Fluid Balance in Children with Congenital Heart Disease

Pediatric cardiac patients

- passive pulmonary blood flow
- restrictive right / left ventricular physiology
- parallel circulations
- marginal coronary reserve
- Intra-cardiac shunting

Cardiopulmonary Bypass

- "Controlled shock"
- Loss of pulsatile blood flow
  - Capillary leak
  - Vasoconstriction
  - Renovascular effects
    - Renin/angiotensin
- Cytokine release
- Endothelial damage and "sheer injury"

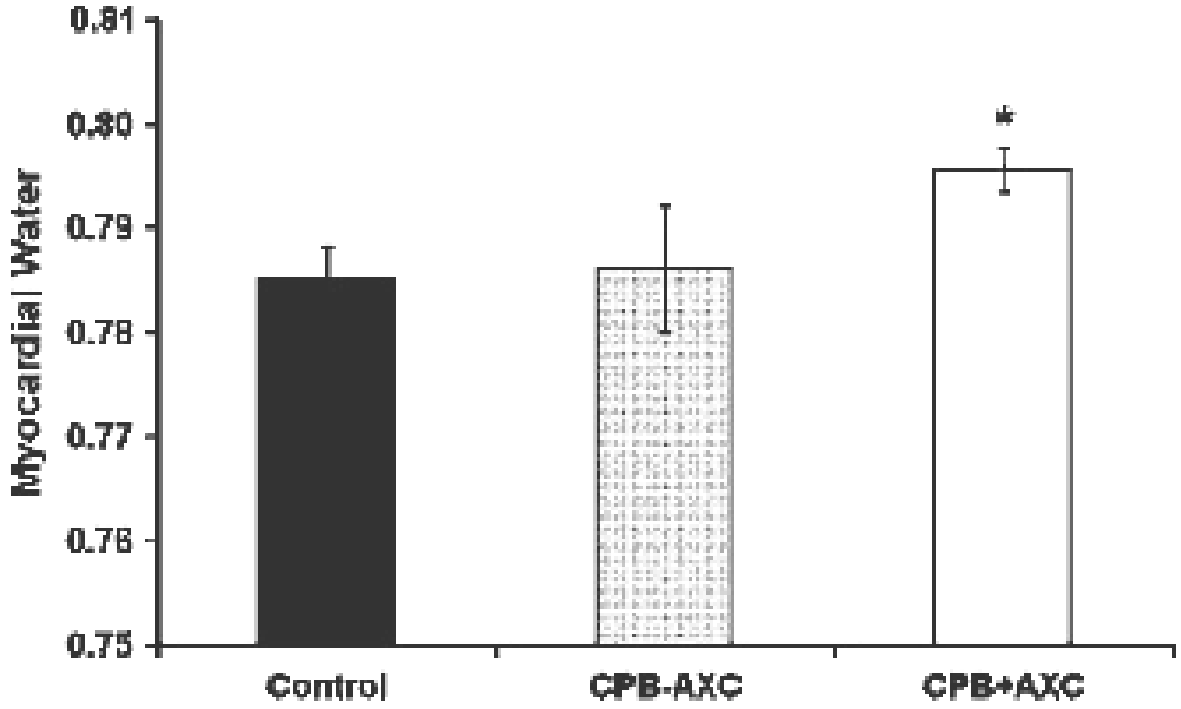


Figure 2. Myocardial water. Proportion of heart as water in non–cardiopulmonary bypass *(CPB)* control animals *(black column)*, lambs undergoing CPB without aortic crossclamping *(AXC; gray column)*, and lambs undergoing CPB with AXC *(white column)*. Significant myocardial edema was present in lambs undergoing CPB+AXC lambs, and a nonsignificant increase in myocardial water occurred in those undergoing CPB–AXC (Mann–Whitney *U* test). $*P < .05$. Data shown are presented as means ± standard error of the mean.

