Characterizing cardiac arrest in children undergoing cardiac surgery: A single-center study

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ABSTRACT

Objectives: To characterize cardiac arrest in children undergoing cardiac surgery using single-center data from the Society of Thoracic Surgeons and Pediatric Advanced Life Support Utstein-Style Guidelines.

Methods: Patients aged 18 years or less having a cardiac arrest for 1 minute or more during the same hospital stay as heart operation qualified for inclusion (2002-2014). Patients having a cardiac arrest both before or after heart operation were included. Heart operations were classified on the basis of the first cardiovascular operation of each hospital admission (the index operation). The primary outcome was survival to hospital discharge.

Results: A total of 3437 children undergoing at least 1 heart operation were included. Overall rate of cardiac arrest among these patients was 4.5% ($n = 154$) with survival to hospital discharge of 84 patients (66.6%). Presurgery cardiac arrest was noted among 28 patients, with survival of 21 patients (75%). Among the 126 patients with postsurgery cardiac arrest, survival was noted among 84 patients (66.6%). Regardless of surgical case complexity, the median days between heart operation and cardiac arrest, duration of cardiac arrest, and survival after cardiac arrest were similar. The independent risk factors associated with improved chances of survival included shorter duration of cardiac arrest (odds ratio, 1.12; 95% confidence interval, 1.05-1.20; $P = .01$) and use of defibrillator (odds ratio, 4.51; 95% confidence interval, 1.08-18.87; $P = .03$).

Conclusions: This single-center study demonstrates that characterizing cardiac arrest in children undergoing cardiac surgery using definitions from 2 societies helps to increase data granularity and understand the relationship between cardiac arrest and heart operation in a better way. (*J Thorac Cardiovasc Surg* 2017;153:450-8)

Cardiac ICU at Arkansas Children's Hospital.

Central Message

Characterizing cardiac arrest using definitions from 2 societies helps to understand the relationship between cardiac arrest and heart operation.

Perspective

The major strength of our single-center study is the use of the Society of Thoracic Surgeons' definitions to characterize heart operations and the use of Pediatric Advanced Life Support Utstein-Style Guidelines to characterize cardiac arrest. Using definitions from 2 societies helps increase data granularity and understand the relationship between cardiac arrest and heart operation in a better way.

See Editorial Commentary page 459.

Cardiac arrest is not rare in pediatric patients, occurring in 2% to 6% of children admitted to a pediatric intensive care unit (ICU).¹⁻³ Children who undergo cardiac surgery are at greater risk of experiencing a cardiac arrest, with cardiac arrest occurring in 6% of infants in the postoperative period compared with less than 2% incidence of cardiac arrest in pediatric ICUs.⁴⁻⁷ It has further been

demonstrated that children with surgical-cardiac disease have significantly better survival to hospital discharge after an in-hospital cardiac arrest compared with children with medical-cardiac disease and noncardiac disease.⁷

Previous studies evaluating cardiac arrest in children undergoing cardiac surgery are limited by data on cardiac diagnoses, heart operations, definition of cardiac arrest, outcomes after cardiac arrest using Utstein-Style Guidelines (eg, return of spontaneous circulation, 24-hour

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Scanning this QR code will take you to supplemental table and video for this article.

Abbreviations and Acronyms

AHA	= American Heart Association
CPB	= cardiopulmonary bypass
CPR	= cardiopulmonary resuscitation
ECMO	= extracorporeal membrane oxygenation
ECPR	= extracorporeal cardiopulmonary resuscitation
GWTG-R	= Get With the Guidelines–Resuscitation
ICU	= intensive care unit
STS-EACTS	= Society of Thoracic Surgeons–European Association for Cardiothoracic Surgery

survival, survival at hospital discharge, good neurologic outcomes), and temporal relationship between heart operation and cardiac arrest.^{7–10} A comprehensive study evaluating this relationship using standardized definitions is missing from the current literature.

We sought to address these knowledge gaps by designing this single-center study to characterize cardiac arrest in children undergoing cardiac surgery using the Society of Thoracic Surgeons and Pediatric Advanced Life Support Utstein-Style Guidelines. The aim of this study was to evaluate the incidence of cardiac arrest and Utstein's outcomes after cardiac arrest in children undergoing heart operations of varying complexity.

MATERIALS AND METHODS**Study Population**

Patients aged 18 years or less having a cardiac arrest for 1 minute or more during the same hospital stay as the heart operation during the period from January 2002 to December 2014 at the Arkansas Children's Hospital qualified for inclusion. Patients having a cardiac arrest both before or after heart operation were included. Heart operations (with or without cardiopulmonary bypass [CPB]) were classified on the basis of the first cardiovascular operation of each hospital admission (the index operation). For patients with multiple qualifying arrests, only the initial arrest event was included. Patients receiving only drugs or positive pressure ventilation without chest compressions or defibrillation were excluded (Figure 1). Patients receiving chest compressions for less than 1 minute were excluded. Patients with no documented index operation, patients associated with surgical closure of an isolated patent ductus arteriosus only, and patients weighing 2.5 kg or less undergoing isolated patent ductus arteriosus ligation were excluded. Patients associated with operations that were not classified into 1 of the Society of Thoracic Surgeons–European Association for Cardiothoracic Surgery (STS-EACTS) Mortality Categories (category 1, lowest mortality risk; category 5, highest mortality risk) (21 patients) were excluded.¹¹ The Institutional Review Board at the University of Arkansas for Medical Sciences approved review of patient medical records, and the need for informed consent was waived.

