6-2019

# Unanticipated admissions to paediatric cardiac critical care after cardiac catheterisations.

Erin Peebles

Michael R Miller

Lee N Benson

Tilman Humpl

*Cardiology in the Young*

**cambridge.org/cty**

# Unanticipated admissions to paediatric cardiac critical care after cardiac catheterisations

Erin Peebles[1,2], Michael R. Miller[3], Lee N. Benson[4] and Tilman Humpl[5]

[1]Department of Pediatrics, Children's Hospital London Health Science Center, Western University, London, Canada; [2]Department of Critical Care Medicine, The Hospital for Sick Children, University of Toronto, Toronto, Ontario, Canada; [3]Department of Pediatrics, The Children's Hospital, Children's Health Research Institute, Western University, London, Canada; [4]Department of Pediatrics, Division of Cardiology, The Hospital for Sick Children, University of Toronto, Toronto, Ontario, Canada and [5]Department of Critical Care Medicine and Department of Pediatrics, Division of Cardiology, The Hospital for Sick Children, University of Toronto, Toronto, Ontario, Canada

## Original Article

**Cite this article:** Peebles E, Miller MR, Benson LN, and Humpl T (2019) Unanticipated admissions to paediatric cardiac critical care after cardiac catheterisations. *Cardiology in the Young* **29**: 777–786.
doi: 10.1017/S1047951119000817

Received: 14 December 2016
Revised: 3 March 2019
Accepted: 13 March 2019

**Key words:**
Children; cardiac catheterisation critical care; extracorporeal membrane oxygenation

**Author for correspondence:**
Dr. Tilman Humpl, The Hospital for Sick Children, 555 University Avenue, Toronto ON, M5G 1X8, Canada. Tel: +1 416 813 4918; Fax: +1 416 813 7299;
E-mail: tilman.humpl@sickkids.ca

**Abstract**

*Objectives:* Cardiac catheterisation is commonly used for diagnosis and therapeutic interventions in paediatric cardiology. The inherent risk of the procedure can result in unanticipated admissions to critical care. Our goals were to provide a qualitative description of characteristics and evaluation of children admitted unexpectedly to the cardiac critical care unit (CCCU). *Methods:* A retrospective single centre review of cardiac catheterisation procedures was done between 1 January, 2003 and 30 April, 2013. *Results:* Of 9336 cardiac catheterisations performed, 146 (1.6%) were admitted from the catheterisation laboratory to the CCCU and met inclusion criteria. Of these 146 patients, 117 (1.3%) met criteria for unexpected admission and 29 (0.3%) were planned admissions. The majority admitted unexpectedly were below 1 year of age without co-morbidity aside from heart disease. Patients with planned admissions were significantly more likely to have single ventricle physiology, undergoing angiography or transferred for observation. Most unplanned admissions were triggered by interventional catheterisations or procedure-related complications. Patients received mechanical ventilation as the main CCCU management. Eighteen patients needed either cardiopulmonary resuscitation and/or extracorporeal membrane oxygenation during their catheterisation. About 106/117 (90.6%) patients survived to hospital discharge with no deaths in the planned admission group. *Conclusions:* Admission to CCCU following cardiac catheterisation was uncommon and tended to occur in younger children undergoing interventional procedures. Outcomes did not differ between patients experiencing planned and unplanned CCCU admission. Ongoing development of risk stratification tools may help to decrease unplanned CCCU admissions. Further studies are needed to determine whether unplanned admission following paediatric cardiac catheterisation should be utilised as a quality indicator.

Cardiac catheterisation is one of the main diagnostic and interventional tools in paediatric cardiology. However, despite increasing experience with cardiac catheterisation, there remains a risk of morbidity and mortality with increasing complexity of patients. In most instances of cardiac catheterisation, regular post-procedure care is provided in a recovery room or regular ward with possible discharge on the same day. In some patients, a planned admission to critical care is anticipated either by anaesthesia or by cardiology prior to the intervention. There remains a third group of patients whose admission to the critical care setting is unanticipated.

Unanticipated admission to a higher level of care is an unintended complication which can result in the prolongation of hospital stay, regardless of whether it is caused by healthcare management or the patient's disease. Unplanned intensive care admission is a validated clinical quality indicator in surgery. Unplanned admissions include all patients admitted unexpectedly to the intensive care unit from a lower level of care and has been recommended as a measure of patient safety and effectiveness of care.[1,2] Tracking unplanned intensive care admissions can detect patients who may have suffered an iatrogenic complication.[2–7] Unplanned admissions negatively impact administrative and clinical workflow, and make facilitating bed space availability more difficult. To our knowledge, unanticipated admission has not been studied as a quality indicator in paediatric cardiac catheterisation.

