**MMED THESIS**

# Incidence of perioperative cardiac arrest in children undergoing cardiac surgery at the Red Cross War Memorial Children's Hospital

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# Contents

# 1. Introduction

## 1.1 Background and problem statement

Perioperative cardiac arrest (POCA) in children under anaesthesia remains a rare and often avoidable event. A systematic review, meta-analysis, and meta-regression of global mortality after POCA in children reported an overall decreasing trend in mortality following arrest in high-income countries (HIC), but a persistently higher incidence of anaesthesia-related paediatric cardiac arrest and mortality in low- and middle-income countries (LMIC)[1]. The rates of POCA and perioperative mortality have been reported to be higher in children undergoing cardiac surgery compared to non-cardiac surgery[2,3]. Cardiovascular causes have been identified as the most common cause of anaesthesia-related cardiac arrest in children undergoing cardiac surgery[4].

There are few studies on the incidence, aetiology, and outcomes of cardiac arrest in children undergoing cardiac surgery in LMICs. Studies typically include a mix of cases, with a limited number of cardiac surgeries, making it difficult to determine their specific contribution [5-11]. The incidence of perioperative cardiac arrest (POCA) in children undergoing cardiac surgery in LMIC also varies widely between studies[5,7]. Direct comparisons between studies are further complicated due to the differing age cut-offs used for paediatric patients, the inclusion of adult and paediatric patients, as well as varying definitions of the time period for perioperative cardiac arrest.

Data on perioperative cardiac arrest in children undergoing non-cardiac and cardiac surgery in South Africa are limited to a single study on severe anaesthetic-related critical incidents and risks - the South African Paediatric Surgical Outcomes Study[7]. The authors reported a tenfold higher incidence of perioperative cardiac arrest compared to studies conducted in high income countries

(HICs). A previous study conducted at our institution found increased odds of 30-day in hospital mortality in children undergoing cardiac surgery and cardiac catheterisation but did not investigate cardiac arrest rates or associated risk factors[2].

## 1.2 Aims and objectives

The objective of this study was twofold: to gain insight into the aetiology of perioperative cardiac arrest, and to establish a benchmark for the incidence of perioperative and anaesthesia-related cardiac arrest in children undergoing cardiac surgery at a high-volume centre in a LMIC setting. By identifying risk factors and analysing modifiable causes for perioperative cardiac arrest, this study aims to facilitate improvements in perioperative care.

The primary outcome was the incidence of perioperative and anaesthesia-related cardiac arrest in children aged less than 16 years undergoing cardiac surgery for congenital and acquired heart disease at the Red Cross War Memorial Children's Hospital (RCWMCH). The secondary outcome was on-table mortality following perioperative cardiac arrest.

## 2. Research Methodology

### 2.1 Research design:

This was a retrospective cohort study of all consecutive patients age less than 16 years captured since the commencement of the paediatric cardiac surgery database, who underwent cardiac surgery for congenital and acquired heart disease over a period of 9 years (January 2012 to December 2020) at the Red Cross War Memorial Children's Hospital (RCWMCH). Our institution performs approximately 350 paediatric cardiac surgeries annually. Perioperative cardiac arrest was defined as any event requiring external chest compression or internal cardiac massage with or without cardioversion[12], or death. Patients who failed to wean from CPB, or who suffered a cardiac arrest prior to theatre, or after handover to ICU were excluded. The perioperative period was defined as the time from placement of monitors in theatre until completion of handover in the ICU.

Ethical approval for the study was granted by the Human Research Ethics Committee of the Faculty of Health Sciences, University of Cape Town (UCT) (HREC REF: 679/2020sa). Hospital approval was granted by the research review committee.

### 2.1 Data Collection and Variables:

Search terms used to identify patients from the paediatric cardiac database who suffered a cardiac arrest included cardiac arrest, hypoxic arrest, cardiopulmonary resuscitation, CPR, cardiac massage, chest compressions, ventricular fibrillation, VF, fibrillation, death, and deceased. The details of these patients were then further reviewed to establish whether they met the criteria for perioperative cardiac arrest. For patients who met the inclusion criteria, relevant data were collected from the paediatric cardiac database and corresponding patient folders. Patient

demographics collected included age, age group (neonates, infants, children), sex, body surface area (BSA), weight, and congenital cardiac lesion. Perioperative data included surgical procedure, use of cardiopulmonary bypass, 24-hour in-hospital mortality, and timing of cardiac arrest.

