



REVIEW ARTICLE

Sedation vs. General Anesthesia: Anesthetic Management for Pediatric Patients Undergoing Cardiac Catheterization, A Focus on Single Ventricle Physiology

Wenyu Bai, MD*

Department of Anesthesiology, University of Michigan Medical School

*Corresponding author: Wenyu Bai, Department of Anesthesiology, University of Michigan Medical School, 1500 E. Medical Center, Dr. Ann Arbor, Michigan 48109, USA, Tel: 1 (734) 7632430



Abstract

Pediatric anesthesia providers in pediatric and congenital cardiac catheterization laboratories face an evolving and complex field. Their responsibilities are complicated by variability in patient demographics, including premature infants to adults and a range of clinical conditions from simple cardiac lesions to complex single ventricle physiology. Procedures can vary significantly from straightforward diagnostic measurements of stable patients to high-risk interventional procedures involving unstable hemodynamics. Single ventricle physiology has been identified as an independent risk factor for increased adverse events during catheterization. Current practices for sedation and anesthesia in pediatric congenital cardiac catheterization laboratories vary widely among institutions. General anesthesia (GA) with controlled ventilation is commonly used. However, growing evidence suggests that sedation with spontaneous respiration may be suitable for low-risk patients undergoing low-to moderate-risk procedures, including younger children.

In this review, we focus on the pathophysiology of Hypoplastic Left Heart Syndrome (HLHS) and anesthetic management strategies in pediatric patients undergoing cardiac catheterization. The current risk stratification protocols specific to congenital cardiac catheterization, focusing on children with HLHS, are also discussed. Additionally, we outline our institution's multidisciplinary approach to the perioperative management of HLHS patients using a case study of a 2-year-old patient undergoing pre-Fontan catheterization. In conclusion, we emphasize the need to tailor anesthetic management in pediatric catheterization laboratories based on patient characteristics, cardiac lesions, and procedural risks. Effective risk stratification and a comprehensive multidisciplinary team approach are essential for informed management decisions and optimizing patient outcomes.

Keywords

General anesthesia, Pediatric cardiac catheterization, Sedation, Single ventricle physiology

Abbreviations

AE: Adverse event; GA: General Anesthesia; HLHS: Hypoplastic Left Heart Syndrome; RV: Right Ventricle; TIVA: Total Intravenous Anesthesia

Introduction

Pediatric anesthesia providers in the pediatric and congenital cardiac catheterization laboratory face an evolving and complex field. Their responsibilities are complicated by the variability in patient demographics, ranging from premature infants to adults, and conditions from simple lesions to complex single ventricle physiology. Procedures can vary significantly, from straightforward diagnostic measurements on stable patients to high-risk interventional procedures involving unstable hemodynamics. Children with single-ventricle physiology frequently require cardiac catheterization for diagnostic assessment or interventional procedures aimed at facilitating staged palliation surgeries or enhancing clinical outcomes post-surgery. The findings from the IMPACT (Improving Paediatric and Adult Congenital Treatment) Registry revealed that among patients undergoing cardiac catheterization for congenital heart disease, 10.0% of diagnostic catheterizations and 11.1% of interventional catheterizations were associated with adverse

events. Furthermore, single ventricle physiology was identified as independent risk factor contributing to a heightened incidence of adverse events during the catheterization process [1]. Current practices for sedation and anesthesia in pediatric congenital cardiac catheterization laboratories vary widely among institutions. There remains a lack of consensus on the optimal anesthetic management for pediatric patients with single ventricle physiology undergoing cardiac catheterization. GA with controlled ventilation is commonly used, including children with HLHS for diagnostic assessments. However, there is growing evidence that sedation with spontaneous respiration may be suitable for low-risk patients undergoing low- to moderate-risk procedures, including younger children. This review aims to critically evaluate the comparative efficacy and safety of sedation versus GA in pediatric patients with single ventricle physiology undergoing cardiac catheterization.

Reference Case

A 2-year-old male, weighing 10.2 kg, diagnosed with HLHS underwent balloon atrial septostomy and Norwood procedure with a 5 mm right ventricle-to-pulmonary artery conduit (Sano shunt) placed at birth. At 6 months of age, the patient underwent pre-bidirectional cavopulmonary anastomosis (hemi-Fontan) with central pulmonary augmentation. The patient is currently active, with baseline oxygen saturation (SpO₂) of 78%, and has been referred for pre-Fontan hemodynamic assessment.

Recent electrocardiogram (ECG) findings indicated a normal sinus rhythm with a ventricular rate of 97 beats per minute.

