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Clinical paper

The effect of hand position on chest compression quality during CPR in young children: Findings from the Videography in Pediatric Resuscitation (VIPER) collaborative

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Abstract

Objective: To determine the effect of hand position on chest compression (CC) quality during CPR in young children.

Methods: Prospective observational exploratory study. Patients < 8 years receiving CC for > 2 minutes were enrolled. Data was collected from video review and CC monitor device and analyzed in 'CC segments' (periods of CC by individual providers). Four techniques were compared: two thumbs (2 T), hands encircling the chest; two fingers (2F) on the sternum; one hand on sternum (1H); two hands on sternum (2H). Univariate analysis of CC rate and depth between hand positions was performed through nonparametric testing, stratified by age category.

Results: 47 patients received 824 minutes of CC. Among 270 CC segments in infants < 1 yo, 2 T was used in 27%; 2F 3%; 1H 18%; 2H 26%. Among 189 CC segments in children aged 1 to 8 yo, 1H was used in 26%; 2H 74%. Across all segments, median CC rate was 117 cpm (IQR 110–125). Median depth was 2.92 cm (IQR 2.44 – 4.04) in infants < 1 yo, 3.56 cm (IQR 2.92 – 4.14) in children 1 to 8 yo. 1H achieved greater depth than 2 T in infants ($p < 0.01$), and 2H achieved greater depth than 1H in children > 1 ($p < 0.001$).

Conclusions: In infants, 1H resulted in greater CC depth than 2 T. In children 1 to 8 yo, 2H resulted in greater depth than 1H.. These data suggest that different hand position during CPR in young children from what is currently recommended may result in better CPR quality.

Keywords: Pediatrics, Cardiopulmonary resuscitation, Chest compressions

Introduction

More than 16,000 children suffer cardiac arrest each year in the United States. High quality cardiopulmonary resuscitation (CPR) remains the cornerstone of therapy for cardiac arrest in children. American Heart Association (AHA) recommendations on chest compression depth and rate in children are largely extrapolated from data in adults, including a recommended rate of 100 to 120 compressions per minute (CPM) and a maximum depth of 6 cm in children after puberty.[1] The ideal depth for compressions in infants and younger children is not known; studies examining anthropometric data in infants and children have suggested that the recommended depth of 1/3 to 1/2 of the anteroposterior chest diameter is unlikely to result in injury.[2].

Clinical data on pediatric chest compression quality using specific hand positions is lacking in published literature. Current AHA recommendations for hand placement during infant and child CPR continue to allow rescuers to choose between two-thumb or two-finger compressions in infants based on the number of rescuers and whether a rescuer's hands encircle the infant's thorax or not. Current guidelines also state that "There [are] no human studies comparing the 1-hand compression versus the 2-thumb–encircling hands technique in infants." In children older than one year, either one or two hands can be used, with guidelines stating that "There are no pediatric-specific clinical data to determine if the

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1-hand or 2-hand technique produces better outcomes for children receiving CPR."[1].

The Videography in Pediatric Resuscitation (VIPER) Collaborative is a multicenter emergency department-based research group using video review of pediatric resuscitation events to examine care processes and patient outcomes.[3] Our group has previously reported on pediatric CPR quality using a combination of video review and pressure/accelerometer devices to measure chest compression quality at the level of individual providers.[4–6] For the present study, we sought to examine hand position during CPR in young children and the association between different hand positions and chest compression quality. We hypothesized that there would be significant differences in chest compression depth and rate when comparing different hand positions during CPR in young children.

Methods

Study design and setting

We conducted an exploratory prospective observational cohort study in the emergency departments (EDs) of three tertiary children's hospitals contributing data to the VIPER Collaborative registry (Children's Hospital of Philadelphia, Children's National Hospital, Children's Hospital Colorado). The study was approved by the Institutional Review Board of the Children's Hospital of Philadelphia.

At each site, resuscitative care in the ED is video recorded as part of intradivisional continuous quality assurance programs. Videorecording occurs automatically for all events and patient/parent consent is included as a part of the overall consent for treatment; events where consent is not obtained are immediately deleted. Videorecording is done using three synchronized camera views plus a view of the patient monitor (LiveCapture, BLine Medical, Washington, DC; Ocularis OnSSI, Qognify Inc., Pearl River, NY). Videos are reviewed and de-identified data is collected on common resuscitative procedures, including tracheal intubation. Following each site's specific retention period, videos are deleted and are not part of the patient medical record.