Data Collection and Outcome Variables

The data collected from hospital database included demographic data, preexisting conditions, operation details, prearrest characteristics, arrest

characteristics, and outcome data. We developed the hospital database on Utstein-style template, which allowed us to standardize and review the resuscitation data.¹² The primary outcome was survival to hospital discharge. Secondary outcome measures included return of spontaneous circulation for more than 20 minutes, 24-hour survival, and neurologic status at discharge. Neurologic status was assessed at the time of discharge using the Pediatric Cerebral Performance Category scale, which divides outcome into the following 6 categories: (1) normal, age-appropriate neurodevelopment function; (2) mild disability; (3) moderate disability; (4) severe disability; (5) coma or vegetative state; and (6) brain death. Good neurologic status was defined as a score of 1, 2, 3, or no change in score from prearrest to hospital discharge.^{13,14}

Definitions

Cardiac arrest was defined as any event characterized by pulselessness or critically compromised perfusion treated with external chest compressions for 1 minute or more or defibrillation that elicited a unit-wide or hospital-wide emergency response. This definition is in consensus with the American Heart Association (AHA) operational definition for a cardiopulmonary resuscitation (CPR) event.^{15,16} CPR was defined as therapies aimed at preserving the integrity of vital organs during cardiopulmonary arrest by restoring spontaneous circulation.^{15,16} Extracorporeal CPR (ECPR) was defined as the use of extracorporeal membrane oxygenation (ECMO) as a resuscitation therapy in children refractory to conventional CPR.^{15,16} The use of ECPR in our institution follows AHA recommendations, thereby limiting the use of ECPR to in-hospital cardiac arrest that is refractory to initial resuscitation efforts when the cause of arrest is reversible or the patient could be a candidate for heart transplantation. A rapid deployment ECMO system exists at the Arkansas Children's Hospital that is jointly managed by the cardiovascular surgery and cardiovascular intensive care team. A preassembled and primed ECMO circuit with the surgical and medical personnel needed for initiation of mechanical support is available at all times in the hospital.

First documented rhythm was defined as the first electrocardiographic rhythm recorded at the time the patient required chest compressions. Arrest event duration was defined as the time from beginning of chest compressions or defibrillation to return of spontaneous circulation or cessation of resuscitation efforts. The primary procedure of each index operation performed was classified by STS-EACTS Mortality Category. Patients were grouped into 2 levels of complexity on the basis of the STS-EACTS Mortality Categories (categories 1, 2, and 3 are classified as “low” complexity, and categories 4 and 5 are classified as “high” complexity).¹¹ The other study definitions are elaborated in study Table 1.

Statistical Analysis

Descriptive statistics were performed using standard summary statistics, such as frequency and percentages or median and quartiles as appropriate. Patient demographics, preexisting conditions, operation characteristics, interventions before cardiac arrest, and arrest characteristics were compared between survivors and nonsurvivors using the Fisher exact test and Wilcoxon rank-sum test as appropriate. We also summarized important cardiac arrest characteristics after stratifying patients by 1 of the 5 surgical risk categories and by 8 benchmark operations. We used multivariate logistic regression models to determine the risk factors associated with survival to hospital discharge among patients with cardiac arrest. For multivariable models, the following patient, operation characteristics, and arrest variables were prospectively selected for inclusion in multivariable models a priori because of their established clinical importance and on the basis of existing literature: age, year of cardiac arrest, complexity of operation performed, arrest before cardiac surgery, recurrent arrest, use of CPB for heart operation, time of arrest (nights/weekends), arrest duration, drugs used during arrest (number of epinephrine doses, use of alkalinizing agents, use of calcium), use of defibrillator, and ECPR.^{7–10}

FIGURE 1. Study patients.

We further used a backward stepwise regression method for variable selection method to better elucidate predictors associated with survival to hospital discharge. At each stage, variables with *P* values less than .2 were retained in the model. We then analyzed risk factors associated with survival to hospital discharge after stratifying data by patients who had cardiac arrest before and after cardiac surgery. Results from the statistical models are presented as odds ratios and 95% confidence intervals and associated *P* values. A 2-sided significance level of 5% was used to determine statistical significance. All statistical analyses were generated using SAS/STAT software, Version 9.4 of the SAS System for Windows 7, Copyright 2002-2012 SAS Institute Inc (Cary, NC), or Stata software, Release 14 (StataCorp LP, College Station, Tex).

RESULTS

A total of 3437 children undergoing at least 1 heart operation at the Arkansas Children's Hospital were included.

