Published in final edited form as:

Resuscitation. 2012 December ; 83(12): 1462–1466. doi:10.1016/j.resuscitation.2012.05.010.

Ability of code leaders to recall CPR quality errors during the resuscitation of older children and adolescents*

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Abstract

Aim—Performance of high quality CPR is associated with improved resuscitation outcomes. This study investigates code leader ability to recall CPR error during post-event interviews when CPR recording/audiovisual feedback-enabled defibrillators are deployed.

Patients and methods—Physician code leaders were interviewed within 24 h of 44 in-hospital pediatric cardiac arrests to assess their ability to recall if CPR error occurred during the event. Actual CPR quality was assessed using quantitative recording/feedback-enabled defibrillators. CPR error was defined as an overall average event chest compression (CC) rate <95/min, depth <38 mm, ventilation rate >10/min, or any interruptions in CPR >10 s. We hypothesized that code leaders would recall error when it actually occurred 75% of the time when assisted by audiovisual alerts from a CPR recording feedback-enabled defibrillators (analysis by χ^2).

Results—810 min from 44 cardiac arrest events yielded 40 complete data sets (actual and interview); ventilation data was available in 24. Actual CPR error was present in 3/40 events for rate, 4/40 for depth, 32/40 for interruptions >10 s, and 17/24 for ventilation frequency. In post-event interviews, code leaders recalled these errors in 0/3 (0%) for rate, 0/4 (0%) for depth, and 19/32 (59%) for interruptions >10 s. Code leaders recalled these CPR quality errors less than 75% of the time for rate ($p = 0.06$), for depth ($p < 0.01$), and for CPR interruption ($p = 0.04$). Quantification of errors not recalled: missed rate error median = 94 CC/min (IQR 93–95), missed depth error median = 36 mm (IQR 35.5–36.5), missed CPR interruption >10 s median = 18 s (IQR

*A Spanish translated version of the abstract of this article appears as Appendix in the final online version at <http://dx.doi.org/10.1016/j.resuscitation.2012.05.010>.

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Conflict of interest statement

Unrestricted research grant support: Vinay Nadkarni and Dana Niles from the Laerdal Foundation for Acute Care Medicine; Dana Niles from Laerdal Medical, Inc. Robert Sutton is supported through a career development award from the Eunice Kennedy Shriver National Institute of Child Health & Human Development (K23HD062629). The remaining authors have no additional conflict of interest to disclose.

Financial disclosure

This study was supported by the Laerdal Foundation for Acute Care Medicine and the Endowed Chair of Pediatric Critical Care Medicine at the Children's Hospital of Philadelphia.

Authors' contributions

All authors have made substantive intellectual contributions to this manuscript including: contributions to conception and design, acquisition of data, and/or data analysis; drafting and/or revision of the manuscript; final approval of the submitted manuscript.

14.4–28.9). Code leaders did recall the presence of excessive ventilation in 16/17 (94%) of events ($p = 0.07$).

Conclusion—Despite assistance by CPR recording/feedback-enabled defibrillators, pediatric code leaders fail to recall important CPR quality errors for CC rate, depth, and interruptions during post-cardiac arrest interviews.

Keywords

Pediatric; Code leader; CPR error

1. Introduction

Cardiac arrest remains an important problem in the pediatric population.¹ The quality of chest compressions (CCs) delivered during pediatric in-hospital cardiac arrests frequently does not meet American Heart Association (AHA) quality targets (non-compliance rates ~30%).² Similar results have been reported in adults.^{3–8} Additionally, ventilation rates delivered during in-hospital pediatric cardiac arrest also exceed AHA recommendations more than half of the time.⁹ This CPR quality data cannot benefit patients unless errors are appreciated, and subsequently, therapy is modified by the code leader.

Even with the success attributed to feedback-enabled CPR-monitoring defibrillators,^{6,10,11} code leaders must act on data provided to them to ensure that high quality CPR is indeed delivered to the patient. Experience with intensive resuscitation debriefing programs suggests that code leaders may fail to recall the presence of errors in CPR quality.^{7,12,13} The aim of this study is to utilize an intensive post-event interview and questionnaire to determine if code leaders are able to recall quantitatively measured deviations from AHA recommended CPR quality targets (i.e., CPR error) during real pediatric in-hospital cardiac arrest events.

