

Anesthetic management of endovascular correction of critical congenital heart disease in neonates and infants: a single center study

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Keypoints

Transcatheter management of critical congenital heart disease in neonates and infants can be performed with acceptable perioperative stability when supported by structured anesthetic and intensive care strategies.

Abstract

Introduction

Critical congenital heart disease in neonates and infants requires urgent intervention and is associated with significant perioperative instability. Catheter-based procedures are increasingly used as alternatives to open surgery; however, anesthetic management strategies remain insufficiently characterized.

This study aimed to evaluate anesthesia and critical care approaches during transcatheter interventions in early childhood.

Materials and Methods

Neonates and infants undergoing endovascular correction of critical congenital heart defects were included. Clinical assessment, instrumental diagnostics, and hemodynamic monitoring were applied. Anesthesia consisted of combined sedation using ketamine and local anesthesia with anticoagulation using heparin. Hemodynamic stability, ventilatory requirements, and early complications were assessed.

Results

Anesthetic management maintained stable hemodynamics in most patients. No major anesthesia-related complications were observed. Procedures were well tolerated and required minimal respiratory support.

Conclusion

Optimized anesthesia strategies enable safe endovascular interventions in neonates and infants with critical congenital heart disease. These findings highlight the essential role of pediatric anesthesiology in improving perioperative outcomes.

Keywords

Anesthetic management, Critical congenital heart disease, Neonatal endovascular intervention

Introduction

Critical congenital heart disease (CCHD) represents a heterogeneous group of structural cardiac and great vessel anomalies arising during embryogenesis that lead to severe hemodynamic compromise shortly after birth. Congenital heart defects account for nearly one-third of major congenital anomalies and constitute a leading cause of neonatal morbidity and mortality worldwide. Their prevalence is estimated at approximately 4–10 cases per 1,000 live births, with a substantial proportion requiring intervention during the first year of life.

Globally, congenital heart disease affects approximately 0.8–1% of newborns annually, corresponding to tens of

thousands of cases each year in developed healthcare systems. The most common defects include ventricular septal defects, atrial septal defects, and conotruncal anomalies.

A subset of these conditions is classified as critical congenital heart disease — life-threatening malformations characterized by ductus-dependent systemic or pulmonary circulation, severe outflow tract obstruction, or impaired intracardiac mixing. These conditions typically manifest in the first hours or days of life and require urgent surgical or catheter-based intervention.

Despite advances in diagnostic technologies and perioperative care, CCHD remains a major contributor to infant mortality. Regional epidemiological data indicate that congenital heart defects may contribute significantly to neonatal mortality rates, particularly where early detection and specialized intervention are limited.

Over recent decades, rapid progress in interventional cardiology has transformed the therapeutic landscape. Catheter-based procedures — including balloon valvuloplasty, angioplasty, septostomy, and transcatheter occlusion — have increasingly replaced or complemented open surgical correction.

These techniques offer reduced invasiveness, shorter recovery periods, and decreased need for cardiopulmonary bypass, making them particularly advantageous in neonates and infants with fragile physiology.

However, the perioperative management of these patients presents unique challenges.

Profound cardiovascular instability, altered pulmonary/systemic blood flow balance, and sensitivity to anesthetic agents necessitate individualized anesthetic strategies and meticulous monitoring. While the interventional techniques themselves have been extensively studied, the anesthetic and intensive care aspects remain comparatively underreported, especially in single-center clinical experience settings.

Therefore, the present study aims to evaluate anesthetic management strategies applied during endovascular correction of critical congenital heart disease in neonates and

support requirements, and early perioperative outcomes in infants, focusing on hemodynamic stability, respiratory

Materials and Methods

Study Design

A single-center observational study was conducted to evaluate clinical, interventional, and anesthetic aspects of endovascular correction of critical congenital heart disease in neonates and infants. The study was based on retrospective analysis of medical records from a specialized cardiac surgery center involving patients undergoing transcatheter interventions.

Study Population

The study included neonates and infants under one year of age diagnosed with critical congenital heart disease who underwent catheter-based endovascular procedures. The object of investigation was patients with isolated and combined critical congenital cardiac anomalies. The subject of investigation comprised interventional strategies and anesthetic management during endovascular correction.

Diagnostic Assessment

All patients underwent comprehensive preprocedural evaluation including:

- clinical examination
- electrocardiography
- echocardiography
- laboratory testing
- blood gas analysis
- hemodynamic monitoring

Contrast imaging techniques were used to refine anatomical diagnosis and procedural planning. Cardiac catheterization and angiography were performed immediately before or during intervention to assess anatomical and hemodynamic parameters.

