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ORIGINAL RESEARCH ARTICLE

Association Between Chest Compression Pause Duration and Survival After Pediatric In-Hospital Cardiac Arrest

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BACKGROUND: The association between chest compression (CC) pause duration and pediatric in-hospital cardiac arrest survival outcomes is unknown. The American Heart Association has recommended minimizing pauses in CC in children to <10 seconds, without supportive evidence. We hypothesized that longer maximum CC pause durations are associated with worse survival and neurological outcomes.

METHODS: In this cohort study of index pediatric in-hospital cardiac arrests reported in pediRES-Q (Quality of Pediatric Resuscitation in a Multicenter Collaborative) from July of 2015 through December of 2021, we analyzed the association in 5-second increments of the longest CC pause duration for each event with survival and favorable neurological outcome (Pediatric Cerebral Performance Category ≤3 or no change from baseline). Secondary exposures included having any pause >10 seconds or >20 seconds and number of pauses >10 seconds and >20 seconds per 2 minutes.

RESULTS: We identified 562 index in-hospital cardiac arrests (median [Q1, Q3] age 2.9 years [0.6, 10.0], 43% female, 13% shockable rhythm). Median length of the longest CC pause for each event was 29.8 seconds (11.5, 63.1). After adjustment for confounders, each 5-second increment in the longest CC pause duration was associated with a 3% lower relative risk of survival with favorable neurological outcome (adjusted risk ratio, 0.97 [95% CI, 0.95–0.99]; P=0.02). Longest CC pause duration was also associated with survival to hospital discharge (adjusted risk ratio, 0.98 [95% CI, 0.96–0.99]; P=0.01) and return of spontaneous circulation (adjusted risk ratio, 0.93 [95% CI, 0.91–0.94]; P<0.001). Secondary outcomes of any pause >10 seconds or >20 seconds and number of CC pauses >10 seconds and >20 seconds were each significantly associated with adjusted risk ratio of return of spontaneous circulation, but not survival or neurological outcomes.

CONCLUSIONS: Each 5-second increment in longest CC pause duration during pediatric in-hospital cardiac arrest was associated with lower chance of survival with favorable neurological outcome, survival to hospital discharge, and return of spontaneous circulation. Any CC pause >10 seconds or >20 seconds and number of pauses >10 seconds and >20 seconds were significantly associated with lower adjusted probability of return of spontaneous circulation, but not survival or neurological outcomes.

Key Words: heart arrest ■ pediatrics ■ quality of health care

Each year, >15 000 children have an in-hospital cardiac arrest (IHCA) in the United States, and fewer than half survive to hospital discharge, with high variance between hospitals.[1,2] A key element to increase survival is to ensure a consistent and adequate perfusion pressure during cardiopulmonary resuscitation (CPR).[3,4]

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Clinical Perspective

What Is New?

- The American Heart Association has recommended minimizing chest compression pauses to <10 seconds for children, despite a lack of supportive evidence.
- We show that a 5-second increment in the longest chest compression pause duration during each pediatric in-hospital cardiac arrest was associated with lower chance of survival and favorable neurologic outcome.
- Any pause >10 seconds and >20 seconds, as well as number of pauses >10 seconds and >20 seconds, were associated with lower adjusted probability of return of spontaneous circulation.

What Are the Clinical Implications?

- These findings suggest that chest compression pause durations should be minimized during pediatric cardiac arrest.
- The findings confirm that the American Heart Association recommendation of keeping pauses <10 seconds is associated with a higher chance of return of spontaneous circulation.
- The results provide important evidence to inform the 2025 resuscitation guidelines and their dissemination.

Nonstandard Abbreviations and Acronyms

aRR	adjusted risk ratio
CC	chest compression
CCF	chest compression fraction
CPR	cardiopulmonary resuscitation
E-CPR	extracorporeal cardiopulmonary resuscitation
IHCA	in-hospital cardiac arrest
pediRES-Q	Quality of Pediatric Resuscitation in a Multicenter Collaborative
ROSC	return of spontaneous circulation
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology

Any pause in chest compressions (CCs) reduces perfusion pressure.[5]

Several studies have investigated the association between CC pauses and survival after adult out-of-hospital cardiac arrest.[6–13] The most widely used metric for CC pauses has been average CC fraction (CCF), defined as the proportion of the resuscitation attempt where CCs are provided, primarily studied in adult out-of-hospital cardiac arrest.[6,11,13–15] Studies report divergent results on the association between average CCF and survival outcomes.[11,14–17] Several studies have therefore investigated perishock pauses and nonshock pauses instead of average CCF for adults with shockable rhythm out-of-hospital cardiac arrest and found that prolonged perishock pauses are associated with worse survival outcomes.[8,10,12,13,18,19] In accordance, international guidelines recommend minimizing CC interruptions and maximizing CCF.[20–23] The American Heart Association recommends keeping pauses <10 seconds and CCF >80% for all patients in cardiac arrest.[24] These recommendations are based on expert consensus without supportive evidence for children.

