Association of Left Ventricular Systolic Function and Vasopressor Support With Survival Following Pediatric Out-of-Hospital Cardiac Arrest*

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Objectives: To characterize the association of hospital discharge survival with left ventricular systolic function evaluated by transthoracic echocardiography and vasoactive infusion support following return of spontaneous circulation after pediatric out-of-hospital cardiac arrest.

Design: Retrospective case series.

Setting: Single-center tertiary care pediatric cardiac arrest and critical care referral center.

Patients: Consecutive out-of-hospital cardiac arrest patients less than 18 years surviving to PICU admission who had a transthoracic echocardiography obtained by the clinical team within 24 hours of admission from January 2006 to May 2012.

Interventions: None.

Measurements and Main Results: Fifty-eight patients had a post–return of spontaneous circulation transthoracic echocardiography performed within 24 hours of admission. The median time from return of spontaneous circulation to echo was 6.5 hours (interquartile range, 4.7, 15.0 hr). Left ventricular systolic function was decreased in 24 of 58 patients (41%). The mortality rate was 67% (39 of 58). Thirty-six patients (62%) received vasoactive infusions at the time of transthoracic echocardiography, and increased vasopressor inotropic score was associated with increased mortality on univariate analysis ($p < 0.001$). After controlling for defibrillation, vasopressor inotropic score, and interaction between vasopressor inotropic score and left ventricular systolic function, decreased left ventricular systolic function was associated with increased mortality (odds ratio, 13.7; 95% CI, 1.54–122).

Conclusions: In patients receiving transthoracic echocardiography within the first 24 hours following return of spontaneous circulation after pediatric out-of-hospital cardiac arrest, decreased left ventricular systolic function and vasopressor use were common. Decreased left ventricular systolic function was associated with increased mortality. (*Pediatr Crit Care Med* 2015; 16:146–154)

Key Words: cardiac arrest; echocardiogram; hemodynamic; resuscitation; vasopressor

Up to 15,000 children in the United States suffer an out-of-hospital cardiac arrest (OHCA) every year (1–3). Between 10% and 30% of pediatric OHCA patients treated in the field have sustained return of spontaneous circulation (ROSC) and survive to be admitted to a PICU. Of these, less than 40% survive to hospital discharge (3–5).

Over the last 2 decades, a post–cardiac arrest syndrome characterized by myocardial dysfunction, brain injury, and a typical ischemia-reperfusion response has been described (6–8). Global myocardial dysfunction peaks within 8 hours of the ischemic insult and is frequently associated with early hemodynamic instability (8, 9). Although this myocardial dysfunction may be transient and reversible, decreased left ventricular (LV) systolic function following cardiac arrest has been associated with increased mortality in adults (7, 10).

We sought to characterize the prevalence of LV systolic dysfunction and vasopressor support after successful ROSC following pediatric OHCA. We hypothesized that decreased LV systolic function on transthoracic echocardiography (TTE) within the first 24 hours following successful resuscitation would be associated with increased mortality.

*See also p. 190.

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Dr. Falkensammer served as board member for the American Board of Pediatrics/Pediatric Cardiology and is employed by the University of Pennsylvania. Dr. Hammond received support for participation in review activities from Westat. Dr. Nadkarni is funded by U01 HL107681 (Heart and Lung Failure-Pediatric Insulin Titration Trial), RO1HL114484 (Coagulation and Fibrinolysis in Pediatric Insulin Titration Trial), Agency for Healthcare Research & Quality 1 R18 HS022464 (The National Emergency Airway Registry for Children), 5R01HL058669-10 (Cardiopulmonary Bypass), and U01HL094345-01 (Therapeutic Hypothermia After Pediatric Cardiac Arrest [THAPCA]). His institution received grant support from the National Institutes of Health (NIH)/NHLBI: U01 co-I for Therapeutic Hypothermia After Pediatric Cardiac Arrest and from the NIH/NHLBI: Co-I UO1 Heart and Lung Failure-Pediatric Insulin Titration trial. Dr. Berg is funded by the NIH award U10 HD063108. Dr. Topjian is funded by the NIH career development award K23NS075363 and U01HL094345-01 (THAPCA). Her institution received grant support from the NIH. The remaining authors have disclosed that they do not have any potential conflicts of interest.

