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INTRAOPERATIVE FLUID BALANCE AND PERIOPERATIVE OUTCOMES FOLLOWING AORTIC VALVE SURGERY

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Abstract

Background: The effect of intraoperative fluid balance on postoperative acute kidney injury (AKI) in cardiac surgical patients is poorly defined.

Methods: Retrospective study of patients undergoing aortic valve replacement (AVR) for aortic stenosis. The primary outcome of interest was postoperative AKI. Secondary outcomes included postoperative fluid balance, cardiac index, vasopressor use, hospital free days, stroke, myocardial infarction (MI), hospital readmission, 30- and 90-day mortality.

Results: 2327 patients were analyzed. Positive intraoperative fluid balance was associated with lower odds of AKI - lowest odds 20-39 mL/kg group [OR=0.56, 95% CI (0.38, 0.81); p=0.002]. Positive intraoperative fluid balance was associated with lower postoperative fluid balance. Increased ultrafiltration volume was associated with increased postoperative fluid resuscitation and vasopressor use. AKI was associated with increased 30- and 90-day mortality. Increased fluid balance was associated with increased odds of MI and 30-day mortality. Increased ultrafiltration volume was associated with increased odds of 30- and 90-day mortality.

Conclusions: In patients who underwent AVR for aortic stenosis, positive intraoperative fluid balance was associated with decreased odds of AKI. Patients developing AKI had increased 30- and 90-day mortality. While the overall incidence was low, increased intraoperative fluid balance was associated with MI and 30-day mortality, while increased ultrafiltration volume was

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associated with 30- and 90-day mortality. Prospective studies are needed to better define proper intraoperative fluid management in patients undergoing cardiac surgery.

Keywords

Fluid balance; cardiac surgery; kidney injury

Intraoperative management of patients undergoing cardiovascular operations with cardiopulmonary bypass (CPB) is a coordinated effort between the surgical, anesthesiology, and perfusion teams. Prior studies evaluating fluid balance in the cardiac perioperative period have included a broad surgical cohort, and concluded that increased perioperative fluid balance is associated with longer hospital length of stay (LOS), intensive care unit (ICU) readmission, transfusion, and 90-day mortality.^{1,2} Of recent, there has been a trend toward a restrictive intraoperative fluid strategies in patients undergoing major surgical procedures in an effort to improve outcomes.³ Given the physiologic differences amongst cardiac surgical sub-types, it is hard to draw generalizable conclusions regarding optimal fluid management in this dissimilar cohort.

Patients with isolated aortic stenosis (AS) often demonstrate a similar and predictable hemodynamic and physiologic response during the perioperative period. Concentric hypertrophy associated results in diastolic dysfunction necessitating adequate preload to maintain stroke volume and cardiac output, particularly in the postoperative period following aortic valve replacement (AVR). Hypovolemia is poorly tolerated in this cohort, resulting in hypotension, low cardiac output, and poor systemic perfusion.⁴ We hypothesize that patients undergoing AVR in the setting of AS with a low or negative intraoperative fluid balance will have a greater degree of physiologic derangement as evidenced by an elevated risk for acute kidney injury (AKI), require more aggressive volume resuscitation in the early postoperative period, and hence have a higher incidence of vasopressor use.

Patients and Methods

This study was approved by the Institutional Review Board and all patients had granted permission to use their medical records for research (consistent with Minnesota Statute 144.295). Patients 18 years of age who underwent primary sternotomy AVR in the setting of AS with use of CPB from 2004-2016 were included. Exclusion criteria included patients having operations other than or in addition AVR, prior sternotomy, American Society of Anesthesiology classification 5, history of dialysis, patients without a cross clamp or CPB time, and patients without intraoperative fluid input/output data.

