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Anaesthesia and paediatric cardiac catheterisation

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Background

Technological advancements and innovation have changed the face of the catheterization laboratory from being a purely diagnostic facility to being a unit for therapeutic interventions as well. Some of these interventions have replaced surgical corrections altogether and some have delayed the surgery allowing the practitioners to buy time to optimize for surgery or for the child to grow before major cardiac surgery. The magnitude and severity of complications that occur in this laboratory has increased significantly because of the number of procedures done and the physiological variability of patients that are now managed in it. The latest advancement being diagnostic and interventional procedures done on patients on ECMO (1). Some patients done on ECMO have had their diagnosis changed and outcomes improved because of the advancement of the laboratory. The cardiac arrest registry for paediatrics has reported that on average 30% of cardiac arrests happen in CHD kids and 17% of those occur in the catheterization laboratory (2, 3). Such a major complication is due to multiple factors namely: - patient's poor cardiorespiratory reserve, anaesthetic and procedural factors. Studies have shown that catheterization teams find it much harder to accept a cardiac arrest during the procedure than the cardiac arrest outside the lab. The speculation is that the teams tend to perform heroism resuscitation as they feel the cause of the death is more procedural than natural. This also has brought to the fore the importance of debriefing sessions after each resuscitation (4).

This summary aims to highlight issues surrounding the anaesthetic role in the catheterisation laboratory to better equip colleagues.

Common procedures

There are a lot of procedures performed in the laboratory, they can be divided into diagnostic and therapeutic interventions. It is not uncommon that a diagnostic procedure turns into a therapeutic one if it is warranted and deemed safe in the same setting.

Table 1
Paediatric cardiac catheter laboratory procedures

Indications	Procedure
Diagnostic	Defining cardiac and vascular anatomy
	Measuring haemodynamic pressures and shunts
	Pulmonary hypertension studies using nitric oxide
	Coronary angiography and endosonography
	Myocardial and endomyocardial biopsy
Interventional	Valvuloplasty
	Septal defect closure
	Atrial septostomy
	Angioplasty and placement of stents
	Percutaneous valve placements
	Closure of systemic to pulmonary shunts, e.g. patent ductus arteriosus
	Hybrid procedure
Electrophysiological studies	Conduction system mapping
	Radiofrequency and cryoablation
	Placement of pacemaker and ICD

CHALLENGES

Patient considerations

There is a wide variety of patients seen in the catheter laboratory, the age range from neonate to adults, stable to critical on ECMO, co-operative patients to patients with psychological and behavioral incapacity. The paediatric population also tends to have other congenital abnormalities that may pose the risk of difficult airway management, intravenous access and positioning. (5) These patients may also be on multiple medications that require certain precautions.

Remote

Catheterization is usually away from the main theatre complex, paediatrics ICU and cardiology centers. (6) This poses a risk for patients if ever additional help is required from other anaesthetists as well if the procedures complicates and an open surgery is life-saving. Another big challenge is the nursing staff in these units that are not anaesthesia trained and therefore not equipped to assist with adequately stocking theatre and this is a source of frustration to the anaesthetist especially in emergencies. (6)

Ergonomics

The required staff personnel can be grouped into the following: - cardiologists, anesthesiologists, nurses, radiographers each group has a minimum of 2 members this alone constitutes overcrowding in theatre. The equipment and machinery include the anaesthetic machine, drug trolley, emergency trolley with defibrillator, airway trolley, suction apparatus, fluoroscopy, ultrasound for echocardiography, blood gas machine and the scrub nurse's trolley. All these are needed inside the catheterization lab creating very difficult ergonomics to navigate as well as major distractions. This can have hazardous effects on the patient management, Society for Cardiovascular Angiography Intervention (SCAI) recommends a minimum of 8 x $10m^2$ area to be reserved for the anaesthesia team. A mini multidisciplinary team(MDT) meeting discussing plans for each case before the slate starts and checklists are suggested to improve communication and better outcomes for the patients (6).

Radiation safety

Radiation exposure is risky for both patients and staff. For younger patients the concern is developmental immaturity, longevity and repeated procedures. Most centers use as low as reasonably practicable (ALARP) principle as a dosing guideline that because of paucity of clear correlation between exposure, duration of exposure and the development of the negative manifestations. (7) Radiation exposure to healthcare providers is a known cause

of cataracts, dermal necrosis, malignancy, cellular mutation, infertility, intrauterine deaths and birth defects on healthcare workers. There are a number of things recommended to protect staff from radiation i.e.- protective clothing, distance and lead screen barriers and minimizing exposure time. (8) Quinn et al published a study in 2019 that helps acknowledge procedures with the highest risk of radiation exposure as depicted in table 2 below. This was suggested to be related to the lengths of the procedures (9).

