Quality management of comprehensive blood conservation strategies during cardiopulmonary bypass in pediatric cardiac surgery

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Word Count: Abstract: 199; Introduction: 347; Discussion: 1354; overall word count for the entire body of text: 4336.

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Running head title: Blood conservation during CPB in children

Abstract

Background: Pediatric cardiac surgery with cardiopulmonary bypass (CPB) carries substantial transfusion requirements, exposing patients to increased risks of complications during hospital stay. This study evaluates the clinical impact of a quality-controlled, multimodal blood conservation strategy during CPB in pediatric cardiac surgery.

Methods: We collected the medical data of 9792 children (aged≤14 years and weight>10 kg) undergoing CPB cardiac surgery between September 2014 and December 2021. Since January 2016, the pediatric CPB center has implemented patient blood management. Subsequently, patients were divided into two groups: conventional management group (premanagement, n=1762) and patient blood management group (postmanagement, n=8030). Compare blood transfusion and outcomes. A 1:1 propensity score matching was performed.

Results: 1760 matched patient pairs were obtained. Compared with the premanagement group, the postmanagement group demonstrated significant reduction in packed red blood cell (PRBC) transfusion rates (during hospital stay: 38.1% vs 33.6%, p =0.007; CPB: 18.2% vs 11.1%, p <0.001), lower plasma transfusion rates (20.7% vs 16.6%, p =0.002), furthermore, decreased CPB priming volume (29.2 vs 29.1 mL/kg, p =0.042), lower incidence of postoperative liver injury (15.7% vs 10.5%, p <0.001) and AKI (7.5% vs 5.5%, p =0.017).

Conclusions: Following the postmanagement, comprehensive blood conservation strategies significantly reduce transfusion requirements and improve clinical outcomes for this vulnerable population, establishing an effective framework for blood resource utilization and safety during hospital stay.

Keywords: pediatric cardiac surgery, quality management, cardiopulmonary bypass, transfusion medicine, blood conservation, patient blood management

Introduction

Pediatric cardiac surgery usually requires full system anticoagulation and cardiopulmonary bypass (CPB). The concomitant effects of surgical trauma and CPB-induced coagulopathy frequently result in substantial transfusion requirements [1]. Multiple physiological and clinical factors modulate pediatric patients' anemia tolerance, bleeding risk, and transfusion needs [2]. Current blood supply systems face mounting pressures from declining donation rates, non-evidence-based transfusion practices, and insufficient adherence to transfusion guidelines - challenges significantly amplified during the COVID-19 pandemic [3]. Compelling evidence demonstrates that allogeneic blood transfusions independently associate with increased morbidity during hospital stay in cardiac surgery patients [4-5]. Patient advocacy organizations support minimizing harm to patients by avoiding transfusions without clear benefits [6]. These critical considerations necessitate the development of comprehensive blood conservation protocols during hospital stay to reduce unnecessary transfusions in pediatric cardiac surgery.

Patient blood management (PBM) represents a systematic, evidence-based, patient-centered approach to optimizing patient outcomes through the preservation of autologous blood and minimization of allogeneic transfusions. In 2010, the 63rd World Health Assembly (WHA63.12) called on all member states to implement PBM programs to improve patient clinical outcomes [7]. Therefore, PBM is particularly important for pediatric cardiac surgery. Since January 2016, the Pediatric CPB center of Fuwai Hospital has implemented multiple blood conservation strategies as a key clinical quality assessment indicator for cardiac surgery [8].

Current evidence remains limited regarding the effects of comprehensive blood conservation strategy quality management during CPB on transfusion requirements and clinical outcomes in pediatric cardiac surgery. This study utilizes large-scale clinical data to evaluate the post-implementation impact on transfusion practices and surgical outcomes in children >10 kg undergoing cardiac procedures. The findings aim to optimize blood management strategies for this vulnerable population and establish evidence-based guidelines for pediatric perfusion practice.

Method

1. Study design and population

Our center routinely performs cardiac surgery on pediatric patients aged ≤14 years. For this retrospective study, we extracted electronic medical records of children (≤14 years) undergoing cardiac surgery at Fuwai Hospital between September 1, 2014, and December 31, 2021. The study was approved by the Institutional Review Board (IRB) of Fuwai Hospital, Beijing, China (Approval No. 2023–2265), and the requirement for informed consent was waived due to its retrospective nature. Exclusion criteria comprised: (1)

weight ≤ 10 kg; (2) non-CPB procedures; (3) heart transplantation cases; (4) incomplete clinical records. The cohort was stratified into two temporal groups: the premanagement group (September 1, 2014, to December 31, 2015) and the postmanagement group (January 1, 2016, to December 31, 2021) of implementing a comprehensive blood conservation strategy quality management. The institutional review board waived informed consent requirements due to the retrospective study design. This study was conducted in accordance with TRIPOD guidelines.

