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Original Article

Association of Hemoglobin Concentrations With Clinical Outcomes and Serum Lactate Concentrations After Open-Heart Surgery in Acyanotic Pediatric Patients

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ABSTRACT

Background: In children, the discrepancy between the cardiopulmonary bypass (CPB) circuit size relative to body size is greater than that in adults. However, hemoglobin and hematocrit levels during and after CPB may lead to hemodynamic and electrolyte disturbances.

Methods: This retrospective, descriptive-analytic study included 441 pediatric patients (weight: 5–15 kg) with congenital heart defects who underwent cardiac surgery and met the eligibility criteria. The association between groups with hemoglobin concentrations of 8 to 10 g/dL and greater than 10 g/dL was assessed. Arterial blood samples, recorded every 12 hours for up to 72 hours of ICU admission after open-heart surgery, were entered into the data collection form.

Results: The groups showed significant differences in mean age, weight, height, and body surface area, as well as the frequency distribution of sex. The independent samples *t* test demonstrated that mean lactate concentration ($P = 0.014$), urinary output ($P = 0.001$), diastolic blood pressure ($P = 0.013$), systolic blood pressure ($P > 0.001$), intubation time ($P = 0.003$), and mean arterial pressure ($P > 0.001$) were significantly higher in Group 2 (hemoglobin ≥10 g/dL) than in Group 1 (hemoglobin 8–10 g/dL).

Conclusions: In acyanotic pediatric patients with low hemoglobin, mean lactate concentration, urinary output, intubation time, and mean arterial pressure were lower, and these patients received greater blood and blood product transfusions compared with patients with high hemoglobin. ***(Iranian Heart Journal 2026; 27(1): 71-80)***

KEYWORDS: clinical outcomes; acyanotic congenital pediatric patients; hemoglobin concentrations; open-heart surgery in pediatrics

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Cardiovascular diseases represent one of the most significant threats to global public health. In the United States, approximately 17 million individuals are diagnosed with cardiovascular diseases annually. Of these, coronary heart disease is present in 7.64% (11 million people), valvular heart disease in 4.29% (5 million people), and congenital heart defects in approximately 8.5% (1 million people). Among patients with cardiovascular disease, around 500,000 undergo cardiac surgery annually. These defects are associated with disorders such as DiGeorge, Shprintzen, and velocardiofacial syndromes.[1-3]

The incidence of congenital heart defects is 6 to 8 per 1000 live births, with more than half requiring surgical intervention within the first year of life. Further, approximately 400,000 open-heart surgeries using cardiopulmonary bypass (CPB) are performed worldwide per year, with children accounting for about 6% of these cases. Today, the correction of congenital heart defects in children and infants, even those younger than 2 months, is performed and has been associated with favorable results. Congenital heart diseases are typically classified into two categories: acyanotic and cyanotic. These conditions are among the leading causes of death in pediatric patients and are usually diagnosed clinically at birth, despite the presence of severe structural heart disease. Many defects that were once fatal in early life can now be cured through cardiac surgery, significantly improving survival. According to annual statistics published in the United States, approximately 8 to 12 of every 1,000 live births have congenital heart defects, and a substantial portion of these infants undergo cardiac surgery and are cured. [4-8]

Many pediatric cardiac surgeries cannot be performed without the use of CPB. Nonetheless, because of salient physiologic and anatomic differences between adults and children, CPB in pediatric patients is linked to more adverse outcomes. One reason for this is that many organ systems, such as coagulation, pulmonary, neurologic, and endocrine systems, are still underdeveloped and immature during infancy. Moreover, infants and newborns have higher metabolic needs and thus require a greater blood flow for perfusion per unit of body surface area. This can culminate in increased contact of pediatric blood with nonphysiologic surfaces of the CPB circuit, which leads to increased postoperative inflammatory complications.[8]