The International commission on radiation recommends 1) a minimum distance of 80cm from isocentre, this is said to reduce scatter dose by 25% 2) Minimizing exposure time less catheterisation laboratory slate, walking out of the lab during screening as far as possible. 3) Shielding oneself using an apron, thyroid and goggles and a stand to catch scatters. It's mandatory to wear a dosimeter for monitoring. The International commission on radiation recommends wearing 2 badges, one on top and another under the apron. Maximum of 5Rem (Roentgen Equivalent Man, a dosage in rads that will cause the same amount of biological injury as one rad of X rays or gamma rays) per year is considered safe (10).

Table 2
Procedures categorized according to radiation risk exposure.

Category I (Low)	Category II (Medium)	Category III (High)
Biopsy	Proximal pulmonary angioplasty or stent	Mitral valvotomy+intervention*
ASD or PFO closure	VSD device closure+intervention*	TPV implantation
PDA device or coil closure	RVOT dilation/stent	≥2 vessel proximal or distal angioplasty or stent
Vasodilator testing	ASD or PFO closure+intervention*	Coil systemic pulmonary collateral+intervention*
Atrial septostomy	Venous collateral closure	Aortic valvotomy+intervention*
Pulmonary valvotomy	Distal pulmonary angioplasty or stent	RVOT dilation/stent and ≥2 vessel proximal or distal pulmonary angioplasty or stent
Biopsy+CA	Aorta dilation/stent+intervention*	TPV implantation and PA intervention*
PDA stent placement	Atrial needle transeptal puncture	≥2 vessel proximal or distal pulmonary angioplasty or stent+intervention*

Contrast

There has been a growing concern of contrast adverse effects which include anaphylaxis reactions and contrast induced nephropathy. This concern is an important consideration especially in this vulnerable group of patients. The practice has shifted from original contrast dyes to non-ionic, iso-or hypo-osmolar types and recommendations to use minimal effective doses. The role of the anaesthetist is to ensure adequate hydration with

precaution to avoid fluid overload and minimize exposure to other nephrotoxic drugs (11, 12).

PREOPERATIVE EVALUATION

Assessment

Detailed history and examination is invaluable in this setting because these patients mostly have been in medical care for a long time. Review of recent investigations done, current medications previous surgery and anaesthetic notes will equip the anaesthetist with a much needed thorough understanding of the patient physiology and how it responds to certain interventions both pharmacological and non-pharmacological. (2, 11, 12)

Premedication

Medications to be given or omitted are best discussed with the treating cardiologists. Consideration for infective endocarditis prophylaxis must be explored.
Patient rapport is especially important in older kids who are familiar with these procedures to reduce perioperative anxiety in the patient as well as caretakers. Midazolam premedication is recommended by most clinicians as that the patient receives 0.5mg/kg dose orally 30minutes before coming to the laboratory.

Fasting

Fasting regulations are the same as for other surgical interventions. The prevalence of erythrocytosis is of major concern in this population group as it impairs microcirculation. Dehydration is difficult to assess in cardiac failure and thus remains a dangerous sign to miss before induction as it exaggerates erythrocytosis.

Risk stratification

The catheterisation was previously run by cardiologist and sedation providers as procedures were purely diagnostic, the advancement in technology allowing more complex patients to undergo interventional procedures has forced the need for more qualified physicians to attend to these cases, namely the anaesthetist or critical care physicians. This transformation has undergone a process of risk stratification that ensures that every team member has a full understanding of the patient's physiological state, the procedure to be undertaken and all the possible complications. The Congenital Cardiac Catheterisation Projects on outcomes developed a CHARM model with the purpose of comparing adverse events between institutions and practitioners to standardize definition of adverse events. (Taylor K et at)
The Congenital Cardiac Interventional Study Consortium developed a risk assessment tool in 2015 known as the CRISP (Catheterisation RISk score for Paediatrics) score. The evolution of novel therapies in catheterisation lab also meant that by 2017 a new tool was needed to incorporate the new procedures, IMPACT score was born, it included

procedures like the transcatheter pulmonary valve replacement. In 2021 Procedural Risk in Congenital Cardiac Catheterisation (PREDIC3T) case type risk categories was published, after studying and grouping cases according to procedures that had the same incidence of the defined high severity adverse events.

Table 3: A **CHARM Model** showing high risk patients

Systemic ventricular end-diastolic pressure ≥18 mmHg
Systemic arterial saturation <95% [or < 78% if single ventricle (SV)]
Mixed venous saturation <60% (or <50% if SV)
Pulmonary artery systolic pressure ≥45 mmHg (or mean ≥17 mmHg if SV
Age <1 year
High-risk procedures

Table 4: High risk procedures

Vavluloplasty	Aortic valve <1 month, mitral valve
Device/coil closure	VSD Perivalvular leak
Balloon angioplasty	≥4 arteries or any number of veins
Stent placement	Ventricular septum; pulmonary artery or vein, Systemic surgical shunt or systemic pulmonary collateral
Stent redilation	Ventricular septum
Other	Atrial septum dilation and stent Any catheterization <4 days after surgery Atretic valve perforation