Pediatric IHCA is distinctly different from adult cardiac arrest in terms of pathogenesis, rhythm, organization, treatment, and prognosis.[2,25] Thus, pediatric data are needed to inform pediatric guidelines in terms of CCs provided by both laypersons and health care professionals. Using pediatric in-hospital CPR data from pediRES-Q (Quality of Pediatric Resuscitation in a Multicenter Collaborative; URL: https://www.clinicaltrials.gov; Unique identifier: NCT02708134), we aimed to investigate the association between the longest CC pause duration during pediatric IHCA and survival with favorable neurological outcome. We hypothesized that the duration of the longest CC pause would be associated with a lower rate of survival with favorable neurological outcomes.

METHODS

We included data from pediRES-Q in this cohort study of children receiving external CCs for IHCA,[26] and report the study design and results in accordance with STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) reporting guidelines. The collection, management, and analysis of data in this study was approved by the Children's Hospital of Philadelphia institutional review board (number 15-12099; Federal Wide Assurance identifier: FWA00000459), which determined that the study met criteria for a waiver of consent per Code of Federal Regulations 45 CFR § 46.116(d) and 45 CFR § 46.408(a). Sites participating in the collaborative were approved by their local institutional review board or research ethics board and a data use agreement was obtained. Requests for data access from qualified researchers can be sent to pediRES-Q@chop.edu.

We included all in-hospital resuscitation attempts on children ≥37 weeks of gestation and <18 years of age in pediRES-Q from July of 2015 to December of 2021. We included data on index events only and excluded events with <1 minute of recorded external CCs measured by Zoll R-series defibrillators (Zoll Medical).

From the pediRES-Q database, we collected information on age, sex, race, ethnicity, illness category (medical cardiac, medical noncardiac, surgical cardiac [eg, cardiac malformations requiring surgery], surgical noncardiac), preexisting medical conditions, interventions in place before cardiac arrest, hospital site, location in hospital, first documented cardiac arrest rhythm, number of defibrillation attempts, use of extracorporeal

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CPR (E-CPR), and duration of resuscitation attempt. We collected the following outcomes: return of spontaneous circulation (ROSC), survival to hospital discharge, and survival to hospital discharge with favorable neurological outcome. We defined favorable neurological outcome as Pediatric Cerebral Performance Category score ≤3 or no change from baseline, as used in previous studies.[27,28] To conduct a sensitivity analysis, we included a second definition of favorable neurological outcome as Pediatric Cerebral Performance Category score ≤2 or no change from baseline. In the pediRES-Q database, we defined all interruptions in CCs >1 second as a pause. To minimize bias from ROSC periods, we checked all pauses >30 seconds, and excluded these pauses if the rhythm and physiological measurements (ie, systolic blood pressure >40, end-tidal CO_2 >20, consistent pulse oximetry tracing, documentation of palpable pulse) were compatible with ROSC, or there was documentation that clinicians declared the pause as a period of ROSC clinically.

Exposures and End Points

We prospectively defined the primary aim as investigating the association between the longest CC pause duration of each event and survival with favorable neurological outcome. We used a unit of 5-second increases for the longest CC pause, in accordance with previous studies.[13,28] To explore other ways of measuring CC pause durations, we conducted sensitivity analyses to investigate presence of any pause >10 seconds, any pause >20 seconds, number of pauses >10 seconds per 2 minutes, number of pauses >20 seconds per 2 minutes, and CCF. We chose the exposures of CC pauses >10 seconds and CCF ≤80% because these have been recommended by the American Heart Association.[24] We investigated CC pauses >20 seconds because this is known to be associated with worse survival outcomes in adult out-of-hospital cardiac arrest.[8] We report on survival with favorable neurological outcome, survival to hospital discharge, and ROSC for all relevant exposures of interest.

