Anesthesia for the patient with congenital heart disease presenting for noncardiac surgery

Erin A. Gottlieb[a] *and Dean B. Andropoulos*[a]

Purpose of review
To summarize recent publications emphasizing the changes in the population of patients with congenital heart disease and trends in the anesthetic and perioperative care of these patients presenting for noncardiac procedures.

Recent findings
It has been reported that children with congenital heart disease presenting for noncardiac surgery are at an increased anesthetic risk. This risk has become better defined. The patients at highest risk are infants with a functional single ventricle and patients with suprasystemic pulmonary hypertension, left ventricular outflow tract obstruction or dilated cardiomyopathy. Familiarity with the physiology and perioperative implications of the stages of single ventricle palliation is critical. The anesthetic approach, monitoring, conduct of surgery and postoperative care and outcomes are variable in this patient population. Recent literature reflects the growing number of children with ventricular assist devices and the management of these patients for noncardiac procedures. Cardiac imaging modalities provide diagnostic information, and strategies for reducing anesthetic risk for these procedures are of great interest. Pharmacologic trends and the application of technology are reviewed.

Summary
The identification of high-risk patients, multidisciplinary decision-making and planning and careful anesthetic management and monitoring are critical for optimizing outcomes in children with congenital heart disease presenting for noncardiac procedures.

Keywords
anesthesia, congenital heart disease, noncardiac surgery, pediatric

INTRODUCTION

The incidence of congenital heart disease (CHD) in the USA is commonly reported to be approximately 8 per 1000 live births. This includes simple and complex defects. With access to surgical and medical treatment, the population of children and adults with CHD is growing between 1 and 5% per year [1]. This growing group requires multiple noncardiac procedures and associated anesthetic care, and multiple studies have shown that this group has an increased risk of anesthetic complications [2,3▪,4,5▪▪]. Previous reviews of patients with CHD presenting for noncardiac surgery have focused on anesthetic technique, pharmacologic agents and monitoring [6,7▪].

A review of the current literature reveals interesting new trends. Arguably, the most important preliminary step in caring for these patients is the recognition of which patients are at a high risk for procedure-related morbidity and mortality. This aids in the development of a multidisciplinary plan for perioperative management to optimize patient care and outcome. In addition, the anesthesiology care team should have a thorough understanding of the anatomy, physiology and anticipated perianesthetic concerns associated with congenital heart lesions, including each stage of single ventricle palliation and staged approaches for two ventricle lesions. There are reports of varying outcomes from different centres using differing anesthetic and surgical techniques. It is apparent that institutional

[a]Division of Pediatric Cardiovascular Anesthesiology, Texas Children's Hospital, Baylor College of Medicine, Houston, Texas, USA

Correspondence to Erin A. Gottlieb, MD, Division of Pediatric Cardiovascular Anesthesiology, Baylor College of Medicine, Texas Children's Hospital, 6621 Fannin Street, WT 17-417B, Houston, TX 77030, USA. Tel: +1 832 826 1919; e-mail: eagottli@texaschildrens.org

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KEY POINTS

- The highest risk groups for anesthetic complications are infants with a functional single ventricle, patients with suprasystemic pulmonary hypertension, patients with left ventricular outflow tract obstruction and those with dilated cardiomyopathy.
- The recognition of high-risk patients, multidisciplinary decision-making and the understanding of the anatomy and physiology of congenital heart disease are critical for optimizing outcomes in this patient population.
- Current practice should be reviewed at intervals to allow changes in institutional practice that may improve outcomes in the population of pediatric patients undergoing noncardiac procedures.

examination of current practice can lead to evolution in perioperative care and improvement in outcome.

This review also emphasizes the anesthetic management of a new population of patients requiring anesthesia for noncardiac procedures, children with ventricular assist devices. Imaging procedures for CHD are being increasingly utilized for diagnosis and surgical planning. The risk of these procedures is almost entirely anesthetic, and ways in which risk can be minimized are of utmost importance. Pharmacologic trends are also reviewed, most notably the multiple uses of dexmedetomidine in this population.

