

Immediate postnatal cardiac surgery versus conventional neonatal cardiac surgery for critical congenital heart disease: a propensity score-matched cohort study

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Research Article

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Abstract

Background

The best timing of cardiac surgery for neonates with critical congenital heart disease is uncertain. Surgery soon after birth may reduce exposure to unstable transitional physiology. It may also increase risk if the neonate is not physiologically ready for cardiopulmonary bypass. We compared immediate postnatal cardiac surgery with conventional neonatal cardiac surgery in a matched cohort.

Methods

This retrospective cohort study included neonates with critical congenital heart disease who underwent cardiac surgery at a tertiary pediatric cardiac center from December 2022 to March 2026. Immediate postnatal surgery was defined as planned surgery performed within hours after birth. Conventional neonatal surgery was defined as surgery performed after initial postnatal stabilization. Propensity score matching was performed using sex, body length, birth weight, prematurity, Risk Adjustment for Congenital Heart Surgery-1 category, diagnosis category, prenatal diagnosis, and inborn status. Matched groups were compared with paired tests. Freedom from post-discharge unplanned reintervention was assessed with Kaplan-Meier analysis and Cox regression.

Results

Among 117 eligible neonates, 24 underwent immediate postnatal surgery and 93 underwent conventional neonatal surgery. After matching, 24 pairs were analyzed. Diagnosis category, prenatal diagnosis, and inborn status were identical between groups. Cardiopulmonary bypass time, aortic cross-clamp time, mechanical ventilation time, and intensive care unit stay were similar. Postoperative adverse events occurred in 6 of 24 neonates (25.0%) in the immediate group and 8 of 24 neonates (33.3%) in the conventional group ($P = 0.791$). In-hospital mortality was 8.3% and 12.5%, respectively ($P = 1.000$). Post-discharge unplanned reintervention occurred in 1 of 24 neonates (4.2%) and 5 of 24 neonates (20.8%), respectively ($P = 0.125$). Immediate postnatal surgery was associated with a lower but non-significant hazard of reintervention (hazard ratio 0.22, 95% confidence interval 0.03–1.86; $P = 0.163$).

Conclusions

In selected neonates with critical congenital heart disease, immediate postnatal cardiac surgery was feasible and was not associated with higher perioperative risk than conventional neonatal surgery. The lower observed reintervention rate is hypothesis-generating and needs confirmation in larger multicenter studies.

Trial registration:

Not applicable. This was a retrospective observational study.

Background

Critical congenital heart disease is an important cause of morbidity and mortality in newborn infants [1, 2]. Many affected neonates rely on the ductus arteriosus, an atrial communication, or high pulmonary vascular resistance to maintain systemic or pulmonary blood flow. After birth, rapid circulatory changes can lead to hypoxemia, acidosis, low cardiac output, and end-organ injury [2, 3]. Early diagnosis and timely intervention are therefore central goals of neonatal care.

The timing of cardiac surgery in these patients is a multidisciplinary decision. It begins with fetal diagnosis and counseling. It then extends to delivery planning, neonatal stabilization, cardiac anesthesia, surgery, and postoperative intensive care. The same surgical strategy may have different results if the perinatal pathway is incomplete. This is especially important for neonates who are diagnosed before birth or soon after delivery and are managed in a center with immediate access to pediatric cardiac surgery [3–7].

Conventional care often includes postnatal stabilization before cardiac surgery. This approach allows time for physiologic adaptation, diagnostic confirmation, and organ support. However, waiting may expose some neonates to persistent cyanosis, circulatory instability, transfer-related risk, and intensive preoperative treatment. Improvements in fetal diagnosis, postnatal diagnostic evaluation, and newborn screening have increased the chance of early recognition and planned specialist care for neonates with critical congenital heart disease [5–7].