2. Patients and methods

2.1. Protocol and consent

The study protocol including consent procedures was approved by the Institutional Review Board at the Children's Hospital of Philadelphia. Data collection procedures were completed in compliance with the guidelines of the Health Insurance Portability and Accountability Act to ensure subject confidentiality. Written consent was obtained from all health care providers who participated in the resuscitation events.

2.2. Quantitative CPR quality data collection and feedback system

The Heartstart MRx defibrillator with Q-CPR technology (accelerometer, force transducer, and impedance sensor) used in this investigation was jointly designed by Philips Healthcare (Andover, MA) and the Laerdal Medical Corporation (Stavanger, Norway) and is currently approved by the US Food and Drug Administration for patients ≥ 8 years of age. CPR data is graphically displayed on a screen for the code leader and rescuers to monitor CPR quality objectively in real time. Additionally the monitor/defibrillator provides the code leader and rescuers with audio-visual alerts if specific CPR quality targets are not being achieved. In our institution, during CPR, the monitor/defibrillator is placed near the code leader, in clear view so that both audio and visual feedback are available. Additionally, other quantitative measures of CPR quality (invasive arterial blood pressure, end-tidal carbon dioxide) are often available to the code leader (i.e., displayed on the patient bedside monitor). Code leaders are encouraged to incorporate all available data (monitor alerts, invasive arterial blood pressure, end-tidal carbon dioxide) into their overall assessment of CPR quality. Post-

event review of quantitative CPR data allows calculation of an overall average chest compression rate (CC/min), average compression depth (mm), and length (time in seconds) of any interruptions in CCs for the entire CPR event.

Changes in chest wall impedance (CWI) as measured by electrode impedance tracings from defibrillator pads were used to obtain ventilation data, allowing the calculation of a ventilation rate (breaths per minute).⁹ Although the monitor/defibrillator has the capability to interpret CWI data and identify ventilation during CPR, previous investigations have established concern that software analysis may fail to detect all ventilation events, particularly in pediatric patients.^{9,14} Given this concern, it is the responsibility of the code leader to determine if the ventilation rate is appropriate. In order to calculate an average event ventilation rate, CWI data was retrospectively reviewed using a Windows-based program (Q-CPR Review: Version 2.1.0.0; Laerdal Medical, Stavanger, Norway) by one clinical investigation team member. As a measure of manual review reliability, a random convenience sample of 20% of CPR events was independently reviewed by a second investigator.⁹

In our institution, responders to a cardiac arrest event include an Intensive Care Unit (ICU) or Emergency Department (ED) attending physician, ICU or ED fellow physician, pediatric resident, critical care nurse, and a critical care respiratory therapist. The composition of the resuscitation team remains consistent during nights/weekends. Code leaders are either a fellow or attending physician in the ICU or ED. During a cardiac arrest event, it is our routine practice to disconnect an already intubated patient from the mechanical ventilator and manually ventilate the patient. Ventilation is typically provided by either the respiratory therapist or fellow physician.

2.3. Subject enrollment

Cardiac arrest events requiring CCs occurring in children ≥ 8 years of age in the pediatric intensive care unit (PICU) or the emergency department (ED) of a children's hospital were screened for inclusion in the study. Our 55-bed PICU consists of both medical and surgical patients. Cardiac surgical patients are cared for in a separate cardiac ICU and these patients were not included in our study.

2.4. Code leader survey

Within 24 h of each CPR event, code leaders (either fellow or attending ICU or ED physicians) were identified, interviewed, and asked to complete a questionnaire (Fig. 1) designed to assess their ability to recall whether or not CPR quality errors occurred during the resuscitation event. The completion of the questionnaire was facilitated by one of the research investigators to ensure that the subjects understood the content of each question. Prior to the interview and questionnaire, leaders confirmed they had sufficient knowledge of the cardiac arrest event to participate in the study. Code leaders were specifically asked if chest compression depth was adequate. This wording, and not "average" compression depth was chosen as it incorporates whether or not a given code leader is aware of the absolute depth recommendations (>38 mm) at the time of the study.¹⁵ In short, "adequate" is equivalent to >38 mm for our analysis. For rate, code leaders were asked if the average event rate was approximately 100 CC/min (2005 AHA recommendations¹⁵), which was compared in the analysis to an actual rate of >95 CC/min. Following identification, code leaders anonymously completed surveys, making it possible that a single code leader could be surveyed on more than one occasion. Code leaders were also asked to comment if they experienced any difficulty using the CPR monitoring device.