DEFINING RISK

The preliminary step in providing well tolerated anesthetic care to any patient is the determination of which patients are at an increased risk. Data from the Pediatric Perioperative Cardiac Arrest (POCA) Registry have been very useful in this regard. In this report, 34% of the 373 cases of anesthesia-related cardiac arrest were in pediatric patients with CHD. The most common lesions in patients with cardiac arrest were single ventricle, left-to-right shunt, left ventricular outflow tract obstruction and cardiomyopathy. Of the 24 patients with single ventricle lesions suffering cardiac arrest, 17 patients were pre-superior cavopulmonary anastomosis (pre-SCPA, pre-Glenn), two patients were post-SCPA and five patients were post-total cavopulmonary anastomosis (post-TCPA, post-Fontan). The lowest mortality rate in patients with CHD after anesthesia-related cardiac arrest was in those with a left-to-right shunt. It is important to note that 75% of the cardiac arrests were in younger patients, those less than 2 years old [2].

van der Griend *et al.* [3▪] examined postoperative mortality in children to help determine which patients are at a higher anesthetic risk. This information helps provide a realistic risk/benefit analysis, and unnecessary elective procedures may be abandoned due to unwarranted risk. Multidisciplinary discussions can take place to guide staffing and intraoperative and postoperative planning. In addition, preoperative discussion with the family and informed consent should reflect not only the risks of the procedure, but should also address anesthetic risk. In this series, half of the anesthesia-related deaths were in patients with pulmonary hypertension. These patients are extremely high risk, and any anesthetic procedure should be seriously considered and entered into with extreme caution [3▪] (Fig. 1 [8]). Friesen and Williams [9] published a review of the anesthetic management of pediatric pulmonary hypertension, which should be a required reading for anyone caring for these patients.

The risk of sudden death associated with anesthesia in patients with supravalvar aortic stenosis with or without Williams syndrome is known. Burch *et al.* [10] provide an excellent review of the

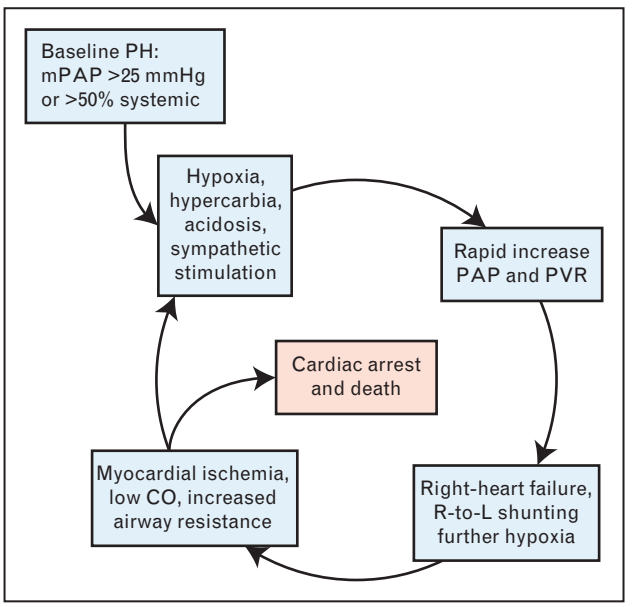

FIGURE 1. Pathophysiology of a pulmonary hypertensive crisis. A patient with baseline pulmonary hypertension experiences a stimulus that rapidly increases pulmonary artery pressure and resistance, leading to a vicious cycle of right heart failure, right-to-left shunting and further hypoxemia, hypotension and low cardiac output. If not interrupted, this crisis can lead to cardiac arrest. CO, cardiac output; mPAP, mean pulmonary artery pressure; PH, pulmonary hypertension; PVR, pulmonary vascular resistance. Reproduced with permission from [8].

pathophysiology of this disease. Patients with this disease continue to be high risk for any anesthetic procedure, require diligent preoperative planning, a review of the need for the procedure and appropriate preanesthetic consent [11]. Despite adequate planning, prehydration, judicious induction and maintenance, unforeseen physiologic changes such as the decrease in systemic vascular resistance and preload that can occur with the release of pneumoperitoneum in laparoscopy can complicate care [12].