It is largely unknown in the current literature which children are admitted unexpectedly to the critical care unit after a cardiac catheterisation and which factors during the procedure are associated with the admission to the cardiac critical care unit (CCCU). A child experiencing a complication is at higher risk for admission to the CCCU. Age <1 year has been found to be a risk factor for complications in some studies,[8–11] but findings are inconsistent. Lower body weight, having cyanotic or complex CHD, higher technical challenge, critical clinical condition and operator in training have also been identified as risk factors for complications.[12,13]

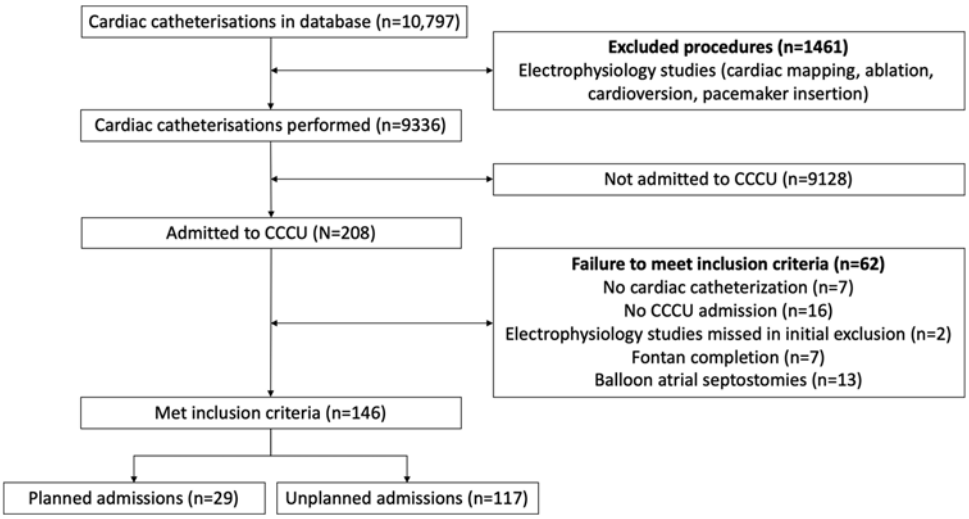


**Figure 1.** Exclusion and inclusion of patients

Interventional procedures have been associated with increased risk compared to diagnostic procedures in some studies,[9,11,13] but findings are again inconsistent.[10,14]

Determination of this cohort of patients may help with risk-stratification, and the avoidance of unplanned intensive care admissions. The objectives of this study were to explore the characteristics of children admitted unexpectedly to the paediatric CCCU after cardiac catheterisation over a 10-year period and evaluate the usefulness of tracking unplanned intensive care admissions in this patient population. We hypothesise that unplanned intensive care admissions will be a useful quality indicator for paediatric cardiac catheterisation.

## Material and methods

All procedures were performed at the Hospital for Sick Children in Toronto, Ontario, Canada, which is a quaternary care centre with the largest paediatric cardiac catheterisation centre in Canada and carried out by senior cardiologists with a previous additional training and focus on cardiac catheterisation and attended by cardiac anaesthetists. Cardiology fellows were not involved in the primary performance of these procedures. The retrospective study was approved by the local research ethics board.

Databases from both the Division of Cardiology and Department of Critical Care Medicine were searched to identify all children (birth to 18 years) who were admitted to the CCCU after cardiac catheterisation between 1 January, 2003 and 30 April, 2013. An admission was considered unanticipated if there was not a CCCU bed pre-booked or there was no mention of possible critical care admission in the anaesthesia record. There were no standardised criteria for planned CCCU admission – the decision to pre-book a bed was at the discretion of the attending anaesthetist and cardiologist. Exclusion criteria included children who went from the CCCU or operating room to the catheterisation laboratory and then returned to the CCCU, as these patients would be expected to be re-admitted to the CCCU. Children who underwent electrophysiology studies or a Fontan completion procedure in the catheterisation lab were also excluded. Children who underwent a balloon atrial septostomy in the catheterisation lab were excluded as these are routinely done at the bedside in the CCCU. Only patients transferred from the catheterisation lab directly to the CCCU were included – patients who were transferred to the cardiac ward or another ward and then admitted to the CCCU within 24–48 hours were not tracked. Patients who underwent multiple procedures had each encounter treated as a discrete event. Patients who went to the catheterisation lab for non-cardiac procedures were also excluded. Medical records were reviewed for demographic data, underlying cardiac diagnosis, past medical history distinct from the underlying cardiac diagnosis (e.g. chromosomal disorders, malignancy, congenital diaphragmatic hernia and prematurity), the planned procedure, procedural complication (i.e. anaesthesia related or procedure related), management in the CCCU, length of stay in the CCCU, total hospital stay and survival to hospital discharge.

SPSS software, version 23 (IBM Corporation, Armonk, NY, United States of America) was used for statistical analysis. Mann–Whitney U-tests and chi-square tests were used to examine relations between continuous and categorical variables, respectively; p-values $<0.05$ were considered statistically significant.

## Results

A total of 10,797 procedures were recorded in the cardiac catheterisation laboratory database during the study period. Excluded cases are summarised in Fig 1. Of the 9336 cardiac catheterisations, 146 (1.6%) were admitted from the catheterisation laboratory to the CCCU and met inclusion criteria. Of these 146 patients, 117 (1.3%) met criteria for unexpected admission and 29 (0.3%) were planned admissions.