Whether surgery immediately after birth improves outcomes remains unclear. Observational comparisons are difficult because timing is influenced by anatomy, prenatal diagnosis, inborn status, institutional practice, and preoperative condition [4, 8–11]. We therefore performed a propensity score-matched cohort study to compare perioperative outcomes and post-discharge unplanned reintervention after immediate postnatal cardiac surgery and conventional neonatal cardiac surgery in neonates with critical congenital heart disease.

Methods

Study design and setting

This retrospective cohort study was conducted at a tertiary pediatric cardiac center. The study was prepared with reference to the Strengthening the Reporting of Observational Studies in Epidemiology guidance for cohort studies. The aim was to compare early safety and post-discharge reintervention after two neonatal surgical timing strategies.

Participants

Consecutive neonates with critical congenital heart disease who underwent cardiac surgery between December 2022 and March 2026 were screened. Eligible diagnosis categories were transposition of the great arteries, pulmonary atresia, severe pulmonary stenosis, and total anomalous pulmonary venous connection. Neonates were included if surgery was performed during the neonatal period and if the required baseline and outcome data were available in the institutional record.

Surgical timing groups

Patients were classified according to surgical timing. Immediate postnatal surgery was defined as planned cardiac surgery performed within hours after birth. Conventional neonatal surgery was defined as cardiac surgery performed after initial postnatal stabilization. The decision about timing was made by the pediatric cardiac team after review of cardiac anatomy, postnatal physiology, operative priority, and readiness of neonatal intensive care resources.

All operations were performed through median sternotomy with cardiopulmonary bypass by the same surgical team. Perioperative care followed institutional neonatal cardiac protocols. In the immediate surgery pathway, prenatal diagnosis allowed delivery to be coordinated with the cardiac surgery, anesthesia, perfusion, and neonatal intensive care teams. Postnatal echocardiography was used to confirm anatomy before surgery. Neonates in the conventional pathway underwent initial stabilization before surgery according to diagnosis and clinical condition.

Variables and outcomes

Baseline variables included sex, body length, birth weight, prematurity, Risk Adjustment for Congenital Heart Surgery-1 category, diagnosis category, prenatal diagnosis, and inborn status. Operative and postoperative variables included cardiopulmonary bypass time, aortic cross-clamp time, vasoactive-inotropic score, duration of mechanical ventilation, and length of intensive care unit stay.

The main clinical outcomes were postoperative adverse events, in-hospital mortality, and post-discharge unplanned reintervention. Postoperative adverse events were defined as major complications that prolonged hospitalization or caused substantial clinical deterioration. Post-discharge unplanned reintervention included catheter-based or surgical procedures after discharge for residual or recurrent disease. Planned staged palliation and routine surveillance procedures were not counted as unplanned reinterventions unless they were performed for clinically important residual or recurrent lesions.

Follow-up was calculated from discharge to the first unplanned reintervention or the last available visit. Neonates who died before discharge were not at risk for post-discharge reintervention and were assigned 0 months for descriptive follow-up summaries.

Propensity score matching and statistical analysis

Propensity score matching was used to reduce baseline imbalance between the two timing groups. The propensity score was estimated with clinically relevant baseline variables: sex, body length, birth weight, prematurity, Risk Adjustment for Congenital Heart Surgery-1 category, diagnosis category, prenatal diagnosis, and inborn status. One-to-one matching was performed to create comparable pairs. Baseline characteristics after matching were summarized to assess comparability. A summary of the variables used in the propensity score model is provided in Additional file 1.

Continuous variables are presented as median and interquartile range. Categorical variables are presented as number and percentage. Matched continuous variables were compared with the Wilcoxon signed-rank test. Matched categorical variables were compared with paired exact tests. Freedom from post-discharge unplanned reintervention was estimated with Kaplan-Meier analysis and compared with the log-rank test. A Cox proportional hazards model was used to estimate the hazard ratio and 95% confidence interval for reintervention. All tests were two-sided. A P value less than 0.05 was considered statistically significant. Because this was an exploratory observational study, results were interpreted by considering effect size, confidence interval width, and clinical plausibility.