Several recent reports highlight the increased anesthetic risk in pediatric patients with cardiomyopathy, of which dilated cardiomyopathy with decreased left ventricular function accounts for over 60%. Lynch *et al.* [13] reported four cardiac arrests on induction of anesthesia in 236 patients (1.7%). Bradycardia and/or hypotension were cited as the cause in all events, highlighting the very limited tolerance for reduction in preload, afterload or heart rate in these patients [13,14▪,15▪,16]. Table 1 summarizes the four cardiac lesions conferring greatest morbidity and mortality risk.

NONCARDIAC SURGERY

A number of recent studies review the outcomes of patients with CHD undergoing noncardiac surgery. When reviewing these articles, it is important to consider a number of factors that make it difficult to compare the patient populations. The first factor to consider is the type of CHD, as it is difficult to compare simple left-to-right shunt lesions with shunted single ventricle lesions. In addition, there are differences in relative haemodynamic stability among the stages of single ventricle palliation that should be considered. Differences in institutional practice should also be assessed.

It is critical for the anesthesiologist to understand the physiology of each stage of single ventricle palliation. It is also important to anticipate the effects of both anesthesia and the noncardiac procedure. Yuki *et al.* [17▪] and Christensen *et al.* [18▪▪] provide very complete reviews of the stages of palliation and the effects of anesthesia and surgery on this population. Single ventricle patients who have not yet undergone an SCPA (or Glenn) may have undergone systemic to pulmonary artery shunt, pulmonary artery banding or no surgery because they have a moderate degree of pulmonary stenosis resulting in a balanced circulation. This is considered the most delicate of the single ventricle stages, as the systemic ventricle handles both systemic and pulmonary blood flow, and the relative balance of each circulation depends on the systemic and pulmonary vascular resistances. This balance is easily perturbed by changes in

Table 1. Cardiac lesions conferring greatest mortality and morbidity risk with anesthesia

Cardiac lesion	Pathophysiological considerations	Anesthetic goals	Risk of cardiac arrest with anesthesia	Reference
Suprasystemic pulmonary artery hypertension	Catecholamine release from light anesthesia, hypercarbia, hypoxemia, acidosis, systemic hypotension leads to elevated pulmonary artery pressure, right ventricular failure, low cardiac output, hypoxemia	Maintain oxygenation, ventilation, adequate depth of anesthesia, administer pulmonary vasodilators including nitric oxide	1.1–5.7% of anesthetics in severe pulmonary hypertension	[9]
Left ventricular outflow tract obstruction: sub, valvar or supravalvar aortic stenosis (e.g. Williams syndrome)	Tachycardia, hypovolemia, systemic hypotension, excessive myocardial depression or hypercontractility reduce stroke volume, lead to coronary ischaemia, low cardiac output	Maintain ventricular filling, systemic vascular resistance, normal to slow heart rate, normal myocardial contractility	16% of POCA registry	[2]
Infant with single functional ventricle and systemic to pulmonary artery shunt	Systemic and pulmonary output both ejected by single functional ventricle; pulmonary to systemic vascular resistance ratio determines systemic cardiac output	Avoid hyperoxygenation / hyperventilation; maintain ventricular function	19% of POCA registry	[2]
Dilated cardiomyopathy	Very increased ventricular volume, ejection fraction 5–25%, cardiac output maintained by near normal stroke volume and tachycardia, very limited reserve for decreased systemic vascular resistance, contractility, preload	Avoid any decrease in myocardial contractility; maintain preload, and systemic vascular resistance	13% of POCA registry; 1.7% of anesthetics with dilated cardiomyopathy	[2,13]

POCA, pediatric perioperative cardiac arrest registry.