Demographic and diagnostic data of planned and unplanned CCCU admissions are presented in Table 1. There were no significant differences in gender, age or weight for unplanned versus planned admissions. Children ranged in age from 7 days old to 18 years old (median 7.4 months) for unplanned admissions and between 9 days of age and 17 years of age (median 6.5 months) for planned admissions. Weight ranged from 2.07 kg to 102.8 kg for unplanned admissions (median 5.6 kg) and 2.8 kg to 100.6 kg (median 6.5 kg) for planned admissions. Significantly more patients with planned admissions had single ventricle physiology ($p<0.001$). Length of stay in the CCCU did not differ significantly between the two groups of patients. Eleven (9.4%) patients with unplanned admissions did not survive to hospital discharge.

**Table 1.** Demographic data of planned and unplanned CCCU admissions post-cardiac catheterisation

| Characteristic | Unplanned CCCU admissions (n = 117) | Planned CCCU admissions (n = 29) | P-value |
|---|---|---|---|
| **Gender** | | | 0.051 |
| Female | 68 (58%) | 11 (38%) | |
| Male | 49 (42%) | 18 (62%) | |
| **Age (years)** | | | 0.550 |
| < 1 | 72 (62%) | 21 (72%) | |
| 1–5 | 26 (22%) | 5 (17%) | |
| 6–18 | 19 (16%) | 3 (10%) | |
| Median (IQR) | 0.62 (0.19, 2.57) | 0.54 (0.40, 2.79) | 0.793 |
| **Weight (kg)** | | | |
| Median (IQR) | 5.6 (3.9, 12.4) | 6.5 (5.2, 11.7) | 0.385 |
| **Cardiac diagnosis** | | | <0.001 |
| No structural heart disease | 11 (9%) | 0 (0%) | |
| Biventricular physiology | 65 (56%) | 8 (28%) | |
| Single ventricle physiology | 26 (22%) | 21 (72%) | |
| Post-cardiac transplant | 5 (4%) | 0 (0%) | |
| Pulmonary hypertension | 10 (9%) | 0 (0%) | |
| **Past medical history** | | | 0.271 |
| No non-cardiac co-morbidities | 65 (56%) | 23 (82%) | |
| 22q11 deletion | 9 (8%) | 1 (4%) | |
| Chromosomal abnormality | 8 (7%) | 1 (4%) | |
| Malignancy | 3 (3%) | 0 (0%) | |
| Congenital diaphragmatic hernia | 1 (1%) | 0 (0%) | |
| Prematurity | 10 (9%) | 0 (0%) | |
| Other* | 21 (18%) | 3 (11%) | |
| **Length of stay in CCCU (days)** | | | |
| Median (IQR) | 2 (1, 6) | 5 (1, 9) | 0.092 |

CCCU = cardiac critical care unit; IQR = interquartile range; SD = standard deviation.
*Other past medical history = biliary atresia, developmental delay, autism, tuberculosis, gastroesophageal reflux, asthma, intra-uterine growth restriction, congenital cystic adenomatoid malformation, tracheobronchomalacia, vesicoureteral reflux, necrotising enterocolitis, Alagille syndrome, Doose syndrome, hypogammaglobulinemia, G-tube feeds, asplenia, chronic renal failure, cystic fibrosis, omphalocele, subglottic stenosis.

The median interquartile range (IQR) weight of these patients was 5.9 kg (4.8, 13.6), and the median (IQR) age was 325 days (181, 809) (Table 2). All patients with a planned admission survived, but there was no statistically significant difference in survival compared to patients with unplanned admission to the CCCU.

Procedural outcome data are summarised in Table 3. The majority of admissions to the CCU, both planned and unplanned, followed interventional catheterisations. All patients with a planned admission were intubated for the catheterisation; about 114 of the 117 unplanned admissions were intubated. Three patients undergoing pericardiocentesis were given local anaesthetic. Significantly more patients in the planned cohort were undergoing angiography; there were otherwise no differences in the planned procedure. There were 43 (37%) anaesthesia-related complications resulting in unplanned CCCU admission; about 37 (86%) of these were caused by complications with extubation. All patients with planned admissions who had anaesthesia complications had problems with extubation and were transferred intubated; there were no complications with induction in this group. Hemodynamic instability during the catheterisation was the most frequent procedure-related complication for unplanned admissions, and this was significantly more common than in planned admissions (p=0.007). Patients were transferred without complication for observation in the CCCU significantly more often in the planned versus unplanned admission group (p<0.001). It was not clearly documented in the medical record why observation in the CCCU was necessary. The database did not contain information on whether the complications were considered avoidable or not.