Use of language-editing tools

An artificial intelligence-based language tool was used only to improve English clarity and consistency during manuscript preparation. It was not used to generate data, perform analyses, or draw conclusions. The authors reviewed and edited all text and take full responsibility for the manuscript.

Results

Study population

A total of 117 neonates met the inclusion criteria. Of these, 24 underwent immediate postnatal surgery and 93 underwent conventional neonatal surgery. After propensity score matching, 24 pairs were included in the final analysis.

Baseline characteristics after matching

Baseline characteristics of the matched cohort are shown in Table 1. Diagnosis category, prenatal diagnosis, and inborn status were identical between groups after matching. Median body length was 50.0 cm (interquartile range 48.8–50.0) in the immediate group and 49.5 cm (interquartile range 48.0–50.0) in the conventional group ($P = 0.080$). Median birth weight was 3.25 kg (interquartile range 2.75–3.40) and 3.35 kg (interquartile range 2.80–3.50), respectively ($P = 0.732$). Risk Adjustment for Congenital Heart Surgery-1 categories were also similar ($P = 0.317$).

Table 1
Baseline characteristics of matched neonates

Variable	Immediate postnatal surgery (n = 24)	Conventional neonatal surgery (n = 24)	P value
Male sex	14/24 (58.3)	13/24 (54.2)	1.000
Body length, cm	50.0 (48.8–50.0)	49.5 (48.0–50.0)	0.080
Birth weight, kg	3.25 (2.75–3.40)	3.35 (2.80–3.50)	0.732
Prematurity	2/24 (8.3)	4/24 (16.7)	0.625
RACHS-1 category			0.317
2	9/24 (37.5)	8/24 (33.3)	
3	9/24 (37.5)	9/24 (37.5)	
4	6/24 (25.0)	7/24 (29.2)	
Diagnosis category			1.000
Transposition of the great arteries	13/24 (54.2)	13/24 (54.2)	
Pulmonary atresia	5/24 (20.8)	5/24 (20.8)	
Pulmonary stenosis	4/24 (16.7)	4/24 (16.7)	
Total anomalous pulmonary venous connection	2/24 (8.3)	2/24 (8.3)	
Prenatal diagnosis	24/24 (100.0)	24/24 (100.0)	1.000
Inborn status	24/24 (100.0)	24/24 (100.0)	1.000
Data are presented as median (interquartile range) or number/total number (%). P values were calculated with paired tests appropriate to the variable type. RACHS-1, Risk Adjustment for Congenital Heart Surgery-1.			

The matched cohort included the main lesion types treated in the immediate neonatal pathway: transposition of the great arteries, pulmonary atresia, severe pulmonary stenosis, and total anomalous pulmonary venous connection. The equal distribution of these diagnoses reduced confounding by anatomy and surgical complexity.

Operative and early postoperative outcomes

Operative and clinical outcomes are shown in Table 2. Cardiopulmonary bypass time did not differ significantly between the immediate and conventional groups: 188.5 min (interquartile range 122.3–223.0) versus 212.5 min (interquartile range 108.5–263.5; $P = 0.212$). Aortic cross-clamp time was also similar: 125.0 min (interquartile range 73.8–157.2) versus 129.0 min (interquartile range 62.2–176.5; $P = 0.700$).

Table 2
Operative and clinical outcomes

Outcome	Immediate postnatal surgery (n = 24)	Conventional neonatal surgery (n = 24)	P value
Cardiopulmonary bypass time, min	188.5 (122.3–223.0)	212.5 (108.5–263.5)	0.212
Aortic cross-clamp time, min	125.0 (73.8–157.2)	129.0 (62.2–176.5)	0.700
Vasoactive-inotropic score	9.28 (4.97–12.00)	5.64 (4.75–9.38)	0.170
Mechanical ventilation, h	93.8 (51.9–122.3)	94.0 (47.5–203.0)	0.584
Intensive care unit stay, d	10.5 (8.8–16.0)	14.5 (9.5–23.5)	0.279
Postoperative adverse events	6/24 (25.0)	8/24 (33.3)	0.791
In-hospital mortality	2/24 (8.3)	3/24 (12.5)	1.000
Post-discharge unplanned reintervention	1/24 (4.2)	5/24 (20.8)	0.125
Follow-up, months	16.0 (10.8–22.5)	29.0 (16.8–33.0)	0.075
Data are presented as median (interquartile range) or number/total number (%). P values were calculated with paired tests appropriate to the variable type.			

