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Survival and CPR Hemodynamics Following Cardiac Arrest in Children with Surgical Compared to Medical Heart Disease

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Abstract

Objective—To assess the association of diastolic blood pressure (DBP) cutoffs (≥25 mmHg in infants and ≥30 mmHg in children) during cardiopulmonary resuscitation (CPR) with return of spontaneous circulation (ROSC) and survival in surgical cardiac versus medical cardiac patients. Secondarily, we assessed whether these DBP targets were feasible to achieve and associated with outcome in physiology unique to congenital heart disease (single ventricle infants, open chest), and influenced outcomes when extra-corporeal CPR (eCPR) was deployed.

Design—Multi-center, prospective, observational cohort analysis

Setting—Tertiary PICU and CICUs within the Collaborative Pediatric Critical Care Research Network

Patients—Patients with invasive arterial lines during CPR and surgical cardiac or medical cardiac admission diagnoses.

Interventions—None

Measurements and Main Results: Hemodynamic waveforms during CPR were analyzed on 113 patients, 88 surgical cardiac and 25 medical cardiac. A similar percent of surgical cardiac (51/88; 58%) and medical cardiac (17/25; 68%) patients reached the DBP targets (p=0.488). Achievement of DBP target was associated with improved survival to hospital discharge in surgical cardiac patients (p=0.018), but not medical cardiac patients (p=0.359). Fifty three percent (16/30) of patients with single ventricles attained the target DBP. In patients with an open chest at the start of chest compressions, 11/20 (55%) attained the target DBP. In the 33 eCPR patients, 16 (48%) patients met the DBP target with no difference between survivors and non-survivors (p=0.296).

Conclusion—During resuscitation in an ICU, with invasive monitoring in place, DBP targets of ≥25 mmHg in infants and ≥30 mmHg in children can be achieved in patients with both surgical and medical heart disease. Achievement of DBP target was associated with improved survival to hospital discharge in surgical cardiac patients, but not medical cardiac patients. DBP targets were feasible to achieve in: 1) single ventricle patients, 2) open chest physiology, and 3) eCPR patients.

BACKGROUND:

Pediatric patients with surgical and medical heart disease have a 10-fold higher rate of in-hospital cardiac arrest than pediatric patients without heart disease.[1] Observational studies consistently demonstrate higher rates of survival to hospital discharge in patients with surgical cardiac disease compared to medical cardiac disease.[1-4] The surgical cardiac patients in these studies were more likely to have arterial access, pre-arrest tracheal intubation, and central vascular access at the time of arrest compared with the medical cardiac patients.[3] Because they were more highly monitored, it is possible that observed survival difference between these groups was due to quality of cardiopulmonary resuscitation (CPR).

A recent American Heart Association (AHA) scientific statement on resuscitation of infants and children with heart disease has supported utilizing standard pediatric CPR techniques (chest compression rate of 100–120 per minute, chest compression fraction (CCF) greater than 0.8, ventilation rate of 10 breaths per minute), with guidance from arterial and central venous pressure monitoring devices to help direct resuscitation.[5] It is unknown whether the use of standard CPR techniques in pediatric patients with heart disease can result in arterial diastolic blood pressure (DBP) targets of ≥ 25 mmHg for infants and ≥ 30 mmHg for children, hemodynamic parameters previously associated with survival.[6-9] Children with heart disease may have alterations in cardiac anatomy and physiology, such as single ventricle physiology and the presence of an open chest, that may impede achievement of these hemodynamic resuscitation goals. Many single ventricle infants are palliated with a systemic to pulmonary artery shunt which results in holodiastolic runoff into the pulmonary vascular bed, and may complicate achievement of diastolic blood pressure goals.[5, 10] The presence of an open chest in post-operative patients may facilitate circumferential open cardiac massage, but could also impair cardiac output when the sternum is open and compressions are performed on the patch or chest wall without circumferential open cardiac massage.[11-13] Other factors unique to this patient population, such as selection for extracorporeal cardiopulmonary resuscitation (eCPR), may provide an additional survival benefit for patients who do not achieve return of spontaneous circulation (ROSC). [4, 5, 14-17]

The PICqCPR (Pediatric Intensive Care Quality of Cardiopulmonary Resuscitation) study evaluated children with invasive hemodynamic data during the first 10 minutes of CPR, including children with heart disease.[6] PICqCPR demonstrated that mean DBP ≥25 mmHg during CPR in infants and ≥30 mmHg in children ≥1 year old was associated with greater likelihood of survival to hospital discharge with favorable neurologic outcome. We thus hypothesized that achieving DBP targets of ≥25mmHg in infants and ≥30mmHg in children would be associated with ROSC and survival to discharge in the subsets of children with surgical and medical cardiac diseases. We also assessed whether arterial blood pressure targets were achievable in patients with single ventricle physiology and open chest physiology, and whether CPR hemodynamics were associated with survival in patients who underwent eCPR.