The creation and testing of the VIPER database have been reported elsewhere.[3] Briefly, the database was created by the investigators through an iterative process using video recorded simulations as a source of test data. Duplicate review of tracheal intubation events by multiple investigators during these simulations yielded very high interrater agreement with $k > 0.8$ for all categorical data fields and intraclass correlation coefficient > 0.96 for continuous (time-based) data fields.[3] The incidence of cardiac arrest at the enrolling centers for VIPER is typically between 30 and 50 cases per year.

Inclusion and exclusion criteria

Patients aged less than eight years receiving chest compressions in the ED as a continuation of ongoing care for out-of-hospital cardiac arrest, or for cardiac arrest and/or critical bradycardia while being cared for in the ED, were eligible for enrollment. All events where chest compressions were performed for > 2 minutes were considered for inclusion. At all VIPER sites, a defibrillator/chest compression monitor device (Zoll R Series, Zoll Medical, Chelmsford, MA, USA) is routinely used during CPR in all patients. Events were included in the analysis only if both the CPR monitor device data was successfully collected and the event was captured by video recording. Data collected on patients included age, initial rhythm, out-of-hospital versus in-hospital arrest, event duration, and outcomes according to Utstein definitions. 2020 AHA Pediatric Advanced Life Support (PALS) Guidelines for rate and depth for child and infant CPR were referenced and included a CC rate of 100–120 compressions per minute and a minimum depth of 3.4 cm for infants and 4.4 cm for children and adolescents.[1].

Data collection: Video review

Videorecorded CPR events were reviewed by study team members. CCs were analyzed by 'compressor segment', defined as the period of time where a single provider performed CC (with or without interruptions) until another provider replaced them. CC rate was expressed as compressions per minute (cpm). Start and stop times for each compression segment were measured to the nearest second.

Hand position during chest compressions was categorized in one of four ways: 1) two thumbs with hands encircling the chest (2 T), 2) two fingers (2nd and 3rd digit) pressing anteriorly on the child's sternum (2F), 3) one hand (heel of palm on child's sternum) (1H), and 4) two hands (heel of one palm on child's sternum with other hand on top) (2H). In the case of segments being performed by a single provider using more than one hand position, video reviewers were instructed to select the hand position used during the majority of the segment.

Data collection: Monitor device

Chest compression rate and depth were measured by the defibrillator monitor device with dual sensor electrode pads in anterior-posterior position. The small pads for this device are approved for use in patients less than 25 kg. Chest compression depth is measured by a combination of accelerometry and impedance. Code Review™ software (ZOLL Medical, Chelmsford, MA, USA) was used to extract and analyze the CPR metric data. Using start and stop time points identified from video for each compressor segment, the software allows for the selection of identical time periods and summarization of CPR parameters for those time periods (i.e., CPR performance by individual providers). The defibrillator monitor device is not calibrated to give audio feedback on compression depth or rate when using the pediatric pads, indicated for use on patients less than 25 kg; the device was not in view of compressors and visual feedback was only incorporated if another person observed the display and gave verbal prompts to the compressor.

AHA PALS guidelines recommend CC depth at least 1/3 AP diameter of chest in children, or about 4.0 cm in infants less than 1 year old and 5.0 cm in children 1 to 8 years old. Congruent with previous pediatric CPR research, we defined a relative CC depth target of 3.6–4.4 cm for infants less than 1 year and 4.5–5.5 cm for children 1 to 8 years old.[7].

Analysis

All data were summarized descriptively. We stratified patients into three age groups: < 1 yo, 1 yo to < 5 yo, and 5 yo to 8 yo. To allow analysis across all three age groups, we reported average CC depth as a percentage of the recommended minimum depth for that age stratum (e,g, average depth / 4 cm for infants; average depth / 5 cm for older groups). The differences in compression depth and rate across all three age strata were analyzed by Kruskal-Wallis testing. Analysis of the differences across all age groups in the proportions of CC segments meeting recommended depth and rate guidelines was done via $\chi 2$ testing.

