Incidence and Outcomes of Cardiopulmonary Resuscitation in PICUs

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Objectives: To determine the incidence of cardiopulmonary resuscitation in PICUs and subsequent outcomes.

Design, Setting, and Patients: Multicenter prospective observational study of children younger than 18 years old randomly selected and intensively followed from PICU admission to hospital discharge in the Collaborative Pediatric Critical Care Research Network December 2011 to April 2013.

Results: Among 10,078 children enrolled, 139 (1.4%) received cardiopulmonary resuscitation for more than or equal to 1 minute and/or defibrillation. Of these children, 78% attained return of circulation, 45% survived to hospital discharge, and 89% of survivors had favorable neurologic outcomes. The relative incidence of cardiopulmonary resuscitation events was higher for cardiac patients compared with non-cardiac patients (3.4% vs 0.8%, $p < 0.001$), but survival rate to hospital discharge with favorable neurologic outcome was not statistically different (41% vs 39%, respectively). Shorter duration of cardiopulmonary resuscitation was associated with higher survival rates: 66% (29/44) survived to hospital discharge after 1-3 minutes of cardiopulmonary resuscitation versus 28% (9/32) after more than 30 minutes ($p < 0.001$). Among survivors, 90% (26/29) had a favorable neurologic outcome after 1-3 minutes versus 89% (8/9) after more than 30 minutes of cardiopulmonary resuscitation.

Conclusions: These data establish that contemporary PICU cardiopulmonary resuscitation, including long durations of cardiopulmonary resuscitation, results in high rates of survival-to-hospital discharge (45%) and favorable neurologic outcomes among survivors (89%). Rates of survival with favorable neurologic outcomes were similar among cardiac and noncardiac patients. The rigorous prospective, observational study design avoided the limitations of missing data and potential selection biases inherent in registry and administrative data. (*Crit Care Med* 2016; 44:798–808)

Key Words: cardiac arrest; cardiopulmonary resuscitation; children; incidence; intensive care; survival

Based on registry and administrative data, more than 6,000 children in the United States receive in-hospital cardiopulmonary resuscitation (CPR) each year, mostly in PICUs (1, 2). In a prospective study from the early 1990s, CPR was provided for 1.8% of 11,165 admissions at 32 North American multidisciplinary PICUs, and 13.7% survived to hospital discharge (3). More recent data from three single-center pediatric *cardiac* ICU studies demonstrate cardiac arrests in 3–6% of children admitted, suggesting a higher incidence in this population (4–6). Although there have been many changes in critical care and increased focus on CPR quality since the 1990s, the current incidence and outcome from CPR in PICUs are not known.

Published outcomes from CPR in PICUs vary (7). Although the survival rate following PICU CPR was 13.7% in the 1990s (3), more recent PICU CPR data from the Get With The Guidelines-Resuscitation (GWTG-R) in-hospital cardiac arrest registry of the American Heart Association found that 22% of children survived to hospital discharge (8). In contrast, a single-center pediatric cardiac ICU study in an overlapping time period reported a survival rate of 46%, suggesting that post-CPR outcomes may be better among children with cardiac disease (4). Similarly, GWTG-R registry data suggest that cardiac arrest outcomes are superior among the children post cardiac surgery compared with others (9).

Much of the published PICU CPR outcome data are based on registry or administrative databases, which are limited by challenges of missing neurologic outcome data and potential patient enrolment ascertainment bias. The *Eunice Shriver Kennedy* National Institute of Child Health and Human Development's Collaborative Pediatric Critical Care Research Network (CPCCRN) embarked on an intensive prospective study of more than 10,000 admissions to its large academic PICUs with the primary aim to investigate the relationship of physiologic instability with the development of morbidity and mortality (10). As part of this effort, we prospectively evaluated the incidence and outcomes of PICU CPR events to accurately determine the current overall incidence of CPR occurring in the PICU, the characteristics of children who received CPR in the PICU, their survival rates, and the neurologic and functional outcomes of the survivors. We also sought to determine whether incidences and outcomes vary between cardiac and noncardiac critically ill children. We hypothesized that CPR events would be more common among children with medical or surgical cardiac disease than those with medical or surgical noncardiac disease and that outcomes would be better for those cardiac patients.

METHODS

The current investigation was performed at the seven sites participating in the CPCCRN during the study period. These sites combined have approximately 17,000 PICU admissions per year. The details of patient selection and data collection have been previously published (10, 11). Patients ranging in ages from newborn to younger than 18 years were randomly selected from both the general/medical PICUs and the cardiac/cardiovascular PICUs. There were no separate general surgical or neurological PICUs. Only the first PICU admission was included, and patients were excluded if their vital signs were incompatible with life for at least the first 2 hours after PICU admission (i.e., moribund patients). Patients were enrolled from December 4, 2011, to April 7, 2013. The protocol was approved by the Institutional Review Boards at all participating institutions.