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DOI: 10.1097/PCC.0000000000000305

MATERIALS AND METHODS

We performed a retrospective study of patients 1 month to 18 years old presenting to the PICU at The Children's Hospital of Philadelphia from January 2006 through May 2012. Patients were included for analysis if they had an OHCA, received any chest compressions, had sustained ROSC greater than 20 minutes, and TTE performed by the clinical team within 24 hours of PICU admission. The study was approved with a waiver of informed consent granted by the Children's Hospital of Philadelphia Institutional Review Board.

Patients were prospectively identified from September 2009 to May 2012 and entered into a cardiac arrest database. Patients from January 2006 through September 2009 were identified from existing hospital cardiac arrest databases. Search terms were "code," "arrest," "cardiac arrest," "CPR," "prior CPR," "hanging," "drowning," "near drowning," "SIDS," and "ALTE." All identified patients underwent chart review to verify they had received chest compressions and qualified as an OHCA.

Prehospital and inpatient medical records were reviewed by a single trained investigator. Data extracted included prearrest patient demographics and characteristics, cardiac arrest event details, vasoactive infusion dosing, hemodynamic variables and laboratory values at the time of TTE, and survival to hospital discharge outcomes. Vital signs and vasopressor data were obtained within 1 hour of TTE; troponin and B-type natriuretic peptide (BNP) were recorded if obtained within 12 hours of TTE; lactate, central venous oxygen saturation, ionized calcium, and pH were recorded if obtained within 4 hours of TTE and were exclusively arterial unless only free flowing venous sample was available.

Vasopressor and inotrope dosing were standardized by calculating a vasopressor inotropic score (VIS) at the time of TTE as previously described (11–13). VIS = (dopamine dose [μg/kg/min] × 1) + (dobutamine dose [μg/kg/min] × 1) + (epinephrine dose [μg/kg/min] × 100) + norepinephrine dose [μg/kg/min] × 100) + (phenylephrine dose [μg/kg/min] × 100) + (milrinone dose [μg/kg/min] × 10) + (vasopressin dose [U/kg/min] × 10,000).

TTE images were reviewed by a board-certified pediatric cardiologist blinded to patient history, VIS, and outcome. Patients were eligible for analysis if there were adequate images for qualitative assessment of LV systolic function because qualitative assessment using TTE is a reliable measure of systolic function when performed by expert echocardiographers (14–17). Additional TTE myocardial performance data (LV shortening fraction by M-Mode, qualitative right ventricular [RV] systolic function, LV diastolic function by ratio of the early (E) to late (A) ventricular filling velocities of the mitral inflow, RV diastolic function by E/A ratio of the tricuspid inflow, and septal wall motion abnormality as well as structural abnormality) were documented for each TTE when available. Myocardial performance abnormality is defined by an abnormality in one or more of these measures. Qualitative LV systolic function was categorized as "decreased" (mild, moderate, or severe dysfunction) or "not decreased" (hyperdynamic or normal).

The primary outcome was in-hospital mortality. Summary statistics are reported as median and interquartile ranges (IQR, 25th–75th percentiles) for continuous variables and proportions as percentages for categorical variables. Fisher exact tests or Wilcoxon rank-sum tests were used to determine differences between groups. Noncollinear covariates were introduced into the multiple regression model if a univariate analysis with mortality revealed a p value less than 0.1. LV systolic function was a priori chosen to be included into the model because of its clinical and intuitive relevance (18). After creating our main effects model, we included the interaction between LV systolic function and VIS given their physiologic interdependence and clinical relevance. C-statistic was performed to determine the predictive accuracy of our model. A significance value of less than 0.05 was used for all analyses. All statistical analyses were conducted using SAS software (version 9.2; SAS Institute, Cary, NC).