With advances in CPB techniques, repairing or palliating complex congenital heart defects in children and infants has become feasible. Modern pediatric and neonatal CPB equipment has tended toward smaller extracorporeal circuit sizes to reduce prime volume. Initial prime volume may exceed an infant's blood volume by 200% to 300%, whereas in adult patients, the prime volume typically constitutes only 25% to 33% of blood volume.[9]

In infants, the discrepancy between the size of the CPB circuit and the patient's body is greater than in adults. Therefore, a high priming volume results in a hematocrit less than 15% in CPB for small infants, prioritizing the use of donor blood. Most patients undergoing cardiac surgery require allogeneic blood transfusion. Given the possible adverse effects of allogeneic blood transfusion, its relatively high cost, limited resources, and the risk of cytomegalovirus transmission via blood because of the newborn's weakened immune system, which can give rise to severe infections and even death, it is considered a substantial risk.[11]

Newborns are among the groups most likely to receive blood products during hospitalization. Considering the numerous complications arising from transfusions and the immature immune system of newborns, the risk of transfusion-induced complications is directly related to the number of blood product transfusions.[12] In most countries, various

methods have been employed to reduce the number of blood transfusions and minimize exposure to multiple donors. These methods include the use of satellite bags, recombinant erythropoietin, and modifications to blood transfusion protocols. A prospective study by Mazine et al [13] of children undergoing open-heart surgery in the pediatric intensive care unit (PICU) who received blood transfusions revealed that patients receiving blood transfusions had a significantly longer duration of stay in the PICU than those who did not. This finding was not associated with intubation time. In a systematic review, research articles published between 2002 and 2015 were retrieved from PubMed and ScienceDirect databases and library resources using keywords such as "blood transfusion," "blood transfusion complications," "clinical outcomes," and "cardiopulmonary bypass." Among 15 reviewed articles, survival rates during the first 30 days and during the first year after cardiac surgery were significantly lower in patients who received blood transfusions than in those who did not. Short- and long-term mortality rates after surgery were significantly higher among patients who received blood transfusions than among those who did not. In addition, complications such as atrial fibrillation, infection, pneumonia, and stroke were significantly more prevalent among blood transfusion recipients.[14] Currently, the optimal hemoglobin concentrations for children after cardiac surgery remain undetermined. Red blood cell (RBC) transfusions are often administered to maintain higher hemoglobin concentrations without clear clinical indications. RBC transfusion is an essential supportive measure after pediatric heart surgery; however, there is no established specific hemoglobin threshold. Intraoperative hemoglobin concentration and RBC transfusion have been associated with adverse outcomes after cardiac surgery. The relationship between hemoglobin concentration and clinical outcomes is influenced by RBC transfusion, because a reduction in hemoglobin concentrations results in a greater percentage of patients requiring transfusion. [15] The incidence of preoperative anemia in cardiac surgery is high, ranging from 16% to 54%. More critically, observational research has reported that preoperative anemia is a significant risk factor for intraoperative RBC transfusion and postoperative complications, including infection, acute kidney injury, stroke, and mortality. [15] Moreover, patient sex may affect outcomes after cardiac surgery, with female sex recognized as an independent risk factor for preoperative anemia.

Studies involving patients with acyanotic congenital heart disease are limited. Based on our search, no study has determined a specific hemoglobin threshold for maintaining hemoglobin in these patients after cardiac surgery. To better understand the optimal hemoglobin concentrations in acyanotic pediatric patients and its association with clinical outcomes and resource utilization, the present study was conducted to assess the relationship between hemoglobin concentrations and clinical outcomes after open-heart surgery at Rajaei Cardiovascular Institute.

