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Clinical paper

Association between time of day and CPR quality as measured by CPR hemodynamics during pediatric in-hospital CPR

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Abstract

Introduction: Patients who suffer in-hospital cardiac arrest (IHCA) are less likely to survive if the arrest occurs during nighttime versus daytime. Diastolic blood pressure (DBP) as a measure of chest compression quality was associated with survival from pediatric IHCA. We hypothesized that DBP during CPR for IHCA is lower during nighttime versus daytime.

Methods: This is a secondary analysis of data collected from the Pediatric Intensive Care Quality of Cardiopulmonary Resuscitation Study. Pediatric or Pediatric Cardiac Intensive Care Unit patients who received chest compressions for ≥1 min and who had invasive arterial BP monitoring were enrolled. Nighttime was defined as 11:00PM to 6:59AM and daytime as 7:00AM until 10:59PM. Primary outcome was attainment of DBP ≥ 25 mmHg in infants

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<1 year and ≥30 mmHg in older children. Secondary outcomes were mean DBP, ROSC, and survival to hospital discharge. Univariable and multivariate analyses evaluated the relationships between time (nighttime vs. daytime) and outcomes.
Results: Between July 1, 2013 and June 30, 2016, 164 arrests met all inclusion/exclusion criteria: 45(27%) occurred at nighttime and 119(73%) during daytime. Average DBPs achieved were not different between groups (DBP: nighttime 28.3 mmHg[25.3, 36.5] vs. daytime 29.6 mmHg[21.8, 38.0], p = 0.64). Relative risk of DBP threshold met during nighttime vs. daytime was 1.27, 95%CI [0.80, 1.98], p = 0.30. There was no significant nighttime vs. daytime difference in ROSC (28/45[62%] vs. 84/119[71%] p = 0.35) or survival to hospital discharge (16/45[36%] vs. 61/119[51%], p = 0.08).
Conclusions: In this cohort of pediatric ICU patients with IHCA, there was no significant difference in DBP during CPR between nighttime and daytime.
Keywords: Cardiopulmonary resuscitation (CPR), Cardiac arrest, Pediatric, In-Hospital, Survival, Outcomes

Introduction

More than 15,000 children receive in-hospital CPR each year in the United States,[1] and the ratio of intensive care unit (ICU) to ward events is 19 to 1.[2] Overall, more than 1% of children admitted to a pediatric intensive care unit have a cardiac arrest in the unit, with the frequency approximately three-fold higher in pediatric cardiac intensive care units.[3,4] While survival rates in the United States have improved over the past decades, most children who suffer from an IHCA do not survive to hospital discharge.[5]

Large studies have consistently established that survival rates are lower following cardiac arrests at nighttime compared with daytime for both in-hospital and out-of-hospital cardiac arrests in children and adults.[6–12] Investigators have postulated that the worse outcomes may be due to worse CPR quality or worse post-resuscitation care at night, and that either could result from lower nighttime staffing or nighttime fatigue among providers. However, these studies emanate from large in-hospital and out-of-hospital cardiac arrest databases that lack data on CPR quality.

The Pediatric Intensive Care Quality of CPR (PICqCPR) study was a multi-institution investigation of 164 children with invasive hemodynamic monitoring during CPR. Consistent with multiple translational laboratory studies the PICqCPR data demonstrated that mean diastolic blood pressure (DBP) of ≥ 25 mmHg in infants and ≥ 30 mmHg children during CPR was associated with greater likelihood of survival to discharge and survival with favorable neurologic outcome.[13] Because the number of patients in the PICqCPR study was deemed to be insufficient to address daytime versus nighttime survival outcomes, our goal was to evaluate whether CPR quality differed at nighttime compared to daytime as evidenced by DBP attained during CPR, using this rich CPR hemodynamic database. Our primary hypothesis was that CPR quality is worse at nighttime. Our primary outcome measure was attainment of mean DBP ≥ 25 mmHg in infants and ≥ 30 mmHg in children, and our secondary outcomes were overall mean DBP during CPR, return of spontaneous circulation (ROSC) and survival to discharge.