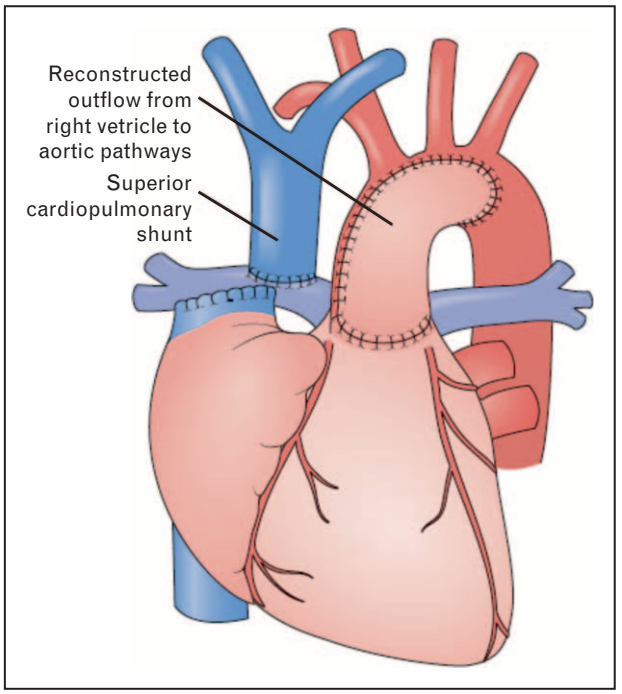

FIGURE 2. Hypoplastic left heart syndrome after the second stage of palliation. The outflow from the right ventricle has been reconstructed during a neonatal surgery. The superior cavopulmonary anastomosis has been performed at age 3–6 months, a procedure that virtually all patients with a single functional ventricle will undergo. Reproduced with permission from [8].

oxygen delivery, ventilation, hypothermia, acidosis, depth of anesthesia and hypovolemia. It is generally recommended that elective noncardiac procedures be postponed until after the SCPA [17▪,18▪▪].

Post-Glenn haemodynamics are generally more resilient (Fig. 2 [8]). The patient is still cyanotic with a baseline saturation of around 85%, but the single ventricle is now partially unloaded, as the systemic venous return from the upper half of the body is diverted directly to the pulmonary circulation. The avoidance of hypovolemia remains important. Pulmonary blood flow is dependent on maintaining a normal pulmonary vascular resistance (PVR). Hypercarbia, pain, vomiting and coughing can increase PVR leading to a decrease in passive pulmonary blood flow from the superior vena cava (SVC) and hypoxemia. However, hypocarbia can also lead to hypoxemia by decreasing the blood flow to the cerebral circulation, reducing SVC return [17▪,18▪▪].

After the Fontan procedure, the total cavopulmonary anastomosis, all systemic venous return is routed directly to the pulmonary arteries (Fig. 3 [8]). Occasionally, a small fenestration in the Fontan circuit provides a pop-off into the common atrium. In the absence of a fenestration, the patient is usually normally saturated, but cardiac output is entirely dependent on passive blood flow through the lungs. This reliance on passive pulmonary blood flow reduces the relative stability of this stage of palliation. When undergoing general anesthesia, it