RESULTS

Patients

Of 169 patients surviving OHCA to PICU admission, 59 (35%) had TTEs performed within 24 hours of ICU admission. One patient did not have interpretable TTE images and was excluded, resulting in 58 patients eligible for analysis. Forty-five percent (26 of 58) of patients had a preexisting condition, including chronic lung disease, asthma, congenital heart disease, developmental delay, cancer, prematurity, epilepsy, and neuromuscular disease. Except for developmental delay (14), congenital heart disease (8), and chronic lung disease (7), all other preexisting conditions were found in less than or equal to five patients, with some patients having more than one preexisting condition. Of the patients with congenital heart disease, five had a prior TTE demonstrating normal LV function and three did not have a prior TTE for evaluation. Of the eight patients with a first documented cardiac arrest rhythm of ventricular fibrillation or pulseless ventricular tachycardia, cause of arrest included arrhythmia (6), drowning (1), and unknown (1). Twenty-five patients (43%) were clinically managed with therapeutic hypothermia targeting a core temperature between 32°C and 34°C in the first 24 hours after ROSC.

Echocardiographic Data

Median time from admission to TTE was 4.5 hours (IQR, 2.9–10.6 hr). Median time from ROSC to TTE ($n = 46$) was 6.5 hours (IQR, 4.7–15.0 hr). Forty-one percent of patients (24 of 58) had decreased LV systolic function. Quantitative shortening fractions were determined in 38 patients (66%). Among patients with qualitatively decreased LV systolic function and M-Mode measurements for quantitative shortening fraction assessment available, all had shortening fractions less than or equal to 27% (18 of 18) (**Table 1**). Other myocardial performance abnormalities included abnormal RV systolic function 18% (10 of 56), abnormal septal wall movement 42% (19 of 44), mitral valve E/A reversal indicative of abnormal LV diastolic function 64% (23 of 36), and tricuspid valve E/A reversal indicative of abnormal RV diastolic function 65% (20 of 31). Overall, 79% of patients (46 of 58) had evidence of a myocardial performance abnormality on initial TTE. Ten patients had repeat TTE within 72 hours. Eight patients had no change in qualitative LV systolic function. One patient transitioned from hyperdynamic LV systolic function to

TABLE 1. Laboratory and Hemodynamic Variable Association at the Time of Transthoracic Echocardiogram by Left Ventricular Systolic Function Category

Variable	*n*	Decreased Left Ventricular Systolic Function (*n* = 24) Median (IQR)	Not Decreased Left Ventricular Systolic Function (*n* = 34) Median (IQR)	*p*
Temperature (°C)	56	34.5 (32.6–36.5)	34.8 (33.3–36.6)	0.69
Heart rate (beats/min)	57	123 (92–142)	126.5 (97.0–153.0)	0.48
Systolic blood pressure (mm Hg)	57	110 (91–126)	107.0 (93.0–124.0)	0.44
Diastolic blood pressure (mm Hg)	57	64 (47–75)	56.5 (46.0–71.0)	0.24
Mean arterial pressure (mm Hg)	52	83 (69.0–91.0)	77.0 (60.0–93.0)	0.49
Central venous pressure (mm Hg)	25	10.0 (6.0–13.0)	10.0 (8.0–15.0)	0.28
Lactate (mmol/L)	54	6.9 (3.3–11.9)	5.2 (1.5–7.9)	0.13
pH	57	7.3 (7.2–7.4)	7.3 (7.2–7.4)	0.91
Ionized calcium (mmol/L)	54	1.1 (1.0–1.2)	1.2 (1.1–1.2)	0.22
B-type natriuretic peptide (pg/mL)	13	169.9 (79.4–1633.6)	93.9 (76.2–195.1)	0.48
Troponin (ng/mL)	**36**	**6.6 (1.0–22.8)**	**0.37 (0.14–1.9)**	**0.01**
Mean airway pressure (cm H_2O)	57	17.0 (15.0–23.0)	14.5 (11.0–20.0)	0.10
Vasopressor inotropic score	58	11.5 (0–28)	5 (0–20)	0.45
Left ventricular shortening fraction (%)	**38**	**26.0 (20.0–28.0)**	**35.0 (33.0–39.0)**	**< 0.001**
Svo_2 (%)	22	56.5 (49.6–79.9)	65.8 (61.6–77.5)	0.37

IQR = interquartile range.
Boldface values indicate statistical significance ($p < 0.05$).

mild dysfunction and died. One patient transitioned from mild LV systolic dysfunction to normal function and survived. Four patients (7%) had a new diagnosis of structural heart disease based on post-ROSC TTE: LV noncompaction (2), anomalous right coronary artery arising from the left coronary sinus (1), and ventricular septal defect (1).

