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Fluid Overload in Infants Following Congenital Heart Surgery

Matthew A. Hazle, MD¹, Robert J. Gajarski, MD¹, Sunkyung Yu, MS¹, Janet Donohue, MPH¹, and Neal B. Blatt, MD, PhD^{2,*}

¹University of Michigan Department of Pediatrics and Communicable Diseases, Division of Pediatric Cardiology, Ann Arbor, Michigan

²University of Michigan Department of Pediatrics and Communicable Diseases, Division of Nephrology, Ann Arbor, Michigan

Abstract

Objective—To describe post-operative fluid overload patterns and correlate degree of fluid overload with intensive care morbidity and mortality in infants undergoing congenital heart surgery.

Design—Prospective, observational study. Fluid overload (%) was calculated by two methods: 1. (Total fluid In – Total fluid Out)/(Pre-op weight) x 100; and 2. (Current weight – Pre-op weight)/(Pre-op weight) x 100. Composite poor outcome included: need for renal replacement therapy, upper quartile time to extubation or intensive care length of stay (> 6.5 and 9.9 days, respectively), or death 30 days post-surgery.

Setting—University hospital pediatric cardiac intensive care unit.

Patients—Forty-nine infants < 6 months of age undergoing congenital heart surgery with cardiopulmonary bypass during the period of July 2009 to July 2010.

Interventions—None

Measurements and Main Results—Patients had a median age of 53 days (21 neonates) and mean weight of 4.5±1.3 kg. 42 patients (86%) developed acute kidney injury by meeting at least AKIN/KDIGO stage 1 criteria (SCr rise of 50% or 0.3 mg/dL). The patients with adverse outcomes (N=17, 35%) were younger [7 (5–10) vs. 98 (33–150) days, p=0.001], had lower pre-operative weight (3.7±0.7 vs. 4.9±1.4 kg, p=0.0002), higher post-operative mean peak serum creatinine (0.9±0.3 vs. 0.6±0.3 mg/dL, p=0.005), and higher mean maximum fluid overload by both method 1 (12±10 vs. 6±4%, p=0.03) and method 2 (24±15 vs. 14±8%, p=0.02). Predictors of a poor outcome from multivariate analyses were cardiopulmonary bypass time, use of circulatory arrest, and increased vasoactive medication requirements post-operatively.

Conclusions—Early post-operative fluid overload is associated with suboptimal outcomes in infants following cardiac surgery. Since the majority of patients developed kidney injury without needing renal replacement therapy, fluid overload may be an important risk factor for adverse outcomes with all degrees of acute kidney injury.

*Corresponding author. Neal B. Blatt, M.D., Ph.D., University of Michigan, Department of Pediatrics & Communicable Diseases, Division of Pediatric Nephrology, F6865 Mott / SPC 5297, 1500 E. Medical Center Drive, Ann Arbor, MI 48109-5297. +1-734-936-4210, FAX: +1-734-763-6997. nblatt@med.umich.edu.

Reprints will not be ordered

Keywords

acute kidney injury; congenital heart disease; fluid overload; cardiopulmonary bypass; infants; dialysis

Introduction

Fluid overload (FO), which often accompanies significant acute kidney injury (AKI), was first recognized in a retrospective study of pediatric bone marrow transplant patients [1]. In that study, the majority of patients (70%) who required dialysis had a FO 10%, and this degree of FO was more likely to be present in the patients who did not eventually recover renal function. Since that initial report, increased FO has been noted in other pediatric populations, especially in those children who have required continuous renal replacement therapy (CRRT) [2–7]. In those studies, FO at the initiation of CRRT has been correlated with poor outcomes and increased mortality, and the degree of FO has been a predictor of mortality independent of illness severity. For survivors, FO has been correlated with increased duration of mechanical ventilation, prolonged intensive care and hospital lengths of stay, and time to renal recovery [8]. These data have led to a growing consensus that FO is an important clinical marker of renal dysfunction, and that minimization of FO may improve patient outcomes.

