitations of older studies on AKI in elective surgical patients include varying definitions of AKI, highly variable populations, and a lack of data on longer-term outcomes. To further evaluate the short- and long-term effects of postoperative AKI, we performed a retrospective analysis of major elective, non-cardiac surgical patients at our institution. Our aim was to determine the association of postoperative AKI severity with high-level outcomes of length of stay (LOS), costs for the surgical admission, in-hospital mortality, and 1-year mortality.

2. Materials and methods

This study was a retrospective, single-center observational study of adults undergoing major elective, non-cardiac surgery at Virginia Commonwealth University Medical Center from January 1, 2015 to May 31, 2020. Our institutional IRB approved the study protocol and informed patient consent was waived. We adhered to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines for this study [13]. We included patients who underwent elective surgical procedures and were at least 18 years of age. We defined "elective" surgical procedures as a previously scheduled surgery performed on a patient who arrives at the hospital that day. We excluded all patients who were admitted to the hospital prior to their operation, and we excluded all patients with a postoperative hospital stay of <24 h. All cardiac surgery, urological surgery, nephrectomy procedures, and organ transplants were excluded. If a patient had multiple procedures in the same hospitalization, we used the first procedure for analysis. For one-year mortality analysis we excluded all patients having surgery after June 1st, 2019. This was necessary as the 1-year mortality data was current only through June 2020. This was also done given the uncertain effects of the COVID-19 pandemic on our mortality data for this period of time.

2.1. Identifying the pre-existing kidney function

Patients with a preoperative diagnosis of end-stage renal disease (ESRD) were excluded using billed discharge diagnosis ICD-10 codes associated with the hospital encounter of their studied procedure. The preoperative estimated glomerular filtration rate (GFR) was calculated using the Chronic Kidney Disease Epidemiology Collaboration equation (CKD-EPI) from the patient's baseline preoperative creatinine [14].

2.2. Definition and classification of AKI

AKI was classified using the Kidney Disease Improving Global Outcomes (KDIGO) initiative recommendations [15]. Baseline creatinine was defined as the preoperative serum creatinine (SCr) value closest to the time of surgery. Only patients with creatinine values within 30 days of surgery were included. AKI was determined using SCr values obtained after surgery through postoperative day 7. Per KDIGO Guidelines, AKI was defined as follows: a 1.5 to 1.9 fold increase or a 0.3 mg/dL increase from a patient's preoperative baseline SCr was defined as Stage 1 AKI, a 2.0 to 2.9 fold increase from baseline was defined as Stage 2, and a 3.0 fold increase from baseline, an increase in SCr to ≥4.0 mg/dL, or initiation of renal replacement therapy was defined as Stage 3. We modified the stage 1 AKI definition to a 0.3 mg/dL increase or 50% increase from baseline over 7 days, rather than the 0.3 mg/dL increase over 48 h in the KDIGO guideline. The reason for this was to identify all patients who had some form of renal injury in the perioperative period. Urine output was not utilized in the determination of AKI. The first SCr value of the day was used for AKI determination if multiple SCr values were obtained on the same day.

2.3. Data collection

We utilized IBM Cognos (Armonk, NY, USA) for electronic data retrieval from our institution's medical, surgical, and financial records. All patient demographics, laboratory values, surgical case details, total hospital costs, LOS data, and in-hospital mortality data were obtained using these sources. Regarding cost data, in this study the surgical hospitalization is defined as the hospital stay during which the patient underwent their elective procedure. Activity cost-based accounting is utilized at our institution for cost determination; costs analyzed did not include physician professional fees. No readmission cost data or outpatient charges were included in our analysis. Patient history of diabetes or congestive heart failure (CHF) was identified using relevant ICD-10 codes in the patient's discharge diagnoses. Baseline hemoglobin was defined as the most recent value prior to the procedure start time within 30 days of surgery. Intraoperative vasopressors were expressed as norepinephrine equivalents [16]. One-year mortality and date of death were determined using our institution's medical records, the United States Social Security Administration's death master data and the state death master data from the Virginia Department of Health. In the latter two datasets we matched patients by all four identifiers: Social Security Number, first name, last name, and date of birth. If a match was made in either database the patient was considered deceased.

