

Factors Associated with Fluid Overload and Major Complications in Neonates with D-TGA Following Arterial Switch Operation

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Abstract

Background: Fluid overload is common following congenital heart surgery and associated with worse clinical outcomes. Evaluations of factors associated with fluid overload in congenital heart disease subtypes are limited.

Objectives: To evaluate perioperative factors associated with fluid overload in neonates with d-transposition of the great arteries following arterial switch operation (ASO) or ASO and ventricular septal defect (VSD) closure. A secondary aim was to evaluate whether fluid overload is associated with major postoperative complication.

Methods: This single-center, retrospective cohort study included term neonates who underwent ASO or ASO and VSD closure between January 1, 2013, and June 1, 2024. Fluid overload was calculated as $[Fluid\ in\ (L) - Fluid\ out\ (L)] / birth\ weight\ (kg) * 100\%$ and defined as greater than 10 % at 7AM on postoperative day two. A major complication was defined according to Pediatric Cardiac Critical Care Consortium postoperative adverse event criteria.

Results: 195 neonates met inclusion criteria. Fluid overload developed in 6% of patients. We did not identify factors associated with fluid overload. However, affected patients required longer postoperative mechanical ventilation and had longer intensive care and hospital stays. Forty patients (21%) developed a major complication. In multivariable analysis, factors associated with major complications included birthweight less than 3kg (adjusted Odds Ratio [aOR] 2.6, 95%CI 1.2-5.8; p=0.021) and fluid overload (aOR 3.9, 95%CI 1.0-5.1; p=0.047). Patients with major complications had higher mortality rates than those without (absolute difference 7.5%, 95%CI 2.0 – 19.9; p=0.008)

Conclusions: Fluid overload following the ASO or ASO and VSD closure is less common than previously reported in heterogeneous pediatric cardiac surgery populations. It remains an important contributor to clinical outcomes.

Introduction

Fluid overload is reported to be common after cardiopulmonary bypass with multifactorial etiologies including post bypass inflammatory response, capillary leak, post-operative myocardial dysfunction as well as activation of the renin-angiotensin-aldosterone system, post operative fluid resuscitation, and renal injury.¹ Fluid overload has been associated with worse clinical outcomes in children recovering from cardiac surgery. An observational study reported a maximal fluid overload above 10%, independent of renal injury, was associated with worse outcomes in infants following cardiac surgery.² A retrospective study showed that fluid overload > 16% after postoperative day 3 in infants following cardiac surgery was associated with a longer ICU and hospital stay.³

Outcomes for children with d-transposition of the great arteries (d-TGA) have improved over time.⁴ **With expected survival, there is increased focus on reducing perioperative morbidity following arterial**

switch operation (ASO). Given the detriments associated with fluid overload, mitigating fluid accumulation is a worthwhile strategy to help reduce acquired morbidity in children recovering from ASO. Previous studies in the general congenital heart surgery population identified age (< 1 year), weight (< 5kg), longer bypass time, and postoperative bleeding as factors associated with greater than 5% fluid overload.^{5,6} Given the heterogeneity of congenital heart disease (CHD), it is worthwhile to focus on specific populations to better guide lesion-specific management. The primary aim of this study was to evaluate for modifiable factors associated with developing fluid overload in neonates with d-TGA following ASO to better target future interventions to prevent fluid overload. A secondary aim was to evaluate the clinical sequelae of fluid overload in a contemporary cohort of neonates after ASO.

Methods

This study was approved by the institutional review board at Boston Children's Hospital (BCH) with waiver of consent (IRB-P00049551). The study was designed as a single-center, retrospective cohort study. Inclusion criteria were neonates with d-TGA who underwent ASO or ASO and ventricular septal defect (VSD) closure between day of life two and eight at BCH between January 1, 2013, and June 1, 2024. Surgery earlier than day of life two or later than day of life eight was felt to represent potential extenuating circumstances that may have influenced the outcome and is not the norm for our program, which is why these infants were excluded. Additional exclusion criteria included: 1) premature infants (< 37 weeks' gestation), 2) patients receiving preoperative extracorporeal membrane oxygenation (ECMO), and 3) patients requiring concurrent aortic arch reconstruction.

Patients were identified via our local Society of Thoracic Surgery Congenital Heart Surgery Database (STS-CHD). Clinical data was extracted via this database and the electronic medical record. The primary outcome for this study was postoperative fluid overload, defined as greater than 10% between arrival to the cardiac intensive care unit from the operating room and 7AM on postoperative day two. Post-operative fluid overload was calculated as $[Fluid\ in\ (L) - Fluid\ out\ (L)] / birth\ weight\ (kg) * 100\%$. The primary exposure variable of interest was excessive post-operative bleeding, defined as any of the following: 1) chest tube output > 7 ml/kg/hour for 2 or more consecutive hours, 2) greater than or equal to 84 ml/kg total for the first 24 post-operative hours, 3) surgical re-exploration for bleeding or cardiac tamponade.⁷ Other exposure variables of interest included demographic, anatomic, preoperative support, intraoperative, and postoperative support variables. Demographic variables included presence of extracardiac anomalies or a genetic diagnosis as captured in the STS-CHD database. Anatomic factors included the presence of a VSD and atypical coronary pattern for d-TGA. Preoperative variables included the receipt of balloon atrial septostomy (BAS), receipt of prostaglandin infusion at the time of surgery, preoperative respiratory support with either invasive mechanical support or noninvasive respiratory support, and highest vasoactive inotropic score (VIS)⁸ before surgery. Intraoperative variables included duration of cardiopulmonary bypass, aortic cross clamp, and circulatory arrest measured in minutes as well as the receipt of modified ultrafiltration. Postoperative variables included the highest VIS and the average inadequate delivery of oxygen index (IDO₂) in the first postoperative 24 hours, which