Overall rate of cardiac arrest among these patients was 4.5% (*n* = 154) with an associated mortality after cardiac arrest of 31.8% (*n* = 49). Among the patients with cardiac arrest, 28 (18.2%) had a cardiac arrest before the index operation with survival to hospital discharge of 21 patients (75%). In contrast, 126 patients (81.8%) had a cardiac arrest after heart operation with survival to hospital discharge of 84 patients (66.6%). The rate of cardiac arrest was higher among patients undergoing high complexity operations (11.8%) compared with patients undergoing low-complexity operations (2.1%). ECPR was used in approximately one third of the patients with cardiac arrest (*n* = 56). Recurrent arrest (>1 arrest) was noted in approximately 20% of the patients with cardiac arrest (*n* = 32).

TABLE 1. Study definitions

Pneumonia	Defined as inflammation of lung parenchyma, characterized by clinical or radiologic evidence of consolidation of the affected portion of lung tissue for which antibiotics have not been started or the infection is still being treated with antibiotics.
Acute respiratory insufficiency	Defined as the need for high-flow nasal cannula or positive pressure ventilation in the form of noninvasive or invasive mechanical ventilation.
Renal insufficiency	Defined as new-onset oliguria with sustained urine output <0.5 mL/kg/h for 24 h or an increase in creatinine >1.5 times upper limits of normal for age (or twice the most recent prearrest values if these were available).
Sepsis or septicemia	Defined as serious life-threatening infection with or without microbiologic evidence of any bacterial, fungal, or viral growth for which the infection is being treated with antibiotics or antifungals.
Cardiac arrest	Defined as any event characterized by pulselessness or critically compromised perfusion treated with external chest compressions for ≥1 min or defibrillation that elicited a unit-wide or hospital-wide emergency response. This definition is in consensus with AHA operational definition for CPR event.
Metabolic/electrolyte abnormality	Defined as any of the following laboratory values before event: blood glucose ≤60 mg/dL, magnesium ≤1.4 mg/dL, potassium ≤2.5 or ≥6 mEq/L, sodium ≤125 or ≥150 mEq/L, or ionized calcium ≤1.1 mmol/L.

AHA, American Heart Association; CPR, cardiopulmonary resuscitation.

TABLE 2. Study demographics and characteristics

	Overall N = 154	Survived N = 105	Died N = 49	P value
Patient demographics				
Age (d)	55 (9, 203)	60 (12, 203)	38 (6, 199)	.22
Male gender	92 (59.7%)	65 (61.9%)	27 (55.1%)	.42
Weight (kg)	3.8 (2.9, 6.9)	4 (3.0, 6.7)	3.5 (2.9, 7.3)	.49
Weight-for-age Z-score	-1.5 (1.6)	-1.5 (1.7)	-1.4 (1.4)	.77
Genetic syndrome	31 (20.1%)	21 (20.0%)	10 (20.4%)	.91
Preexisting conditions				
Respiratory insufficiency	100 (64.9%)	62 (59.0%)	38 (77.6%)	.03
Hypotension	62 (40.3%)	45 (42.9%)	17 (34.7%)	.34
Metabolic/electrolyte abnormality	18 (11.7%)	14 (13.3%)	4 (8.2%)	.35
Septicemia	8 (5.2%)	2 (1.9%)	6 (12.2%)	.01
Renal insufficiency	18 (11.7%)	8 (7.6%)	10 (20.4%)	.02
Pneumonia	3 (1.9%)	2 (1.9%)	1 (2%)	.95
Operation characteristics				
Arrest before cardiac surgery	28 (18.2%)	21 (20.0%)	7 (14.3%)	.39
Use of CPB for heart operation	115 (74.7%)	77 (73.3%)	38 (77.6%)	.58
CPB time (min)	142 (91, 210)	133 (83, 197)	152 (97, 225)	.26
Crossclamp time (min)	55 (24, 115)	55 (29, 118)	54 (9, 99)	.58
STS-EACTS category				.37
1	11 (7.1%)	6 (5.7%)	5 (10.2%)	
2	29 (18.8%)	23 (21.9%)	6 (12.2%)	
3	14 (9.1%)	10 (9.5%)	4 (8.2%)	
4	72 (46.8%)	50 (47.6%)	22 (44.9%)	
5	28 (18.2%)	16 (15.2%)	12 (24.5%)	
Heart transplant	19 (12.3%)	13 (12.4%)	6 (12.2%)	.98
Immediate factors related to arrest				
Airway compromise	13 (8.4%)	9 (8.6%)	4 (8.2%)	.93
Acute respiratory insufficiency	26 (16.9%)	19 (18.1%)	7 (14.3%)	.56
Hypotension	74 (48.1%)	49 (46.7%)	25 (51%)	.61
Metabolic/electrolyte abnormality	15 (9.7%)	7 (6.7%)	8 (16.3%)	.06
Arrhythmia	50 (32.5%)	36 (34.3%)	14 (28.6%)	.48
Interventions in place before arrest				
Intubated before arrest	104 (67.5%)	67 (63.8%)	37 (75.5%)	.15
Central venous access	48 (31.2%)	26 (24.8%)	22 (44.9%)	.01
Arterial line	93 (60.4%)	63 (60%)	30 (61.2%)	.88
Chest tube	56 (36.4%)	38 (36.2%)	18 (36.7%)	.95
Prostaglandins	7 (4.5%)	5 (4.8%)	2 (4.1%)	.85
Vasoactive infusions	72 (46.8%)	49 (46.7%)	23 (46.9%)	.97

Continuous variables are summarized as median and interquartile range (Q1, Q3), and categoric variables are summarized as N (%). CPB, Cardiopulmonary bypass; STS-EACTS, Society of Thoracic Surgeons European Association for Cardiothoracic Surgery.