MATERIAL AND METHODS:

Setting and Design

The *Eunice Kennedy Shriver* National Institute of Child Health and Human Development Collaborative Pediatric Critical Care Research Network (CPCCRN) conducted the PICqCPR study between July 2013 and June 2016. PICqCPR was a prospective, observational study approved with waiver of informed consent by the Institutional Review Board at each clinical site and the data coordination center. All children in a PICU/CICU within CPCCRN and with an invasive arterial blood pressure monitoring line prior-to and during CPR who received chest compressions for at least 1 minute were eligible for inclusion if ≥37 weeks gestation and <19 years old. Subjects were excluded if the first compression was not captured on the waveform data or compression starts and stops could not be determined.

Data collected on each subject included Utstein-style standardized cardiac arrest and CPR data, including but not limited to demographics, preexisting conditions, illness categories, interventions in place at time of arrest, first documented rhythm, immediate cause of arrest, duration of CPR, resuscitation interventions, and outcome data including pediatric cerebral performance category (PCPC) and Functional Status Scale (FSS).[18] Survival to hospital discharge with a favorable neurologic outcome was defined as PCPC 1–3 or no worse than pre-arrest PCPC, as per recommended guidelines.[19, 20] The illness categories included in this analysis were categorized as either surgical cardiac or medical cardiac using definitions from the American Heart Association "Get with the Guidelines – Resuscitation." Surgical Cardiac illness category specifically includes only patients who are post-operative following cardiac surgery at the time of the event. Medical Cardiac illness category includes patients with a primary medical illness that is cardiovascular at the time of the event, but the event does not occur in the post-operative period.[21]

Measurements

The first 10 minutes of hemodynamic data were collected for each CPR event. Data extraction methodology has previously been published for systolic, diastolic and mean blood pressure[6] , chest compression rate and fraction[22], ventilation rate and end tidal CO_2 analysis. [23]

Statistical Analysis

Patient and event characteristics were summarized using frequencies and percentages or medians and interquartile ranges. Differences in these characteristics between surgical cardiac and medical cardiac admission categories were examined using Fisher's exact test for categorical variables and the Wilcoxon rank-sum test for continuous variables. Event-level averages were used for outcome analyses. P-values are reported based on a 2-sided alternative and considered statistically significant when less than 0.05.

A compression rate of 100–120 per minute was considered to be compliant with AHA Guideline recommendations.[7] Guideline recommendation for CCF of 0.80 and ventilation rate of 10 breaths per minute were utilized.[7, 9] Patient admission categories were analyzed for achievement of hemodynamic targets associated with improved survival, specifically for DBP target of ≥ 25 mmHg for infants or ≥ 30 mmHg for children.[5-7, 9, 24-26]

RESULTS:

A total of 164 patients were enrolled in the PICqCPR cohort with analyzable events. Of these, 88 patients (54%) had an admission diagnosis category of surgical cardiac and 25 (15%) were designated as medical cardiac patients. Patient characteristics are outlined in Table 1. Surgical cardiac patients tended to be younger (p<0.001) and more likely to have congenital heart disease (p<0.001) than medical cardiac patients. Surgical cardiac patients were less likely to have pre-existing renal insufficiency than medical cardiac patients (5/88, 6% vs. 7/25, 28%; p=0.004). For patients with congenital heart disease, the only anatomic diagnosis data available was for patients with hypoplastic left heart syndrome as outlined in Table 1.

The surgical cardiac and medical cardiac patient groups were both highly instrumented as demonstrated by similar prevalence of vascular access, arterial catheters, vasoactive infusions and respiratory support (Supplemental Table 1). Supplemental Table 1 also contains data on immediate cause of arrest, time category of arrest (day, night or weekend), initial cardiac rhythm, duration of CPR, and pharmacologic interventions. Hypotension was present in >50% of patients in both categories prior to arrest. Hemodynamics achieved during the first 10 minutes of CPR (Table 2) demonstrated lower systolic, diastolic and mean blood pressure in surgical cardiac patients than medical cardiac patients. The two groups did not differ in the rate of achievement of DBP goals (DBP ≥25 mmHg for infants and DBP ≥30 mmHg for children): 51/88 (58%) among surgical cardiac versus 17/25 (68%) among medical cardiac patients (p=0.488).