Demographic, laboratory and medical data were collected. Intraoperative variables included CPB and aortic cross clamp time, crystalloid/colloid volume, transfusion volume (red blood cells [RBC], fresh frozen plasma [FFP], platelets, cryoprecipitate, cell saver), estimated blood loss, conventional ultrafiltration volume, and urine output. Postoperative variables included any vasopressor infusion on ICU arrival, cardiac output/index upon ICU arrival, postoperative fluid balance at 6 and 24 hours after initial ICU admission, AKI, hospital free days (defined by subtracting the hospital length of stay in days from 28, with patients dying during hospital stay receiving a score of zero and patients with hospital lengths of stay

greater than 28 days also received a score of zero), 30-day or hospital discharge morbidity (renal failure requiring renal replacement therapy, stroke, myocardial infarction), 30-day hospital readmission, and mortality data (30 and 90 day) were reviewed and collected. Acute kidney injury was defined by Acute Kidney Injury Network (AKI-N) criteria as on absolute rise in serum creatinine of $\geq 0.3\text{mg/dL}$ or 50% / 1.5 fold increase from baseline, within 48 hours of surgery.⁵

Statistical Methods

Fluid balance and ultrafiltration volume per mL/lean body weight was defined using the Boer formula: $\text{volume} / (0.252 * \text{weight}[\text{kg}] + 0.473 * \text{height}[\text{cm}] - 48.3)$ for females and $\text{volume} / (0.407 * \text{weight}[\text{kg}] + 0.267 * \text{height}[\text{cm}] - 19.2)$ for males.⁶ Fluid balance and ultrafiltration were categorized into four groups: <0 , 0-19, 20-39 and 40+ mL/kg. Intraoperative blood transfusion volumes were categorized as none, and rough tertiles for volumes >0 mL. These variables were categorized since the dose-response relationship was not linear.

Clinical and demographic characteristics were summarized by intraoperative fluid balance categories using frequencies and percentages for categorical variables and medians and quartile ranges for continuous variables. Comparisons across levels of fluid balance were performed using chi-square/fisher exact tests (where appropriate) for categorical data and Kruskal-Wallis tests for continuous data.

Associations between intraoperative fluid balance, ultrafiltration volume, and postoperative outcomes were analyzed using multivariable regression models. The primary outcome of AKI and secondary outcome of new postoperative dialysis after surgery were analyzed using logistic regression. Continuous secondary outcomes (fluid balance at 6 and 24 hours, hospital free days, and cardiac index) were analyzed using linear regression. Dichotomous secondary outcomes (vasopressor use) were analyzed using logistic regression. RBC volume, Non-RBC volume, age, gender, year, BMI, eGFR, diabetes, hypertension, cross clamp time, and bypass time were included as adjustment terms in all regression models (except new postoperative dialysis). Due to the small number of patients requiring new postoperative dialysis (19), only intraoperative fluid balance and ultrafiltration volume were included in the model when analyzing for new hemodialysis. All outcomes and adjustment terms were specified *a priori* (with the exception of year, which was added as a post-hoc adjustment term). Interactions between intraoperative fluid balance and ultrafiltration volume, RBC volume, and non-RBC volume were analyzed in separate models to determine if the association between fluid balance and outcomes were modified by other intraoperative characteristics.

Associations between fluid balance and ultrafiltration volume and major adverse outcomes were analyzed using multivariable logistic regression. Due to rarity of these outcomes, models were additionally adjusted for the effects of STS risk score and AKI within 48 hours and categorized fluid balance and ultrafiltration volume were treated as ordinal variables. STS score was available on 78% of the cohort, so multiple imputation with 25 independent datasets was used to handle the missing data. All analyses were performed using SAS version

9.4 (SAS Institute Inc., Cary, NC). All tests were 2-sided, and $P < 0.05$ was determined to be significant.

Results

Of the 2,488 patients undergoing AVR during the study period, 2327 met inclusion for analysis (Figure 1). Demographic and intraoperative characteristics by fluid balance are presented in Table 1. The prevalence of diabetes mellitus, hypertension, and chronic obstructive pulmonary disease was similar amongst quartiles (data not shown). Intraoperative fluid balance was significantly associated with the primary outcome of postoperative AKI (Table 2, Figure 2). Compared to negative fluid balance patients, all groups with a positive fluid balance had significantly lower odds of postoperative AKI - lowest odds 20-39 mL/kg group [OR=0.56, 95% CI (0.38, 0.81); $p=0.002$]. Compared to negative fluid balance patients, positive fluid balance patients required significantly less fluid resuscitation at 6 hours and 24 hours (Table 2). Increased ultrafiltration volume was associated with increased fluid balance at 24 hours in the 10-29 mL/kg ultrafiltration volume and the 40+ mL/kg ultrafiltration volume group. Variables associated with increased AKI after multivariable adjustment included increased RBC volume transfused, older age, male gender, years 2004-2006, higher BMI, higher baseline eGFR, diabetes mellitus, and longer CPB time.

