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2010 American Heart Association Recommended Compression Depths During Pediatric In-hospital Resuscitations are Associated with Survival

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Abstract

Aim—Gaps exist in pediatric resuscitation knowledge due to limited data collected during cardiac arrest in real children. The objective of this study was to evaluate the relationship between the 2010 American Heart Association (AHA) recommended chest compression (CC) depth (≥ 51mm) and survival following pediatric resuscitation attempts.

Methods—Single-center prospectively collected and retrospectively analyzed observational study of children (> 1 year) who received CCs between October 2006 and September 2013 in the intensive care unit (ICU) or emergency department (ED) at a tertiary care children's hospital. Multivariate logistic regression models controlling for calendar year and known potential confounders were used to estimate the association between 2010 AHA depth compliance and survival outcomes. The primary outcome was 24-hour survival. The primary predictor variable was event AHA depth compliance, prospectively defined as an event with ≥ 60 percent of 30-second epochs achieving an average CC depth ≥ 51mm during the first 5 minutes of the resuscitation.

Results—There were 89 CC events, 87 with quantitative CPR data collected (23 AHA Depth Compliant). AHA depth compliant events were associated with improved 24-hour survival on both

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Conflicts of Interest:

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univariate analysis (70% vs. 16%, $p<0.001$) and after controlling for potential confounders (calendar year of arrest, gender, first documented rhythm; aOR 10.3; CI95: 2.75 – 38.8; $p<0.001$).

Conclusions—2010 AHA compliant chest compression depths (≥ 51 mm) are associated with higher 24-hour survival compared to shallower chest compression depths, even after accounting for potentially confounding patient and event factors.

Keywords

cardiac arrest; cardiopulmonary resuscitation; quality

Introduction

Thousands of children and adolescents suffer an in-hospital cardiac arrest each year in the United States.¹⁻³ Adult investigations have demonstrated that cardiopulmonary resuscitation (CPR) quality is associated with survival outcomes.⁴⁻¹² As a result, in an effort to improve cardiac arrest outcomes, the American Heart Association (AHA) now recommends monitoring and titrating CPR performance to specific CPR quality metrics.¹³

The International Liaison Committee on Resuscitation (ILCOR) comprehensively evaluates existing resuscitation science every 5 years to ensure that published CPR guidelines are based upon the best available scientific evidence.¹⁴ Unfortunately, pediatric resuscitation guidelines have largely been developed by expert clinical consensus, using extrapolated data due to a paucity of evidence collected from actual children in cardiac arrest.¹⁵ To our knowledge, no study has associated CPR quality with survival outcomes during pediatric resuscitations, highlighting one of the major gaps in the pediatric resuscitation science knowledge base.

Therefore, the objective of this study was to evaluate the association between 2010 AHA recommended chest compression (CC) depths (≥ 51 mm)¹⁶ and survival during pediatric and adolescent in-hospital resuscitation attempts. As a secondary objective, we sought to determine the association between CC depth and other quality parameters, a relationship that has been evident in previous adult investigations.^{7, 11} We hypothesized that CC depths exceeding the 2010 AHA recommendations (≥ 51 mm) would be associated with improved 24-hour survival after in hospital pediatric and adolescent cardiac arrest.

Methods

Design - Consent

This is a prospectively acquired, retrospectively analyzed, single-center observational study with the primary objective to evaluate the association of 2010 AHA chest compression (CC) depth compliance (≥ 51 mm)¹⁶ with survival outcomes for cardiac arrest events in an intensive care unit (ICU) or emergency department (ED). The Institutional Review Board at the Children's Hospital of Philadelphia approved this study protocol, including consent procedures, as well as the prospective in-hospital cardiac arrest database that was accessed to provide descriptive cardiac arrest event data. Data collection procedures were completed

in compliance with the guidelines of the Health Insurance Portability and Accountability Act to ensure subject confidentiality.

Study Setting

The study hospital is an academic, tertiary care pediatric facility with 516 inpatient beds. The ICU at this institution is a combined medical - surgical unit with 55 beds and ~3000 admissions per year during this study period. The ED at the study hospital is a Level 1 trauma center and treats ~ 90,000 patients each year. An attending physician is present at all arrests. All ICU and ED physicians, respiratory therapists and nurses are pediatric advanced life support (PALS) and / or advanced cardiovascular life support (ACLS) certified.