Surgical cardiac and medical cardiac patients had no difference in the achievement of ROSC for ≥ 20 min (59/88, 67% vs. 15/25, 60%; p=0.634) but surgical cardiac patients had greater survival to hospital discharge compared to medical cardiac patients (49/88, 56% vs. 8/25, 32%; p=0.043). All surgical cardiac patients either achieved ROSC for ≥ 20 minutes (59/88, 67%) or underwent eCPR (29/88, 33%) while only 4/10 (40%) medical cardiac patients without ROSC for ≥ 20 minutes were cannulated for eCPR. Surgical and medical cardiac patients that survived had similar rates of favorable neurologic outcome based on PCPC scores (45/49, 92% vs. 8/8, 100%; p=1.000).

Achievement of a DBP target of ≥ 25 mmHg for infants or ≥ 30 mmHg for children was associated with improved survival to hospital discharge in surgical cardiac patients (34/49 [69%] versus 17/39 [44%], p=0.018), but not in medical cardiac patients (4/8 [50%] versus 13/17 [77%], p=0.359). As shown in Tables 3 and 4, performance of CPR within AHA resuscitation guideline targets was not associated with achievement of ROSC or survival to hospital discharge.

Hypoplastic left heart syndrome (HLHS) (31/113; 27%) was the only diagnosis used to classify patients as a single ventricle (Table 5). In palliated single ventricle patients, 16/30 (53%) attained the target DBP of ≥ 25 mmHg for infants or ≥ 30 mmHg for children. The median DBP achieved during the first 10 minutes of CPR was nearly identical in HLHS patients with either a Norwood with modified Blalock-Taussig (MBT) shunt or a Norwood with right ventricle to pulmonary artery (RVPA) shunt. The MBT group was more likely to survive to hospital discharge than the RVPA group (8/9, 89% vs. 3/8, 38%; p=0.05).

As noted in Table 6, twenty patients in the surgical cardiac cohort had an open chest at the start of chest compressions, and 11/20 (55%) attained the target DBP of ≥ 25 mmHg for infants or ≥ 30 mmHg for children. The open chest patients tended to be younger (p=0.008), and more often required eCPR compared to the cardiac patients without an open chest (10/20 (50%) vs. 23/93 (24.7%), p=0.032). Average SBP, DBP, and achievement of a DBP target of ≥ 25 mmHg for infants or ≥ 30 mmHg for children during the first 10 minutes of CPR was no different in those patients with an open chest compared to those without an open chest. The chest was opened during the course of CPR in an additional 5/70 (7.1%) surgical patients.

Of the 33 eCPR patients, 16 (48%) patients met the DBP target. In children who underwent cannulation for eCPR, neither the average DBP during CPR nor the frequency of achieving the DBP targets differed between survivors and non-survivors to hospital discharge (Table 7).

DISCUSSION:

These PICqCPR data establish that invasive diastolic blood pressure targets during CPR ≥ 25mm Hg in infants and ≥ 30mmHg in children were attained in 51/88 (58%) surgical cardiac and 17/25 (68%) medical cardiac patients. Importantly, surgical cardiac patients who attained these DBP targets during CPR were more likely to survive to hospital discharge. Additionally, these DBP targets were attained during CPR in 16/30 (53%) single ventricle patients and 11/20 (55%) open chest patients. Although both the chest compression rates and ventilation rates were not compliant with AHA guidelines for most of these children, 50% survived to hospital discharge and favorable neurologic outcome occurred in 93% of the survivors. The significant survival benefit when DBP targets are met, despite deviations from AHA guidelines, suggests reevaluation of chest compression rates and ventilation rates is warranted.

The recent AHA statement on the resuscitation of infants and children with heart disease highlights the lack of data available to provide specific hemodynamic targets to guide resuscitation.[5] Our data support targeting DBP goals of ≥25mm Hg for infants and ≥30mmHg for children post cardiac surgery, consistent with the data for the overall PICqCPR population (7). However, it is not known if the optimal targets are different in that our smaller sample size did not allow for evaluation of alternative target goals.

Interestingly, surgical cardiac patients had a higher rate of survival to discharge than medical cardiac patients, despite similar rates of achievement of DBP targets (58% surgical and 68% medical), and similar rates of ROSC (67% of surgical and 60% of medical patients). Presumably, surgical cardiac patients had acute, reversible physiologic derangements (e.g., post-pump cardiomyopathy), whereas medical cardiac patients may have had less reversible processes. In other words, successful CPR could provide surgical cardiac patients a bridge to survival, whereas medical cardiac patients may have had more limited potential to survive despite excellent CPR and successful ROSC. Recognition of high risk of mortality, either perceived or actual, may have contributed to lower overall use of eCPR in medical cardiac patients (33% surgical cardiac vs. 16% medical cardiac).