FO is also common following infant congenital heart surgery with cardiopulmonary bypass (CPB). Excessive fluid accumulation has the potential to impact perioperative outcome by prolonging the duration of mechanical ventilation, delaying chest closure after neonatal cardiac repairs, and limiting delivery of optimal nutrition. We sought to elucidate post-operative FO patterns in infants undergoing congenital heart surgery to determine if the degree of FO negatively impacts morbidity and mortality.

Materials and Methods

This prospective study was approved by the Institutional Review Board of the University of Michigan. Infants under 6 months of age undergoing cardiac surgery with CPB between July 2009 and July 2010 were eligible for enrollment. Fifty families were approached, and one family declined participation in the study. Patients with gestational age below 35 weeks were excluded. After obtaining informed consent, patient demographics, cardiac diagnosis, and surgical information were collected. Surgical complexity was assigned according to the Risk Adjustment for Congenital Heart Surgery 1 (RACHS-1) consensus based scoring system [9].

All patients received routine standard of care during the study period which included the use of dextrose-containing crystalloid solutions (75–100 cc/kg/day) during the first 24–48 hours postoperatively, followed by the initiation of total parenteral nutrition. Patients were started on bolus furosemide (1 mg/kg/dose q6h) within the first 24 h post-operatively. One of the study patients had a peritoneal drain placed. Primary providers were aware that the patients were enrolled in a study looking at urinary AKI biomarkers and renal near-infrared spectroscopy [10], however, they were not aware that FO was an outcome measure.

Pre-operative S_{Cr} and weight were recorded. Following surgery, S_{Cr} was measured for seven days as part of routine daily laboratory studies. In addition, daily weights were obtained for seven days post-operatively according to unit nursing policies as part of routine standard of care. Daily fluid balance was recorded for the first three post-operative days and the time to negative fluid balance was determined based on the first 8 hour shift in which the total fluid

out exceeded total fluid in. Daily FO as a percentage of pre-operative weight was calculated using two methods [3, 7]:

1. $[(\text{Total mL fluid In} - \text{Total mL fluid Out}) / \text{Pre-operative kg weight}] \times 100$
2. $[(\text{Current kg weight} - \text{Pre-operative kg weight}) / \text{Pre-operative kg weight}] \times 100$.

AKI was defined using criteria proposed by the Acute Kidney Injury Network and Kidney Disease Improving Global Outcomes group, and recently validated in a study of infants with congenital heart disease [11–13]. Infants had AKI if they met AKIN stage 1 criteria, defined as an increase in S_{Cr} by either 0.3 mg/dL or a 50% rise from pre-operative baseline within the first three days post-operatively. Post-operative degree of cardiovascular support was quantified by calculation of a daily maximum vasoactive-inotropic score (VIS) for the first three post-operative days [14].

Due to relatively small CRRT and death rates, a composite poor outcome was used for analysis, including any of the following: need for CRRT, upper quartile time to first extubation or intensive care length of stay, or death within 30 days of surgery. Upper quartile values for ventilator time and intensive care length of stay were determined to be >6.5 and >9.9 days, respectively, based on an internal database of infants under 6 months of age who have recently undergone cardiac surgery.

Data are presented as mean $\pm$ standard deviation or median with interquartile range, as appropriate, for continuous variables, and frequency with percentage for categorical variables. The distributional assumption for continuous variables was examined graphically using normal probability plot and by Shapiro-Wilk test (data not shown). Demographic and clinical characteristics were compared using t-tests or Wilcoxon rank sum tests, as appropriate, for continuous variables, Fisher's exact tests for nominal variables, and Mantel-Haenszel tests for ordinal variables. Variables found to be significantly associated with a poor outcome in the univariate analysis were further investigated using multivariate logistic regression models; age at surgery, pre-operative weight, RACHS-1 classification, cardiopulmonary bypass time, hypothermic circulatory arrest, maximum VIS, peak S_{Cr} , and time to negative fluid balance. Using backward elimination, significant predictors obtained from the multivariate analysis were used as covariate adjustments to determine independent relations of FO with poor outcome. Additionally, separate logistic regression was conducted to examine associations between FO and a poor outcome controlling only for peak S_{Cr} . Results of the logistic regression are presented as odds ratios with their 95% confidence intervals. All analyses were performed using SAS Version 9.2 (SAS Institute Inc., Cary, NC), with statistical significance set at p -values < 0.05 using 2-sided tests.