METHODS

This study was a retrospective analysis conducted at Rajaie Cardiovascular Institute in Tehran, Iran, during 2023. The study population included all pediatric patients with acyanotic congenital heart disease who underwent open-heart surgery using CPB between January 2020 and December 2022. Inclusion criteria were pediatric patients undergoing elective surgery for acyanotic congenital heart disease and patients weighing 5 to 15 kg. Exclusion criteria were occurrence of cardiogenic shock before surgery, occurrence of cardiac arrest prior to surgery, surgery performed on an emergency basis, occurrence of noncardiac infectious

complications that could affect recovery, requirement for reoperation, history of previous sternotomy, and incomplete information in the medical records.

Sampling Source and Method

Through a systematic sampling method, patients were selected from eligible files based on the last two digits of the file number to obtain a representative sample.

By examining the medical files of patients in both groups after separation from CPB and transfer to the cardiac intensive care unit (CICU), the investigator assessed the association between hemoglobin concentrations and clinical outcomes: lactate concentrations, kidney dysfunction, blood and blood product transfusion requirements, ICU stay duration, intubation time, systolic and diastolic blood pressure, heart rate, neurologic disorders, and cardiac arrhythmias. Variables were recorded on CICU admission and every 12 hours for the first 3 days. The 2 groups were then compared.

Neurologic status was assessed with the Glasgow Coma Scale and vital-sign flow sheets in the medical record. Systolic and diastolic blood pressure, heart rate, intubation status, lactate concentrations, kidney dysfunction, and ICU stay duration were extracted from ICU report forms. Transfusion number was obtained from blood-bank records. No adverse events or patient costs occurred because the study was retrospective and involved no invasive interventions. Required data were collected from medical records, nursing reports, vital-sign sheets, and laboratory results.

Statistical Analysis

Continuous variables are presented as mean (SD), and categorical variables are summarized as number (%). The distribution of continuous data was assessed for normality via the Shapiro-Wilk test. Comparisons between two independent groups were performed using the independent samples *t* test for normally distributed data and the Mann-Whitney *U* test for those that violated this assumption. Associations between categorical variables were evaluated using the chi-square or Fisher exact test, where appropriate. Changes in quantitative outcomes over time were analyzed using repeated-measures analysis of variance.

All analyses were conducted using IBM SPSS Statistics software, version 26. A 2-tailed *P* value less than 0.05 was considered statistically significant for all tests.

RESULTS

Lactate concentrations

Trend analysis showed a significant decrease in mean lactate concentrations in both groups ($P < 0.001$ for both). Repeated-measures analysis revealed a significant difference in the mean rate of change between the two groups during the study period, after adjustments for age ($P = 0.014$). Mean lactate concentration at all measured time points differed significantly between the hemoglobin 8–10 and hemoglobin 10 or greater groups; the slope of lactate changes during the study period differed between the two groups. Paired comparisons showed a significant difference in the rate of change after the first 12 hours of day 2 between the two groups ($P = 0.007$). The two groups also had a significant difference in mean lactate changes during the second 12 hours of day 2 ($P < 0.001$). No significant differences were observed at other time points (Table 1).

Urinary output

Repeated-measures analysis showed a significant decreasing trend in mean urinary output in both groups ($P < 0.001$). A significant difference was observed in the mean rate of change between the two groups during the study period, after adjustments for age ($P = 0.001$). Mean urinary output differed significantly between the two groups at all

measured times, and the slope of change over time differed between groups. Paired comparisons showed a significant difference between the two groups in the rate of change after the second 12-hour period of day 1 ($P = 0.002$) and during the first 12 hours of day 2 ($P < 0.001$). No significant differences were observed at other time intervals.

Mean arterial blood pressure (MAP)

Trend analysis showed a significant upward trend in mean MAP in both groups ($P < 0.001$ for both). Repeated-measures analysis showed a significant difference in the mean rate of change of MAP between the two groups during the study period, after adjustments for age ($P < 0.001$). Mean MAP values differed significantly between the two groups at all time points, and the slope of change over time differed between the two groups. Paired comparisons showed significant differences in the rate of change after the first 12 hours of day 3 ($P < 0.001$) and after the second 12 hours of day 3 between the two groups ($P < 0.001$). No significant differences were observed at other measurement times (Table 2).

