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Clinical paper

# Pauses in compressions during pediatric CPR: Opportunities for improving CPR quality

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## Abstract

**Objective:** Minimizing pauses in chest compressions during cardiopulmonary resuscitation (CPR) is recommended by the American Heart Association (AHA) and is associated with improved patient outcomes. We studied the quality of pediatric CPR performed in a tertiary pediatric emergency department (ED) with a focus on pauses in chest compressions.

**Methods:** We conducted an observational study of CPR quality in two pediatric EDs using video review during pediatric cardiac arrest. Events were reviewed for AHA guideline adherence. Parameters of CPR performance were described according to individual compressor segment. Pauses in compressions were analyzed for duration and pause activities.

**Results:** From a 30-month period, 81 cardiac arrests were analyzed, including 1003 individual compressor segments and 900 pauses. Median chest compression fraction was 91%, with a median pause duration of 4 s (IQR 2, 10); 22% of pauses were prolonged (>10 s). Pulse checks occurred in 23% of pauses; 62% were prolonged. Checking a single pulse site ($p < 0.001$) and having fingers ready pre-pause ($p = 0.001$) were associated with significantly

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shorter pause duration. Pause duration was correlated with the number of pause tasks ($r=0.559$, $p<0.001$). "Coordinated pauses" (pulse check, rhythm check and compressor change) were rare (6%) and long in duration (19 s; IQR 11, 30).
**Conclusions:** Prolonged pauses in chest compressions occurred frequently during CPR and were associated with pulse checks and multiple simultaneous tasks. Checking a single pulse site with fingers ready on the pulse site pre-pause could decrease pause duration and improve CPR quality.
**Keywords:** Resuscitation, Cardiopulmonary resuscitation, Pediatric, CPR

## Introduction

Each year, approximately 16,000 pediatric cardiac arrests occur in the United States. While in-hospital cardiac arrest (IHCA) survival rates have recently improved, survival from out-of-hospital cardiac arrests (OHCA) remains unchanged.[1,2] Adherence to the American Heart Association (AHA) cardiopulmonary resuscitation (CPR) quality guidelines for compression rate and depth has been associated with both improved survival and patient outcomes.[3–5] Recent pediatric CPR quality studies report poor adherence to AHA guidelines, but more in-depth analysis of CPR pauses is needed.[1,6–8]

Minimizing pauses in chest compressions has been identified as one of the most important components of high-quality CPR, with prolonged pauses being associated with decreased survival and reperfusion success after defibrillation.[1,9,10] The 2015 AHA guidelines recommend limiting pauses to no more than 10 s and coordinating tasks during pauses.[1] One prior study evaluating pediatric CPR quality reported that a third of pauses lasted longer than 10 s.[6] Further delineation of the activities that occur during chest compression pauses is needed to be able to perform team activities in a timely fashion to minimize pause duration. Having an in-depth understanding of pause data will help guide CPR quality improvement and educational interventions. Our study aimed to provide a detailed analysis of pediatric CPR quality and the activities that occurred during pauses in chest compressions in the emergency department (ED) setting.

## Methods

### Study design and setting

We conducted an observational study of pediatric cardiac arrests over a 30-month period using video review as the data collection modality. This study was conducted at the two associated EDs within a single pediatric tertiary health care system that collectively manages care for approximately 135,000 children each year. All cardiac arrests are managed by pediatric emergency medicine attending physicians who are Pediatric Advanced Life Support (PALS) certified. A monitor/defibrillator (Zoll®, R series, Chelmsford, MA) was available during cardiac arrests for rhythm detection and defibrillation if applicable. Real time audio feedback on CPR performance was not available during the study period. All ED resuscitations are recorded as part of an ongoing quality and safety assurance program. Each resuscitation room is equipped with a motion-activated, audio-video recording system, including three cameras with microphones and direct digital output from patient monitors. This study was approved by our Institutional Review Board.