were obtained as a marker for level of illness which might serve as a propensity for fluid administration. The IDO₂ index, provided through Etiometry, Inc. (Boston, MA), has U.S. Food and Drug Administration 510(k) clearance for predicting the probability of inadequate oxygen delivery (defined as a mixed venous oxygen saturation below 50%).⁹ The IDO₂ index is calculated from physiologic data (vital signs, blood gas values, hemoglobin concentration) with values ranging between 0 and 100. Higher values represent increased probability of a mixed venous oxygen saturation below 50%.

The secondary outcome of this study was occurrence of a major complication as defined by the Pediatric Cardiac Critical Care Consortium (PC4). These include need for mechanical circulatory support, bleeding requiring reoperation, unplanned reoperation or reintervention, arrhythmia requiring permanent pacemaker, stroke, dialysis or other renal replacement therapy for acute renal failure, pleural effusion requiring drainage, chylothorax requiring intervention, urinary tract infection, seizure, intraventricular hemorrhage more than grade II, or paralyzed diaphragm. We used fluid overload as the primary predictor for this secondary outcome.

Continuous variables are presented as medians with interquartile ranges (IQRs). Categorical data are presented as numbers, proportions, and percentages. For each outcome of interest, patients were compared using Wilcoxon rank-sum test for continuous variables and chi-square or Fisher exact test for categorical variables. Logistic regression was used to assess the association (odds ratio) between each exposure variable with the outcome of interest. A multivariable logistic regression model was constructed for the primary outcome of interest (fluid overload) using the primary predictor (excessive postoperative bleeding) as well as candidate variables with a *p* value less than 0.05 on univariate association. Similarly, a multivariable logistic regression model was constructed for the secondary outcome of interest (PC4 major complication) using the primary predictor (fluid overload) as well as candidate variables with a *p* value less than 0.05 on univariate association. For both models, variables with a *p* value of less than 0.05 were classified as independently associated with the dichotomous outcome of interest using adjusted odds ratio (aOR) and 95% confidence intervals (CIs). All analyses and figures were completed using Stata/BE 19.0 (StataCorp, College Station, TX).

Results

The cohort included 195 patients of which 69% were male (Table 1). The median age at the time of surgery was 4.3 days with 22% of the cohort less than 3 kg at birth. Less than 10% of patients had an identified genetic syndrome. From an anatomic standpoint, 39% had intact ventricular septum (IVS) with a usual coronary pattern, 53 (27%) had IVS with an atypical coronary pattern, 44 (23%) had VSD with a usual coronary pattern, and 22 (11%) had VSD with an atypical coronary pattern. Just over half of the cohort required invasive or non-invasive respiratory support preoperatively and 53% of the cohort underwent preoperative balloon atrial septostomy, while 35% continued to receive prostaglandin infusion at the time of surgery.

Table 1
Characteristics of Fluid Overload^a

Variable	All (n = 195)	No FO (n = 184, 94.4%)	FO (n = 11, 5.6%)	p
Age, days (IQR)	4.3 (3.3, 5.3)	4.3 (3.3, 5.3)	3.3 (2.4, 4.3)	0.064
Weight < 3kg, n (%)	42 (21.5)	37 (20.1)	5 (45.5)	0.061
Extracardiac anomaly ^b , n (%)	6 (3.1)	6 (3.3)	0 (0.0)	0.54
Genetic syndrome ^c , n (%)	16 (8.2)	15 (8.2)	1 (9.1)	1.00
Male sex, n (%)	134 (68.7)	128 (69.6)	6 (54.5)	0.30
VSD present, n (%)	66 (33.8)	60 (32.6)	6 (54.5)	0.14
Atypical coronary pattern, n (%)	75 (38.5)	70 (38.0)	5 (45.5)	0.75
Preoperative MV, n (%)	89 (45.6)	85 (46.2)	4 (36.4)	0.76
Preoperative NRS, n (%)	33 (16.9)	32 (17.4)	1 (9.1)	0.69
Preoperative MV or NRS, n (%)	100 (51.3)	96 (52.2)	4 (36.4)	0.36
Preoperative BAS, n (%)	103 (52.8)	100 (54.3)	3 (27.3)	0.12
Highest preoperative VIS (IQR)	3 (0, 3)	0 (0, 3)	0 (0, 0)	0.28
On PGE at OR, n (%)	68 (34.9)	65 (35.3)	3 (27.3)	0.75
CPB time, minutes (IQR)	184 (164, 211)	183 (163, 211)	212 (177, 232)	0.053
CC time, minutes (IQR)	129 (110, 149)	128 (110, 149)	132 (120, 158)	0.23
CA time, minutes (IQR)	0 (0, 8)	0 (0, 8)	0 (0, 0)	0.36
Delayed sternal closure, n (%)	42 (22.1)	40 (21.7)	3 (27.3)	0.71
Modified ultrafiltration, n (%)	147 (75.4)	137 (74.5)	10 (90.9)	0.22
IDO ₂ -24h (IQR)	0.6 (0.1, 3.2)	0.6 (0.1, 3.2)	2.0 (0.2, 4.0)	0.36
Highest postoperative VIS ^d (IQR)	5 (3, 9)	5 (3, 8)	8 (5, 20)	0.028
Major bleeding ^e , n (%)	29 (14.9)	25 (14.9)	4 (36.4)	0.062