J Thorac Cardiovasc Surg 2008

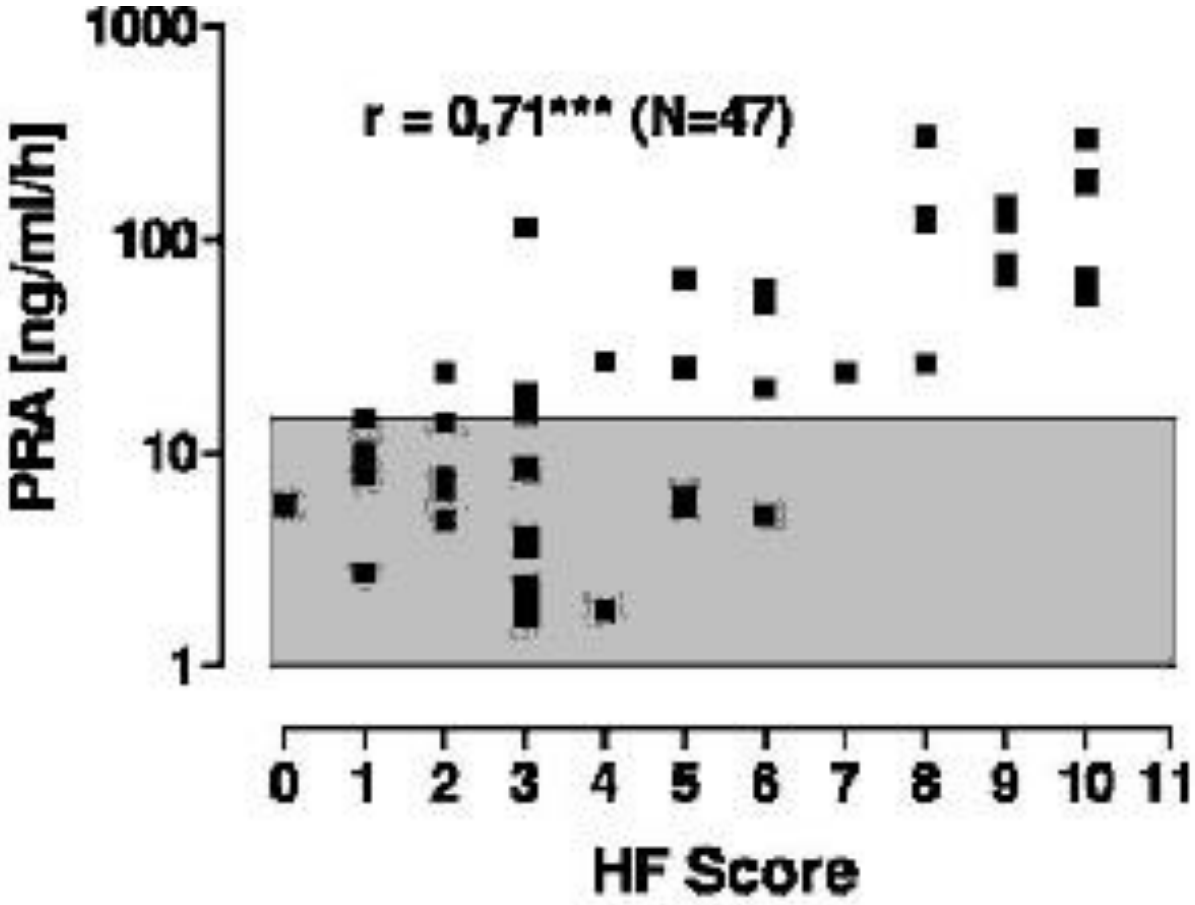
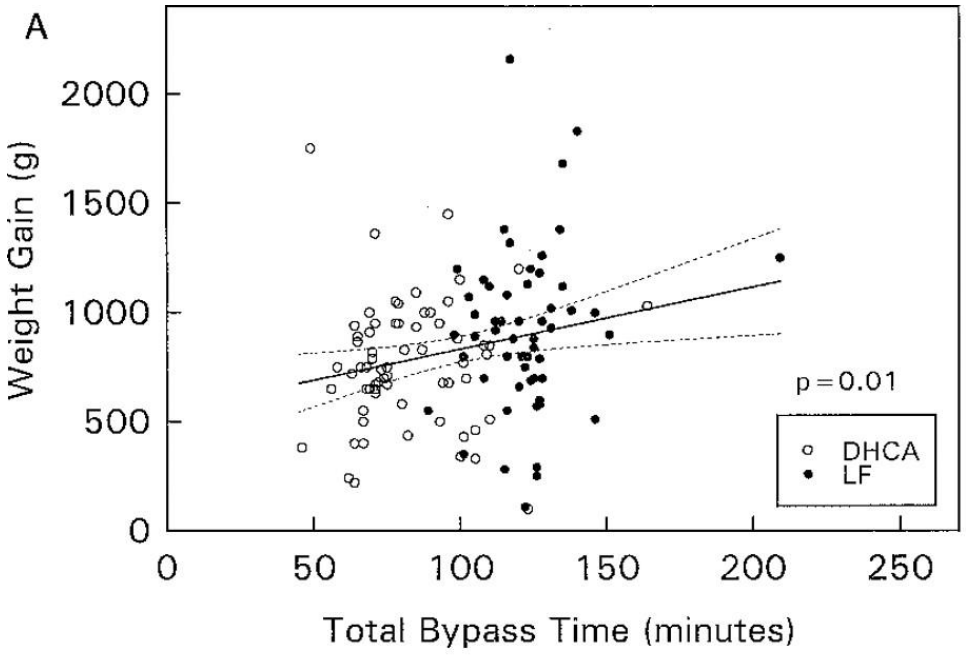