Unadjusted univariate analysis was done comparing CC rate and depth within each age stratum between different hand positions using nonparametric (Wilcoxon rank sum) testing. In comparing the four different hand positions used during CC on infants, we did individual pairwise comparisons between 2 T (AHA recommended technique) and the other three categories. Pairwise analysis of differences within each age group in the proportions of CC segments meeting recommended guidelines with different hand positions was done using $\chi 2$ analysis. Statistical significance was defined as a p value < 0.05. All statistical analysis was performed using STATA version 16.1 (College Station, TX, USA).

Results

Complete data for analysis were available for 47 CPR events. Table 1 summarizes the enrollment periods, number of patients and age categories, and cumulative time of CC (in segments and in total) over

Table 1 – Enrollment periods and number of patients enrolled per site stratified by age category.

Site	Enrollment period	CPR events by age category			CC segments
		< 1 year	1 – < 5 years	5 – < 8 years	
1	8/2016 – 5/2020	15	9	3	276
2	2/2017 – 6/2018	7	2	3	89
3	8/2018 – 6/2020	4	4	0	37

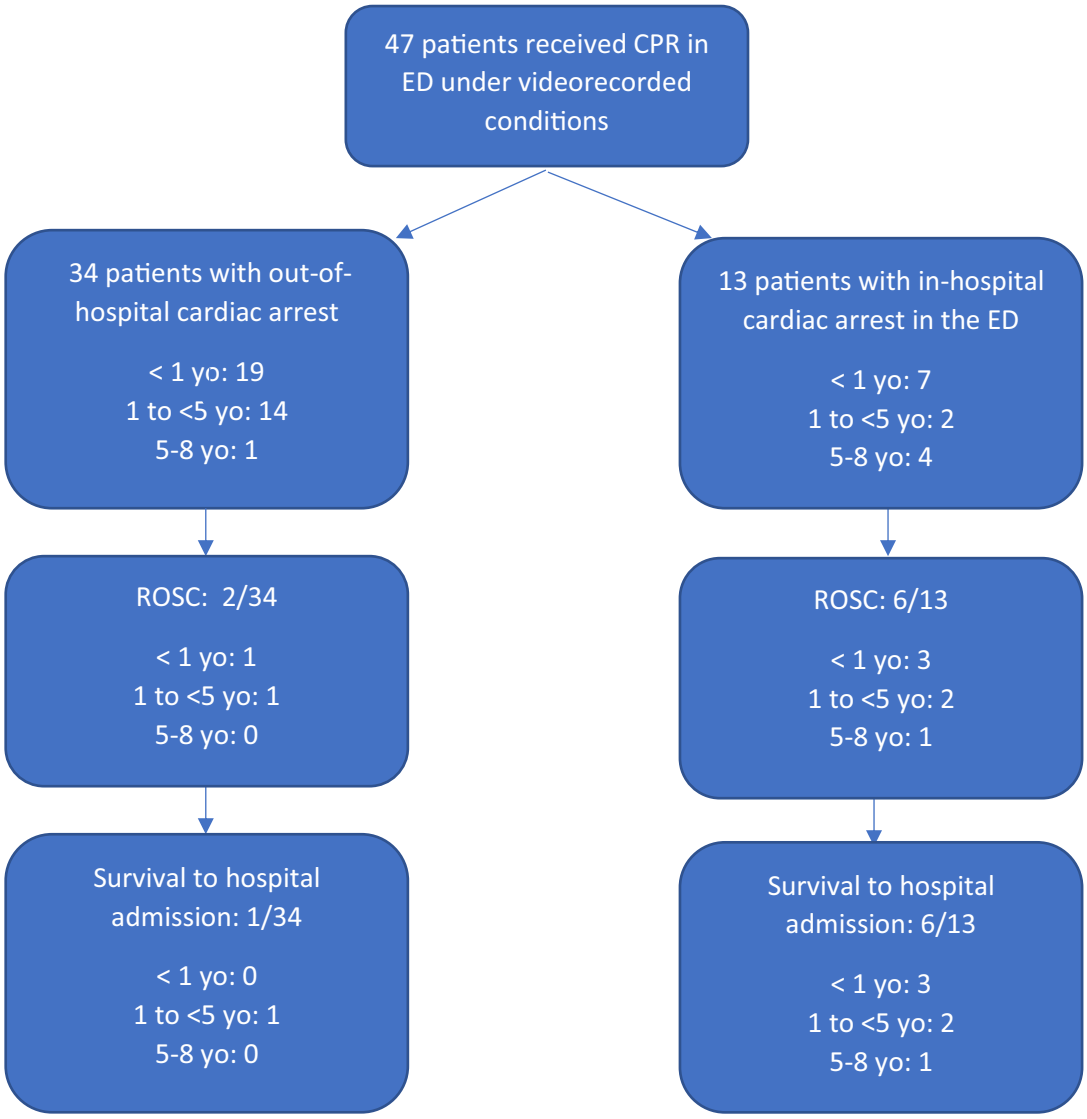

Fig. 1 – Utstein outcomes by arrest location and age category.

the respective study periods. Utstein outcomes for all patients by arrest location and age group are summarized in Fig. 1. Four hundred and two CC segments totaling 824.6 minutes of CCs were included in the analysis. All enrolled patients were infants and children without significant thoracic dysmorphology based on the teams' video reviews. The median duration of CC segments was 87 seconds (IQR 60 – 115 s).

The scatterplots in Fig. 2 show the rate and depth of all CC segments stratified by age group. Median CC rate across all segments was 117 cpm (IQR 110 – 125 cpm). Median CC depth in < 1 yo was 2.92 cm (IQR 2.44 – 4.04 cm); median CC depth in children aged 1 to < 5yo was 3.39 cm (IQR 2.74 – 3.91 cm); median CC depth in children aged 5 to 8 yo was 3.57 cm (IQR 3.00 – 4.14 cm). On Kruskal-Wallis analysis across all age groups, there were no significant differences in transformed CC rate data ($\chi 2$ = 2.8, 2 df, p = 0.24), but there weresignificant differences were found between age groups for CC rate ($\chi 2$ 14.7, 2 df, p < 0.001).