Variable	All (n = 195)	No FO (n = 184, 94.4%)	FO (n = 11, 5.6%)	p
BAS: balloon atrial septostomy; CAT: circulatory arrest; CC: aortic cross clamp; CPB: cardiopulmonary bypass; FO: fluid overload; IDO ₂ -24: average inadequate delivery of oxygen index over first 24 hours post-operatively; MV: mechanical ventilation; NRS: noninvasive respiratory support; PGE: prostaglandin E1; OR: operating room; VIS: vasoactive inotropic score; VSD: ventricular septal defect				
^a Fluid overload: >10% as of 7AM on postoperative day 2				
^b Extracardiac anomaly: bronchomalacia, cleft lip/palate, imperforate anus, pyloric stenosis, tracheoesophageal fistula				
^c Syndrome: 22q11 deletion, Cat eye, DiGeorge, Goldenhaar, Hurler's, Pierre-Robin, Other genetic mutation or chromosomal abnormality				
^d Highest vasoactive inotropic score in first post-operative 24 hours				
^e Major bleeding: chest tube output > 7 mL/kg/hr for ≥ 2 consecutive hours in first 12 postoperative hours and/or ≥ 84 mL/kg total for the first 24 postoperative hours and/or surgical re-exploration for bleeding or cardiac tamponade physiology in the first 24 postoperative hours				

Only 11 patients (6%) in the cohort developed fluid overload > 10% on POD 2. Patients developing fluid overload received more total fluids in comparison to those not developing fluid overload on both the first postoperative night (arrival to the intensive care unit and 7AM the following day; 95.1 vs 66.8 mL/kg/d; $p = 0.004$) and from postoperative day 1 into day 2 (136.1 vs 100.2 mL/kg/d; $p < 0.001$) (Fig. 1). Patients who developed fluid overload, compared to those who did not, were more likely to weigh less than 3 kg (absolute difference 25.3%, 95% CI 0.3–55.4%; $p = 0.047$) and were exposed to a higher postoperative VIS (8 vs 5, $p = 0.028$). Although not meeting pre-specified criteria of significance at the $p < 0.05$ level, patients experiencing fluid overload were younger at the time of operation (3.3 days vs 4.3 days, $p = 0.06$), were exposed to longer cardiopulmonary bypass times (212 minutes vs 183 minutes, $p = 0.053$), and experienced a higher rate of major bleeding (absolute difference 22.8%; 95% CI -2.0–54.1%; $p = 0.062$). In a multivariable model that included cardiopulmonary bypass duration and highest postoperative VIS, we failed to find an association between major bleeding and developing fluid overload (aOR 2.3, 95% CI 0.5–9.4; $p = 0.26$) (Table 2).

Table 2
Univariable and Multivariable Logistic Regression Models for Fluid Overload^a

Variable	OR (95% CI)	p	aOR (95% CI)	p
195 patients; 11 events; c-statistic = 0.755				
Major bleeding ^b	3.6 (1.0, 13.3)	0.052	2.3 (0.5, 9.4)	0.26
CPB Time (per 10-minute increase)	1.09 (1.0, 1.2)	0.025	1.1 (1.0, 1.2)	0.101
Highest postoperative VIS ^c	1.08 (1.0, 1.2)	0.042	1.1 (1.0, 1.1)	0.104
CPB: cardiopulmonary bypass; VIS: vasoactive inotropic score				
^a Fluid overload: >10% as of 7AM on postoperative day 2				
^b Major bleeding: chest tube output > 7 mL/kg/hr for ≥ 2 consecutive hours in first 12 postoperative hours and/or ≥ 84 mL/kg total for the first 24 postoperative hours and/or surgical re-exploration for bleeding or cardiac tamponade physiology in the first 24 postoperative hours				
^c Highest vasoactive inotropic score in first post-operative 24 hours				

There were 40 patients (21%) who experienced a PC4-defined major complication (Table 3). The most common complications included unplanned reoperation or reintervention (not including bleeding; 14 patients), postoperative neurologic injury (including stroke, seizure, and intracranial hemorrhage; 10 patients), chylothorax requiring intervention (7 patients), and postoperative mechanical circulatory support (6 patients). While the overall degree of fluid accumulation was low, patients experiencing a major complication did accrue a significantly higher fluid balance on postoperative day one compared to those who did not experience a complication (Fig. 2). Patients acquiring a major complication were more likely to weigh less than 3kg (absolute difference 23.2%, 95% CI, 8.0-39.4%; $p = 0.001$), more likely to undergo delayed sternal closure (absolute difference 16.3%, 95% CI 1.7–32.7%; $p = 0.027$), and more likely to have developed fluid overload (absolute difference 11.8%, 95% CI 2.8–26.0%; $p = 0.004$). In a multivariable model that included weight < 3kg, cardiopulmonary bypass duration, and delayed sternal closure in addition to the primary predictor of fluid overload, we identified that both fluid overload (aOR 3.9, 95% CI 1.0-1.5; $p = 0.047$) and weight < 3 kg (aOR 2.9, 95% CI 1.2–5.8; $p = 0.021$) were independently associated with developing a major postoperative complication (Table 4).