Each perioperative death was reviewed by two senior anaesthetists. The experts reviewed the cardiothoracic database, anaesthetic chart(s) and clinical notes, where available, to reach a consensus on each perioperative cardiac arrest, deciding whether: a) anaesthesia caused the cardiac arrest; b) anaesthesia may have contributed to or influenced the cardiac arrest; or c) anaesthesia was entirely unrelated to the cardiac arrest. Where no consensus was reached, these cases were reviewed by the head of paediatric cardiothoracic surgery for a final decision. In addition, the likely aetiology of arrest was described including one or more of a combination of cardiovascular, respiratory, equipment-related, medication-related, surgical, or unknown.

### 2.3 Sample Size:

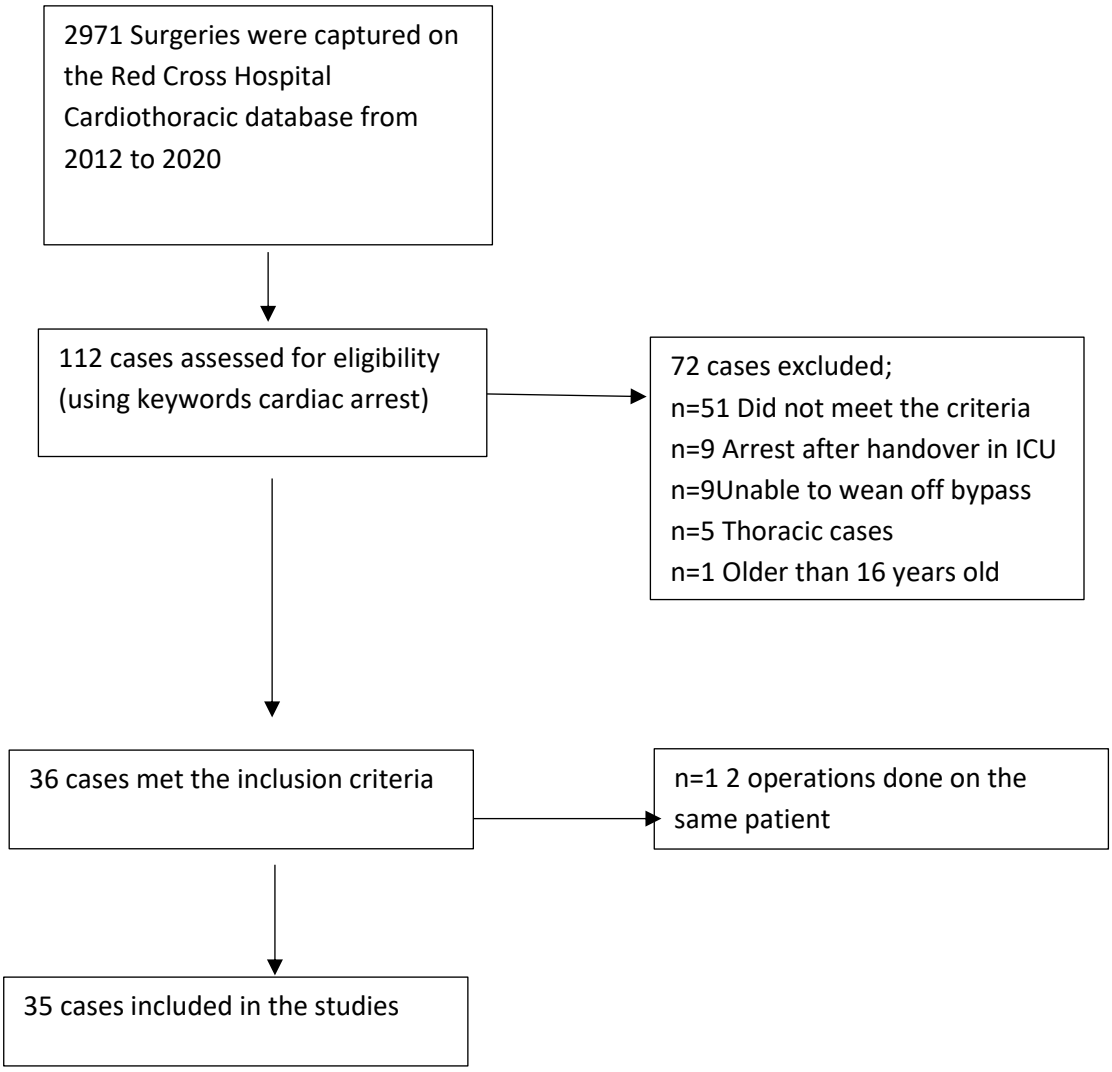
The sample size was limited to the number of patients entered into the paediatric cardiac surgery database at RCWMCH from the commencement of the database on 1st January 2012 to 31st December 2020.