2.4. Statistical analysis

All statistical tests were performed using R version 4.0.2 [17]. Analysis of Variance, Kruskal-Wallis, Chi-squared, and Fisher's Exact tests were used to test for differences in numeric and categorical data as appropriate. P values of 0.05 were considered significant. Unadjusted and adjusted logistic regression were used for the mortality analyses. Linear regression was used for LOS and cost analyses. Adjusted models were built to control for patient and procedural variables including age, American Society of Anesthesiology physical status classification, chronic kidney disease, surgery duration, surgical specialty, and preoperative diagnoses of congestive heart failure and diabetes. Backwards selection was used to create the final adjusted models with a P-to-enter set at 0.25 with a significance level of 0.05. Details of variables used in each analysis are contained in the supplementary tables in the Appendix.

3. Results

We initially identified 84,238 patients undergoing elective procedures over 5 years. After applying our inclusion criteria, we identified 8887 patients for analysis (Fig. 1). Of these, 6729 met criteria for 1-year mortality analysis based on their date of surgery.

3.1. Incidence and risk factors for AKI

We identified 648 (7.3%) patients with postoperative AKI. Of these, 513 (79.2%) were stage 1, 78 (12.0%) were stage 2, and 57 (11.1%) were stage 3. Patient factors and their relation to AKI are shown in Table 1. AKI incidence was highest in general surgery procedures. Patients who did not have AKI were most likely to have a preoperative GFR >90 ml/min/1.73 m^2(n = 3882, 47.1%). Seventy-five percent (n = 43) of stage 3 AKI patients had a preoperative GFR of <90 ml/min/1.73 m^2, while 38.6% (n = 22) had a preoperative GFR of <30 ml/min/1.73 m^2. Similar trends were shown in the 1-year mortality analysis subpopulation (Table A1).

3.2. AKI stage and mortality

All stages of AKI were associated with severity-dependent increases in mortality rates. In-hospital mortality rates following surgery were higher in patients with any stage of AKI (no AKI 0.3%, stage 1–2.0%, stage 2–3.8%, and stage 3–12.5%, $p < 0.001$) (Fig. 2). This incremental