### Study subjects

All pediatric patients <21 years of age who presented to one of the two EDs in cardiac arrest and received chest compressions for at least two compressor segments in the resuscitation rooms between January 1st, 2014 and June 30th, 2016 were eligible for inclusion. A compressor segment was defined as the time frame during which a single provider was performing uninterrupted chest compressions. Cardiac arrest patients were excluded if: (1) chest compressions did not occur in the ED resuscitation rooms and thus were not video recorded; (2) the resuscitation efforts did not include at least one recorded pause during compressions; and (3) the quality of video recording did not allow for reliable data collection.

### Data collection

We reviewed consecutive video recordings of pediatric patients presenting in cardiopulmonary arrest. Video review methodology was performed in accordance with our site policy. Two independent researchers reviewed the study videos, with interrater reliability testing performed for 10%; published studies with similar methods of video-based data collection have reported high inter-rater reliability at our institution.[6,11,12] Patient and event demographic data were collected for each case and included: patient age, date and time of arrival, location of arrest (in-hospital cardiac arrest [IHCA] or out-of-hospital cardiac arrest [OHCA]), pre-hospital interventions if applicable, ED interventions, number of CPR events, event duration, and patient outcomes according to Utstein criteria (return of spontaneous circulation lasting at least 20 min (ROSC), survival to hospital admission, and survival to hospital discharge).[13] OHCA is defined as an event that occurred in the prehospital setting; IHCA as one that initiated in the hospital/emergency department setting.[3,6,13] A CPR event was defined as the time from when chest compressions were started while in the resuscitation room to the time of compression cessation, whether from identification of a palpable pulse or time of death was pronounced. All study data was entered into a secure, hospital-based password protected database.

### Chest compression and ventilation data

A detailed data dictionary was created and tested for reliable and accurate data collection. All definitions, including specifics related to event start and stop times, were confirmed prior to data collection, and are consistent with previous video review research and AHA guidelines.[1,4,6,12,14–16] Specific CPR parameters included chest compression and ventilation rates, pause duration, compressor segment duration, and chest compression fraction (CCF).

### Ancillary tasks

Ancillary tasks that were recorded during resuscitations included defibrillator pad placement, backboard placement, step stool usage, epinephrine administration, and tracheal intubation attempts. Defibrillator pad placement was defined as placement

of both anterior and posterior pads. Intubation data, as it related to chest compressions and pauses, was also collected. A tracheal intubation attempt was defined as any time the laryngoscope blade was inserted into the mouth, in concordance with previous study methodology by co-investigators.[17,18] An intubation attempt was classified as either "interrupted", if chest compressions were paused for any period of time during the intubation attempt, or "uninterrupted".

### *Pauses in chest compressions*

A pause was defined as any interruption in chest compressions of any duration longer than one full second.[6] Pause durations were rounded to the nearest second according to timestamps on the video recordings and assigned a minimum duration of one second consistent with previous studies.[6,19] Prolonged pauses were defined as lasting greater than 10 s in concordance with AHA guidelines.[1] All activities occurring during pauses were categorized. We determined a pause to be "coordinated" when there was a combination of compressor change, pulse check, and rhythm check, similar to previously defined methodology.[6] Durations of pauses for compressor changes were measured for the Emergency Medical Services (EMS)-to-ED team transition and for the compressor changes within the ED team. A pulse check was defined as any attempt to palpate a pulse when compressions were paused. For each pause, pulse check data included the location of each pulse check (site), the number of sites checked (by one or more team members), and whether any team member had their finger on a pulse site prior to the pause (designated as "finger-ready" or "finger not ready"). Rhythm checks were defined as any time a team member verbalized the patient's rhythm or was visibly evaluating the monitor for rhythm detection. Patient positioning was defined as any time the patient was repositioned in association with a resuscitation task (e.g., positioning for intubation, for placement of posterior defibrillator pad, etc.). Physical assessment was defined as the performance of any physical exam component (e.g., auscultation for breath sounds or heart rate, examination of pupillary response, etc.).