2. **Comprehensive blood conservation strategy during CPB.** The comprehensive blood conservation strategy comprised eight key components:

1. Restrictive packed red blood cell (PRBC) transfusion protocol (single-ventricle and other palliative patients requires individualized assessment)

Transfusion indications were assessed based on concurrent fulfillment of the following criteria: 1) Lactate >3mmol/L; 2) Base excess >-3mmol/L; 3) Mixed venous oxygen saturation (SvO_2) <60%; 4) Cerebral oxygen saturation decrease > 20% or ≥50% compared with the baseline. During CPB, age-specific thresholds were applied:

a. For children aged 1-7 years: 1. Hemoglobin (Hb) <75 g/L, or Hb <90 g/L after ultrafiltration with residual machine blood and washed RBC reinfusion.

b. For children aged 7-14 years: 1. Hb <70 g/L or Hb <80 g/L after ultrafiltration with residual machine blood and washed RBC reinfusion.

2. Blood component priming protocol

The priming solution consisted of: a. 0-1 U of PRBCs (preoperative Hb <100 g/L priming with 1U PRBC). b. An

appropriate volume of 4 % succinylated gelatin (Gelofusine, GEL). C. 20 mL of 5% sodium bicarbonate. This mixture was prepared in the venous reservoir before CPB initiation.

3. Intraoperative cell saver

The intraoperative cell saver system was routinely employed for complex and redo surgeries. In addition to aspirating blood from the surgical field, the washing solution from blood-soaked gauze was also recovered, and the modified ultrafiltration (MUF) circuit and oxygenator lines were flushed.

4. Miniaturized pediatric CPB circuit

The system comprised: a roller pump, an infant tubing pack, an oxygenator with integrated arterial microfilter, and a vacuum-assist venous drainage (VAVD) device.

5. MUF circuit configuration

The MUF system was established by connecting the venous return circuit to the cardioplegia delivery circuit. This configuration enabled the recovery of residual blood from the venous circuit and enhanced ultrafiltration efficiency during MUF (Figure 1).

6. Pediatric circuit selection protocol

Type C: For infants 10-15 kg (priming volume 200-250 mL); Type D: For infants ≤10 kg (priming volume 170-200 mL); Type X: For neonates (priming volume 120-150 mL).

7. Retrograde autologous priming (RAP).

8. Near infrared spectroscopy (NIRS).

The detailed protocols of our comprehensive blood conservation strategies and anesthesia protocol are available in the Supplementary Materials.

3. **Quality management framework for pediatric blood conservation during CPB**

3.1 Incorporated transfusion metrics into perfusionists' quality assessments and reinforced blood conservation principles during weekly departmental meetings.

3.2 Implemented an electronic reporting system to enable immediate documentation and tracking of blood product utilization by perfusionists.

3.3 Conducted tri-monthly audits of transfusion data to guide evidence-based practice modifications.

3.4 Retraining for perfusionists failing to meet established standards, with the ultimate goal of achieving uniform transfusion practices across the team.

3.5 Performed year-end program assessments, incorporating multidisciplinary feedback (surgical team, anesthesiologists, pediatric intensive care unit (PICU) physicians) via structured surveys to make timely improvements.

4. Data collection and definitions

For each enrolled patient, we extracted the following parameters: demographic characteristics, preoperative variables and laboratory tests, type of congenital heart disease (CHD) surgery, intraoperative variables, and postoperative variables. For patients with multiple hospitalizations, only data from the initial admission were included in the analysis. All clinical information was obtained from the hospital electronic medical record system.

Surgical complexity was classified according to the Society of Thoracic Surgeons-European Association for Cardio-Thoracic Surgery (STAT) mortality categories [9-10], with STAT 1 indicating the lowest mortality risk and STAT 5 representing the highest risk. The definition of cyanotic congenital heart disease (CCHD) is based on the anatomy of CHD and includes tetralogy of fallot (TOF), double outlet right ventricle (DORV), pulmonary stenosis (PS), pulmonary

atresia (PA), transposition of the great arteries (TGA), tricuspid atresia (TA), single ventricle (SV), total anomalous pulmonary venous connection (TAPVC), atrioventricular septal defect (AVSD), and corrected transposition of the great arteries (CTGA). Transfusion timing was categorized as: Preoperative: PRBC administration before surgery. Intraoperative: PRBC administration from CPB weaning through operating room discharge. Postoperative: PRBC administration in the PICU until hospital discharge. During hospital stay: PRBC administration during hospitalization. Baseline characteristics were selected based on established transfusion risk factors from prior clinical studies, clinical practice, and published literature.

5. Outcome measures

5.1 Primary outcome: PRBC transfusion rate.

5.2 Secondary outcomes: plasma and platelets transfusion rates, PRBC and plasma transfusion volumes during hospital stay, CPB priming volume, postoperative chest drainage volume, mechanical ventilation (MV) duration, postoperative PICU stay >5 days, postoperative hospitalization time >7 days, last laboratory test before discharge, postoperative complication rate, in-hospital mortality.

5.3 The definitions of outcomes are as follows:

Acute kidney injury (AKI): Diagnosed or classified according to the KDIGO (Kidney Disease: Improving Global Outcomes) guidelines [11].

Liver injury: Alanine aminotransferase (ALT) or aspartate aminotransferase (AST) levels exceeding twice the upper limit of normal within the first postoperative week [12].

The composite endpoint: The occurrence of one or more of the following postoperative complications: AKI, liver injury, chest

drainage volume >1000 mL, pulmonary infection, or ECMO placement.