### 2.4 Statistical Analysis

Categorical variables are reported as number and percentage. Normal distribution of continuous variables was determined by Shapiro-Wilk testing and summarised appropriately as means ± standard deviation for normally distributed variables, or as medians ± interquartile range (IQR) for non-normally distributed variables. Statistical analyses were performed using JMP Pro (version 17.2.1, Cary, NC).

## 2.5 Results

***Fig 1. Study Patient Flow Diagram***




A total of 112 potential patients from 2971 cardiac surgeries were initially identified from the paediatric cardiac database using the specified search terms. On further review, 36 surgeries involving 35 patients who suffered a perioperative cardiac arrest were identified. The overall incidence of perioperative cardiac arrest was 121.1 per 10,000 (95% CI 84.9 to 167.8). Seventy-six cases were excluded because they: did not meet the definition for cardiac arrest (n=51), were

older than 16 years (n=1), arrested after handover in the ICU (n=9), were thoracic cases (n=5), were unable to be weaned from CPB without any attempt at external chest compression or internal cardiac massage with or without cardioversion (n=9). One patient who required internal cardiac massage after weaning from CPB was subsequently placed onto extra-corporeal membrane oxygenation.

### 2.5.1 Patient Demographics and Characteristics

The median age of children who had an arrest was 2.5 months and the median weight was 4.3 kg (*Table 1).* Almost one third of these patients were neonates, and three quarters were aged less than 1 year. The commonest presenting cardiac lesions were Tetralogy of Fallot (14.3%) aortic stenosis (11.4%), truncus arteriosus (8.6%), Tricuspid atresia (8.6%) and (Pulmonary atresia (8.6).

| Table 1. Patient demographics and characteristics | |
|---|---|
| **Variable** | **All patients (N=35)** |
| **Age (months), median (IQR)** | **2.5 (0.8 – 17.1)** |
| **Weight (kg), median (IQR)** | **4.3 (3.0 – 10.2)** |
| **BSA, median (IQR)** | **0.26 (0.20 – 0.42)** |
| **Sex, n (%)** | |
| Male | 19 (54.3) |
| Female | 16 (45.7) |
| **Congenital cardiac lesion, n (%)** | |
| **Acyanotic** | **16(45.7)** |
| **Left-to-right shunts** | **5(14.3)** |
| Ventricular septal defect; Patent ductus arteriosus | 1(2.9) |
| Atrioventricular septal defect | 1(2.9) |
| Ventricular septal defect | 1(2.9) |
| Patent ductus arteriosus; Atrial septal defect; Ventricular septal defect | 1(2.9) |
| Patent ductus arteriosus | 1(2.9) |
| **Obstructive lesions** | **9(25.7)** |
| Aortic stenosis | 4(11.4) |
| Interrupted aortic arch | 2(5.7) |
| Pulmonary stenosis | 1(2.9) |
| Hypoplastic arch | 1(2.9) |
| Coarctation of aorta | 1(2.9) |
| **Other** | **2(5.7)** |
| Aortic regurgitation | 1(2.9) |
| Anomalous coronary artery from pulmonary artery | 1(2.9) |
| **Cyanotic** | **19(54.3)** |
| **Decreased pulmonary blood flow** | **12(34.3)** |
| Tetralogy of Fallot | 5(14.3) |
| Tricuspid atresia | 3(8.6) |
| Pulmonary atresia | 3(8.6) |
| Double outlet right ventricle | 1(2.9) |
| **Increased pulmonary blood flow** | **7(20)** |
| Truncus arteriosus | 3(8.6) |
| Transposition of the great arteries | 2(5.7) |
| Total anomalous pulmonary venous connection | 2(5.7) |

### 2.5.2 Surgical Procedure

The most common surgical procedures during which cardiac arrest occurred were Tetralogy of Fallot repair (4/36, 11.1%), Truncus arteriosus repair (3/36, 8.3%) and Central shunt (3/36, 8.3%) (*Table 2.*). The majority of cardiac arrests (30/36, 83.3%) occurred during procedures that required cardiopulmonary bypass (CPB).