Intraoperative fluid balance was not associated with the secondary outcomes of cardiac index, hospital free days, or vasopressor use. Increased ultrafiltration volumes were associated with a higher cardiac index for the 30-39 mL/kg and 40+ mL/kg volume groups, but all groups had a normal mean cardiac index. Increased ultrafiltration volumes were associated with increased odds of vasopressor use in the 30-39 mL/kg and 40+ mL/kg groups.

Nineteen (0.8%) patients with AKI required postoperative dialysis. When interpreted by fluid balance quartiles, there was no significant association between fluid balance or ultrafiltration volume and AKI requiring hemodialysis (data not shown).

Compared to patients who received no RBCs, patients who received RBCs had significantly higher odds of AKI across all transfusion quartiles (data not shown). There was no evidence of a significant interaction between intraoperative fluid balance and RBC volume administered, non-RBC volume administered, and ultrafiltration volume and the outcomes of AKI, fluid balance at 6 hours, and fluid balance at 24 hours (data not shown).

Development of AKI within 48 hours of surgery was associated with increased odds of death at 30 and 90 days. Within 30 days, 28 patients (1.2%) had a stroke, 35 (1.5%) had an MI, and 147 (6.3%) were readmitted. The 30- and 90-day mortality rates were, 1.1% and 1.7% respectively. Increased fluid balance was associated with increased odds of MI and death within 30 days. Increased ultrafiltration volume was associated with increased odds of death within 30 and 90 days (Table 3).

Comment

Previous studies assessing perioperative fluid balance and outcomes in cardiac surgery have trended toward worse outcomes with increasing fluid balance.^{1,2,7} The authors here present the first study assessing the relationship between intraoperative fluid balance in a homogenous cardiac surgical population and postoperative outcomes including AKI. The main finding of this study was that patients undergoing AVR for AS with a positive intraoperative fluid balance had significantly lower odds of postoperative AKI, and required less aggressive volume resuscitation after surgery compared to patients with a negative intraoperative fluid balance.

Intraoperative Fluid Balance

Appropriate intraoperative fluid balance is complex, and varies depending on the surgical type and physiologic demands. There has been a recent trend toward a restrictive fluid strategy in patients undergoing major surgical procedures.³ In cardiac surgery, several studies have associated higher intravenous fluid volumes and positive postoperative fluid balance with increased rates of AKI, transfusion, hospital LOS, and 90-day mortality.^{1,2,7} Limitations of these studies is that the populations are often heterogeneous with differing physiology and perioperative management goals. Myles et al., compared a restrictive fluid regimen (net even fluid balance intraoperative and 24 hours postoperatively) with a liberal fluid regimen in patients undergoing major abdominal surgery and found the restrictive fluid regimen was associated with higher rates of AKI.⁸ In patient's undergoing thoracic surgery, a balanced approach to perioperative fluid administration has been proposed as postoperative pulmonary complications and AKI are multifactorial processes that are not solely determined by a fluid regimen.⁹ Maintenance of euvolemia and preserving adequate renal perfusion has long been a hallmark in the prevention of AKI in the perioperative period.⁹⁻¹¹

Acute kidney injury is of interest in patients undergoing cardiac surgery given the association with morbidity and mortality.¹²⁻¹⁵ Perioperative hypovolemia risks renal hypoperfusion, while fluid overload may lead to multi-organ dysfunction. Other risk factors for AKI in cardiac surgical patients include history of congestive heart failure, diabetes, hypertension, hyperlipidemia, renal disease, peripheral vascular disease, cerebrovascular disease, chronic obstructive pulmonary disease, low cardiac output, age, prolonged CPB and cross clamp time.¹⁶ The etiology of AKI in cardiac surgery patients is multifactorial with insults such as the use of CPB, microemboli, nephrotoxins, venous congestion, oxidative stress, genetics, inflammation, and ischemia-reperfusion injury.^{12,15,16} Similar to prior reports, this study found that patients who developed AKI after cardiac surgery had increased odds of mortality, highlighting the importance of preventative strategies.