6. Statistical analysis

A 1:1 propensity score matching (PSM) was performed with a caliper width of 0.1. The standardized mean difference (SMD) was calculated to assess the balance within the model, and SMD < 0.1 was considered balanced [13]. For subgroup analysis, multivariate logistic regression included parameters with p <0.1 in the univariate logistic regression and potential confounders, and stratification factors included STAT score, sex, CCHD, age, and weight to assess the reliability of the study results. Data normality was evaluated using the Kolmogorov-Smirnov test. Continuous variables were described as mean±SD for normally distributed or as medians (P25, P75) for not normally distributed and analyzed using the Mann-Whitney U test. Categorical variables were described as counts (percentages) and analyzed using x^2 or Fisher's exact tests as appropriate.

All statistical analyses were performed using SPSS 26.0 (SPSS Inc., Chicago, IL, USA) and R version 4.1.2 software (R Foundation for Statistical Computing, Vienna, Austria). The significance level was set at p <0.05.

Results

1. Baseline and surgical characteristics

From September 2014 to December 2021, a total of 9792 children aged ≤14 years undergoing cardiac surgery with CPB were identified (Figure 2). In the entire cohort, the median age of the children was 3.7 years. The demographic and clinical characteristics of the study population are presented in Supplementary Table 1. Details of PRBC usage during hospital stay in the cohort are shown

in Supplementary Table 2.

2. Clinical characteristics and outcomes of patients without versus with PRBC transfusion during hospital stay

The impact of PRBC transfusion was explored on this population, which is a key prerequisite for whether the necessity of PBM. Of the 9792 enrolled patients, 65.9% did not receive PRBC transfusion and 34.1% reveived PRBC transfusion. After PSM, 2421 well-balanced pairs (SMD <0.1; supplementary tables 3 and 4). PRBC-transfused patients demonstrated significantly greater postoperative chest drainage volume, prolonged MV duration, higher rates of postoperative PICU stay >5 days, hospitalization >7 days, and chest drainage volume >1000 mL. No significant between-group differences were observed in AKI, pulmonary infection, ECMO insertion, and in-hospital mortality. (supplementary table 5)

3. Clinical characteristics of patients in the premanagement and postmanagement groups

The above results indicate that increased PRBC transfusion lead to adverse outcomes during hospital stay, therefore, we proceeded with our core analysis. A total of 9792 pediatric patients were included, comprising 1762 (18.0%) in the premanagement group and 8030 (82.0%) in the postmanagement group. The baseline characteristics of the patients are presented in Supplementary Table 6. After PSM, 1760 patient pairs were matched, with the characteristics of the two groups remaining comparable (SMD <0.1). (Table 1)

4. Primary outcomes of patients in the premanagement and postmanagement groups

Compared with the premanagement group, the postmanagement

group showed a significantly lower PRBC transfusion rate, a significantly higher PRBC transfusion-free rate, and a significantly lower rate of 1U PRBC transfusion. No significant difference was observed in the rate of ≥2U PRBC transfusion during hospital stay or CPB. In addition, there were no significant differences in intraoperative or postoperative PRBC transfusion rates. (Table 2)

5. Secondary outcomes of patients in the premanagement and postmanagement groups

Compared with the premanagement group, the postmanagement group had a significantly lower plasma transfusion rate and a significantly higher plasma transfusion-free rate. The rate of 100-1000 mL plasma transfusion was significantly reduced during hospital stay, whereas no significant differences were observed in the rates of plasma transfusion >1000 mL or platelet transfusion during hospital stay. The mean PRBC transfusion volumes during hospital stay and CPB were significantly lower, as were the plasma transfusion volume and CPB priming volume during hospital stay. Postoperative levels of Hb, Hct, SCr, and BUN were significantly reduced. The incidence of the composite endpoint was significantly lower. No significant differences were found in postoperative chest drainage volume, MV duration, PICU stay >5 days, hospital stay >7 days, postoperative chest drainage volume >1000 mL, pulmonary infection, ECMO insertion, and in-hospital mortality. (Table 3)

6. Subgroup analysis

Children were classified by STAT score, gender, CCHD, age, and weight. Subgroup analysis showed that postmanagement significantly reduced the incidence of the composite endpoint across all subgroups. No interaction was observed between STAT score,

gender, CCHD, age, weight, and postmanagement, indicating that the findings were comparable for all pediatric populations. (Figure 3)

Discussion

In this study, a total of 9792 children who underwent cardiac surgery with CPB were included. First, we demonstrated that blood transfusion increases the incidence of adverse events, provides a clinical basis for formulating and implementing quality management of comprehensive blood conservation strategies. Subsequently, core analysis showed that compare to the premanagement, postmanagement effectively conserved blood resources and reduced the incidence of postoperative complications. Subgroup analysis further indicated that, during CPB, postmanagement significantly reduced the incidence of the composite endpoint in children undergoing cardiac surgery.

The WHO has classified blood as an essential medicine, underscoring its importance in national healthcare systems [14]. With the increasing number of surgeries, global blood resources are in short supply. Consistent with previous studies [4-5], our findings showed that blood transfusion is associated with a higher incidence of adverse events during hospital stay. Transfusion-related adverse reactions are being continuously explored, and transfusion-free cardiac surgery or CPB is developing rapidly. Several guidelines have recommended strategies for blood conservation during cardiac surgery to guide precise transfusion practices. Many of these strategies have been validated to be safe and effective [15-16]. However, due to differences in management decisions, medical equipment, technical expertise, and transfusion indications across cardiac centers, these recommendations have not been fully validated in many hospitals worldwide [17]. Our study demonstrated

that postmanagement can effectively conserve blood resources and help alleviate the imbalance between blood supply and demand.