### *Data analysis*

Inter-rater agreement was analyzed for 10% of the videos using a random number generator. Discrepancies in time data duration greater than two seconds were reviewed by a third investigator until a consensus was reached by the study team. We used Cohen's Kappa to assess interrater agreement for dichotomous data and intra-class correlation (ICC) using a two-way random effects model for continuous, time-based data. Main outcomes and CPR performance data are presented using descriptive statistics- medians with interquartile range (IQR 1, 3) for continuous (time-based) variables and proportions for categorical variables. Median times were compared using Mann–Whitney U testing; for comparing pause times between different task numbers, a Kruskal–Wallis test was used followed by Mann–Whitney U. Categorical data was compared using Chi-squared analysis. Number of tasks and pause time was also correlated using Spearman's correlate (reported as *r).* All statistical tests and distribution determination were performed using R Core Team, and descriptive and graphical illustrations were performed using SPSS (Chicago, IL). All tests were two-sided and $p < 0.05$ was considered statistically significant. Sample size calculations were not employed, as study subjects were consecutively enrolled over a fixed period of time.

## Results

Between January 1st, 2014 and June 30th, 2016, 68 patients received CPR. Four patients were excluded due to uninterpretable video quality, leaving 64 patients meeting inclusion criteria. Outcomes stratified by arrest location are shown in an Utstein diagram (Fig. 1). Twenty-two percent (14/64) achieved Utstein-defined ROSC, with

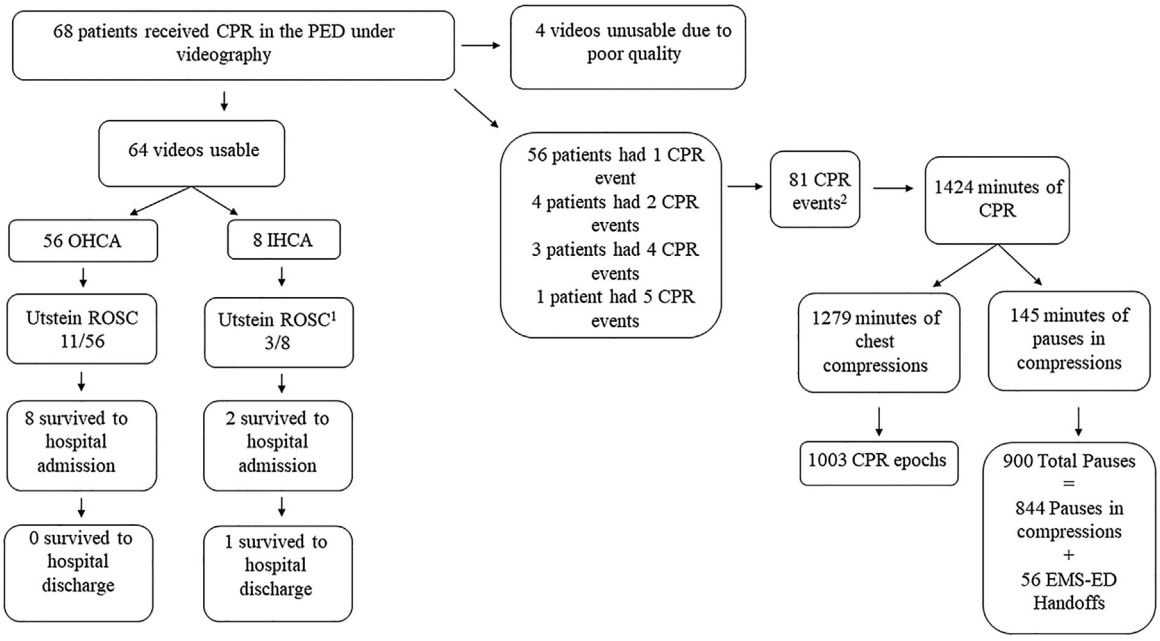


**Fig. 1 – Utstein Criteria sorted by OHCA and IHCA.**

10 surviving to hospital admission and 1 surviving to hospital discharge. There was no difference in ROSC for IHCA vs. OHCA arrest location (p = 0.253). Median age was 7 months (IQR 3, 36 months); 47% (30/64) were female; 87% (56/64) were OHCA. There were 81 total CPR events: 56 patients had one contiguous event; 8 had multiple isolated events. There were 1003 compressor segments with 1424 min of CPR analyzed (Fig. 1). Inter-rater agreement between reviewers had a Cohen's kappa for dichotomous data of 0.84 (95% CI, 0.50, 1.0) and an ICC for continuous data of 0.87 (95% CI, 0.70, 0.96).