Methods

The PICqCPR study was a prospective multicenter cohort study of CPR occurring in the ICUs of 11 institutions in the CPCCRN network between July 1, 2013 and June 30, 2016.[13] This study is a secondary observational analysis of the original multi-center cohort study, which was approved with waiver of informed consent by the Institutional Review Boards at the University of Utah Data Coordinating Center (DCC) and at each participating clinical site. CPCCRN research coordinators obtained Utstein-style standardized cardiac arrest and CPR data,[14,15] including 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, with assessments of neurological outcomes by Pediatric Cerebral Performance Categories (PCPC) and functional status by Functional Status Scale (FSS)[16] scores for pre-admission status and at hospital discharge. The FSS is scored over 6 domains with a total score from 6 points up to a maximum of 30 points, with higher values indicating worse outcomes.[16]

In order to be included in the parent study, patients were required to have an arterial line in place at the time of arrest. Arterial BP waveforms were printed from study sites, de-identified, and stored at the DCC. Waveforms were analyzed by Children's Hospital of Philadelphia investigators who were blinded to patient outcomes (PlotDigitizer; Version 2.0; Department of Physics, University of South Alabama).

Patient population

Patients in a CPCCRN ICU ≥37 weeks' gestation and <19 years old who received chest compressions for ≥ 1 min and had invasive arterial BP monitoring during CPR were eligible for inclusion. In addition, patients were required to have central venous pressures, respiratory plethysmography or electrocardiographic waveform data sufficient to determine stops and starts in CPR. Patients were excluded if the first chest compression of CPR was not captured, if they did not have at least 1 min of continuous arterial BP waveform, or if CPR starts and stops could not be determined. Research coordinators identified potential cardiac arrest patients via paging systems and daily screening of the ICU census.

Time of day and day of week definitions

Nighttime was defined as 11:00 PM to ≤6:59 AM and daytime was defined as 7:00 AM until 10:59 PM, as per previous investigations.[6,8,11] Similarly, weekdays were defined as 7:00 AM Monday until 10:59 PM Friday, weekends were defined as 10:59 PM Friday until 7:00 AM on Monday.

Blood pressure determination

For each minute of CPR, a mean DBP and mean SBP were determined. Subsequently, mean DBP and mean SBP for each patient event was calculated as the average BP over the first 10 min of CPR. If the patient received <10 min of CPR, the mean BPs could only be determined for the minutes of CPR performed. The original publication has further details regarding parent study methods and arterial blood pressure data determination.[13] The DBP threshold was defined as mean DBP ≥ 25 mmHg during CPR in infants and ≥30 mmHg in children ≥1 year old. Systolic BP threshold was defined as mean SBP ≥ 60 mmHg during CPR in infants and ≥80 mmHg in children ≥1 year old. For the first 20 min post-ROSC, SBP and DBP values were measured at 5-min intervals. Systolic and diastolic hypotension were defined as any one of these 5-min values being below the age-based 5th percentile for SBP and DBP, respectively based on normative data for age, sex and height.[17]

Outcomes

Our primary outcome measure was attainment of DBP associated with improved outcomes (mean DBP ≥ 25 mmHg in infants and ≥30 mmHg in older children), and our secondary outcomes were overall mean DBP, ROSC, and survival to discharge. We also assessed intra-arrest SBP, post-ROSC hypotension, 24-h survival, survival with favorable neurologic status, and change in FSS from baseline. New morbidity at hospital discharge is defined as an increase in FSS of at least 3 points or increase of 2 in a single FSS domain.[16]

Statistical analysis

Standard descriptive statistics were used to summarize patient and event characteristics. Differences in characteristics and outcomes between patients who received CPR during the nighttime versus daytime as well as weekday versus weekend were examined using Fisher's exact test for categorical variables or the Wilcoxon rank-sum test for continuous variables. Primary and secondary outcomes were further compared between groups using Poisson regression models with robust error estimates, adjusting for age category (<1 year, ≥ 1 year), first documented rhythm (asystole/PEA,VF/VT, bradycardia with poor perfusion), illness category (surgical cardiac, medical cardiac, surgical non-cardiac, medical non-cardiac), and location of CPR (pediatric ICU, pediatric cardiac ICU). These results were

Table 1 – Patient Characteristics by CPR Time of Day.