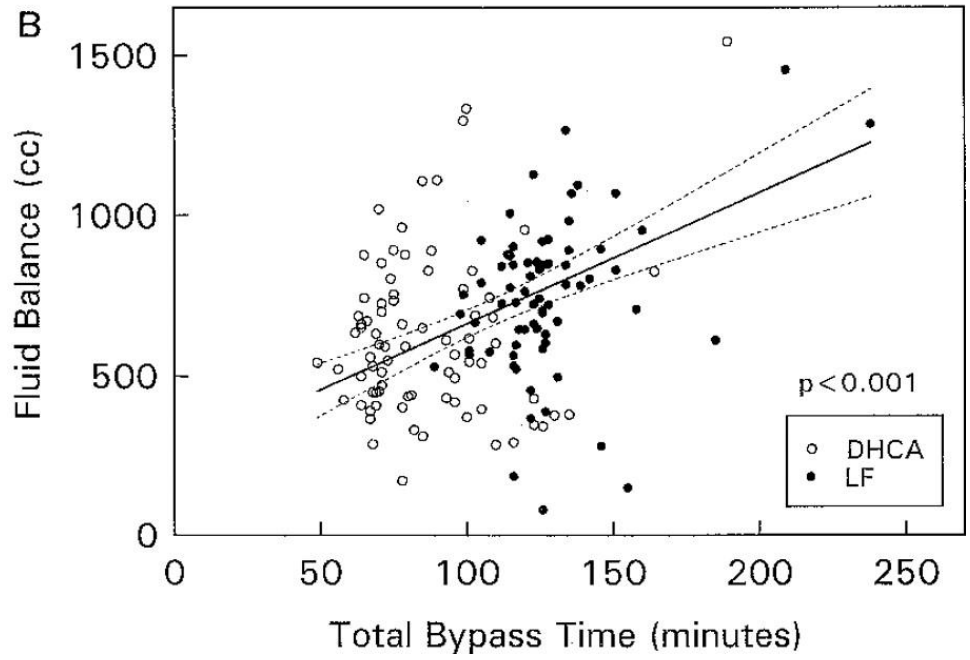
Fig. 1. Plasma renin activity (PRA) and clinical heart failure score (HF Score) in infants with left-to-right shunts. *y* axis: log scale; gray shaded bar: normal range for PRA in infants. Result of Spearman correlation: $r=0.71$; $^{***}P<0.0001$.

Pediatr Crit Care Med 2016

Reasons for disturbances in intravascular and total body fluid status

- intrinsic myocardial dysfunction
- neuroendocrine response
- renal dysfunction
- systemic inflammation with endothelial dysfunction.