Single ventricle patients have the highest incidence, and lowest survival, of cardiac arrest of all pediatric patients with heart disease.[1, 27, 28] Not surprisingly, the single ventricle population was a large percentage of the PICqCPR cardiac patients (31/113, 27%). These data establish that a DBP of ≥25mmHg in an infant with a MBT shunt is an achievable hemodynamic target. There was very little difference in the DBP achieved in HLHS with MBT shunt compared to the RVPA shunt. Our data suggest a higher survival rate after CPR following Norwood with MBT shunt compared to Norwood with RVPA, in contrast to a previous single center study.[27] Interestingly, multicenter data found a higher incidence of CPR in MBT shunted patients compared to RVPA patients, with no difference in overall 30 day survival, which may similarly suggest improved survival following CPR in MBT shunted patients compared to RVPA.[28]

A second unique patient cohort was 20/113 (18%) pediatric cardiac patients with open chest. There is limited published data on open chest CPR in pediatric patients. [29] Current knowledge of resuscitation physiology with an open chest is primarily related to animal studies which reported improvement in ROSC and survival with circumferential open cardiac massage compared to closed chest compressions.[12, 13, 30] The PICqCPR study did not specifically collect data on which method of compressions was performed (i.e., circumferential open cardiac massage, focal compressions on the patch with an open chest, abdominal CPR, versus some combination) precluding comments on ideal technique. Regardless, current practice in PICqCPR units resulted in similar SBP, DBP and achievement of age specific SBP and DBP targets during resuscitation with an open chest as in those patients with a closed chest. Not surprisingly, 50% of open chest patients underwent cannulation for eCPR as higher surgical complexity is one indication for leaving the chest open following surgery. A recent Society of Thoracic Surgeons guideline for post-operative cardiac arrest in adults recognized that re-sternotomy was common (20–50% of patients) during arrest and recommended early sternal opening within 5 minutes. [26] However, our data would suggest a lower rate of chest opening in pediatric surgical cardiac patients, as only 5/70 (7%) in this PICqCPR series had re-sternotomy despite a median duration of CPR of 11 minutes. This rate may be influenced by enrollment bias and by a greater percentage of post-operative open chest in the pediatric patient cohort, but may be an intervention requiring further study.

The most recent AHA guideline statement also recommended early deployment of eCPR for the resuscitation of patients with CHD. Thirty three of 113 cardiac patients (29%) obtained return of circulation (ROC) with eCPR. Interestingly, all surgical cardiac patients achieved ROSC or ROC with eCPR. Our data demonstrated 39.4 % survival to hospital discharge, consistent with reports of 20–50% survival in the pediatric cardiac eCPR population.[14, 16, 17] A recently published study found that DBP during CPR was no different in a small number of eCPR patients compared to conventional CPR, similar to our data.[31] However, we have also demonstrated that attaining DBP targets for age was not associated with improved survival in our patients undergoing eCPR. Systolic blood pressure may better reflect “stroke volume” during CPR, and thereby flows to non-cardiac organ (e.g., brain and kidney). This may be more important in ECPR than conventional CPR as the duration of CPR prior to cannulation is longer and thus maintaining adequate organ perfusion ultimately improves survival. The selection bias and high utilization of eCPR may impact the increased survival in the surgical cardiac patient population compared to medical cardiac patients.

The PICqCPR dataset has several limitations in that patients were selected based on presence of invasive arterial lines and adequate waveforms for blood pressure analysis. Although the relevance of these DBP data may not be generalizable to patients without an invasive arterial line, it is precisely these patients with an invasive arterial line for whom we can titrate our CPR and advanced life support to attain a DBP hemodynamic target. Hemodynamic data was only collected for the first 10 minutes of CPR (or less when CPR duration was <10 minutes), thereby precluding assessment of the entire CPR period when the duration of CPR was >10 minutes. The PICqCPR database did not specify cardiac diagnosis other than HLHS, and thus does not differentiate patients who may have had shunt physiology, elevated end diastolic pressures, or other regurgitant lesions which may influence hemodynamics (e.g., severe aortic regurgitation). It is also unknown whether the shunt was found to be obstructed in the HLHS patients with MBT shunts. Additionally, the medical cardiac and HLHS patient groups constituted small sample sizes for comparisons. Although some central venous or right atrial pressure tracings were submitted for analysis, frequent interruptions for medication administration prevented adequate estimates of coronary perfusion pressure.

