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ORIGINAL RESEARCH

Changes in Respiratory Function Before and After Cardiopulmonary Bypass in Children with Congenital Heart Disease with Increased or Decreased Pulmonary Blood Flow

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Objective: Cardiopulmonary bypass (CPB) is a fundamental approach for managing complex congenital heart diseases (CHD). This study aims to examine the changes in respiratory function before and after CPB in children under 12 years diagnosed with CHD with different types of shunts.

Methods: A retrospective analysis was conducted on the clinical data of 60 pediatric patients with CHD admitted to the hospital between January 2022 and December 2023. Based on shunt type, the patients were divided into Group A (increased pulmonary blood flow, n = 30) and Group B (decreased pulmonary blood flow, n = 30). Changes in the diameters of the pulmonary artery and aorta, as well as respiratory mechanics before and 24 hours after CPB, were assessed in both groups.

Results: There were no significant differences in general characteristics between the two groups ($p > 0.05$). The external diameter of the pulmonary artery among patients in Group A was significantly larger than that in Group B (2.50±0.38 vs 1.31±0.29 cm, $p < 0.05$), while the external diameter of the aorta was significantly smaller in those in Group A compared to Group B (1.60±0.26 vs 1.91±0.37, $p < 0.05$). Significant differences were observed in the respiratory mechanics indexes before and after CPB within and between the two groups, including peak airway pressure, plateau airway pressure, inspiratory resistance, expiratory resistance, and lung-thorax compliance ($p < 0.05$).

Conclusions: Significant differences in the diameters of the pulmonary artery and aorta were observed among pediatric patients with CHD, depending on the type of shunt used. Dynamic monitoring of respiratory mechanics before and after CPB is essential for optimizing clinical respiratory management to facilitate timely adjustments in respiratory support strategies.

Keywords: cardiopulmonary bypass, CPB, children, congenital heart disease, CHD, different types of shunts, respiratory function

Introduction

With continuous advancements in cardiac surgical techniques in recent years, cardiopulmonary bypass (CPB) has become a fundamental approach for managing complex congenital heart diseases (CHD). However, CPB is associated with complex alterations in cardiopulmonary functions and may cause structural and functional damage to the pulmonary vascular endothelium, potentially resulting in pulmonary hypertension, increased pulmonary vascular resistance, and other complications.[1] This is particularly significant in infants and children with CHD, whose respiratory systems have not yet fully matured, amplifying the impact of CPB on lung function.[2]

Given the insufficient research on changes in respiratory function before and after CPB in pediatric patients with CHD with different shunt types, and considering that distinct pulmonary pathological changes have been noted in CHDs with

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different types of shunts,[3] this study retrospectively analyzed changes in respiratory function before and after CPB in children with CHD admitted to a hospital between January 2022 and December 2023, stratified by shunt type (increased vs decreased pulmonary blood flow), to provide evidence for optimizing perioperative respiratory management.

Study Participants and Methods

General Characteristics of Study Participants

With approval from the Ethics Committee of the medical institution, a retrospective analysis was conducted on the clinical data of 60 pediatric patients with CHD who were admitted between January 2022 and December 2023. Patients were consecutively recruited based on predefined inclusion/exclusion during the study period criteria. The patients were divided into Group A (increased pulmonary blood flow, n = 30) and Group B (decreased pulmonary blood flow, n = 30) based on their shunt types. Group A consisted of 12 male and 18 female pediatric patients, while Group B had 16 male and 14 female pediatric patients.

Inclusion criteria: (1) aged under 12 years; (2) diagnosis of CHD was confirmed by echocardiography or other imaging modalities, requiring cardiac surgery under CPB; and (3) signed informed consent was obtained from parents of the patients.

Exclusion criteria: (1) a history of previous cardiac surgery; (2) congenital immunodeficiency; (3) diagnosed with a genetic disease known to affect the respiratory system; and (4) allergy to drugs or materials used in CPB.

Methods

A standardized anesthesia protocol was used all pediatric patients in both groups. General tracheal intubation combined anesthesia was used, with similar agents administered for both induction and maintenance. Depending on the severity of the malformation, CPB under mild hypothermia was used for mild malformations, while CPB under deep hypothermia was utilized for severe malformations. Following the procedure, the pediatric patients were transferred to the intensive care unit (ICU) once hemodynamic parameters were stabilized. The patients received similar medication regimens before and after operation, thereby excluding variability caused by differences in drug administration.