Figure 1: A table showing the PREDIC3T score

	Risk Group 1	Risk Group 2	Risk Group 3	Risk Group 4
Diagnostic Case	Age ≥ 1 year	Age ≥ 1 month < 1 year	Age < 1 month	
Valvuloplasty		Pulmonary Valve ≥ 1 month	Aortic Valve ≥ 1 month Pulmonary valve < 1 month Tricuspid valve	Mitral Valve Aortic Valve < 1 month
Device or Coil Closure	Venous collateral LSVC	PDA ASD or PFO Fontan Fenestration Systemic to Pulmonary Artery collaterals	Systemic Surgical Shunt Baffle Leak Coronary Fistula	VSD Perivalvar leak
Balloon Angioplasty		RVOT Aorta dilation < 8 ATM	Pulmonary artery < 4 vessels Pulmonary artery ≥ 4 vessels all < 8 ATM Aorta > 8 ATM or CB Systemic Artery (not aorta) Systemic Surgical Shunt Systemic to Pulmonary Collaterals Systemic vein	Pulmonary Artery ≥ 4 vessels Pulmonary vein
Stent Placement		Systemic vein	RVOT Aorta Systemic artery (not aorta)	Ventricular septum Pulmonary artery Pulmonary vein Systemic Surgical Shunt Systemic Pulmonary Collateral
Stent Redilation		RVOT Atrial Septum Aorta Systemic Artery (not Aorta) Systemic vein	Pulmonary Artery Pulmonary vein	Ventricular septum
Other	Myocardial Biopsy	Snare foreign body Trans-septal puncture	Atrial septostomy Recannulation of Jailed Vessel in Stent Recannulation of Occluded Vessel	Atrial Septum Dilation and Stent Any Catheterization < 4 days of Surgery Atretic valve perforation

VOT includes RV to PA conduit or status post RVOT surgery with no conduit; ATM = atmospheres; CB = Cutting Balloon

Figure 2: The CRISP score

	Assigned points for CRISP calculation by category		
Age	>1 year	30 days – 1 year	<30 days
	0	2	2
Weight	>5 kg	2.5–5.0 kg	<2.5 kg
	0	2	2
Inotropic support	None	Yes – Stable	Yes – Unstable/ ECMO
	0	0	2
Systemic illness/organ failure	None	Medically controlled or 1 organ failure	Uncontrolled or > 1 organ failure
	0	0	3
Physiologic category*	Category 1	Category 2	Category 3
	0	1	4
Pre-catheterisation category*	Category 1	Category 2	Category 3
	0	2	2
Procedure risk category*	Category 1	Category 2	Category 3
	0	1	3
Procedure type	Diagnostic	Interventional	Hybrid
	0	3	3

Figure3. Recommended Anaesthesia provider expertise based on the CRISP Score.

	Minimum Level of Anesthesia Provider Expertise		
CRISP Score	Sedation Team[a]	Anesthesiologist With Special Expertise in CHD	Pediatric Cardiac Anesthesiologist[b]
0–1	X		
2–4		X	
≥5			X

Abbreviations: CHD, congenital heart disease; CRISP, catheterization risk score for pediatrics.

[a]Sedation provided by nonanesthesiologists with training and certification in sedation practices.

[b]Pediatric anesthesiologist with either advanced training or extensive experience in congenital cardiac anesthesia.

SPECIFIC PROCEDURES

Coarctation of the aorta

Most patients with CoA present in infancy with absent, delayed or reduced femoral pulses, a supine arm-leg blood pressure gradient (> 20 mm Hg), or a murmur due to rapid blood flow across the CoA or associated lesions. This lesion is treated with balloon angioplasty in infancy and older children are treated with stents. BP measurement is recommended on the right arm to get a true reflection and the main goal is to avoid hypotension. Common complications are aortic rupture, aortic dissection, CVAs and femoral artery trauma. This necessitates the availability of blood transfusion. The main objective is to avoid severe reduction in arterial pressure. Anaesthetic options include ketamine and small fentanyl boluses and volatiles. Anesthetists should anticipate the sudden reduction in arterial pressure once stent done as this may cause coronary ischemia.

Valvotomy

This procedure is commonly done for the pulmonary and the aortic stenotic lesions. The pulmonary valvotomy is indicated when the pulmonary pressure gradient exceeds 50mmHg. Catheter will be passed through the opening causing severe desaturation momentarily, then dilation held until saturation normalizes. A 10mmHg reduction in pressure gradient is acceptable. Patients with severe aortic stenosis present with LVH and features of impaired LV function and coronary ischemia. Balloon dilatation is indicated when pressure gradient exceeds 70mmHg or when it's above 50mmHg with ischemia features. The success of the procedure requires a transient reduction in cardiac output as it dislodges the catheter, for this purpose a rapid overdrive pacing is instrumental. Post procedure the patient remains at risk of coronary ischemia due to aortic insufficiency that results.