Tables 2a and 2b show CC depth and rate respectively for CC segments performed with each hand position stratified by age category. On unadjusted univariate analysis, 1H compressions were deeper than 2 T compressions in infants, and 2H compressions were deeper than 1H in all age categories greater than 1 year. In infants < 1 yo and children aged 1 to < 5 yo, there were no differences in CC rate between hand positions; in children aged 5 to 8 years, 2H compressions were slower than 1H compressions.

Table 3 shows the proportion of CC segments performed with each hand position that met AHA PALS guidelines for rate and depth for CC segments stratified by age category. Minimum recommended CC depth was achieved in 79/208 segments (38%) in < 1 yo; 19/82 segments (11%) in ages 1 to < 5 yo; 12/110 segments (11%) in 5 to 8 yo ($\chi 2$ p < 0.001). A median compression rate within the recommended range of 100 to 120 compression per minute was achieved in 226/398 of segments (57%) of CC segments. In infants < 1 yo, 2 T was associated with fewer guideline compliant CC segments for both depth and rate compared with 1H or 2H. In children older than 1 year, 2H was associated with better guideline compliance for CC depth; among children 5 to 8 yo, 2H was also associated with better guideline compliance for CC rate.

Discussion

In our study, we found that 2H compressions were deeper than 1H in all children older than one year, and compressions across all age groups rarely exceeded a depth of 5 cm, irrespective of hand position. In infants, 1H and 2H compressions led to greater depth than 2 T, although only 1H compressions yielded a statistically significant difference; the 2F technique was rarely used and we were not able to make meaningful comparisons between this technique and any others. We also found that most CC across all pediatric age strata were too shallow, a finding that is consistent with prior multicenter studies using compression monitor data to quantify CPR performance in children[5,7]; additionally, the deepest CCs noted in each age stratum rarely reached a depth likely to be associated with injury based on published data in adults, although extrapolating this data to pediatric patients is challenging.[14] These data may suggest that compressions using different hand placement techniques than currently recommended in AHA guidelines (1H in infants, 2H after age 1 year) result in better depth and better guideline compliance without being likely to result in a greater incidence of CC-associated injury.