Echocardiographic evaluation revealed the following findings:

1. Unobstructed hemi-Fontan pathway with no evidence of a baffle leak.
2. Normal-sized pulmonary arteries exhibiting unobstructed antegrade flow.
3. Unrestrictive flow across the atrial septum.
4. Absence of right ventricle (RV) dilation, moderate RV hypertrophy, qualitatively normal RV systolic function, and trivial tricuspid valve regurgitation were noted.
5. The neo-aorta demonstrated no significant obstruction, with a peak-corrected gradient of 11 mm Hg across the arch.

Physiology of HLHS and Staged Palliative Surgeries

HLHS involves severe hypoplasia or atresia of the left ventricle, mitral valve, aortic valve, and ascending aorta. This condition results in the right ventricle supporting

both systemic and pulmonary circulations in parallel rather than in series [2]. The pathophysiology of HLHS relies on the right ventricle to maintain both pulmonary and systemic circulation, often through the patent ductus arteriosus. Without early intervention, HLHS can be fatal. The standard treatment approach consists of a series of staged palliative surgeries designed to reconfigure the circulatory system.

Stage I (Norwood Procedure): The initial surgery reconstructs the aorta and connects it to the right ventricle, establishing an unobstructed systemic blood flow. It also creates a shunt (modified Blalock-Taussig or Sano shunt) to provide controlled pulmonary blood flow [3]. An atrial septectomy is performed to ensure unrestricted mixing of blood at the atrial level. The second stage, pre-bidirectional cavopulmonary anastomosis, either the Glenn procedure or hemi-Fontan procedure, usually occurs between 3 and 6 months of age. This involves connecting the superior vena cava to the pulmonary arteries, thereby reducing the volume load on the right ventricle. The final stage, Fontan procedure, connects the inferior vena cava to the pulmonary circulation, completing the separation of systemic and pulmonary circulation and further reducing the workload on the right ventricle [4]. Patients diagnosed with HLHS who are scheduled to undergo either the Glenn procedure or the Fontan operation often requires preoperative diagnostic and/or interventional catheterization. This assessment is critical for evaluating the anatomical and hemodynamic parameters, thereby facilitating the successful execution of surgical interventions. Given the complex physiology of HLHS, a thorough risk assessment is imperative before contemplating an anesthetic approach.

Risk Assessment in Pediatric Congenital Cardiac Catheterization Laboratory

A 2008 multicenter study published in *Congenital Heart Disease* characterized the frequency, severity, and attributability of adverse events (AE) in congenital cardiac catheterization procedures [5] (Table 1). Key findings indicated that the incidence of AEs was significantly higher in the interventional cases (20%) than in the diagnostic cases (10%). Similarly, higher severity AEs (level 3-5) were more common in interventional procedures (9%) than in diagnostic procedures (5%). This study highlighted the importance of standardized data collection and risk assessment in improving the safety and outcomes of patients with congenital heart disease undergoing cardiac catheterization.

Since that time, several risk adjustment and stratification tools have been developed, including the Catheterization Risk Score for Pediatrics (CRISP), the Congenital Heart Disease Adjustment for Risk Method II (CHARM II), and various models derived from the IMPACT Registry [6-9]. These tools integrate

Table 1: Definitions for adverse event severity.

Severity Level	Definition	Examples
1. None	No harm, no change in condition, may have required monitoring to assess for potential change in condition with no intervention indicated.	Balloon rupture Equipment problem
2. Minor	Transient change in condition, not life-threatening, condition returns to baseline, required monitoring, required minor intervention such as holding a medication, or obtaining laboratory test.	Groin hematoma Self-resolving arrhythmia
3. Moderate	Transient change in condition may be life-threatening if not treated, condition returns to baseline, required monitoring, required intervention such as reversal agent, additional medication, transfer to the intensive care unit for monitoring, or moderate transcatheter intervention to correct condition.	Unstable arrhythmia with preserved blood pressure requiring intervention Vascular damage not life-threatening but requiring intervention
4. Major	Change in condition, life-threatening if not treated, change in condition may be permanent, may have required an intensive care unit admission or emergent readmit to hospital, may have required invasive monitoring, required interventions such as electrical cardioversion or unanticipated intubation or required major invasive procedures or transcatheter interventions to correct condition.	Event requiring cardiopulmonary resuscitation Event leading to surgery or repeat catheterization Stroke
5. Catastrophic	Any death, and emergent surgery or heart lung bypass support (ECMO) to prevent death with failure to wean from bypass support.	Event resulting in death