Study Population

Consecutive ED and ICU CC events in children > 1 year of age that had CPR recording defibrillators deployed during the resuscitation were included in the analysis. Of note, at time of quantitative CPR quality assessment, all events were receiving invasive mechanical ventilation and continuous CCs.

Institutional Resuscitation Care Practices

The Heartstart MRx defibrillator with Q-CPR option (Q: Quality), jointly designed by Philips Health Care (Andover, MA) and the Laerdal Medical Corporation (Stavanger, Norway) was used to collect quantitative CPR data and to provide real-time audiovisual feedback during events. This monitor is FDA approved for children 8 years of age, but can be deployed “off-label” in younger children at the discretion of the rescuers. Please see our previous publication for details regarding “off-label” use of the MRx in younger children.¹⁷ During the study period, there were no substantial changes to the resuscitation team composition, ED physician staffing, 24/7 in- hospital critical care attending presence, or the mock code and rolling refresher CPR training¹⁸⁻²⁰ programs. A quantitative post-cardiac arrest debriefing program was initiated in 2010.²¹ It is important to note that the target for CC depth was increased with release of the 2010 CPR guidelines¹⁶ in October 2010 (2005: 38mm; 2010: 51mm). However, at our institution, we were targeting our training programs to exceed 51mm for children > 1 year during all calendar years of this investigation, as we established that actual CC can be overestimated by as much as 13mm when CPR recording defibrillators are used on soft ICU mattresses.²²

Outcome Variables

The primary outcome was 24-hour survival of all CC events. This proximate CPR outcome was chosen based upon the following considerations: 1) we would be underpowered to detect a significant change in return of spontaneous circulation (ROSC) due to a ceiling effect²¹; and 2) our previous studies demonstrated low rates of survival to hospital discharge in this population (ICU patients with CPR of sufficient duration (>3 minutes on average) to enable compression sensor placement^{17, 23, 24}) which would limit our ability to adjust for potential confounders in multivariable models. Secondary outcomes included ROSC, survival to hospital discharge, and survival with favorable neurological outcome. Favorable neurological outcome was defined using the pediatric cerebral performance category score

(PCPC)²⁵ recommended by the Utstein guidelines²⁶ and defined as a score of 1 - 2 at discharge or no change from baseline. Additional standard event data were obtained from our ongoing prospective in-hospital cardiac arrest database.

Resuscitation Quality—Quantitative CPR data was downloaded from the MRx defibrillators within 24 hours of each event. As in previous studies^{8, 11}, CPR quality parameters from only the first 5 minutes of each resuscitation were used for analyses and included CC depth (mm), rate (CC/min), CC fraction (i.e., the percentage of time during cardiac arrest that compressions are provided) and percentage of CC with significant leaning (> 2.5 kg). The primary predictor variable was AHA depth compliance defined as 60 percent⁷ of 30-second epochs achieving an average CC depth 51mm during the first 5 minutes of the resuscitation event. As a secondary predictor, *a priori* we also defined AHA depth compliance as an average CC depth over the first 5 minutes exceeding 51mm. AHA compliance for other quality variables was as follows: rate 100 and 125 CC/min¹¹, chest compression fraction (CCF) 0.80^{8, 9}, and 10% of CCs with significant leaning (>2.5kg)^{16, 23}.

Statistical Analysis

Q-CPR Review (Version 2.1.0.0, Laerdal Medical, Stavanger, Norway) was used for initial extraction of the quantitative CPR quality data. Standard descriptive statistics, appropriate for the underlying distribution of the variable, were calculated, and compared between groups defined by AHA depth compliance. Sixty-percent of epochs was selected as the primary predictor in accordance with a previous adult investigation associating CC depth and survival.¹¹ Unadjusted rates of AHA depth compliance and 24-hour survival were calculated by calendar year; adjusted rates were calculated using predicted margins from logistic regression models for compliance and 24-hour survival as the dependent variables and calendar year as the primary independent variable (**Figure 2**). Logistic regression models were used to estimate the association between AHA depth compliance and survival outcomes. Calendar year and other potential confounders that differed between depth compliance groups or were associated with survival in unadjusted analyses ($p < 0.1$) were screened for inclusion in multivariable models. Potential confounders included: age, sex, interventions at time of arrest, pre-existing conditions at arrest, initial rhythm, and time and location of arrest. Variables that did not exhibit a significant association with outcomes ($p > 0.1$) in multivariable models were eliminated to form parsimonious models. Statistical analysis was completed using Stata (Version 12.0, StataCorp, College Station, TX) or R (Version 3.0.2, R Development Core Team, Vienna, Austria).