CONCLUSION:

These PICqCPR data demonstrate that during resuscitation in an ICU with invasive monitoring, DBP targets of ≥25 mmHg in infants and ≥30 mmHg in children can be achieved in most patients with both surgical and medical heart disease, and attaining these target DBPs was associated with higher rates of survival to hospital discharge among cardiac surgical patients. Additionally, these DBP targets could be achieved during CPR among most children with single ventricle physiology and most children with open chest physiology.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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ABBREVIATIONS

AHA	American Heart Association
CPCCRN	Collaborative Pediatric Critical Care Research Network
CPR	cardiopulmonary resuscitation
DBP	diastolic blood pressure
eCPR	extracorporeal cardiopulmonary resuscitation
FSS	Functional Status Scale
HLHS	hypoplastic left heart syndrome
ICU	intensive care unit
MAP	mean arterial pressure
PCPC	Pediatric Cerebral Performance Category
PICqCPR study	Pediatric Intensive Care Quality of CPR study
ROSC	return of spontaneous circulation
ROC	return of circulation
SBP	systolic blood pressure

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Table 1

Patient Characteristics by Cardiac Illness Category

		Illness Category		
Variable	**Overall (N = 113)**	**Surgical cardiac (N = 88)**	**Medical cardiac (N = 25)**	**P-value**
Age Category				<.001[2]
< 1 month	38 (33.6%)	37 (42.0%)	1 (4.0%)	
1 month - < 1 year	39 (34.5%)	32 (36.4%)	7 (28.0%)	
1 year - < 8 years	23 (20.4%)	13 (14.8%)	10 (40.0%)	
8 years - < 19 years	13 (11.5%)	6 (6.8%)	7 (28.0%)	
Sex				0.063[2]
Male	69 (61.1%)	58 (65.9%)	11 (44.0%)	
Female	44 (38.9%)	30 (34.1%)	14 (56.0%)	
Race				0.139[2]
White	58 (51.3%)	47 (53.4%)	11 (44.0%)	
Black or African American	22 (19.5%)	13 (14.8%)	9 (36.0%)	
Other	4 (3.5%)	3 (3.4%)	1 (4.0%)	
Unknown or Not Reported	29 (25.7%)	25 (28.4%)	4 (16.0%)	
Pre-existing Conditions				
Respiratory insufficiency	86 (76.1%)	66 (75.0%)	20 (80.0%)	0.792[2]
Hypotension	88 (77.9%)	70 (79.5%)	18 (72.0%)	0.424[2]
Congestive heart failure	18 (15.9%)	11 (12.5%)	7 (28.0%)	0.117[2]
Pneumonia	4 (3.5%)	3 (3.4%)	1 (4.0%)	1.000[2]
Sepsis	19 (16.8%)	16 (18.2%)	3 (12.0%)	0.559[2]
Renal insufficiency	12 (10.6%)	5 (5.7%)	7 (28.0%)	0.004[2]
Malignancy	2 (1.8%)	1 (1.1%)	1 (4.0%)	0.395[2]
Congenital heart disease	89 (78.8%)	77 (87.5%)	12 (48.0%)	<.001[2]
HLHS[3]	31 (27.4%)	27 (30.7%)	4 (16.0%)	1.000[2]
HLHS Anatomy (N=31)				0.743[2]
Preoperative	1 (3.2%)	1 (3.7%)	0 (0.0%)	
Norwood with MBT shunt	9 (29.0%)	7 (25.9%)	2 (50.0%)	
Norwood with RVPA shunt	8 (25.8%)	8 (29.6%)	0 (0.0%)	
Hybrid procedure	2 (6.5%)	2 (7.4%)	0 (0.0%)	
Bi-directional Glenn (Hemi-Fontan)	6 (19.4%)	5 (18.5%)	1 (25.0%)	
Fontan	5 (16.1%)	4 (14.8%)	1 (25.0%)	
Baseline PCPC score				0.997[1]
1 - Normal	54 (47.8%)	42 (47.7%)	12 (48.0%)	
2 - Mild disability	35 (31.0%)	28 (31.8%)	7 (28.0%)	

Variable	Overall (N = 113)	Illness Category: Surgical cardiac (N = 88)	Illness Category: Medical cardiac (N = 25)	P-value
3 - Moderate disability	14 (12.4%)	9 (10.2%)	5 (20.0%)	
4 - Severe disability	8 (7.1%)	7 (8.0%)	1 (4.0%)	
5 - Coma/vegetative state	2 (1.8%)	2 (2.3%)	0 (0.0%)	
Baseline total FSS	8 [6,10]	8 [6,12]	6 [6,8]	0.026[1]

[1] Wilcoxon rank-sum test.