	Time of CPR			
	Overall(N = 164)	Night[e](N = 45)	Day[e](N = 119)	p-Value
Age (Years)	0.0 [0.0, 2.5]	0 [0,3]	0 [0,2]	0.55[b]
Age Category				0.93[a]
<1 month	41 (25%)	10 (22%)	31 (26%)	
1 month - <1 year	57 (35%)	16 (36%)	41 (34%)	
1 year - <8 years	41 (25%)	11 (24%)	30 (25%)	
8 years - <19 years	25 (15%)	8 (18%)	17 (14%)	
Male	90 (55%)	25 (56%)	65 (55%)	1.00[a]
Race				0.18[a]
White	82 (50%)	26 (58%)	56 (47%)	
Black or African American	37 (23%)	12 (27%)	25 (21%)	
Other	8 (5%)	0 (0%)	8 (7%)	
Not Reported	37 (23%)	7 (16%)	30 (25%)	
Preexisting conditions				
Respiratory insufficiency	132 (80%)	38 (84%)	94 (79%)	0.51[a]
Hypotension	128 (78%)	37 (82%)	91 (76%)	0.53[a]
Congestive heart failure	19 (12%)	6 (13%)	13 (11%)	0.79[a]
Pneumonia	13 (8%)	3 (7%)	10 (8%)	1.00[a]
Sepsis	44 (27%)	10 (22%)	34 (29%)	0.55[a]
Renal insufficiency	24 (15%)	6 (13%)	18 (15%)	1.00[a]
Malignancy	5 (3%)	2 (4%)	3 (3%)	0.62[a]
Congenital heart disease	99 (60%)	29 (64%)	70 (59%)	0.59[a]
Illness Category				0.76[a]
Surgical cardiac	88 (54%)	24 (53%)	64 (54%)	
Medical cardiac	25 (15%)	8 (18%)	17 (14%)	
Surgical non-cardiac	13 (8%)	2 (4%)	11 (9%)	
Medical non-cardiac	37 (23%)	11 (24%)	26 (22%)	
Unknown	1 (1%)	0 (0%)	1 (1%)	
Baseline PCPC[c]				0.46[b]
Normal	77 (47%)	23 (51%)	54 (45%)	
Mild disability	47 (29%)	12 (27%)	35 (29%)	
Moderate disability	23 (14%)	7 (16%)	16 (13%)	
Severe disability	13 (8%)	3 (7%)	10 (8%)	
Coma/vegetative state	4 (2%)	0 (0%)	4 (3%)	
Baseline FSS[d]	8 [6,11]	6 [6,9]	8 [6,12]	0.02[b]

[a] Fisher's exact test.
[b] Wilcoxon rank-sum test.
[c] Pediatric cerebral performance category.
[d] Functional status scale.
[e] Day = 7:00AM – 10:59PM. Night = 11:00PM - 6:59AM.

reported as relative risk with 95% confidence intervals. P-values are reported based on a 2-sided alternative and considered statistically significant when less than 0.05. All analyses were performed using SAS software v9.4 (Cary, NC).[4,12,18–22]

Results

All 164 patients from the original study who met inclusion criteria were included in this secondary analysis. Of the 164 arrests, 45 (27%) occurred at nighttime and 119 (73%) occurred during the daytime. Table 1 describes pre-arrest patient characteristics in the overall cohort, as well as characteristics by time of CPR. Sixty percent of patients were <1 year old; 90 (55%) were male; 82 (50%) were white. Patient pre-existing conditions included 132 (80%) with respiratory insufficiency, 128 (78%) with hypotension, and 99 (60%) with congenital heart disease. Eighty-eight (54%) were surgical cardiac patients (i.e., had cardiac arrest during the post-operative period). Baseline PCPC scores were normal in 77 (47%) patients and 47 (29%) had mild disability. Baseline FSS was lower for patients whose arrest occurred during the nighttime versus those with arrests during daytime (median [IQR]: nighttime: 6 [6,9] vs. daytime: 8 [6,12], p = 0.02). Supplemental Table 1 describes pre-arrest patient characteristics by day of week.

Event characteristics for the cohort by time of day and day of week are described in Table 2 and Supplementary Table 2, respectively. The median duration of CPR was 8 min and 100 (61%) events occurred in pediatric cardiac ICUs. The first documented rhythm at the time of CPR was bradycardia with poor perfusion for 91 (55%) of the arrests, followed by 48 (29%) with asystole or PEA. The immediate cause of cardiac arrest was hypotension in 110 (67%) cases. Vasoactive infusions were present at the time of cardiac arrest in 128 (78%) of the cases and there was a non-significant trend toward higher number of vasoactive infusions in place during nighttime arrests (night: 40 (89%) vs. day: 88 (74%), p = 0.06). During CPR, the average DBP was 29.3 mmHg, the average SBP was 74.4, the average chest compression rate was 126 compressions/minute and the average chest compression fraction was 90%. There were no differences in DBP, SBP, chest compression rate, or chest compression fraction between nighttime and daytime arrests.