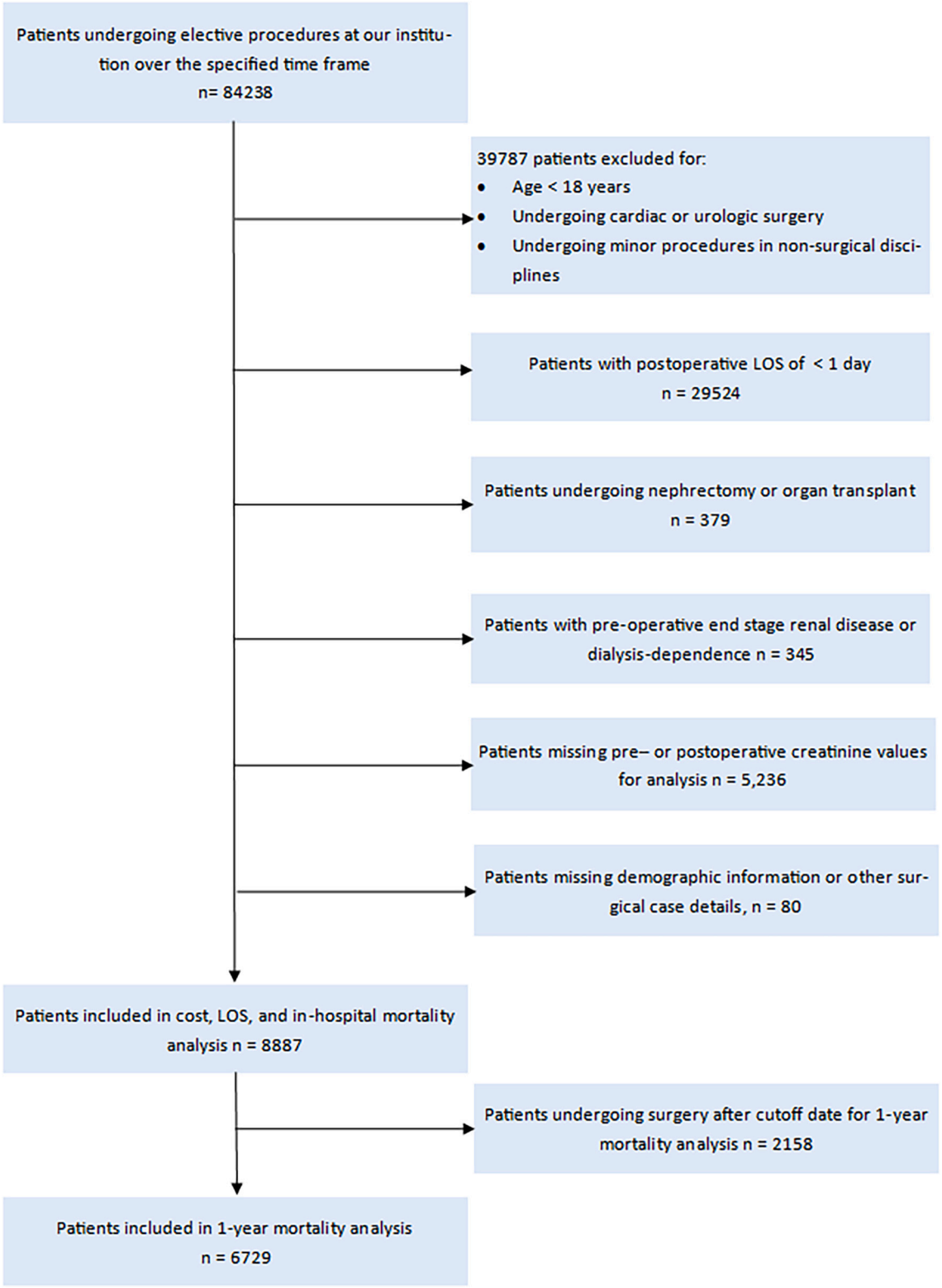


Fig. 1. Patient selection.

increase was mirrored in the 1-year mortality, in which 13.9% ($n = 53$) of patients with stage I AKI had died within 1 year of surgery compared to 5.2% ($n = 325$) of patients without AKI (Fig. 3).

3.3. Implication of AKI on LOS and costs

Patients with postoperative AKI had longer LOS compared to those without AKI. Median LOS was 3.0 (IQR 2.0, 5.0) days for patients without AKI and was 5.2 (IQR 3.2, 8.9), 6.9 (IQR 3.2, 7.4), and 11.0 (IQR 7.3, 17.2) days for stage 1, 2, and 3 AKI respectively ($p < 0.001$) (Fig. 2). In cost analysis, there was a significant increase in mean total costs of the surgical hospitalization with increasing stage of AKI. Stage 1, 2, and 3 AKI patients had mean total hospital costs of $33,042 (SD$27,155), $39,133 (SD$34,006) and $73,216 (SD$82,290) respectively compared

Table 1
Patient factors and relation to postoperative acute kidney injury by stage.

