

Original Article

Renal Function in Children With Congenital Heart Disease After Cardiopulmonary Bypass

Negar Saadaat¹, MD; Saeed Abtahi^{2*}, MD; Mahmood Hosseinzadeh Maliki³, MD; Farhad Samadieh³, MD; Fereshteh Najafi⁴, PhD

ABSTRACT

Background: Kidney dysfunction is a known complication in children with congenital heart disease (CHD). While numerous studies have explored risk factors for nephropathy in this population, research specifically comparing renal function before and after open-heart surgery remains limited. This study aimed to evaluate kidney function in children with CHD both before and after cardiopulmonary bypass and open-heart surgery.

Methods: This prospective observational study included children with CHD, aged 1 month to 5 years, who underwent open-heart surgery. Demographic information and serum levels of creatinine, urea, albumin, and glomerular filtration rate (GFR) were collected at 24 hours pre-surgery and at 24, 48, and 72 hours, and 1 week post-surgery. Data analysis and comparisons were performed based on the type of CHD (cyanotic versus acyanotic).

Findings: Twenty-six cyanotic and 40 acyanotic children with CHD, with a mean age of 16.34 ± 15.50 months, were included in the study. Serum levels of creatinine, urea, and albumin significantly increased 24 hours after the operation ($P < 0.05$). GFR significantly decreased at 24 and 48 hours postoperatively ($P < 0.05$). Moreover, 72 hours after the operation, creatinine levels were significantly higher in the cyanotic group than in the acyanotic group ($P = 0.007$). At 24 hours ($P = 0.02$) and 72 hours ($P = 0.05$) postoperatively, higher mean urea levels were observed in the cyanotic group. Patients undergoing surgeries lasting over 60 minutes had higher serum urea levels than those with shorter surgical durations ($P = 0.05$).

Conclusions: These results suggest that renal function indices were altered during the first two days following open-heart surgery in children with CHD. (*Iranian Heart Journal 2025; 26(4): 6-14*)

KEYWORDS: Congenital heart disease, Kidney function, Open-heart surgery, Cardiopulmonary bypass

¹ Student Research Committee, Faculty of Medicine, Mashhad Medical Sciences Branch, Islamic Azad University, Mashhad, IR Iran.

² Faculty of Medicine, Mashhad Medical Sciences Branch, Islamic Azad University, Mashhad, IR Iran.

³ Department of Cardiac Surgery, Imam Reza Hospital, Mashhad University of Medical Sciences, Mashhad, IR Iran.

⁴ Department of Epidemiology and Biostatistics, School of Public Health, Tehran University of Medical Sciences, Tehran, IR Iran.

*Corresponding Author: Saeed Abtahi, MD; Faculty of Medicine, Mashhad Medical Sciences Branch, Islamic Azad University, Mashhad, IR Iran.
Email: sabbahim@yahoo.com Tel: +985138535379

Received: July 23, 2024

Accepted: December 17, 2024

Congenital heart disease (CHD) is one of the most common congenital anomalies in infants and adolescents.¹ It encompasses a range of defects in the heart's structure or function that develop during the fetal period.¹ CHD is classified as acyanotic or cyanotic based on the presence or absence of clinical cyanosis in the patient.² Worldwide, the prevalence of CHD is approximately 1.35 million affected births annually,³ with an estimated incidence of 5 to 8 per 1,000 live births.⁴ CHD causes alterations and disturbances in the function of other organs, including the kidneys, blood vessels, and lungs.⁵ Renal damage is one of the most significant complications of CHD and can have long-term negative effects on patients' lives.⁶ The renal disorders associated with CHD include a wide spectrum of glomerular and tubular dysfunctions.⁷ In patients with glomerular dysfunction, the glomerular filtration rate (GFR) can decrease, and macroalbuminuria or microalbuminuria may occur.⁸ CHD can lead to glomerular enlargement, capillary dilatation, mesangial cell proliferation, glomerular sclerosis, and tubular dysfunction with a loss of integrity.⁹ The duration of cyanosis and elevated hematocrit levels are primary contributors to nephropathy in patients with CHD.¹⁰ Kidney damage secondary to CHD is one of the side effects of cardiopulmonary bypass for children with CHD who undergo this surgery to address their cardiac disorders.¹¹ Kidney damage caused by cardiopulmonary bypass can lead to acute kidney injury (AKI) and more severe complications, such as dialysis. AKI occurs in 15–64% of children who undergo cardiac surgery^{12,13} and results in 10–89% mortality rates.^{13,14} The mortality rate and clinical consequences of AKI are much higher in infants who undergo surgery due to congenital heart disorders.¹³ Different factors, such as young age, small body size,¹⁵ complexity of the congenital