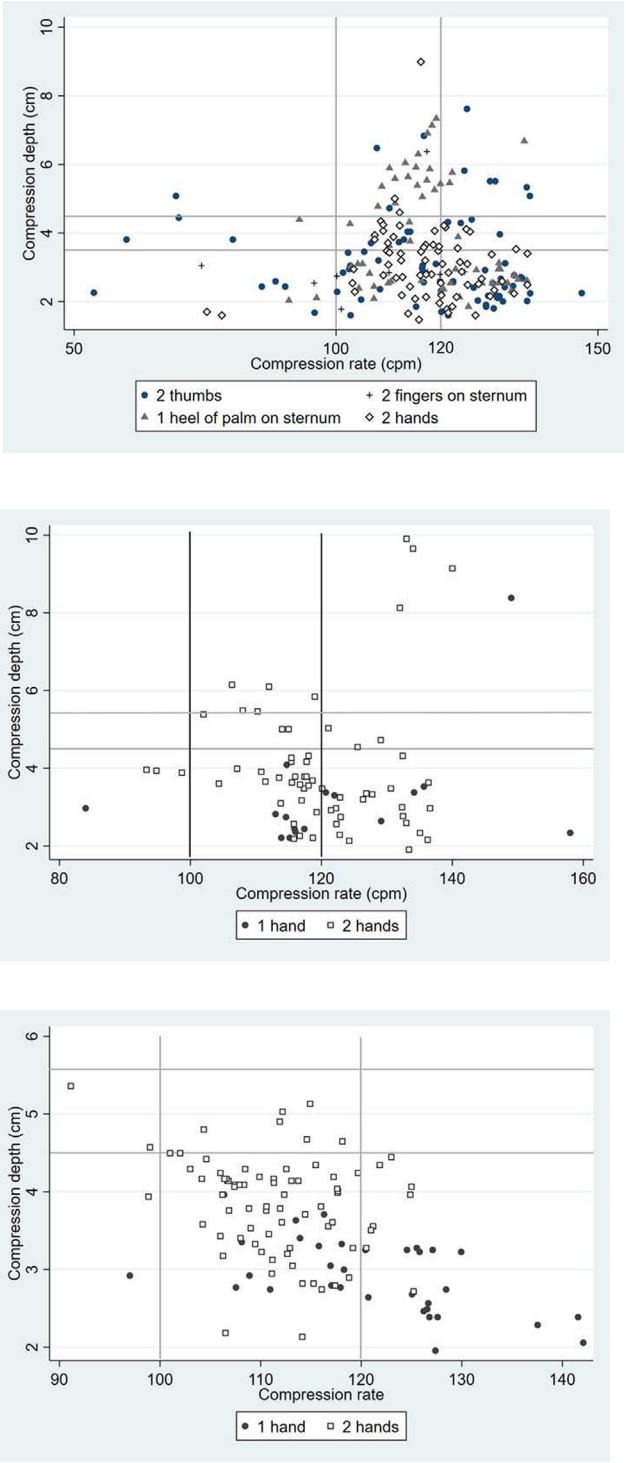

Fig. 2 – Scatterplots of chest compression segment average rate and depth by age: a) infants, b) ages > 1 to < 5 years, c) ages 5 to 8 years. In each plot, the vertical and horizontal lines correspond to the range of AHA PALS recommendations for CC rate and depth, respectively.

While the enrollment period varied across the VIPER centers (largely due to changes in research staffing during the COVID pandemic), our findings remained consistent across centers.

Table 2a – Chest compression depth by hand position stratified by age category.

Hand position	CC segments (n)	Depth (cm)			
		Median (IQR)	5th %ile	95th %ile	p*
< 1 year					
2 thumbs	72	2.57 (2.17 – 3.20)	1.68	4.72	Ref
2 fingers	9	2.79 (2.54 – 3.30)	1.78	3.04	0.67
1 hand	58	2.87 (2.54 – 4.88)	1.99	6.30	0.007
2 hands	70	3.01 (2.34 – 3.66)	1.65	4.34	0.76
Children aged 1 year to < 5 years					
1 hand	16	2.78 (2.40 – 3.38)	2.21	4.09	0.009
2 hands	63	3.63 (2.18 – 4.32)	2.18	5.84	
Children aged 5 years to < 8 years					
1 hand	33	2.92 (2.57 – 3.25)	2.06	3.71	<0.001
2 hands	77	3.96 (3.43 – 4.19)	2.74	4.90	

* Wilcoxon ranksum.