VSD Closure

This procedure requires skilled surgeons and anaethetist as it presents major CVS instability. It has been done successfully undersedation with propofol with ketamine or propofol and dexmedetomidine however GA is the most preferred choice. It is recommended to be done in specialized centres under general anaesthesia with TOE guidance. TOE use can stimulate the patients under sedation causing them to move. The most common complication is residual

shunting and complete AVB block. Some patients have required permanent pacemakers. Studies show that general anaesthesia has better outcomes.

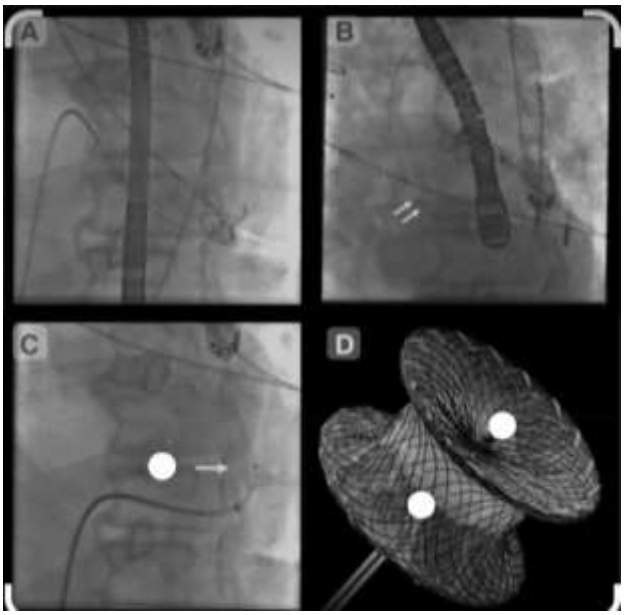

Figure 5. Images illustrating the stages of VSD closure using the Amplatzer device.A) shows a ventriculogram with contrast passing through the septal defect into the left ventricle.B) The hydrophilic wire indicated by 2 arrows passes from Right ventricle to the left ventricle.C) The arrow points to the left ventricular disc of the amplatzer device that has been deployed. D) The Amplatzer device.

ASD Closure

Indications for this procedure include excessive pulmonary shunt fraction Qp:Qs>1.5. Percutaneous intervention under TOE and angiographic guidance. Prophylactic antibiotics are mandatory within half an hour of initiating the procedure. Heparin is required thus bleeding is an important complication in the immediate post procedural period. Possible complications are arrhythmias, trauma and air embolization. The transjugular approach is the newer surgical approach that is considered safer.

Nitrous oxide avoided and patients remained supine for 2hours until venous sheath removed and homeostasis obtained. Aspirin and clopidogrel are indicated for 6months and the follow up echocardiography, during this 6 monthly period prophylactic antibiotics is indicated for dental and invasive procedures. Main anaesthetic goals are prevention of paradoxical embolism and shunt reversal by maintaining SVR: PVR ratio (avoid laryngospasm, bronchospasm,vigorous ventilation, deep anaesthesia and hypovolaemia.)

Patent Ductus Arteriousus

This lesion causes excessive pulmonary blood flow and patients present with recurrent chest infections, failure to thrive and CCF. It is important to avoid decreasing the PVR as it increases the shunt flow worsening the pulmonary congestion. Lowest possible FiO2 is recommended. Most anaesthetics decrease SVR which is favourable as it decreases the flow, this is however deleterious in patients who are PDA dependent. Anaesthetic recommendations are balanced techniques with volatiles and ketamine for spontaneously ventilating patients.