[2] Fisher's exact test.

[3] Hypoplastic left heart syndrome.

Table 2:

Event Characteristics by Cardiac Illness Category

		Illness Category		
Variable	**Overall (N = 113)**	**Surgical cardiac (N = 88)**	**Medical cardiac (N = 25)**	**P-value**
Average over (up to) the first 10 minutes				
Chest compression rate (/min)	127.1 [114.5,139.2]	128.4 [113.9,140.2]	122.7 [117.5,129.8]	0.217[2]
DBP (mmHg)	27.7 [22.0,36.5]	26.4 [21.9,34.8]	33.0 [27.4,42.0]	0.031[2]
DBP (mmHg) ≥ 25 for infants or ≥30 for children	68 (60.2%)	51 (58.0%)	17 (68.0%)	0.488[1]
SBP (mmHg)	69.3 [53.0,93.2]	66.3 [50.9,87.6]	79.0 [67.6,100.0]	0.037[2]
SBP (mmHg) ≥ 60 for infants or ≥ 80 for children	61 (54.0%)	47 (53.4%)	14 (56.0%)	1.000[1]
MAP (mmHg)	43.0 [33.9,54.5]	42.5 [33.0,50.7]	48.3 [38.7,60.7]	0.023[2]
Ventilation rate (/min)[3]	32.7 [24.9,37.4]	34.9 [30.2,48.4]	24.9 [20.2,33.1]	0.043[2]
ETCO2 (mmHg)[3]	15.8 [9.4,25.2]	10.9 [8.7,20.5]	24.7 [16.4,26.3]	0.149[2]
Chest compression fraction	0.9 [0.8,1.0]	0.9 [0.8,1.0]	0.9 [0.8,0.9]	0.507[2]
Outcomes				
ROSC ≥ 20 min	74 (65.5%)	59 (67.0%)	15 (60.0%)	0.634[1]
ROC with eCPR	33 (29.2%)	29 (33.0%)	4 (16.0%)	0.136[1]
Survival to hospital discharge	57 (50.4%)	49 (55.7%)	8 (32.0%)	0.043[1]
Neurologic outcomes in survivors (N=57)				
Favorable neurologic outcome based on PCPC[4]	53 (93.0%)	45 (91.8%)	8 (100.0%)	1.000[1]
Pediatric Cerebral Performance Category at hospital discharge				0.080[2]
Normal	21 (36.8%)	20 (40.8%)	1 (12.5%)	
Mild disability	21 (36.8%)	18 (36.7%)	3 (37.5%)	
Moderate disability	10 (17.5%)	7 (14.3%)	3 (37.5%)	
Severe disability	5 (8.8%)	4 (8.2%)	1 (12.5%)	
Total FSS score at hospital discharge	8.0 [8.0,12.0]	8.0 [8.0,12.0]	11.0 [9.5,11.5]	0.095[2]
Change from baseline to hospital discharge total FSS	0.0 [-1.0,3.0]	0.0 [-1.0,2.0]	2.5 [1.0,4.0]	0.140[2]
New morbidity at hospital discharge[5]	16 (28.1%)	12 (24.5%)	4 (50.0%)	0.202[1]

[1] Fisher's exact test.

[2] Wilcoxon rank-sum test. Continuous variables are summarized using median [Q1, Q3].

[3] Ventilation rate and ETCO2 data were available for N=20 total subjects (N=14 surgical cardiac, N=6 medical cardiac).

[4] Favorable neurologic outcome defined as discharge PCPC of normal, mild disability, or moderate disability or a discharge PCPC no worse than baseline PCPC.

[5] New morbidity defined as an increase of at least 3 between baseline and discharge FSS.

Table 3

Resuscitation Guidelines by Cardiac Illness Category and Survival to Hospital Discharge