Table 3
Characteristics of Acquiring a PC4-defined^a Major Complication

Variable	All (n = 195)	No Major Complications (n = 155, 79.5%)	Major Complication (n = 40, 20.5%)	p
Age, days (IQR)	4.3 (3.3, 5.3)	4.3 (3.3, 5.3)	3.9 (3.3, 5.3)	0.62
Weight < 3kg, n (%)	42 (21.5)	26 (16.8)	16 (40.0)	0.001
Extracardiac anomaly ^b , n (%)	6 (3.1)	4 (2.6)	2 (5.0)	0.6
Genetic syndrome ^c , n (%)	16 (8.2)	11 (7.1)	5 (12.5)	0.33
Male sex, n (%)	134 (68.7)	109 (70.3)	25 (62.5)	0.34
VSD present, n (%)	66 (33.8)	50 (32.3)	16 (40.0)	0.36
Atypical coronary pattern, n (%)	75 (38.5)	63 (40.6)	12 (30.0)	0.22
Preoperative MV, n (%)	89 (45.6)	67 (43.2)	22 (55.0)	0.18
Preoperative NRS, n (%)	33 (16.9)	25 (16.1)	8 (20.0)	0.56
Preoperative MV or NRS, n (%)	100 (51.3)	76 (49.0)	24 (60.0)	0.22
Preoperative BAS	103 (52.8)	83 (53.5)	20 (50.0)	0.69
Highest preoperative VIS (IQR)	3 (0, 3)	0 (0, 3)	0 (0, 4)	0.3
On PGE at OR, n (%)	68 (34.9)	56 (36.1)	12 (30.0)	0.47
CPB time, minutes (IQR)	184 (164, 211)	181 (162, 210)	194 (174, 221)	0.025
CC time, minutes (IQR)	129 (110, 149)	128 (106, 149)	131 (117, 149)	0.22
CA time, minutes (IQR)	0 (0, 8)	0 (0, 8)	0 (0, 8)	0.54
Delayed sternal closure, n (%)	42 (22.1)	29 (18.7)	14 (35.0)	0.027
Modified ultrafiltration, n (%)	147 (75.4)	115 (74.2)	32 (80.0)	0.45

Variable	All (n = 195)	No Major Complications (n = 155, 79.5%)	Major Complication (n = 40, 20.5%)	p
IDO ₂ -24h (IQR)	0.6 (0.1, 3.2)	0.5 (0.1, 2.5)	1.5 (0.3, 4.2)	0.089
Highest postoperative VIS ^d (IQR)	5 (3, 9)	5 (3, 8)	6 (3, 12)	0.21
Fluid overload ^e	11 (5.6)	5 (3.2)	6 (15.0)	0.011
BAS: balloon atrial septostomy; CAT: circulatory arrest; CC: aortic cross clamp; CPB: cardiopulmonary bypass; IDO ₂ -24: average inadequate delivery of oxygen index over first 24 hours post-operatively; MV: mechanical ventilation; NRS: noninvasive respiratory support; PGE: prostaglandin E1; OR: operating room; PC4: Pediatric Cardiac Critical Care Consortium; VIS: vasoactive inotropic score; VSD: ventricular septal defect				
^a PC4 Major Complication: mechanical circulatory support, bleeding requiring reoperation, unplanned reoperation or reintervention, arrhythmia requiring permanent pacemaker, stroke, dialysis, pleural effusion requiring drainage, chylothorax requiring intervention, urinary tract infection, seizure, intraventricular hemorrhage > Grade II, intracranial hemorrhage, paralyzed diaphragm, continuous renal replacement therapy for acute renal failure				
^b Extracardiac anomaly: bronchomalacia, cleft lip/palate, imperforate anus, pyloric stenosis, tracheoesophageal fistula				
^c Syndrome: 22q11 deletion, Cat eye, DiGeorge, Goldenhaar, Hurler's, Pierre-Robin, Other genetic mutation or chromosomal abnormality				
^d Highest vasoactive inotropic score in first post-operative 24 hours				
^e Fluid overload: >10% as of 7AM on postoperative day 2				

Table 4

Univariable and Multivariable Logistic Regression Models for Major Complication^a