Table 2b – Chest compression rate by hand position stratified by age category.

Hand position	CC segments (n)	CC per min			
		Median (IQR)	5th %ile	95th %ile	p*
< 1 year					
2 thumbs	72	120 (107 – 130)	70	136	Ref
2 fingers	9	110 (100 – 117)	74	125	0.05
1 hand	58	117 (110 – 125)	96	135	0.52
2 hands	70	117 (111 – 123)	103	134	0.32
Children aged 1 year to < 5 years					
1 hand	16	116 (115 – 132)	84	158	0.97
2 hands	63	119 (115 – 128)	102	133	
Children aged 5 years to < 8 years					
1 hand	33	121 (116 – 127)	106	142	<0.001
2 hands	77	112 (107 – 116)	101	123	

* Wilcoxon ranksum.

Table 3 – Proportion of CC segments compliant with AHA PALS guidelines by hand position stratified by age group.[7]

Hand position	CC segments (n)	Rate (100–120 cpm)	Minimum depth or greater (Infants: 3.4 cm; Children: 4.5 cm)
< 1 year			
2 thumbs	72	25/72 (35%)*	24/72 (33%)*
2 fingers	9	6/9 (67%)	0
1 hand	58	33/58 (57%)	27/58 (47%)
2 hands	70	41/70 (59%)	28/70 (40%)
Children aged 1 year to < 5 years			
1 hand	16	8/16 (50%)	1/16 (6%)*
2 hands	63	32/63 (51%)	15/63 (24%)
Children aged 5 years to < 8 years			
1 hand	33	14/33 (42%)*	0*
2 hands	77	66/77 (86%)	12/77 (16%)

* $\chi 2$: $p < 0.001$.

The AHA PALS guidelines for hand placement during chest compressions has been consistent over the past few decades.[1] Current guidelines recommend that lone rescuers performing CPR on an infant should compress the sternum with two fingers, and when two providers are present, rescuers can choose either two thumbs encircling the chest or the two-finger technique. For children > 1 year of age, providers should compress with the heel of 1 or 2 hands, whichever ensures adequate compression depth of one third the AP dimension of the chest. Hand position has been studied on manikins, with two hand compressions producing higher

mean and peak pressures, and one hand positioning being associated with a significant decrease in compression rate over time, presumed due to provider fatigue.[8–10] Hand position in infant manikins has also been studied and suggests that the two-thumb technique results in better compression quality than two fingers anteriorly.[11] In a systematic review of studies comparing the two techniques, the two-thumb positioning was associated with higher chest compression quality over time and less provider fatigue.[12] Manikin studies have reported less compressor fatigue when using two thumbs encircling the chest; other studies have reported lower chest compression fractions and less complete chest recoil.[13–16] In our study involving actual patients, the 2H position yielded deeper chest compressions compared to the 1H position in children aged 5 to < 8 years of age, but still was frequently too shallow. In infants, 1H compressions achieved better depth than 2 T. 2F compressions were infrequently used, with most provider choosing one of the other positions; as a result, we were unable to meaningfully compare this technique with the others.

The incidence of injuries due to CPR in children is not well understood. For the first time in 2015, AHA guidelines recommended a maximum depth of 6 cm for chest compressions in adults; this change was prompted by a single study of IHCA in 170 adults where a higher prevalence of CPR-associated injury was found in patients who received compressions with a mean depth of > 6 cm.[17] Analogous maximum depth recommendations for pediatric patients do not exist. Radiologic studies using computed tomography have yielded conflicting results about the appropriateness of the 1/3 to 1/2 AP diameter recommendation.[18–20] Reports of CPR-associated injury to children suggest that they are uncommon occurrences. A recent forensic report by Ondruschka and colleagues found that 9 of 51 (18%) percent of children younger than 4 years who died despite CPR for non-traumatic cardiac arrest were found on autopsy to have damage to internal organs, and that none of the noted injuries were judged by pathologists to be significant.[21] Importantly, neither this study nor any other published report of injuries from pediatric CPR report any association to chest compression depth. In our study, the 95th percentiles for compression depth in all age strata greater than one year of age were less than the recommended maximum of 6 cm for older children.