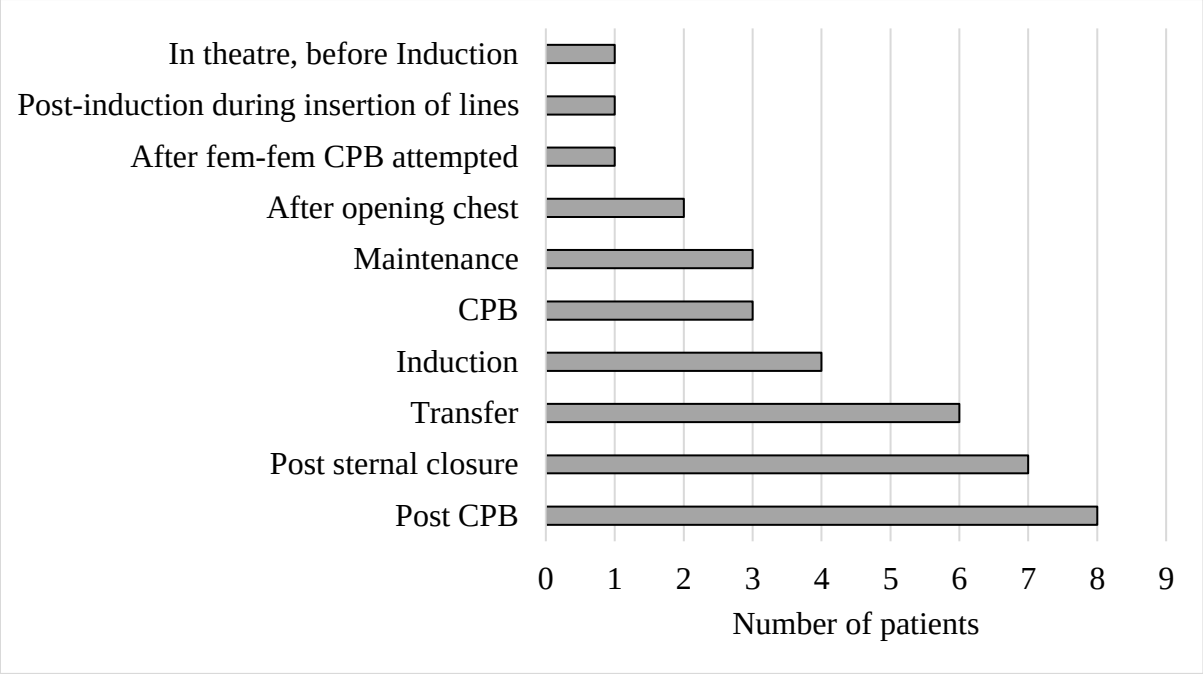
**Table 2. Characteristics of surgical procedure and outcomes**

| Variable | All surgeries (N=36) |
|---|---|
| **Cardiopulmonary bypass** | |
| Yes | 30 (83.3%) |
| No | 6 (16.7%) |
| **Surgical procedure, n (%)** | |
| Tetralogy of Fallot repair | 4(11.1) |
| Truncus arteriosus repair | 3(8.3) |
| Central shunt | 3(8.3) |
| Modified Blalock-Taussig shunt | 2(5.6) |
| Arterial switch operation | 2(5.6) |
| Total anomalous pulmonary venous connection repair | 2(5.6) |
| Ventricular septal defect repair | 2(5.6) |
| Anomalous origin of coronary artery from pulmonary artery repair | 2(5.6) |
| Aortic stenosis, supravalvar, repair | 1(2.8) |
| Aortic valve repair | 1(2.8) |
| Aortic valve replacement | 1(2.8) |
| Arch reconstruction | 1(2.8) |
| Cardiac tamponade evacuation | 1(2.8) |
| Coarctation repair | 1(2.8) |
| Double outlet right ventricle repair | 1(2.8) |
| Glenn shunt | 1(2.8) |
| Interrupted aortic arch repair | 1(2.8) |
| Pulmonary artery banding & patent ductus arteriosus ligation | 1(2.8) |
| Pulmonary artery debanding | 1(2.8) |
| Patent ductus arteriosus ligation | 1(2.8) |
| Removal of clot from left pulmonary artery | 1(2.8) |
| Ross-Konno procedure | 1(2.8) |
| Surgical aortic valvotomy & ventricular septal defect closure | 1(2.8) |
| Thrombectomy from Glenn shunt | 1(2.8) |
| **Outcome, n (%)** | |
| Death on table | 9(25.0%) |
| Survived | 27(75.0%) |

### 2.5.3 Characteristics of Perioperative Cardiac Arrest

The most frequent timing of arrest was post- separation from CPB (8/36, 22.2%) and following closure of the chest (7/36, 19.4%) (*Fig 2.*).