The vasoactive-inotropic score was numerically higher in the immediate group than in the conventional group: 9.28 (interquartile range 4.97–12.00) versus 5.64 (interquartile range 4.75–9.38; $P = 0.170$). Mechanical ventilation time was similar: 93.8 h (interquartile range 51.9–122.3) versus 94.0 h (interquartile range 47.5–203.0; $P = 0.584$). Intensive care unit stay was also similar: 10.5 d (interquartile range 8.8–16.0) versus 14.5 d (interquartile range 9.5–23.5; $P = 0.279$).

Clinical outcomes and reintervention

Postoperative adverse events occurred in 6 of 24 neonates (25.0%) in the immediate group and 8 of 24 neonates (33.3%) in the conventional group ($P = 0.791$). In-hospital mortality was 8.3% (2 of 24) and 12.5% (3 of 24), respectively ($P = 1.000$).

Post-discharge unplanned reintervention occurred in 1 of 24 neonates (4.2%) after immediate postnatal surgery and 5 of 24 neonates (20.8%) after conventional neonatal surgery ($P = 0.125$). Median follow-up was 16.0 months (interquartile range 10.8–22.5) in the immediate group and 29.0 months (interquartile range 16.8–33.0) in the conventional group ($P = 0.075$). Kaplan-Meier analysis showed numerically higher freedom from reintervention after immediate postnatal surgery, but the difference was not statistically significant (log-rank $P = 0.122$; Fig. 1). In the Cox model, immediate postnatal surgery was associated with a lower but non-significant hazard of reintervention (hazard ratio 0.22, 95% confidence interval 0.03–1.86; $P = 0.163$).

Discussion

In this propensity score-matched cohort of neonates with critical congenital heart disease, immediate postnatal cardiac surgery was not associated with worse perioperative outcomes than conventional neonatal surgery. Operative times, mechanical ventilation time, and intensive care unit stay were similar between groups. Postoperative adverse events and in-hospital mortality were also comparable. Post-discharge unplanned reintervention was less frequent after immediate surgery, but this difference was not statistically significant.

These findings are relevant for pediatric and neonatal care. Surgery within hours after birth may raise concerns about myocardial adaptation, renal and hepatic immaturity, coagulation, inflammatory response to cardiopulmonary bypass, and limited physiologic reserve. In this cohort, these concerns did not lead to longer ventilation, longer intensive care stay, or higher in-hospital mortality. This suggests that immediate surgery can be feasible when the neonate is selected carefully and when delivery, diagnosis confirmation, surgery, anesthesia, perfusion, and postoperative care are coordinated in one pathway.

The results should be interpreted in the context of contemporary neonatal cardiac care. Registry and multicenter studies show that outcomes after neonatal congenital heart surgery have improved, although risk remains high and varies by lesion and center [8–11]. Prenatal detection of critical congenital heart disease is still incomplete and differs across populations [5–7, 12]. Newborn screening and early postnatal evaluation can identify additional affected neonates and support timely referral [5–7]. When prenatal diagnosis is available, perinatal planning can reduce delays and may prevent deterioration before surgery [13–18]. The present study supports the view that surgical timing is not only an operative variable. It is also a marker of the surrounding care system.

A previous comparative study in newborns with critical congenital heart disease reported that different early management strategies may produce different clinical courses [4]. Our study adds two points. First, matching on diagnosis category, surgical complexity, prenatal diagnosis, and inborn status reduced important baseline differences. Second, post-discharge reintervention was analyzed as a time-to-event outcome. This is important because crude reintervention rates can be misleading when follow-up differs between groups.