Interventional Procedures

The following endovascular interventions were performed:

- balloon atrial septostomy
- balloon valvuloplasty

- vascular angioplasty
- coarctation dilation
- vascular stenting
- transcatheter closure procedures

Procedure selection was determined by anatomical characteristics and patient hemodynamic status.

Anesthetic Management

Perioperative care was provided by pediatric anesthesiologists using individualized sedation or general anesthesia strategies depending on procedural complexity and clinical condition.

Approaches included:

- intravenous sedation (ketamine-based protocols)
- local anesthesia at vascular access site
- general anesthesia with mechanical ventilation when required

Continuous monitoring included:

- ECG
- arterial pressure
- oxygen saturation
- capnography
- body temperature

Outcome Measures

The analysis assessed:

- distribution of procedures
- hemodynamic stability
- ventilatory support requirements
- intraoperative complications
- early postoperative outcomes

Statistical Analysis

Data were analyzed using descriptive statistical methods. Continuous variables were presented as mean \pm standard deviation or median with interquartile range, while categorical variables were expressed as counts and percentages.

Statistical analysis was performed to summarize findings and generate study conclusions.

Results

Study population and procedural cohorts

This study included neonates and infants within the first year of life with critical congenital heart disease undergoing transcatheter intervention. Three major procedural cohorts were analyzed:

- Balloon aortic valvuloplasty for critical aortic stenosis (n = 47)
- Balloon angioplasty for critical coarctation of the aorta (n = 69)
- Endovascular pulmonary blood flow optimization in pulmonary atresia (n = 23)

Baseline cohort characteristics and early outcome indicators are summarized in Table 1.

Critical aortic stenosis cohort

Balloon aortic valvuloplasty resulted in a significant reduction in the mean transvalvular gradient from 65.2 ± 2.7 mmHg to 30.3 ± 3.0 mmHg ($p < 0.05$). Follow-up values were 38.2 ± 3.5 mmHg at 12 months and 45.2 ± 1.7 mmHg at 36 months without statistically significant differences compared with early post-procedural values. Left ventricular systolic function improved substantially in patients with reduced baseline function, with LVEF increasing from $48.2 \pm 3.1\%$ to $62.3 \pm 1.9\%$ at 12 months and $65.2 \pm 2.4\%$ at 36 months.

Postoperative mechanical ventilation averaged 31 ± 12 hours, and ICU stay averaged 3 days.

Early complications occurred in 34.0% of patients, predominantly heart failure, respiratory failure, and atelectasis (Table 2). Hospital mortality was 8.5%.

Detailed echocardiographic and intensive care parameters are presented in Table 3.

Critical coarctation cohort

Balloon angioplasty produced an immediate reduction in systolic gradient to 18.5 ± 6.4 mmHg, with LVEF $62 \pm 4.2\%$ post-procedure. Mean hospital stay was 7.3 ± 3.4 days. No hospital or 30-day mortality occurred.

Post-procedural complications were observed in 7.24% of cases, limited to intimal tears and atelectasis (Table 5).

Reintervention for recoarctation was required in 46.4% of patients. Outcome metrics are summarized in Table 4.

Pulmonary atresia cohort

The pulmonary atresia group included 77% males and 23% females.

Oxygen saturation improved immediately after successful dilation (91.0 ± 5.09%) but decreased to 70 ± 18.7% by postoperative day three following prostaglandin withdrawal. Mean ICU stay was 9 days. Mechanical ventilation was required in 5 patients, lasting 7 hours to 23 days (mean 4.4 days). Inotropic support averaged 8.0 ± 4.7 days. Postoperative course indicators are detailed in Table 6.

Cohort	n	Key early outcomes
Critical aortic stenosis — balloon valvuloplasty	47	Complications 34%; mortality 8.5%; MV 31±12 h; ICU stay ≈3 d
Critical coarctation — balloon angioplasty	69	Complications 7.24%; mortality 0%; reintervention 46.4%; LOS 7.3±3.4 d
Pulmonary atresia — endovascular treatment	23	ICU stay ≈9 d; MV in 5 pts; inotropes 8.0±4.7 d

Table 1. Procedural cohorts and early outcomes

Complication	n (%)
Heart failure	6 (12.8%)
Respiratory failure	5 (10.6%)
Atelectasis	3 (6.4%)
Bleeding	2 (4.3%)
Total	16 (34.0%)