There were no significant differences in demographics, pre-event, or arrest characteristics between groups with and without LV systolic dysfunction (**Table 2**). Low systolic, diastolic, mean, and central venous blood pressures at the time of echocardiographic assessment were not associated with decreased LV systolic function (Table 1). Troponin level was the only other laboratory or hemodynamic variable significantly associated with decreased LV systolic function ($p = 0.01$) (Table 1). Thirty-six patients (62%) were treated with vasopressor support at the time of TTE. Of those on support, 27 patients (75%) were treated with dopamine, 25 (69%) with epinephrine, four (11%) with vasopressin, two (6%) with norepinephrine, two (6%) with dobutamine, two (6%) with phenylephrine, and one (3%) with milrinone. VIS at the time of TTE was not associated with LV systolic function ($p = 0.45$) (Table 1).

Survival Outcome

In our cohort of post-ROSC patients evaluated by TTE within 24 hours of PICU admission, mortality was 67% (39 of 58). The overall mortality of patients admitted to the PICU after OHCA during that same time period was 48% (81 of 169). Within our cohort, no demographic or prearrest characteristics were associated with mortality. Arrest characteristics associated with mortality were witnessed status, first documented cardiac arrest rhythm, number of epinephrine doses, defibrillation, primary cause of arrest, and duration of chest compressions (**Table 3**). No patient with a first documented rhythm of ventricular fibrillation or pulseless ventricular tachycardia died.

Seven patients (18%) died from a cardiac etiology, specifically rearrest or withdrawal due to refractory circulatory failure, which were not associated with decreased LV systolic function (odds ratio [OR] = 0.8 [0.15, 4.18]; $p = 0.79$). In patients with decreased LV systolic function who died, cause of death included brain death (9 [50%]), withdrawal due to neurologic failure (5 [28%]), withdrawal due to respiratory failure (1 [6%]), and withdrawal due to refractory circulatory failure (3 [17%]). No patients with decreased LV systolic function died after rearrest. Patients who had a lower temperature, higher heart rate, higher lactate level, and higher mean airway pressure at the time of TTE were more likely to die. Patients managed with targeted temperature management less than 34°C composed 42% of survivors (8 of 19) and 44% of non-survivors (17 of 39). A higher VIS at the time of TTE was also associated with increased mortality ($p < 0.001$) (**Table 4**). No myocardial performance measures, including LV ($p = 0.09$) or RV ($p = 0.05$) diastolic dysfunction, were associated with mortality on univariate analysis (Table 4).

TABLE 2. Patient Demographics and Preevent and Event Data by Left Ventricular Systolic Function Category