### *Overall CPR data*

Overall CPR quality data is reported in Table 1. The median CCF was 91% (IQR 87%, 95%). Median chest compression rate was 133 compressions per minute, with 75% of compressor segments having rates higher than AHA recommendations. Median ventilation rate was 22 breaths per minute (bpm), with the majority (79%) being ventilated at >10 bpm.

### *Pauses in chest compressions*

A total of 978 pauses in chest compressions were identified; 78 (8%) were not analyzed due to poor video quality, leaving 900 total pauses for analysis. Seventy-eight percent of analyzed pauses were compliant with the AHA recommended duration of ≤10 s (Table 2). The median total pause duration was 4 s (IQR 2, 10). Pauses involving compressor changes were associated with the shortest pause durations (2 s, IQR 1,6), with similar median pause times between EMS to ED compressor transitions (5 s, IQR 2,9) and ED to ED transitions (4 s, IQR 4,10; $p = 0.365$). There were no differences in median pause time or frequency of pauses lasting less than 10 s for the first CPR event compared to subsequent CPR events (Table 2). There was also no association between ROSC verses no ROSC events and median pause time (4 s [2,10] vs. 4 s [2,16], p = 0.175)

**Table 1 – CPR event characteristics and compliance with 2015 AHA guidelines.**

| Chest compression segments (n = 1003) | |
|---|---|
| Median compressor segment duration, seconds (IQR) | 66 (28, 110) |
| Segments ≤120 s | 801/1003 (80%) |
| Segments >120 s | 202/1003 (20%) |
| Median chest compression fraction, % (CCF) (SD) | 91% (87, 95) |
| Events with CCF ≥80%[a] | 78/81 (96%) |
| Median chest compression rate, beats per minute (IQR) | 133 (120, 151) |
| Slower than AHA recommended rate: <100 per minute | 38/1003 (3%) |
| AHA recommended rate: 100–120 per minute[a] | 217/1003 (22%) |
| Faster than AHA recommended rate: >120 per minute | 748/1003 (75%) |
| **Ventilations (n = 989)** | |
| Median ventilation rate, breaths per minute (bpm) (IQR)[b] | 22 (14,34) |
| Slower than AHA recommended rate: <8 bpm | 99/989 (11%) |
| AHA recommended rate 8–10 bpm[a] | 111/989 (10%) |
| Faster than AHA recommended rate: >10 bpm | 779/989 (79%) |

[a] AHA recommendation for parameter per 2015 guidelines.
[b] Ventilation rate could not be calculated for 14 (1.4%) of the compressor segments due to poor video quality.

Twenty-three percent (208/900) of pauses involved a pulse check, with median pause duration of 15 s (IQR 7, 27). The femoral location was checked in the vast majority of pauses (190/208, 91%). There was a significant difference in pause time between one pulse check site and multiple sites ($p < 0.001$), as well as between fingers ready and not ready ($p = 0.001$) (Table 3).

The number of tasks performed during each of the 900 pauses was also evaluated (Table 4). Eighty-nine percent of pauses that included a single task were ≤10 s in duration, with a median pause time of 2 s (IQR 1, 5). There was a significant correlation between pause duration and the number of tasks per pause ($r = 0.559$, $p < 0.001$) (Fig. 2). Six percent (57/900) of pauses met our definition of coordinated, with a median pause time of 19 s (IQR 11, 30); 23% (12/57) were ≤10 s in duration. Eighty-four percent (48/57) of coordinated pauses involved only a pulse check, rhythm check and compressor change. When one additional task was added, the median pause time doubled from 15 s (IQR 9, 23) to 30 s (IQR 18, 49) ($p = 0.008$) (Table 4).