heart disorder, and duration of bypass, are known risk factors for renal dysfunction. Due to differences in the definitions of AKI, the small sample size of the studies, and the small number of investigated variables, there is a scarcity of information regarding the exact prevalence and risk factors of this disorder in Iran. Most studies have examined the risk factors of nephropathy in patients with CHD, but the number of studies comparing kidney function before and after open-heart surgery is very limited. Therefore, this study compared kidney function in children with CHD before and after open-heart surgery by type of CHD in Iran.

METHODS

This was a prospective longitudinal study.

Participants

The study population comprised children who underwent cardiopulmonary bypass and open-heart surgery for CHD between July 2022 and July 2023 at Imam Reza and Razavi hospitals in Mashhad, Iran. Inclusion criteria were an age between 1 month and 5 years and a diagnosis of CHD. Exclusion criteria included a history of known kidney diseases, metabolic diseases, or systemic diseases (other than CHD).

Measurements

Demographic information for all patients, including age, gender, and body surface area, was collected. Clinical variables such as the duration of cardiopulmonary bypass, ventilator use, and aortic clamping were also recorded. Performance evaluation factors, including GFR and serum creatinine, albumin, and urea levels, were documented. These blood tests were part of the routine pre- and post-open-heart surgery and ICU admission protocols, and they incurred no additional cost to patients.

The specified measurements were taken exactly 24 hours before the operation, and at 24, 48, and 72 hours, and 1 week after the operation by the laboratories of the respective hospitals. Estimated GFR was calculated using the Schwartz formula [$\text{GFR (mL/min/1.73m}^2) = k \times \text{height (cm) / serum Cr (mg/dL)}$], where $k = 0.45$ for term infants up to 1 year of age and $k = 0.55$ for children aged 1 to 13 years.¹⁶ All surgeries were performed by the same surgeon across both centers.

Data Analysis

Quantitative data were summarized using means and standard deviations, while qualitative data were presented as frequencies and percentages. The Shapiro–Wilk test was applied to assess data normality. After confirming normal distribution, the Student *t*-test and one-way analysis of variance (ANOVA) were conducted. The Bonferroni test was used for pairwise comparisons. Repeated-measures ANOVA was performed to control for baseline values of the factors and to evaluate overall changes over time between the two CHD groups. Data were analyzed using

SPSS version 26, with a significance level set at 5%.

Ethical Considerations

Informed consent was obtained from all participants in the study. This research received approval under the ethics code R.IAU.MSHD.REC.1401.024 from the Faculty of Medicine at Islamic Azad University, Mashhad branch.

RESULTS

Out of a total of 72 candidate children for cardiopulmonary bypass with open-heart surgery, 6 were excluded based on the exclusion criteria. Sixty-six children with CHD who underwent cardiopulmonary bypass with open-heart surgery were examined. Twenty-six children had cyanotic CHD (39.39%), and the others had acyanotic CHD (60.61%). The distribution of study variables by type of CHD is presented in Table 1. The durations of cardiac bypass, aortic clamping, and ventilator use in patients with cyanotic CHD were significantly longer than those in patients with acyanotic CHD. The other variables did not differ significantly between the two groups.