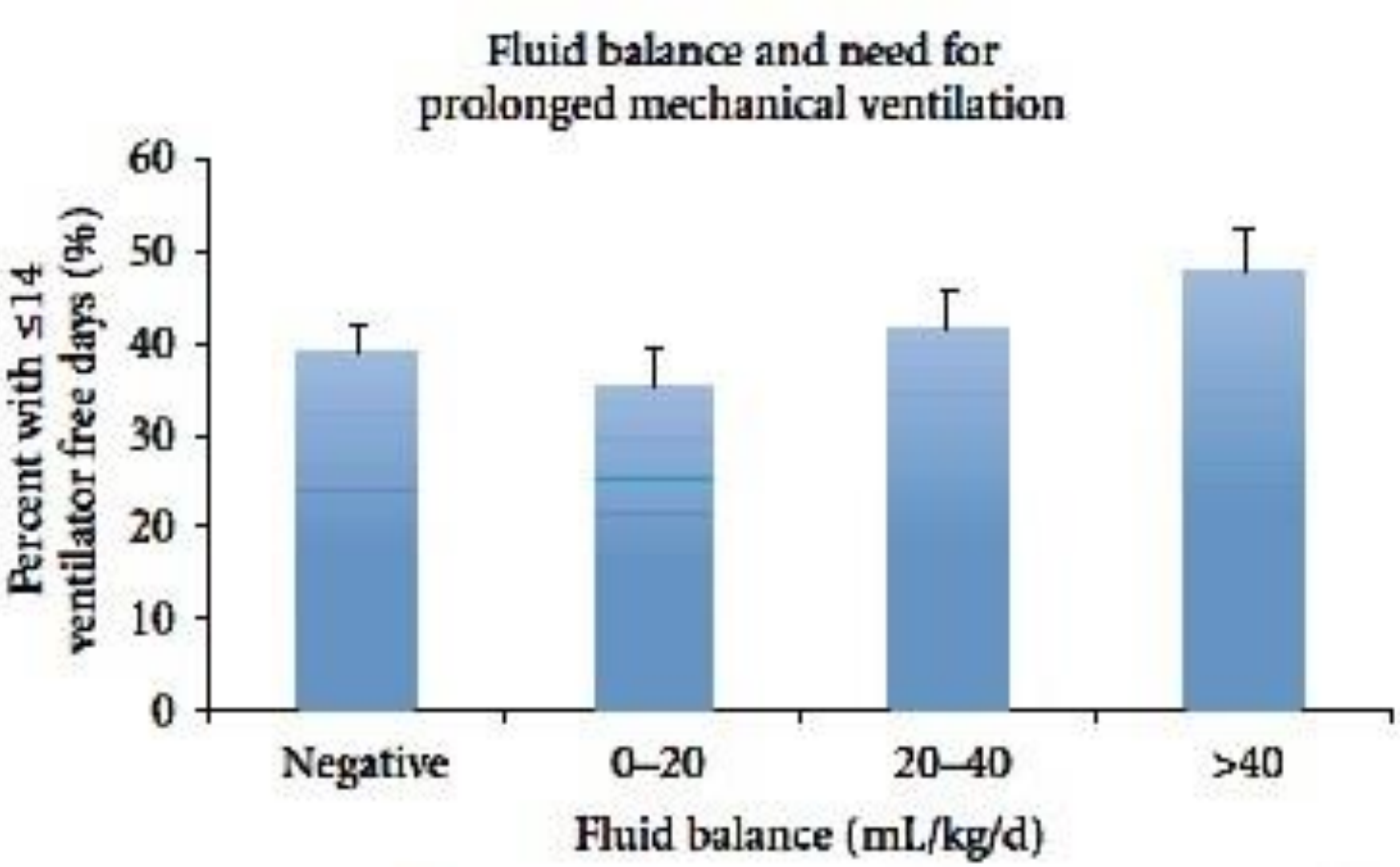




Average fluid accumulation of 664 mL (≈ 30% weight gain) following the arterial switch operation.

Circulation 1995

Positive Fluid Balance is Associated with Higher