Demographics and Data	*n* (%)	Decreased Left Ventricular Systolic Function (*n* = 24) *n* (%)	Not Decreased Left Ventricular Systolic Function (*n* = 34) *n* (%)	*p*
Gender				0.58
Male	41 (71)	18 (75)	23 (68)	
Preexisting condition				
Any	26 (45)	10 (42)	16 (47)	0.68
Witnessed arrest	22 (38)	11 (46)	11 (32)	0.41
Bystander CPR	35 (60)	14 (58)	21 (62)	0.99
First documented cardiac arrest rhythm				0.93
Asystole/pulseless electrical activity	31 (53)	14 (58)	17 (50)	
Ventricular fibrillation/ventricular tachycardia	19 (33)	3 (13)	5 (15)	
Unknown	8 (14)	7 (29)	12 (35)	
No. of epinephrine doses				0.71
0	11 (19)	5 (21)	6 (18)	
1	7 (12)	1 (4)	6 (18)	
2	4 (7)	2 (8)	2 (6)	
3	14 (24)	5 (21)	9 (26)	
4	10 (17)	6 (25)	4 (12)	
5	2 (3)	1 (4)	1 (3)	
≥ 6	9 (16)	4 (17)	5 (15)	
Unknown	1 (2)	0 (0)	1 (3)	
Defibrillation	16 (28)	9 (37)	7 (21)	0.23
Primary cause of arrest				0.73
Acute life-threatening event/sudden infant death syndrome	14 (24)	6 (25)	8 (24)	
Drowning	8 (14)	1 (4)	7 (21)	
Respiratory failure	2 (3)	1 (4)	1 (3)	
Airway obstruction	6 (10)	3 (13)	3 (9)	
Arrhythmia	7 (12)	4 (17)	3 (9)	
Hypotension/shock	3 (5)	2 (8)	1 (3)	
Trauma	9 (16)	4 (17)	5 (15)	
Ingestion/toxin	2 (3)	1 (4)	1 (3)	
Unknown	7 (12)	2 (8)	5 (15)	

Demographics and Data	Median (IQR)	Decreased Left Ventricular Systolic Function (*n* = 24) Median (IQR)	Not Decreased Left Ventricular Systolic Function (*n* = 34) Median (IQR)	*p*
Age (yr)	4.1 (0.57–11.0)	6.0 (0.52–14.4)	3.7 (0.57–8.9)	0.49
Duration CPR (min, *n* = 54)	25.0 (13.0–42.0)	25.0 (15.0–45.0)	25.5 (13.0–41.0)	0.75

CPR = cardiopulmonary resuscitation, IQR = interquartile range.

TABLE 3. Patient Demographics and Preevent and Event Data by Discharge Survival Outcomes

Demographics and Data	*n* (%)	Nonsurvival (*n* = 39) (%)	Survival (*n* = 19) (%)	*p*
Male gender	41 (71)	25 (64)	16 (84)	0.14
Preexisting condition	26 (45)	17 (44)	9 (47)	0.79
Witnessed arrest	22 (38)	11 (28)	11 (58)	**0.04**
Bystander CPR	35 (60)	24 (62)	11 (58)	0.99
First documented cardiac arrest rhythm				**< 0.001**
Asystole/pulseless electrical activity	31 (53)	26 (67)	5 (26)	
Ventricular fibrillation/ventricular tachycardia	19 (33)	0 (0)	8 (42)	
Unknown	8 (14)	13 (33)	6 (32)	
No. of epinephrine doses				**< 0.001**
0	11 (19)	1 (3)	10 (53)	
1	7 (12)	5 (13)	2 (11)	
2	4 (7)	3 (8)	1 (5)	
3	14 (24)	10 (26)	4 (21)	
4	10 (17)	9 (23)	1 (5)	
5	2 (3)	1 (3)	1 (5)	
≥ 6	9 (16)	9 (23)	0 (0)	
Unknown	1 (2)	1 (3)	0 (0)	
Defibrillation	16 (28)	5 (13)	11 (58)	**< 0.001**
Primary cause of arrest				**0.01**
Acute life-threatening event/sudden infant death syndrome	14 (24)	11 (28)	3 (16)	
Drowning	8 (14)	3 (8)	5 (26)	
Respiratory failure	2 (3)	2 (5)	0 (0)	
Airway obstruction	6 (10)	4 (10)	2 (11)	
Arrhythmia	7 (12)	1 (3)	6 (32)	
Hypotension/shock	3 (5)	3 (8)	0 (0)	
Trauma	9 (16)	9 (23)	0 (0)	
Ingestion/toxin	2 (3)	2 (5)	0 (0)	
Unknown	7 (12)	4 (10)	3 (16)	

		Nonsurvival (*n* = 39)	Survival (*n* = 19)	
Demographics and Data	**Median (IQR)**	**Median (IQR)**	**Median (IQR)**	*p*
Age (yr)	4.1 (0.57–11)	3.2 (0.4–9.7)	6.8 (0.57–14.6)	0.17
Duration CPR (min, *n* = 54)	**25.5 (13.0–42.0)**	**36.0 (21.0–50.0)**	**10.0 (2.0–20.0)**	**< 0.001**

CPR = cardiopulmonary resuscitation, IQR = interquartile range.
Boldface values indicate statistical significance ($p < 0.05$).