The effectiveness of postmanagement during CPB in adult cardiac surgery patients has been demonstrated in our adult CPB center [18]. However, results from the adult population should not be generalized to pediatric patients, as they differ markedly in physiological characteristics and disease profiles. Pediatric cardiac surgery has several unique features, including a relatively small blood volume compared with the CPB circuit priming volume, immature vascular and coagulation systems, high oxygen metabolism demands, and prolonged CPB duration and operative time for the correction of complex CHD. These factors not only increase the incidence of complications but also their severity, and they make transfusion management particularly challenging in this population. Therefore, blood conservation in pediatric cardiac surgery requires meticulous planning and multidisciplinary collaboration throughout all stages of care during hospital stay. In our study, efforts to reduce blood transfusion during CPB primarily focused on adjusting the transfusion threshold, modifying the priming method, and upgrading hardware facilities. Maintaining an appropriate Hct and Hb level at the end of CPB allows greater flexibility for subsequent fluid management. The decision to transfuse blood after CPB is made jointly by the anesthesiologist and PICU physician, based on the child's clinical course, volume status, and Hb level. Intraoperative transfusion practices are also strongly influenced by the pediatric perfusionist's PBM concept.

VAVD was also incorporated into the blood conservation strategy. The technique reduces the priming volume by elevating the oxygenator to shorten the distance between the CPB machine and

the surgical field. The use of oxygenator with integrated arterial filter can further reduce the priming volume to 180-200 mL. Our study demonstrated that postmanagement can significantly reduce CPB priming volume in children undergoing cardiac surgery.

CPB can cause coagulation disorders; therefore, FFP is often used as an important component of the CPB circuit priming fluid to maintain an appropriate colloid-to-crystalloid ratio, protect postoperative coagulation function, and reduce dilutional coagulopathy. McCall et al. reported that adding FFP to the CPB priming fluid can reduce postoperative bleeding and the need for blood products [19], whereas wang et al. found no obvious benefit [20]. Based on these findings, our study modified the CPB priming strategy by replacing FFP with GEL. The safety of priming without FFP has been demonstrated in our previous research [21]. Our results showed that postmanagement significantly reduced both plasma transfusion rate and volume during hospital stay without increasing adverse outcomes.

There are few studies on restrictive or non-restrictive PRBC transfusion strategies in pediatric patients, and no consistent conclusions have been reached [22-23]. We believe that under a restrictive transfusion strategy, reducing transfusion should not rely solely on controlling the transfusion threshold. Therefore, our study adopted a comprehensive blood conservation strategy, which included both transfusion threshold control and additional blood-saving measures. Our results showed that there was no significant difference in in-hospital mortality between children undergoing cardiac surgery in the premanagement and postmanagement periods, indicating that the strategies used in our study were safe. Postmanagement significantly reduced the PRBC transfusion rate

and volume during hospital stay and CPB, without increasing during hospital stay or postoperative PRBC transfusion rates. This approach effectively conserved blood resources and alleviated the imbalance between blood supply and demand. In addition, our protocol significantly reduced the incidence of the composite endpoint, postoperative SCr and Bun levels, and the incidence of liver injury and AKI, suggesting that postmanagement may confer protective effects on hepatic and renal functions in children. Although postmanagement reduced postoperative Hb and Hct levels, it did not increase the incidence of composite endpoint or mortality in the short term, indicating that these lower levels are well tolerated in pediatric patients. This finding is consistent with that of Cholette et al. [24], who studied infants weighing ≤ 10 kg undergoing biventricular repair or palliative surgery. They reported that, compared with the non-restrictive transfusion group, the restrictive transfusion group had significantly lower Hb levels on the first postoperative day, and these levels persisted for more than 10 days. Despite maintaining lower Hb concentrations, there were no significant differences in oxygen delivery parameters or adverse event rates, and no signs of tissue hypoxia were observed, indicating tolerance to lower Hb concentrations. Although the primary goal of PRBC transfusion is to improve oxygen delivery, inappropriate transfusion of PRBCs does not reliably increase oxygen delivery. Previous studies have demonstrated no change in arteriovenous oxygen difference [25] or oxygen delivery/consumption [26] after PRBC transfusion. Most children can tolerate lower Hb levels than previously considered appropriate for their age group without detrimental effects [27-28].

It is worth noting that the comprehensive blood conservation

strategy for quality management implemented in this study primarily targeted the CPB stage of pediatric cardiac surgery. Our results showed that both the transfusion rate and volume of PRBCs and plasma during CPB were significantly reduced, as were those during hospital stay, indicating that PBM during CPB has a positive impact on transfusion practices during hospital stay. Importantly, these improvements were achieved without increasing intraoperative or postoperative transfusion rates, underscoring the key role of CPB in pediatric cardiac surgery. The substantial reduction in CPB transfusion rates was closely associated with heightened blood conservation awareness among pediatric perfusionists and upgrades in clinical hardware facilities. After adopting the blood conservation concept, pediatric perfusionists consciously adhered to relevant guidelines, emphasized blood management during CPB in children undergoing cardiac surgery, and employed multiple blood conservation strategies to minimize unnecessary transfusions, thereby achieving favorable clinical outcomes. To enhance the quality of clinical care, the transfusion quality management process was integrated into the routine clinical workflow of our pediatric CPB center. At present, PBM programs for CPB in pediatric cardiac surgery remain scarce. The series of blood conservation strategies and quality management practices implemented at our center may serve as a useful reference for other institutions.