Table defining adverse event severity in pediatric cardiac catheterization as described by Bergesen, et al. [5].

variables such as patient characteristics, hemodynamic vulnerability, and procedural complexity to predict the likelihood of serious adverse events (SAEs) or major complications. Specific patient characteristics—including younger age (particularly under 1 year, and especially under 30 days), low body weight (less than 4 kg), renal insufficiency, single-ventricle physiology, low systemic and mixed venous oxygen saturation, elevated pulmonary arterial pressure, and overall hemodynamic instability requiring continuous pressor or inotrope support—are consistently recognized as risk factors for AEs. Additionally, high-risk procedures and increased technical complexity are correlated with an elevated risk of life-threatening events.

Children with single ventricle physiology experience considerable hemodynamic vulnerability due to their distinct circulatory challenges, particularly during infancy and in the context of surgical interventions. The elevated ventricular end-diastolic pressures and reduced oxygen saturation associated with this condition render single-ventricle physiology a significant independent risk factor for major adverse events (MAEs) during cardiac catheterization in pediatric patients. The overall incidence of major adverse events in a large registry of congenital cardiac catheterization ranges from 1.9% to 7.1%; however, this rate is markedly elevated in individuals with single ventricle physiology and concomitant hemodynamic vulnerabilities [10]. Moreover, single ventricle physiology is recognized as a major independent risk factor for adverse events during catheterization, alongside other factors such as young age, renal insufficiency, low oxygen saturation, elevated ventricular pressures, and complex procedures [6,9]. A large multicenter study focusing exclusively on patients with single ventricle physiology undergoing elective cardiac catheterization reported an overall adverse event rate of 14.4%, with specific rates of 20% for pre-

bidirectional cavopulmonary anastomosis, 11% for pre-Fontan, and 14% for post-Fontan catheterizations [11]. Accurate risk assessment in this patient population is essential for enhancing outcomes, informing clinical decision-making, and identifying individuals who may benefit from alternative diagnostic strategies or more intensive postprocedural monitoring.

Anesthetic Management in Pediatric Cardiac Catheterization: A Comparison of Sedation and General Anesthesia, Focusing On Children with Single Ventricle Physiology

Anesthetic management in pediatric cardiac catheterization is an integral part of the process and significantly affects the quality of the procedure, patient safety, and comfort. Sedation and GA are employed in cardiac catheterization procedures for infants with congenital heart disease, including those with single-ventricle physiology; however, the safety profiles and effects on patient outcomes remain subjects of ongoing debate. Expert consensus has indicated that no specific ventilation strategy, whether spontaneous or assisted, is universally preferred within the cardiac catheterization laboratory. Nonetheless, it is imperative to consider the influence of anesthetic agents and ventilation strategies on hemodynamic parameters during the case planning process [12].

Spontaneous ventilation maintains a more natural intrathoracic physiology and can result in the acquisition of more accurate hemodynamic data. However, oversedation can cause airway obstruction, hypoventilation and subsequent respiratory acidosis [13]. This increases pulmonary vascular resistance, may alter shunt physiology, and affect hemodynamic measurements. GA using an endotracheal tube and positive pressure ventilation provides a secure airway

and control of PaCO₂, but increased intrathoracic pressure may cause IVC compression, reducing venous return and preload, and subsequently, cardiac output. These reductions are particularly pronounced in patients with right heart failure, hypovolemia, or Fontan physiology [12].

A multicenter analysis involving over 13,000 prospectively collected cases of congenital cardiac catheterization demonstrated significant institutional variation in the preference for controlled versus spontaneous ventilation. Notably, 31% of the procedures were performed using a natural airway with spontaneous respiration [14]. In this cohort, the incidence of serious sedation- and anesthesia-related adverse events was 0.69%, with hypotension identified as the most common adverse event. Airway and ventilation-related complications included post-extubation hypoxia, hypoventilation, and other airway issues, such as unplanned extubation and right mainstem bronchus intubation. AEs were more prevalent among smaller patients, those with non-cardiac comorbidities, and that exhibiting low mixed venous oxygen saturation. Additionally, patients managed with spontaneous ventilation presented with lower rates of adverse events than those managed with controlled airways. In this group, a 1.8% incidence of conversion to a controlled airway via intubation was observed, correlating with a more than tenfold increase in the incidence of all high-severity adverse events during catheterization. Young age, high-risk procedures, and continuous pressor/inotrope requirements were independently associated with conversion to controlled airway management.