Eighteen patients with unanticipated admissions received cardiopulmonary resuscitation or extracorporeal membrane oxygenation during the procedure. The median (IQR) weight of these patients was 5.5 kg (4.3, 11.4), and the median (IQR) age was 206 days (90.8, 796) (Table 4). One patient with a planned admission received extracorporeal membrane oxygenation; this was not statistically significant from unplanned admissions. The patient who

**Table 2.** Characteristics of patients admitted to CCCU who did not survive to hospital discharge

| Weight (kg) | Age | Cardiac diagnosis | Major past medical history | Planned procedure | Complication | CCCU management | Cause of death | LOS in CCCU (days) | LOS in Hospital before Death (days) |
|---|---|---|---|---|---|---|---|---|---|
| 3.3 | 6m | DORV sub-aortic VSD | Prematurity | Pulmonary hypertension study | Hemodynamic instability | Ventilation | Died 2 weeks post-surgical repair of DORV | 5 | 16 |
| 3.8 | 2m 5d | Tricuspid atresia with ASD, VSD, hypoplastic arch | | Stent of PDA | Device-related (ST depression and hypotension when stent passed. Underwent sternotomy and direct cannulation of MPA) | Ventilation | Extubated 3 days post cath, transfer to ward 1 week later. Cardiac arrest 1 day later with neurologic injury and withdrawal of care | 9 | 55 |
| 4.8 | 6m | Pulmonary atresia, TGA, hypoplastic left ventricle | NEC with ileostomy | Diagnostic | Hemodynamic instability | Ventilation | Transferred to ward 1 day post-cath. Arrested on floor 2 days later. Back to CCCU on ECMO. Did not regain consciousness, one way extubation | 25 | 25 |
| 5.3 | 9m | Absent RPA, aorto-pulmonary collaterals | | Diagnostic | Pulmonary haemorrhage | Observation | Arrived extubated to CCCU and transferred to floor same day. Acute pulmonary haemorrhage that night causing cardiac arrest. On ECMO. Brain death declared following day | 0 | 1 |
| 5.6 | 5.5m | Pulmonary atresia, tricuspid atresia | T-cell ALL | Diagnostic (? BT shunt stenosis) | Device-related (severe LPA stenosis - LPA balloon–> thrombus moved to BTS and LPA causing desaturation – required heparin for possible PE, fluid boluses) | Ventilation | Extubated 1 day post cath., developed fever, desaturation and cardiac arrest 3 days later. On ECMO but severe neurologic injury and ECMO withdrawn | 5 | 5 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5.9 | 10.5m | PDA, pulmonary hypertension | Prematurity | Pulmonary hypertension study | Uncomplicated, transferred intubated | Inotropes and ventilation | Pulmonary hypertensive crisis overnight; remained ventilated, muscle relaxed, on nitric oxide until OR (Coles procedure) ~10 days later. Death from right heart failure | 76 | 78 |
| 6.8 | 11m | Left atrial isomerism, ASD, multiple VSD | Biliary atresia, tracheobronchomalacia | Perimembranous VSD closure | Uncomplicated, transferred intubated | Inotropes and ventilation | Unknown; >90 days post catheterization | 19 | 115 |
| 10.2 | 1y 7m | Pulmonary atresia with VSD, MAPCA | DiGeorge, microdeletion of XXII | Diagnostic (branch PA not well seen, could not advance catheter) | Device-related (during manipulation around RVOT – bradycardia and hypotension, no effusion, embolus in LCA. tPa given into LCA. ECMO initiated and transferred to CCCU) | ECMO | On ECMO, intractable bleeding. Abdominal compartment syndrome and hemoperitoneum, blood from LV. Unable to resuscitate | 3 | 3 |
| 13.6 | 2y 2.5m | AVSD, coarctation of the aorta | Trisomy 21 | Diagnostic | Observation | Observation | Arrived extubated, but developed endocarditis. To OR for replacement of LAVV. ECMO run post OR. Died of LV failure and septic shock | 2 | 38 |
| 33.9 | 14y 2m | AVSD | | Closure of paravalvular leak | Hemodynamic instability | Inotropes and ventilation | Arrived intubated, but extubated and remained on amiodarone. Transferred to floor, but readmitted with septic hip, upper GI bleed, renal failure. On renal replacement, bled and brain death | 1 | 77 |
| 42.9 | 14y 7.5m | Pulmonary hypertension | Developmental delay, hypogammaglobulinemia | Pulmonary hypertension study | Cardiac arrest recovering from anaesthesia | ECMO | Remained on ECMO, cooled x36hrs, no cough/gag; pupils fixed and dilated. Brain death | 3 | 3 |

ASD = atrial septal defect; AVSD = atrioventricular septal defect; CCCU = cardiac critical care unit; CPR = cardiopulmonary resuscitation; d = day; DORV = double outlet right ventricle; ECMO = extracorporeal membrane oxygenation; LOS = length of stay; MAPCA = major aorto-pulmonary collateral artery; ; m = month; PDA = patent ductus arteriosus; PS = pulmonary stenosis; RPA = right pulmonary artery; TGA = transposition of the great arteries; VSD = ventricular septal defect; Wt. = weight; y = year.