In addition to the restrictive transfusion strategy, other blood conservation measures applied in this study contributed to maintaining appropriate Hb levels and ensuring adequate oxygen delivery. Subgroup analysis showed that postmanagement significantly reduced the incidence of the composite endpoint across all pediatric subgroups. Clinicians should carefully weigh the

benefits and risks of blood transfusion to avoid imposing unnecessary physiological burden on the child and to prevent adverse outcomes.

This study has several limitations. First, it was a single-center retrospective study, which may have introduced selection bias. Second, in low-weight children with CHD (≤10 kg), blood management is more complex due to disease-specific factors, body weight, and other variables; therefore, this population will be specifically addressed in future research. Third, no long-term follow-up was conducted. Fourth, this study included pediatric patients who underwent CPB cardiac surgery from 2014 to 2021, a relatively long time span that may have introduced potential temporal effects.

In summary, quality management evaluation demonstrated that implementing a comprehensive blood conservation strategy during CPB is safe and effective in children weighing more than 10 kg undergoing cardiac surgery. This approach can effectively conserve blood resources and reduce postoperative complications in pediatric patients.

Declarations:

Funding: This study was supported by the CAMS Innovation Fund for Medical Sciences(CIFMS) 2024-12M-C&T-B-045, the Fundamental Research Funds for the Central Universities, Peking Union Medical College (3332025040), the Academic Enhancement Support Program of Hainan Medical University (XSTS2025095), and the New Star Program of the South China Sea, Hainan Province (NHXX-WJW-2025011)

Author contributions: Wenting Wang: Data curation, Writing-Original draft preparation, Software, Validation. **He Wang:** Data curation. **Jia Liu:** Visualization. **Yu Jin:** Wring-Reviewing and Editing. **Jinping Liu:** Conceptualization, Methodology, Software. All authors reviewed this manuscript.

Ethical approval: This work was approved by the ethical committee of Fuwai Hospital of the Chinese Academy of Medical Sciences (Beijing, China) (NO.2023-2265) and was conducted in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Written informed consent was waived due to the retrospective nature of the study.

Data availability statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflict of interest statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Consent for publication: Not applicable.

Clinical Trial Number: Not applicable.

Acknowledgements: We sincerely appreciated BioRender (https://www.biorender.com/) for the construction of our figures.

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Figure Legends:

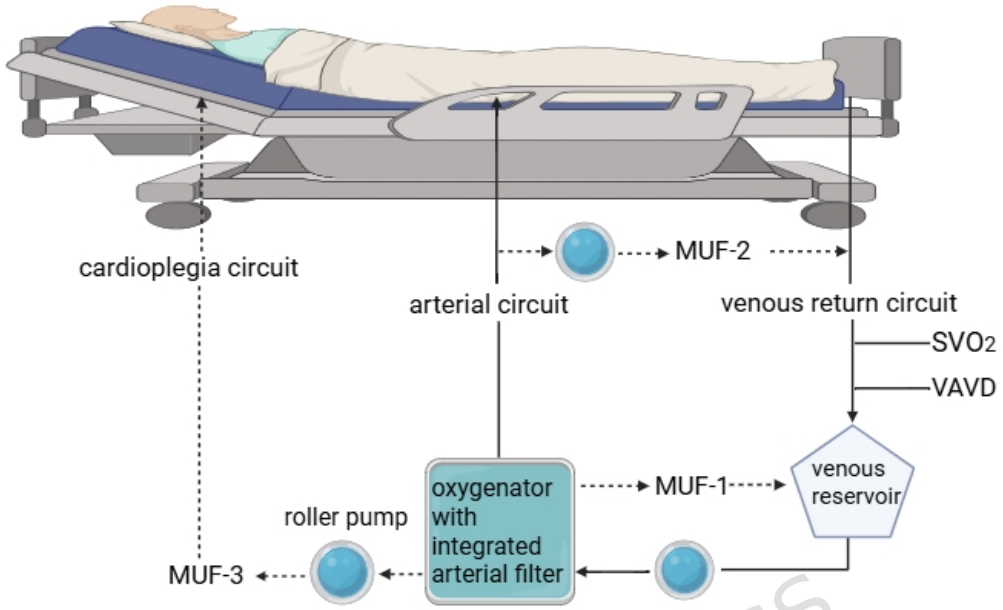

Figure 1. MUF-1: Conventional ultrafiltration; MUF-2: Modified ultrafiltration; MUF-3: Fuwai modified ultrafiltration.