In a multivariable analysis controlling for defibrillation, there is a significant interaction between VIS and LV systolic function. Specifically, when VIS equals 0, the odds of death is decreased for those with normal LV systolic versus those with decreased LV systolic function (adjusted OR, 13.7 [1.54–121.9]; $p = 0.019$) (**Table 5**). Further, as VIS increases, the odds of death is significantly increased for those with normal LV systolic function such that the difference in odds of death between the two LV function groups no longer differs (Table 5). The c-statistic for our final model was 93.6%.

TABLE 4. Laboratory and Hemodynamic Variable Association at the Time of Transthoracic Echocardiogram by Discharge Survival Outcomes

Variable	*n*	Nonsurvival (*n* = 39) Median (IQR)	Survival (*n* = 19) Median (IQR)	OR (95% CI)	*p*
Temperature (°C)	**56**	**34.2 (32.6–35.4)**	**36.5 (33.4–36.9)**	**0.68 (0.49–0.94)**	**0.018**
Heart rate (beats/min)	**57**	**136.5 (103.0–165.0)**	**109.0 (82.0–132.0)**	**1.02 (1.00–1.04)**	**0.03**
Systolic blood pressure (mm Hg)	57	108.5 (81.0–124.0)	110.0 (102.0–129.0)	0.98 (0.96–1.00)	0.073
Diastolic blood pressure (mm Hg)	57	60.5 (46.0–74.0)	57.0 (48.0–66.0)	1.00 (0.98–1.04)	0.59
Mean arterial pressure (mm Hg)	52	79.0 (60.0–91.0)	77.0 (69.0–89.0)	0.99 (0.97–1.03)	0.84
Central venous pressure (mm Hg)	25	10.5 (7.0–15.0)	9.0 (8.0–10.0)	1.12 (0.89–1.39)	0.32
Lactate (mmol/L)	**54**	**7.0 (4.1–11.9)**	**3.0 (1.5–3.4)**	**1.42 (1.11–1.81)**	**0.005**
pH	56	7.3 (7.2–7.4)	7.3 (7.2–7.4)	1.96 (0.37–10.4)	0.43
Ionized calcium (mmol/L)	54	1.1 (1.0–1.2)	1.2 (1.1–1.2)	0.03 (0.00–7.2)	0.22
B-type natriuretic peptide (pg/mL)	13	93.9 (37.1–234.2)	140.1 (84.4–206.0)	1.00 (0.99–1.00)	0.42
Troponin (ng/mL)	36	2.5(0.2–13.3)	0.6 (0.2–1.9)	1.17 (0.92–1.47)	0.19
Svo_2 (%)	22	59.5 (46.9–76.0)	71.4 (63.8–78.7)	0.96 (0.89–1.04)	0.32
Mean airway pressure (cm H_2O)	57	16.5 (14.0–24.0)	12.0 (9.0–19.0)	1.08 (0.99–1.18)	0.058
Vasopressor inotropic score	**58**	**13.0 (5.0–50)**	**0.0 (0.0–0.0)**	**1.12 (1.02–1.23)**	**0.02**
Variable	***n* (%)**	**Nonsurvival (*n* = 39) (%)**	**Survival (*n* = 19) (%)**	**OR (95% CI)**	***p***
Left ventricular systolic function	58				
Not decreased	34 (59)	21 (54)	13 (68)		
Decreased	24 (41)	18 (46)	6 (32)	1.86 (0.59–5.89)	0.29
Left ventricular diastolic dysfunction[a]	35	22	13		
Present	22 (63)	16 (73)	6 (46)	3.1 (0.74–13.11)	0.12
Absent	13 (37)	6 (27)	7 (54)		
Right ventricular diastolic dysfunction[a]	31	21	10		
Present	20 (65)	16 (76)	4 (40)	4.8 (0.95–24.1)	0.057
Absent	11 (35)	5 (24)	6 (60)		

IQR = interquartile range, OR = odds ratio.
[a]Echo data assessing diastolic dysfunction not complete.
p values presented are from univariate regression model.
Boldface values indicate statistical significance ($p < 0.05$).