Table 1. Characteristics of children with CHD undergoing cardiopulmonary bypass and open-heart surgery by type of congenital heart disease

	Type of CHD			P*
	Cyanotic (n=26)	Acyanotic (n=40)	Total (n=66)	
Gender (male)	9 (34.62)	22 (55.00)	31 (46.97)	0.10
Gender (female)	17 (65.38)	18 (45.00)	35 (53.03)	
Age (months)	16.11 (14.32)	16.50 (16.41)	16.34 (15.50)	0.10
Weight (kg)	9.13 (3.51)	8.00 (4.16)	8.47 (3.92)	0.13
Height (cm)	77.38 (15.77)	73.55 (15.43)	75.14 (15.69)	0.32
Body surface area (m ²)	0.43 (0.13)	0.40 (0.15)	0.41 (14)	0.17
Cardiac bypass duration (minutes)	92.29 (26.00)	65.88 (25.70)	76.67 (28.69)	0.0001
Aortic clamp duration (minutes)	70.13 (20.87)	42.40 (16.47)	53.77 (22.90)	0.0001
Duration of ventilator use (days)	1.74 (0.66)	1.23 (0.48)	1.44 (0.61)	0.001

Data are presented as mean (standard deviation), except for gender, which is expressed as number (percentage). A *P*-value <0.05 was considered statistically significant. CHD: congenital heart disease

Table 2 shows the serum levels of creatinine, urea, albumin, and GFR at different timepoints. Serum creatinine increased during the first 24 and 48 hours following the operation compared with the preoperative value; 1 week after the operation, the creatinine level decreased significantly compared with the first 48 hours post-operation ($P < 0.05$).

Serum urea also increased during the first 24 and 48 hours after the operation compared with the preoperative level ($P < 0.05$).

Serum albumin increased significantly during the first 24 hours compared with baseline; nonetheless, 1 week after the operation, it was significantly reduced compared with the first 24 hours post-operation ($P < 0.05$).

GFR decreased 24 and 48 hours after the operation compared with the baseline value,

then increased 72 hours after the operation, and rose significantly to its highest level within 1 week after the operation ($P < 0.05$).

Table 3 shows the serum levels of creatinine, urea, albumin, and GFR at different time points based on the type of CHD. Seventy-two hours after the operation, the mean creatinine level was significantly higher in the cyanotic group than in the acyanotic group ($P = 0.007$). At 24 and 72 hours after surgery, the cyanotic group had higher urea levels than the acyanotic group ($P = 0.02$ and $P = 0.05$, respectively). No significant differences were observed in albumin levels at any other time points. Both cyanotic and acyanotic groups had similar mean GFR values at all timepoints. Figure 1 illustrates the increasing and decreasing trends of kidney function indices by type of CHD.

Table 2. Comparison of renal function indices at different time points in children with CHD undergoing cardiopulmonary bypass and open-heart surgery

Renal Function Index	24 Hours Before ¹	24 Hours After ²	48 Hours After ³	72 Hours After ⁴	1 Week After ⁵	<i>P</i>
Serum creatinine (mg/dL)	0.53 (0.13)	0.60 (0.18)	0.61 (0.24)	0.59 (0.27)	0.53 (0.31)	$P_{\text{overall}} = 0.03$ $P^{1,2}, P^{1,3}, P^{3,5}$ < 0.05
% change from baseline	-	+ 0.70	+0.80	+0.6	0.0	
Serum urea (mg/dL)	23.12 (8.61)	31.38 (12.38)	31.45 (18.69)	27.95 (21.61)	27.98 (24.69)	$P_{\text{overall}} = 0.05$ $P^{1,2}, P^{1,3} < 0.05$
% change from baseline	-	+ 8.26	+8.33	+4.38	+4.86	
Serum albumin (g/L)	3.68 (0.48)	3.90 (0.45)	3.79 (0.39)	3.70 (0.37)	3.83 (0.40)	$P_{\text{overall}} = 0.04$ $P^{1,2}, P^{2,4} < 0.05$
% change from baseline	-	+0.22	+0.11	+ 0.02	+ 0.15	
GFR (mL/min)	77.00 (32.90)	66.57 (22.32)	67.47 (24.21)	71.28 (26.13)	84.00 (47.57)	$P_{\text{overall}} = 0.008$ $P^{1,2}, P^{1,3}, P^{2,5},$ $P^{3,5} < 0.05$
% change from baseline	-	- 10.43	- 9.53	- 5.72	- 7.0	

Data are presented as mean (standard deviation).

A *P*-value < 0.05 was considered statistically significant.