### *Ancillary tasks*

Defibrillator pads were placed in 51% of CPR events (41/81), 71% of which occurred within the first five minutes of patient arrival in the resuscitation room. The median time to pad placement was 137 s (IQR 80, 304); two patients received defibrillation. A CPR backboard was used in 95% and step stool in 56% of compressor segments. Epinephrine was administered in 70% (57/81) of the CPR events. The majority (75%) of patients who received epinephrine in the ED had it administered within the first five minutes of arrival. Eighty percent (51/64) of patients had intubation attempted with a total of 84 individual tracheal intubation attempts. Most intubation attempts (70%; 59/84) occurred during a pause in compressions, with a median pause time of 18 s (IQR 3, 38) (Supplementary Table S1).

## Discussion

We evaluated CPR quality and team performance during pediatric cardiac arrest in two pediatric EDs from a single institution, with a focus on describing the factors that affect chest compression pause duration. We found certain resuscitation tasks to be associated with prolonged pauses in chest compressions: pulse checks, rhythm checks, and attempts at tracheal intubation. Pause duration for pulse checks was shorter when teams focused on having fingers ready on the pulse site before the pause and when only one pulse site was checked. Pauses involving a single task, in particular compressor change, regardless of team configuration (EMS to ED or ED to ED), were associated with minimal interruptions in chest compressions. Pauses involving multiple resuscitation tasks were significantly prolonged.

Improving CPR quality during cardiac arrest has been a targeted quality improvement priority that affects patient outcomes.[7,20-22] Despite evidence-based guidelines and a focus on skills training, the quality of CPR remains variable.[4,23] We found performance gaps in our CPR quality similar to those reported in prior pediatric studies.[1,4,6,18] Most children in our study received chest compressions and assisted ventilations at rates higher than current recommendations.[1] Hyperventilation and rapid compression rates can impede venous return and affect cardiac output during CPR.[1,22,24] Improvements in adherence to

**Table 2 – Tasks performed and associated pause durations during compression pauses.**

| | Median time (seconds) (IQR1, IQR3) | Pauses ≤10 s (%) | All pauses n = 900 (%)[a] |
|---|---|---|---|
| All pauses | 4 (2,10) | 756/900 (78%) | 900/900 (100%) |
| First CPR event pauses (n = 835) | 4 (2,11)* | 626/835 (75%)+ | 835/900 (93%) |
| Subsequent CPR event pauses (n = 65) | 3 (1,10)* | 51/65 (78%)+ | 65/900 (7%) |
| *p = 0.433; +p = 0.590 | | | |
| Coordinated pause activities | | | |
| Compressor change | | 493/588 (84%) | |
| | 2 (1,6) | | 588/900 (65%) |
| Pulse check | | 78/208 (38%) | |
| | 15 (7,27) | | 208/900 (23%) |
| Rhythm check | | 63/181 (35%) | |
| | 15 (8,29) | | 181/900 (20%) |
| Coordinated pauses[b] | | 12/57 (23%) | |
| | 19 (11,30) | | 57/900 (6%) |
| Ancillary tasks | | | |
| Patient positioning | | 32/95 (34%) | |
| | 6 (4,12) | | 95/900 (11%) |
| Defibrillator pad placement | | 51/69 (75%) | |
| | 6 (3,11) | | 69/900 (7%) |
| Physical assessment | | 35/88 (40%) | |
| | 17 (7,31) | | 88/900 (10%) |
| Intubation attempts | | 32/70 (46%) | |
| | 18 (3,38) | | 70/900 (7%) |

[a] Multiple tasks were performed during pauses; thus, the percentages do not total 100%.
[b] Coordinated pauses required at least compressor change, rhythm check, pulse check, but could include other pause activities.