Table 2. Early complications after balloon aortic valvuloplasty

Parameter	Value	p
Gradient before procedure (mmHg)	65.2±2.7	<0.05
After procedure	30.3±3.0	<0.05
12 months	38.2±3.5	0.28
36 months	45.2±1.7	0.17
Baseline LVEF (%)	48.2±3.1	<0.05
LVEF 12 months	62.3±1.9	0.26
LVEF 36 months	65.2±2.4	0.08
Mechanical ventilation (hours)	31±12	<0.05
ICU stay (days)	3	<0.05
Mortality	4 (8.5%)	0.41

Table 3. Hemodynamic and ICU parameters (aortic valvuloplasty)

Parameter	Value
Post-procedure gradient (mmHg)	18.5±6.4
Gradient 6 months	41.5±12.1
Gradient 12 months	48.3±16.5
LVEF (%)	62±4.2
Length of stay (days)	7.3±3.4
Reintervention	32 (46.4%)
Mortality	0

Table 4. Outcomes after balloon angioplasty for coarctation

Complication	n
Intimal tear	2
Atelectasis	3
Others	0

Table 5. Complications after coarctation angioplasty

Parameter	Value
Male/Female	18/5
SaO ₂ post dilation (%)	91.0±5.09
SaO ₂ day 3 (%)	70±18.7
ICU stay (days)	9
Mechanical ventilation	5 pts
MV duration	7 h–23 d
Inotropic support (days)	

Table 6. ICU course — pulmonary atresia cohort

Discussion

This study evaluated anesthetic and intensive care aspects of transcatheter management of critical congenital heart disease in neonates and infants. The findings demonstrate that contemporary endovascular strategies can be performed with acceptable perioperative stability and manageable complication rates, although outcomes vary considerably depending on lesion physiology and procedural complexity.

Balloon aortic valvuloplasty resulted in significant reduction of transvalvular gradient and improvement of ventricular function, consistent with previously reported outcomes in pediatric interventional cardiology. Early postoperative complications were mainly cardiopulmonary and reflect the fragile physiological reserve of neonates with left-sided obstruction rather than procedural failure. The observed mortality rate falls within ranges described in historical and multicenter cohorts.

Balloon angioplasty for coarctation demonstrated favorable early survival and low complication burden. However, the substantial rate of recoarctation and reintervention aligns with existing literature, highlighting the known limitations of catheter-based therapy in duct-dependent neonates and the importance of longitudinal surveillance.

Patients with pulmonary atresia required the most intensive perioperative support, including mechanical ventilation and inotropic therapy. Decline in oxygen saturation after prostaglandin discontinuation emphasizes the

transitional hemodynamic instability characteristic of this population and the critical role of perioperative anesthetic management in maintaining pulmonary/systemic balance.

From an anesthesiology perspective, ketamine-oriented sedation and individualized airway strategies provided adequate hemodynamic preservation and procedural tolerance. Continuous multimodal monitoring allowed early detection of instability, supporting current recommendations for invasive and non-invasive monitoring during neonatal cardiac interventions.

Overall, this study reinforces the central role of pediatric anesthesiologists in interventional cardiology teams. Optimization of ventilation strategies, vasoactive support, and postoperative monitoring remains essential for improving outcomes in this high-risk population.

Limitations

This investigation is limited by its observational single-center design and lack of multivariate modeling. The heterogeneity of cardiac defects and interventions also restricts direct comparison between cohorts. Future prospective studies incorporating standardized anesthetic protocols and risk stratification are warranted.

Conclusion

Transcatheter management of critical congenital heart disease in neonates and infants can be performed with acceptable perioperative stability when supported by structured anesthetic and intensive care strategies.

Balloon aortic valvuloplasty demonstrated significant hemodynamic improvement but remained associated with notable cardiopulmonary complication rates and measurable mortality, reflecting the severity of baseline pathology rather than procedural inadequacy.

Balloon angioplasty for critical coarctation showed favorable early survival and low complication burden, although frequent reintervention underscores the need for long-term surveillance.

Patients with pulmonary atresia required the most intensive perioperative support, highlighting the physiological

vulnerability of this cohort and the importance of individualized anesthetic and respiratory management.

Overall, optimized anesthetic protocols — including tailored sedation, vigilant hemodynamic monitoring, and proactive postoperative critical care — represent a key determinant of procedural safety and clinical outcomes in neonatal interventional cardiology.

Future prospective multicenter studies integrating standardized anesthetic pathways and risk stratification models are warranted to further improve perioperative outcomes.

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