The observed lower rate of reintervention after immediate surgery is plausible but not conclusive. Earlier correction may reduce exposure to hypoxemia, acidosis, abnormal ventricular loading, and preoperative organ injury. These factors may affect postoperative recovery and later procedures [19]. However, reintervention is also strongly related to anatomy and procedure-specific factors. In transposition of the great arteries, coronary anatomy and perioperative condition influence outcomes after the arterial switch operation [20–22]. In total anomalous pulmonary venous connection and right ventricular outflow tract obstruction, anatomic complexity and preoperative instability also affect postoperative course [23, 24]. Our sample was too small for lesion-specific analyses.

These results do not support immediate surgery for all neonates with critical congenital heart disease. Surgical timing should be individualized. Important factors include diagnosis, hemodynamic status, extracardiac disease, transport risk, institutional experience, and the availability of neonatal cardiac intensive care. These decisions require a structured perioperative pathway, including clear protocols for anesthesia, surgery, intensive care, and recovery [25]. A delayed strategy remains appropriate when the neonate needs stabilization, when extracardiac disease needs evaluation, or when transfer to a more experienced center is safer [26].

The main strength of this study is that the comparison was performed after propensity score matching and included both early clinical outcomes and post-discharge reintervention. The analysis also focused on a clinically important question in a setting where prenatal diagnosis and inborn delivery made immediate surgery possible.

This study also has limitations. First, it was retrospective and conducted at a single center. Residual confounding may remain despite matching. Second, the matched sample was small, which limited statistical power and produced wide confidence intervals. Third, the included diagnoses were heterogeneous, and lesion-specific subgroup analysis was not possible. Fourth, follow-up was shorter in the immediate group, which may have reduced the detection of later reinterventions. Fifth, neurodevelopmental outcomes, family-centered outcomes, and detailed preoperative physiologic markers such as oxygen saturation, lactate, prostaglandin use, ventilation status, and organ function were not available.

Future studies should use standardized timing definitions, including the exact interval from birth to skin incision. They should include larger multicenter cohorts, lesion-specific analyses, longer follow-up, neurodevelopmental assessment, and standardized adjudication of reintervention. These data would help separate the effect of early surgery from the effect of patient selection and institutional pathway quality.

Conclusions

In selected neonates with critical congenital heart disease, immediate postnatal cardiac surgery was feasible and was not associated with increased perioperative risk compared with conventional neonatal surgery. The lower observed rate of post-discharge unplanned reintervention is hypothesis-generating. Larger multicenter studies with longer follow-up are needed before immediate surgery can be recommended as a broad strategy.

Abbreviations

CCHD
critical congenital heart disease
CI
confidence interval

CPB
cardiopulmonary bypass
ICU
intensive care unit
IQR
interquartile range
PSM
propensity score matching
RACHS-1
Risk Adjustment for Congenital Heart Surgery-1
VIS
vasoactive-inotropic score

Declarations

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Beijing Anzhen Hospital, Capital Medical University. The requirement for informed consent was waived because of the retrospective study design.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available because they contain potentially identifiable patient information, but are available from the corresponding author on reasonable request and with institutional approval.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

WD contributed to study conception and design, data collection, statistical analysis, data interpretation, and drafting of the manuscript. QW and GL contributed to study conception, surgical management, supervision, data interpretation, and critical revision of the manuscript. HZ and ZS contributed to data

collection, clinical interpretation, and critical revision of the manuscript. All authors read and approved the final manuscript. QW and GL are the guarantors of the work.

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Authors' information

Not applicable.