Table 3 summarizes outcomes by time of day. The DBP thresholds were met during 101/164 (62%) events and SBP thresholds were met during 93/164 (57%) events. Return of spontaneous circulation was achieved in 112/164 (68%) cases and 77/164 (47%) patients survived to hospital discharge. Among patients with ROSC and evaluable post-ROSC BPs, 40/103 (39%) had post-ROSC SBP <5th percentile and nine percent had post-arrest DBP <5th percentile. Post-arrest diastolic BP <5th percentile was nominally more frequent at nighttime (night: 5/37 [19%] vs. day: 4/76 [5%], p = 0.05). There were no differences in rates

Table 2 – Event Characteristics by CPR Time of Day.

	Time of CPR			
	Overall(N = 164)	Night[c](N = 45)	Day[c](N = 119)	p-Value
Location of CPR Event				1.00[b]
PICU	64 (39%)	18 (40%)	46 (39%)	
CICU	100 (61%)	27 (60%)	73 (61%)	
Duration of CPR (min)	8 [3,27]	7 [4, 44]	9 [3,24]	0.33[a]
First documented rhythm				0.90[b]
Asystole/PEA	48 (29%)	14 (31%)	34 (29%)	
VF/VT	19 (12%)	6 (13%)	13 (11%)	
Bradycardia with pulses	91 (55%)	25 (56%)	66 (55%)	
Unknown	6 (4%)	0 (0%)	6 (5%)	
Immediate cause				
Hypotension	110 (67%)	32 (71%)	78 (66%)	0.58[b]
Respiratory decompensation	72 (44%)	14 (31%)	58 (49%)	0.05[b]
Cyanosis without respiratory decompensation	2 (1%)	1 (2%)	1 (1%)	0.48[b]
Arrhythmia	31 (19%)	11 (24%)	20 (17%)	0.27[b]
Interventions in place				
Central venous catheter	142 (87%)	38 (84%)	104 (87%)	0.61[b]
Vasoactive infusion	128 (78%)	40 (89%)	88 (74%)	0.06[b]
Invasive mechanical ventilation	134 (82%)	39 (87%)	95 (80%)	0.37[b]
Non-invasive ventilation	19 (12%)	4 (9%)	15 (13%)	0.60[b]
Pharmacologic Interventions				
Epinephrine	143 (87%)	41 (91%)	102 (86%)	0.44[b]
Calcium	78 (48%)	21 (47%)	57 (48%)	1.00[b]
Sodium bicarbonate	93 (57%)	26 (58%)	67 (56%)	1.00[b]
Hemodynamics/CPR Mechanics				
Average DBP (mmHg)	29.3 [22.8, 37.9]	28.3 [25.3, 36.5]	29.6 [21.8, 38.0]	0.64[a]
Average SBP (mmHg)	74.4 [54.9, 98.2]	77.7 [55.5, 98.2]	72.7 [54.8, 99.0]	0.33[a]
Average chest compression rate (/min)	125.6 [114.3, 139.4]	120.4 [108.3, 135.5]	126.7 [115.1, 140.1]	0.11[a]
Chest compression fraction	0.9 [0.8, 1.0]	0.9 [0.9, 1.0]	0.9 [0.8, 1.0]	0.69[a]

[a] Wilcoxon rank-sum test.
[b] Fisher's exact test.
[c] Day = 7:00AM - 10:59PM. Night = 11:00PM - 6:59AM.

Table 3 – CPR Quality and Outcomes by Time of Day.