Observation Indexes

Differences in general characteristics of patients, external diameters of the pulmonary artery and aorta, and respiratory mechanics were assessed before and 24 hours after CPB drainage. General characteristics included age, body weight, duration of the bypass procedure, and findings from X-ray examinations. Respiratory mechanics parameters, including peak airway pressure, plateau airway pressure, inspiratory resistance, expiratory resistance, and lung-thorax compliance, were measured before and after CPB drainage using a pulmonary mechanics monitor. Measurements were taken during mechanical ventilation under standardized ventilator settings.

Statistical Analysis

Sample size was determined based on previous literature and preliminary data. The research data were analyzed using SPSS 22.0 statistical software. Measurement data were expressed as mean ± standard deviation ($\bar{x} \pm s$) and analyzed using *t*-tests. Categorical data were presented as frequency and percentage (n,%) and analyzed using χ^2 tests. A p-value < 0.05 was considered statistically significant.

Results

Comparison of General Characteristics Between the Two Groups

As shown in Table 1, there were no statistically significant differences ($p > 0.05$) between the two groups of pediatric patients in terms of age, body weight, duration of the bypass procedure, or X-ray examination results.

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Table 1 Comparison of General Characteristics Between the Two Groups of Pediatric Patients ($\bar{x} \pm s$)

Group	Number	Age (y)	Body Weight (kg)	Duration of the Bypass Procedure (h)	X-ray Examination Findings
Group A	30	5.51±1.28	14.62±3.39	80.08±4.67	Clear lung fields
Group B	30	5.64±1.14	14.40±3.61	81.10±3.96	Increased lung markings
t	-	0.415	0.243	0.912	-
P	-	0.679	0.809	0.365	-

Table 2 Comparison of the Diameters of Pulmonary Artery and Aorta Between the Two Groups of Pediatric Patients ($\bar{x} \pm s$)

Group	Number	External Diameter of the Pulmonary Artery (cm)	External Diameter of the Aorta (cm)
Group A	30	2.50±0.38	1.60±0.26
Group B	30	1.31±0.29	1.91±0.37
t	-	13.635	3.755
P	-	0.000	0.000

Table 3 Comparison of Respiratory Mechanics Before and After CPB Drainage Between the Two Groups of Pediatric Patients ($\bar{x} \pm s$)

	Peak Airway Pressure (kPa)		Plateau Airway Pressure (kPa)		Inspiratory Resistance (kPa ·L/s)		Expiratory Resistance (kPa ·L/s)		Lung-Thorax Compliance (ml/kPa)	
	Before CPB Drainage	After CPB Drainage	Before CPB Drainage	After CPB Drainage	Before CPB Drainage	After CPB Drainage	Before CPB Drainage	After CPB Drainage	Before CPB Drainage	After CPB Drainage
Group A	1.60±0.31	2.02±0.32*	1.18±0.25	1.39±0.30*	2.38±0.61	3.11±0.08*	4.36±0.97	5.12±1.20*	1.10±0.41	0.91±0.27*
Group B	1.20±0.21	1.38±0.29*	0.91±0.20	1.11±0.19*	1.41±0.30	1.81±0.44*	2.39±0.57	3.51±1.17*	1.59±0.40	1.28±0.40*
t	5.851	8.117	4.619	4.319	7.816	15.922	9.591	5.262	4.685	4.199
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Note: Compared to results before CPB drainage, $*p < 0.05$.

Comparison of the Diameters of the Pulmonary Artery and Aorta Between the Two Groups

As presented in Table 2, the external diameter of the pulmonary artery among patients in Group A was significantly larger than that in Group B (2.50±0.38 vs 1.31±0.29 cm, $p < 0.05$), while the external diameter of the aorta was significantly smaller compared to Group B (1.60±0.26 vs 1.91±0.37 cm, $p < 0.05$).

Comparison of Respiratory Mechanics Parameters Before and After CPB Drainage Between the Two Groups

As indicated in Table 3, significant differences were observed in various respiratory mechanics indexes before and after CPB drainage within and between the two groups, including peak airway pressure, plateau airway pressure, inspiratory resistance, expiratory resistance, and lung-thorax compliance ($p < 0.05$).