A CPR event was defined as chest compressions for at least 1 minute and/or defibrillation. The reasons for initiation of chest compressions were categorized as a pulseless cardiac arrest or poor perfusion with bradycardia and/or hypotension, as per American Heart Association Guidelines (12). Immediate outcomes from the CPR event were categorized as return of spontaneous circulation (ROSC) for more than 20 minutes, return of circulation (ROC) by extracorporeal life support (ECLS), or no ROC (12, 13). Survival-to-hospital discharge was reported for the index (or first) CPR event of each patient because a patient can only survive to discharge once per hospitalization (13).

Diagnostic, demographic, and functional status data, including Pediatric Cerebral Performance Category (PCPC) and Functional Status Scale (FSS) scores, were determined at PICU admission. The functional status evaluation included documentation of preillness baseline status (i.e., prior to the event that brought the child to the hospital) and later determination at PICU discharge and hospital discharge (10, 11, 13, 14). Diagnoses were classified by the system of dysfunction accounting for the primary reason for PICU admission. Operative status included both operating room and interventional catheterization procedures but not diagnostic catheterization procedures. Patients were classified as surgical or medical based on operative status prior to the CPR event and then further classified into four subgroups based on acute admission diagnoses and operative type: cardiac surgical, cardiac medical, noncardiac surgical, and noncardiac medical. Physiologic status was assessed with the Pediatric Risk of Mortality III score with a shortened observation time period (10). Investigators, research coordinators, and research assistants were trained in data collection with in-person training on multiple occasions; bi-weekly teleconference calls were also conducted (10, 11).

Functional status was assessed by the PCPC and FSS scores. The FSS was developed to provide assessment of functional status suitable for large studies. It is composed of six domains (mental status, sensory, communication, motor function, feeding, and respiratory) with domain scores ranging from 1 (normal) to 5 (very severe dysfunction). Therefore, total scores may range from 6 to 30 with lower scores indicating better function. The operational definitions and manual for the classifications have been published (14). The FSS validation consisted of comparison with the Adaptive Behavioral Assessment Scale II, a validated measure of pediatric adaptive behavior, and comparison with the PCPC (10, 14, 15). A PCPC score of 1 describes children with normal age-appropriate neurodevelopmental functioning, 2 for mild cerebral disability, 3 for moderate disability, 4 for severe disability, 5 for coma/vegetative state, and 6 for brain death. As previously reported, favorable neurologic outcome was defined as a PCPC score of 1–3 at discharge or no increase compared with admission PCPC status (1, 8, 9, 16, 17). In addition, we categorized FSS scores of 6–7 as good, 8–9 as mildly abnormal, 10–15 as moderately abnormal, 16–21 as severely abnormal, and more than 21 as very severely abnormal (10, 11, 14). These category ranges were chosen based on the dysfunction reflected in the score. This categorization was designed such that the equivalent FSS groups would approximately correspond to the PCPC categories (9, 13, 14). Newborns who had never achieved a stable baseline function were assigned an FSS score of 6; this was operationalized by assigning a baseline FSS score of 6 to all admissions for infants 0–2 days old and to transfers from another facility for infants 3–6 days old (10, 15). As previously reported, new morbidity was defined as an increase in the FSS total score at least 3 (10).

The primary study outcomes were the rate of CPR events and survival-to-hospital discharge with favorable neurologic outcomes. Secondary outcomes included ROC for more than 20 minutes, 24-hour survival, survival-to-hospital discharge, and survival without new morbidities.

All descriptive and inferential analyses are based on the index (i.e., first) qualifying CPR event. Categorical data are expressed as counts and percentages or rate per 100 admissions. Continuous data are expressed as median and interquartile range (IQR, 25th and 75th percentiles). Associations of patient and event characteristics with patient type were assessed using the Pearson chi-square or the Fisher exact test for categorical variables and the Wilcoxon signed rank test for continuous variables. Observed associations between duration of compressions and outcome were evaluated using the Cochran-Armitage trend test. Univariable associations of other key patient and event characteristics with outcome were evaluated using modified Poisson regression, a method that implements generalized estimating equations to facilitate direct estimation of rate ratios with robust variance estimates (18). Differences between cardiac and noncardiac subgroups were further evaluated in a multivariable model. This model adjusted for patient age and whether compressions were started for poor perfusion or pulselessness, factors determined a priori to be potential covariates. In addition, any variables with p value less than 0.15 in univariable analyses were included in the final model. Relative risks and associated 95% CIs are reported. Analyses were performed using SAS version 9.4 (SAS Institute, Cary, NC).