Results

In total, 49 patients were enrolled in the study. With the exception of one infant who underwent a stage 2 hemi-Fontan operation, all study patients underwent their initial surgery to repair or palliate their primary cardiac diagnosis: ventricular septal defect (n=12), Tetralogy of Fallot (n=9), Hypoplastic Left Heart Syndrome (n=9), atrioventricular septal defect (n=6), D-transposition of the great arteries (n=5), Heterotaxy Syndrome (n=3), severe coarctation or interrupted aortic arch with ventricular septal defect (n=3), truncus arteriosus (n=1), and total anomalous pulmonary venous return (n=1).

Six patients required ECMO support for low cardiac output in the immediate post-operative period. Three infants died, 2 required CRRT, 12 had a prolonged time to first extubation, and 16 had a prolonged ICU length of stay. Both patients requiring CRRT were neonates on ECMO who subsequently died. In these cases, CRRT was initiated on the second post-operative day due to severe FO. After the initiation of CRRT, data from these patients was

censored from further analysis. In total, there were 17 (35%) patients with at least one poor outcome. Infants with a poor outcome were younger in age, smaller, underwent more complex surgical procedures, had higher maximum post-operative VIS, and were more likely to require ECMO support post-operatively (Table 1).

As shown in Table 2, kidney injury was common in this study population. In total, 42/49 (86%) of study patients met AKI criteria (28/49 (57%) AKIN/KDIGO stage I, 11/49 (22%) AKIN/KDIGO stage II, and 3/49 (6%) AKIN/KDIGO stage III). Infants with a poor outcome had a higher mean peak S_{Cr} , and all but one poor outcome patient had AKI, although the presence of AKI based on the AKIN criteria did not predict if a patient would have a good or poor outcome. During the study period, poor outcome patients had a greater degree of maximal FO by both fluid balance and daily weight methods, and they took longer to achieve a negative fluid balance. Daily FO was higher in poor outcome infants on post-operative day 1 by the fluid balance method and on post-operative day 3 by the daily weight method (Figure 1). When treated as a categorical variable, maximal FO less than 10% was associated with a good outcome and maximal FO above 20% was associated with a poor outcome by both methods ($p=0.02$ for fluid balance, $p=0.01$ for weight). There were 13 patients that had $>10\%$ FO by both methods; 8 of these patients (62%) had a poor outcome ($p=0.04$).

Univariate analysis demonstrated that younger age, lower pre-operative weight, longer duration of CPB, and the use of hypothermic circulatory arrest were associated with an increased risk of a poor outcome (Table 3). Infants undergoing the most complex procedures (RACHS-1 category 5 or 6) had a nearly 11-fold increased risk of a poor outcome compared to RACHS-1 category 2–4 infants. Within the first 3 post-operative days, each point increase in maximum VIS was associated with a 17% increased risk of a poor outcome, and each 0.1 mg/dL increase in peak S_{Cr} increased the risk of a poor outcome by 36%. Each percentage increase in maximal FO was associated with a 13% increased risk of a poor outcome by the fluid balance method and a 9% increased risk by the weight-based method. Each additional day required to achieve a negative fluid balance increased the risk of a poor outcome by 3.4-fold.

From multivariate analysis, CPB time, use of circulatory arrest, and maximum VIS remained statistically significant predictors of a poor outcome (Table 4). Due to correlation between the two methods of FO calculation ($r=0.65$, $p<0.0001$), the adjusted OR for each FO method was obtained from separate analyses, controlling for the same covariates listed above. FO as a continuous or a categorical variable (cut-off 10% and 20%) did not reach statistical significance as an independent predictor of a poor outcome with multivariate modeling; however, FO assessed by the daily weight method was a significant predictor of a poor outcome after adjusting for S_{Cr} (Table 5).