Table 1. Mean (SD) lactate concentrations (dL) over the study period in the investigated groups

Group	Day 1, 0–12 h	Day 1, 12–24 h	Day 2, 0–12 h	Day 2, 12–24 h	Day 3, 0–12 h	Day 3, 12–24 h	*P**	*P***
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)		
Hemoglobin 8-10	1.64 (0.87)	0.78 (1.37)	1.17 (0.35)	0.91 (0.21)	1.36 (0.76)	1.00 (0.25)	<0.001	0.014
Hemoglobin ≥ 10	1.96 (1.34)	1.65 (1.38)	0.76 (1.36)	0.39 (1.00)	1.07 (0.71)	0.81 (0.45)	<0.001	
*P****	-	0.106	0.007	<0.001	0.645	0.411	-	

**P* value for the change trend within each of the two groups
** *P* value for the comparison between the two groups
*** *P* value for the comparison between the specified time point and the previous time point

Table 2. Mean (SD) mean arterial pressure (mm Hg) over the study period in the investigated groups

Group	Day 1, 0–12 h	Day 1, 12–24 h	Day 2, 0–12 h	Day 2, 12–24 h	Day 3, 0–12 h	Day 3, 12–24 h	*P**	*P***
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)		
Hemoglobin 8–10 g/dL	87.68 (3.20)	80.42 (2.37)	81.15 (2.42)	81.71 (2.86)	82.17 (3.63)	83.07 (4.14)	<0.001	0.001<
Hemoglobin ≥10 g/dL	82.84 (2.15)	84.49 (2.38)	85.33 (2.69)	85.93 (2.76)	87.35 (3.19)	88.21 (3.17)	<0.001	
*P ****	-	0.098	0.473	0.153	<0.001	<0.001	-	

**P* value for the change trend within each of the two groups
** *P* value for the comparison between the two groups
*** *P* value for the comparison between the specified time point and the previous time point

Heart rate

Trend analysis showed a significant upward trend in mean heart rate in both groups ($P < 0.001$ and $P = 0.009$, respectively). Repeated-measures analysis demonstrated a significant difference in the mean rate of change of heart rate between the two groups during the study period, after adjustments for age ($P < 0.001$). Mean heart rate values differed significantly between the two groups at all times, and the pattern of change (slope) differed during the study. Pairwise comparisons showed a significant difference in the rate of change after the first 12 hours

of day 2 between the two groups ($P < 0.001$). Mean heart rate changes differed significantly between the two groups during the second 12 hours of day 1 and the second 12 hours of day 2 ($P < 0.001$ for both). No significant differences were observed at other time points.

Length of stay and complications

No significant difference in length of stay between the two groups was identified ($P = 0.968$). Transfusion rates for blood and blood products differed significantly between the two groups ($P < 0.001$); rates were significantly higher in the hemoglobin 8–10 group than in the hemoglobin 10 or greater group. No significant differences were observed in the incidence of neurological disorders ($P = 0.128$), renal dysfunction ($P = 0.171$), or respiratory disorders ($P = 0.139$) between the two groups (Table 2).

Extubation status

No significant difference in extubation status between the two groups was observed during the first 12 hours of day 1, the second 12 hours of day 1 ($P = 0.140$), or the second 12 hours of day 2 ($P = 0.588$). During the first 12 hours of day 2, the number of extubated patients was significantly higher in the hemoglobin 8–10 g/dL group than in the hemoglobin 10 g/dL or greater group ($P = 0.003$). In the hemoglobin 8–10 g/dL group, 84 of 108 patients (77.7%) were extubated, and 24 (22.2%) were intubated. In the hemoglobin 10 g/dL or greater group, 207 of 333 patients (62.2%) were extubated, and 126 (37.8%) were intubated (Table 3).