Mortality, Prolonged Mechanical Ventilation and acute kidney injury in Critically ill Patients



Heidi et al. Critical Care Research, 2011

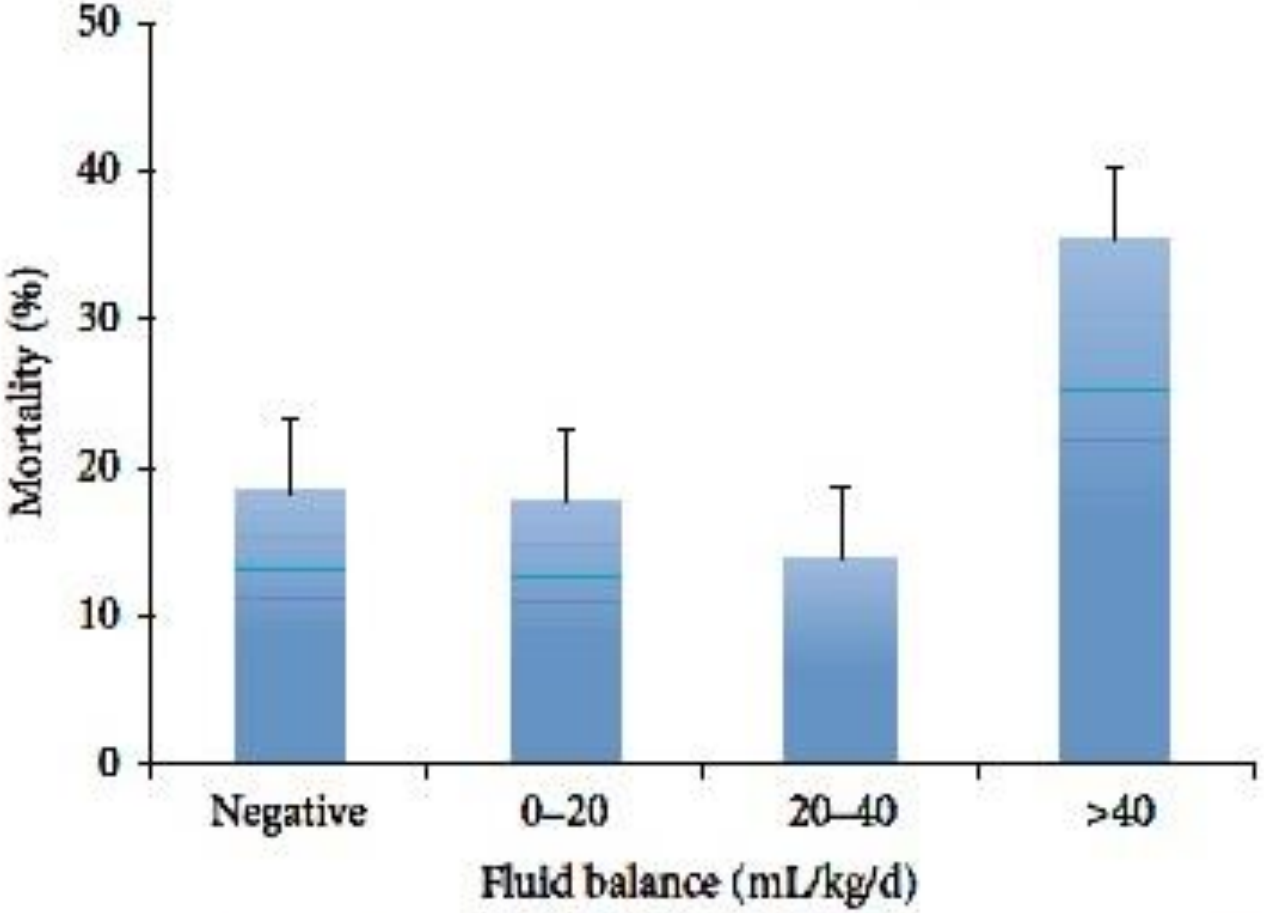
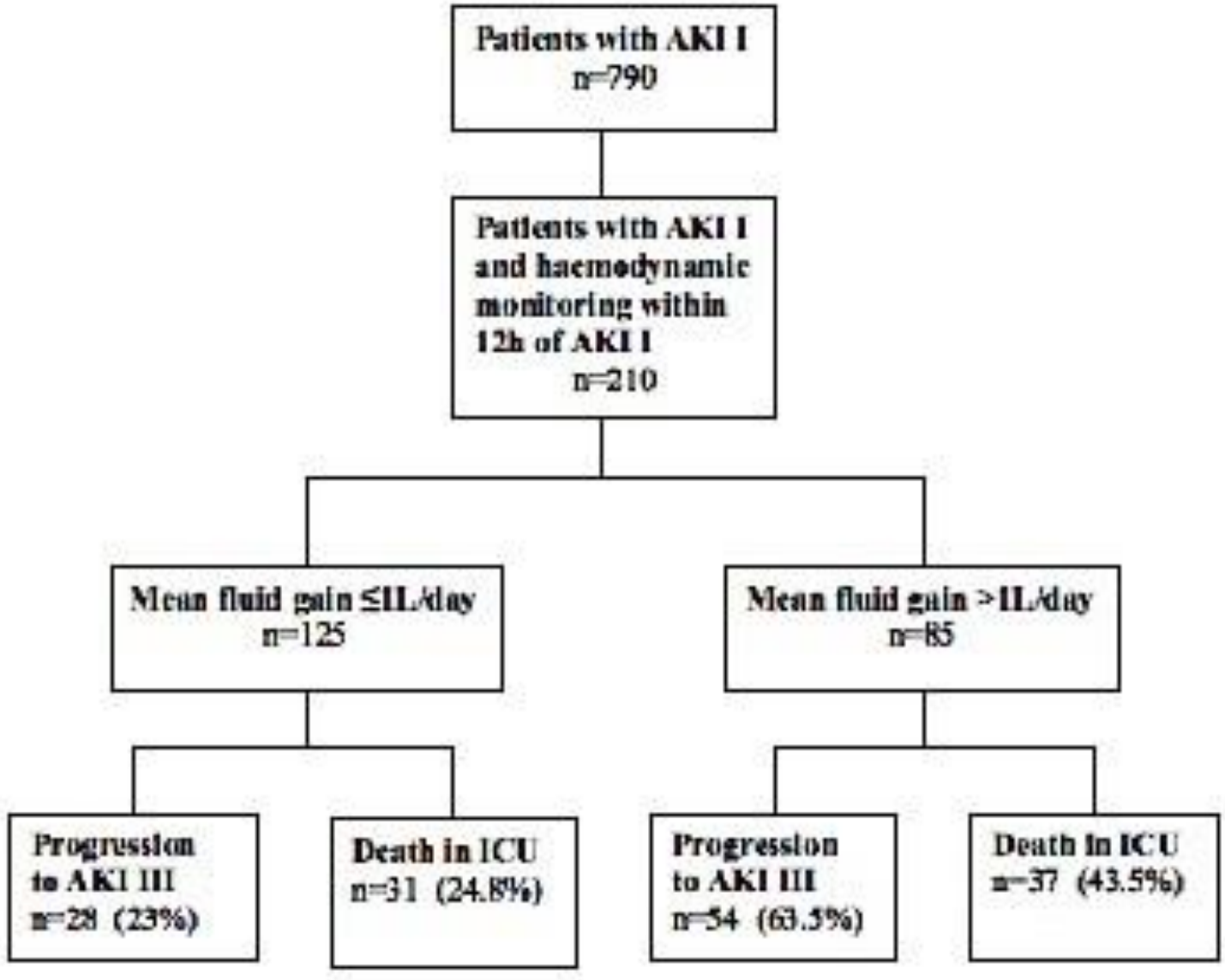