Patient and Arrest Characteristics

Table 2 compares the patient characteristics between the survivors and nonsurvivors before cardiac arrest. By univariate analysis, there was no difference in baseline characteristics (eg, age, gender, weight) between the survivors and nonsurvivors. Patients who survived after cardiac arrest were less commonly associated with respiratory insufficiency, septicemia, and renal insufficiency before cardiac arrest. To our surprise, we did not find any difference in operation characteristics between the 2 groups (eg, use of CPB, duration of CPB, complexity of surgery performed). Airway compromise or acute respiratory insufficiency was documented as immediate factors related

to arrest among 20 patients with presurgery arrest (71.4%). In contrast, hypotension or arrhythmia was documented as immediate factors related to arrest among 102 patients with postsurgery arrest (80.9%). The median duration between the cardiac arrest and the heart operation among patients with presurgery arrest was 4 days (interquartile range, 1-10), whereas the median duration between the cardiac arrest and the heart operation among patients with postsurgery arrest was 1 day (interquartile range, 0-30).

Table 3 compares the arrest characteristics between the survivors and nonsurvivors after cardiac arrest. Duration of cardiac arrest was shorter among survivors compared with nonsurvivors. There was no difference

TABLE 3. Arrest characteristics and outcomes

	Overall N = 154	Survived N = 105	Died N = 49	P value
Arrest characteristics				
Nights/weekends	78 (50.6%)	50 (47.6%)	28 (57.1%)	.27
Arrest duration (min)	5 (3, 25)	5 (3, 15)	7 (4, 41)	.02
Arrest location				.02
ICU	82 (53.2%)	50 (47.6%)	32 (65.3%)	
Ward	34 (22.1%)	22 (20.9%)	12 (24.4%)	
Operating room	4 (2.6%)	3 (2.9%)	1 (2.0%)	
Other/unknown	34 (22.1%)	30 (28.6%)	4 (8.2%)	
No. of arrest events				.85
1	122 (79.2%)	37 (75.5%)	85 (81.0%)	
2	22 (14.3%)	9 (18.4%)	13 (12.4%)	
3	6 (3.9%)	1 (2.0%)	5 (4.8%)	
≥4	4 (2.6%)	2 (4.1%)	2 (1.9%)	
Year of arrest				.23
2002-2008	77 (50.0%)	56 (53.3%)	21 (42.9%)	
2009-2014	77 (50.0%)	49 (46.7%)	28 (57.1%)	
First pulseless rhythm				.69
Asystole	11 (7.1%)	6 (5.7%)	5 (10.2%)	
Pulseless electrical activity	75 (48.7%)	51 (48.6%)	24 (49.0%)	
Ventricular fibrillation	2 (1.3%)	2 (1.9%)	0 (0%)	
Ventricular tachycardia	9 (5.8%)	5 (4.8%)	4 (8.2%)	
Unknown	9 (5.8%)	6 (5.7%)	3 (6.1%)	
Interventions during arrest				
Use of epinephrine	117 (76%)	76 (72.4%)	41 (83.7%)	.13
No. epinephrine doses	2 (1, 5)	2 (1, 4)	3 (1, 7)	.09
Antiarrhythmic	20 (13.0%)	13 (12.4%)	7 (14.3%)	.74
Atropine	30 (19.5%)	20 (19%)	10 (20.4%)	.84
Calcium	83 (53.9%)	51 (48.6%)	32 (65.3%)	.05
Magnesium	13 (8.4%)	6 (5.7%)	7 (14.3%)	.07
Alkalinizing agents	44 (28.6%)	25 (23.8%)	19 (38.8%)	.06
Vasoactive infusions	60 (39.0%)	45 (42.9%)	15 (30.6%)	.15
Prostaglandins	3 (1.9%)	2 (1.9%)	1 (2.0%)	.95
Use of defibrillator	18 (11.7%)	14 (13.3%)	4 (8.2%)	.35
Pacemaker	10 (6.5%)	9 (8.6%)	1 (2.0%)	.13
Airway insertion	117 (76%)	76 (72.4%)	41 (83.7%)	.13
ECPR	56 (36.4%)	31 (29.5%)	25 (51.0%)	.01
Outcomes				
Return of spontaneous circulation	154 (100%)	105 (100%)	49 (100%)	.99
Survival at 24 h	150 (97.4%)	105 (100%)	45 (91.8%)	<.001
Good neurologic outcome	99 (94.3%)	99 (94.3%)	—	—
Length of stay (d)	55 (25, 127)	52 (26, 116)	87 (24, 148)	.33