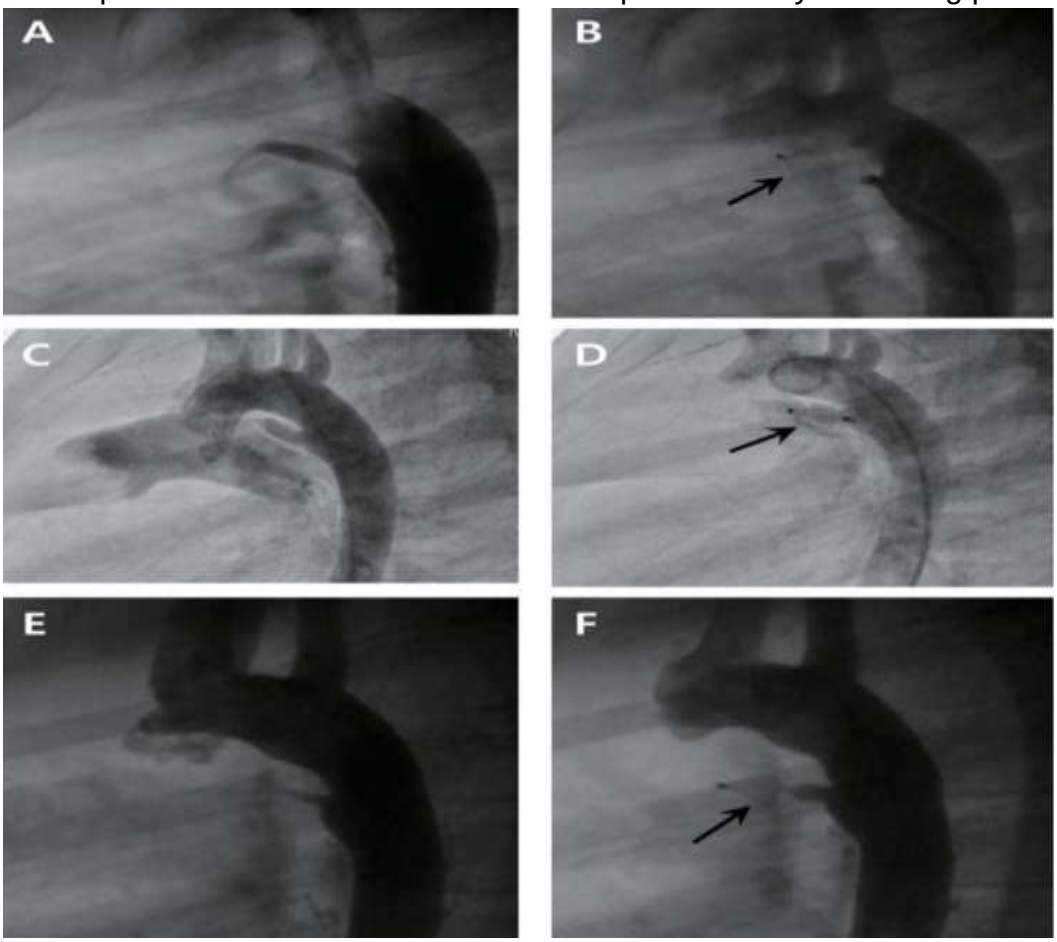

Figure 5. Images obtained during the transcatheter closure of a small PDA using a Amplatzer vascular plug.Images A, C and E show evidence of PDA.The images labelled B,D and F have black arrows indicating the plugs insitu obliterating the PDAs.

Anaesthetic drugs and their effect

Propofol

Propofol is a drug of choice for its many favourable characteristics, in this setting the rapid emergence and prevention of emergence agitation makes it more attractive. It is used as a bolus or infusion. Data in CHD children shows that it decreases SVR but still causes an increased systemic cardiac output without changing the heart rate and PVR. However, in children with shunts the drop in SVR was consequential in a dose dependent manner. Therefore, it must be used with great caution in patients with right to left shunts. Propofol studies have reported excellent safety and efficacy with less delirium and PONV, however haemodynamically unstable. A dose of 100mgc/kg/min was shown to preserve the shunt fraction despite the hypotension. Precaution must be taken in patients with high risk lesions.

Etomidate

Etomidate as an induction agent is known to maintain the SVR: PVR ratio however the adrenal suppression can be harzardous in sick children so it is best avoided. A small study done in patients undergoing ASD closure or ablation for tachyarrhythmias showed no haemodynamic instability. It is also a poorly studied drug in this population (13).

Midazolam

Jobeir et al (2003) reported great efficacy of midazolam infusion at 0.14mg/kg/hr with no complications as a solo agent. Midazolam has been used successfully without significant cardiorespiratory effects even as a premedication in anaesthesia. Its combination with fentanyl as the only anaesthetic has been described and noted to avoid bradycardia. Its use is preferred in sick children who will remain intubated after the procedure because of its duration of action (14).

Ketamine

Ketamine has been favoured because of its ability to preserve airway reflexes and cardiac function. It is important to note that it uses sympathetic stimulation to preserve this cardiac function which may be deleterious in lesions like aortic stenosis. Midazolam has been used with ketamine to offset the emergence agitation noted with ketamine (14). Ketamine has been recommended because of its analgesio-sedative properties with maintained ventilation. Some studies have reported unaltered PVR/PAP and PaCo2 levels (2). It still carried the disadvantage of hyper salivation, non-purposeful movements, nausea and dysphoria as a result a combination with propofol has been suggested.[1](15)

[1]

Opiods

Opiods are excellent to obtund the PVR response to painful stimuli but cannot be used as sole agents. Remifentanil is more stable however the bradycardia affects electrophysiological studies. If you must it must be less than 0.2mcg/kg/min infusion (2).

Benzodiazepines

Benzodiazepines have been used as premedications and to smoothen the emergence and ketamine induce dysphoria.