FIGURE 1: Bar graph depicting the association between cumulative fluid balance within the first 72 hours after ALI and all-cause mortality.

Heidi et al. Critical Care Research, 2011



Abbreviations: AKI = acute kidney injury; ICU = intensive care unit;

SHOCK NOVEMBER 2015

- Consensus definitions for fluid overload do not exist

- Fluid overload may be defined as a positive fluid balance of at least 50–100 mL/kg on a given day

- Percentage fluid overload 5 %

([volume fluid in (L) – volume fluid out(L)]/[weight] × 100)

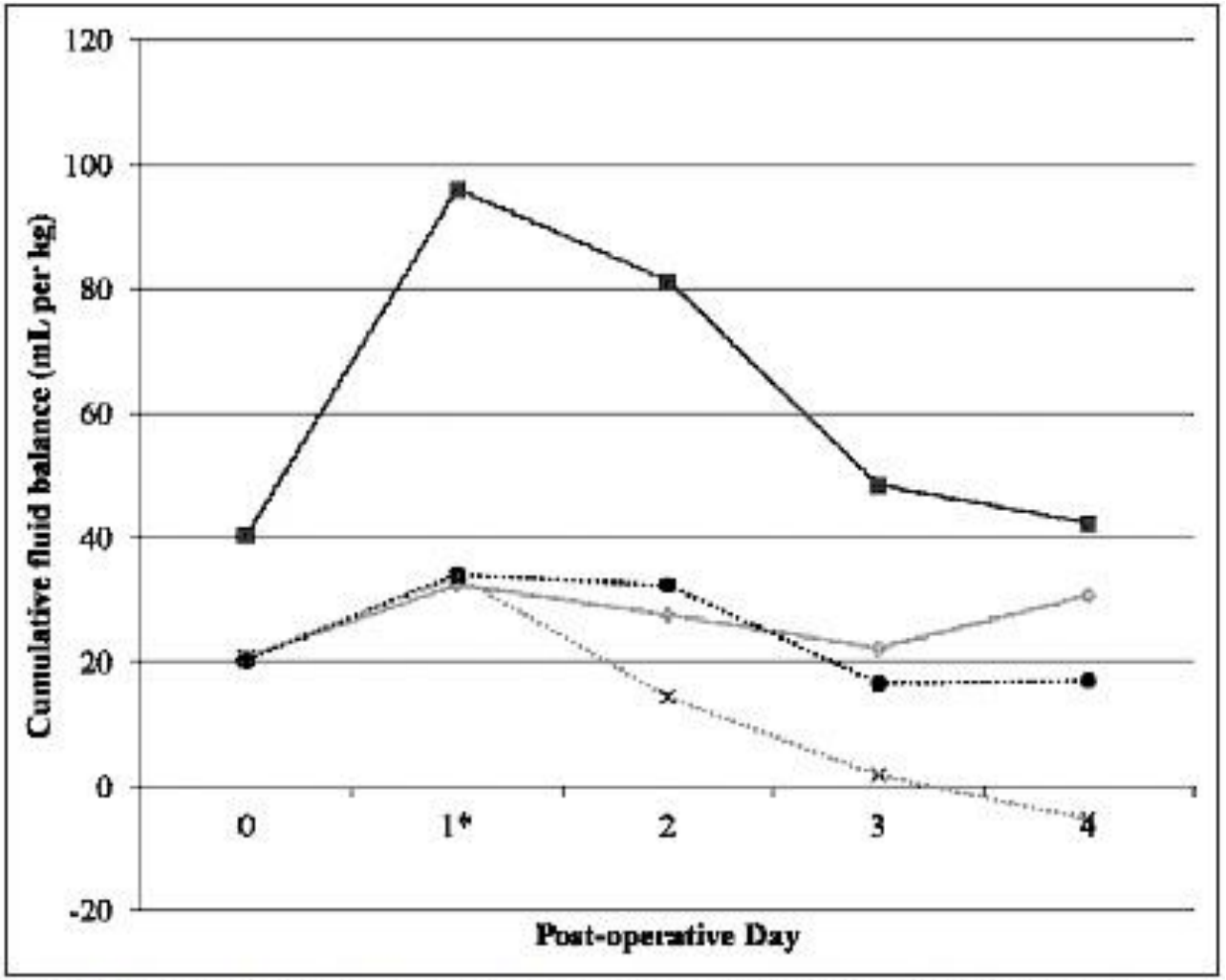


Figure 1. Median cumulative fluid balance in milliliters per kilogram body weight in patients in each category of acute kidney injury using pediatric-modified Risk, Injury, Failure, Loss, and End-stage criteria over the study period. Risk = more than 25% loss of renal function, Injury = more than 50%, Failure = more than 75% loss or an absolute function less than 35 mL/min/1.73 m². *Significant comparisons as obtained using Kruskal-Wallis comparison between all groups. None = *gray diamond*, Risk = *closed circle*, Injury = "*x*" *mark*, Failure = *closed*

Pediatr Crit Care Med 2014

Attention to "early fluid overload"

(e.g., first 24 postoperative hours)

and cumulative fluid overload

TABLE 3. Multivariable Analysis of the Predictors of Prolonged Mechanical Ventilation

Variable	Adjusted OR (95% CI)	p
Early fluid overload	3.15 (0.58–17.12)	0.1835
Cardiopulmonary bypass time	1.04 (1.02–1.07)	0.0001
Age (mo)	0.98 (0.96–0.99)	0.0277

OR = odds ratio.

p values obtained by logistic regression controlling for presence of a cyanotic lesion, cardiopulmonary bypass time, baseline estimated glomerular filtration rate, and pediatric-modified Risk, Injury, Failure, Loss, and End-stage category.

Pediatr Crit Care Med 2014; 15:131–138

Association between mean fluid balance, urinary output, and fluid intake between AKI and progression to AKI III or recovery and hospital mortality

	Multivariable analysis			
	Progression to AKI III		Death in hospital	
	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Model 1*				
Fluid gain (per liter/day)	2.7 (1.8–4.1)	<0.001	1.6 (1.2–2.1)	0.001
Model 2*				
Urine output (per liter/day)	0.8 (0.3–2.2)	0.6	0.8 (0.4–1.4)	0.66
Fluid intake (per liter/day)	1.8 (1.1–6.8)	0.02	1.3 (1.0–1.8)	0.09

AKI, acute kidney injury; APACHE, Acute Physiology and Chronic Health Evaluation; CAD, coronary artery disease; CCF, congestive cardiac failure; CI, confidence interval; MAP, mean arterial pressure; OR, odds ratio; SOFA, sequential organ failure assessment.
*All models adjusted for age, sex, CAD and/or CCF, DO_2I, MAP, diuretic use, type of fluids administered, SOFA, and APACHE scores on admission.