	Time of CPR				Multivariable Regression	
	Overall	Night[e]	Day[e]	P-value	Relative of Risk of Outcome for Night vs. Day (95% C.I.)	p-Value
CPR Quality						
DBP Threshold[a]	101/164 (62%)	31/45 (69%)	70/119 (59%)	0.28[h]	1.27 (0.80, 1.98)	0.30[i]
SBP Threshold[b]	93/164 (57%)	25/45 (56%)	68/119 (57%)	0.86[h]	0.93 (0.56, 1.48)	0.76[i]
Compression Rate per Guidelines[c]	54/164 (33%)	18/45 (40%)	36/119 (30%)	0.26[h]	1.19 (0.63, 2.17)	0.57[i]
Post-arrest hypotension						
Any post-arrest systolic BP $<$5th percentile[d]	40/103 (39%)	14/27 (52%)	26/76 (34%)	0.12[h]	1.54 (0.77, 2.96)	0.20[j]
Any post-arrest diastolic BP $<$5th percentile[d]	9/103 (9%)	5/27 (19%)	4/76 (5%)	0.05[h]		
Outcomes						
Immediate Outcome of CPR event				0.55[h]		
ROSC $\geq$ 20 min	112/164 (68%)	28/45 (62%)	84/119 (71%)			
ROC with e-CPR	36/164 (22%)	12/45 (27%)	24/119 (20%)			
Died	16/164 (10%)	5/45 (11%)	11/119 (9%)			
ROSC $\geq$ 20 min	112/164 (68%)	28/45 (62%)	84/119 (71%)	0.35[h]	0.98 (0.61, 1.52)	0.93[i]
Survival to hospital discharge	77/164 (47%)	16/45 (36%)	61/119 (51%)	0.08[h]	0.72 (0.39, 1.25)	0.27[i]
24-h survival	135/164 (82%)	35/45 (78%)	100/119 (84%)	0.37[h]	0.98 (0.64, 1.46)	0.93[i]
Survival with favorable neurologic outcome[f]	70/164 (43%)	14/45 (31%)	56/119 (47%)	0.08[h]	0.70 (0.37, 1.26)	0.25[i]
New morbidity at hospital discharge[g]	22/77 (29%)	5/16 (31%)	17/61 (28%)	0.77[h]	1.09 (0.35, 2.83)	0.87[j]

[a] DBP Threshold defined as mean DBP $\geq$ 25 mmHg for infants; DBP $\geq$ 30 for children $\geq$ 1 year old.
[b] SBP Threshold defined as mean SBP $\geq$ 60 mmHg for infants; SBP $\geq$ 80 mmHg for children $\geq$ 1 year old.
[c] Compression rate Per Guidelines defined as 100–120 chest compressions/minute.
[d] Population: Subjects with post-arrest blood pressure data available. ECMO subjects are excluded.
[e] Day = 7:00AM - 10:59PM. Night = 11:00PM - 6:59 AM.
[f] Favorable neurologic outcome was defined as no more than moderate disability or no worsening from baseline Pediatric Cerebral Performance Category (PCPC).
[g] New morbidity is assessed only among survivors to hospital discharge and is defined as an increase in Functional Status Score (FSS) of 3 or greater from baseline to hospital discharge.
[h] Fisher's exact test.
[i] Results are based on Poisson regression models with robust error estimates, adjusting for age category ($\leq$ 1 year, $>$ 1 year), first documented rhythm (asystole/PEA,VF/VT, bradycardia with poor perfusion), illness category (surgical cardiac, medical cardiac, surgical non-cardiac, medical non-cardiac), location of CPR (PICU, CICU), and study site.
[j] Results are based on Poisson regression models with robust error estimates, adjusting for age category ($\leq$ 1 year, $>$ 1 year), first documented rhythm (asystole/PEA,VF/VT, bradycardia with poor perfusion), illness category (surgical cardiac, medical cardiac, surgical non-cardiac, medical non-cardiac), and location of CPR (PICU, CICU).

of ROSC, 24-h survival, survival with favorable neurologic outcome, or new morbidity at hospital discharge between patients who arrested during nighttime versus daytime. There was no difference in survival to hospital discharge among patients who arrested at nighttime (night: 16/45 [36%] vs. day: 61/119 [51%], p = 0.08). Supplemental Table 3 summarizes outcomes by day of week.

In Table 4, nighttime and daytime arrests are compared according to whether or not they met intra-arrest DBP targets and whether they had post-arrest systolic or diastolic hypotension. There were no associations between intra-arrest DBP and post-arrest systolic hypotension based on the time of day of cardiac arrest. Similarly, there was no association between intra-arrest DBP and post-arrest diastolic hypotension based on the time of day of cardiac arrest.