Variable	No AKI [*n* = 8239, 92.7%]	Stage 1 [*n* = 513, 6.2%]	Stage 2 [*n* = 78, 0.9%]	Stage 3 [*n* = 57, 0.6%]
Age (years)	60 (51, 69)	63 (55, 70)	60 (54, 68)	63 (56, 69)
Baseline hemoglobin (g/dL)	12.8 (11.3, 14.0)	12.1 (10.4, 13.5)	11.1 (9.0, 13.0)	10.7 (9.7, 12.1)
Baseline creatinine (mg/dL)	0.8 (0.7, 1.7)	1.0 (0.8, 1.2)	0.8 (0.6, 1.0)	1.2 (0.8, 2.8)
ASA status				
1	83 (1.0%)	2 (0.4%)	0 (0%)	0 (0%)
2	2538 (30.1%)	77 (15.0%)	14 (17.9%)	3 (5.3%)
3	5308 (64.4%)	389 (75.8%)	53 (68.0%)	46 (81%)
4	310 (3.8%)	45 (8.8%)	11 (14.1%)	8 (14%)
BMI (kg/m^2)	29.4 (25.1, 34.7)	30.9 (26.1, 36.9)	32.0 (25.5, 38.0)	32.1 (26.6, 40.0)
Surgery Duration (min.)	144 (96, 221)	172 (110, 277)	204 (121,313)	180 (95, 285)
Estimated Blood Loss in OR (ml)	100 (20, 250)	125 (25, 350)	200 (42, 475)	125 (25, 450)
Norepinephrine Equivalents in OR (mcg)	4 (0,32)	12 (0, 43)	4 (0, 56)	20 (0, 79)
Gender male	3614 (43.9%)	294 (57.3%)	34 (43.6%)	32 (56.1%)
History of Congestive Heart Failure	398 (4.8%)	78 (15.2%)	12 (15.4%)	17 (29.8%)
History of Diabetes Mellitus	1936 (23.5%)	187 (36.5%)	24 (30.8%)	29 (50.9%)
Specialty				
General	1827 (22.2%)	163 (31.8%)	32 (41.0%)	20 (35.1%)
Gynecologic	291 (3.5%)	23 (4.5%)	7 (9.0%)	2 (3.5%)
Head & Neck	276 (3.3%)	13 (2.5%)	3 (3.8%)	3 (5.3%)
Neurosurgery	1975 (24.0%)	65 (12.7%)	7 (9.0%)	0 (0.0%)
Orthopedic	2501 (30.4%)	129 (25.1%)	14 (17.9%)	10 (17.5%)
Plastic	111 (1.3%)	10 (1.9%)	0 (0.0%)	2 (3.5%)
Thoracic	963 (11.7%)	72 (14.0%)	13 (16.7%)	11 (19.3%)
Vascular	295 (3.6%)	38 (7.4%)	2 (2.6%)	9 (15.8%)
Preoperative GFR (ml/min/1.73 m^2)				
GFR > 90	3882 (47.1%)	157 (30.6%)	43 (55.1%)	14 (24.6%)
GFR 60–90	3182 (38.6%)	194 (37.8%)	25 (32.1%)	14 (24.6%)
GFR 30–60	1062 (12.9%)	139 (27.1%)	10 (12.8%)	7 (12.3%)
GFR < 30	113 (1.4%)	23 (4.5%)	0 (0.0%)	22 (38.6%)

Abbreviations: ASA-American Society of Anesthesiologists, BMI-Body Mass Index, OR-Operating room, GFR-Glomerular Filtration Rate.
Statistics presented: median (IQR), n (%). American Society of Anesthesiology (ASA) status presented as mean (SD).

to $23,896 (SD$23,736) for patients with no postoperative AKI (p < 0.001).

3.4. Multivariate analysis of AKI and outcomes

We created multivariate models to account for key patient factors in the relationship between AKI and LOS, in-hospital mortality, 1-year mortality, and costs. Univariate analyses, along with the variables identified for inclusion in the multivariate models, are presented in Tables A3-A10 in the Appendix. After adjusting for confounding variables, AKI had strong associations with all outcomes when evaluated by stage (Table 2). Stage 1 AKI was associated with an additional 1.9 postoperative hospital days (95% CI 1.5, 2.3 $p < 0.001$) compared to patients without AKI. Stage 3 AKI was associated with an additional 10.1 days in-hospital after surgery (95% CI 9.9,11.5 p < 0.001). As the stage of AKI increased, so did the likelihood of in-hospital mortality. Compared with no AKI, stage 1 AKI patients were 5.5 times more likely to die in-hospital following surgery (OR 5.5, 95% CI 2.3, 12.3 p < 0.001). Odds ratios for in-hospital mortality were 10.9 (95% CI 2.3, 36.2 $p = 0.005$) for stage 2 and 13.9 (95% CI 4.0, 42.8 p < 0.001) for stage 3 compared to patients without AKI.

Similar to in-hospital mortality, in the adjusted model patients with stage 1 AKI had a higher likelihood of 1-year mortality compared to patients without AKI. The odds ratio for stage 1 AKI and 1-year mortality was 1.9 when compared to no AKI (95% CI 1.3, 2.6 $p = 0.001$). Stage 2 AKI more than doubled the probability of 1-year mortality (OR 2.4, 95% CI 1.1, 4.7 $p = 0.022$). The odds ratio for stage 3 was 2.3 (95% CI 0.96, 5.12 $p = 0.06$) but was not statistically-significant in this model. After adjustment the total costs of the surgical hospitalization also significantly increased with any AKI (Table 2). Patients with stage 1 AKI had an estimated increase of $4391 in total costs compared to patients without AKI (95% CI $2498, $6285 $p < 0.001$), while stage 3 AKI was associated with $41,493 in additional costs compared to no AKI (95% CI $36,004, $46,983 p < 0.001).