DISCUSSION

In this single-center retrospective study, 41% of children (24 of 58) evaluated with TTE following OHCA had decreased LV systolic function. Importantly, decreased LV systolic function was associated with increased mortality when VIS was 0. Clinical variables such as heart rate, blood pressure, and central venous pressure assessed near the time of echocardiogram were not useful in differentiating patients with and without decreased LV systolic function.

The demographic and arrest characteristics associated with survival in our cohort are similar to previously published pediatric OHCA populations (1, 19). We chose LV systolic function as our primary exposure as it is often evaluated after cardiac arrest for treatable causes of hypotension and has been associated with increased mortality in pediatric and adult populations following cardiac arrest (7, 10, 20, 21). Decreased LV systolic function was common in our cohort and, after controlling for defibrillation, VIS, and interaction between VIS and LV systolic function, was associated with increased mortality. When comparing patients with good and poor LV systolic function, as VIS increased from 5 to 15, the odds of death between these two groups was not different.

A heterogeneous pattern of myocardial performance abnormalities were found on TTE. Although our hypothesis focused

TABLE 5. Odds of Death if Left Ventricular Shortening Fraction Qualitatively Decreased After Controlling for Defibrillation, Vasopressor Inotropic Score, and the Interaction Between Left Ventricular Shortening Fraction and Vasopressor Inotropic Score

Variable	OR (95% CI)	*p*
Decreased qualitative LVSF	13.71 (1.54–121.95)	**0.019**
Defibrillated	0.06 (0.008–0.44)	**0.006**
VIS	**1.7 (1.09–2.65)**	**0.019**
LVSF + VIS interaction	0.61 (10.39–0.95)	**0.031**

LVSF = left ventricular shortening fraction, VIS = vasopressor inotropic score. Boldface values indicate statistical significance ($p < 0.05$).

on postarrest LV systolic function, diastolic dysfunction was even more common. No prearrest or arrest characteristics evaluated were associated with abnormal LV systolic function postarrest. Chang et al (10) demonstrated an association between number of epinephrine doses and decreased LV systolic function in their cohort of adult OHCA patients. Laurent et al (7) also demonstrated an association between number of epinephrine doses and hemodynamic insufficiency defined by vasopressor requirement. It is unclear why, within our cohort, we did not find this association. It is possible that children and adults are distinctly different as 47% and 33% of patients in the study by Laurent et al (7) and Chang et al (10), respectively, had coronary artery occlusion as likely cause of arrest. Further, Chang et al (10) found that history of myocardial infarction was an independent predictor of abnormal LV systolic function on multivariate analysis. Epinephrine, as theorized in their discussion, may serve to increase myocardial oxygen demand in a setting of decreased supply and distribution. Such precipitating coronary pathology infrequently occurs in children. It is also possible that post–cardiac arrest syndrome is distinctly different in its hemodynamic manifestation within the pediatric population, similar to septic shock. Use of echocardiography may not also be the most precise means of evaluating hemodynamic status, though remains a safe and readily available resource within larger centers.

Usual clinical and laboratory variables to assess LV systolic function such as heart rate, blood pressures, and BNP documented near the time of echocardiogram were not helpful in discriminating our patients with decreased LV systolic function. Despite our continued reliance upon clinical examination and serum biomarkers to construct individual hemodynamic profiles, surrogate markers thought to represent core physiologic variables are frequently not reliable or validated in the literature (22–24). The data from our study suggest the need for improved individual post–cardiac arrest hemodynamic characterization and perhaps the development of a personalized, goal-directed approach to management as recommended by The International Liaison Committee on Resuscitation in their 2008 Consensus Statement (6).