2.5. Outcome variables/data analysis

Using daily bedside CPR teaching,^{16–18} our healthcare facility and staff prioritize training for the delivery of high quality CPR as defined by AHA guidelines.¹⁵ During this training, we define and reinforce CPR quality error as an overall event average CC rate <95/min (approximately 100 CC/min as per 2005 AHA guidelines), CC depth <38 mm, and any CC interruption >10 s. Excessive ventilation is also defined according to AHA guidelines¹⁵ with >10 bpm considered a CPR quality error. Overall event averages were used as in previous publications on CPR quality.^{3–8,11} A CPR event was defined as an individual patient requiring CPR with an outcome of either the return of spontaneous circulation (ROSC) or death. Patients requiring more than one CPR event after achieving one of these outcomes were considered a new event. We postulated that with our focus on high quality CPR and the availability of viewable, real time, continuous quantitative measures of CPR quality (CC rate, depth, and interruptions) a *conservative* estimate would be for *code leaders to recall at least 75% of CPR quality errors* that occurred. Thus, we compared the proportion of code leaders who recalled CPR quality errors to an a priori expected proportion of 0.75. Categorical variables were compared using a χ^2 test, with *p*-values less than 0.05 considered significant. Statistical analysis was accomplished using Stata-IC 10.0 (Stata Corp., College Station, TX).

3. Results

Between October 2006 and June 2009, 810 min of quantitative CPR data (CC rate, CC depth, and CC interruptions >10 s) were collected on 44 consecutive cardiac arrest events. Data analysis yielded 40 events for which all CPR quality data (actual CPR quantitative data vs. code leader interviews) was complete. CWI data were collected from 26 of the 44 events where defibrillator pads were applied during the resuscitation. Twenty four of these events (92%) provided complete and interpretable CWI waveforms and were included in the assessment of ventilation CPR quality error. Continuous end-tidal CO₂ data was available real-time to code leaders in 27 of 40 events (67.5%) and invasive arterial catheters in 20 of 40 events (50%). Please refer to Table 1 for enrolled patient demographic data.

CPR quality error was documented in 3 of 40 (7.5%) events for CC rate, 4 of 40 (10%) events for CC depth, and 32 of 40 (80%) events had an interruption in CCs >10 s. The median duration of CPR interruption was 16.5 s (IQR: 11.1–27.7). The average ventilation rate was greater than the AHA recommended rate of 10 bpm in 17 of 24 (71%) events. The response rate for the code leader questionnaire was 100%. Code leaders did not report any problems in being able to see or hear the CPR monitor. During the post-event interview, code leaders recalled the presence of CPR errors in: 0 of 3 (0%) events for CC rate, 0 of 4 (0%) events for CC depth, and only 19 of 32 (59%) events that had an interruption in CCs >10 s. Quantification of errors *not recalled* is as follows: rate error median = 94 CC/min (IQR 93–95), depth error median = 36 mm (IQR 35.5–36.5), CPR interruption median = 18 s (IQR 14.4–28.9). Code leaders recalled these CPR quality errors less than 75% of the time for rate (*p* = 0.06), for depth (*p* < 0.01) and for CPR interruption (*p* = 0.04). For CC data, code leaders only self-reported CPR quality errors that were documented with the quantitative CPR data (i.e., no false positive CC errors). Code leaders were asked to provide reasons for CPR interruptions, with greater than 50% of the explanations related to a pulse check, a rhythm check, and/or defibrillation attempt (Fig. 2). Code leaders correctly recalled the presence of excessive ventilation CPR quality errors in 16/17 (94%) of events, exceeding our a priori hypothesis of 75% (*p* = 0.07). Of note, the single event with a ventilation error not recalled had an overall ventilation rate of 14.2 bpm. Interestingly, for ventilation data, code leaders reported that the patient received excessive ventilation (rates greater than 10 bpm) in 5 of the 7 events where the quantitative data showed actual ventilation rates delivered <10 bpm (i.e., false positives).