Dexmedetomidine

Dexmedetomidine has been described as closest to natural sleep state, however intolerable to heart rate dependent patients as it causes hypotension, bradycardia and hypertension (peripheral alpha agonist effect) (2). Munro et al conducted a study using dexmedetomidine loading dose and infusion, he reported that more than 50% required propofol bolus for either moving or increased BIS values despite the stable haemodynamics(16, 17). Tosun et al compared the combination of dexmedetomidine with ketamine to that of propofol with ketamine and concluded that patients that received dexmedetomidine regimen had discomfort requiring ketamine boluses and also had twice as long recovery times. (18)

Volatiles

Sevoflurane shows an overall decrease in cardiac output because of decrease in SVR plus no tachycardia and reduced inotropy whereas isoflurane maintained the cardiac output because of the compensatory tachycardia. Hemodynamically unstable children do not tolerate MAC levels of volatiles. Sevoflurane or isoflurane with or without nitrous oxide can be used. This carries a risk of low SVR and HPV hence the increased VQ mismatch. Mac of 0.5 is adequate if muscle relaxant is added. Nitrous oxide increase PVR more in adults than children and should be used with caution as it poses the risk of paradoxical air embolism. (2)

Figure 7. A table summarizing the pharmacokinetics of the commonly used drugs.

Anesthetic agent	SVR	PVR	Dosing
Potent Volatiles	↓	–, ↓	0.5–1 MAC
N_2O	–	– (infants)	
Opioids			
Fentanyl	–, ↓	–	1–2 $\mu g \cdot kg^{-1}$ 0.5–2 $\mu g \cdot kg^{-1} \cdot h^{-1}$
Remifentanil	–, ↓	↓	0.5–1 $\mu g \cdot kg^{-1}$ 0.05–1.3 $\mu g \cdot kg^{-1} \cdot min^{-1}$
Morphine	↓	–, ↑	0.05–0.2 $mg \cdot kg^{-1}$ 0.02–0.2 $mg \cdot kg^{-1} \cdot h^{-1}$
Midazolam	–	–	0.5 $mg \cdot kg^{-1}$ PO 0.1 $mg \cdot kg^{-1}$ IV 0.02–0.3 $mg \cdot kg^{-1} \cdot h^{-1}$
Propofol	↓	–	2–3 $mg \cdot kg^{-1}$ 100–300 $\mu g \cdot kg^{-1} \cdot min^{-1}$
Dexmedetomidine	↑	–, ↓	1 $\mu g \cdot kg^{-1}$ (over 10 min) 0.2–1 $\mu g \cdot kg^{-1} \cdot h^{-1}$
Ketamine	–, ↑	– (if CO_2 normal)	1–2 $mg \cdot kg^{-1}$ 5–20 $\mu g \cdot kg^{-1} \cdot min^{-1}$

Anaesthesia Conduct

Given the evolution of procedures feasible in the catheterisation lab, the decision of who qualifies to sedate or anaesthetize the patient has also changed from sedation Practitioners (nurses, general practitioners and medical officers in cardiology) has also changed. The SCAI now suggests that anaesthetists must play the role of sedation/ anaesthesia, however for complex high risk cases the anaesthetist must have at minimum the special interest in paediatric cardiac anaesthesia. The options of anaesthesia have also changed from sedation/ monitored care anaesthesia to mostly general anaesthesia (19).

Figure 8: The table below shows the commonest complications associated with each procedure. (20)

High-Risk Patients and Procedures for Anesthesia	Possible Adverse Events From Anesthesia
Williams–Beuren syndrome	Hypotension, coronary ischemia, cardiac arrest
Hypertrophic cardiomyopathy	Coronary ischemia, cardiac arrest
Single-ventricle physiology	Coronary ischemia, cardiac arrest
Aortic valve stenosis	Low CO, coronary ischemia, cardiac arrest
Mitral valve stenosis	Low CO, RV failure
Pulmonary hypertension	RV failure, pulmonary hypertensive crisis, cardiac arrest
Pulmonary vein dilation	RV failure, pulmonary edema, hypoxia
VSD device closure	Arrhythmia, low CO, cardiac arrest
Balloon atrial septostomy (newborns with single-ventricle physiology and left AV valve hypoplasia or atresia)	Hypoxia, atrial perforation, cardiac tamponade
s/p Heart transplant	VF, myocardial ischemia

Abbreviations: CO, cardiac output; RV, right ventricular; VF, ventricular fibrillation; VSD, ventricular septal defect.

Goals of anaesthesia

Studies concerning anesthesia-related morbidity and mortality in recent decades have demonstrated that pediatric patients and especially patients with CHD are at increased risk for adverse events and cardiac arrest during surgery. Common complications in children undergoing sedation or general anesthesia include airway events (laryngospasm, bronchospasm, apnea and aspiration), cardiovascular events (hypotension, arrhythmias and cardiac arrest) and postoperative issues such as nausea and vomiting, emergence agitation, hypoxemia and apnea.