	Surgical Cardiac			Medical Cardiac		
	Status at Hospital Discharge			Status at Hospital Discharge		
Variable	Dead (N = 39)	Alive (N = 49)	P-value	Dead (N = 17)	Alive (N = 8)	P-value
Compression rate in guidelines (100-120 per min)	15 (38.5%)	12 (24.5%)	0.172[1]	7 (41.2%)	3 (37.5%)	1.000[1]
DBP (mmHg) ≥ 25 for infants or ≥ 30 for children	17 (43.6%)	34 (69.4%)	0.018[1]	13 (76.5%)	4 (50.0%)	0.359[1]
SBP (mmHg) ≥ 60 for infants or ≥ 80 for children	18 (46.2%)	29 (59.2%)	0.283[1]	9 (52.9%)	5 (62.5%)	1.000[1]
Ventilation Rate[4] (/min)	34.7 [26.7,49.4]	34.9 [30.2,48.4]	0.944[2]	24.7 [20.2,33.1]	25.1 [25.1,25.1]	1.000[2]
ETCO2 < 10 (mmHg)[4]	2 (50.0%)	2 (20.0%%)	0.520[1]	1 (20.0%)	0 (0.0%)	1.000[1]
ETCO2 ≥ 20 (mmHg)[4]	0 (0.0%)	4 (40.0%%)	0.251[1]	3 (60.0%)	1 (100.0%)	1.000[1]
CCF[3] ≥ 90%	22 (56.4%)	25 (51.0%)	0.829[1]	10 (58.8%)	3 (37.5%)	0.411[1]

[1] Fisher's exact test.

[2] Wilcoxon rank-sum test.

[3] Chest compression fraction

[4] Ventilation rate and ETCO2 data were not available for all cardiac subjects (N=14 surgical cardiac, N=6 medical cardiac).

Table 4

Resuscitation Guidelines by Cardiac Illness Category and ROSC

Variable	Surgical Cardiac ROSC ≥ 20 mins No (N = 29)	Surgical Cardiac ROSC ≥ 20 mins Yes (N = 59)	P-Value	Medical Cardiac ROSC ≥ 20 mins No (N = 10)	Medical Cardiac ROSC ≥ 20 mins Yes (N = 15)	P-value
Compression rate in guidelines (100-120 per min)	14 (48.3%)	13 (22.0%)	0.015[1]	3 (30.0%)	7 (46.7%)	0.678[1]
DBP (mmHg) ≥ 25 for infants or ≥30 for children	13 (44.8%)	38 (64.4%)	0.108[1]	6 (60.0%)	11 (73.3%)	0.667[1]
Ventilation Rate[4] (/min)	48.8 [35.9,61.7]	33.0 [29.4,43.1]	0.235[2]	24.7 [20.2,34.1]	25.1 [19.9,33.1]	1.000[2]
ETCO2 < 10 (mmHg)[4]	1 (3.4%)	3 (5.1%)	0.505[1]	1 (10.0%)	0 (0.0%)	1.000[1]
ETCO2 ≥ 20 (mmHg)[4]	1 (3.4%)	3 (5.1%)	0.505[1]	1 (10.0%)	3 (20.0%)	0.400[1]
CCF[3] ≥ 90%	16 (55.2%)	31 (52.5%)	1.000[1]	6 (60.0%)	7 (46.7%)	0.688[1]

[1] Fisher's exact test.

[2] Wilcoxon rank-sum test.

[3] Chest compression fraction

[4] Ventilation rate and ETCO2 data were not available for all cardiac subjects (N=14 surgical cardiac, N=6 medical cardiac).

Table 5

Event Characteristics and Outcomes in Hypoplastic Left Heart Syndrome Subjects

	HLHS Anatomy				
Variable	**MBT shunt (N = 9)**	**RVPA shunt (N = 8)**	**Hybrid (N = 2)**	**Cavopulmonary Anastamosis (N = 11)**	**Other CHD (N = 58)**
Average over (up to) the first 10 minutes[1]					
Chest Compression Rate (/min)	141.1 [109.7,143.1]	119.7 [112.7,132.4]	132.0 [121.0,143.0]	125.3 [118.4,155.9]	128.3 [114.0,139.6]
DBP (mmHg)	25.0 [20.0,33.3]	23.6 [22.8,27.8]	27.3 [18.6,36.0]	33.0 [24.0,49.1]	28.0 [22.9,36.1]
DBP (mmHg) ≥ 25 for infants or ≥ 30 for children	5 (55.6%)	3 (37.5%)	1 (50.0%)	7 (63.6%)	38 (65.5%)
SBP (mmHg)[2]	67.6 [49.0,74.5]	93.9 [64.6,102.0]	47.6 [26.2,69.0]	68.0 [48.7,83.0]	67.6 [55.0,90.0]
SBP (mmHg) ≥ 60 for infants or ≥ 80 for children[3]	6 (66.7%)	6 (75.0%)	1 (50.0%)	5 (45.5%)	31 (53.4%)
MAP (mmHg)	39.2 [29.7,47.0]	44.7 [37.5,51.4]	34.1 [21.1,47.0]	42.5 [34.5,67.0]	42.9 [35.2,53.0]
Chest Compression Fraction	0.86 [0.85,0.92]	0.95 [0.87,0.96]	0.75 [0.73,0.77]	0.93 [0.88,0.98]	0.90 [0.84,0.96]
Outcomes					
ROSC ≥ 20 min	5 (55.6%)	5 (62.5%)	1 (50.0%)	10 (90.9%)	41 (70.7%)
ROC with eCPR	4 (44.4%)	3 (37.5%)	1 (50.0%)	1 (9.1%)	15 (25.9%)
Survival to hospital discharge[4]	8 (88.9%)	3 (37.5%)	1 (50.0%)	6 (54.5%)	30 (51.7%)

[1] Continuous variables are summarized using median [Q1,Q3].