Discussion

In this ICU cohort of children with invasive hemodynamic monitoring at the time of in-hospital cardiac arrest, CPR quality was not worse at nighttime compared to daytime, as determined by frequency of attaining DBP thresholds known to be associated with improved outcomes (69% versus 59%). Moreover, there were no differences in median DBPs (28 mmHg [25, 37] vs. 30 mmHg [22, 38]), chest compression rates, or chest compression fractions between groups. In addition, the mean SBP did not differ (78 mmHg [56, 98] versus 73 mmHg [55, 99]), suggesting that the force of chest compressions was similar at nighttime and daytime.[23] Interestingly, diastolic hypotension during the first 20 min post-ROSC was nominally more frequent at nighttime (19% versus 6%, p = 0.05), however survival to hospital discharge was not different after nighttime arrests (36% nighttime versus 51% daytime, p = 0.08). While previous papers have addressed CPR mechanics at nighttime versus daytime; to our knowledge this is the first study of IHCA that compared CPR hemodynamics at nighttime versus daytime.

Using this prospectively generated database with rich invasive hemodynamic data during CPR, we showed that CPR hemodynamics were not demonstrably different in this highly resourced and monitored cohort of patients that had cardiac arrests in large academic ICUs. The clinical teams were able to provide high-quality CPR regardless of the time of day and achieved DBP $\geq$ 25 mmHg for

Table 4 – Intra-arrest DBP Target and Post-Arrest Hypotension by Time of Day.

	Time of CPR			
	Overall(N = 103)	Night[e](N = 27)	Day[e](N = 76)	p-Value
Intra-arrest DBP Threshold[b] and Post-arrest Systolic Hypotension[c]				0.23[a]
Above DBP threshold and no hypotension	44/103 (43%)	9/27 (33%)	35/76 (46%)	
Above DBP threshold and hypotension	26/103 (25%)	11/27 (41%)	15/76 (20%)	
Below DBP threshold and no hypotension	19/103 (18%)	4/27 (15%)	15/76 (20%)	
Below DBP threshold and hypotension	14/103 (14%)	3/27 (11%)	11/76 (14%)	
Intra-arrest DBP Threshold[b] and Post-arrest Diastolic Hypotension[d]				0.08[a]
Above DBP threshold and no hypotension	66/103 (64%)	17/27 (63%)	49/76 (64%)	
Above DBP threshold and hypotension	4/103 (4%)	3/27 (11%)	1/76 (1%)	
Below DBP threshold and no hypotension	28/103 (27%)	5/27 (19%)	23/76 (30%)	
Below DBP threshold and hypotension	5/103 (5%)	2/27 (7%)	3/76 (4%)	

[a] Fisher's exact test.
[b] DBP Threshold defined as mean DBP $\geq$ 25 mmHg for infants; DBP $\geq$ 30 for children $\geq$1 year old.
[c] Post-arrest Systolic Hypotension defined as average values below the age-based 5th percentile.
[d] Post-arrest Diastolic Hypotension defined as average values below the age-based 5th percentile.
[e] Day = 7:00AM - 10:59PM. Night = 11:00PM - 6:59 AM.

infants and $\geq$30 mmHg for older children in 62% of resuscitations. Esangbedo et al. reported CPR mechanics data in a large cohort of hospitals participating in a CPR quality collaborative (pediRES-Q).[6] They similarly found no difference in CPR quality indicators including CC depth, CC rate and CCF during the nighttime compared to daytime cardiac arrest. Esangbedo et al. found a significant difference in survival to hospital discharge between the two groups (22% nighttime survival vs. 39% daytime survival) which is consistent with other large registry pediatric studies.[6] The populations studied were slightly different between the two investigations; with non-ICU arrests included (19% ED and ward) as well as an older population (66% older than 1 year) in the Esangbedo pediRES-Q investigation. The differences in daytime survival between the two studies (51% daytime in the PICqCPR cohort vs. 39% in the pediRES-Q cohort) are possibly accounted for by the younger age, higher percentage of cardiac patients, and inclusion of only ICU arrests in the PICqCPR cohort.[4,18] Taking both studies into account, two themes emerge: 1) resuscitation parameters (mechanics and hemodynamics of CPR) were not different between nighttime and daytime events and 2) survival to hospital discharge is less likely for arrests that occur during the nighttime.