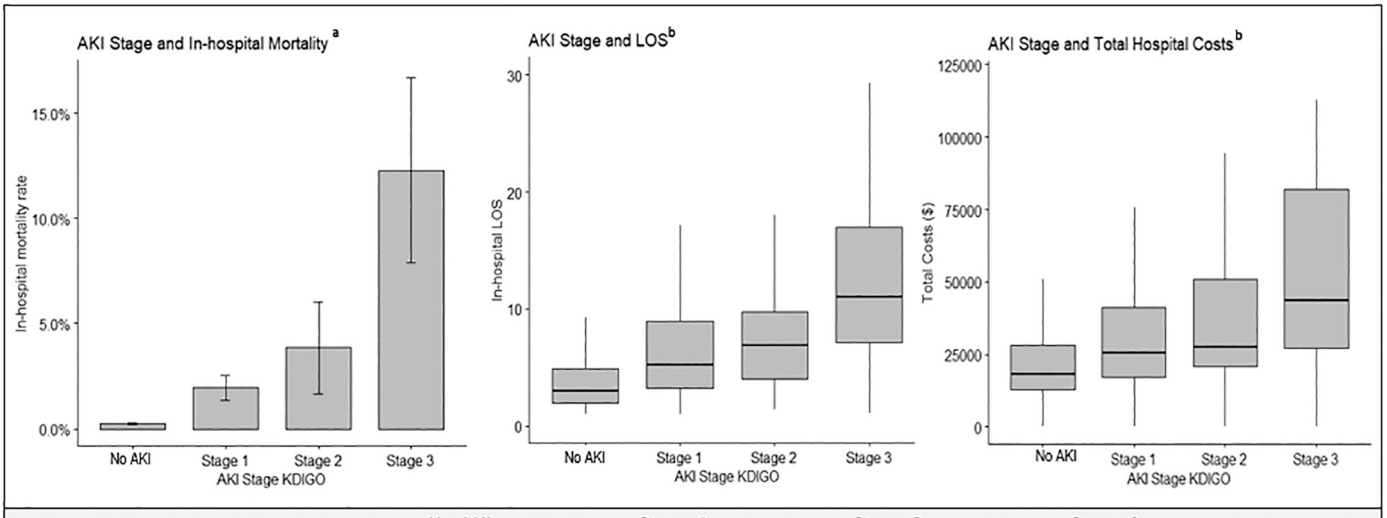
4. Discussion

In our cohort of 8887 adult patients undergoing elective, non-cardiac surgery with a postoperative LOS over 1 day, the presence of any stage of AKI was associated with higher rates of inpatient and 1-year mortality, longer LOS, and higher hospital costs. Our study also confirms the established role of various patient and procedure factors, such as anemia, baseline renal function, and surgical procedure type on the risk of postoperative AKI [18,19].

4.1. Effect of AKI on mortality

We show that postoperative AKI was associated with a significant increase in mortality at all AKI stages with 1-yr mortality rates of 13.9%, 19.4%, and 22.7% in AKI stage 1, 2, and 3 compared to 5.2% in patients without AKI (Figs. 2, 3). A similar pattern was found for in-hospital mortality. Additionally, after controlling for known risk factors, even stage 1 AKI was associated with an OR of 5.5 for in-hospital mortality and 1.8 for 1-year mortality compared to those without AKI (Table 2). Our findings are similar to prior studies demonstrating an association of postoperative AKI with worse long-term outcomes. Within cardiac surgery, AKI is associated with increased long-term mortality and changes in renal function [20–23]. Similar findings have been described in non-cardiac surgery [7–12]. Bihorac et al. evaluated over 3000 cardiac and non-cardiac surgical patients with postoperative AKI defined by RIFLE criteria [8,24]. After controlling for type of surgery, they found patients with a "Risk" class AKI, or a 50% increase in SCr from baseline, had increased long-term mortality following hospital discharge. Turan et al. in a recent retrospective study analyzed long-term renal function in 15,621 patients, of whom 599 had AKI by the KDIGO definition [12,15]. They found that even a stage 1 AKI postoperatively increased the likelihood of chronic renal dysfunction by 2.4 times between 1 and 2 years following surgery, but they found no significant difference in 2-year mortality between patients with no AKI and those with stage 1 AKI. This differed from our results in 1-year mortality, although our methodology and study populations were different, particularly in their exclusion of patients with a preoperative GFR < 60 ml/min/1.73 m^2 or a baseline SCr > 1.5 mg/dL [12]. Such patients with pre-existing reduced renal function made up a significant proportion of our AKI population, and they were likely at a higher risk of mortality in general [25,26]. The association of AKI with long-term mortality was shown in a retrospective cohort study by O'Connor et al. that, when combining all stages of AKI, identified a 26.6% rate of mortality 8 to 365 days following surgery compared to 6.1% of patients without AKI [7].