[2] Average SBP was not significantly different between MBT shunt and RVPA shunt subjects (p=0.075, Wilcoxon rank-sum test).

[3] Rate of SBP target achievement was not significantly different between MBT shunt and RVPA shunt subjects (p=1.000, Fisher's exact test).

[4] Survival to hospital discharge was significantly different between MBT shunt and RVPA shunt subjects (p=0.050, Fisher's exact test).

Table 6

Comparison of Cardiac Subjects with Open vs. Closed Chest at Start of CPR

Variable	Open Chest at Start of CPR No (N = 93)	Open Chest at Start of CPR Yes (N = 20)	P-value
Age Category			0.008[1]
< 1 month	25 (26.9%)	13 (65.0%)	
1 month - < 1 year	37 (39.8%)	2 (10.0%)	
1 year - < 8 years	20 (21.5%)	3 (15.0%)	
8 years - < 19 years	11 (11.8%)	2 (10.0%)	
Sex			0.453[1]
Male	55 (59.1%)	14 (70.0%)	
Female	38 (40.9%)	6 (30.0%)	
Average DBP (mmHg)	29.0 [22.7,38.4]	25.7 [17.9,32.4]	0.080[2]
Average DBP (mmHg) ≥ 25 for infants or ≥30 for children	57 (61.3%)	11 (55.0%)	0.622[1]
Average SBP (mmHg)[4]	69.3 [53.0,93.2]	70.0 [53.1,91.0]	0.931[2]
Average SBP (mmHg) ≥ 60 for infants or ≥ 80 for children	49 (52.7%)	12 (60.0%)	0.626[1]
ROSC ≥ 20 min	64 (68.8%)	10 (50.0%)	0.125[1]
ROC with eCPR	23 (24.7%)	10 (50.0%)	0.032[1]
Survival to Hospital Discharge	48 (51.6%)	9 (45.0%)	0.630[1]

[1] Fisher's exact test.

[2] Wilcoxon rank-sum test.

Table 7

Event Characteristics and Outcomes in eCPR Patients

	Vital status at hospital discharge		
	Dead (N = 20)	Alive (N = 13)	P-value
Age Category			0.184[1]
< 1 month	7 (35.0%)	9 (69.2%)	
1 month - < 1 year	5 (25.0%)	3 (23.1%)	
1 year - < 8 years	5 (25.0%)	1 (7.7%)	
8 years - < 19 years	3 (15.0%)	0 (0.0%)	
Sex			0.087[1]
Male	9 (45.0%)	10 (76.9%)	
Female	11 (55.0%)	3 (23.1%)	
Duration of CPR (minutes)	48.5 [38.5,55.5]	28.0 [16.0,52.0]	0.109[2]
CPR Time Category			0.284[1]
Weekday	9 (45.0%)	9 (69.2%)	
Weeknight/Weekend	11 (55.0%)	4 (30.8%)	
Illness Category			0.136[1]
Surgical cardiac	16 (80.0%)	13 (100.0%)	
Medical cardiac	4 (20.0%)	0 (0.0%)	
Pharmacologic Interventions			
Epinephrine	19 (95.0%)	13 (100.0%)	1.000[1]
Total number of epi doses	5.0 [3.0,9.0]	4.0 [3.0,5.0]	0.599[2]
Calcium	11 (55.0%)	10 (76.9%)	0.278[1]
Sodium bicarbonate	17 (85.0%)	11 (84.6%)	1.000[1]
Average DBP (mmHg)	23.5 [16.1,29.4]	26.6 [23.0,32.0]	0.204[2]
Average DBP (mmHg) ≥ 25 for infants or ≥30 for children	8 (40.0%)	8 (61.5%)	0.296[1]
Average SBP (mmHg)	55.1 [48.3,80.8]	83.7 [64.0,98.2]	0.156[2]
Average SBP (mmHg) ≥ 60 for infants or ≥ 80 for children	7 (35.0%)	10 (76.9%)	0.032[1]

[1] Fisher's exact test.

[2] Wilcoxon rank-sum test.