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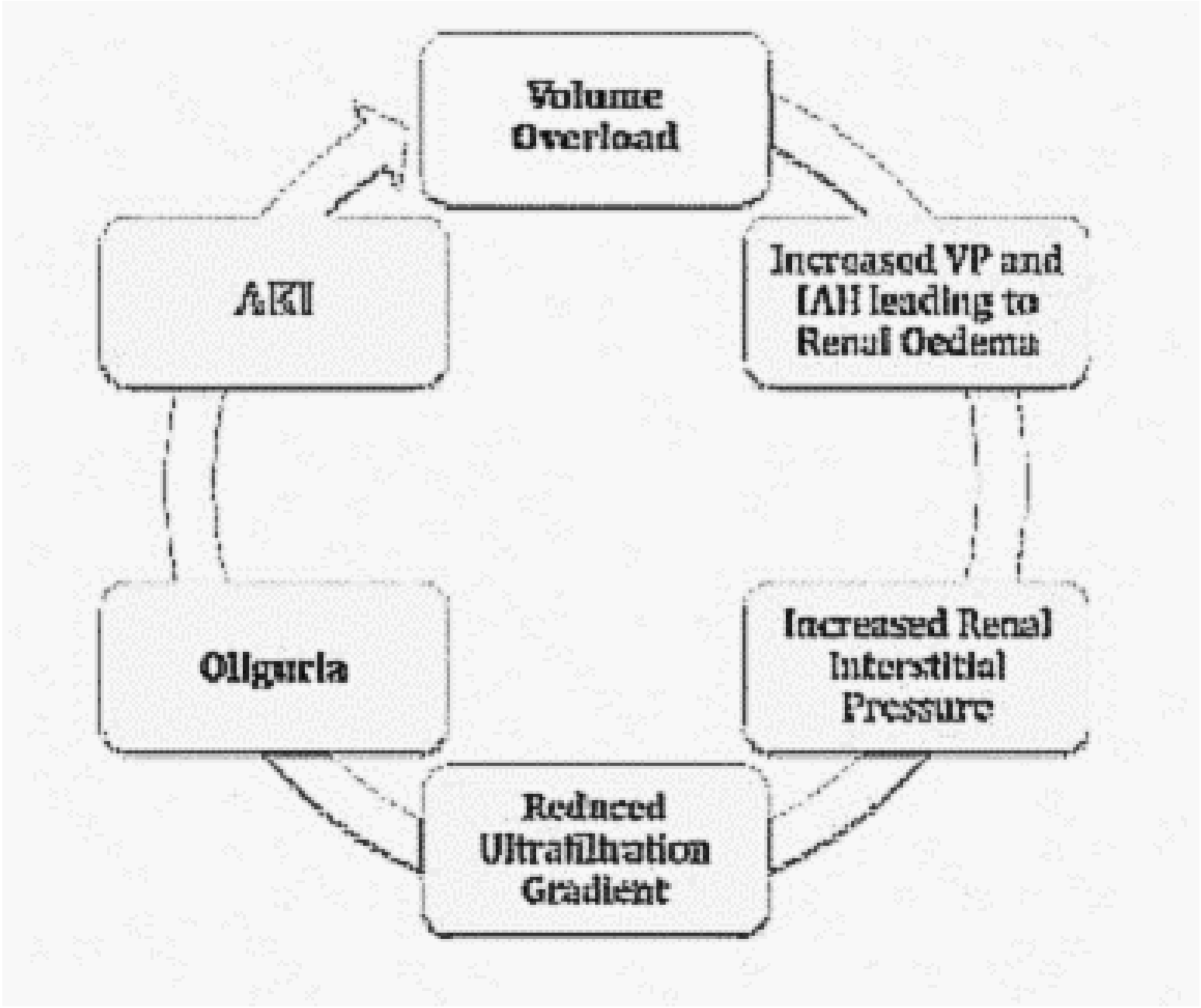

Volume Overload
Increased VP and [AII leading to Renal Oedema
Increased Renal Interstitial Pressure
Reduced Ultrafilhation Gradient
Oligurla
AKI

- Specific guidelines for the composition and rate of IV fluid administration for the pediatric cardiac patient do not exist

- Adequate organ perfusion requires **appropriate circulating blood volume**

- **Renal perfusion pressure = MAP – CVP**

- Widely accepted values for normal renal perfusion pressure in the pediatric cardiac population have not been established

- A number of variables should be considered to determine whether an individual patient has adequate renal perfusion pressure

Considering Factors

- younger age/gestational age
- preoperative mechanical ventilation
- type of repair
- longer CPB
- hypothermic circulatory arrest times