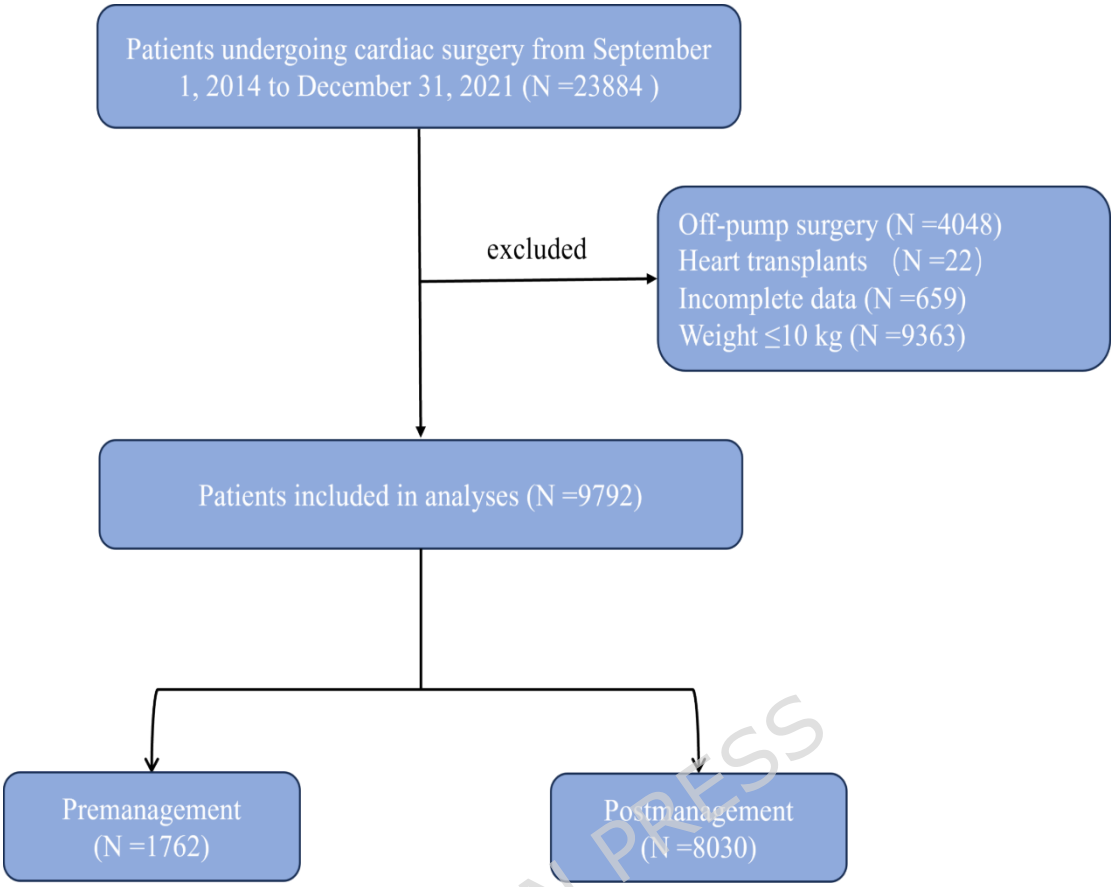

Figure 2. Flowchart of patients selection for the study.