Data Analysis

Patient demographic and arrest characteristics were tabulated and reported as number (percentage) for categorial variables, mean±SD for normally distributed continuous variables, or median (quartile 1, quartile 3) for non-normally distributed continuous variables. To investigate the association between CC pauses and survival outcomes, we used modified, multivariate Poisson regression with log-link function and mixed effects to account for clustering by hospital site. We used directed acyclic graphs (ie, causal diagrams) to pre-identify potentially important confounders that were visualized using the DAGitty online tool (Figure S1). We adjusted for age category (<1, 1 to <8, or ≥8 years), cardiac surgical illness category, hypotension as immediate cause of arrest, an arterial line in place before arrest, an endotracheal tube in place before arrest, average CC depth, defibrillation, and location (pediatric intensive care, cardiac intensive care, other departments).[28–30]

For the binary outcomes of presence of CC pauses >10 seconds, CC pauses >20 seconds, and CCF ≤80%, we also conducted additional sensitivity analysis using a propensity score with inverse probability-weighted regression and trimming. The propensity scores were calculated on the basis of a multivariate regression model including age category (<1, 1 to <8, or ≥8 years), endotracheal tube in place before arrest, arterial line in place before arrest, surgical cardiac illness category, hypotension as immediate cause, and location. We trimmed for propensity weights in the lower and upper fifth percentile and applied the score using modified, multivariate Poisson regression with log-link function and additional adjustment for defibrillation and CC depth.

For the primary exposure of interest, we conducted subgroup analyses on the basis of sex, shockable versus nonshockable rhythm, age groups (<1, 1 to <8, or ≥8), E-CPR cannulation, and respiratory cause of arrest.

All tests were 2-sided, and a *P* value of <0.05 was considered statistically significant. No adjustment for multiple comparisons was performed. Data were analyzed using Stata version 16.0 (StataCorp LP).

RESULTS

We identified 562 children with CPR for IHCA across 27 hospitals with available data on CCs from the bedside defibrillators with CPR mechanics monitoring capabilities. Overall, 64.6% were in the intensive care unit, 16.2% were in the cardiac intensive care unit, and 19.2% were in other hospital locations. Patient characteristics are shown in the Table.

In total, 54.8% attained ROSC, 17.4% attained return of circulation with E-CPR, and 27.8% did not survive the event. Survival to hospital discharge was 34.3% and survival with favorable neurological outcome (Pediatric Cerebral Performance Category score ≤3 or no change from baseline) was 28.2%.

Median (quartile 1, quartile 3) length of the longest CC pause was 29.8 seconds (11.5, 63.1) (Figure 1) and median CCF was 0.90 (0.80, 0.96). Median number of CC pauses >10 seconds per 2 minutes was 0.33 (0.12, 0.60) and median number of CC pauses >20 seconds per 2 minutes was 0.10 (0, 0.25).

After adjustment for confounders, each 5-second increment in the longest CC pause duration was associated with lower relative risk for survival with favorable neurological outcome (adjusted risk ratio [aRR], 0.97 [95% CI, 0.95–0.99]; *P*=0.01; Figure 2). The sensitivity analysis for survival with favorable neurological outcome defined as Pediatric Cerebral Performance Category score ≤2 or no change from baseline showed similar results (aRR, 0.97 [95% CI, 0.96–0.99]; *P*=0.01). Longest CC pause duration was also associated with survival to hospital discharge (aRR, 0.98 [95% CI, 0.96–0.99]; *P*=0.01) and ROSC (aRR, 0.93 [95% CI, 0.91–0.94]; *P*<0.001).

For the sensitivity analyses, any CC pause >10 seconds and any pause >20 seconds were associated with a lower chance of ROSC but were not significantly associated with survival to hospital discharge or survival with favorable neurological outcome because of wide CIs (Figure 3). Number of CC pauses >10 seconds and >20

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Table. Demographic Characteristics

Characteristics	Patients (n=562)
Female sex	43.2
Race and ethnicity	
White	47.0
Black	21.4
Asian	6.9
Other or unknown	24.7
Age, y	2.9 (0.6, 10.0)
CPR duration, min	17.6 (8.0, 42.0)
Preexisting medical conditions	
Sepsis	13.9
Renal insufficiency	16.4
Cardiac malformation	27.8
Metastatic or hematological malignancy	9.4
Illness category	
Medical cardiac	21.5
Surgical cardiac	13.9
Medical noncardiac	51.4
Surgical noncardiac	8.4
Immediate cause of arrest	
Hypotension	35.1
Respiratory decompensation	30.4
Arrhythmia	16.9
Hypoxia	27.4
Other	23.8
Intra-arterial catheter in place	28.8
Endotracheal tube in place	58.9
Initial pulseless rhythm	
VF/VT	2.9
PEA	61.9
Asystole	18.3
Other/unknown	6.9