**Table 3.** Procedural outcome data

| | Unplanned CCCU admissions (n = 117) Frequency (%) | Planned CCCU admissions (n = 29) Frequency (%) | P-value |
|---|---|---|---|
| **Planned intervention** | | | <0.001 |
| Diagnostic | 32 (27%) | 5 (17%) | |
| Pulmonary hypertension study | 15 (13%) | 0 (0%) | |
| Dilation of PV (including RF) | 12 (10%) | 0 (0%) | |
| Angiography | 4 (7%) | 10 (35%) | |
| Pericardiocentesis | 8 (7%) | 2 (7%) | |
| Endomyocardial biopsy | 15 (13%) | 0 (0%) | |
| Other* | 38 (33%) | 12 (41%) | |
| **Complication resulting in CCCU transfer** | | | <0.001 |
| Anaesthesia | 43 (37%) | 13 (45%) | |
| Hemodynamic instability | 37 (32%) | 2 (7%) | |
| Reperfusion injury or pulmonary haemorrhage | 9 (8%) | 0 (0%) | |
| Device-related | 18 (15%) | 1 (3%) | |
| No complication, observation required | 10 (9%) | 13 (45%) | |
| **CPR/ECMO required during catheterisation** | 18 (15%) | 1 (3%) | 0.123 |
| **Management in CCCU** | | | 0.118 |
| Observation | 21 (18%) | 11 (38%) | |
| Ventilation | 67 (57%) | 14 (48%) | |
| Ventilation and inotropes | 22 (19%) | 3 (10%) | |
| ECMO | 7 (6%) | 1 (3%) | |
| **Survival to hospital discharge** | 106 (91%) | 29 (100%) | 0.122 |

CCCU = cardiac critical care unit; CPR = cardiopulmonary resuscitation; ECMO = extracorporeal membrane oxygenation; PV = pulmonary valve; RF = radiofrequency.
*Other = stenting, dilation, occlusion, embolisation.

received extracorporeal membrane oxygenation in the planned admission group was a 5-month-old, 5 kg baby with hypoplastic left heart syndrome undergoing a hemodynamic study. A stent was placed in the RV-PA conduit; however, this failed and the child received extracorporeal membrane oxygenation and then proceeded to a Blalock-Taussig shunt. Most patients receiving extracorporeal membrane oxygenation or cardiopulmonary resuscitation did not have additional co-morbidities in addition to their cardiac disease.

## Discussion

To our knowledge, this is the first report on unanticipated admissions to the critical care setting after cardiac catheterisation in children. In our experience, admissions to the CCCU were uncommon, and most of these admissions were unplanned. The majority of admissions (planned and unplanned) occurred in children who were under 1 year of age, with no medical comorbidity in addition to their cardiac disease. Genetic syndromes were present in 17 patients with unplanned admissions, with 9 patients having 22q11 deletion. The only significant difference between unplanned and planned patients was that more patients with planned admissions had single ventricle physiology. There were no significant differences in length of stay in the CCCU, and need for cardiopulmonary resuscitation or extracorporeal membrane oxygenation during the procedure or survival to hospital discharge in planned admissions versus unplanned admissions.

Our results indicate that there is a cohort of children whose admission is unexpected, and that tracking this cohort is an achievable target. Unanticipated admissions to an intensive care area should be avoided where possible. CCCU clinicians and leaders prefer to know about admissions in advance to ensure bed space availability and resource planning. Planned CCCU admissions also allow the clinical team to review patient data beforehand.

Risk stratification is an ongoing and quickly developing area of research in paediatric cardiac catheterisation, as clinicians attempt to delineate which patients are at increased risk for serious adverse events, which can potentially lead to CCCU admission. The Congenital Cardiac Catheterization Project on Outcomes (C3PO) Improving Paediatric and Adult Congenital Treatment (IMPACT) and the Congenital Cardiac Interventional Study Consortium (CCISC) registries are recent attempts to develop risk stratification scores.[15–17] Data from the C3PO registry showed that procedure-type risk group, hemodynamic indicators, age below 1 year and weight under 5 kg were associated with increased risk of high-severity adverse events.[15,18–20] These data were used to develop the Catheterization for Congenital Heart Disease