RESULTS

Enrolment at each of the seven CPCCRN sites varied from 1,252 (12%) to 1,617 (16%) of the 10,078 admissions in the overall study. The PICU mortality rate for these 10,078 admissions was 2.3% (227 PICU deaths), and overall hospital mortality rate was 2.7% (275 hospital deaths). A total of 139 (1.4%) received CPR for at least 1 minute and/or defibrillation within the initial PICU admission (**Fig. 1**). Only four had defibrillation without chest compressions. Twenty-eight (20%) of these children received CPR on multiple occasions for a total of 182 CPR events (1.8 CPR events per 100 admissions). Demographic and event data are displayed in **Tables 1** and **2**. The seven CPCCRN sites each contributed anywhere from 8 (6%) to 30 (22%) of the 139 children with CPR events. The incidence of index CPR events (i.e., the number of index CPR events per 100 ICU admissions) ranged across sites from 0.6 to 2.3 per 100 admissions ($p < 0.001$). Among the 139 children with a CPR event, 31 (22%) failed to attain ROC during the initial CPR event, 91 (65%) attained ROSC for more than 20 minutes, and 17 (12%) attained ROC via ECLS instituted during CPR.

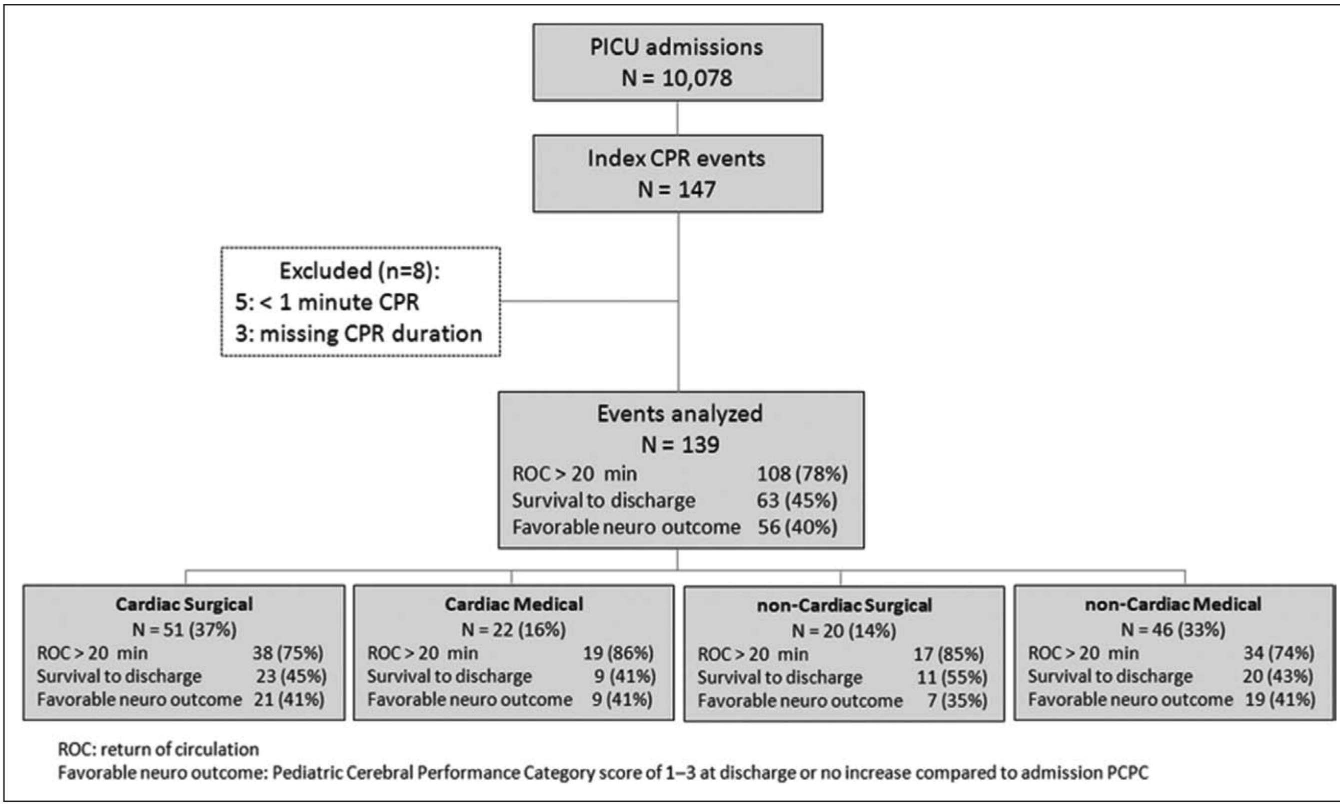

Figure 1. Flow diagram of patients evaluated, cardiopulmonary resuscitation (CPR) events, overall outcomes, and outcomes among major subgroups. PCPC = Pediatric Cerebral Performance Category, ROC = return of circulation.