Our study adds to existing literature suggesting there is no such thing as a "minor" postoperative AKI [12,27,28]. The association in our study



Variable	No AKI [n=8239]	Stage 1 [n=513]	Stage 2 [n=78]	Stage 3 [n=57]	P value
Inpatient Mortality - no. (%)	24 (0.3)	11 (2.0)	3 (3.8)	8 (12.5)	<0.001
Median Postoperative LOS (IQR) - days	3.0 (2.0, 5.0)	5.2 (3.2, 8.9)	6.9 (3.2, 7.4)	11.0 (7.3, 17.2)	<0.001
Mean Total Costs (SD)	$23,896 ($23,736)	$33,042 ($27,115)	$39,133 ($34,006)	$73,216 ($82,290)	<0.001
Median Total Costs (IQR)	$18,174 ($12,780-$28,101)	$25,525 ($17072-$41,111)	$27,679 ($20,767-$50,811)	$43,428 ($27,165-$82,091)	<0.001
1-year Mortality - no. (%)[c]	325 (5.2)	53 (13.9)	12 (19.4)	10 (22.7)	<0.001

Abbreviations: AKI - Acute Kidney Injury, LOS - Length of Stay
[a]Bar plot displays in-hospital mortality rate with standard error.
[b]Box plots display median and IQR. Whiskers extend to 1.5 times the IQR from the 1st and 3rd quartiles.
[c]1-year mortality analysis performed for cases prior to June 1st, 2019, n = 6242, 381, 62, 44 for no AKI and stages 1, 2, and 3, respectively.

Fig. 2. Severity of postoperative AKI and patient outcomes.

of even stage 1 AKI with higher rates of adverse outcomes in our data argue for this. In our determination of AKI, the use of only those baseline creatinine values obtained within 30 days prior to the index procedure also helps increase the likelihood that we identify a real change in renal function postoperatively. We believe this is a major strength of our study. The etiology and causes of postoperative AKI are complex, however it is likely that AKI acts as a marker of cellular injury and organ dysfunction in surgical patients [29,30]. While this has not been well-elucidated in clinical practice, animal models have shown that the inflammatory mediators associated with acute kidney injury, particularly from renal hypoperfusion, have far-reaching effects throughout the body, including on the lungs, liver, heart, and brain [31–33]. Evidence has also demonstrated that the presence of any major postoperative complication and the duration of its morbidity are both associated with worse long-term survival [34,35]. From our data we cannot ascertain a mechanism in which a reduction in renal function leads to mortality. Rather, we believe our findings demonstrate that patients with AKI, viewed through a lens of postoperative organ dysfunction, should be considered at higher-risk for adverse short- and long-term outcomes. This holds true in our data even for stage 1 AKI, which represents only an increase of 0.3 mg/dL or a 50% rise in SCr from the preoperative baseline.

4.2. Effect of AKI on LOS and costs

Our findings also show that any stage of AKI, including stage 1 AKI alone, was associated with longer LOS and costs. In our adjusted analysis, we showed that a stage 1 AKI was associated with nearly a 2-day increase in LOS compared to no AKI, while this increase was 10 days for a stage 3 AKI (Table 2). We also showed that AKI following surgery is associated with significantly increased costs in all stages of AKI (Fig. 2). In our adjusted models, we found that stage 1 and stage 2 AKI were associated with an additional $4391 and $6739 in total costs of the surgical hospitalization. Stage 3 AKI, which by definition includes patients who require renal replacement therapy, was associated with an increase in costs of $41,493 (Table 2). The association between higher costs and AKI in hospitalized patients has been described [6,36]. A study by Hobson et al. evaluated costs in all surgical patients with AKI defined by RIFLE criteria and found that patients with any postoperative AKI had risk-adjusted mean costs of $42,600 compared to $26,700 for no AKI. In their cohort, patients in the RIFLE Risk class (which most closely resembles KDIGO stage 1) had a risk-adjusted 44% increase in costs as compared to patients without AKI [1]. We found similar associations in our study, and we believe our findings add more evidence for the higher costs imposed by postoperative AKI in elective surgery.