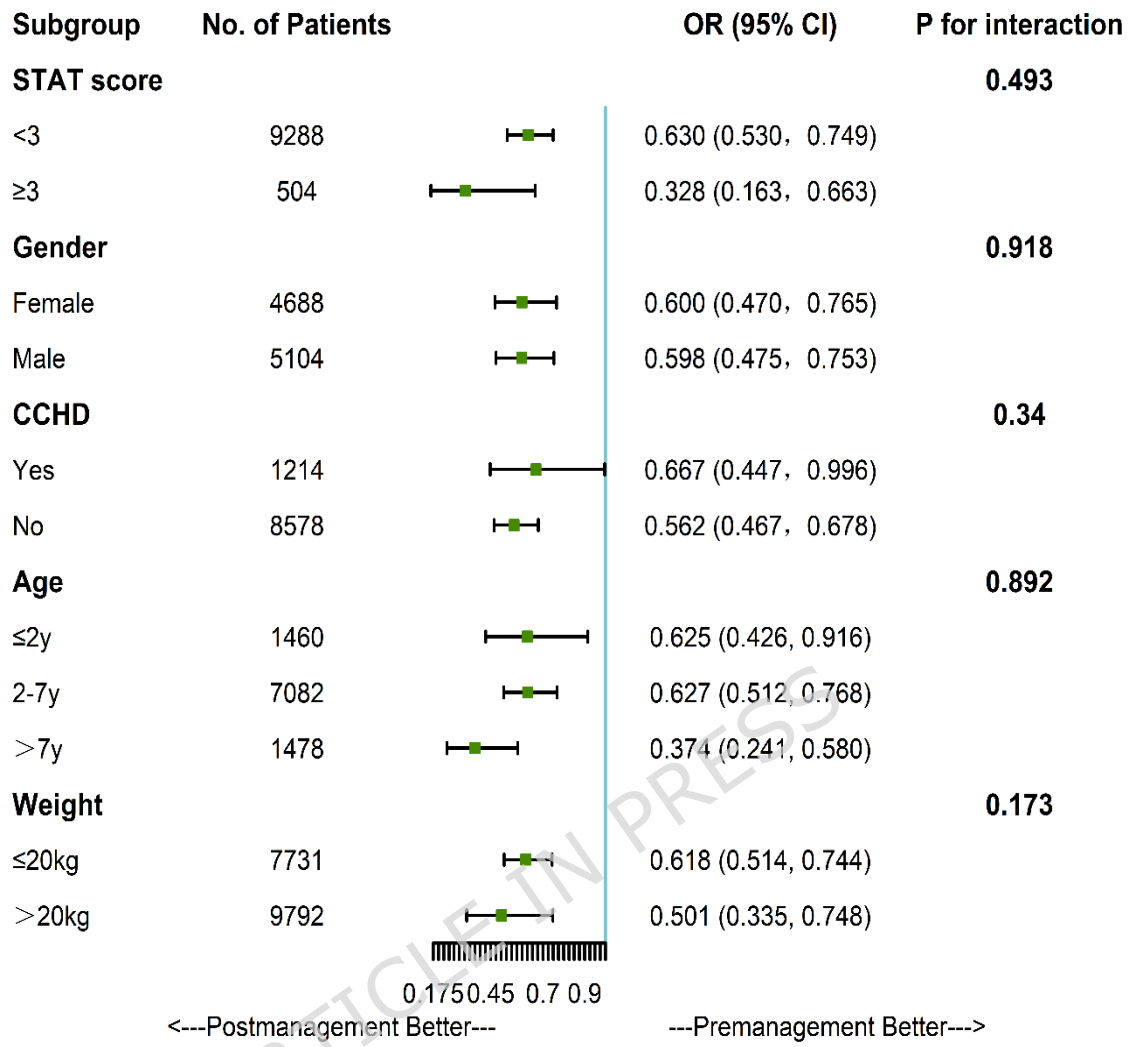

Figure 3. Comparison of the composite endpoint between premanagement and postmanagement in subgroup analysis. STAT, society of thoracic surgeons-european association for cardio-thoracic surgery; CCHD, cyanotic congenital heart disease; OR: odds ratio; CI: confidence interval.

Table 1. Baseline characteristics and intraoperative variables after PSM between the premanagement and postmanagement groups

Variable	premanagement group (n=1760)	postmanagement group (n=1760)	SMD
Demographic characteristics			
Sex, male, n (%)	954 (54.2)	949 (53.9)	0.006
Age (y)	3.5 (2.4, 5.7)	3.7 (2.5, 5.5)	0.003
Weight (kg)	15.0 (12.0, 19.0)	15.0 (12.2, 19.0)	0.028
Birth weight (kg)	3.3 (3.0, 3.6)	3.3 (3.0, 3.6)	0.042
Gestational age (week)	39.0 (38.0, 40.0)	39.0 (38.0, 40.0)	0.009
Preoperative variables			
Emergency surgery, n (%)	10 (0.6)	11 (0.6)	0.007
STAT score, n (%)			0.068
I	1399 (79.5)	1399 (79.5)	
II	260 (14.8)	266 (15.1)	
III	81 (4.6)	70 (4.0)	
IV	18 (1.0)	25 (1.4)	
V	2 (0.1)	0 (0)	
Cyanotic congenital heart disease, n (%)	283 (16.1)	268 (15.2)	0.023
Blood transfusion history, n (%)	23 (1.3)	15 (0.9)	0.044
Previous cardiac surgery, n (%)	2 (0.1)	6 (0.3)	0.048
Preoperative blood transfusion, n (%)	2 (0.1)	1 (0.1)	0.019
Endocarditis	4 (0.2)	8 (0.5)	0.039
Preoperative laboratory			

measurements			
Hb (g/L)	124.5 (124.5, 133.0)	127.0 (124.0, 133.0)	0.020
Hct (%)	38.1 (36.3, 40.4)	38.0 (36.4, 40.0)	0.027
Creatinine (μmol/L)	33.7 (29.0, 40.1)	35.1 (30.2, 41.0)	0.101
BUN (mmol/L)	4.5 (3.9, 5.3)	4.5 (3.8, 5.3)	0.057
Type of congenital cardiac surgery, n (%)			
Atrial septal defect	504 (28.6)	577 (32.8)	0.090
Ventricular septal defect	898 (51.0)	869 (49.4)	0.033
Transposition of great arteries	34 (1.9)	44 (2.5)	0.039
Double outlet right ventricle	43 (2.4)	41 (2.3)	0.007
Tetralogy of Fallot	110 (6.2)	78 (4.4)	0.081
Pulmonary stenosis	123 (7.0)	149 (8.5)	0.055
Pulmonary atresia	19 (1.1)	29 (1.6)	0.049
Total anomalous pulmonary venous connection	7 (0.4)	10 (0.6)	0.025
Coarctation of the aorta	21 (1.2)	24 (1.4)	0.015
Interrupted aortic arch	8 (0.5)	4 (0.2)	0.039
Tricuspid atresia	13 (0.7)	4 (0.2)	0.074
Other surgeries	255 (14.5)	239 (13.6)	0.078
Intraoperative variables			
CPB time (min)	58.0 (42.0, 88.0)	59.0 (41.0, 87.0)	0.024
Aortic clamping time (min)	35.0 (22.0, 56.0)	34.0 (21.0, 57.0)	0.022
Operation time (h)	3.10 (2.60, 3.80)	3.1 (2.70, 3.80)	0.011
The minimum rectal temperature	33.0 (31.9, 34.1)	33.3 (32.1, 34.3)	0.079

during CPB (℃)

Values are expressed as M±SD/median (P25, P75) or n (%). PSM, propensity score matching; PRBC: packed red blood cell; SMD, standardized mean difference; STAT, society of thoracic surgeons-european association for cardio-thoracic surgery; Hct, hematocrit; Hb, hemoglobin; BUN, blood urea nitrogen; CPB, cardiopulmonary bypass.