**Fig 2. Timing of perioperative cardiac arrest**

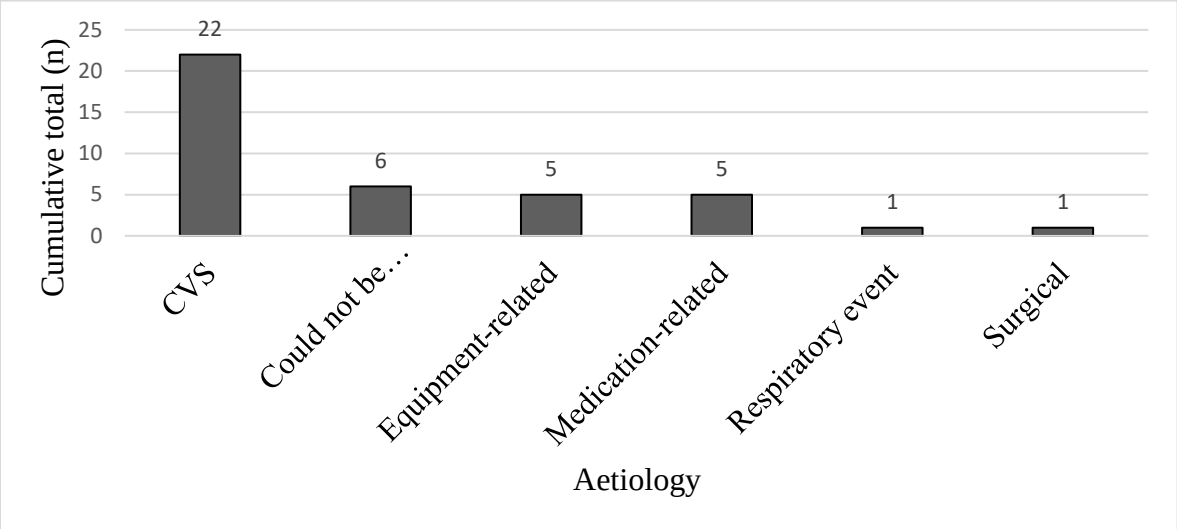



Four of 36 (11.1%) cardiac arrests occurred during induction of anaesthesia. These included: one patient with a cardiac tamponade who required one minute of external chest compressions and two minutes of internal cardiac massage before return of spontaneous circulation (ROSC) having decompensated and arrested during induction of anaesthesia, one patient with pulmonary atresia who returned to theatre with a right ventricular outflow obstruction and persistently poor pulmonary blood flow and low oxygen saturation requiring continuous chest compressions whilst being prepared and draped for surgery, one patient who required cardiopulmonary resuscitation (CPR) following a cardiac arrest on intubation, and one patient undergoing a total anomalous

pulmonary venous connection repair who required 15 minutes of CPR until ROSC. Three patients required internal cardiac massage due to complications related to CPB. These included air embolus in the aortic cannula, dislodgement of aortic cannula, and cardiopulmonary pump failure.

In 5/36 (13.9%) of perioperative cardiac arrest events the panel deemed that there were multiple contributing factors. The most frequent aetiology contributing to perioperative cardiac arrest was cardiovascular in 22/36 (61.1%) of surgeries (*Fig 3*).

***Fig. 3. Aetiology of Perioperative Cardiac Arrest***




## 2.5.4 Anaesthesia Related Cardiac Arrest

The crude anaesthesia related cardiac arrest rate was 13.5 per 10,000 cases (95% CI  3.7−34.5). There were three cases identified in which the panel agreed that factors related to anaesthesia may have contributed to the cardiac arrest, and one case in which the cardiac arrest was caused by anaesthesia due to a medication error (*Table 3.1*)

***Table 3.1 Anaesthesia-Related Cardiac Arrest***

| Age | Sex | Diagnosis | Surgical procedure | Aetiology | Probable cause of arrest | Outcome |
|---|---|---|---|---|---|---|
| 2.2 m | F | Tetralogy of Fallot | Central shunt | Medication-related | Inappropriately high dose of potassium given precipitating asystolic cardiac arrest | Survived |
| 26 d | M | Truncus arteriosus | Truncus arteriosus repair | Equipment-related | Delayed recognition and treatment of hypotension due to inappropriate position of arterial line transducer which had dropped lower than the heart | Survived |
| 4.2 m | F | Ventricular septal defect | Pulmonary artery debanding | CVS & Medication-related | Poor ventricular function, weaned off inotropes, administered alpha-2 agonist | Survived |
| 5.1 y | F | Tetralogy of Fallot | Tetralogy of Fallot repair | Equipment-related | Delayed recognition of hole in breathing circuit causing hypoxic arrest during insertion of vascular access | Survived |