AKI may be associated with multi-organ dysfunction, but AKI by itself, particularly stage 1 AKI, likely does not explain all of the downstream effects of increased LOS and hospital costs [37]. Rather than an endpoint, if we again view AKI as a marker of cellular injury secondary to global inflammation and physiologic dysfunction, then the presence of even mild AKI can more easily explain these outcomes. Grams and Rabb hypothesize that renal injury has far-reaching effects throughout the body [31]. In patients that demonstrate this injury, postoperative complications such as infection, hemorrhage, or cardiac injury become increasingly more likely. The hospitalization costs that are incurred to manage complications and mitigate further physiologic deterioration are likely to rise in correlation to the severity of derangement. If renal injury is merely a marker for global inflammation and pervasive end-organ effects, research should likely be geared towards prevention of this response [31]. We believe our study emphasizes the relevance of

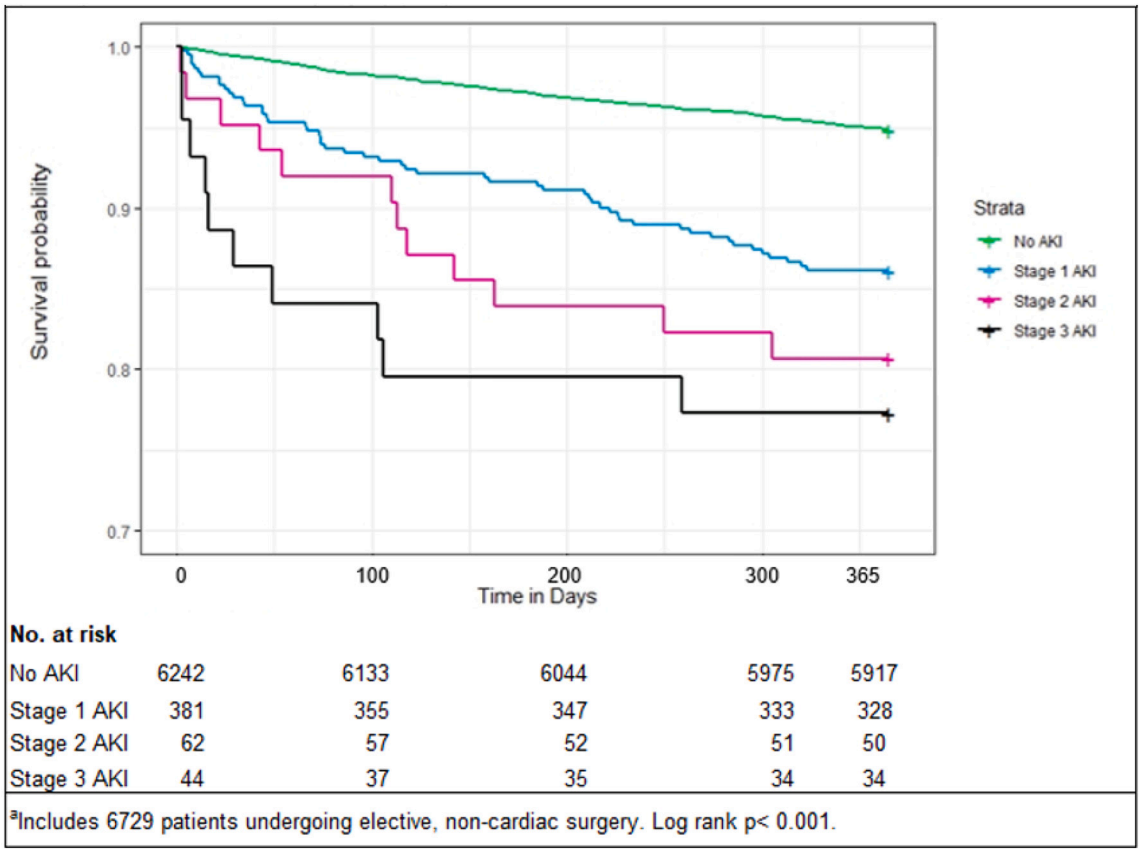


Fig. 3. Unadjusted survival curve for 1-year mortality following surgery, displayed by severity of postoperative Acute Kidney Injury (AKI)[a].