Patients who died had lower body temperature at the time of echocardiogram than those who survived although there were similar rates of therapeutic hypothermia between groups. There is evidence that impaired thermoregulation postarrest may be associated with injury severity and mortality (25–27). Further, brain injury is a known component of post–cardiac arrest syndrome. Within brain injury literature, extremes of temperature dysregulation appear to be associated with poor outcomes (28, 29).

In the mid-1990s, post–cardiac arrest myocardial dysfunction was first described in animal models of cardiac arrest, including both systolic and diastolic LV dysfunction (8, 30, 31). Without inotropic support, the myocardial dysfunction became progressively worse over the first several hours post–cardiac arrest and resolved within 24 hours. Further laboratory studies showed that the post–cardiac arrest LV dysfunction could be ameliorated by continuous inotropic infusions (31, 32).

Soon after the descriptions of post–cardiac arrest myocardial dysfunction in animal investigations, Laurent et al (7) demonstrated that myocardial dysfunction was common following OHCAs in adults. Importantly, they showed that a low cardiac index at 24 hours postresuscitation was associated with worse multiple organ dysfunction and mortality. Further, Chang et al (10) noted that LV ejection fraction less than 40% 6 hours after adult OHCA resuscitation predicted mortality. Consistent with animal studies, the myocardial dysfunction typically resolved within 24–72 hours in adult survivors following OHCA (7).

In addition to the animal and adult data, Checchia et al (20) evaluated troponins and echocardiograms in 24 children with OHCAs who survived to hospital admission. Among their patients who had echocardiographic evaluations within 24 hours of hospital admission, higher troponin levels were associated with worse LV systolic function, and decreased LV systolic function was associated with increased mortality (20). They did not report diastolic data. Our echocardiographic findings in a substantially larger population (58 children) were generally consistent with their data: LV systolic dysfunction was common and associated with both increased troponin levels and increased mortality. Our data also demonstrated that postarrest diastolic dysfunction was common when data were available for evaluation.

Our study had several limitations. As with all retrospective studies, there is also potential for bias. First, of the 169 pediatric patients surviving OHCA and presenting to the PICU, 111 did not receive TTE evaluations within 24 hours of presentation. Forty-two of these patients (38%) died prior to discharge compared with a 67% mortality in our cohort. It is likely that clinicians performed echocardiograms on patients with greater severity of illness, which may have contributed to differences in outcome. Despite this, our cohort of patients with TTE have similar demographics and survival outcome compared to previously described pediatric OHCA populations (1, 2, 19). Second, the timing of echocardiogram after ROSC was variable, so the trajectory of myocardial dysfunction could not

be delineated and some patients may have developed myocardial dysfunction at other times post-ROSC. However, the median time to echocardiogram was 6.5 hours, which is within the window of peak myocardial dysfunction as described in adult and animal models. Third, we selected qualitative measure of LV systolic function as our primary exposure, in part, because not all images allowed for quantitative metric assessment. Importantly, 67% of our patients had quantitative assessments, and the quantitative assessments were strongly associated with the qualitative grouping. However, given the retrospective nature of this descriptive study, it is difficult to interpret whether LV dysfunction is a significant contributor to the cause of death or simply a surrogate marker for severity of illness. Finally, although we noted a large proportion of diastolic dysfunction in our postarrest population, we were not able to obtain measures of diastolic dysfunction in all of our evaluated patients. Prospective standardized TTE measures of systolic and diastolic function at specific time points after ROSC is a logical next step toward determining potential goal-directed therapy targets.

CONCLUSIONS

In patients receiving TTE within the first 24 hours following admission after pediatric OHCA, 41% of patients with TTE data had decreased LV systolic function. Clinical variables such as heart rate, blood pressure, and central venous pressure were not useful in differentiating patients with and without decreased LV systolic function. Importantly, LV systolic dysfunction was associated with increased mortality.

ACKNOWLEDGMENTS

This study used the Research Electronic Data Capture database.

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