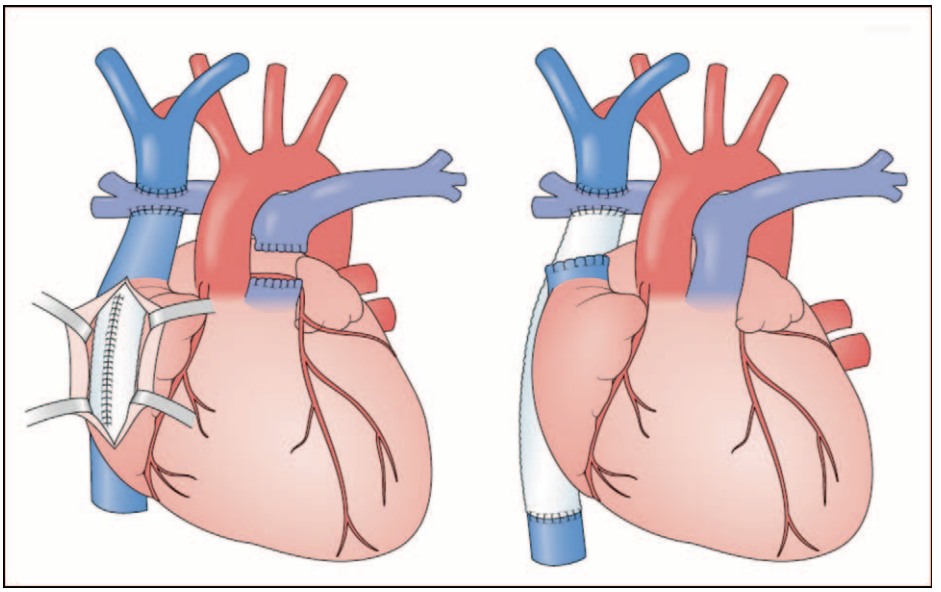

FIGURE 3. Lateral tunnel Fontan (left) and extracardiac Fontan (right). In both configurations, there is no pulmonary (right) ventricle. A total cavopulmonary connection is created where pulmonary blood flow depends on pressure gradient between vena cavae, pulmonary artery and left atrium. Spontaneous ventilation augments this flow, whereas positive pressure ventilation reduces the pressure gradient and can reduce pulmonary blood flow. A fenestration can be placed with either of these configurations. Reproduced with permission from [8].

is important to avoid hypovolemia or increases in PVR, as this can reduce pulmonary blood flow. In addition, positive pressure ventilation can decrease venous return resulting in a decrease in cardiac output. An increase in blood loss can be anticipated in the patient with a Fontan circulation due to higher than normal systemic venous pressures and coagulation abnormalities [17▪,18▪▪,19]. Decreased venous return and cardiac output should be anticipated, and volume and vasoconstrictors should be readily available. Spontaneous ventilation is haemodynamically favourable at this stage, and therefore, early tracheal extubation is preferred after any anesthetic. Table 2 summarizes considerations at each stage of single ventricle palliation.

Post-Norwood gastrostomy and fundoplication

Abdominal procedures, usually a gastrostomy and/or fundoplication, are controversial in the post-Norwood, pre-Glenn patient with hypoplastic left heart due to the delicate balance of pulmonary and systemic circulations and the volume loading of the single right ventricle. The stability of this stage must be weighed against the need for adequate nutrition and the avoidance of gastroesophageal reflux. Several recent articles report anesthetic practice and outcomes after open and laparoscopic procedures. It is difficult to compare these articles, as surgical techniques, anesthetic practices and patient populations differ between institutions. However, all of these articles make excellent points that can help guide the perioperative care of these delicate patients [20–24].

Controversy exists over the safety of performing laparoscopic procedures on patients with CHD and especially those with hypoplastic left heart syndrome (HLHS) after the Norwood operation. Laparoscopic surgery raises concerns about increases in systemic vascular resistance and decreases in cardiac index leading to haemodynamic instability in this patient population. Gillory *et al.* [20] reviewed the charts of 111 patients with CHD undergoing laparoscopic procedures and reported no increase in instability with laparoscopic vs. open procedures. Of the patients studied, only 12 out of 111 had single ventricle physiology. They did find that the patients with single ventricle physiology tolerated laparoscopy and had similar outcomes to patients with two ventricles [20].

Mariano *et al.* [21] and Slater *et al.* [22] reviewed the anesthetic management, conduct of laparoscopy and outcomes of infants with HLHS undergoing laparoscopic surgery. All of these patients were anesthetized by pediatric cardiac