Why was there no difference in CPR quality at nighttime in either this PICqCPR cohort or the pediRES-Q cohort? Previous investigators postulated that resuscitation practices may be worse at night because of lower staffing ratios and/or provider fatigue at nighttime.[8,24,25] However, the time of day of cardiac arrest does not impact survival outcomes for subpopulations such as trauma patients or arrests that occur in emergency departments.[11,26] Peberdy et al. suggested this may be due to consistent staffing of senior residents and attendings for such patients regardless of time of day or day of week.[11] While ICU staffing at nighttime may have overall fewer physician team providers, nursing staffing is similar at nighttime and daytime,[27] and large academic pediatric ICUs may be able to rally forces around a critical event to briefly provide the same care during CPR as is done during the daytime. Although current overall pediatric physician staffing is lower at night, many hospitals have in-house 24 h pediatric and pediatric cardiac intensivist coverage leading to more senior staffing presence in pediatric ICUs,[24] which is apparently sufficient to assure excellent CPR quality.[28]

The bulk of published data indicate that outcomes from pediatric IHCAs are worse at night, but the reasons for worse outcomes have not been established. Survival to hospital discharge is affected by multiple factors including patient pre-arrest illness, quality of CPR provided, as well as post-cardiac arrest care delivery.[18,29] Hypotension, fever, hyperoxia, hypocarbia and severe left ventricular dysfunction in the post-cardiac arrest period are associated with worse neurologic and survival outcomes.[30–32] Implementation of post-cardiac arrest care is a complex knowledge and time intensive endeavor. Perhaps post-cardiac arrest care was less effective at nighttime. Overnight resources may be sufficient to deal with brief acute emergencies, but the apparently less intense and longer duration post-arrest care may be a greater challenge to manage at nighttime. Supporting the contention that the differences in outcomes may be related to differences on post-arrest care, post-arrest diastolic hypotension was nominally more frequent at nighttime in this small cohort (19% versus 5%, $p = 0.051$). Because the PICqCPR database did not include post-cardiac arrest care variables beyond the first 20 min post-arrest, we were not able to evaluate the quality of post-arrest care further. Future studies focused on the delivery of post-cardiac arrest care should investigate the quality of post-cardiac arrest care delivered by time of day and its impact on survival to hospital discharge.

These data establish that ICU providers can provide high quality of CPR regardless of the time of day or day of the week. If differences are seen in this quality of CPR at nighttime within a center, quality improvement initiatives may be able to improve the disparity.[33,34] If high quality CPR is provided, post-arrest care for children with nighttime ICHAs is the next logical focus for potential quality improvement.

This study has several limitations. The relatively small patient cohort available limited the power to demonstrate true differences in survival to hospital discharge at nighttime. The fact that we did not observe survival differences in this study limits our ability to comment on the role of intra-arrest quality and hemodynamics in the outcome differences seen between day and night arrests in previous studies. Also, this cohort represents a group of monitored patients in large academic ICUs with arterial lines and may not be generalizable to other ICU patients or patients outside of the ICU setting. However, previous studies have established that the majority of pediatric IHCAs in the United States occur in ICUs, and that arterial lines are often in place at the time of arrest.[2] For this report we used DBP, SBP, chest compression rate, and chest compression fraction as indicators of CPR quality, but we did not have data regarding chest compression depth, release velocity, or ventilation rate which may be important contributors to outcomes. The median baseline FSS was lower among patients with nighttime versus daytime IHCAs; although this could have conceivably influenced the vigor of resuscitation efforts, there were nevertheless no differences in DBP, SBP, chest compression rate, or chest compression fraction between nighttime and daytime arrests.

Conclusions

In this monitored cohort of pediatric ICU patients who experienced IHCA, CPR quality was not different during nighttime versus daytime. Differences in patient outcomes by time of day are presumably explained by other unmeasured factors to be explored in future research.

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Conflicts of interest

The Authors have the following disclosures. Dr. Wolfe has received research funding for NHLBI (funds to institution), as well as speaking honoraria from Zoll Medical. Robert A Berg received research grants from NHLBI and NICHD to study pediatric in-hospital cardiopulmonary resuscitation (funds to institution), as well as speaking honoraria from Japan Pediatric Society for lecture on pediatric cardiopulmonary resuscitation. Dr. Sutton has received research grants from NHLBI and NICHD to study pediatric in-hospital cardiopulmonary resuscitation (funds to institution), Pediatric Advance Life Support authorship via the American Heart Association, membership on the Emergency Cardiovascular Care Committee and past speaking honoraria for Zoll Medical. The rest of the authors report no COI.

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Appendix B. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2020.06.027.

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