Continuous data are reported as median (quartile 1; quartile 3), and binary data are reported as percentages. CPR indicates cardiopulmonary resuscitation; PEA, pulseless electrical activity; VF, ventricular fibrillation; and VT, ventricular tachycardia.

seconds per 2 minutes were not significantly associated with survival with favorable neurological outcome or survival to hospital discharge but were significantly associated with lower adjusted relative risk of ROSC (Figure 3).

CCF was not associated with survival with a favorable neurological outcome (aRR, 0.93 [95% CI, 0.38–2.30]; *P*=0.88), survival to hospital discharge (aRR, 0.74 [95% CI, 0.37–1.51]; *P*=0.42), or ROSC (aRR, 1.49 [95% CI, 0.91–2.43]; *P*=0.11). CCF below American Heart Association recommendations (≤80%) was not associated with a lower relative risk of survival with favorable neurological outcome (aRR, 1.09 [95% CI, 0.72–1.64]; *P*=0.72), survival to hospital discharge (aRR, 1.26 [95% CI, 0.90–1.78]; *P*=0.18), or ROSC (aRR, 1.00 [95% CI, 0.80–1.26]; *P*=0.97).

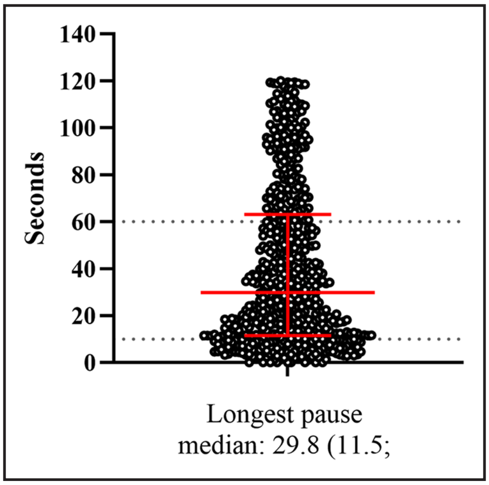

Figure 1. Longest chest compression pause duration recorded during each resuscitation attempt.
The dotted lines mark 10 seconds (maximum pause as recommended by the American Heart Association) and 60 seconds. The red bars mark quartile 1, median, and quartile 3 of the longest pause duration.

The stratified analyses on the effect of longer CC pause durations with survival outcomes for specific subgroups (eg, use of E-CPR) did not reveal significant differences within subgroups (Figure S2).

DISCUSSION

This is the first study to investigate the association between the longest CC pause duration and survival outcomes for a diverse cohort of pediatric patients with IHCA. We found that the longest CC pause duration was associated with a lower chance of survival with favorable neurological outcome, survival to hospital discharge, and ROSC. These data demonstrate that each 5-second incremental increase in the longest CC pause duration was associated with a 3% (95% CI, 1%–5%) reduction in survival to hospital discharge and survival with favorable neurological outcome. These findings suggest that focusing on decreasing longest CC pause duration during CPR is a potentially actionable approach to improve outcomes of pediatric IHCA. In addition, we confirmed that any pause >10 seconds and the number of pauses >10 seconds per 2 minutes (but not CCF ≤80%) were associated with a lower probability of ROSC.

Our findings on the clinical relevance of the longest CC pause are consistent with previous clinical studies in adults and the well-established physiological importance of maintaining adequate coronary and cerebral perfusion during CPR.[4,31,32] Brower et al[13] showed that the longest CC pause duration was associated with worse survival outcomes for adult out-of-hospital cardiac arrest with shockable rhythms. Moreover, our