Discussion

Our study demonstrates that increasing FO, as measured by either daily fluid balance or daily weight, is associated with worse outcomes following congenital heart surgery in infants. The etiology of FO in this patient population is multifactorial. Cardiopulmonary bypass results in both hemodilution and increased capillary permeability, both of which promote extravasation of fluid into the extracellular fluid compartment [15]. Fluid resuscitation and blood product administration in the immediate postoperative period further contributes to third spacing. As body wall edema increases, intra-abdominal pressure is increased and renal perfusion pressure is decreased [16]. When combined with postoperative myocardial dysfunction, there is also a stimulus to retain fluid via the renin-angiotensin-aldosterone system [17].

Given the acute nature of CPB mediated kidney injury and the observation that most infants have normal renal function prior to surgery, these patients may be ideal candidates for aggressive postoperative goal-directed protocols aimed at minimization of FO. Peritoneal dialysis has been shown to be a safe and effective method of fluid removal in post-cardiotomy infants [18, 19], and early initiation of this therapy can improve hemodynamics [20] and ICU outcomes [21]. While a potentially attractive therapeutic strategy, the studies supporting the routine use of peritoneal dialysis in the post-operative setting are limited by their retrospective design and lack of a control population. While conservative fluid management strategies have shown benefit in adult ICU patients [22, 23], application of this concept to cardiac surgical patients has not been tested.

Previous reports have indicated that FO above 10–20% is a clinically significant threshold for adverse outcomes in critically ill children [2, 4, 5]. Similarly, our study shows that patients with a poor outcome had a mean maximal FO of 12% and 24% by fluid balance and daily weight methods, respectively. Daily and maximal FO was higher by the weight-based method, which may be due to a net fluid gain in the operating room not accounted for in the fluid balance calculation, which started after admission to the intensive care unit. The weight-based method may be limited by the addition of surgical tubes and catheters during surgery, but it does incorporate insensible fluid losses, and can be easier to calculate at the bedside than the fluid balance method. Since a consensus has not been reached on the optimal definition of FO [7], we presented both methods, but due to our small sample size, we cannot comment on the superiority of either method to calculate FO. We do note that not all institutions weigh patients daily as part of routine care, in which case the fluid balance method will be more appropriate. However, in institutions such as ours that record both daily fluid balance and daily weight, our data suggests that each method may be clinically useful at different phases of the post-operative period (see Figure 1).

Previous reports have focused on FO at the time of CRRT initiation. In this study, many patients had AKI (86%), but only two received CRRT. This suggests that FO may be an important risk factor for a poor outcome among all degrees of AKI. Multivariate analysis showed that maximal FO by daily weight remained a significant predictor of poor outcome after adjusting for SC_r , indicating that FO may be a clinically useful parameter independent of the degree of AKI based on current definitions. This concept is supported by a recent study by Arikan and colleagues, in which a positive fluid balance was correlated with increased ICU morbidity in critically ill children who did not receive CRRT [24].

In this study, FO was not a risk factor for poor outcome independent of illness severity based on RACHS-1 score or maximal VIS. Using these scoring systems as surrogates for illness severity is somewhat limited because these parameters are closely linked. The infants who undergo the most complex operations have significant cardiac dysfunction following surgery and thus require the most aggressive fluid resuscitation and have high inotropic medication requirements. Controlling for the degree of illness is important for outcome analysis, and while both are likely relevant, further study is needed to determine whether FO is a marker of illness severity or an independent risk factor for poor outcomes in this population.

Our study is limited by a relatively small sample size and low frequency of definitive adverse events. We, therefore, used a composite poor outcome, which is less robust than CRRT or mortality. However, the surrogate parameters used in this study are important clinical end points that are well established in the pediatric cardiac critical care literature [14, 25, 26].

Conclusions

Early post-op FO is associated with poor outcomes in infants under 6 months of age following cardiac surgery. Calculation of early FO by fluid balance or daily weight represents a practical method to identify patients with AKI who are at risk for post-operative morbidity and mortality. Since the majority of our patients developed AKI without requiring CRRT, our findings suggest that FO may be a risk factor for adverse outcomes with all degrees of AKI. Additional prospective study is needed to determine if FO can be used to guide post-operative medical management in this patient population.