## 2.5.5 Medication Related Cardiac Arrest

There were three (3) medication related cardiac arrests. In two cases, medication related cardiac arrest were noted to have occurred after multiple medications were administered at the same time *(Table 3.2).* In one of these cases, during skin closure, the patients' blood pressure dropped despite inotropic administration, whilst the other patient had a cardiac arrest while awaiting transfer to an ICU bed. There was one incident where a cardiac arrest occurred on induction of anaesthesia due to a high dose of an inhalational induction agent.

***Table 3.2 Medication-Related Cardiac Arrest***

| Age | Sex | Diagnosis | Surgical procedure | Aetiology | Probable cause of arrest | Outcome |
|---|---|---|---|---|---|---|
| 0.9 m | F | Interrupted aortic arch | Interrupted aortic arch repair | Medication-related<br>Surgical<br>CVS | Multiple medication administered at the same time. During skin closure, patient blood pressure begins to drop despite inotropic administration. | Survived |
| 4.2 y | M | Pulmonary stenosis<br>Cardiac tamponade | Cardiac tamponade evacuation | Medication-related | High sevoflurane dose. Patient taken to theatre with imminent tamponade. Patient arrest on induction. | Survived |
| 0.9 m | F | Interrupted aortic arch | Truncus arteriosus repair | Medication-related | Multiple medication administered at the same time. Patient had a cardiac arrest while awaiting transfer to the bed and dressings were removed expeditiously and internal cardiac massage was performed. | Survived |

### 2.5.6 Equipment Related Cardiac Arrest

There were also three (3) Equipment related cardiac arrest. In one instance, the aortic cannula dislodged which necessitated stopping of the pump and the patient requiring chest compressions. In another, during placement of the aortic cannula, air was noticed in the aortic cannula which caused the cardiac arrest. In the third instance, at the end of surgery, a cardiopulmonary bypass pump failure resulted in a brief loss of cardiac output.

***Table 3.3. Equipment-Related Cardiac Arrest***

| Age | Sex | Diagnosis | Surgical procedure | Aetiology | Probable cause of arrest | Outcome |
|---|---|---|---|---|---|---|
| 1.4 y | M | Ventricular septal defect Patent ductus arteriosus | Ventricular septal defect repair | Equipment-related | Air in the aortic cannula. While placing the aortic cannula in the right atrium, a lot of air was seen causing cardiac output and cerebral oxygenation dropped significantly. | Survived |
| 0.7m | M | Transposition of the great arteries | Arterial switch operation | Equipment-related | Aortic canula dislodged. During placement, the aortic cannula dislodged necessitating stopping the pump and patient required compressions. | Survived |
| 1.7m | F | Tetralogy of Fallot | Tetralogy of Fallot repair | Equipment-related | Bypass pump failure. At end of surgery brief loss of cardiac output necessitating open cardiac massage. | Survived |

### 2.5.7 Perioperative Mortality

A quarter of perioperative cardiac arrest events (9/36, 25.0%) resulted in death in the operating theatre (*Table 1*). Mortality following cardiac arrest was highest for patients with pulmonary atresia (3/3, 100%) and hypoplastic arch (1/1, 100%), followed by aortic stenosis (2/4, 50%), transposition of the great arteries (1/2, 50%), truncus arteriosus (1/3, 33%), and tricuspid atresia (1/3, 33%).

## 3. Discussion

The principal finding of this study was an overall incidence of 121.1 perioperative cardiac arrests per 10,000 anaesthetics and an overall incidence of 13.5 per 10,000 anaesthesia-related cardiac arrests in children undergoing cardiac surgery at a tertiary academic hospital in South Africa. The most frequent timing of perioperative cardiac arrest was post-separation from CPB and following chest closure. The most frequent aetiology of cardiac arrest was cardiovascular, and perioperative cardiac arrest was associated with a high perioperative mortality rate.