Continuous variables are summarized as median and interquartile range (Q1, Q3), and categoric variables are summarized as N (%). ICU, Intensive care unit; ECPR, extracorporeal cardiopulmonary resuscitation.

in the number of cardiac arrest events and first pulseless rhythm between the 2 groups. Use of epinephrine, calcium, and alkanizing agents was less commonly used among the survivors, although this was not statistically significant. Deployment of ECMO as a rescue therapy (ECPR) was less commonly used among the survivors. Return of spontaneous circulation and survival at 24 hours was noted between 100% (n = 154) and 97.4% (n = 150) of the study patients. Mortality at hospital discharge was noted among

31.8% patients (n = 49). Of these, 22 patients died after withdrawal of care, 15 patients died after a subsequent cardiac arrest, and 3 patients died after prolonged illness due to multiorgan dysfunction.

Stratification of Cardiac Arrest by Operations of Varying Complexity

Table 4 depicts the landscape of cardiac arrest among children undergoing operations of varying complexity. Rate of cardiac arrest increased with increasing complexity

TABLE 4. Summary for study patients stratified by surgical risk category

	STS-EACTS category 1 N = 11	STS-EACTS Category 2 N = 29	STS-EACTS Category 3 N = 14	STS-EACTS Category 4 N = 72	STS-EACTS Category 5 N = 28
No. of patients receiving heart operations	911	1391	291	701	143
Incidence of cardiac arrest	11/911 (1.2%)	29/1391 (2.1%)	14/291 (4.8%)	72/701 (10.2%)	28/143 (19.5%)
Arrest before cardiac surgery	1 (9.1%)	7 (24.1%)	2 (14.3%)	15 (20.8%)	3 (10.7%)
Days between heart operation and cardiac arrest	1 (0, 5)	1 (0, 12)	1 (0, 21)	2 (1, 19)	2 (1, 25)
Duration of cardiac arrest (min)	10 (1, 43)	4 (3, 13)	3 (3, 5)	6 (3, 22)	10 (4, 34)
Use of CPB for heart operation	8 (72.7%)	16 (55.1%)	13 (92.9%)	50 (69.4%)	28 (100.0%)
CPB time (min)	79 (61, 135)	103 (54, 153)	142 (121, 193)	178 (108, 226)	175 (139, 210)
ECPR	5 (45.5%)	8 (27.6%)	2 (14.3%)	27 (37.5%)	14 (50.0%)
No. of arrest events					
1	10 (90.9%)	24 (82.8%)	11 (78.6%)	54 (75.0%)	23 (82.1%)
2	1 (9.1%)	4 (13.8%)	2 (14.3%)	12 (16.7%)	3 (10.7%)
3	0	1 (3.4%)	1 (7.1%)	3 (4.2%)	1 (3.6%)
≥4	0	0	0	3 (4.2%)	1 (3.6%)
Return of spontaneous circulation	11 (100%)	29 (100%)	14 (100%)	72 (100%)	28 (100%)
Survival at 24 h	10 (90.9%)	27 (93.1%)	14 (100%)	71 (98.6%)	28 (100%)
Survival at hospital discharge	6 (54.5%)	23 (79.3%)	10 (71.4%)	50 (69.4%)	16 (57.1%)
Good neurologic outcome	6 (100%)	21 (91.3%)	10 (100%)	47 (94.0%)	15 (93.8%)

Continuous variables are summarized as median and interquartile range (Q1, Q3), and categoric variables are summarized as N (%). STS-EACTS, Society of Thoracic Surgeons European Association for Cardiothoracic Surgery; CPB, cardiopulmonary bypass; ECPR, extracorporeal cardiopulmonary resuscitation.

of heart operation performed. Patients undergoing heart operation in the STS-EACTS category 5 had approximately 16 times higher prevalence of cardiac arrest compared with patients undergoing heart operation in STS-EACTS category 1. The majority of the study patients in all surgical risk categories had a cardiac arrest within the first 2 days after their heart operation. ECMO was deployed as a rescue therapy (ECPR) in more than one third of patients in STS-EACTS categories 1, 4, and 5. The prevalence of recurrent arrest (>1 arrest) was similar among all surgical risk categories. We did not note any specific trends in survival to hospital discharge among different STS-EACTS categories, with the lowest survival noted in STS-EACTS categories 1 and 5. Table E1 of the online supplement depicts the landscape of cardiac arrest by 8 benchmark operations defined by Society of Thoracic Surgeons specifications.

Factors Associated With Survival to Hospital Discharge After Cardiac Arrest

After adjusting for baseline characteristics, operation characteristics, and arrest characteristics, shorter duration of cardiac arrest and use of defibrillator were associated with improved chances of survival to hospital discharge (Table 5). Among patients who had a cardiac arrest before heart operation, higher doses of epinephrine were associated with lower odds of survival to hospital discharge (Table 6). Among patients who had a cardiac arrest after heart operation, cardiac arrest in recent years (2009-2014 vs 2002-2008) and use of ECPR were associated with lower odds of survival to hospital discharge.