Variable	OR (95% CI)	p	aOR (95% CI)	p
195 patients; 40 events; c-statistic = 0.73				
Weight < 3kg	3.3 (1.5, 7.1)	0.002	2.6 (1.2, 5.8)	0.021
CPB Time (per 10-minute increase)	1.1 (1.0, 1.2)	0.006	1.1 (1.0, 1.1)	0.104
Delayed sternal closure	2.3 (1.1, 5.0)	0.029	1.5 (0.6, 3.7)	0.354
Fluid overload ^b	5.3 (1.5, 18.4)	0.009	3.9 (1.0, 15.1)	0.047
CPB: cardiopulmonary bypass				
^a PC4 Major Complication: mechanical circulatory support, bleeding requiring reoperation, unplanned reoperation or reintervention, arrhythmia requiring permanent pacemaker, stroke, dialysis, pleural effusion requiring drainage, chylothorax requiring intervention, urinary tract infection, seizure, intraventricular hemorrhage > Grade II, intracranial hemorrhage, paralyzed diaphragm, continuous renal replacement therapy for acute renal failure				
^b Fluid overload: >10% as of 7AM on postoperative day 2				

Patients who developed fluid overload received longer postoperative mechanical ventilation (5.9 vs 2.7 days, $p = 0.001$) and experienced longer postoperative cardiac intensive care unit (9.8 vs 4.9 days, $p = 0.004$) and hospital (18.4 vs 12.4 days, $p = 0.029$) lengths of stay (Table 5, **Fig. 3**). Patients who experienced a major complication similarly experienced longer postoperative mechanical ventilation, postoperative lengths of stay, and experienced a higher mortality rate (absolute difference 7.5%, 95% CI 2.0–19.9; $p = 0.008$).

Table 5
Secondary Clinical Outcomes by Fluid Overload and Acquired Major Complication

Variable	All (n = 195)	No FO (n = 184)	FO (n = 11)	p
Postoperative MV Duration, days (IQR)	2.8 (1.9, 4.8)	2.7 (1.8, 4.2)	5.9 (3.6, 8.1)	0.001
Postoperative CICU LOS, days (IQR)	4.9 (3.7, 7.1)	4.9 (3.6, 7.0)	9.8 (5.9, 13.7)	0.004
Postoperative Hospital LOS, days (IQR)	13.4 (10.2, 18.3)	12.4 (10.2, 18.2)	18.4 (13.4, 23.3)	0.029
Mortality, n (%)	3 (1.5)	2 (1.1)	1 (9.1)	0.16
Variable	All (n = 195)	No Major Complications (n = 155)	Major Complications (n = 40)	p
Postoperative MV Duration, days (IQR)	2.8 (1.9, 4.8)	2.5 (1.8, 3.9)	5.0 (2.9, 9.4)	< 0.001
Postoperative CICU LOS, days (IQR)	4.9 (3.7, 7.1)	4.7 (3.2, 6.3)	7.8 (5.8, 15.4)	< 0.001
Postoperative Hospital LOS, days (IQR)	13.4 (10.2, 18.3)	12.3 (9.5, 17.4)	17.8 (14.4, 29.8)	< 0.001
Mortality, n (%)	3 (1.5)	0 (0.0)	3 (7.5)	0.008
CICU: cardiac intensive care unit; LOS: length of stay; MV: mechanical ventilation				

Discussion

In this retrospective study evaluating fluid overload in a single center cohort of neonates with d-TGA following ASO, there was a low incidence of fluid overload postoperatively defined as > 10% on POD 2. Neonates who developed fluid overload were more likely to weigh less than 3kg and be exposed to higher vasoactive doses in the immediate postoperative period. However, none of these variables were independently associated with developing fluid overload. Despite its low incidence, the clinical significance of fluid overload was demonstrated with its independent association with major postoperative complications. As such, preventing fluid overload remains an essential component of postoperative care for neonates following ASO.

Neonates following cardiopulmonary bypass are susceptible to developing fluid overload as described by multiple studies.^{2,3,5,10} **Evaluating fluid overload is challenging given that thresholds for defining fluid overload vary by both definition (ranging 5 to 20%) as well as timing of evaluation.**¹¹ Accordingly, the reported incidence of fluid overload in these studies is highly variable, with ranges of 2–65%.^{2,5,10,12–13} The threshold of 10% chosen for this study is the most commonly utilized, and assessing fluid balance

in the early postoperative period allows for an assessment of perioperative factors that might significantly contribute towards developing fluid overload. With this assessment, there was a low incidence of postoperative fluid overload identified on POD 2 relative to the previously cited studies. General strategies employed by our institution include modified ultrafiltration in most patients weaning from bypass (75% in this cohort), placement of peritoneal drainage catheter (for drainage only, not renal replacement therapy), fluid restriction in the early postoperative period, and early diuretic administration early on postoperative day one. Modified ultrafiltration, peritoneal dialysis catheter placement (independent of use for renal replacement therapy) and early diuretic administration have all demonstrated reduction in fluid overload after cardiac surgery.^{14–16} Our fluid restriction practice is to limit total fluids to half maintenance in the first 24 hours after cardiopulmonary bypass. It is notable that patients who developed fluid overload received more total fluid in (near or above maintenance) and had a higher VIS in the early postoperative period, suggesting a more vulnerable hemodynamic state contributing to development of higher fluid intake.