The underlying cardiac physiology

- Noncompliant right ventricle (e.g., PA with IVS, TOF)
  elevated RA pressure and systemic venous pressure

- Functional SV palliated with TCPC
  nonphasic, elevated CVP

=> higher MAP to achieve adequate renal perfusion

- Note that pressure alone may not correlate well with regional organ perfusion and quantification of flow to end organs is often impractical at the bedside

- Urine output is quite sensitive to renal perfusion pressure and should be followed closely

- Serum blood urea nitrogen, creatinine, Ccr

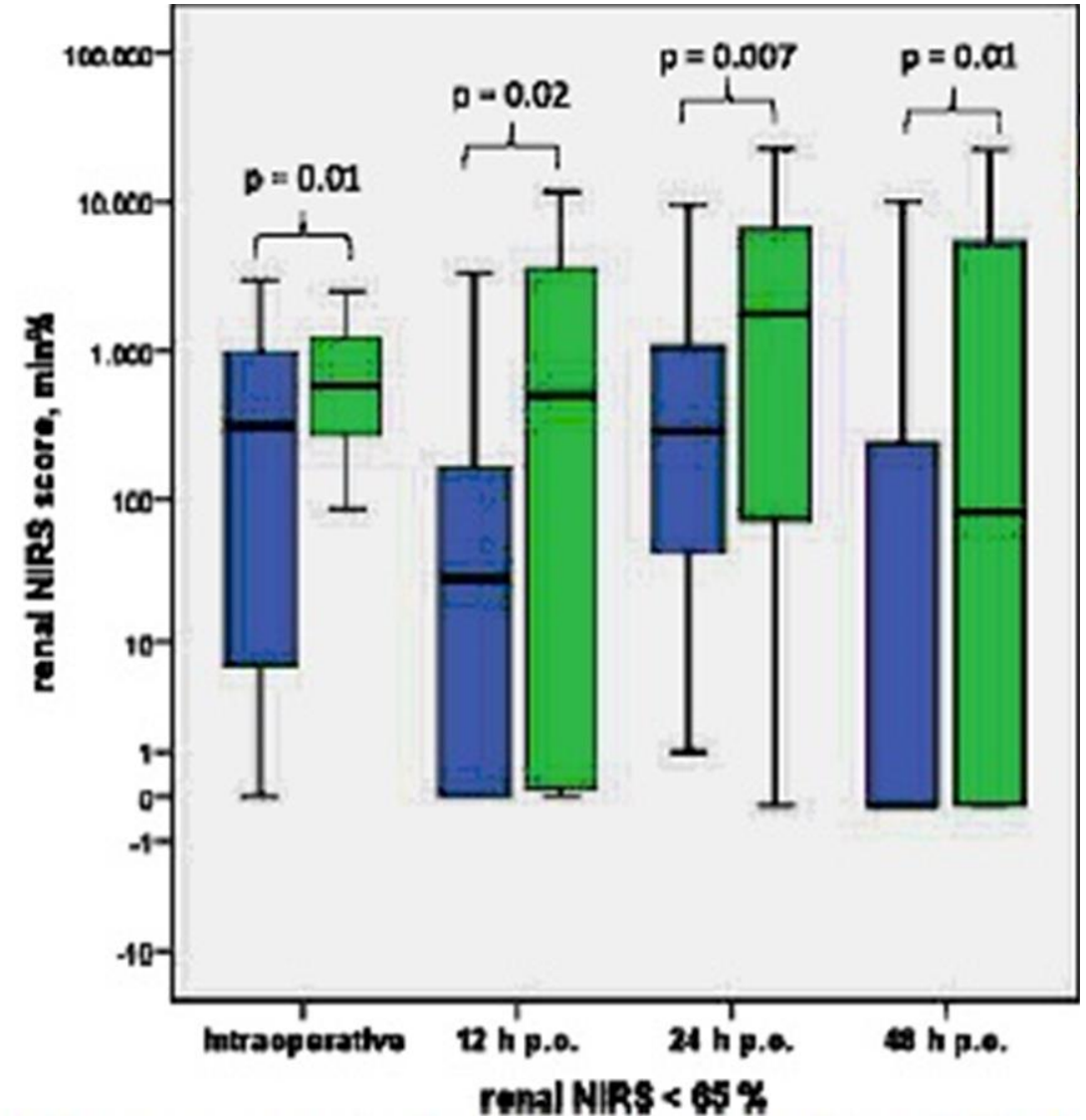
  may assist in the assessment of renal perfusion

  pressure and evolving renal dysfunction

- Serum creatinine (S_{Cr}) is a delayed marker for AKI after cardiopulmonary bypass (CPB)

- Rapidly detectable AKI biomarkers could allow early intervention and improve outcomes (JACC 2011, Nov 22)

- Biomarkers, such as neutrophil gelatinase–associated lipocalin (NGAL) and cystatin C, are useful for early identification of AKI and may become part of routine clinical care in the near future



Near-infrared spectroscopy may be used to measure renal tissue oxygenation

World J Pediatr Congenit Heart Surg 2011