Neurologic Outcomes

Good neurologic outcomes were noted among the majority of the survivors (94.3%). Postarrest hypothermia for at least 24 hours was implemented in 84 patients (54.5%). Electroencephalogram was performed in only 24 patients in the first 48 hours after cardiac arrest. Of these, abnormal electroencephalogram was noted among only 8 patients (33.3%). Brain imaging with head ultrasound or computed tomography scan or magnetic resonance imaging was performed among 116 patients before hospital discharge. Of these, abnormal imaging (ischemia or hemorrhage) was noted among 52 patients (44.8%). Among the 52 patients with abnormal imaging, 30 did not survive at hospital discharge.

DISCUSSION

Data from our single-center study characterize the cardiac arrest in children undergoing cardiac surgery using the Society of Thoracic Surgeons and Pediatric Advanced Life Support Utstein-Style Guidelines (Video 1). Our study establishes that cardiac arrest occurs in 4.5% of the children undergoing cardiac surgery with an associated mortality of approximately 32%. We demonstrated that the rate of cardiac arrest and use of ECMO for CPR increases with increasing case complexity. Regardless of surgical case complexity, the median days between heart operation and cardiac arrest, duration of cardiac arrest, and survival after cardiac arrest were similar. The independent risk factors associated with mortality after cardiac arrest included duration of cardiac arrest, use of ECMO for CPR, and use of alkalinizing agents during cardiac arrest.

TABLE 5. Multivariable model predicting survival to hospital discharge

Variable	Comparison	OR (95% CI)	P value
Full multivariable model			
Age	12 mo increase	0.92 (0.80-1.06)	.25
Year of cardiac arrest	2009-2014 vs 2002-2008	0.51 (0.23-1.15)	.11
High complexity case	Yes vs no	0.79 (0.34-1.83)	.58
Arrest before cardiac surgery	Yes vs no	1.48 (0.51-4.30)	.47
Recurrent arrest (≥ 2 arrests)	Yes vs no	0.48 (0.19-1.21)	.12
Use of CPB for heart operation	Yes vs no	0.76 (0.31-1.90)	.56
Time of arrest (nights/weekends)	Yes vs no	0.99 (0.46-2.16)	.99
Arrest duration (min)	3 min increase	0.91 (0.83-0.99)	.02
No. of epinephrine doses*	≥ 2 vs <2	2.06 (0.75-5.65)	.16
Alkalinizing agents*	Yes vs no	0.51 (0.20-1.30)	.16
Calcium*	Yes vs no	0.85 (0.37-1.95)	.70
Use of defibrillator*	Yes vs no	4.64 (1.10-19.57)	.03
ECPR*	Yes vs no	0.72 (0.25-2.09)	.55
Backward selection model			
Age	12 mo increase	0.92 (0.80-1.04)	.18
Year of cardiac arrest	2009-2014 vs 2002-2008	0.48 (0.22-1.04)	.06
Recurrent arrest (≥ 2 arrests)	Yes vs no	0.46 (0.19-1.14)	.09
Arrest duration (min)	3 min increase	0.89 (0.83-0.95)	.001
No. of epinephrine doses*	≥ 2 vs <2	1.96 (0.74-5.21)	.18
Alkalinizing agents*	Yes vs no	0.51 (0.21-1.26)	.15
Use of defibrillator*	Yes vs no	4.51 (1.08-18.87)	.03

OR, Odds ratio; CI, confidence interval; CPB, cardiopulmonary bypass; ECPR, extracorporeal cardiopulmonary resuscitation. *Depicts use of intervention during cardiac arrest.

The major strength of our single-center study is the use of the Society of Thoracic Surgeons definitions for characterizing heart operations and the use of Pediatric Advanced Life Support Utstein-Style Guidelines to characterize cardiac arrest. A recent study from the Society of Thoracic Surgeons Congenital Heart Surgery database evaluating cardiac arrest in children undergoing cardiac surgery lacked data on the definition of cardiac arrest per the AHA's guidelines and outcomes after cardiac arrest using Utstein-Style Guidelines (eg, return of spontaneous circulation, 24-hour survival, survival at hospital discharge, good neurologic outcomes).⁸ Likewise, previous studies from the AHA's Get With the Guidelines database lacked granular data on cardiac diagnoses and heart

operations.^{7,9,10} To our knowledge, this is the first study evaluating cardiac arrest in children undergoing cardiac surgery using guidelines for these 2 societies.

In a recent multicenter study, the incidence of cardiac arrest was reported among 2.6% of patients after cardiac surgery.⁸ In contrast, our study reports a higher incidence of cardiac arrest (4.5%) in this select patient population. One of the possible reasons for a higher rate of cardiac arrest in our study could have been the fact that our study also reported cardiac arrests occurring before the heart operation. Of the 154 cardiac arrests reported in our study, 28 (18%) occurred before the cardiac surgery. With increased data granularity, our study also reported the temporal relationship of cardiac arrest with heart operation.