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References

1. Lane PH, Mauer SM, Blazar BR, et al. Outcome of dialysis for acute renal failure in pediatric bone marrow transplant patients. *Bone Marrow Transplant*. 1994; 13:613–617. [PubMed: 8054914]
2. Sutherland S, Zappitelli M, Alexander S, et al. Fluid overload and mortality in children receiving continuous renal replacement therapy: the prospective pediatric continuous renal replacement therapy registry. *Am J Kidney Dis*. 2010; 55:316–325. [PubMed: 20042260]
3. Goldstein SL, Currier H, Graf CdCC, et al. Outcome in children receiving continuous venovenous hemofiltration. *Pediatrics*. 2001; 107:1309–1312. [PubMed: 11389248]
4. Gillespie R, Seidel K, Symons J. Effect of fluid overload and dose of replacement fluid on survival in hemofiltration. *Pediatr Nephrol*. 2004; 19:1394–1399. [PubMed: 15517417]
5. Foland J, Fortenberry J, Warshaw B, et al. Fluid overload before continuous hemofiltration and survival in critically ill children: a retrospective analysis. *Critical Care Med*. 2004; 32:1771–1776. [PubMed: 15286557]
6. Goldstein S, Somers MJG, Baum M, et al. Pediatric patients with multi-organ dysfunction syndrome receiving continuous renal replacement therapy. *Kidney Int*. 2005; 67:653–658. [PubMed: 15673313]
7. Selewski DT, Cornell TT, Lombel RM, et al. Weight-based determination of fluid overload status and mortality in pediatric intensive care unit patients requiring continuous renal replacement therapy. *Intensive Care Med*. 2011; 37:1166–1173. [PubMed: 21533569]
8. Hayes L, Oster R, Tofil N, et al. Outcomes of critically ill children requiring continuous renal replacement therapy. *J Crit Care*. 2009; 24:394–400. [PubMed: 19327959]
9. Jenkins K, Gauvreau K, Newburger J, et al. Consensus-based method for risk adjustment for surgery for congenital heart disease. *J Thorac Cardiovasc Surg*. 2002; 123:110–118. [PubMed: 11782764]
10. Hazle MA, Aiyagari R, Gajarski RJ, et al. Urinary Biomarkers and Renal Near-Infrared Spectroscopy in Infants Under 6 Months of Age Predict ICU Outcomes Following Cardiac Surgery. manuscript in preparation.
11. Mehta R, Kellum J, Shah S, et al. Acute Kidney Injury Network: report of an initiative to improve outcomes in acute kidney injury. *Crit Care*. 2007; 11:R31–R31. [PubMed: 17331245]
12. Kdigo. Clinical practice guideline for acute kidney injury. Section 2: AKI definition. *Kidney Int Suppl*. 2012; 2:19–36.
13. Blinder JJ, Goldstein SL, Lee V-V, et al. Congenital heart surgery in infants: Effects of acute kidney injury on outcomes. *J Thorac Cardiovasc Surg*. 2012; 143:368–374. [PubMed: 21798562]
14. Gaies MG, Gurney JG, Yen AH, et al. Vasoactive-inotropic score as a predictor of morbidity and mortality in infants after cardiopulmonary bypass. *Pediatr Crit Care Med*. 2010; 11:234–238. [PubMed: 19794327]
15. Hirleman E, Larson DF. Cardiopulmonary bypass and edema: physiology and pathophysiology. *Perfusion*. 2008; 23:311–322. [PubMed: 19454559]