**Table 4.** Patients who received CPR or ECMO during cardiac catheterization

| Wt. (kg) | Age | Cardiac diagnosis | PMHx | Procedure | Complication | Received CPR alone or CPR + ECMO? | ICU management | LOS in CCCU (days) | LOS in hospital (days) | Survival to hospital D/C? |
|---|---|---|---|---|---|---|---|---|---|---|
| 2.7 | 1m 18d | Pulmonary atresia with VSD | Probable DiGeorge | Diagnostic | Anaesthesia-related | CPR | Ventilation | 2 | 5 | Y |
| 3.26 | 1m 11d | DORV, unbalanced AVSD, absent left AVV, hypoplastic LV, subvalvar PS | | Balloon dilation of RVOT | Hemodynamic instability | CPR | Ventilation and inotropes | 3 | 14 | Y |
| 3.46 | 16d | Pulmonary atresia with AVSD and PDA | | RF balloon dilation of PV | Device-related (perforation of anterior wall of RV) | CPR | Ventilation | 9 | 25 | Y |
| 4.2 | 5m 4d | Double inlet right ventricle with TGA, VSD | | BT shunt assessment and possible stent insertion | Hemodynamic instability | ECMO | ECMO | 6 | 49 | Y |
| 4.32 | 7m 6d | Post-heart transplant | Chylothorax | EMB | Hemodynamic instability | CPR | Ventilation | 3 | 50 | Y |
| 4.6 | 5m 3d | Pulmonary stenosis; Bicuspid aortic valve with ASD | | Balloon dilation of PV | Device-related (perforation of RVOT) | CPR | Ventilation | 8 | 29 | Y |
| 4.9 | 2m 6d | Transposition of the great arteries | | Diagnostic | Hemodynamic instability | CPR | Ventilation | 1 | 11 | Y |
| 5.2 | 4m 21d | Hypoplastic left heart syndrome | | Diagnostic | Anaesthesia-related: hypotension/bradycardia on induction | CPR | Ventilation | 3 | 78 | Y |
| 5.25 | 3m 8d | Dilated cardiomyopathy | | EMB | Device-related (perforation of IVS, LV free wall and RV free wall) | CPR | Ventilation | 7 | 17 | Y |

(*Continued*)

**Table 4.** (*Continued*)

| Wt. (kg) | Age | Cardiac diagnosis | PMHx | Procedure | Complication | Received CPR alone or CPR + ECMO? | ICU management | LOS in CCCU (days) | LOS in hospital (days) | Survival to hospital D/C? |
|---|---|---|---|---|---|---|---|---|---|---|
| 5.82 | 6m 10d | Pulmonary atresia; intact ventricular septum; tricuspid atresia | | Diagnostic | Device-related (shunt initially patent but clotted after instrumentation) | ECMO | ECMO | 7 | 12 | Y |
| 7 | 11m 12d | Post-heart transplant | Developmental delay | EMB | Device-related (perforation of superior caval vein) | CPR | Ventilation and inotropes | 2 | 7 | Y |
| 8.7 | 7m 12d | Primary pulmonary hypertension | | PH study | Hemodynamic instability | CPR | Ventilation and inotropes | 10 | 33 | Y |
| 9.4 | 11m 16d | No CHD. Pericardial effusion post-URTI | | Diagnostic | Hemodynamic instability (ruptured LV aneurysm) | ECMO | ECMO | 8 | 11 | Y |
| 10.2 | 1y 7m | Pulmonary atresia with VSD | DiGeorge | Diagnostic | Device-related (during manipulation around RVOT - bradycardia and hypotension, no effusion, embolus in LCA. tPa given into LCA) | ECMO | ECMO | 3 | 3 | N |
| 15 | 3y 11.5m | Post-heart transplant | | EMB | Device-related (perforation of RV free wall) | CPR | Ventilation | 2 | 4 | Y |
| 39.7 | 13y 8.5m | Post-heart transplant | Renal dysfunction | EMB | Hemodynamic instability | ECMO | ECMO | 7 | 74 | Y |
| 42.9 | 14y 7.5m | Primary pulmonary hypertension | Developmental delay; hypogammaglobulinemia | PH study | Cardiac arrest recovering from anaesthesia | ECMO | ECMO | 3 | 3 | N |
| 102.8 | 13y 5m | Tetrology of Fallot | Obesity | RVOT stenting | Anaesthesia-related: cardiac arrest on induction | CPR | Ventilation | 6 | 15 | Y |

ASD = atrial septal defect; AVSD = atrioventricular septal defect; AW = atrioventricular valve; CCCU = cardiac critical care unit; CPR = cardiopulmonary resuscitation; d = day; DORV = Double outlet right ventricle; ECMO = extracorporeal membrane oxygenation; EMB = endomyocardial biopsy; IVS = intact ventricular septum; LOS = length of stay; LV = left ventricle; m = month; PDA = patent ductus arteriosus; PS = pulmonary stenosis; TGA = transposition of the great arteries; VSD = ventricular septal defect; Wt. = weight; y = year.

Adjustment for Risk Method (CHARM). CHARM was developed to adjust for varying case complexities and allow the comparison of adverse events among sites.[21] The IMPACT registry identified patient age, renal insufficiency, single ventricle physiology, procedure-type risk group and hemodynamic indicators as important variables for risk stratification.[22] The CCISC registry data were analysed to develop the Catheterization Risk Score for Pediatrics (CRISP), with the goal of predicting which individual patients were at risk for a serious adverse event. A higher score was indicative of a higher-risk category. Age, weight, need for inotropic support, uncontrolled or multi-organ failure, physiologic category, pre-catheterisation diagnosis, procedural category and type were all found to be predictive of a serious adverse event.[17]