Discussion

CHD is one of the most common congenital anomalies in neonates, with an incidence rate of approximately 0.8 to 1.2%.[4] CHD can be categorized into various types based on its complexity, necessitating surgical intervention in early childhood in some cases to improve physiological function and quality of life. CPB is a commonly employed technique in surgical management that can temporarily substitute cardiopulmonary function and provide essential conditions for the

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procedure.[5] However, the use of CPB induces a series of physiological changes in pediatric patients, particularly affecting respiratory function. These changes may vary considerably among patients with different types of CHD.[6,7] In this study, there were no statistically significant differences between the two groups of pediatric patients with regard to age, body weight, duration of the bypass procedure, and X-ray examination results ($p > 0.05$). However, the external diameter of the pulmonary artery among patients in Group A was significantly larger than that in Group B, while the external diameter of the aorta was significantly smaller compared to Group B ($p < 0.05$).

CHD is typically classified into three types based on the direction and mechanism of blood flow: left-to-right shunt, right-to-left shunt, and non-shunt. CHD with a left-to-right shunt is associated with increased pulmonary blood flow, whereas CHD with a right-to-left shunt results in decreased pulmonary blood flow. An increase in pulmonary blood flow can cause elevated pulmonary artery pressure, and prolonged pulmonary hypertension may induce structural changes in the pulmonary artery wall, including thickening and dilation.[8] Conversely, decreased pulmonary blood flow may result in lower pulmonary artery pressure. Since the pulmonary artery does require dilation to accommodate high blood flow under these conditions, a significant increase in its external diameter is typically not observed.[9]

From additional analyses in the current study, statistically significant differences were noted in respiratory mechanics indexes, including peak airway pressure, plateau airway pressure, inspiratory resistance, expiratory resistance, and lung-thorax compliance, both before and after CPB drainage within and between the two groups of pediatric patients ($p < 0.05$). These variations were closely associated with systemic and pulmonary pathophysiological changes induced by CPB. During CPB, blood comes into contact with non-endothelial surfaces, potentially activating the complement system, leukocytes, and other inflammatory mediators. These inflammatory mediators subsequently enter the pulmonary tissue via the bloodstream, triggering pulmonary inflammation and leading to pulmonary edema. The formation of pulmonary edema increases the elastic resistance of lung tissue, resulting in elevated peak airway pressure and plateau airway pressure, along with decreased lung-thorax compliance.[10] Additionally, CPB has been reported to affect pulmonary surfactant function and pulmonary vascular resistance, further influencing respiratory mechanics indexes in pediatric patients.[11] It has also been indicated in previous studies[12,13] that the decrease in lung-thorax compliance after CPB is primarily attributable to pulmonary edema, atelectasis, and increased elastic resistance of lung tissue—all of which can also contribute to the overall increase in peak airway pressure and plateau airway pressure. Furthermore, respiratory mechanics indexes can be influenced to a certain extent by adjustments in mechanical ventilation parameters. These findings highlight the need for clinicians to implement more refined intraoperative and postoperative management strategies to optimize pulmonary function and improve overall prognosis in pediatric patients undergoing CPB.

This study has several limitations. As a retrospective, single-center study with a relatively small sample size, its findings may not be widely generalizable. Additionally, only one postoperative time point (24 hours after CPB) was analyzed, which cannot reflect the dynamic changes in respiratory function over time. Important confounding factors such as postoperative complications were not accounted for. Future studies using a prospective, multicenter design with larger cohorts and include multiple postoperative time points are needed. Incorporating additional clinical parameters such long-term respiratory outcomes may further inform individualized respiratory management strategies in children with congenital heart disease undergoing CPB.

In summary, in this study on pediatric patients with CHD, it was found that patients with different types of shunts exhibited significant differences in the external diameter of the pulmonary artery and aorta. Dynamic monitoring of respiratory mechanics indexes before and after CPB is essential in clinical respiratory management to promptly assess changes in pulmonary function and adjust respiratory support strategies accordingly.

Data Availability Statement

All data generated or analysed during this study are included in this article. Further enquiries can be directed to the corresponding author.

Ethics Approval and Consent to Participate

This study was conducted with approval from the Ethics Committee of Shanxi Children's Hospital, Shanxi Women and Children Hospital.(Approval number: IRB-KYYN-2021-005) This study was conducted in accordance with the declaration of Helsinki. Written informed consent was obtained from all participants.

Consent for Publication

All patient guardians signed a document of informed consent.

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Disclosure

The authors declare that they have no competing interests in this work.

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