Furthermore, in a comparable multicenter study concentrating exclusively on patients with single ventricle physiology undergoing elective cardiac catheterization, it was observed that only 20% or fewer were managed with spontaneous ventilation. The mode of airway management was associated with statistically significant, albeit clinically minor, differences in hemodynamic measures in both the pre- and post-Fontan cohorts [11].

Sedation in pediatric catheterization laboratories is underutilized, even among low-risk patients. Various pharmacological agents are available for achieving deep sedation in pediatric patients undergoing cardiac catheterization. Propofol is characterized by its rapid onset and short duration of action, rendering it suitable for brief procedures. Midazolam induces anxiolysis and amnesia and is frequently used as a premedication or in conjunction with other agents. Dexmedetomidine offers sedation without significant respiratory depression, which is advantageous for procedures requiring preserved respiratory function. Ketamine induces dissociative anesthesia and analgesia while maintaining airway reflexes. The combination of various agents, such as dexmedetomidine with

midazolam and ketamine, or propofol with ketamine, may yield potential synergistic effects, thereby reducing the necessary doses and minimizing side effects while ensuring adequate sedation depth and hemodynamic stability. The selection of medications for sedation is contingent upon institutional preferences, specific procedures, patient characteristics, and desired level of sedation.

A growing body of evidence indicates that sedation can be used for low-risk patients, including younger children, undergoing low-risk procedures in the catheterization laboratory. Two recent single-center retrospective studies on children with congenital heart disease undergoing cardiac catheterization showed favorable outcomes regarding sedation in specific pediatric age groups. One study, focusing on adverse events during catheterization for children under two years of age and using a propensity score-adjusted model, found that sedation (with propofol and ketamine) did not increase AEs and reduced the need for hemodynamic support compared to GA. However, 4% of subjects required conversion to intubation, primarily due to apnea, pulmonary arterial hypertension crises, or rhythm disturbances [15]. A comparative study examined procedural outcomes in pediatric cardiac catheterization among children aged 1-12 years undergoing low-risk procedures with GA using controlled airways versus total intravenous anesthesia (TIVA) with natural airways. The study aimed to assess differences in procedural efficiency, safety, and physiological effects between the two anesthetic techniques. Findings showed that TIVA was linked to a significantly shorter total patient time in the catheterization laboratory, averaging a 25-minute reduction compared to GA, without increasing procedure duration, hospital stay, or complication rates. Safety assessments indicated no significant differences in major adverse events, hospital length of stay, or procedural complexity between TIVA and GA, suggesting TIVA is as safe as traditional methods for low-risk cases [16].

Anesthetic Management for Reference Case in Author's Institution

A multidisciplinary discussion involving a pediatric cardiac interventionalist, nursing staff and anesthesiologists was conducted in the morning. Following a comprehensive review of the patient's condition and procedural requirements during the multidisciplinary discussion, it was decided that sedation with spontaneous ventilation would be the appropriate anesthetic plan for scheduled low- to moderate-risk procedures. The patient received pre-medication with oral midazolam (0.5 mg/kg), which effectively provided anxiolysis during separation from family members. Standard ASA monitors were used upon patient arrival at the laboratory.

Brief inhalational induction was performed using sevoflurane with mask ventilation, followed by successful placement of a peripheral intravenous catheter. The patient received a bolus of 5-10 cc/kg of Lactated Ringer's solution, and a dexmedetomidine infusion was initiated at 1 mcg/kg over 10 min, followed by a continuous infusion at 1 mcg/kg/h. A ketamine bolus 0.5-1 mg/kg was also administered before vascular access. A nasal cannula with carbon dioxide monitoring was placed for respiratory assessment, and buffered lidocaine was infiltrated into the right femoral and left internal jugular sites before getting vascular access.

An arterial blood gas sample from the descending aorta indicated a pH of 7.38, PaCO₂ of 35 mmHg, PaO₂ of 54 mmHg, HCO₃ of 21 mmol/L, and a lactate level of 0.7 mmol/L on room air.

Hemodynamic measurements were performed during the procedure. Additional sedation was provided with 0.1 mg/kg of midazolam and 0.5 mg/kg of ketamine, during which a coil device was placed to embolize the veno-venous collateral. The patient tolerated the procedure well and was transported to the PACU in a lightly sedated state.