TABLE 6. Backward selection model predicting survival to hospital discharge among presurgery arrest patients and postsurgery arrest patients

Variable	Comparison	OR (95% CI)	P value
Cardiac arrest before heart operation			
Arrest duration	3 min increase	0.85 (0.69-1.04)	.11
No. of epinephrine doses*	≥ 2 vs <2	22.48 (1.48-341.23)	.02
Cardiac arrest after heart operation			
Year of cardiac arrest	2009-2014 vs 2002-2008	0.38 (0.16-0.89)	.02
Recurrent arrest (≥ 2 arrests)	Yes vs no	0.38 (0.14-1.01)	.06
Alkalinizing agents*	Yes vs no	0.47 (0.18-1.20)	.11
Use of defibrillator*	Yes vs no	2.58 (0.66-10.11)	.17
ECPR*	Yes vs no	0.24 (0.10-0.60)	.002

Variables dropped in backward selection models: Presurgery arrest model: age, year of cardiac arrest, weight-for-age Z-score, genetic syndrome, time of arrest (nights/weekends). Postsurgery arrest model: age, arrest before cardiac surgery, high complexity case, use of CPB for heart operation, time of arrest (nights/weekends), arrest duration, number of epinephrine doses (during arrest), and calcium use (during arrest). OR, Odds ratio; CI, confidence interval; ECPR, extracorporeal cardiopulmonary resuscitation. *Depicts use of intervention during cardiac arrest.

VIDEO 1. Introduction to the study. Video available at: [http://www.jtcvsonline.org/article/S0022-5223\(16\)31387-3/addons](http://www.jtcvsonline.org/article/S0022-5223(16)31387-3/addons).

The majority of cardiac arrests occurred in the first 48 hours after the heart operations.

In the existing literature, the reported survival to hospital discharge after cardiac arrest in children undergoing heart operations has been reported to vary between 37% and 56%.⁷⁻¹⁰ Despite a higher incidence of cardiac arrest, our study reports a higher survival to hospital discharge (62%). From the current data, the exact reason for this higher survival to hospital discharge is unknown. It is possible that the increased use of ECPR could have contributed to higher survival to hospital discharge. In our study, 36% of the patients with cardiac arrest used ECMO for return of spontaneous circulation. The use of ECMO to support patients failing conventional CPR has been shown to rescue some who would face imminent mortality without this intervention.¹⁷ Another postulated reason for better outcomes could be a higher proportion of surgical-cardiac patients in this cohort. Surgical-cardiac patients are associated with significantly better survival to hospital discharge after an in-hospital cardiac arrest compared with children with medical-cardiac disease and noncardiac disease.^{7,10}

The majority of the cardiac arrests in our study were noted in the postoperative period (postoperative vs preoperative, 82% vs 18%). The survival to hospital discharge was higher among the patients with preoperative cardiac arrest (75%) compared with postoperative cardiac arrest (66%). Because of the retrospective nature of the study, we do not have the exact pathophysiology mechanism leading to cardiac arrest in the 2 patient populations. However, the majority of the cardiac arrests in the preoperative period in our study were related to respiratory or airway issues, whereas the cardiac arrests in the postoperative period were related to cardiac issues (eg, hypotension, arrhythmias). It is possible that varied underlying pathophysiologic mechanisms in the 2 patient populations (preoperative cardiac arrest and postoperative cardiac arrest) led to different outcomes.

The AHA suggests special recommendations for adult postcardiac surgery cardiac arrests. As an example, the adult algorithm for postcardiac surgery arrest recommends

attempts to pace or defibrillate before chest compressions for bradycardia or shockable rhythms (if this can be accomplished within 1 minute of cardiac arrest). If unsuccessful, this is followed by external chest compressions and then reopening of the sternotomy at 5 minutes if there is still no perfusing rhythm.¹⁸ No such recommendations exist for postcardiac surgery pediatric cardiac arrest. Children with congenital heart disease have less myocardial reserves, are compromised hemodynamically, and are associated with complex physiologic and technical management issues.^{19,20} It is also unknown from the current literature if the management of cardiac arrest is different among children with univentricular and biventricular physiology. In a recent study, Park and colleagues¹⁹ suggested that the optimal chest compression level for patients with a single ventricle is lower than that suggested in the current guidelines for the normal population.

One potential solution that may address some of these limitations and allow for more comprehensive future analyses would be linkage of the Society of Thoracic Surgeons Congenital Heart Surgery Database with the AHA's Get with the Guidelines–Resuscitation (GWTG-R) registry, a large multicenter registry of in-hospital cardiac arrests. This linkage would mitigate many of the limitations outlined earlier by improving data granularity for patients experiencing a cardiac arrest. Some of the advantages of linked dataset would be the use of standardized definitions of cardiac arrest and Utstein's outcomes associated with cardiac arrest, and use of standardized definitions for cardiac diagnoses and heart operations. Furthermore, a linked database will help us understand the temporal relationship between heart operation and cardiac arrest, and potentially help us identify events leading to cardiac arrest in this complex patient population.