GFR: glomerular filtration rate, CHD: congenital heart disease

Table 3. Comparison of renal function indices at different time points in children with CHD undergoing cardiopulmonary bypass and open-heart surgery, by type of CHD

Renal Index	Function	Type of CHD	24 Hours Before ¹	24 Hours After ²	48 Hours After ³	72 Hours After ⁴	1 Week After ⁵
Serum creatinine (mg/dL)		Cyanotic	0.55 (0.13)	0.63 (0.21)	0.66 (0.31)	0.67 (0.36)	0.61 (0.48)
		Acyanotic	0.51 (0.13)	0.58 (0.15)	0.57 (0.16)	0.53 (0.18)	0.47 (0.13)
			0.22	0.28	0.24	0.007	0.09
Serum urea (mg/dL)		Cyanotic	21.74 (6.81)	32.96(13.71)	35.52 (21.82)	33.92 (27.68)	31.05 (36.48)
		Acyanotic	24.08 (9.63)	28.90(10.87)	28.64 (15.87)	23.82 (15.21)	26.14 (13.92)
			0.25	0.02	0.17	0.05	0.97
Serum albumin		Cyanotic	3.60 (0.50)	3.89 (0.47)	3.74 (0.38)	3.72 (0.38)	3.87 (0.36)

(g/L)	Acyanotic	3.74 (0.46)	3.91 (0.45)	3.83 (0.40)	3.69 (0.36)	3.81 (0.43)
<i>P</i> *		0.23	0.88	0.33	0.78	0.63
GFR (mL/min)	Cyanotic	76.27 (32.02)	67.86 (24.21)	67.69 (28.00)	66.88 (26.05)	82.78 (56.05)
	Acyanotic	77.51 (33.91)	65.67 (21.19)	67.31 (21.60)	74.33 (26.08)	84.73 (42.57)
<i>P</i> *		0.96	0.70	0.95	0.26	0.62

Data are presented as mean (standard deviation).

A *P*-value <0.05 was considered statistically significant.

GFR: glomerular filtration rate, CHD: congenital heart disease

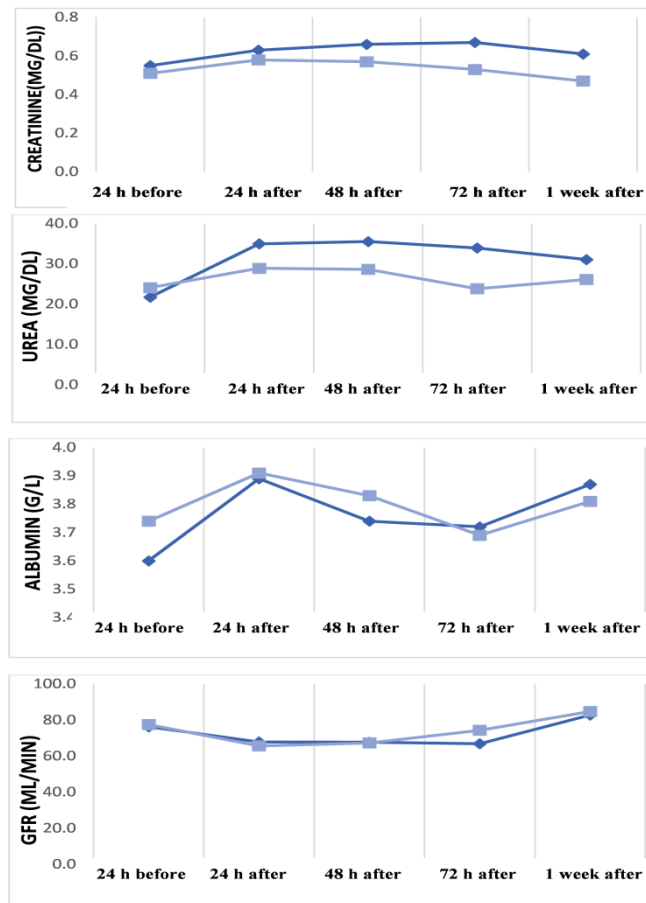


Figure 1. Serum levels of creatinine, urea, albumin, and GFR at different time points by type of CHD. The square markers represent the cyanotic group, and the diamond markers represent the acyanotic group.