Following their 139 index CPR events, 89 (64%) children survived for 24 hours, 64 (46%) survived to PICU discharge, 63 (45%) survived to hospital discharge, and 56 (40%) survived to hospital discharge with a favorable neurologic outcome (**Table 3**). Importantly, 56 of 63 survivors (89%) had favorable neurologic status at hospital discharge, and 48 of 63 (76%) had a PCPC score of 1 or no change from baseline. Notably, 35 of 63 (56%) had a discharge PCPC score of 1, 13 (21%) had a discharge PCPC score of 2, and five (8%) had a PCPC score of 3. Ten (16%) survivors were severely disabled or in a vegetative state at hospital discharge, but three of these had no change from the baseline PCPC. Only four survivors (6%) had a change in the PCPC score of 2 categories or more. Among the 63 who survived to hospital discharge, 46 (73%) had no new morbidities, as defined by an FSS score increase of at least 3 (10), whereas 17 (27%) had an FSS score increase of at least 3. The median change in FSS scores was 1 (IQR, 0–3), and 26 of 63 (41%) had no change or slight improvement in the FSS score from baseline.

Seventy-three (53%) children with ICU CPR were cardiac patients (51 surgical/22 medical), and 66 (47%) were noncardiac (20 surgical/46 medical). Twenty-one had open-chest CPR; of whom, 19 were cardiac surgical patients, one was a cardiac medical patient, and one was a noncardiac surgical patient. Based on disease classification at PICU admission, the cardiac group had a higher incidence of index CPR events than the noncardiac group (3.4% vs 0.8%; $p < 0.001$). However, among those with a CPR event, there were no apparent differences in survival-to-hospital discharge or survival with a favorable neurologic outcome between the cardiac and noncardiac groups (Table 3; and **Appendix Table 1**).

The median duration of the initial CPR event was 9 minutes (IQR, 3–30) for the 135 CPR events with chest compressions at least 1 minute (range, 1–122 min). Among the 90 patients receiving CPR for poor perfusion with bradycardia and/or hypotension, the median duration of the initial CPR event was 8 minutes (IQR, 3–30); 17 (19%) did not attain ROC, 61 (68%) attained ROSC for more than 20 minutes, and 12 (13%) had ROC by ECLS during CPR. Among the 45 patients receiving CPR for pulselessness, the median duration of the initial CPR event was 14 minutes (IQR, 3–28); 14 (31%) did not attain ROC, 28 (62%) attained ROSC for more than 20 minutes, and 3 (7%) had ROC via ECLS during CPR.

Shorter duration CPR was associated with higher survival rates (**Table 4**). Among the 44 children with CPR for 1–3 minutes (12 cardiac surgical, 6 cardiac medical, 6 noncardiac surgical, and 20 noncardiac medical), only one failed to attain ROC (because of withdrawal of technological support), 41 had ROSC, 2 had ROC via ECLS, and 29 of 44 (66%) survived to hospital discharge. In contrast, among 32 children with CPR for more than 30 minutes, 14 (44%) failed to attain ROC, 9 (28%) had ROSC, 9 (28%) had ROC via ECLS, and only 9 of 32 (28%) survived to hospital discharge. However, the duration of CPR was not associated with favorable neurologic outcomes for children who survived to hospital discharge. Among the 29 survivors with 1–3 minutes of CPR, 26 (90%) had a favorable neurologic outcome. Similarly, 8 of 9 (89%) children

TABLE 1. Characteristics of Patients Who Received Cardiopulmonary Resuscitation

Variable	Overall, *n* = 139	Cardiac, *n* = 73	Noncardiac, *n* = 66	*p*[a]
Women (%)	69 (50)	36 (49)	33 (50)	0.94
Age at time of cardiopulmonary resuscitation event (%)				
< 1 mo	24 (17)	22 (30)	2 (3)	< 0.001
1 mo to < 1 yr	58 (42)	33 (45)	25 (38)	
1 yr to < 8 yr	36 (26)	10 (14)	26 (39)	
8 yr to < 18 yr	21 (15)	8 (11)	13 (20)	
Race (%)				
Black or African American	34 (24)	15 (21)	19 (29)	0.49
White	56 (40)	31 (42)	25 (38)	
Other	10 (7)	4 (5)	6 (9)	
Unknown or not reported	39 (28)	23 (32)	16 (24)	
Ethnicity (%)				
Hispanic or Latino	25 (18)	13 (18)	12 (18)	0.92
Not Hispanic or Latino	76 (55)	39 (53)	37 (56)	
Unknown or not reported	38 (27)	21 (29)	17 (26)	
Payer (%)				
Commercial	47 (34)	24 (33)	23 (35)	0.23
Government	79 (57)	39 (53)	40 (61)	
Other	5 (4)	3 (4)	2 (3)	
Unknown	8 (6)	7 (10)	1 (2)	
Baseline Functional Status Scale score (%)				
Good (6–7)	93 (67)	54 (74)	39 (59)	0.04
Mild (8–9)	21 (15)	12 (16)	9 (14)	
Moderate (10–15)	20 (14)	6 (8)	14 (21)	
Severe (16–21)	2 (1)	1 (1)	1 (2)	
Very severe (> 21)	3 (2)	0 (0)	3 (5)	
Baseline Pediatric Cerebral Performance Category (%)				
1 (normal)	87 (63)	48 (66)	39 (59)	0.16
2 (mild disability)	30 (22)	17 (23)	13 (20)	
3 (moderate disability)	12 (9)	3 (4)	9 (14)	
4 (severe disability)	8 (6)	3 (4)	5 (8)	
5 (coma/vegetative)	2 (1)	2 (3)	0 (0)	
Primary disorder for ICU admission (%)				
Respiratory	41 (29)	11 (15)	30 (45)	< 0.001[b]
Cancer	3 (2)	0 (0)	3 (5)	
Cardiovascular disease, acquired[c]	21 (15)	9 (12)	12 (18)	
Cardiovascular disease, congenital	53 (38)	52 (71)	1 (2)	
Gastrointestinal disorder	5 (4)	0 (0)	5 (8)	
Hematologic disorder	1 (1)	0 (0)	1 (2)	
Musculoskeletal condition	1 (1)	0 (0)	1 (2)	
Neurologic	8 (6)	0 (0)	8 (12)	
Renal	1 (1)	0 (0)	1 (2)	
Miscellaneous	5 (4)	1 (1)	4 (6)	
Pediatric Risk of Mortality III, median (IQR)	8 (3–15)	8 (3–12)	8 (3–17)	0.50