Fluid overload has been associated with both morbidity and mortality in children recovering from cardiac surgery.^{2,5,10,12–13} Our study adds to this growing literature in that, despite a low overall incidence, fluid overload was still independently associated with developing a major complication. Additionally, patients who developed fluid overload received longer postoperative mechanical ventilation and longer postoperative length of stay. The major complication rate identified in this cohort was higher than has previously been reported in a heterogeneous group of children recovering from cardiac surgery.¹⁷ This may be related to a targeted analysis of a higher risk population of neonates vulnerable to postoperative complications. Nonetheless, it highlights the importance of continued emphasis on perioperative management that focuses on more than just preventing mortality to improve overall quality of life for patients. Developing programmatic strategies to mitigate fluid overload is a worthwhile effort in preventing the development of postoperative complications.

In this study of term neonates, patients weighing less than 3kg were more likely to develop fluid overload. Additionally, weighing less than 3kg was independently associated with developing a postoperative complication. In follow up analysis, only five patients had a weight below 2.5kg. Low birth weight is a known risk factor associated with worse outcomes in infants undergoing cardiac surgery.^{18–19} Infants with low birth weight may have additional comorbidities such as genetic syndrome or extracardiac anomalies that contribute to worse outcomes. In our study, 5/42 (12%) of neonates weighing less than 3kg had an identified genetic syndrome and 3/42 (7%) had an extracardiac anomaly. Additional contributing factors to the challenge in caring for low-birth-weight neonates include immature organ systems and technical challenges with small anatomic features.²⁰ A multidisciplinary approach with strategies to optimize pre- and postoperative nutrition and perioperative fluid management are essential in improving outcomes for this vulnerable population.^{21–22}

Limitations

Limitations of this study include its retrospective design and single-center setting. Fluid balance measurements are reliant on accurate documentation in the electronic medical record and do not account for insensible fluid losses. Additionally, infants who undergo complex procedures are at higher risk of needing fluid and vasoactive resuscitation which may make it challenging to differential fluid overload as a predictor of the secondary outcome independent of illness severity. We attempted to account for this with concurrent evaluation of VIS and IDO₂. Nonetheless, a lack of consensus around the definition of low cardiac output syndrome makes it challenging to accurately account for hemodynamic status. Finally, we were unable to evaluate the nature of individual contributors to fluid intake or output making it challenging to draw inferences on the types of fluid contributing to total fluid balance.

Conclusions

In a targeted evaluation of neonates with d-TGA or d-TGA and VSD recovering from an ASO or ASO and VSD closure, development of fluid overload was rare. However, fluid overload was independently associated with developing postoperative complications. Strategies to address fluid overload remain a worthwhile effort in improving short term outcomes for neonates recovering from an arterial switch operation.

Declarations

Author Contribution

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Kathryn Restaino, Nora Alfakhri, Marlon Delgado, John Kheir, Katie Moynihan and Danny Hames. The first draft of the manuscript was written by Kathryn Restaino and Nora Alfakhri and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. Drs. Restaino and Alfakhri contributed equally as first authors. Drs. Moynihan and Hames contributed equally as senior authors.

References

1. Hirleman E, Larson D (2008) Cardiopulmonary bypass and edema: physiology and pathophysiology. *Perfusion* 23(6):311–322
2. Hazle MA, Gajarski RJ, Yu S, Donohue J, Blatt NB (2013) Fluid Overload in Infants Following Congenital Heart Surgery. *Pediatr Crit Care Med* 14(1):44–49
3. Wilder NS, Yu S, Donohue JE, Goldberg CS, Blatt NB (2016) Fluid Overload Is Associated with Late Poor Outcomes in Neonates Following Cardiac Surgery. *Pediatr Crit Care Med* 17(5):420–427
4. Fricke TA, Buratto E, Weintraub RG et al (2022) Long-term outcomes of the arterial switch operation. *J Thorac Cardiovasc Surg* 163(1):212–219