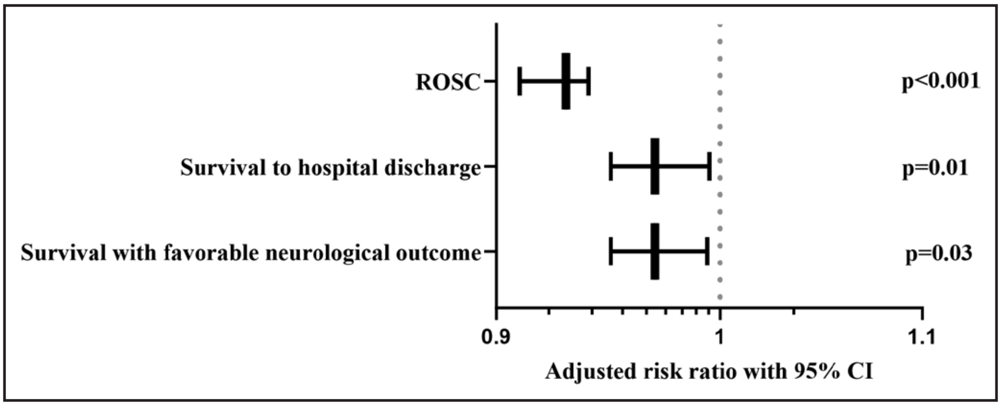

Figure 2. Association between each 5-second increment in the longest chest compression pause duration and survival outcomes reported as adjusted risk ratios with 95% CIs on a logarithmic scale.
ROSC indicates return of spontaneous circulation.

findings correspond well with a recent study investigating the effect of pause durations during the last 5 minutes of recorded CPR before return of circulation with extracorporeal membrane oxygenation.[28] This E-CPR study reported that each 5-second increment in the longest CC pause during the last 5 minutes of recorded CPR was negatively associated with survival to hospital discharge and survival with favorable neurological outcomes.[28] Whereas this E-CPR study focused on a highly selective cohort of pediatric IHCAs with prolonged resuscitation attempts and cannulation for extracorporeal membrane oxygenation, our pediRES-Q data represent a large unselected diverse cohort of pediatric IHCAs analyzing CC pause durations during the entire resuscitation attempt. This has important implications for the 2025 resuscitation guideline recommendations and their dissemination among laypersons and health care professionals.

Our findings of the longest pause duration being associated with worse survival outcomes and any pauses >10 seconds being associated with worse ROSC are important, because the literature on effect of CC pause durations in pediatric cardiac arrest is sparse. This study suggests that minimizing the duration of CC pauses may be as important for pediatric cardiac arrests as for adult cardiac arrests.[13]

We identified a more pronounced effect of the longest CC pause duration on ROSC as compared with survival to hospital discharge and favorable neurological outcomes. This is an expected finding, because intra-arrest interventions should affect the more proximate outcome of ROSC, whereas many other unmeasured factors,