Study Limitations

The retrospective and observational nature of the study render it susceptible to study design flaws and bias. This study is subject to the limitations of all observational analyses, including selection bias, residual confounding, and measurement by error. Training backgrounds of the treating physicians and ancillary staff are not included in our analysis. In addition, there could have been other unmeasured patient confounders that we were unable to account for. We could not adjust for ICU-level organizational factors, such as intensivist physician staffing, multidisciplinary care, or nurse-to-patient ratios. We could not adjust for critical care training program status or availability of various residents and fellows that may be involved in the care of these critically ill infants. Because of the retrospective nature of the study, we lacked the data on the number of short CPRs discontinued because of cessation of resuscitation efforts. Another limitation is the classification of neurologic outcome using crude Pediatric Cerebral

Performance Category scores and the absence of postdischarge neurologic and neurodevelopmental follow-up. In our study, we did not capture patients who could not undergo operation because of bad outcomes associated with cardiac arrest. These patients could have introduced a bias among the children experiencing preoperative cardiac arrest.

CONCLUSIONS

The single-center study demonstrates that characterizing cardiac arrest in children undergoing cardiac surgery using the Society of Thoracic Surgeons and Pediatric Advanced Life Support Utstein-Style Guidelines help increase data granularity and understand relationship between cardiac arrest and heart operation in a better way. Our study demonstrates that the rate of cardiac arrest and use of ECMO for CPR increases with increasing case complexity. Regardless of surgical case complexity, the median days between heart operation and cardiac arrest, duration of cardiac arrest, and survival after cardiac arrest are similar. Future multicenter analyses by linking the Society of Thoracic Surgeons Congenital Heart Surgery Database with the AHA's GWTG-R could help us identify strategies that improve survival after an arrest.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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Key Words: cardiac arrest, children, heart operations, Society of Thoracic Surgeons, Utstein

TABLE E1. Summary for study patients stratified by 8 Society of Thoracic Surgeons benchmark operations

	VSD repair (N = 6)	TOF repair (N = 1)	AVC repair (N = 2)	ASO (N = 4)	ASO + VSD repair (N = 6)	Fontan (N = 2)	Truncus arteriosus repair (N = 2)	Norwood Operation (N = 15)
No. of patients receiving heart operations	225	127	91	60	31	133	24	99
Incidence of cardiac arrest	6/225 (2.6%)	1/127 (0.7%)	2/91 (2.2%)	4/60 (6.6%)	6/31 (19.3%)	2/133 (1.5%)	2/24 (8.3%)	15/99 (15.2%)
Arrest before cardiac surgery	0	0	1 (50%)	0	0	0	0	1 (6.7%)
Days between heart operation and cardiac arrest	1 (0, 2)	3	25 (25, 25)	0 (0, 0.5)	0 (0, 1)	12 (1, 24)	15 (12, 24)	2 (1 to 28)
Duration of cardiac arrest (min)	6 (1, 15)	2	2 (2, 3)	4 (3, 14)	4.5 (3, 7)	2 (1, 4)	39 (1, 77)	27 (7, 41)
Use of CPB for heart operation	5 (83.3%)	1 (100%)	2 (100%)	4 (100%)	6 (100%)	2 (100%)	2 (100%)	15 (100%)
CPB time (min)	76 (73, 83)	122 (122, 122)	286 (145, 428)	161 (126, 212)	203 (177, 312)	102 (102, 103)	146 (146, 233)	175 (139, 210)
ECPR	2 (33.3%)	0	0	0	0	0	1 (50%)	10 (66.7%)
No. of arrest events								
1	5 (83.3%)	1 (100%)	1 (50%)	3 (75%)	4 (66.7%)	2 (100%)	1 (50%)	12 (80%)
2	1 (16.7%)	0	1 (50%)	0	1 (16.7%)	0	1 (50%)	3 (20%)
3	0	0	0	1 (25%)	0	0	0	0
≥4	0	0	0	0	1 (16.7%)	0	0	0
Return of spontaneous circulation	6 (100%)	1 (100%)	2 (100%)	4 (100%)	6 (100%)	2 (100%)	2 (100%)	15 (100%)
Survival at 24 h	6 (100%)	1 (100%)	2 (100%)	4 (100%)	6 (100%)	2 (100%)	2 (100%)	15 (100%)
Survival at hospital discharge	4 (66.7%)	1 (100%)	1 (50%)	4 (100%)	5 (83.3%)	1 (50%)	0	7 (46.7%)
Good neurologic outcome	4 (100%)	1 (100%)	1 (100%)	4 (100%)	5 (100%)	1 (100%)	0	7 (100%)

Continuous variables are summarized as median and interquartile range (Q1, Q3), and categorical variables are summarized as N (%). VSD, Ventricular septal defect; TOF, tetralogy of Fallot; AVC, atrioventricular canal; ASO, arterial switch operation; CPB, cardiopulmonary bypass; ECPR, extracorporeal cardiopulmonary resuscitation.