Table 2. Stages of single ventricle palliation and anesthetic considerations

Stage of palliation	Cardiac lesion	Surgical palliation	Pathophysiological considerations	Anesthetic considerations after palliation
Neonatal	Hypoplastic left heart syndrome	Norwood Stage I palliation (aortic arch reconstruction and systemic to pulmonary artery or right ventricle to pulmonary artery shunt)	Systemic and pulmonary output both ejected by single functional ventricle; pulmonary to systemic vascular resistance ratio determines systemic cardiac output	Avoid hyperoxygenation and hyperventilation; maintain ventricular function; maintain systemic oxygen saturation 80–90%,
Neonatal	Tricuspid atresia (hypoplastic right heart) with no pulmonary stenosis, significant pulmonary stenosis or mild pulmonary stenosis	Pulmonary artery banding, systemic to pulmonary artery shunt, or no intervention	For shunted patients, see above; management of pulmonary to systemic vascular resistance ratio not as critical in banded patients	Maintain ventricular function; maintain systemic oxygen saturation 80–90%,
Infant: cavopulmonary connection (3–6 months)	Any single ventricle lesion: hypoplastic left or right heart	Superior cavopulmonary connection (bidirectional cavopulmonary anastomosis or Glenn operation)	Cerebral-pulmonary-cardiac circulation is predominant in youngest infants	Avoid hyperventilation; most stable stage for elective noncardiac surgery
Fontan completion (2–4 years)	Any single ventricle lesion: hypoplastic left or right heart	Total cavopulmonary connection; lateral tunnel or extracardiac Fontan; fenestrated or nonfenestrated	Positive pressure ventilation decreases venous return and cardiac output; intolerant of hypovolemia or nonsinus rhythm	Minimize positive pressure ventilation; maintain ventricular volume, sinus rhythm, myocardial contractility; perform elective noncardiac surgery before this stage when possible

anesthesiologists. Invasive arterial blood pressure monitoring was used in almost every case. All patients recovered in the cardiovascular ICU. Packed red blood cells were transfused to maintain a haematocrit of more than 40–45%. Arterial blood gases were monitored very closely throughout the case, and hypercarbia related to insufflation was treated with an increase in minute ventilation. Dopamine or dobutamine was initiated prophylactically for anticipated haemodynamic instability. All but one of these patients were extubated on postoperative day 1. Laparoscopy was conducted such that insufflation pressures were kept between 8 and 12 mmHg at a low flow. No intraoperative or postoperative mortality or intraoperative haemodynamic instability was reported [21,22]. These good outcomes are likely due to a comprehensive multidisciplinary approach and highly vigilant, tight control of haemodynamic and ventilatory parameters.

Other authors do not report favourable outcomes. Outcomes in patients with HLHS after the Norwood procedure undergoing open fundoplication were reported by Garey *et al.* [23] in 39 patients over 19 years. There were postoperative complications in 41% of this patient group and 30-day mortality was 4%. [23]. Watkins *et al.* [24] reviewed the perioperative management of 39 abdominal operations performed at a single institution on post-Norwood patients with HLHS. There were two cases of cardiac arrest requiring ECMO and one death within 7 days. There were a number of patients requiring an escalation in care postoperatively, and as a review of these events, the institution made a practice change to have all post-Norwood HLHS patients recover from noncardiac surgery in an intensive care setting [24].

Spinal anesthesia

In some centres, spinal anesthesia is used for noncardiac surgery in infants with CHD. Both Shenkman *et al.* [25] and Kachko *et al.* [26] report their experiences with the technique. Advantages include a lack of haemodynamic perturbation, lack of respiratory depression, avoidance of anesthetic-related toxicity in the developing brain and a reduction in the risk of postoperative apnoea and hypoxemia [25,26].

Approach and technique

The literature reflects the number of children with CHD undergoing noncardiac surgery. The recurrent themes revolve around the recognition of high-risk patients, the importance of multidisciplinary decision-making and the understanding of the anatomy and physiology of CHD. Almost any anesthetic technique and any anesthetic agent can be used as long as potential risks are recognized in the context of the individual patient's heart disease. White [7▪] published a narrative summarizing the literature and providing an evidence-based approach to anesthetic management in this patient population.

VENTRICULAR ASSIST DEVICES

In pediatric patients with severe heart failure and/or structural heart disease, options for ventricular assist devices as a bridge to transplantation have been limited. A complete review of options for mechanical cardiac support in pediatric patients was reviewed by Mossad *et al.* [27▪]. Patients with the longer term devices can be expected to require multiple anesthetics for noncardiac procedures, including imaging, device pump changes and others. For these noncardiac procedures, it is important to understand the basic device technology and how to evaluate and treat haemodynamic changes [27▪,28,29].