Conclusion

Understanding patient anatomy and physiology, the objectives of the catheterization procedure and the associated risks are crucial for successful outcomes. Knowledge of the unique physiology of HLHS, along with advancements in surgical and catheterization techniques, and perioperative care, has improved patient outcomes. However, challenges persist, particularly in high-risk patients. In the catheterization laboratory, careful planning along with vigilant monitoring is essential to maximize the benefits and minimize the risks of general anesthesia and sedation. In conclusion, we underscore the necessity of customizing anesthetic management in pediatric catheterization laboratories according to individual patient characteristics, specific cardiac lesions, and procedural risks. Effective risk stratification and a comprehensive multidisciplinary team approach are vital for informed management decisions and optimization of patient outcomes.

Source of Support

N/A.

References

- Vincent RN, Moore J, Beekman RH, Benson L, Bergersen L, et al. (2016) Procedural characteristics and adverse events in diagnostic and interventional catheterisations in paediatric and adult CHD: Initial report from the IMPACT Registry. *Cardiol Young* 26: 70-78.
- Norwood WI, Kirklin JK, Sanders SP (1980) Hypoplastic left heart syndrome: Experience with palliative surgery. *Am J Cardiol* 45: 87-91.
- Pigott JD, Murphy JD, Barber G, Norwood WI (1988) Palliative reconstructive surgery for hypoplastic left heart syndrome. *Ann Thorac Surg* 45: 122-128.
- Ohye RG, Schranz D, D'Udekem Y (2016) Current therapy for hypoplastic left heart syndrome and related single ventricle lesions. *Circulation* 134: 1265-1279.
- Bergersen L, Gauvreau K, Jenkins KJ, Lock JE (2008) Adverse event rates in congenital cardiac catheterization: A new understanding of risks. *Congenit Heart Dis* 3: 90-105.
- Quinn BP, Gunnerson LC, Kotin SG, Gauvreau K, Yeh MJ, et al. (2024) Catheterization for congenital heart disease adjustment for risk method II. *Circ Cardiovasc Interv* 17: e012834.
- Bergersen L, Gauvreau K, Marshall A, Kreutzer J, Beekman R, et al. (2011) Procedure-type risk categories for pediatric and congenital cardiac catheterization. *Circ Cardiovasc Interv* 4: 188-194.
- Lin CH, Hegde S, Marshall AC, Porras D, Gauvreau K, et al. (2014) Incidence and management of life-threatening adverse events during cardiac catheterization for congenital heart disease. *Pediatr Cardiol* 35: 140-148.
- Jayaram N, Beekman RH 3rd, Benson L, Holzer R, Jenkins K, et al. (2015) Adjusting for risk associated with pediatric and congenital cardiac catheterization: A report from the NCDR IMPACT Registry. *Circulation* 132: 1863-1870.
- Jayaram N, Spertus JA, Kennedy KF, Vincent R, Martin GR, et al. (2017) Modeling major adverse outcomes of pediatric and adult patients with congenital heart disease undergoing cardiac catheterization: Observations from the NCDR IMPACT Registry (National Cardiovascular Data Registry Improving Pediatric and Adult Congenital Treatment). *Circulation* 136: 2009-2019.
- Goldstein BH, Holzer RJ, Trucco SM, Porras D, Murphy J, et al. (2016) Practice variation in single-ventricle patients undergoing elective cardiac catheterization: A report from the congenital cardiac catheterization project on outcomes (C3PO). *Congenit Heart Dis* 11: 122-135.
- Odegard KC, Vincent R, Bajjal RG, Daves SM, Gray RG, et al. (2016) SCAI/CCAS/SPA expert consensus statement for anesthesia and sedation practice: Recommendations for patients undergoing diagnostic and therapeutic procedures in the pediatric and congenital cardiac catheterization laboratory. *Anesth Analg* 123: 1201-1209.
- Friesen RH, Alswang M (1996) Changes in carbon dioxide tension and oxygen saturation during deep sedation for paediatric cardiac catheterization. *Paediatr Anaesth* 6: 15-20.
- Lin CH, Desai S, Nicolas R, Gauvreau K, Foerster S, et al. (2015) Sedation and anesthesia in pediatric and congenital cardiac catheterization: A prospective multicenter experience. *Pediatr Cardiol* 36: 1363-1375.
- Mikus M, Welchowski T, Schindler E, Schneider M, Mini N, et al. (2021) Sedation versus general anesthesia for cardiac catheterization in infants: A retrospective, monocentric, cohort evaluation. *J Clin Med* 10: 5648.
- Fashina OA, Vogel ER, Swan EA, Anderson JH, Aganga DO, et al. (2025) General endotracheal anesthesia vs total intravenous anesthesia for children undergoing low-risk cardiac catheterization. *Pediatr Cardiol*.