5. Lex DJ, Tóth R, Czobor NR et al (2016) Fluid Overload Is Associated with Higher Mortality and Morbidity in Pediatric Patients Undergoing Cardiac Surgery. *Pediatr Crit Care Med* 17(4):307–314
6. Castañuela-Sánchez V, Hernández-Suárez A, García-Benítez L, Díaz-García L, Martínez-Jasso G, Palacios Macedo-Quenot A (2022) Fluid overload as a predictor of morbidity and mortality in pediatric patients following congenital heart surgery. *Bol Méd Hosp Infant México* 79(3):7985
7. Bercovitz RS, Shewmake AC, Newman DK et al (2018) Validation of a definition of excessive postoperative bleeding in infants undergoing cardiac surgery with cardiopulmonary bypass. *J Thorac Cardiovasc Surg* 155(5):2112–2124e2
8. Gaies MG, Gurney JG, Yen AH et al (2010) Vasoactive-inotropic score as a predictor of morbidity and mortality in infants after cardiopulmonary bypass. *Pediatr Crit Care Med* 11:234–238
9. Teele SA, Gazit AZ, Futterman C et al (2025) Investigation of a novel noninvasive risk analytics algorithm with laboratory central venous oxygen saturation measurements in critically ill pediatric patients. *Crit Care Explor* 6(1):1–6
10. Hassinger AB, Wald EL, Goodman DM (2014) Early postoperative fluid overload precedes acute kidney injury and is associated with higher morbidity in pediatric cardiac surgery patients. *Pediatr Crit Care Med* 15(2):131–138
11. Alobaidi R, Morgan C, Basu RK et al (2018) Association between fluid balance and outcomes in critically ill children: a systematic review and meta-analysis. *JAMA Pediatr* 172(3):257–268
12. Mah KE, Hao S, Sutherland SM et al (2018) Fluid overload independent of acute kidney injury predicts poor outcomes in neonates following congenital heart surgery. *Pediatr Nephrol* 33:511–520
13. Brandewie KL, Selewski DT, Bailly DK et al (2023) Early postoperative weight-based fluid overload is associated with worse outcomes after neonatal cardiac surgery. *Pediatr Nephrol* 38(9):3129–3137
14. Bierer J, Stanzel R, Henderson M, Sett S, Horne D (2019) Ultrafiltration in Pediatric Cardiac Surgery Review. *World J Pediatr Congenit Heart Surg* 10(6):778–788
15. Kwiatkowski DM, Menon S, Krawczeski CD, Goldstein SL, Morales DL, Phillips A, Manning PB, Eghtesady P, Wang Y, Nelson DP, Cooper DS (2015) Improved outcomes with peritoneal dialysis catheter placement after cardiopulmonary bypass in infants. *J Thorac Cardiovasc Surg* 149(1):230–236
16. Stegmeier N, Alten J, Borasino S et al (2025) Early diuretic administration after neonatal cardiac surgery and association with clinical outcomes: a report from NEPHRON. *J Intensive Care Med*. Online ahead of print <https://doi.org/10.1177/08850666251393180>
17. Gaies M, Pasquali SK, Banerjee M et al (2019) Improvement in pediatric cardiac surgical outcomes through interhospital collaboration. *J Am Coll Cardiol* 74:2786–2795
18. Anderson BR, Blancha Eckels VL, Crook S, Duchon JM, Kalfa D, Bacha EA, Krishnamurthy G (2020) The Risks of Being Tiny: The Added Risk of Low Weight for Neonates Undergoing Congenital Heart Surgery. *Pediatr Cardiol* 41(8):1623–1631

19. Hornik CP, He X, Jacobs JP, Li JS, Jaquiss RD, Jacobs ML, O'Brien SM, Peterson ED, Pasquali SK (2011) Complications after the Norwood operation: an analysis of The Society of Thoracic Surgeons Congenital Heart Surgery Database. *Ann Thorac Surg* 92(5):1734–1740
20. Alsoufi B, Manlhiot C, Mahle WT et al (2014) Low-weight infants are at increased mortality risk after palliative or corrective cardiac surgery. *J Thorac Cardiovasc Surg* 148:2508–2514
21. Mills KI, Kim JH, Fogg K et al (2022) Nutritional considerations for the neonate with congenital heart disease. *Pediatrics* ; 150(Suppl 2)
22. Bojan M (2019) Recent achievements and future developments in neonatal cardiopulmonary bypass. *Pediatr Anaesth* 29(5):414–425