The anaesthetist must be able to manage the patient at steady state. The steady state is when there is steady cardiovascular (constant heart rate and vascular resistance) and oxygen saturation and consumption and respiratory function. This is required for measurement of intracardiac shunts, pressure gradients and cardiac output and blood sampling. (2)

Fluid management

CHD is known for its prevalence of erthrocytosis, while this improves oxygen carrying capacity it also creates hyperviscous blood flow impeding microcirculation. During the fasting period these patients are at risk of dehydration, this is further unmasked by induction causing severe hypotensive episodes. Some lesions have very poor tolerance of even brief periods of marked drop in SVR for example pulmonary hypertension, and aortic stenosis (2, 20)

Ventilation

Generally spontaneous ventilation is better tolerated by most patients and allows more accurate hemodynamic readings because positive pressure ventilation alters intrathoracic pressures which affect pressure readings. Sedation and anesthetic drugs do cause hypoventilation and subsequent hypercarbia which is also not well tolerated by patients with pulmonary hypertension. For this reason, there are no hard and fast rules on how to ventilate, discretion is used on individual patient physiology as well as procedure to be undertaken. (20)

Choice of anaesthesia

Sedation

Sedation has more CVS stability, maintenance of spontaneous respiration and calmer emergence. It carries the risk of airway obstruction, hypoventilation and thus high PVR and a risk of unreliable patient immobility. Patients were noted to cough and move during contrast injection which could have deleterious effects on their outcomes. It has been phased out by the evolution to more complex patient physiologies and procedures scheduled. These are the regimens that have been used successfully.

Mild sedation: Phenobarbitone given the night before 2.5mg/kg. If patient became restless at the start of the procedure, Pethidine 25mg + chlorpromazine 6.25mg+ promethazine 6.25mg was given m IMI or 0.25ml/9kg was given via the catheter.

Heavy sedation drug options are Barbiturates rectally, tribromethyl alcohol, morphine, papaverectum, pethidine, diphenhydramine, diazepam, ketamine and halothane. Disadvantages was that steady state was difficult to achieve and haemoglobin levels were uncertain due to altered consumption by the drugs. Ketamine was given as 9-11mg/kg preceded by atropine 1mg/kg IVI as illustrated by Bernard et al.

General anaesthesia

This is the anaesthetic of choice for current practice because of its many advantages namely: - better immobility, minimal response to painful stimuli and psychologically better tolerance for future interventions. Induction plan is determined by the patient's physiology.In a patient with no intravenous access, midazolam oral, intranasal fentanyl,clonidine or dexmedetomidine and intramuscular ketamine can be used to facilitate iv access. Invasive lines are required pre induction if high risk, otherwise they are inserted by cardiologists. PaCO2 is easier to control and has no fear of airway obstruction. Disadvantages are venovasodilation, myocardial depression as these alter angiographic measurements and shunt fractions. Positive pressure ventilation causes low venous return, low flow across valves lowering metabolic rate and oxygen consumption

worsening the inaccuracy of measurements. Positioning of hands above head carries a risk of brachial plexus injury. Wedge under the left hip to assist with access to the left femoral, this may negatively affect ventilation. Respiratory VO2 monitors may cause extra dead space. Anaemia is poorly tolerated. Bleeding has been noted in 6.6%., the anaesthetist must remain vigilant in order to prevent hypovolaemia. Sudden fluid replacement affects the filling pressures of the heart as such must be communicated with the interventionist. Cardiac arrest has been noted in heart transplant recipients after a neostigmine bolus however no conclusive explanations had been met for this. Calm emergence necessary to preserve homeostasis at the vascular access site and if not attained it can cause prolonged emergence.

Post anaesthetic care

The recovery must thus be fully equipped with monitors and resuscitation equipment. Special consideration is to exclude bleeding from vascular access sites before discharge. Agitation can be very dangerous as it may dislodge clots formed in these access sites. Patients must be discharged to the ward once fully awake, haemodynamically stable, calm with no nausea and vomiting. (2, 3, 14)

COMPLICATIONS

Complications can be divided into three main categories namely: - anaesthetic related, procedural related and environmental related. The anaesthetic complications are hypoxia and loss of cardiac output and this is mainly because all agents depress myocardium to different degrees. Ketamine induced myocardial depression is counteracted by catecholamine release. Ketamine associated delirium is preventable and treatable with midazolam.

Procedural complications

cardiac arrest, arrhythmias, pulmonary hypertensive crisis, air embolism, thrombus formation, haemorrhage, hypo/hypertension stuck guide wires or devices failures and embolization.

Environmental complication is mainly hypothermia with the resultant delayed emergence.

The main independent risk predictors of complications are age less than 1 year and hypoplastic left heart syndrome. Studies have also shown that interventional procedures have a higher risk of complications than diagnostic procedures. (21)

Cardiac arrest

Cardiac arrest in the catheterisation laboratory is rare but quite devastating because it is mostly iatrogenic and this puts pressure on the team to resuscitate beyond reason. It's a

relatively safe place to have a cardiac arrest because the skills, drugs and mechanical support devices there are present. (22) The main problem is however the difficulty in performing chest compressions because of the procedure in progress, safety to the rescuer (mechanical and radiation exposure). That is when the circulatory support options LUCAS, Life stat and Autopulse come in if you are in the 1st world country. ECMO and Impella devices are our available percutaneous options, highly recommended as they can be inserted and initiated rapidly. LUCAS has been studied in comparison to manual compressions and shown no significant difference in survival and outcomes (3, 13). That is good news for a catheterisation laboratory emergency.