IMAGING

A number of recent publications consider the risks and benefits of different diagnostic imaging modalities for patients with CHD. Ntsinjana *et al.* [30▪] examine the role of cardiovascular magnetic resonance (CMR) imaging in patients with CHD. CMR provides valuable information regarding extracardiac arteries and veins, assessment of vascular or valvular flow, quantification of shunts and measurement of myocardial function. However, CMR can rarely be accomplished without general anesthesia in pediatric patients less than 7 years of age. Therefore, the need for information obtainable by CMR and the perceived anesthetic risk should be discussed in a multispecialty setting. In addition, the cardiac imaging and anesthetic teams should discuss the haemodynamic and cardiac imaging issues prior to the study. It is critically important to be able to recognize the patient at a high risk for CMR. In these patients, computerized tomography imaging with its brief scan time (<5 min as opposed to 30 min or longer for CMR) using a 'feed and wrap' technique avoids the risks of general anesthesia and provides the necessary images for clinical decision-making [30▪].

Two groups looked at the safety issues associated with CMR in children with CHD. Rangamani *et al.* [31] reviewed the records of 143 neonates and small infants with CHD undergoing CMR under general anesthesia, deep sedation or comfort measures.

They found an 8% incidence of adverse events, most of which were minor and included hypothermia, desaturation and bradycardia. There was one major adverse event, a respiratory arrest that was successfully resuscitated. The incidence of adverse events was slightly higher in patients undergoing general anesthesia than in those undergoing deep sedation. It is of note that 20% of outpatients were admitted overnight for observation due to desaturation [31]. A prospective study of safety issues associated with general anesthesia for CMR in pediatric patients with CHD was conducted by Stockton *et al.* [32▪]. The majority of cases were for intersurgical stage assessment, and 48% of the patients had single ventricle physiology. A significant adverse event was reported in 28% of the 120 procedures. The most common significant event was hypotension, and two infants suffered cardiac arrest, one before the anesthetic. This group emphasizes that fasting time should be minimized in order to decrease the risk of hypotension and potential shunt thrombosis [32▪].

Computerized tomography imaging provides another option for diagnostic evaluation of the pediatric patient with CHD. Han *et al.* [33] compared a second-generation, dual-source, 128-slice multidetector computed tomography (CT) angiographic scanner using a high-pitch sequence with a standard-pitch, single-source, 64-slice multidetector CT angiographic scanner. Images using the newer generation scanner could be obtained with less exposure to radiation (7 vs. 66 mGy), the avoidance of general anesthesia for breath-holding and excellent diagnostic accuracy despite a mild reduction in image quality [33].

Although some groups report favourable and acceptable safety profiles with relatively minor and reversible adverse events, it is important to recognize that the risk of CMR/CT imaging is almost exclusively anesthesia-related with a real risk of cardiac arrest and death. A multidisciplinary discussion should take place prior to scheduling the study to determine clinical questions and to perform a risk–benefit analysis. The potential utility of new generation CT should also be explored.

Fasting times should be minimized to decrease the risk of perianesthetic hypotension and potential shunt thrombosis. High-risk patients, especially shunted single ventricle patients and patients with left ventricular outflow tract obstruction (e.g. Williams syndrome), should be anesthetized early in the day with a minimal fasting time. This also allows for a long postanesthetic observation period. The parent or guardian should also be prepared in advance to stay overnight for continued observation and potential continuation of intravenous fluids. In addition, the cardiac imaging team should review images in a timely manner for potentially life-threatening findings: a critically-narrowed modified Blalock-Taussig shunt, for example, should not be discovered post-discharge.

PHARMACOLOGIC TRENDS

The use of dexmedetomidine (Hospira Inc., Lake Forest, Illinois, USA) in the pediatric patient with CHD has been of increasing interest. Its applications in the population extend beyond sedation to the prevention and control of tachyarrhythmias during and after congenital heart surgery [34,35].