Figures

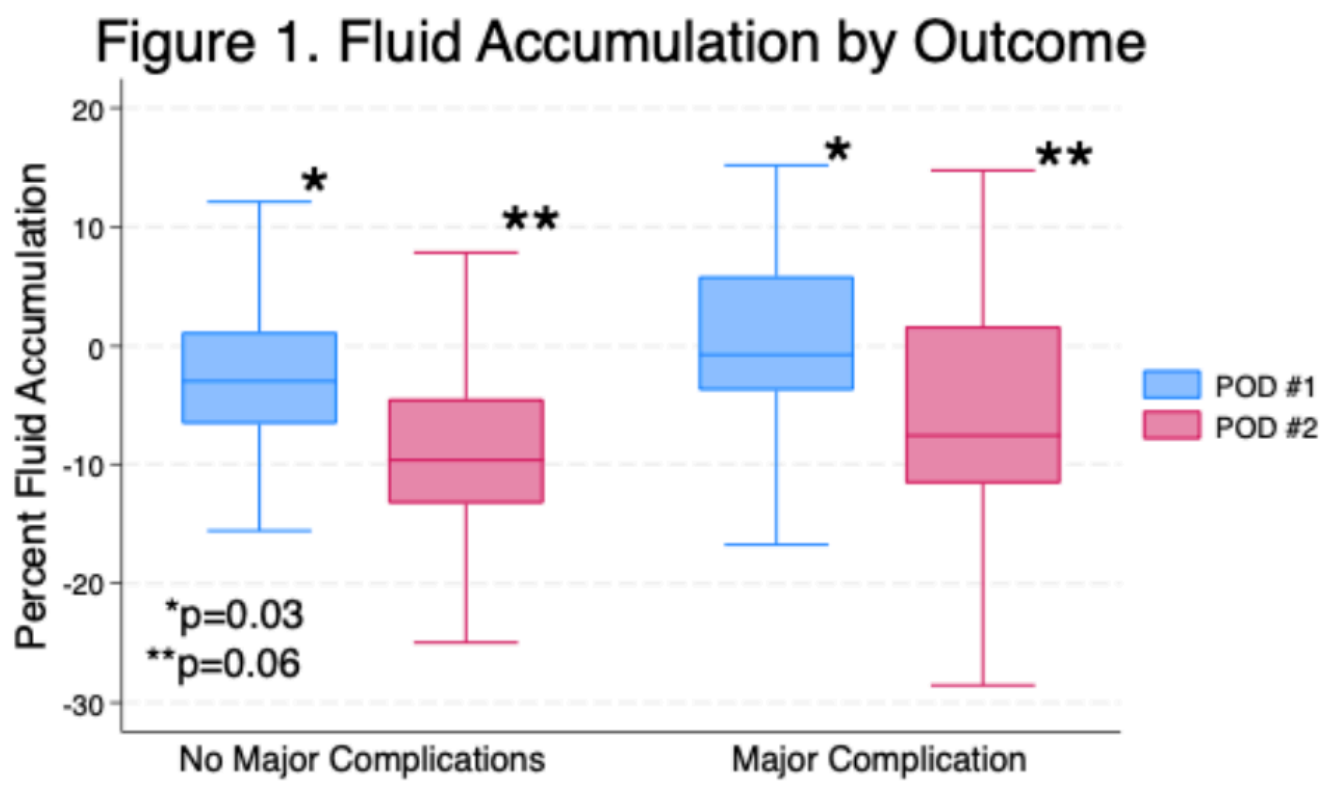


Figure 1

Fluid accumulation by acquisition of major complication. Blue boxes are fluid balance as of postoperative day 1 and red boxes are fluid balance as of post-operative day 2. Patients who developed a major complication had higher fluid accumulation on postoperative day 1 compared with those who did not develop a major complication.

Figure 2. Time to CICU Discharge by Outcome

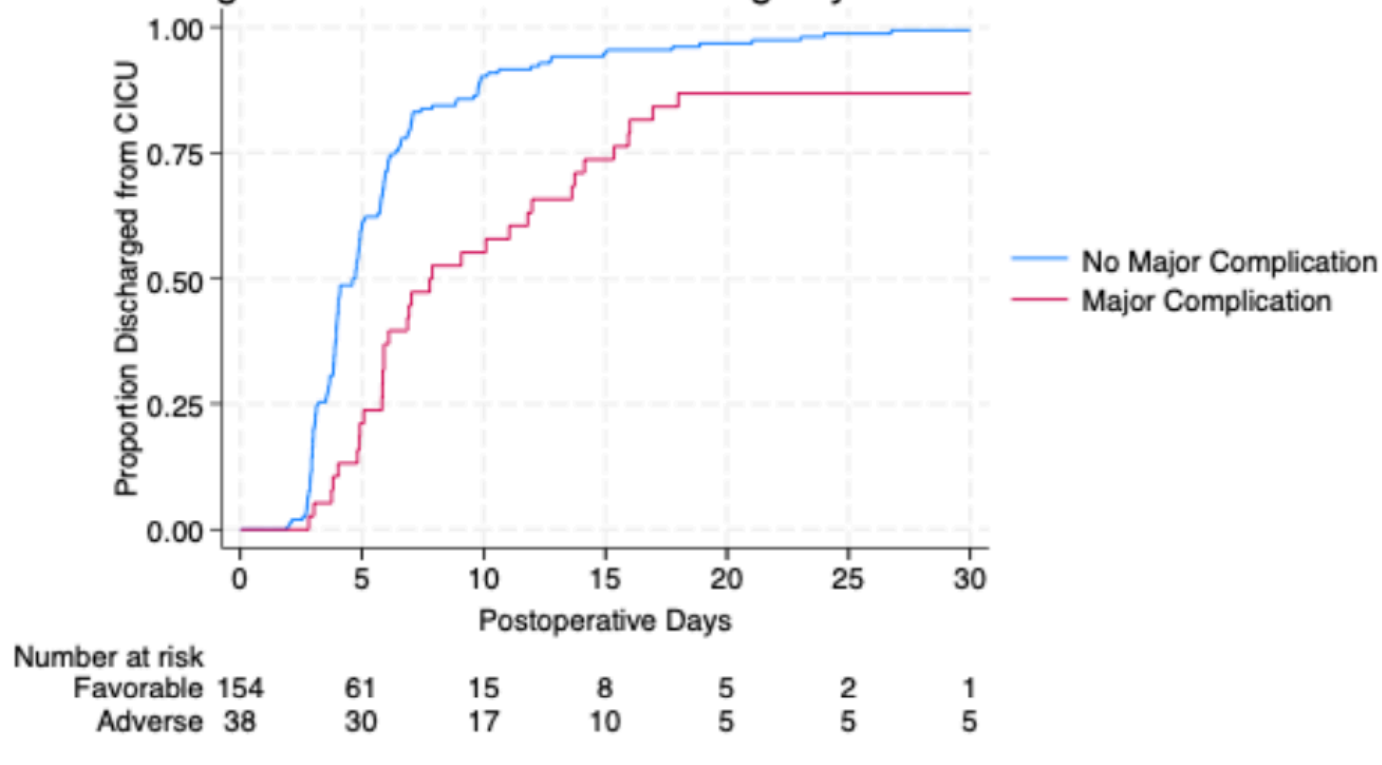


Figure 2

Proportion of patients discharged from the cardiac intensive care unit in the first 30 postoperative days based on development of a major complication. A higher proportion of patients remained in the CICU in the first 30 postoperative days if a major complication developed.