Our results are in keeping the risk stratification models developed in studies mentioned earlier. The majority of our unplanned admissions were under 1 year of age, approximately 5 kg in weight and without serious co-morbid conditions. The majority of planned admissions had no non-cardiac comorbidities; thus, other pre-existing medical conditions were not a determining factor in pre-booking a CCCU bed in our study. We did not collect measures of physiologic data in detail (pre-catheterisation oxygen saturation, haemoglobin, etc.). The majority of patients in our cohort who received extracorporeal membrane oxygenation or cardiopulmonary resuscitation were also under 1 year of age, although median weight was slightly greater than 5 kg. Using CRISP scoring, the majority of patients who received extracorporeal membrane oxygenation or cardiopulmonary resuscitation were risk category 2 (medium risk) for pre-catheterisation diagnosis, and risk category 1 for procedural category[17] (lower risk). A useful quality indicator may be to track unplanned intensive care admissions going forward as scoring tools such as CRISP become more widespread. Because the CRISP scoring tool was released after our data collection was completed, we did not collect all elements of the scoring system. Future studies that assess the correlation between elevated CRISP score and unplanned intensive care admissions may help facilitate future efforts to reduce these unplanned admissions.

There were 11 deaths (9.4%) among the cohort of patients admitted unexpectedly to the CCCU. Three of these patients died within 48 hours of the catheterisation, but deaths may not have been directly related to the procedure. Published death rates due to cardiac catheterisation are low (ranging from 0.29 to 1.6%); however, our cohort is not directly comparable to these results as we looked only at unexpected admissions to the CCCU.[8,15,23,24]

Limitations of this study included its retrospective nature, single-centre design and observational methods. Thus, we were unable to comment on causality and were limited by a small sample size. As well, given the single-centre design, the generalisability of the findings to other centres is limited. We were dependent on written records to determine unplanned intensive care admissions and therefore may have included patients where the decision to admit was planned, but not recorded. As well, as there were no clinical criteria in place to determine whether a CCCU bed should be pre-booked, and given the small sample size, our comparison of planned and unplanned admissions was limited. We did not collect physiologic data, such as ejection fraction and pre-catheterisation saturation, limiting our ability to comment on the overall health of patients. We were limited to commenting on whether they had other co-morbidities in addition to their cardiac diagnosis, which may not be representative of their actual state of health. Our study population focused on children admitted to the CCCU post-cardiac catheterisation, and the sample size was in keeping with other published studies.[15,25]

## Conclusions

Unanticipated admissions to the CCCU in our setting were uncommon, and most of these were unscheduled. Outcomes did not differ between patients who had scheduled and unscheduled admissions. The majority of children did not have other co-morbidities in addition to their cardiac diagnosis. Children who had a planned admission to the CCCU were more likely to have single ventricle physiology and to be transferred for observation compared to children with unplanned admission. About 90.6 % of children admitted unexpectedly to the CCCU after catheterisation survived to hospital discharge, with only three deaths within 48 hours of the procedure. Stratification tools such as IMPACT and CRISP should allow more accurate predictions of patients at risk for serious adverse events. Further study using these robust scoring tools will determine if unanticipated admissions to the CCCU after cardiac catheterisation should be considered as part of a quality indicator to ensure accurate risk stratification and high quality of care. Minimising unplanned CCCU admissions may help to optimise workflow and resource allocation in the CCCU.

**Acknowledgement.** None

**Conflicts of Interest.** None

**Financial Support.** This research received no specific grant from any funding agency, commercial, or not-for-profit sectors.

**Ethical Standards.** The authors assert that all procedures contributing to this work comply with the ethical standards of the relevant national guidelines on human experimentation and with the Helsinki Declaration of 1975, as revised in 2008, and has been approved by the Institutional Review Board.

## References

1. Landry EK, Gabriel RA, Beutler S, Dutton RP, Urman RD. Analysis of unplanned intensive care unit admissions in postoperative pediatric patients. J Intensive Care Med 2017; 32(3): 204–211. doi: 10.1177/0885066616661152.
2. Haller G, Myles PS, Langley M, Stoelwinder J, McNeil J. Assessment of an unplanned admission to the intensive care unit as a global safety indicator in surgical patients. Anaesth Intensive Care 2008; 36(2): 190–200.
3. Collopy BT. Clinical indicators in accreditation: an effective stimulus to improve patient care. Int J Qual Heal Care 2000; 12(3): 211–216. doi: 10.1093/intqhc/12.3.211.
4. Lehmann LS, Puopolo AL, Shaykevich S, Brennan TA. Iatrogenic events resulting in intensive care admission: frequency, cause, and disclosure to patients and institutions. Am J Med 2005; 118(4): 409–413. doi: 10.1016/j.amjmed.2005.01.012.
5. Mercier E, Giraudeau B, Giniès G, Perrotin D, Dequin PF. Iatrogenic events contributing to ICU admission: a prospective study. Intensive Care Med 2010; 36(6): 1033–1037. doi: 10.1007/s00134-010-1793-9.
6. Marquet K, Claes N, De Troy E, et al. One fourth of unplanned transfers to a higher level of care are associated with a highly preventable adverse event: a patient record review in six Belgian hospitals. Crit Care Med 2015; 43(5): 1053–1061. doi: 10.1097/CCM.0000000000000932.
7. Australian Council on Healthcare Standards (ACHS). Australasian Clinical Indicator Report: 2007–2014. 16th ed. The Australian Council on Healthcare Standards, Sydney, Australia, 2015.
8. Yılmazer M, Üstyol A, Guven B, et al. Complications of cardiac catheterization in pediatric patients: a single center experience. Turk J Pediatr 2012; 54: 478–485.
9. Vitiello R, Mccrindle BW, Nykanen D, Freedom RM, Benson LN. Complications associated with pediatric cardiac catheterization. J Am Coll Cardiol 1998; 32(5): 1433–1440. doi: 10.1016/S0735-1097(98)00396-9.