Table 2. Primary outcomes after PSM between the premanagement and postmanagement groups

Variable	premanagement group (n=1760)	postmanagement group (n=1760)	*P*□
PRBC transfusion			
PRBC transfusion during hospital stay	670 (38.1)	592 (33.6)	0.007
PRBC transfusion composition ratio during hospital stay			
0U	1090 (61.9)	1168 (66.4)	0.007
1U	515 (29.3)	447 (25.4)	0.011
2U	94 (5.3)	90 (5.1)	0.820
>2U	47 (2.7)	40 (2.3)	0.515
PRBC transfusion during CPB	320 (18.2)	196 (11.1)	<0.001
PRBC transfusion composition ratio during CPB			
0U	1440 (81.8)	1564 (88.9)	<0.001
1U	300 (17.0)	169 (9.6)	<0.001
2U	14 (0.8)	19 (1.1)	0.484

>2U	5 (0.3)	7 (0.4)	0.772
PRBC transfusion during intraoperative	61 (3.5)	63 (3.6)	0.927
PRBC transfusion during postoperative	385 (21.9)	405 (23.0)	0.443

Values are expressed as M±SD/median (P25, P75) or n (%). PSM, propensity score matching; PRBC, packed red blood cell; U, unit; CPB, cardiopulmonary bypass.

Table 3. Secondary outcomes after PSM between the premanagement and postmanagement groups

Variable	**premanagement group (n=1760)**	**postmanagement group (n=1760)**	***P* value**
Plasma transfusion			
Plasma transfusion during hospital stay	365 (20.7)	292 (16.6)	0.002
Plasma transfusion composition ratio during hospital stay			
0 mL	1396 (79.3)	1468 (83.4)	0.002
100-1000 mL	350 (19.9)	284 (16.1)	0.004
>1000 mL	19 (1.1)	11 (0.6)	0.199
Platelet transfusion			
Platelet transfusion during hospital stay	138 (7.8)	129 (7.3)	0.611

PRBC transfusion volume			
PRBC transfusion volume during hospital stay (U)			
Mean ± SD	0.5±1.2	0.4±0.9	0.041
Median（P25, P75）	0.0 (0.0, 1.0)	0.0 (0.0, 1.0)	0.006
PRBC transfusion volume during CPB (U)			
Mean ± SD	0.2±0.5	0.1±0.4	<0.001
Median（P25, P75）	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	<0.001
Plasma transfusion volume			
Plasma transfusion volume during hospital stay （mL）			
Mean ± SD	60.0±237.2	46.7±159.6	0.051
Median（P25, P75）	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.004
Intraoperative variables			
CPB priming volume (mL/kg)	29.2 (25.3, 33.3)	29.1 (24.4, 33.0)	0.042
Postoperative laboratory measurements			
Hb (g/L)	110.0 (101.8, 119.0)	105.0 (97.0, 114.0)	<0.001
Hct (%)	31.0 (28.9, 33.5)	30.4 (28.4, 32.5)	<0.001
Creatinine (μmol/L)	38.6 (32.2, 46.8)	36.4 (30.8, 43.2)	0.001
BUN (mmol/L)	6.9 (5.7, 8.6)	6.3 (5.1, 7.8)	<0.001
Postoperative variables			
Thoracic drainage volume（mL）	123.0 (91.9, 182.0)	124.0 (88.0, 182.0)	0.904
Mechanical ventilation time（h）	4.0 (3.0, 8.0)	4.0 (3.0, 7.0)	0.565
PICU stay >5 days, n (%)	74.0 (4.2)	98.0 (5.6)	0.072

postoperative hospital stay >7 days, n (%)	694.0 (39.4)	721.0 (41.0)	0.371
Postoperative complications			
composite endpoint, n (%)	387 (22.0)	289 (16.4)	<0.001
Liver injury, n (%)	277 (15.7)	185 (10.5)	<0.001
Acute kidney injury, n (%)	132 (7.5)	96 (5.5)	0.017
I	108 (6.1)	80 (4.5)	0.043
II	22 (1.2)	14 (0.8)	0.241
III	2 (0.1)	2 (0.1)	1
Thoracic drainage volume>1000 mL, n (%)	33 (1.9)	32 (1.8)	1
Pulmonary infection, n (%)	0 (0)	2 (0.1)	0.479
ECMO insertion	2 (0.1)	2 (0.1)	1
In-hospital mortality, n (%)	3 (0.2)	1 (0.1)	0.617

Values are expressed as M±SD/median (P25, P75) or n (%). PSM, propensity score matching; PRBC, packed red blood cell; U, unit; CPB, cardiopulmonary bypass; Hct, hematocrit; Hb, hemoglobin; BUN, blood urea nitrogen; PICU, pediatric intensive care unit; ECMO, extracorporeal membrane oxygenation. Laboratory test results were the last test before discharge.