IQR = interquartile range.

[a] *p* value reflects the Wilcoxon signed rank test for the association between Pediatric Risk of Mortality III and cardiac versus noncardiac patient type and the chi-square or Fisher exact test for all other variables.

[b] All primary disorders with overall count of up to 5 were combined with miscellaneous prior to *p* value calculation.

[c] Cardiovascular disease (acquired) includes septic shock, systemic inflammatory response syndrome, and postcardiac arrest syndrome.

TABLE 2. Characteristics of the Cardiopulmonary Resuscitation Events

Variable	Overall, *n* = 139	Cardiac, *n* = 73	Noncardiac, *n* = 66	*p*[a]
CPR performed (%)				
Chest compressions only	122 (88)	60 (82)	62 (94)	0.03
Defibrillation only	4 (3)	2 (3)	2 (3)	
Chest compressions and defibrillation	13 (9)	11 (15)	2 (3)	
Reason chest compressions started (%)				
Poor perfusion (i.e., bradycardia and hypotension)	90 (67)	50 (70)	40 (63)	0.33
Pulselessness	45 (33)	21 (30)	24 (38)	
CPR performed open or closed chest (%)				
Open chest	21 (16)	20 (28)	1 (2)	< 0.001
Closed chest	114 (84)	51 (72)	63 (98)	
Chest compression duration (min) (%)				
1–3	44 (33)	18 (25)	26 (41)	0.03
4–9	26 (19)	12 (17)	14 (22)	
10–30	33 (24)	17 (24)	16 (25)	
> 30	32 (24)	24 (34)	8 (13)	
Time from PICU admission to index CPR event (%)				
< 1 hr	9 (6)	4 (5)	5 (8)	0.25
1 to < 6 hr	17 (12)	5 (7)	12 (18)	
6 to < 24 hr	21 (15)	11 (15)	10 (15)	
24 hr to < 1 wk	50 (36)	27 (37)	23 (35)	
1 wk or more	42 (30)	26 (36)	16 (24)	

CPR = cardiopulmonary resuscitation.

[a]*p* value reflects the Wilcoxon signed rank test for the association between Pediatric Risk of Mortality III and cardiac versus noncardiac patient type and the chi-square or Fisher exact test for all other variables.

TABLE 3. Outcomes of Children Following PICU Cardiopulmonary Resuscitation

Variable	Overall, *n* = 139 (%)	Cardiac, *n* = 73 (%)	Noncardiac, *n* = 66	Relative Risk (95% CI)[a]
Return of circulation achieved	108 (78)	57 (78)	51 (77)	0.89 (0.74–1.08)
Alive 24 hr following the first event	89 (64)	50 (68)	39 (59)	1.00 (0.76–1.32)
Alive at the time of hospital discharge	63 (45)	32 (44)	31 (47)	0.84 (0.57–1.24)
Favorable neurologic outcome at hospital discharge (Pediatric Cerebral Performance Category score of 1–3 or no change)	56 (40)	30 (41)	26 (39)	0.91 (0.60–1.38)

[a]Relative risk and 95% CI based on modified Poisson regression model (*n* = 135) with adjustment for patient age, Pediatric Risk of Mortality III score, time from PICU admission to index cardiopulmonary resuscitation event, and whether compressions started for poor perfusion or pulselessness. The four patients who had defibrillation without chest compressions were excluded from the relative risk model because of variables that are only applicable to patients with chest compressions.

who survived after more than 30 minutes of CPR had a favorable neurologic outcome.

Among the 139 children with a CPR event, six (4%) had a cardiac arrest prior to hospital admission and another four (3%) had an in-hospital cardiac arrest prior to PICU admission. Of these 10 patients with CPR events prior to the ICU admission, four (40%) survived to hospital discharge, and all four had favorable neurologic outcomes with a PCPC score of 1 at discharge or no change from admission.