Only half of CC segments in our study had a median compression rate within the AHA recommended range of 100 to 120 compression per minute. While there are outliers in both directions of compression rate, there was a tendency to compress at too fast of a rate in infants. These findings are consistent with previous reports of CC performance in children.[4,5,7] Sutton et al reported on CC rate and survival from IHCA in pediatric ICU patients, finding that CC rates above 120 were associated with higher survival rates, but also that a small group of patients with mean CC rates of < 100 cpm also had improved survival.[22] Despite these conflicting findings, AHA recommendations for CC rate in children have not changed.

Several limitations to our study should be mentioned. The VIPER Collaborative currently consists of a group of tertiary children's hospitals in the United States. Enrollment of eligible patients occurred over a different time span at each site; these differences were the result of different times when the sites joined the collaborative, along with site-specific changes in research staffing. The epidemiology of cardiac arrest among pediatric patients is similar at each of these centers and typical for most urban catchment areas in the United States. Additionally, the background, training, and team composition of care providers in the emergency department are similar to other tertiary centers; nonetheless, it may not be possible to generalize our findings to other centers.

For providers using the two-thumb technique, we were not able to determine whether that technique was appropriate for a given provider and patient (i.e. we did not measure each patient's actual thoracic circumference) so it is not clear that a given hand position chosen by a provider was the appropriate one for that patient. The ideal application of the two-thumb technique required the provider's hands to completely encircle the infant's thorax, resulting in circumferential pressure (so-called 'thoracic pump' mechanism). We believe that our data collection methodology is feasible for examining these variations in technique in more detail in the future.

Our study examined the performance of CPR in the pediatric ED; the overall survival of the cohort was poor, in keeping with most published studies of pediatric CPR in the ED. Most of our patients were out-of-hospital cardiac arrest patients, representing an epidemiologic group among cardiac arrest patients for whom outcomes have remained poor and improved negligibly over several decades.[1] Additionally, previously published data has consistently shown that chest compressions on younger children, especially infants, very frequently fail to achieve guideline recommended depth.[7] Our study could not show the effects of CC technique on clinical outcome, and we believe that future research should focus on that topic. The combination of infrequent occurrence along with poor outcomes makes it particularly difficult to isolate the effect of CPR quality from other potentially contributing factors (e.g. high incidence of SIDS, low bystander CPR rates, etc.). Finally, we have no information about the prevalence of CPR-related injury among the enrolled patients.

Conclusions

During cardiopulmonary resuscitation of pediatric patients < 8 years of age, we found significant differences in CC rate and depth dependent on hand placement. The 1H technique was correlated with deeper CC in infants relative to the 2 T technique currently recommended by AHA guidelines. The 2H technique yielded deeper compressions than the 1H technique in patients > 1 year old. CC depth across all ages did not meet AHA recommended guidelines. Our data suggest that using one or two hands for CC in infants and using two hands for all children older than 1 year may yield better depth without frequently exceeding a depth of 6 cm. Future research should better characterize the relationship between CC depth and CPR-related injury in children.

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CRediT authorship contribution statement

Karen J. O'Connell: Conceptualization, Visualization, Investigation, Supervision, Writing – original draft. **Alexis Sandler:** Visualization, Investigation, Writing – review & editing. **Anuj Dutta:** Investigation, Writing – review & editing. **Ramzy Ahmed:** Investigation, Writing – review & editing. **Tara Neubrand:** Conceptualization, Visualization, Investigation, Supervision, Writing – review & editing. **Sage Myers:** Conceptualization, Visualization, Investigation, Supervision, Writing – review & editing. **Benjamin Kerrey:** Conceptualization, Visualization, Investigation, Supervision, Writing – review & editing. **Aaron Donoghue:** Conceptualization, Visualization, Investigation, Supervision, Writing – original draft.

Conflicts of Interest

The authors have no relevant financial conflicts of interest to declare.

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