Limited data exist on perioperative and anaesthesia-related cardiac arrest specific to paediatric cardiac surgery in other LMICs. A study of 12,143 cardiac and non-cardiac surgeries in adults and children from a University Hospital in Nigeria reported an overall incidence of 25.5 cardiac arrests occurring under anaesthesia per 10,000[8]. Mortality following cardiac arrest during cardiothoracic surgery was high (6/8, 80%), but the incidence of cardiac arrest specific to cardiothoracic surgery is not reported. Details on the individual cases are not presented, and it is not possible to ascertain whether the cases were adult or paediatric, or the type of cardiac lesion or operation. The authors also noted that non-cardiac operations were included within the cardiothoracic surgical category, such as femoral embolectomy and modified Heller's operation which would have been excluded from our study. Other studies reporting on paediatric perioperative cardiac arrest rates from Nigeria, Niger and Benin did not include cardiac surgery[13-16].

There are few studies from higher volume centres in LMIC reporting on perioperative and anaesthesia-related cardiac arrest in paediatric cardiac surgery. The only published data from South Africa on paediatric perioperative cardiac arrest during paediatric cardiac surgery is from the analysis of severe anaesthesia-related critical incidents from the SAPSOS study, a multi-centre

prospective study conducted over a 2-week period across 43 hospitals in South Africa[7]. The incidence of cardiac arrest in our study cohort is much lower compared to the findings of the SAPSOS study which reported an incidence of POCA of 6.0% (3/50) or 600.0 per 10,000 anaesthetics in patients aged <16 years undergoing cardiac surgery. These findings should be interpreted with caution due to the small number of cardiac surgeries within the SAPSOS study cohort. In comparison, a retrospective study of 15,253 patients under 17 years who underwent cardiac and non-cardiac surgeries over a 9-year period at a tertiary academic centre in Brazil reported a much lower incidence (33.4 per 10,000) of perioperative cardiac arrest during cardiac surgeries[5].

Further comparison with our findings is limited as the authors did not report on the total number of cardiac surgeries, specific cardiac lesions or operative procedures or details on the aetiology and outcomes following perioperative cardiac arrests during cardiac surgery. However, the authors did comment that complications due to cardiac surgery were a common cause of perioperative cardiac arrest. The authors also reported seven anaesthesia-related cardiac arrests within their entire patient cohort, though none of these occurred during cardiac procedures. These findings highlight the importance of defining the case mix and definitions used for perioperative cardiac arrest during cardiac surgery, to facilitate accurate interpretation of epidemiological studies on perioperative cardiac arrest in children undergoing cardiac surgery.

The most comprehensive data published focusing on POCA and outcomes in children undergoing cardiac surgery are from high-income country (HIC) settings. A large retrospective study of 92,881 anaesthetics conducted in a single centre in the United States reported a similar incidence of perioperative cardiac arrest (127 per 10,000) in children undergoing cardiac procedures in comparison with our findings[17]. However, if cases in which there was failure to separate from CPB

were excluded, the overall incidence of perioperative cardiac arrest during cardiac surgery was much lower (40.1 per 10,000) when compared to our study cohort. Another retrospective study of 5,123 anaesthetics for congenital cardiac surgery from a large paediatric tertiary referral centre in the United States reported an overall incidence of cardiac arrest of 78.6 per 10,000 anaesthetics[12]. This incidence of cardiac arrest is lower than our findings, and comparable as the investigators also excluded patients who failed to wean from CPB. The median patient age in this study (2.9 months) and median weight (4.0 kg) of patients who suffered a cardiac arrest were also similar to our patient cohort. The authors noted that the highest risk procedures were truncus arteriosus repair, modified Blalock-Taussig shunt operation for pulmonary atresia with intact ventricular septum, neonates with coarctation or interruption of the aorta with ventricular septal defect repair, and Stage I palliation for hypoplastic left heart syndrome. Unfortunately, we could not comment on the relative incidence of cardiac arrest per type of procedure, but we did find that the most common surgical procedures during which cardiac arrest occurred were Tetralogy of Fallot repair and truncus arteriosus repair. It is important to note that given the limited resources in our setting, our institution does not offer surgery for hypoplastic left heart syndrome.

The POCA registry in the United States has provided further insights into the aetiology and outcomes of perioperative cardiac arrest and anaesthesia-related cardiac arrest in children with heart disease undergoing surgery. Similar to findings reported in other studies, younger age, significant comorbidities, and emergency surgery are independently associated with cardiac arrest in children undergoing both cardiac and non-cardiac surgery[18].