Seventy-six patients died prior to hospital discharge; 48 (63%) did not attain ROC during a resuscitation event (the initial resuscitation or a subsequent resuscitation), 23 (30%)

TABLE 4. Outcomes by Duration of Chest Compressions

Variables	1–3 min, *n* = 44 (%)	4–9 min, *n* = 26 (%)	10–30 min, *n* = 33 (%)	> 30 min, *n* = 32 (%)	*p*[a]
Return of circulation achieved	43 (98)	23 (88)	20 (61)	18 (56)	< 0.001
Alive 24 hr following the first event	39 (89)	19 (73)	14 (42)	14 (44)	< 0.001
Alive at the time of hospital discharge	29 (66)	12 (46)	11 (33)	9 (28)	< 0.001
Favorable neurologic outcome at hospital discharge (Pediatric Cerebral Performance Category score of 1–3 or no change)	26 (59)	10 (38)	10 (30)	8 (25)	0.001

[a]*p* value reflects Cochran-Armitage trend test for differences in outcome relative to the categorized length of cardiopulmonary resuscitation.
The four patients who had defibrillation without chest compressions could not be included in this table.

had withdrawal of technological support, three (4%) had limitation of technological support, and two (3%) were declared dead by the absence of brain function. Among the 23 patients with withdrawal of technological support, 17 (77%) had withdrawal of mechanical ventilation, 10 (45%) had withdrawal of extracorporeal membrane oxygenator, 12 (55%) had withdrawal of vasoactive medications, three (14%) had withdrawal of renal replacement therapy, and 2 (9%) had withdrawal of cardiac compressions during CPR.

Twenty-eight children had multiple CPR events during their initial PICU admission; 20 had only one additional CPR event, and 8 had with more than one additional CPR event (**Appendix Table 2**). Of these 28 children, 13 (46%) attained ROC in a subsequent CPR event, and only seven (25%) survived to hospital discharge (**Appendix Table 3**). Among the seven survivors, six survived to hospital discharge with a PCPC score of 1 or no change from baseline and the other with a PCPC score of 2. Subsequent CPR events were not more common after ROC from an initial CPR event of more than 30 minutes versus ROC from an initial CPR event of up to 30 minutes (5/18 [28%] vs 23/86 [27%]; $p = 1.0$).

DISCUSSION

In this prospective study of more than 10,000 pediatric admissions to these large academic PICUs, 139 children received 1 minute or more of chest compressions and/or defibrillation in the PICU, a incidence of 1.4%. Among these children, 78% attained ROC during their initial CPR event, 45% survived to hospital discharge, and 89% of the survivors had a favorable neurologic outcome; 73% survived without new morbidities. Consistent with previous single-center studies (3–6), the relative incidence of CPR events in our multicenter study was higher for cardiac patients compared with noncardiac patients (3.4% vs 0.8%). In contrast to previous single-center study data and multicenter registry data (4–9), the survival and neurologic outcomes did not differ between the cardiac and noncardiac patients. Although the likelihood of survival decreased with increased duration of CPR, there was no demonstrable difference in neurologic outcome or new morbidities among those who survived after longer durations of CPR.

Pediatric and adult studies suggest that rapid response teams have successfully decreased the number of cardiac arrests in wards and increased the proportion in ICUs (1, 19). For example, over the last decade, more than 93% of PICU and ward CPR events in the United States occurred in a PICU (1). However, rapid increases in the size and number of PICUs over the last 2–3 decades might have resulted in a lower incidence of PICU CPR events (20). Nevertheless, the 1.4% incidence of PICU CPR events among PICU admissions in the current study is similar to the 1.8% incidence in 32 North American PICUs in the early 1990s (3).

Although our data suggest that the incidence of PICU CPR events has not changed much over the last 20 years, the outcomes are now substantially better. Only 13.7% of patients with a PICU CPR event survived to discharge in the early 1990s (3). In contrast, 45% of the contemporary CPCCRN patient cohort with PICU CPR events from 2011 to 2013 survived to hospital discharge, and 89% of the survivors had favorable neurologic outcomes. The reasons for these improved outcomes are not certain. All of the CPCCRN PICU sites had 24/7 in-house call with critical care attendings and/or fellows in 2011–2013 in contrast to the rarity of attending and/or fellow in-house call in the early 1990s, and this higher level of in-hospital expertise has been associated with improved patient care (21). Perhaps a resurgence in focus on CPR quality, PICU CPR training, and CPR implementation science has translated into superior outcomes (1, 7–9, 12). All of these PICU sites participate in the multicenter Therapeutic Hypothermia After Pediatric Cardiac Arrest trial (22). Therefore, it is plausible that the better outcomes are in part due to improvements in CPR and postcardiac arrest care among providers who know that they are being monitored as part of that trial (the Hawthorne effect). Notably, GWTG-R registry data have also demonstrated that outcomes from pediatric in-hospital cardiac arrests (ICU plus non-ICU) have improved over the last decade (23).