Results

Between October 2006 and September 2013, a total of 89 CC events occurred, 87 with quantitative CPR data collected (23 AHA Depth Compliant). Of these events, 78 were index events (first arrest), 22 of which were AHA Depth Compliant (**Figure 1**). Compliant events tended to occur more often in the PICU ($p = 0.073$), and these compliant events tended to be characterized by more bradycardia with poor perfusion and ventricular tachycardia /

ventricular fibrillation (i.e., shockable rhythms) and less pulseless electrical activity (PEA) / asystole ($p=0.097$) (**Table 1**).

CPR Quality Analysis

Descriptive summaries (median (IQR)) for the CPR quality variables are as follows: depth 44.7 (38.8 – 51.2) mm; rate 108.6 (101 – 115.3) CC/min; CCF 0.94 (0.86 – 0.97); and leaning between CCs 10.5 (4.3 – 20.3) %. Number of events compliant with AHA Guidelines was 23 / 87 (26%) for depth, 61 / 87 (70%) for rate, 79 / 87 (91%) for CCF, and 41 / 87 (47%) for leaning between CCs. We found no correlation between CC depth and the other quality parameters, and no significant differences between events AHA Depth Compliant vs. those not depth compliant (median (IQR)) for: rate (111 (100 – 116) vs. 108 (102 – 115) CC/min, $p=0.88$); CCF (0.92 (0.86 – 0.95) vs. 0.94 (0.87 – 0.97), $p=0.38$); or leaning (8 (4 – 11) vs. 12 (4 – 24) %, $p=0.09$). In our cohort, after adjusting for age, we observed a non-linear association between AHA depth compliance and calendar year ($p=0.011$) and between 24-hour survival and calendar year ($p=0.006$) (**Figure 2**).

Survival Analysis

AHA compliant events (60% of epochs with average CC depth 51mm) were associated with a greater 24-hour survival rate in an unadjusted analysis (70% vs. 16%) and after controlling for potential confounders (calendar year of arrest, gender, first documented rhythm; aOR 10.3, CI⁹⁵: 2.75 – 38.8, $p<0.001$). The secondary outcome of return of spontaneous circulation (ROSC) was also significantly different between groups in an unadjusted analysis (74% vs. 31%), and after controlling for potential confounders (calendar year of arrest and first documented rhythm; aOR 4.21, CI⁹⁵: 1.34 – 13.2, $p = 0.014$). Unadjusted survival to discharge rates trended higher in the AHA compliance events (23% vs. 7%, $p=0.11$), as did rates of survival with good neurological outcome (PCPC 1 or 2; 18% vs. 5%, $p=0.094$), but these differences were not statistically significant. Due to the small number of events with survival to discharge, adjusting for multiple potential confounders was not possible (**Figure 3**). Of note, there was an indication that performing CC depth in compliance with 2010 AHA Guidelines led to shorter CPR duration (median (IQR)) of CPR: 6.7 (4 – 19) vs. 15.2 (8 – 23) minutes; $p=0.062$).

In the *a priori* planned secondary analysis, defining AHA depth compliance as an event with an average CC depth 51mm during the first five minutes did not change the relationship between AHA depth compliance and survival. Both 24-hour survival and ROSC were significantly higher in the group with this alternative AHA depth compliance definition. With both AHA depth compliance definitions, separate sensitivity analyses that included either AHA compliant rate, CCF, or leaning, did not demonstrate significant changes in the estimated association between CC depth and survival.

Discussion

To our knowledge, this is the first study to associate AHA compliant chest compression depth (51mm) during the in-hospital resuscitation of real children and adolescents with survival outcome. We found significantly higher rates of ROSC and 24-hour survival when

CPR was provided in compliance with 2010 AHA depth guidelines (≥ 51 mm). This relationship was evident even after controlling for the effect of improved outcomes over time. In contrast to previous investigations^{7, 11}, we did not observe an association between CC depth and other quality variables – specifically, CC depth did not decline as rates increased.