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Figures

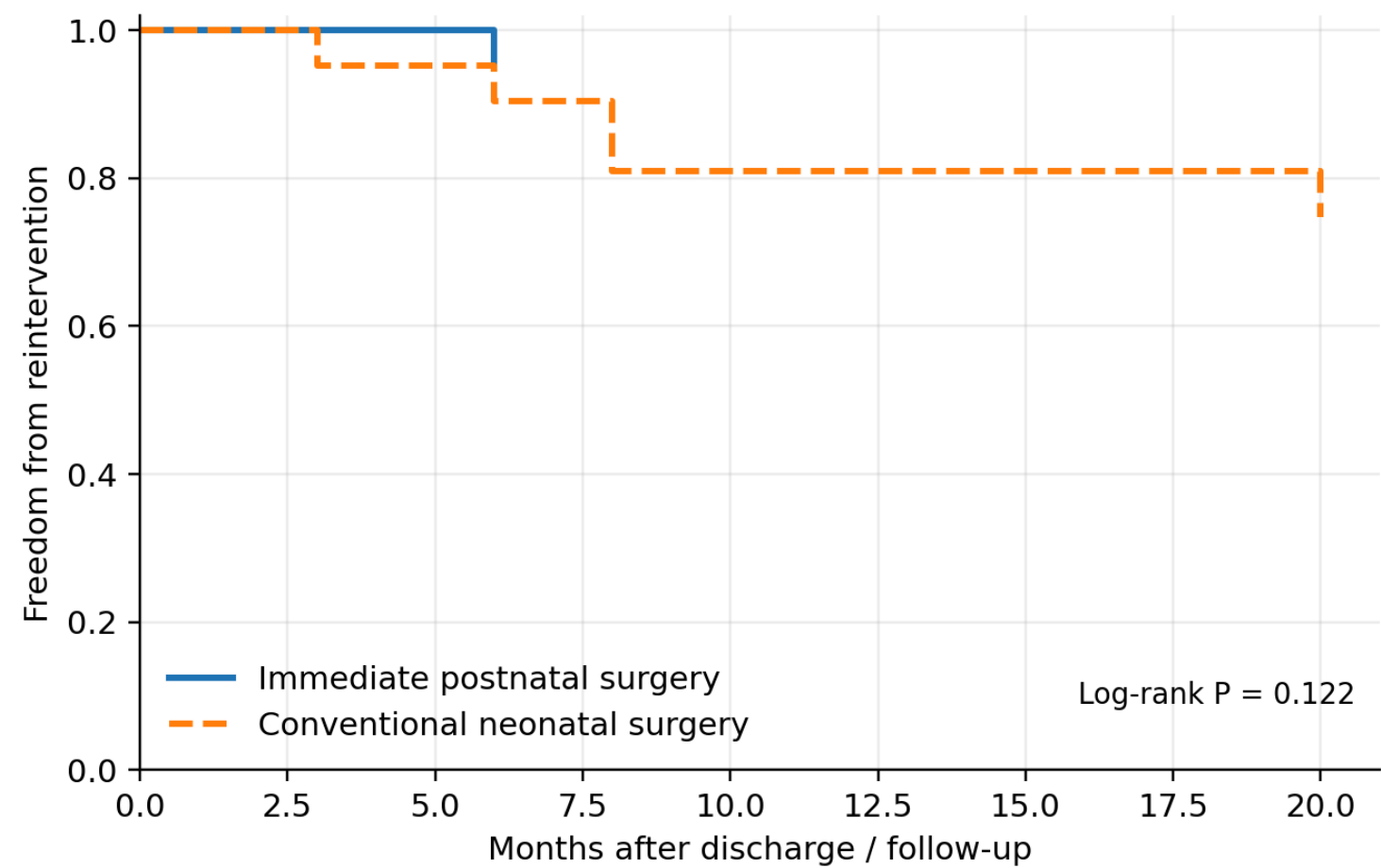


Figure 1

Freedom from unplanned reintervention

Kaplan-Meier analysis showed numerically higher freedom from post-discharge unplanned reintervention in the immediate postnatal surgery group than in the conventional neonatal surgery group, but the difference was not statistically significant (log-rank $P = 0.122$). In the Cox proportional hazards model, immediate postnatal surgery was associated with a lower but non-significant hazard of reintervention (hazard ratio 0.22, 95% confidence interval 0.03-1.86; $P = 0.163$).

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