In this study, we defined favorable neurologic outcomes as PCPC scores at hospital discharge of 1–3 or no change compared with baseline, consistent with other pediatric cardiac arrest/CPR investigations (1, 8, 9, 16, 17). Favorable neurologic outcomes in most adult studies use adult Cerebral Performance Categories 1–2 that are identical to the PCPC scores of 1–3 (24). Using this definition, 89% of survivors in our cohort had favorable neurologic outcomes. This contrasts markedly from the 37% to 65% rate of favorable neurologic outcomes among pediatric survivors following out-of-hospital cardiac arrest/CPR over the last decade (25–27). Perhaps a more important outcome is survival without new functional morbidities (10, 11). Among the children surviving to hospital discharge following PICU CPR in our cohort, 73% had no new functional morbidities.

In single-center studies, 3–6% of patients admitted to a pediatric cardiac ICU had cardiac arrests (4–6). Our data confirm this higher risk of PICU CPR events for cardiac versus noncardiac patients (3.4% vs 0.8%). However, the absolute number of CPR events was similar among cardiac and noncardiac PICU admissions because noncardiac admissions were almost four-fold more common. In contrast to data from single-center studies and an in-hospital cardiac arrest registry, rates of survival to discharge and survival with a favorable neurologic outcome were quite similar among cardiac and noncardiac patients in our cohort (44% vs 47% and 41% vs 39%, respectively) (4–9).

Recent studies from the large multicenter GWTG-R in-hospital cardiac arrest registry of the American Heart Association have found that CPR durations more than 10 minutes are common among adults and children, and many patients survive after more than 30 minutes of CPR (9, 28). However, the authors of those reports noted multiple limitations in the study designs, including potential ascertainment biases, as well as the absence of neurologic data for many of the survivors after more than 30 minutes of CPR (9, 28). Consistent with the GWTG-R data, the likelihood of survival decreased with longer durations of CPR in our cohort. The median duration of CPR was 9 minutes (IQR, 3–30), and 67% of children survived to hospital discharge following 1–3 minutes of CPR compared with only 28% following more than 30 minutes of CPR. Surprisingly, favorable neurologic outcome was attained in 90% of survivors following 1–3 minutes of CPR compared with 89% following more than 30 minutes of CPR. These data suggest that ICU CPR efforts adequate for successful myocardial resuscitation may also be adequate for cerebral resuscitation. Neurologic outcomes seem much better for children with in-hospital CPR compared with pediatric out-of-hospital CPR where severe neurologic impairments have been reported to occur in 35–63% of cases (25–27). The differences can likely be explained by longer periods of untreated cardiac arrest with no cerebral blood flow during out-of-hospital cardiac arrests and perhaps suboptimal basic and advanced life support in the challenging out-of-hospital setting. In addition, difficulty in monitoring and treating postcardiac arrest hypotension and myocardial dysfunction in the prehospital setting may contribute to the worse outcomes.

The findings in this multicenter study are limited because of the lack of data regarding CPR quality and postcardiac arrest care (7, 29). It is possible that the quality of CPR and postcardiac arrest care are superior in these large, academic CPCCRN PICUs. If so, outcomes may not be generalizable to institutions with less effective CPR quality and/or postcardiac arrest care. These data may differ from registry data or data from administrative databases because our research team reviewed the care of each patient in this PICU outcome study on a daily basis with a specific focus on collecting prospectively determined data from all children receiving CPR for more than 1 minute or defibrillation. Therefore, we are confident that all CPR events were documented in this study, avoiding ascertainment biases inherent in registry data and administrative databases. The neurologic outcome data do not include long-term outcomes, neurobehavioral outcomes, or detailed neuropsychologic outcomes (30). Nevertheless, this study includes measures of both neurologic outcomes (PCPC) and functional outcomes (FSS) at the time of discharge for all surviving patients. Notably, adult data show that outcomes of individual patients improve over time, suggesting that the long-term outcomes of these children may ultimately be superior to outcomes at discharge (31). Finally, the incidence of PICU CPR can be influenced by differences in the numerator (e.g., decreased by "do not attempt resuscitation" orders) and in the denominator (affected by admission criteria and illness severity of patients admitted to a specific PICU). Despite concerns that the incidence data might reflect increases in "do not attempt resuscitation" orders and increased admissions of children to PICUs with lower severity of illness, the incidence of PICU CPR has apparently not changed greatly over the last two decades.

CONCLUSIONS

CPR is provided for many children admitted to the PICU despite close monitoring and many therapies intended to prevent cardiac arrest and the need for CPR. Fully, 1.4% of children admitted to a large academic CPCCRN PICU received CPR and/or defibrillation. These data establish that contemporary PICU CPR, including long durations of CPR, results in high rates of survival-to-hospital discharge (45%), favorable neurologic outcome among survivors (89%), and survival without new morbidities (73%). Rates of survival to discharge and survival with favorable neurologic outcomes were similar among cardiac and noncardiac patients. The rigorous prospective, observational study design avoided the limitations of missing data and potential selection biases inherent in registry and administrative data.