**Table 3 – Comparison of pause duration by pulse check characteristics, n = 208.**

| | Median pause time (seconds) (IQR1,3) | Pauses ≤10 s (%) |
|---|---|---|
| Pulse checks by site[a] | | |
| Femoral (n = 190) | 15 (8,27) | 66/190 (35%) |
| Brachial (n = 34) | 12 (7,29) | 15/34 (44%) |
| Carotid (n = 32) | 21 (11,35) | 7/32 (22%) |
| Radial (n = 6) | 40 (13,37) | 1/6 (17%) |
| Dorsalis pedis (n = 2) | 13 (*N/A*) | 1/2 (50%) |
| Pulse checks by number of sites | | |
| One site (n = 162) | 12 (6,22) | 70/162 (43%)* |
| Multiple sites (n = 46) | 22 (12,38) | 6/46 (13%)* |
| Pulse checks by finger readiness | | |
| Finger ready (n = 114) | 11 (6,19) | 54/114 (47%)+ |
| Finger not ready (n = 94) | 20 (10,34) | 25/94 (27%)+ |

[a] Pulse check sites do not total 208, as some pulse checks had multiple, simultaneous sites checked NA: Not applicable, as only 2 pulse checks involved the dorsalis pedis site.
* Significant difference between these two groups at $p < 0.001$.
+ Significant difference between these two groups at p = 0.001 (Mann Whitney U).

**Table 4 – Comparison of pause duration to number and combination of tasks performed.**

| | Median pause time (seconds), (IQR) | Proportion with a pause of ≤10 s (%) |
|---|---|---|
| 1 task | 2 (1,5) | 553/618 (89%)[a] |
| 2 tasks | 9 (5,19) | 103/181 (57%)[a] |
| 3 tasks | 19 (11,32) | 20/86 (23%)[a] |
| ≥4 tasks | 33 (20, 40) | 0/15 (0%)[a] |
| Compressor change only | 2 (1,3) | 415/428 (97%) |
| Pulse check only | 9 (6,18) | 17/32 (53%) |
| Rhythm check only | 8 (5,10) | 16/20 (80%) |
| Compressor change and pulse check | 7 (3,13) | 19/27 (70%) |
| Compressor change and rhythm check | 18 (10,30) | 16/65 (25%) |
| Pulse check and rhythm check | 15 (8,26) | 27/71 (38%) |
| Coordinated pause (pulse check, rhythm check, and compressor change) only (48/57) | 15 (9,23) | 12/48 (25%)[b] |
| Coordinated pause and ≥1 ancillary task (9/57) | 30 (18, 49) | 0/9 (0%)[b] |

[a] Correlation at r = 0.559, $p < 0.001$.
[b] Difference between these two groups, p = 0.008.

recommended ventilation and compression rates during simulated and actual CPR have been demonstrated with the use of audio-feedback defibrillator devices.[25–27] Upon conclusion of this study, defibrillator monitors with audio-visual CPR quality feedback capabilities have been incorporated into the ED resuscitation workflow at our institution.

The AHA guidelines highlight the importance minimizing pause duration to improve CPR quality with a goal chest compression fraction (CCF) of ≥80% and pause duration of no more than 10 s. Prolonged CPR pauses decrease coronary and cerebral blood

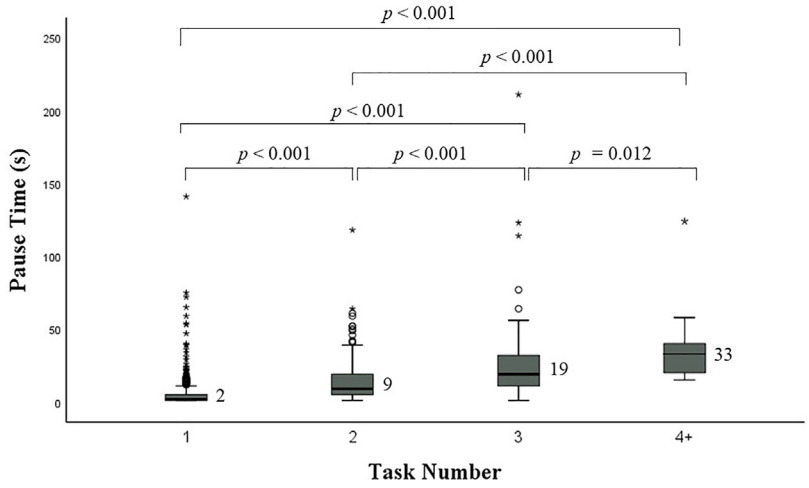


**Fig. 2 – Pause time by number of tasks performed during pause. Number labels correspond to median pause time (also black bar on boxplot). P-values based on Mann-Whitney test for each sample. Stars are extreme outliers.**