Table 3. Intubation status (h) over the study period in the investigated groups

Time	Status	Hemoglobin 8–10 g/dL, No. (%)	Hemoglobin ≥10 g/dL, No. (%)	*P*
Day 1, 0–12 h	Intubated	108 (100)	333 (100)	NA
	Extubated	0 (0)	0 (0)	
Day 1, 12–24 h	Intubated	67 (62)	232 (69.7)	0.140
	Extubated	41 (38)	101 (30.3)	
Day 2, 0–12 h	Intubated	24 (22.2)	126 (37.8)	0.003
	Extubated	84 (77.8)	207 (62.2)	
Day 2, 12–24 h	Intubated	23 (21.3)	270 (81.1)	0.588
	Extubated	85 (78.8)	63 (18.9)	

NA: not applicable

DISCUSSION

The association between hemoglobin concentrations and clinical outcomes following open-heart surgery in acyanotic pediatric patients was investigated. A significant difference in mean blood lactate concentration was detected between the two groups. Mean lactate concentration was lower in Group 1 compared with Group 2. The Cholette et al[16] review examined various studies. One study of infants 9 months of age undergoing open-heart surgery assigned patients to two groups: a hemodilution protocol group (hematocrit 20%) and a group with a hematocrit of 30%. Postoperative outcomes of these two groups were compared. Low hematocrit substantially increased lactate concentrations and decreased cardiac indices. A target hematocrit during CPB greater than 20% is appropriate. In the present study, mean lactate concentrations were lower in Group 1 than in Group 2 because of a higher proportion of overweight acyanotic pediatric patients in Group 2 compared with Group 1. Mean length of ICU stay for acyanotic pediatric patients following open-heart surgery did not differ significantly between Group 1 and Group 2. A study conducted in Germany found that reducing prime volume and CPB circuit size

and using smaller oxygenators while maintaining hemoglobin concentrations decreased ICU stay duration. This finding differs from the current study because of the different patient populations (cyanotic and acyanotic) involved.[17] The Wu et al[18] study investigated 86 infants weighing less than 5 kg with acyanotic heart disease in two groups: a blood conservation strategy group and a control group. Infants were monitored from pre-CPB until 72 hours post-CPB; no significant reduction in ICU length of stay was reported. This finding differed from our study because of the inclusion of patients weighing less than 5 kg (cyanotic and acyanotic). The Mazine et al[13] prospective cohort study of 175 children who remained in the PICU for 48 hours or more found that patients who received blood transfusions (attaining higher hemoglobin concentrations) had substantially longer lengths of stay in the PICU than those who did not receive transfusions. Mean urinary output was significantly lower in Group 1 than in Group 2. No similar results for urinary output were reported in the reviewed articles. No significant difference in the incidence of kidney dysfunction was detected between the two groups.

The Haase et al[19] study of 920 cardiac surgery cases found that 19.5% (n = 179) developed acute kidney injury (AKI). Hemoglobin was an independent risk factor for AKI (hemoglobin <8 g/dL increased postoperative AKI by 15%–30%). The finding that AKI during CPB may occur with anemia differs from the current findings, likely because of the higher hemoglobin concentrations in the present study compared with the cited research.

The Park et al [20] study of 220 cyanotic and acyanotic patients who underwent open-heart surgery in 2012 found that preoperative hemoglobin less than 11 g/dL was an independent risk factor for AKI. This finding differs from the current study because hemoglobin was evaluated preoperatively rather than postoperatively.

Median blood transfusion in the PICU differed significantly between the two groups of acyanotic pediatric patients after open-heart surgery. Mean blood and blood product transfusion was higher in Group 1 compared with Group 2.