It is well established in the adult literature that performing high quality CPR is associated with higher survival rates^{4-9, 11}; yet, data supporting this claim in children has been less robust. Much of the science supporting our pediatric guidelines comes from extrapolation of adult data and expert clinical consensus.¹⁵ There are a number of reasons why this evidence, which requires collecting quantitative CPR data from actual children in cardiac arrest, has been elusive. Not only are there technological limitations with many of the currently available CPR recording devices (i.e., not FDA cleared for use in children)¹⁷, but also cardiac arrest in children is relatively uncommon compared to adults.³ This study only begins to fill the knowledge gap. We look forward to data from other centers and/or multi-center registries of pediatric CPR quality to better inform evidence-based pediatric CPR guidelines.

In previous adult studies, when rescuers compressed the chest at a high rate, the compressions were less deep.^{7, 11} Those findings suggest that rescuers might compromise adequate chest compression depth when trying to increase compression rate. We did not observe an inverse correlation between CC depth and rate. One potential reason as to why we did not observe a similar relationship was the minimal variance in CC rate at our institution (interquartile range (101 – 115.3), all within AHA recommendations). Excessively fast compression rates were rarely observed, making it less likely for us to observe this negative correlation. We attribute the small variation in CC rates to an ongoing and successful CPR quality improvement program at our institution, which consists of a daily CPR retraining program¹⁸⁻²⁰, feedback-enabled defibrillators, and post-cardiac arrest debriefings.²¹ As an alternative explanation, the higher compliance of pediatric chest walls²⁷ may have also made it easier for providers to achieve sufficient CC depths even when pushing fast. Irrespective of reason, this data supports that providing high quality CPR with excellent chest compression depths AND rates – PUSHING HARD AND FAST – is possible.

As in previous adult investigations^{8, 11}, we chose to limit our evaluation to the first five minutes of resuscitation. We chose this analysis *a priori* in an attempt to include those critical first minutes when it is likely that the quality of resuscitation most influences short-term survival. Early in the resuscitation, several interventions may occur (e.g., rhythm determination, defibrillation, back board placement), and providing high quality CPR during this time is critical.^{5, 12} This also allowed us to omit later periods in the resuscitation when CPR may not be performed with the same rigor, particularly in those situations when providers think the CPR may be futile or only being performed to allow family members to say “good-bye.”

There is exciting new data establishing that survival outcomes after both adult and pediatric cardiac arrest are improving. In a recent article by Girotra, et. al., as part of the Get with the

Guidelines – Resuscitation Investigators, approximately 40% of children survived their in-hospital cardiac arrest²⁸, nearly double what we report here. This discrepancy warrants discussion and is explained by the particular population under study. Our evaluation was limited to those children who were in cardiac arrest of sufficient duration to allow CPR quality assessment (i.e., compression sensor placement). Our group has previously described how placement of the CPR quality sensor can take as long as 3 -5 minutes^{17, 23, 24}, thereby selecting children with longer arrest times (and subsequent decreased survival rates) for inclusion in this survival study. Moreover, as previously mentioned due to technological limitations of the available devices, most of these subjects were $\geq$ 8 years of age. Previous studies have also established that age is an independent predictor of survival²⁹, with older children having worse survival compared to younger children, a population mostly excluded from this analysis.

While the primary predictor chosen in this study was termed compliance with 2010 AHA Guidelines ($\geq$ 51mm), it is important to note that the depths reported in this investigation are not corrected for mattress deflection. There is a substantial body of evidence establishing that accelerometer based technology, like the one used in this study, can overestimate actual thorax compression during CCs.^{22, 30, 31} Our own study reported that as much as 13mm of depth can be assigned to the mattress when CCs are performed on soft intensive care unit beds, as many were in this study, even when a backboard was in place.²² However, in order for our reporting to be consistent with other publications on CPR quality, we reported uncompensated depths. We caution the reader when interpreting our findings – achieving 51mm of uncompensated deflection likely provides approximately 38mm of actual thorax compression, a depth more consistent with the 2005 Guidelines, not 2010.

This study has notable limitations. First, this study was completed in a clinical environment with a long history of CPR quality research, with an active interest and infrastructure to evaluate and improve resuscitation care. Unmeasured resuscitation process of care variables that could potentially have affected survival outcomes (e.g., time to first chest compression or first epinephrine dose³²) may not be fully accounted for in the analysis. Moreover, we cannot determine with certainty what target rescuers were using to guide CPR quality (i.e., quantitative measurements vs. physiologic markers). This is particularly interesting as the presence of an arterial line in this study did not result in deeper CCs (Table 1). Perhaps, clinicians refrained from providing even deeper CCs if they noted adequate arterial blood pressure. Unfortunately, the authors do not know. Second, due to the size limitations of the existing technology, we were unable to accurately report ventilation quality, a CPR quality variable associated with survival outcomes in animal studies.³³ Third, patients included in this study may have suffered an out-of-hospital cardiac arrest, placing them at risk for poor outcome. Although we did not record that variable as part of this study, it is our experience that after stabilization at the nearest emergency department, the majority of these patients are admitted directly to our PICU. As there was a trend towards improved depth compliance in the PICU compared to the ED, this unmeasured confounder may have weakened our observed association between quality and 24-hour survival. Finally, this study took several years to complete; therefore, time trends on the outcome of interest may not be fully accounted for in studies of this duration.