GFR: glomerular filtration rate, CHD: congenital heart disease

Table 4 presents the serum levels of creatinine, urea, albumin, and GFR at different time points based on the duration of cardiopulmonary bypass. Serum urea levels were significantly lower 24 hours before the operation in children whose surgical duration was longer than 60 minutes ($P=0.04$) but increased significantly during

the first 24 hours after the operation ($P=0.05$).

When we controlled for the initial values, repeated measures ANOVA showed significant changes over time for creatinine, albumin, and GFR ($P=0.02$, $P=0.02$, and $P=0.01$, respectively). Nevertheless, no statistically significant difference was observed in these changes between the two

cardiac bypass groups (cyanotic and acyanotic). No statistically significant difference was seen in serum urea levels

over time or between the two cardiac bypass groups (Table 5).

Table 4. Comparison of renal function indices at different time points in children with CHD undergoing cardiopulmonary bypass, by duration of surgery

Renal Function Index	Duration of cardiopulmonary bypass	24 Hours Before ¹	24 Hours After ²	48 Hours After ³	72 Hours After ⁴	1 Week After ⁵
Creatinine (mg/dL)	30-60 min (n=23)	0.50 (0.13)	0.58 (0.09)	0.57 (0.08)	0.52 (0.10)	0.51 (0.12)
	> 60 min (n=43)	0.54 (0.13)	0.61 (0.21)	0.63 (0.29)	0.62 (0.33)	0.54 (0.38)
<i>P</i> *		0.14	0.92	0.87	0.23	0.59
Urea (mg/dL)	30-60 min (n=23)	26.09 (9.43)	27.78 (9.84)	25.30 (9.13)	21.30 (8.79)	26.40 (7.97)
	> 60 min (n=43)	21.53 (7.79)	33.30 (13.25)	34.74 (21.56)	31.51 (25.39)	28.86 (30.35)
<i>P</i> *		0.04	0.05	0.09	0.12	0.32
Albumin (g/L)	30-60 min (n=23)	3.81 (0.46)	4.02 (0.47)	3.88 (0.44)	3.63 (0.36)	3.85 (0.48)
	> 60 min (n=43)	3.61 (0.48)	3.84 (0.44)	3.75 (0.37)	3.74 (0.37)	3.82 (0.36)
<i>P</i> *		0.24	0.13	0.18	0.24	0.64
GFR (mL/min)	30-60 min (n=23)	81.37 (32.39)	66.74 (18.99)	67.33 (17.99)	76.64 (26.23)	82.41 (40.44)
	> 60 min (n=43)	74.66 (33.31)	66.47 (24.13)	67.54 (27.16)	68.42 (25.93)	84.89 (51.64)
<i>P</i> *		0.24	0.96	0.97	0.23	0.97

Data are presented as mean (standard deviation).

A *P*-value <0.05 was considered statistically significant.

GFR: glomerular filtration rate, CHD: congenital heart disease

Table 5. Changes in renal function indices at different time points based on repeated-measures analysis of variance in children with CHD undergoing cardiopulmonary bypass and open-heart surgery

	Creatinine	Urea	Albumin	GFR
Sources of change				
Time (<i>P</i> *)	0.02	0.12	0.02	0.01
Time * Type of CHD (<i>P</i> *)	0.23	0.09	0.06	0.38

* A *P*-value <0.05 was considered statistically significant.

GFR: glomerular filtration rate, CHD: congenital heart disease

DISCUSSION

The objective of the present study was to examine renal function in children with cyanotic and acyanotic CHD prior to and following open-heart surgery in Mashhad. Cardiac bypass, aortic clamp, and ventilator use durations were significantly greater in patients with cyanotic CHD than in those with acyanotic CHD. Moreover, creatinine, urea, and albumin levels increased during the first two days post-surgery, while mean GFR decreased.

In our study, serum creatinine and urea levels increased 24, 48, and 72 hours postoperatively compared with preoperative

levels. These indices were consistently higher in the cyanotic group at all timepoints. Li et al.¹² conducted a prospective central cohort study on the outcomes of AKI following pediatric cardiac surgery, reporting a 42% incidence of AKI three days after surgery and a doubling of serum creatinine levels within.