16. Wauters J, Claus P, Brosens N, et al. Pathophysiology of renal hemodynamics and renal cortical microcirculation in a porcine model of elevated intra-abdominal pressure. *J Trauma*. 2009; 66:713–719. [PubMed: 19276743]
17. Shotan A, Dacca S, Shochat M, et al. Fluid overload contributing to heart failure. *Nephrol Dial Transplant*. 2005; 20 (Suppl 7):24–27.
18. Pedersen KR, Hjortdal VE, Christensen S, et al. Clinical outcome in children with acute renal failure treated with peritoneal dialysis after surgery for congenital heart disease. *Kidney Int Suppl*. 2008:S81–S86. [PubMed: 18379554]
19. Sorof JM, Stromberg D, Brewer ED, et al. Early initiation of peritoneal dialysis after surgical repair of congenital heart disease. *Pediatr Nephrol*. 1999; 13:641–645. [PubMed: 10502118]
20. Dittrich S, Dhert I, Vogel M, et al. Peritoneal dialysis after infant open heart surgery: observations in 27 patients. *Ann Thorac Surg*. 1999; 68:160–163. [PubMed: 10421133]
21. Chien JC, Hwang BT, Weng ZC, et al. Peritoneal dialysis in infants and children after open heart surgery. *Pediatr Neonatol*. 2009; 50:275–279. [PubMed: 20025141]
22. Wiedemann H, Wheeler A, Bernard G, et al. Comparison of two fluid-management strategies in acute lung injury. *N Engl J Med*. 2006; 354:2564–2575. [PubMed: 16714767]
23. Adesanya A, Rosero E, Timaran C, et al. Intraoperative fluid restriction predicts improved outcomes in major vascular surgery. *Vasc Endovascular Surg*. 2008; 42:531–536. [PubMed: 18583299]
24. Arian AA, Zappitelli M, Goldstein SL, et al. Fluid overload is associated with impaired oxygenation and morbidity in critically ill children. *Pediatr Crit Care Med*. 2012; 13:253–258. [PubMed: 21760565]
25. Krawczeski CD, Woo JG, Wang Y, et al. Neutrophil gelatinase-associated lipocalin concentrations predict development of acute kidney injury in neonates and children after cardiopulmonary bypass. *J Pediatr*. 2011; 158:1009–1015. e1. [PubMed: 21300375]
26. Parikh CR, Devarajan P, Zappitelli M, et al. Postoperative Biomarkers Predict Acute Kidney Injury and Poor Outcomes after Pediatric Cardiac Surgery. *J Am Soc Nephrol*. 2011; 22:1737–1747. [PubMed: 21836147]

Figure 1. Fluid Overload by Post-Operative Day

Daily fluid overload in patients with a good (dashed grey line) versus poor (solid black line) outcome by daily weight (A) or fluid balance (B) methods. Data is presented as mean $\pm$ 95% confidence intervals, * indicates $P < 0.05$ for good versus poor outcome.

Table 1

Demographics and Clinical Characteristics by Outcome Status (N=49)

	All	Poor Outcome		P-value
		Yes (N=17)	No (N=32)	
Gender, N (%)				
Female	14 (29)	5 (36)	9 (64)	1.00
Male	35 (71)	12 (34)	23 (66)	
Age at surgery, days, median (IQR)	53 (8–127)	7 (5–10)	98 (33–150)	0.001
Pre-Op Weight, kg	4.5 ± 1.3	3.7 ± 0.7	4.9 ± 1.4	0.0002
RACHS-1 classification, N (%)				
2 to 4	37 (76)	8 (22)	29 (78)	0.001
5 or 6	12 (24)	9 (75)	3 (25)	
Cardiopulmonary bypass time, min	107 ± 55	149 ± 61	84 ± 35	0.001
Aortic cross-clamp time, min	48 ± 32	52 ± 40	45 ± 25	0.55
Hypothermic circulatory arrest, N (%)	15 (31)	10 (67)	5 (33)	0.003
Post-operative ECMO, N (%)	6 (12)	6 (100)	0 (0)	0.001
Maximum Vasoactive Inotrope Score	16 ± 9	23 ± 9	12 ± 7	< 0.0001

Data are presented as mean ± SD unless otherwise indicated.