Current evidence regarding the prevention of AKI centers around controlled fluid resuscitation with crystalloids, avoiding fluid overload, titration of vasopressors to a target mean arterial pressure of 65–70 mmHg and avoiding diuretics or levosimendan for kidney protection.¹⁷ This study is unique in that it is the first to assess a homogenous cardiac surgical population to examine the impact of intraoperative fluid balance on postoperative outcomes. The findings suggest that in contrast to other studies, positive intraoperative fluid balance reduces odds of AKI.

Given the incidence of AKI following cardiac surgery, severe AKI requiring dialysis is not infrequent with rates between 0.6% and 5% depending on preoperative renal function.¹⁸ In this study, the overall low incidence of patients requiring dialysis (0.8%) makes drawing clinical correlation to this statistical finding challenging. The increased rate of dialysis in the higher intraoperative fluid balance group may represent oliguric patients who failed fluid challenge attempts to increase urine output and became increasingly fluid positive/volume overloaded necessitating early dialysis (in lieu of potentially more conservative treatments in patients not volume overloaded).

The overall incidence of major adverse outcomes was quite low in this study; however, increased intraoperative fluid balance was associated with higher rates of MI and 30-day mortality. While these outcomes met statistical significance, the event infrequencies did not allow for control of likely confounding.

One unique aspect to fluid management in patients undergoing cardiac surgery is the ability to remove fluids (ultrafiltration) during CPB. Ultrafiltration is common during CPB and can greatly impact the intraoperative fluid balance. While modified ultrafiltration (performed after separation from CPB) has been shown to reduce blood loss, improve cardiac output and systemic vascular resistance and mitigate the risk of AKI associated with hemodilution, data supporting conventional ultrafiltration during CPB is lacking.¹⁹ Additionally, previous studies have shown that conventional ultrafiltration during CPB is associated with higher lactate levels and increased inotropic requirements.²⁰ Conventional ultrafiltration was routinely used at our institution during the study period to reduce hemodilution, remove excessive volume, increase coagulation factors and limit blood loss to cell salvage after separation from CPB. Ultrafiltration volume was case dependent to achieve a goal cardiac index between 1.8 - 2.4 L/min/m², maintain a mean arterial pressure between 60-80 mmHg, and have sufficient volume in the reservoir to transition from CPB. While conventional ultrafiltration volume was not associated with AKI in this study, excessive volume removal leading to an overall net negative intraoperative fluid balance places patients at increased risk for AKI and greater need for postoperative volume resuscitation. A goal-directed perfusion strategy during CPB has been shown to be effective in reducing AKI following cardiac surgery. Components of a goal-directed perfusion strategy include: minimum oxygen delivery of 300 mL/min/m², slow patient rewarming, reduced CPB circuit volume, avoidance of mannitol and hypovolemia, zero balance ultrafiltration, minimizing vasopressor use during CPB, and optimizing CPB flow to achieve appropriate tissue perfusion.^{21,22} While the overall incidence of mortality was low in this study, increased ultrafiltration volumes were associated with higher rates of 30- and 90-day mortality.

Postoperative Fluid Balance

With regard to postoperative fluid administration, Shen et al. found that in cardiac surgical patients, a postoperative (not including intraoperative fluid balance) zero fluid balance was associated with decreased AKI compared to a positive postoperative fluid balance.⁷ In the current study, a positive intraoperative fluid balance was associated with less need for fluid resuscitation at 6 and 24 hours postoperatively while an increased ultrafiltration volume was

associated with increased fluid resuscitation postoperatively. Thus, intraoperative fluid balance impacts postoperative fluid requirements in patients undergoing cardiac surgery.

Limitations

Limitations of this study include those inherent to a retrospective analysis. AKI was defined by AKI-N criteria using serum creatinine alone. Patients with AKI by alternative metrics may have been missed. Specifically, a creatinine rise in patients with positive fluid balance in the postoperative period may have been masked/diluted, leading to a falsely lower rate of AKI. Postoperative urine output was not analyzed as the charting of this data point is variable and often time insensitive. The cardiac index and vasopressor requirements during CPB were not available on all patients during the study period and may influence AKI rates. Additionally, this study was conducted over a 12-year period during which minor changes in the perioperative management of cardiac surgical patients occurred. During the study period there was a consistent transfusion algorithm, hemodynamic goals with regard to mean arterial pressure and cardiac index were similar, and CPB protocols were similar. While patient comorbidities across the specialty likely did not change, there may have been a shift toward TAVR in high risk patients in the latter study period. The authors controlled for relevant confounding variables to limit this impact.