Zappitelli et al.¹⁷ observed an elevation in creatinine levels on the first and second days following cardiac surgery in children, suggesting that the percentage increase in creatinine could serve as a predictor of AKI. One possible explanation for the increased creatinine and urea levels may be the impact

of hypoxia and secondary erythropoiesis on kidney function, which hinders the maximum compensatory hyperfiltration needed to counteract the decrease in renal plasma flow during cardiopulmonary bypass.¹⁸ Further, the influence of cyanosis on renal tubules and glomerular structures should be taken into account, as these structures are also affected.¹⁹

In our study, serum albumin and GFR levels did not significantly differ between the cyanotic and acyanotic groups at any time point. Nonetheless, both indices exhibited significant changes over time. Amoozgar et al.⁹ conducted a study in Shiraz to assess kidney function in children with CHD before and after heart surgery, with a higher mean participant age than that in our study. They reported no significant difference in mean GFR before and after the operation and found no correlation between microalbuminuria and age, GFR, or hematocrit percentage.

The absence of significant differences in serum albumin levels between the cyanotic and acyanotic groups in our study may be attributable to the younger age of participants and the early stages of CHD.

In the present study, no significant differences were observed in serum creatinine, albumin, and GFR levels at any time points before and after bypass between patients with bypass durations of 30 to 60 minutes compared with those with procedures exceeding 60 minutes. However, 24 hours before the operation, the mean serum urea level was significantly lower in the group with procedures longer than 60 minutes, which increased significantly during the first 24 hours postoperatively.

These findings differ from those reported by Sethi et al.,²⁰ who identified cardiopulmonary bypass duration as an independent risk factor for the development of postoperative acute renal failure in patients under 18 years old. Potential

explanations for this discrepancy include the larger sample size, higher mean age, and heavier weight of participants in the aforementioned study. Moreover, the mean duration of cardiopulmonary bypass was shorter in that study.

Regardless of the cardiopulmonary bypass duration, serum creatinine, albumin, and urea levels increased 24 hours after surgery compared with 24 hours before surgery in our study, while GFR decreased. This suggests a temporary impact of cardiopulmonary bypass surgery on renal function and glomerular filtration, emphasizing the significance of extended follow-up for patients following cardiopulmonary bypass.

The simultaneous assessment of multiple renal function indices represents one of the strengths of this study. Another strength is the comparison of patients according to the type of CHD. The study's limitations include the relatively small sample size (66 patients), the absence of data from multiple medical centers, and the short follow-up period after heart surgery, all of which should be considered when generalizing the findings. In this study, it was not determined whether changes in renal function indices were associated with the development of AKI. Prospective studies with longer follow-up are needed to monitor patients and to evaluate routine renal function tests, urinary output, and hematological parameters, particularly in those with cyanotic CHD.

CONCLUSIONS

Serum levels of creatinine, urea, and albumin increased during the first two days after open-heart surgery in children with CHD, while mean GFR decreased. Further long-term follow-up is warranted to assess kidney damage and to monitor the recovery of renal function.

Statements and Declarations

Conflicts of Interest: The authors have no conflicts of interest to declare that are relevant to the content of this article.

Sources of Funding: The authors did not receive support from any organization for the submitted work.

Ethics Approval: This research was approved under the ethics code IR.IAU.MSHD.REC.1401.139 by the Faculty of Medicine of Islamic Azad University, Mashhad Branch.

Consent to Participate: Informed consent was not required because recorded information was used.

Authors' Contributions: All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Negar-Saadaat Haidari, Saeed Abtahi, Mahmood Hosseinzadeh Maliki, Farhad Samadieh, and Fereshteh Najafi. The first draft of the manuscript was written by Negar-Saadaat Haidari and Saeed Abtahi. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript. All authors had full "freedom of investigation" before, during, and after this study.