10. Tavli V, Kayhan B, Okur FF, Kirman M, Tekdoğan M. Complications of pediatric cardiac catheterization: 18-month study. Turk J Pediatr 2000; 42(4): 294–297.
11. Mehta R, Lee K-J, Chaturvedi R, Benson L. Complications of pediatric cardiac catheterization: a review in the current era. Catheter Cardiovasc Interv 2008; 72(2): 278–285. doi: 10.1002/ccd.21580.
12. O'Byrne ML, Glatz AC, Shinohara RT, et al. Effect of center catheterization volume on risk of catastrophic adverse event after cardiac catheterization in children. Am Heart J 2015; 169(6): 823–832.e5. doi: 10.1016/j.ahj.2015.02.018.
13. Mori Y, Takahashi K, Nakanishi T. Complications of cardiac catheterization in adults and children with congenital heart disease in the current era. Heart Vessels 2013; 28(3): 352–359. doi: 10.1007/s00380-012-0241-x.
14. Phillips BL, Cabalka AK, Hagler DJ, Bailey KR, Cetta F. Procedural complications during congenital cardiac catheterization. Congenit Heart Dis 2010; 5(2): 118–123. doi: 10.1111/j.1747-0803.2010.00385.x.
15. Bergersen L, Marshall A, Gauvreau K, et al. Adverse event rates in congenital cardiac catheterization – a multi-center experience. Catheter Cardiovasc Interv 2010; 75(3): 389–400. doi: 10.1002/ccd.22266.
16. Vincent RN, Moore J, Beekman RH, et al. Procedural characteristics and adverse events in diagnostic and interventional catheterisations in paediatric and adult CHD: initial report from the IMPACT Registry. Cardiol Young 2016; 26(1): 70–78. doi: 10.1017/S1047951114002637.
17. Nykanen DG, Forbes TJ, Du W, et al. CRISP: catheterization risk score for pediatrics: a report from the Congenital Cardiac Interventional Study Consortium (CCISC). Catheter Cardiovasc Interv 2016; 87(2): 302–309. doi: 10.1002/ccd.26300.
18. Bergersen L, Gauvreau K, Marshall A, et al. Procedure-type risk categories for pediatric and congenital cardiac catheterization. Circ Cardiovasc Interv 2011; 4(2): 188–194. doi: 10.1161/CIRCINTERVENTIONS.110.959262.
19. Lin CH, Hegde S, Marshall AC, et al. Incidence and management of life-threatening adverse events during cardiac catheterization for congenital heart disease. Pediatr Cardiol 2014; 35(1): 140–148. doi: 10.1007/s00246-013-0752-y.
20. Backes CH, Cua C, Kreutzer J, et al. Low weight as an independent risk factor for adverse events during cardiac catheterization of infants. Catheter Cardiovasc Interv 2013; 82(5): 786–794. doi: 10.1002/ccd.24726.
21. Bergersen L, Gauvreau K, Foerster SR, et al. Catheterization for Congenital Heart Disease Adjustment for Risk Method (CHARM). JACC Cardiovasc Interv 2011; 4(9): 1037–1046. doi: 10.1016/j.jcin.2011.05.021.
22. Jayaram N, Beekman RH, Benson L, et al. Adjusting for risk associated with pediatric and congenital cardiac catheterization: a report from the NCDR IMPACT registry. Circulation 2015; 132(20): 1863–1870. doi: 10.1161/CIRCULATIONAHA.114.014694.
23. Agnoletti G, Bonnet C, Boudjemline Y, et al. Complications of paediatric interventional catheterisation: an analysis of risk factors. Cardiol Young 2005; 15(4): 402–408. doi: 10.1017/S1047951105000843.
24. Bennett D, Marcus R, Stokes M. Incidents and complications during pediatric cardiac catheterization. Paediatr Anaesth 2005; 15(12): 1083–1088. doi: 10.1111/j.1460-9592.2005.01677.x.
25. Bergersen L, Gauvreau K, Jenkins KJ, Lock JE. Adverse event rates in congenital cardiac catheterization: a new understanding of risks. Congenit Heart Dis 2008; 3(2): 90–105. doi: 10.1111/j.1747-0803.2008.00176.x.