flow, and are associated with worse survival outcomes.[28–32] Increased CCF has been an independent predictor of improved survival in pre-hospital cardiac arrest due to ventricular fibrillation and ventricular tachycardia.[33] Most of our CPR events had pauses that were not prolonged (78%), contributing to our median CCF of 91%, comparable to a prior pediatric study.[6] We studied pauses of all durations because we believe that there might be opportunities for improved CPR quality, and potentially improved clinical outcomes, with the knowledge of all tasks and their influence on chest compression pauses.

The type of resuscitation task being performed during compression pauses affected pause duration. The task of checking for a pulse was involved in a quarter of all pauses, and was associated with prolonged pause durations. Performing pulse checks at multiple sites was also associated with prolonged pauses. Having a provider's finger ready on the pulse site prior to a compression pause helped minimize pause duration. Rhythm checks and attempts at tracheal intubation were also significantly associated with prolonged pauses in our study, consistent with findings from a similar previous study.[6]

The number of tasks performed during a pause in our study was also associated with a significant increase in the pause duration, a finding consistent with a recent simulation study but not reported in the clinical setting.[19] Team coordination during pauses is of utmost importance when performing multiple simultaneous tasks. Teamwork training and the 'pit crew' approach to synchronous task performance while minimizing pauses during CPR has been shown to improve survival to hospital admission and discharge, and neurologic outcome in adults.[34,35] In our study, coordinated pauses where a pulse check, rhythm check, and compressor swap occurred simultaneously were rare and associated with a median pause time of almost twice the recommended maximum duration of 10 s. Adding an additional task to a coordinated pause tripled the recommended maximum pause duration. Our findings can help give guidance to future CPR quality improvement efforts and guideline recommendations. Consideration of how, when, and if certain resuscitation activities occur, either in isolation or in combination, should be further discussed and studied.

## Limitations

There were several limitations to this study. First, this study occurred in two EDs within a single pediatric tertiary health care system which may limit generalizability of our findings to non-pediatric, general emergency departments. Second, 6% of cases were excluded due to poor video quality and an additional 8% had segments of data that were not interpretable. Our experience with data loss due to poor video quality is comparable to other video-based CPR quality studies, which report a 6% to 39% rate of uninterpretable data.[6,36,37] Also, pediatric resuscitation studies have been limited by small sample size and flaws in methodology, but the use of video assessment of time-sensitive, team oriented tasks has improved the accuracy and accessibility of resuscitation data.[6,11,17,19] Third, our study looked at skills-based tasks, with a focus on adherence to AHA high-quality CPR guidelines. There are human and team-based factors that were beyond the scope of this study that may have affected team coordination, especially with regards to pauses involving multiple tasks.[38] In addition, we chose to define pauses involving a pulse check, rhythm check, and compressor change as 'coordinated'. We were not able to determine if these pauses were truly pre-determined to be 'coordinated' by the teams or simply had multiple tasks performed simultaneously. This distinction is important with regards to teamwork training and the increasing focus on performing 'pit crew' style pauses.[34,35] Last, we utilized the 2015 AHA guidelines to assess our CPR performance. We understand that the recommended performance parameters may change over time in response to new clinical and research findings. As of publication, the core recommendations for chest compression and ventilation rates, and limitations in pause duration between compression cycles have not changed.

## Conclusion

Prolonged pauses in chest compressions occurred frequently during CPR and were associated with pulse checks and multiple simultaneous tasks. Checking a single pulse site with fingers ready on the pulse site pre-pause could decrease pause duration and improve CPR quality.

## Disclosures

The authors of this study have no conflicts of interest or other disclosures.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.resuscitation.2019.08.015.

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