REFERENCES

- Fahed AC, Gelb BD, Seidman J, Seidman CE. Genetics of congenital heart disease: the glass half empty. *Circulation research*. 2013; 112(4):707-720.
- Rao PS. Diagnosis and management of cyanotic congenital heart disease: part I. *The Indian Journal of Pediatrics*. 2009; 76:57-70.
- Van Der Linde D, Konings EE, Slager MA, et al. Birth prevalence of congenital heart disease worldwide: a systematic review and meta-analysis. *Journal of the American College of Cardiology*. 2011; 58(21):2241-2247.
- Rohit M, Shrivastava S. Acyanotic and cyanotic congenital heart diseases. *The Indian Journal of Pediatrics*. 2018; 85:454-460.
- Asrani SK, Asrani NS, Freese DK, et al. Congenital heart disease and the liver. *Hepatology*. 2012; 56(3):1160-1169.
- Morgan C, Al-Aklabi M, Guerra GG. Chronic kidney disease in congenital heart disease patients: a narrative review of evidence. *Canadian journal of kidney health and disease*. 2015; 2:63.
- Agras PI, Derbent M, Ozcay F, et al. Effect of congenital heart disease on renal function in childhood. *Nephron Physiology*. 2005; 99(1):p10-p15.
- Awad H, El-Said S, El-Safty I, Abdel-Gawad M. Glomerular and tubular dysfunction in children with congenital cyanotic heart disease: effect of palliative surgery. *The American journal of the medical sciences*. 2003; 325(3):110-114.
- Amoozgar H, Basiratnia M, Ghasemi F. Renal function in children with cyanotic congenital heart disease: pre-and post-cardiac surgery evaluation. *Iranian Journal of Pediatrics*. 2014; 24(1):81.
- El Sayegh S, Ephrem G, Wish JB, Moe S, Lim K. Kidney disease and congenital heart disease: Partnership for life. *Frontiers in physiology*. 2022; 13:970389. doi:10.3389/fphys.2022.970389
- Ali F, Sr., Khan MK, Mirza B, Qureshi S, Jr., Abbas Q. Acute Kidney Injury after Congenital Heart Disease Surgery: A Single-Center Experience in a Low- to Middle-Income Country. *Cureus*. Apr 18 2020; 12(4):e7727. doi:10.7759/cureus.7727
- Li S, Krawczeski CD, Zappitelli M, et al. Incidence, risk factors, and outcomes of acute kidney injury after pediatric cardiac surgery: a prospective multicenter study. *Critical care medicine*. 2011; 39(6):1493-1499.

13. Aoun B, Daher GA, Daou KN, et al. Acute Kidney Injury Post-cardiac Surgery in Infants and Children: A Single-Center Experience in a Developing Country. *Frontiers in Pediatrics*. 2021; 9:637463.
14. Yuan S-M. Acute kidney injury after cardiac surgery: risk factors and novel biomarkers. *Brazilian Journal of Cardiovascular Surgery*. 2019; 34:352-360.
15. Pedersen K, Povlsen J, Christensen S, et al. Risk factors for acute renal failure requiring dialysis after surgery for congenital heart disease in children. *Acta anaesthesiologica scandinavica*. 2007; 51(10):1344-1349.
16. Schwartz G, Haycock G, Edelmann Jr C, Spitzer A. A simple estimate of glomerular filtration rate in children derived from body length and plasma creatinine. *Pediatrics*. 1976; 58(2):259-263.
17. Zappitelli M, Bernier P-L, Saczkowski RS, et al. A small post-operative rise in serum creatinine predicts acute kidney injury in children undergoing cardiac surgery. *Kidney international*. 2009; 76(8):885-892.
18. Basile DP, Anderson MD, Sutton TA. Pathophysiology of acute kidney injury. *Comprehensive Physiology*. Apr 2012; 2(2):1303-53. doi:10.1002/cphy.c110041
19. Hongsawong N, Khamdee P, Silvilairat S, Chartapisak W. Prevalence and associated factors of renal dysfunction and proteinuria in cyanotic congenital heart disease. *Pediatric Nephrology*. 2018; 33:493-501.
20. Sethi SK, Kumar M, Sharma R, Bazaz S, Kher V. Acute kidney injury in children after cardiopulmonary bypass: risk factors and outcome. *Indian pediatrics*. 2015; 52:223-226.