IQR, interquartile range (25th percentile – 75th percentile)

RACHS, Risk Adjustment for Congenital Heart Surgery

ECMO, extracorporeal membrane oxygenation

Table 2

Kidney Injury and Fluid Overload Following Congenital Heart Surgery (N=49)

	Poor Outcome			
	All	Yes (n=17)	No (n=32)	P-value
Peak Serum Creatinine (mg/dL)	0.7 ± 0.3	0.9 ± 0.3	0.6 ± 0.3	0.005
Acute Kidney Injury, N (%)				
No	7 (14)	1 (14)	6 (86)	0.40
Yes	42 (86)	16 (38)	26 (62)	
AKIN/KDIGO stage 1	28 (57)	11 (39)	17 (61)	0.81
AKIN/KDIGO stage 2	11 (22)	3 (27)	8 (73)	
AKIN/KDIGO stage 3	3 (6)	2 (67)	1 (33)	
Maximum Fluid Overload (Total Fluid In/Out), %	8 ± 8	12 ± 10	6 ± 4	0.03
< 10, N (%)	34 (69)	9 (26)	25 (74)	0.02
10 – 20	12 (24)	5 (42)	7 (58)	
> 20	3 (6)	3 (100)	0 (0)	
Maximum Fluid Overload (Daily Weight), %	17 ± 12	24 ± 15	14 ± 8	0.02
< 10, N (%)	16 (33)	3 (19)	13 (81)	0.01
10 – 20	16 (33)	3 (19)	13 (81)	
> 20	17 (35)	11 (65)	6 (35)	
Time to Negative fluid balance, days	1.6 ± 0.5	1.8 ± 0.6	1.4 ± 0.5	0.046

Data are presented as mean ± SD unless otherwise indicated

Table 3

Univariate Predictors of a Poor Outcome

	OR (95% CI)	P-value
Age at surgery (days)	0.98 (0.97 – 0.99)	0.004
Pre-Op Weight (kg)	0.35 (0.16 – 0.74)	0.006
RACHS-1 classification		
2 – 4	Ref	0.002
5 or 6	10.9 (2.4 – 49.9)	
Cardiopulmonary bypass time (min)	1.03 (1.01 – 1.06)	0.002
Hypothermic circulatory arrest	7.7 (1.98 – 29.99)	0.003
Maximum Vasoactive Inotrope Score	1.17 (1.06 – 1.29)	0.001
Peak Serum Creatinine (0.1 mg/dL)	1.36 (1.07 – 1.72)	0.01
Maximum Fluid Overload (Total Fluid In/Out), %	1.13 (1.02 – 1.25)	0.02
Maximum Fluid Overload (Daily Weight), %	1.09 (1.02 – 1.16)	0.01
Time to Negative fluid balance (days)	3.4 (1.03 – 13.4)	0.04

OR, odds ratio; CI, confidence interval; Ref, reference category

Table 4
Multivariate Predictors of a Poor Outcome

	AOR (95% CI)	P-value
Maximum Fluid Overload (Total Fluid In/Out), %	1.07 (0.9 – 1.29)	0.44 ^a
Maximum Fluid Overload (Daily Weight), %	0.98 (0.89 – 1.08)	0.68 ^a
Cardiopulmonary Bypass Time, min	1.03 (1.002 – 1.05)	0.04 ^b
Hypothermic Circulatory Arrest	7.98 (1.12 – 56.6)	0.04 ^b
Maximum Vasoactive Inotropic Score	1.18 (1.02 – 1.35)	0.02 ^b

AOR, adjusted odds ratio; CI, confidence interval

^aP-values from multivariate logistic regression controlling for CPB time, hypothermic circulatory arrest, and maximal VIS.

^bP-values from multivariate logistic regression, not including FO.

Table 5

Odds of a Poor Outcome Adjusted for Peak Serum Creatinine

	AOR (95% CI)	P-value ^a
Maximum Fluid Overload (Total Fluid In/Out), %	1.10 (0.99 – 1.23)	0.08
Maximum Fluid Overload (Daily Weight), %	1.07 (1.01 – 1.14)	0.03

AOR, adjusted odds ratio; CI, confidence interval

^aP-values from multivariate logistic regression controlling for peak S_{Cr}.