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APPENDIX 1. Univariable Associations[a] With Favorable Neurologic Outcome

Variable	Favorable Outcome, *n* (%)	Relative Risk (95% CI)	*p*
Sex			
Female	29 (42)	1.09 (0.73–1.63)	0.68
Male	27 (39)	Reference	
Age at time of CPR event			
< 1 mo	9 (38)	Reference	0.46
1 mo to < 1 yr	27 (47)	1.24 (0.69–2.23)	
1 to < 8 yr	11 (31)	0.81 (0.40–1.66)	
8 to < 18 yr	9 (43)	1.14 (0.56–2.34)	
Race			
Black or African American	10 (29)	Reference	0.35
White	27 (48)	1.64 (0.91–2.95)	
Other	4 (40)	1.36 (0.54–3.41)	
Unknown or not reported	15 (38)	1.31 (0.68–2.52)	
Ethnicity			
Hispanic or Latino	11 (44)	Reference	0.84
Not Hispanic or Latino	31 (41)	0.93 (0.55–1.56)	
Unknown or not reported	14 (37)	0.84 (0.46–1.54)	
Payer			
Commercial	20 (43)	Reference	0.39
Government	29 (37)	0.86 (0.56–1.34)	
Other	4 (80)	1.88 (1.08–3.26)	
Unknown	3 (38)	0.88 (0.34–2.29)	
Patient type			
Cardiac	30 (41)	1.04 (0.69–1.57)	0.84
Noncardiac	26 (39)	Reference	
Baseline Functional Status Scale score			
Good/mild (6–9)	45 (39)	Reference	0.90
Moderate (10–15)	9 (45)	1.14 (0.67–1.95)	
Severe/very severe (> 16)	2 (40)	1.01 (0.34–3.04)	
Baseline Pediatric Cerebral Performance Category			
1–3 (normal, mild, and moderate)	53 (41)	Reference	0.52
4–5 (severe and coma/vegetative)	3 (30)	0.73 (0.28–1.92)	
Primary disorder for ICU admission			
Respiratory	19 (46)	Reference	0.34
Cardiovascular disease (acquired)	9 (43)	0.92 (0.51–1.67)	
Cardiovascular disease (congenital)	22 (42)	0.90 (0.57–1.42)	
Neurologic	1 (13)	0.27 (0.04–1.74)	
Miscellaneous	5 (31)	0.67 (0.30–1.50)	
Pediatric Risk of Mortality III, median (IQR)	8 (3–11) (vs 8 [3–16])	0.97 (0.95–1.00)[b]	0.046

(*Continued*)

APPENDIX 1. (*Continued*). Univariable Associations[a] With Favorable Neurologic Outcome

Variable	Favorable Outcome, *n* (%)	Relative Risk (95% CI)	*p*
Time from PICU admission to index CPR event			
<24 hr	19 (40)	Reference	0.11
24 hr to <1 wk	25 (50)	1.24 (0.79–1.93)	
1 wk or more	12 (29)	0.71 (0.39–1.28)	
Defibrillation performed			
Yes	5 (29)	0.70 (0.33–1.51)	0.37
No	51 (42)	Reference	
Reason chest compressions started			
Poor perfusion	39 (43)	1.30 (0.81–2.09)	0.28
Pulselessness	15 (33)	Reference	
CPR performed open or closed chest			
Open chest	8 (38)	0.94 (0.52–1.70)	0.85
Closed chest	46 (40)	Reference	

CPR = cardiopulmonary resuscitation, IQR = interquartile range.
[a]Unadjusted relative risk, 95% CI, and *p* value based on modified Poisson regression model.
[b]Reflects relative risk of favorable outcome for one-unit increase in total Pediatric Risk of Mortality score.

APPENDIX 2. Number of Cardiopulmonary Resuscitation Events Among Patients

No. of Cardiopulmonary Resuscitation Events	Patients, *n* (%)
1	111 (80)
2	20 (14)
3	4 (3)
4	1 (1)
5	3 (2)

APPENDIX 3. Outcomes Among Patients With Single Versus Multiple Cardiopulmonary Resuscitation Events Within the Initial PICU Admission

Variable	One CPR Event, *n* = 111	Two or More CPR Events, *n* = 28
Return of circulation achieved for all events (%)	80 (72)	13 (46)[a]
Alive at the time of hospital discharge (%)	56 (50)	7 (25)
Favorable neurologic outcome at hospital discharge (Pediatric Cerebral Performance Category 1–3 or no change) (%)	49 (44)	7 (25)[b]

CPR = cardiopulmonary resuscitation.
[a]15 (54%) failed to achieve return of circulation during a subsequent cardiopulmonary resuscitation event.
[b]6 survived to discharge with Pediatric Cerebral Performance Category score of 1 or no change from baseline and the other with Pediatric Cerebral Performance Category score of 2.