Conclusions

Intraoperative fluid balance in patients undergoing cardiac surgery is complex and requires an individualized strategy. While prior studies across a wide spectrum of cardiac surgical sub-types have associated higher fluid balance with inferior clinical outcomes, these findings may not be generalizable. In patients undergoing primary AVR for AS, positive intraoperative fluid balance was associated with a lower rate of AKI. Perioperative management based on physiologic demands should guide therapy with regard to proper intraoperative fluid balance. Further studies are needed to evaluate risk factors and prevention strategies for AKI in patients undergoing cardiac surgery, and help better define appropriate perioperative fluid management.

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Figure 1:
Study Subject Flowchart.

Figure 2:
Acute Kidney Injury (%) by Level of Intraoperative Fluid Balance.

Table 1.

Demographics and Intraoperative Characteristics by Fluid Balance (mL/kg)

Characteristic	<0 N=247	0-19 N=519	20-39 N=655	40+ N=906	p-value
Clinical Demographics					
Age ^a (years)	65.1 (54.7, 74.8)	68.4 (58.8, 77.1)	70.8 (61.4, 77.9)	74.0 (64.3, 80.7)	<.001 ^b
Gender					
Female	50 (20.2%)	133 (25.6%)	219 (33.4%)	500 (55.2%)	<.001 ^c
Male	197 (79.8%)	386 (74.4%)	436 (66.6%)	406 (44.8%)	
Year					<.001 ^c
2004-2007	25 (10.1%)	90 (17.3%)	143 (21.8%)	331 (36.5%)	
2008-2010	70 (28.3%)	128 (24.7%)	171 (26.1%)	218 (24.1%)	
2011-2013	81 (32.8%)	149 (28.7%)	168 (25.6%)	188 (20.8%)	
2014-2016	71 (28.7%)	152 (29.3%)	173 (26.4%)	169 (18.7%)	
BMI ^a (kg/m ²)	30.5 (26.5, 35.2)	29.9 (26.2, 34.0)	29.3 (25.7, 33.5)	28.1 (25.1, 32.0)	<.001 ^b
LVEF	61.5 (53.0, 65.0)	63 (57, 67)	64 (58, 68)	65 (60, 68)	<.001 ^b
Preoperative creatinine ^a	0.9 (0.8, 1.1)	0.9 (0.8, 1.1)	1.0 (0.8, 1.1)	1.0 (0.8, 1.1)	0.10 ^b
Preoperative GFR ^a	86.6 (63.0, 105.5)	79.1 (63.2, 103.8)	76.8 (59.8, 101.8)	68.0 (55.9, 89.9)	<.001 ^b
Cross Clamp Time (minutes) ^a	66 (47, 84)	54.8 (38.0, 72.0)	52.0 (35.8, 69.0)	54 (40, 70)	<.001 ^b
CPB Time (minutes) ^a	82 (60, 111)	68 (50, 92)	66 (46, 86)	70 (51, 92)	<.001 ^b
STS Risk Score (%)	1.4 (0.9, 2.4)	1.5 (0.9, 2.4)	1.6 (1.0, 2.7)	2.3 (1.4, 3.9)	<.001 ^b
Intraoperative Input/output Inputs					
Inputs					
RBCs	40 (16.2%)	96 (18.5%)	157 (24.0%)	524 (57.8%)	<.001 ^c
Volume ^a	341.5 (319.7, 660.0)	464.0 (330.0, 687.5)	401.9 (330.0, 660.0)	621.9 (330.0, 957.9)	<.001 ^b
Non-RBC blood products	45 (18.2%)	68 (13.1%)	130 (19.8%)	360 (39.7%)	<.001 ^c
Volume ^a	485 (264, 750)	516.5 (224.0, 663.4)	447.5 (280.0, 810.5)	650.1 (295.7, 1060.5)	<.001 ^b