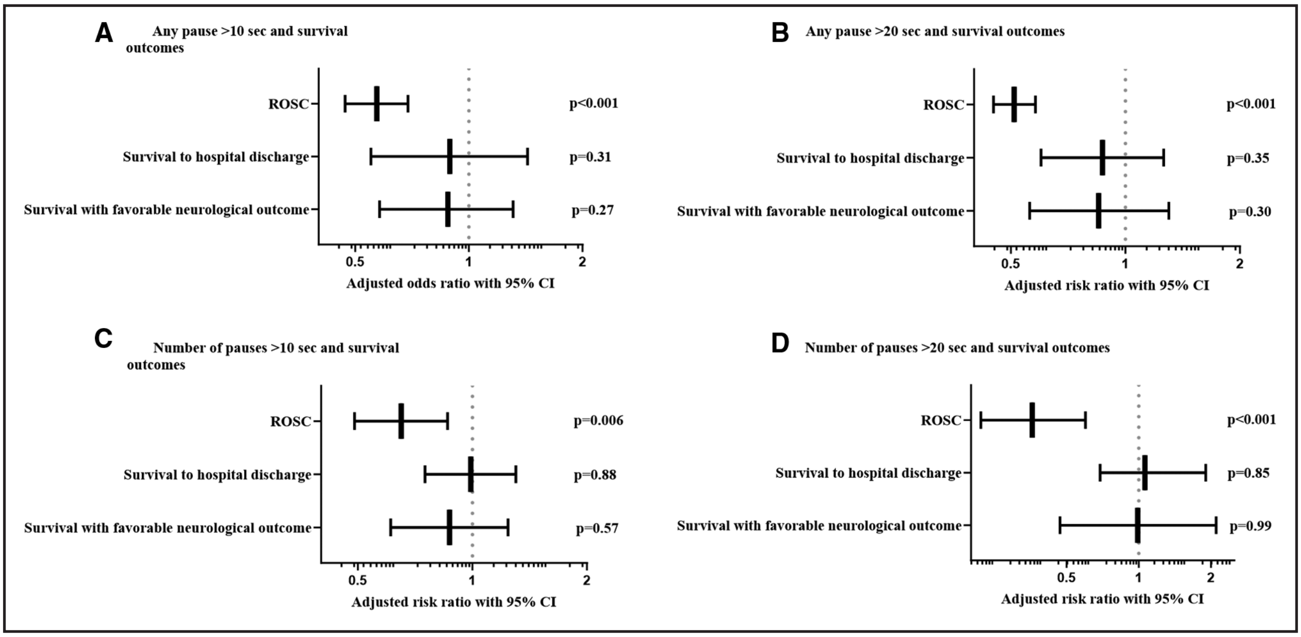

Figure 3. Association between secondary exposures and survival outcomes reported as adjusted risk ratios with 95% CIs on a logarithmic scale.
Number of pauses in **C** and **D** are calculated as number of pauses per 2 minutes. ROSC indicates return of spontaneous circulation.

such as postarrest care, may influence longer-term survival and neurological outcomes. Thus, studies on CPR interventions generally show a greater effect on ROSC when compared with longer-term survival outcomes.[33,34] In addition, we may lack power to find an association with favorable neurological outcomes for specific CC pause durations >10 and >20 seconds, which were not significantly associated with survival with favorable neurological outcome, but were significant for ROSC.

In contrast to our findings of longer CC pause durations being associated with worse survival outcomes, CCF was not associated with survival outcomes. In addition, multiple adult and adolescent cardiac arrest studies either did not show an association between CCF and survival outcomes or paradoxically showed an association between higher CCF and worse survival outcomes.[13,14,17,35–38] This lack of association between CCF and outcomes may have several reasons. First, several shorter CC pauses may result in lower CCF but not worse survival outcomes. A possible mechanism could be that blood pressure increases very rapidly on resumption of CC after short pauses during pediatric cardiac arrest.[5] Thus, frequent and short pauses may not decrease survival. Second, prolonged resuscitation attempts with intubated patients tend to have much higher CCF during the last minutes of the event because of continuous CCs with few CC pauses but lower survival outcomes.[39,40]

Overall, our study reaffirms and provides validation of training efforts and clinical focus on avoiding long CC pauses, and particularly on limiting the duration of the longest CC pause. This may be especially relevant in situations such as rhythm check and pulse check, defibrillation, tracheal intubation, E-CPR cannulation, and point-of-care ultrasound.[41–43] We found that the large majority of resuscitation attempts had pauses >10 seconds, indicating that more could be done to optimize teamwork to reduce pause durations. Whereas it may not be feasible to identify a simple cutoff for when a CC pause duration becomes detrimental, our study provides evidence suggesting that the American Heart Association recommendation on keeping pauses <10 seconds is reasonable. To accommodate this, elements of effective teamwork, including team choreography, effective communication, and preparation for CC pauses with countdowns, should be emphasized, as they may reduce duration of pauses.[41,42,44]

Limitations

This is an observational study. We do not know the cause for each CC pause. We used data from bedside defibrillators, and there might have been CPR performed before or after electrode pad attachment or detachment that was not recorded. Although we assessed long pauses for ROSC, we cannot rule out misclassification of some shorter pauses with a rhythm of pulseless electrical activity because of lack of hemodynamic measurements. Although this is the largest cohort on pediatric cardiac arrest with CPR quality metrics to date, we may lack power to detect an association with favorable neurological outcome for some secondary end points. The study included data from hospitals participating in a pediatric resuscitation quality improvement collaborative (https://www.pedires-q.org), and participating sites may be more dedicated to high-quality CPR than nonparticipating hospitals, which may limit the power to find associations between pause durations and survival outcomes.

Conclusions

Longer CC pause duration is associated with a lower chance of favorable neurological outcome, survival to hospital discharge, and return of spontaneous circulation after pediatric IHCA. Each 5-second increment in longest CC pause duration was associated with a 3% (95% CI, 1%–4%) lower chance of survival with favorable neurological outcome. Any CC pause and the number of CC pauses per 2 minutes >10 seconds and >20 seconds were significantly associated with lower adjusted probability of ROSC, but not survival or favorable neurological outcome, whereas CCF was not associated with any outcome.

ARTICLE INFORMATION

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Supplemental Material

Figures S1–S3

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