Conclusions

In this study of children > 1 year of age, performance of CPR compliant with the 2010 American Heart Association chest compression depth recommendations (≥ 51 mm) was associated with higher rates of ROSC and 24-hour survival after in-hospital cardiac arrest. In contrast to previous investigations, we did not observe an association between CC depth and other quality variables – specifically, CC depth did not decline as rates increased. Larger studies are needed to assess the relationship of pediatric CPR quality with long-term survival outcomes.

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Abbreviations

AHA	American Heart Association
CPR	cardiopulmonary resuscitation
CC	chest compression

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Figure 1.
Utstein style diagram.

Figure 2.

Rates, adjusted for age, for 24-hour survival and AHA Depth Compliance (≥ 60 percent of epochs with average CC Depth ≥ 51mm) over calendar year. *No estimate for compliance in 2010 (zero cell).

Figure 3.

Multivariable logistic regression controlling for potential confounders. ROSC refers to Return of Spontaneous Circulation 20 minutes. Discharge indicates Survival to Hospital Discharge. Good Neuro indicates Survival to Discharge with PCPC score of 1 - 2 at discharge or no change compared to admission PCPC status. *indicates aOR 4.21, CI⁹⁵: 1.34 – 13.2, $p = 0.014$ after all CPR events. †indicates aOR 10.3, CI⁹⁵: 2.75 – 38.8, $p < 0.001$ after all CPR events. ‡univariate analysis for survival to discharge (23% vs. 7%, $p = 0.11$) and §good neurological outcome (18% vs. 5%, $p = 0.094$) after index events.

Table 1

Subject and cardiac arrest event data between groups of primary predictor: 60% of epochs with average CC depth ≥ 51 mm.

	Depth < 51mm	Depth ≥ 51 mm	p
Age: years mean (sd)	13.7 (5.0)	12.8 (5.3)	0.48
Age Category, n (%)			0.54
Younger Child (1 yr. to < 8 yrs.)	5 (9)	3 (14)	
Older Child (8 yrs. to <18 yrs.)	51 (91)	19 (86)	
Sex: male, n (%)	28 (50)	11 (50)	0.99
Interventions at time of index arrest, n (%)			
Arterial line *	17 (27)	5 (22)	0.78
Vasoactive infusion †	17 (32)	7 (37)	0.71
Mechanical ventilation ‡	17 (32)	6 (32)	0.97
Pre-existing conditions index arrest, n (%) †			
Sepsis	5 (9)	1 (5)	0.99
Tracheostomy or Ventilator Dependent	12 (23)	3 (16)	0.74
Congenital Heart Disease	5 (9)	0 (0)	0.32
Cancer	9 (17)	5 (26)	0.50
Immunodeficiency	3 (6)	0 (0)	0.56
Immediate Cause of Index Arrest, n (%) †			
Respiratory Failure	32 (60)	11 (58)	0.85
Inadequate Airway / Obstructed Airway	6 (11)	0 (0)	0.33
Hypotension / Shock	29 (55)	13 (68)	0.29
Electrolyte Abnormality	18 (34)	6 (32)	0.85
Trauma	7 (13)	1 (5)	0.67
Initial Rhythm, n (%) *			
Bradycardia	20 (31)	11 (48)	0.097
Asystole / PEA	36 (56)	7 (30)	
VF / Pulseless VT	8 (13)	5 (22)	
Time of Arrest, n (%) *			
Night / Weekends (11PM – 6:59AM) ‡	37 (58)	11 (48)	0.41
Location of Arrest: PICU, n (%) *			
	39 (61)	19 (83)	0.073

* Data available for all 87 chest compression events.

† Data available for 72 of 78 index events.

‡ Weekend indicates time between Friday 11PM and Monday 6:59AM.