Characteristic	<0 N=247	0-19 N=519	20-39 N=655	40+ N=906	p-value
Crystalloid volume (mL)	3264.2 (2650.0, 3979.5)	3507.3 (2973.9, 4150.6)	3793.6 (3234.5, 4532.9)	4387.2 (3689.3, 5332.6)	<.001 ^c
Colloid	192 (77.7%)	399 (76.9%)	521 (79.5%)	771 (85.1%)	<.001 ^b
Volume ^a	503.3 (100.0, 649.5)	600.0 (153.2, 1000.0)	600.0 (461.5, 1003.0)	600 (500, 1100)	<.001 ^c
Total Intraoperative Input (mL) ^a	4525.6 (3712.2, 5516.8)	4681.0 (4068.5, 5534.0)	5116.8 (4432.2, 6058.1)	6219.4 (5325.0, 7441.8)	<.001 ^b
Output					
Urine output (mL)	725.3 (500.4, 1170.0)	710.0 (531.0, 988.8)	740 (540, 1033)	743 (515, 1090)	0.67 ^b
EBL (mL) ^a	1346 (900, 1752)	1110 (874, 1426)	1054 (844, 1350)	1000 (850, 1350)	<.001 ^b
Ultrafiltration Volume (mL) ^a	3000 (2200, 4000)	2000 (1500, 2650)	1500 (900, 2100)	1000 (300, 1700)	<.001 ^b
none	2 (0.8%)	7 (1.3%)	48 (7.3%)	193 (21.3%)	
1300	7 (2.8%)	87 (16.8%)	243 (37.1%)	384 (42.4%)	
1301-2100	45 (18.2%)	195 (37.6%)	212 (32.4%)	223 (24.6%)	
2101+	193 (78.1%)	230 (44.3%)	152 (23.2%)	106 (11.7%)	
Total Intraoperative Output (mL) ^a	5227.2 (4350.0, 6550.0)	3943.0 (3379.8, 4815.0)	3394.0 (2760.0, 4190.6)	2948.1 (2240.4, 3802.0)	<.001 ^b
Hemoglobin: at ICU admit ^a	12.5 (10.9, 13.4)	12.5 (11.3, 13.4)	12.5 (11.3, 13.4)	11.8 (10.6, 12.8)	<.001 ^b

Numbers indicate N (%) unless otherwise noted.

^aMedian (Q1, Q3)

^bKruskal-Wallis

^cChi-square

Abbreviations: EBL, estimated blood loss; GFR, glomerular filtration rate; ICU, intensive care unit; LVEF, left ventricular ejection fraction; N, number; mL, milliliters; RBC, red blood cell; STS, Society of Thoracic Surgeons.

Table 2.

Associations Between Fluid Balance, Ultrafiltration and Outcomes

Characteristic (mL/kg lean body weight)	Total N=2327	AKI ^a			Fluid Balance 6 Hrs ^b			Fluid Balance 24 Hrs ^b		
		N AKI	Odds Ratio (95% CI)	p-value	Mean (SD) Fluid Balance	Mean (95% CI)	p-value	Mean (SD) Fluid Balance	Mean (95% CI)	p-value
Fluid balance										
<0	247	81 (32.8%)	1.00 (ref)	0.02	19.1 (18.1)	0.00 (ref)	<.001	27.1 (26.6)	0.00 (ref)	<.001
0-19	519	116 (22.4%)	0.63 (0.44, 0.92) *		16.2 (19.1)	-3.09 (-6.04, -0.14) *		22.1 (26.3)	-3.85 (-8.06, 0.36)	
20-39	655	130 (19.8%)	0.56 (0.38, 0.81) **		14.2 (19.5)	-5.41 (-8.40, -2.43) ***		17.3 (29.8)	-8.60 (-12.86, -4.34) ***	
40+	906	219 (24.2%)	0.56 (0.38, 0.85) **		11.9 (21.4)	-8.09 (-11.27, -4.90) ***		11.6 (30.2)	-15.06 (-19.60, -10.51) ***	
Ultrafiltration Volume										
<10	370	81 (21.9%)	1.00 (ref)	0.12	10.0 (17.9)	0.00 (ref)	0.44	9.1 (25.2)	0.00 (ref)	0.14
10-29	918	204 (22.2%)	1.02 (0.74, 1.40)		13.4 (19.2)	1.75 (-0.60, 4.10)		15.0 (27.9)	2.70 (-0.65, 6.06)	
30-39	461	92 (20.0%)	0.95 (0.65, 1.38)		15.4 (20.5)	0.81 (-1.95, 3.56)		18.3 (29.3)	1.09 (-2.85, 5.02)	
40+	578	169 (29.2%)	1.36 (0.93, 1.97)		17.4 (22.1)	0.57 (-2.24, 3.38)		24.9 (32.2)	4.08 (0.07, 8.09) *	
Cardiac Index ^a										
Hospital Free Days ^a										
Vasopressor Use ^b										
Fluid balance										
<0	247	2.8 (1.0)	0.00 (ref)	0.45	21.4 (3.8)	0.00 (ref)	0.33	128 (51.8%)	1.00 (ref)	0.76
0-19	519	2.8 (0.9)	0.02 (-0.12, 0.16)		21.8 (3.7)	0.33 (-0.33, 0.98)		221 (42.6%)	0.93 (0.66, 1.30)	
20-39	655	2.8 (0.9)	0.08 (-0.06, 0.23)		21.8 (3.4)	0.55 (-0.12, 1.21)		249 (38.0%)	0.84 (0.60, 1.18)	
40+	906	2.8 (0.9)	0.09 (-0.06, 0.25)		20.8 (5.6)	0.63 (-0.08, 1.34)		399 (44.0%)	0.90 (0.62, 1.30)	
Ultrafiltration Volume										
<10	370	2.7 (0.9)	0.00 (ref)	<.001	21.3 (4.9)	0.00 (ref)	0.57	134 (36.2%)	1.00 (ref)	0.002
10-29	918	2.7 (0.9)	0.00 (-0.11, 0.11)		21.6 (4.1)	-0.10 (-0.62, 0.43)		349 (38.0%)	1.19 (0.90, 1.56)	
30-39	461	2.9 (1.0)	0.20 (0.07, 0.33) **		21.6 (4.4)	0.12 (-0.50, 0.74)		195 (42.3%)	1.34 (0.98, 1.85)	
40+	578	2.9 (1.0)	0.25 (0.11, 0.38) ***		20.9 (4.8)	-0.25 (-0.88, 0.37)		319 (55.2%)	1.81 (1.31, 2.51) ***	