Tobias *et al.* [36▪▪] published a very thorough review of dexmedetomidine. Although this alpha-2 adrenergic receptor agonist does not hold US Food and Drugs Administration (FDA) approval for any pediatric indications, it is being used increasingly in pediatric patients with and without CHD. It is being used intraoperatively during noncardiac as well as cardiac procedures to help blunt the sympathetic stress response, decrease anesthetic requirements and aid in postoperative pain control. Dexmedetomidine is an attractive drug due to its potential neuroprotective effects and lack of proneuroapoptotic activity. Dexmedetomidine can also be used for procedural sedation for cardiac catheterization and cardiac MRI, as well as post-procedural sedation. Its relative lack of respiratory depressant effects and effect on airway tone make dexmedetomidine useful in this population in which hypercarbia and increases in PVR may be poorly tolerated. This agent can also be useful in the prevention of emergence delirium. Important side-effects include hypertension, hypotension and bradycardia [36▪▪]. It is critical to consider these side-effects and be vigilant when administering this drug to patients.

With regard to newer nonanesthetic drugs, the perioperative use of clevidipine (Cleviprex; The Medicines Company, Parsippany, New Jersey, USA) to control hypertension in pediatric patients with CHD has also recently been reported. This dihydropyridine calcium channel blocker is short-acting with a half-life of 1–3 min. It is administered intravenously and metabolized by nonspecific blood and tissue esterases. It decreases mean aterial pressure primarily by arterial vasodilation. Due to its titratability, it is well suited for treating hypertension on emergence and postoperatively. Side-effects can include reflex tachycardia and an increase in triglycerides with coadministration of propofol. Special care to avoid bacterial growth is required, as it is dispensed in a lipid emulsion [37].

CARDIAC RHYTHM MANAGEMENT DEVICES

Many patients presenting for noncardiac procedures may have permanent pacemakers and implantable cardioverter defibrillators. It is critical that the anesthesiologist be familiar with these devices and how to care for these patients perioperatively. Navaratnam and Dubin [38▪▪] present a very thorough review of the perioperative management of these patients.

ANESTHETIC BUNDLING

Children with CHD undergo multiple procedures with exposure to anesthesia, especially during the first year of life. This includes cardiac surgery, direct laryngoscopy and bronchoscopy, gastrostomy, fundoplication, Ladd's procedure for malrotation, imaging studies, cardiac catheterization and other procedures common in infants. It has been reported that the brain of the neonate with CHD is less mature than that of a neonate without CHD [39]. There is much concern about the potential risk of anesthetic neurotoxicity in the developing central nervous system, and it is possible that the brain of the neonate/infant with CHD is at an increased risk as a result [40,41,42▪]. In order to decrease the risk of morbidity and mortality associated with anesthesia and to decrease the potential risk of anesthetic neurotoxicity, it makes sense to avoid unnecessary anesthetics by accomplishing multiple procedures under the same anesthetic, termed 'anesthetic bundling'. The anesthetic care team often acts as a coordinator between services, which can present many logistical challenges. However, it is the authors' opinion that anesthetic bundling is an important factor in optimizing patient care.

CONCLUSION

The number of noncardiac procedures performed in patients with CHD is increasing. In order to optimize outcomes, the anesthesiologist must understand the physiology and perioperative implications of the cardiac lesion, be able to identify patients at a high risk for anesthetic complications and communicate effectively with the other practitioners involved in the patient care. The highest risk groups for anesthetic complications are infants with a functional single ventricle, patients with suprasystemic pulmonary hypertension, patients with left ventricular outflow tract obstruction and those with dilated cardiomyopathy. In addition, it is critical to stay updated on changes in the pharmacologic armamentarium and advances in technology that may be beneficial in caring for these patients.

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Conflicts of interest

There are no conflicts of interest.

REFERENCES AND RECOMMENDED READING

Papers of particular interest, published within the annual period of review, have been highlighted as:
- ▪ of special interest
- ▪▪ of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (p. 395).

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