Table 2
Adjusted models for inpatient mortality, 1-year mortality, postoperative LOS, and total costs associated with severity of postoperative AKI.

	Postoperative LOS[a]			Inpatient Mortality[b,c]			1-year Mortality[b]			Total Costs[a]		
	Additional days[c]	95% CI	P value	OR	95% CI	P value	OR	95% CI	P value	Additional costs [c]	95% CI	P value
Stage 1 AKI vs No AKI	1.9	(1.5, 2.3)	<0.001	5.5	(2.3, 12.3)	0.001	1.9	(1.3, 2.6)	0.001	$4391	($2498, $6285)	<0.001
Stage 2 AKI vs No AKI	2.6	(1.5, 3.7)	<0.001	10.9	(2.3, 36.2)	0.005	2.4	(1.1, 4.7)	0.022	$6739	($2054, $11,423)	0.005
Stage 3 AKI vs No AKI	10.1	(8.8, 11.5)	<0.001	13.9	(4.0, 42.8)	<0.001	2.3	(0.96, 5.1)	0.061	$41,493	($36,004, $46,983)	<0.001

[a],[b],[c] Refer to Tables A3-A10 in the appendix to reference other factors in the models.
[a] Adjusted linear regression models for LOS and total costs.
[b] Adjusted logistic regression models for inpatient and 1-year mortality.
[c] Linear regression estimates, interpreted as the additional hospital days and dollar cost amount associated with the variable listed for the patient's hospitalization for surgery.

AKI in the immediate postoperative period on both long-term outcomes and costs in current practice. A reduction in AKI may lead to improvement in postoperative mortality, LOS, and costs while providing superior care. Quality improvement efforts aimed at reducing complications and costs in surgical patients should likely target populations where AKI is highly prevalent.

4.3. Limitations

There are several limitations to our study. This was a retrospective observational study and does not prove a causal relationship. Our use of an institutional electronic database did not allow for in-depth analysis of clinical factors contributing to AKI or for detailed economic analysis. We also do not account for the duration of AKI in this study, which evidence suggests has an impact on long-term outcomes [38–40]. Our requirement of a pre-operative baseline creatine present within 30 days of surgery also may have led to a selection bias towards higher-acuity patients, as they would be more likely to have recently updated laboratory testing just prior to elective surgery. While our retrospective methods do not allow us to remove all potential confounders, we produced models that adjusted for known major patient and procedure-related factors that affect outcomes. Our data extraction method's use of the first creatinine of the day, when multiple lab values are obtained, risks under-diagnosis in some cases of AKI, but would still identify a sustained elevation in creatinine. Additionally, our method of using governmental databases to ascertain long-term mortality may not identify all patients who are deceased from the studied time period. We did not adjust for other postoperative complications occurring with or without AKI, although this would be difficult to interpret given the expected correlation of AKI with acute illness. Our cost data is also specific

to our institution (a large urban, academic medical center) and the cost differences between patient groups may differ to varying degrees in other health systems. A detailed assessment of the cost drivers such as laboratory testing, medications, consultant fees, and equipment was outside the scope of this study but should be evaluated in the future.

5. Conclusions

In this retrospective study of patients undergoing major elective, non-cardiac surgery we demonstrate that patients who developed any stage of postoperative AKI had higher rates of in-hospital mortality and 1-year mortality, longer postoperative LOS, and higher hospital costs. These risks were associated with even stage 1 AKI in this population.

Declaration of Competing Interest

Dr. Michael Scott reports honoraria from and serves on advisory boards of Baxter, Edwards Lifesciences, Deltex, Trevena, and Merck. There are no conflicts to report for the remaining authors. There are no sources of funding to disclose for this study.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclinane.2022.110933.

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