The Hogervorst et al[21] study of 23,860 patients who underwent cardiac surgery from 1997 to 2013 investigated associations between intraoperative hemoglobin concentrations and postoperative outcomes. Two separate analyses evaluated the effect of RBC infusions on postoperative outcomes. Jehovah's Witness patients who refused blood transfusions were compared with non-Jehovah's Witness patients who received 1 unit of RBC. In a second comparison, non-Jehovah's Witness patients who did not receive RBC transfusions were compared with those who did. Postoperative complications increased as intraoperative hemoglobin concentrations decreased; a marked rise occurred when nadir hemoglobin was less than 8 g/dL. Approximately 31% of non-Jehovah's Witness patients receiving 1 unit of RBCs required additional blood products, such as fresh frozen plasma and platelets. Jehovah's Witness patients had shorter mechanical ventilation durations. No significant differences in clinical outcomes or complications were observed between non-Jehovah's Witness individuals receiving 1 unit of RBC and those who did not. Intraoperative anemia was associated with adverse postoperative outcomes; a single RBC transfusion did not appear to influence outcomes.

The Mazine et al[13] prospective observational cohort study of 175 children remaining in the pediatric intensive care unit (PICU) for 48 hours or more included 56% with cyanotic heart disease and 44% with acyanotic heart disease. Patients receiving blood transfusions had substantially longer PICU stays compared

with those who did not; no differences were observed in intubation time. The study by Mazine et al[13] is in line with our research. The Haase et al[19] study of 920 patients who underwent cardiac surgery found that AKI during CPB might occur with anemia. Blood transfusions were associated with increased risk of AKI. Unnecessary blood transfusions in patients with hemoglobin concentrations greater than 8 g/dL (5 mmol/L) appeared unfavorable. These two studies are consistent despite the inclusion of both cyanotic and acyanotic pediatric patients in the study by Haase et al.[19] Mean intubation time in the PICU differed significantly between the two groups. Mean intubation time was shorter in Group 1 compared with Group 2. The Boettcher et al[17] study of 173 neonatal and pediatric patients undergoing open-heart surgery found that reducing prime volume and CPB circuit size while using smaller oxygenators (increasing hemoglobin concentrations) decreased length of stay. This finding differed from previous research because of the maintenance of hemoglobin concentrations. The hemodynamic index of mean MAP differed significantly between the two groups of acyanotic pediatric patients. Mean MAP was lower in Group 1 than in Group 2.

The Haase et al[19] study of 920 patients who underwent cardiac surgery found that AKI during CPB occurred with anemia, but MAP and vasopressor administration alone were not associated with AKI. Intraoperative MAP was maintained at 60 to 70 mm Hg using vasopressors. Hemoglobin less than 8 g/dL was significantly associated with kidney dysfunction, but hemoglobin concentrations were not associated with systolic blood pressure. The current study found no association between hemoglobin concentrations and kidney dysfunction, possibly because hemoglobin concentrations were greater than 8 g/dL. Hemoglobin concentrations were significantly correlated with MAP; lower concentrations were associated with lower MAP. Mean heart rate and dysrhythmia differed significantly between the two groups. Mean heart rate was higher in Group 1 than in Group 2. Incidence of dysrhythmia was significantly higher in Group 1 than in Group 2. No significant associations between pulmonary and neurological disorders were observed. No similar findings were reported in the reviewed articles.

CONCLUSIONS

In acyanotic pediatric patients undergoing open-heart surgery, Group 1 (hemoglobin 8-10 g/dL) had lower mean lactate concentrations, urinary output, intubation time, systolic and diastolic blood pressure, and MAP than Group 2 (hemoglobin ≥ 10 g/dL). Group 1 had a higher mean heart rate and received more blood and blood product transfusions than Group 2. No significant differences in kidney dysfunction, respiratory disorders, or neurological disorders were observed between the two groups.

Human Ethics

Ethical approval was received from the Research Ethics Committees of Rajaie Cardiovascular Institute (IR.RHC.REC.1402.101).

Consent to Participate

Informed consent was obtained from the patients' parents or guardians.

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