A subsequent analysis of the POCA registry described the characteristics and risk factors associated with anaesthesia-related cardiac arrest (ARCA) in children with acquired and congenital

heart disease[3]. In comparison to children without heart disease, those with heart disease who experienced ARCA were more likely to have a higher ASA physical status, and the arrest was more likely to be of cardiovascular origin. This differs from our findings, where equipment-related and medication-related causes were the most common aetiologies of ARCA. The authors also noted that patients with single ventricle physiology had the highest incidence of cardiac arrest.

The 24-hour mortality rate observed in our patient cohort (25.0%) was similar to the mortality rate (33%) reported by Ramamoorthy et al.[3] The authors noted that mortality was highest following cardiac arrest in patients with cardiomyopathy (50%) and aortic stenosis (62%). In contrast, our findings demonstrated that the highest mortality occurred in patients with pulmonary atresia (100%) and hypoplastic aortic arch (100%). However, it is important to consider these findings in the context of the limited number of patients who experienced ARCA in our study cohort.

The results of the study are reassuring, given the observation that overall paediatric perioperative mortality rates in South Africa have been reported to be almost ten times higher compared to high-income countries (HIC)[19]. It is important to acknowledge that the perioperative mortality rate in the study cohort would be higher if patients who died on the operating table due to an unsuccessful separation from CPB were included. It is possible that the availability of ECMO in the institution may have influenced the outcome in these patients, potentially reducing the overall incidence of perioperative mortality. Although a limited ECMO service was initiated at the RCWMCH in 2018, the ability to offer ECMO support remains frequently restricted by the lack of adequately trained staff and intensive care beds. Development of a more comprehensive ECMO services continues to be a focus towards improving outcomes in our patients undergoing cardiac surgery.

## 4. Limitations

This study has several major limitations. These findings are retrospective and represent outcomes from a single centre. Implications from this study and generalisability should be interpreted within this context. Due to the retrospective nature of these data the true incidence of perioperative cardiac arrest may have been over- or more likely, under-estimated. The statistical method did also not consider analysis of repeated measures which would likely have influenced the overall results. This was unfortunately not possible with the dataset.

Data for pre-operative and post-operative cardiac arrest was not captured, which may enable further understanding into the broader perioperative course of patients undergoing cardiac surgery in our institution. Further studies would be needed to further define the association between perioperative cardiac arrest and in-hospital mortality beyond the 24-hour postoperative period.

We were also unable to identify independent risk factors for perioperative cardiac arrest from our dataset, but this could be further evaluated using the cardiothoracic database. Comparison of the incidence of perioperative cardiac arrest in our cohort and other studies remains challenging due to differing definitions of the time period during which cardiac arrest occurs, the decision to include or exclude patients in whom death resulted as a failure to separate from CPB, as well as the small number of patients undergoing cardiac surgery included within these studies. The development of unified definitions and outcomes would aid the identification of patients at risk of cardiac arrest. Further studies are needed to advance insight into the aetiology of perioperative cardiac arrest in these patients and gain understanding into the longer-term outcomes following cardiac arrest.

## 5. Recommendations

In as much as the outcome of the study is encouraging, as shown by the difference in the previously reported incidence and the outcome of this study, the aim should be a continuous reduction in the incidence of cardiac arrest. A multipronged approach that considers patient factors, personnel and medication, monitoring and equipment and after care should be employed.

Early identification and optimisation of children with complex cardiac lesion is key. From the time the patient has been identified as a candidate for cardiac surgery, there should be multidisciplinary input, which includes the anaesthesia team.

Simulation has been shown to be an effective tool of improving technical and non-technical skills and performance of complex diverse teams. Regular multidisciplinary simulation involving all members of the cardiac team should be incorporated into the cardiac service.

Medication related cardiac arrests could be avoided by increased vigilance and meticulous preparation, and improved team communication. RCWMCH has already instituted various measures to minimise drug errors which is commendable. An audit into drug errors, potential causes and contributing factors is suggested.

## 6. Conclusion

This is first study reporting on the incidence and mortality of perioperative and anaesthesia-related cardiac arrest in children undergoing cardiac surgery in a high-volume centre in a LMIC. Important findings are a high incidence of cardiac arrest during paediatric cardiac surgery in comparison to a high-income setting, and a high mortality rate associated with cardiac arrest. Cardiac arrests can be significantly reduced by applying a multipronged approach with a greater emphasis on team work and other mitigating factors such as patient care, personnel, monitoring and medication and after care. However, further studies are needed to advance insight into the aetiology of perioperative cardiac arrest in these patients and gain understanding into the longer-term outcomes following cardiac arrest.

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