Model included row covariate, plus all other covariates listed in the table, plus age, gender, year, BMI, GFR, history of diabetes, history of hypertension, cross clamp time, and bypass time

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a Analyzed using multivariable logistic regression
b Analyzed using multivariable linear regression
* $P < .05$
** $P < .01$
*** $P < .001$

Abbreviations: AKI, acute kidney injury; CI, confidence interval; mL, milliliters; N, number; RBC, red blood cell; ref, reference; SD, standard deviation.

Table 3.

Associations Between Fluid Balance, Ultrafiltration and Major Adverse Outcomes

Outcome	Odds Ratio (95% CI)	p-value
Stroke 30 days (N=28, 1.2%)		
Fluid balance ^a	0.93 (0.62, 1.38)	0.72
Ultrafiltration Volume ^a	1.08 (0.73, 1.59)	0.71
AKI within 48 hours	0.47 (0.16, 1.36)	0.16
MI 30 days (N=35, 1.5%)		
Fluid balance ^a	1.62 (1.04, 2.54) [*]	0.03
Ultrafiltration Volume ^a	0.80 (0.56, 1.15)	0.23
AKI within 48 hours	0.72 (0.30, 1.74)	0.47
Readmission 30 days		
Fluid balance ^a	0.97 (0.81, 1.16)	0.75
Ultrafiltration Volume ^a	1.04 (0.87, 1.24)	0.69
AKI within 48 hours	1.44 (0.99, 2.09)	0.06
Death 30 days (N=26, 1.1%)		
Fluid balance ^a	1.74 (1.11, 2.73) [*]	0.02
Ultrafiltration Volume ^a	1.70 (1.14, 2.52) ^{**}	0.009
AKI within 48 hours	4.06 (1.76, 9.34) ^{**}	0.001
Death 90 days (N=40, 1.7%)		
Fluid balance ^a	1.40 (0.99, 1.98)	0.06
Ultrafiltration Volume ^a	1.49 (1.09, 2.06) [*]	0.01
AKI within 48 hours	4.26 (2.16, 8.40) ^{***}	<.001

Fluid Balance and Ultrafiltration were modeled as ordinal terms using the four categories <0, 0-19, 20-39, and 40+.

^a (ml/lean body weight) Per category increase^{*} P < .05

Abbreviations: AKI, acute kidney injury; MI, myocardial infarction; N, number

P < .001

P < .01

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