Flick et al. found that the cardiac arrest rate was 0.03% in children undergoing non-cardiac surgery and 1.27% in cardiac surgical procedures, with a mortality rate of 0.016% [3]. Eighty-eight percent of those who experienced a cardiac arrest had CHD. The rate of cardiac arrest was highest in neonates undergoing cardiac surgery at 435/10,000 and mortality at 389/10,000(20).

Vitiello et al. found that patient age and interventional catheterization procedures were risk factors for morbidity and mortality in the paediatric cardiac catheterisation. (23) The specific risk factors for anesthesia and sedation were young age, low weight and need for intubation. Bennet et al. examined adverse events in the cardiac catheterization lab specifically from an anesthetic perspective and found in 4454 catheterizations an adverse event rate of 9.3% for diagnostic procedures and 11.6% for interventional procedures. There were 90 incidents; 33 were respiratory, of which 20 were airway events, and 22 were cardiovascular events, of which 17 were transient arrhythmias. The mortality rate (4 deaths) was 0.08%. All the deaths were in patients under 18 months of age. Adverse events occurred most frequently in patients <1 year of age and in those having interventional procedures other than persistent ductus arteriosus (PDA) and atrial septal defect (ASD) closure. These rates of adverse events are similar to those published in the IMPACT (Improving Pediatric and Adult Congenital Treatment) Registry in nearly 20,000 patients, with adverse events occurring in 10% of diagnostic and 11.1% of interventional procedures (20, 24).

The Pediatric Perioperative Cardiac Arrest (POCA) Registry collected data on 373 anesthesia-related cardiac arrests in children, 34% of whom had congenital or acquired heart disease. (24) Of the patients with heart disease, anesthesia-related cardiac arrests occurred 54% of the time in the general pediatric OR, 26% in the cardiac OR and 17% in the catheterization laboratory. Fifty-nine percent of patients with uncorrected and 26% with palliated single-ventricle physiology had the highest risk of cardiac arrest, whereas patients with aortic stenosis or cardiomyopathy had the highest risk of mortality following a cardiac arrest, at 62% and 50%, respectively. These lesions accounted for more than 75% of all deaths reported to the POCA registry. Nearly half (47%) of cardiac arrests in children with heart disease occurred in those younger than 6 months of age. (3, 20)

Figure 2: Left picture shows the Lund university cardiopulmonary assistance system(LUCAS). Right picture is the LifeStat device.

Lund university cardiopulmonary assistance system (

ig. (2). LifeStat™.

Special considerations

Pulmonary hypertension

This condition has a higher risk of cardiac arrest; major complications were seen at 8 times more. Retrospective studies have shown no significant difference in outcome when using all sedation or general anaesthesia. Ketamine is still considered safe despite the theoretic increase in PVR. Different drug choices also did not yield statistically significant differences on the risk of complications. (2)

Cyanotic heart diseases

The evolution of CHD also means there are more adults with CHD than kids, these adults would have undergone multiple procedures to survive. Acyanotic Congenital heart disease patients present to catheterisation laboratory for valvuloplasties, angioplasties, Septal Occlusive Device placements, ablation and pacemaker/defibrillator insertions. There are n standing protocols for management of these, the practitioners must understand the physiology and procedure to be carried out.

Hybrid procedures

This refers to the combination of catheterisation and surgical therapy in one setting e.g.:
- per atrial and perventricular SOD(septal occlusive device) placement, surgical repair after failed SOD placement and stage 1 palliation surgery eg:-hypoplastic left heart syndrome. This is beneficial as it avoids CPB and its complications, stable HD and allows time for resolution of other neonatal problems. However, there is a risk of poor perfusion due to retrograde aortic arch obstruction, distortion of pulmonary arteries due to repeat procedures and greater need for surgical interventions. (1, 2)

ECMO

The logistics and risks associated with getting these patients to the catheterisation laboratory can be overwhelming. However, studies have shown that some patients have benefited from it. Kato et al published a study done between 2000 and 2014 on patients who underwent catheterisation while on ECMO (25). Their results showed that 70% of them were decannulated and 51% survived to hospital discharge. There was significantly less respiratory complication noted in the 48 hours post catheterisation. (1, 2)

Summary

The advancements of cardiac catheterization laboratory services have greatly improved the quality of care, enabled early interventions and consequently prolonged quality life spans for paediatrics with congenital heart diseases. They have also increased the number and severity of potential complications during the procedure. Ergonomics and distractions are amongst the avoidable contributors to adverse events. Good communication and leadership skills are important non-technical skills necessary to minimize these complications.

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