4. Discussion

Using real-time acquisition of quantitative CPR quality data combined with a code leader post-event interview and questionnaire process, this investigation establishes that in-hospital code leaders frequently fail to recall CPR quality errors during the resuscitation of pediatric victims of cardiac arrest. Despite the availability of real-time continuous quantitative measures of CPR quality and a clinical environment primed to deliver high quality CPR, pediatric code leaders often failed to recall CPR quality errors in CC rate, CC depth, and CPR interruptions >10 s. Code leaders were more likely to recall ventilation rates exceeding the AHA recommended 10 bpm, but sometimes over-estimated ventilation errors.

While there were statistical differences between actual CPR quality errors and our a priori hypothesis of 75% recollection by code leaders, the clinical significance of these errors, particularly for rate and depth, is questionable. The “missed” errors for these two quality variables were not egregious (rate median was 94 (IQR 93–95)); depth median was 36 (IQR 35.5–36.5), and the clinical significance of these minor deviations is likely small. However, we have demonstrated significant non-recall of interruptions (median was 18 s (IQR 14.4–28.9)), with the lower quartile being nearly 5 s greater than that recommended by the AHA. In accordance with several previous adult studies, this magnitude of deviation from AHA recommendations (i.e., interruptions of these lengths) has been associated with worse outcomes during resuscitation.^{19–21}

In the chaotic environment of a cardiac arrest resuscitation, identification of CPR quality error is an important challenge. Out-of-hospital studies demonstrate that front line rescuers and first responders often have distortion in their retrospective assessment of time spent in the field on paramedic runs.²² Moreover, in scenario-based CPR training sessions, physician and nurse rescuers both over- and under-estimate duration of resuscitative efforts.²³ Previous observations of pediatric resident physicians have also demonstrated the gap between provider perception and performance.²⁴ In a cohort study of pediatric residents, Nadel et al. noted that only 18% of residents properly performed airway positioning, bag-valve-mask ventilation, and naso-pharyngeal airway placement; however, 100% of these pediatric residents were confident in their ability to provide bag-valve-mask ventilation.²⁴ These studies are consistent with our in-hospital findings, even in a pediatric ICU environment that is highly trained and primed to recognize and avoid CPR quality errors.

In a previous publication our investigator group reported on the quality of CPR delivered to a smaller cohort (20 events) of pediatric victims of cardiac arrest.² In this smaller cohort, we documented approximately 30% non-compliance with existing AHA recommendations for CC rate, CC depth, and CPR interruption. Similar findings are reported during adult CPR.^{4,8} Despite these reports, code leaders continue to under appreciate the occurrence of CPR quality errors. While speculative, we can offer two possible explanations for our results. First, code leaders may be hesitant to disclose their awareness of CPR quality errors for fear that they will be criticized. Second, the use of quantitative monitors of CPR quality that provide real-time feedback may lead to complacency among code leaders. Code leaders did not report any concern with their ability to see or hear the CPR monitor, making this an unlikely source of CPR error. Code leaders must be informed that despite the presence of CPR quality monitors, CPR quality errors can, and do still occur. It should be reinforced that resuscitation team members determine CPR quality, not the CPR quality monitor. In order to reduce the occurrence of CPR quality errors, resuscitation educators must develop methods for front line clinicians to review their CPR performance.^{25,26} The use of resuscitation debriefing programs can significantly improve provider confidence, compliance, process of care, and patient outcomes.^{7,13} In fact, we hypothesize that our institutional debriefing

program may in part be responsible for the reduction in CPR error that seems to have occurred since the time of our prior publication.

Excessive ventilation during CPR has been documented in both pediatric and adult victims of cardiac arrest. Animal models of cardiac arrest suggest that excessive ventilation during CPR leads to decreased survival.^{9,27,28} It is somewhat reassuring that code leaders were able to appreciate almost all instances of excessive ventilation, but unfortunately falsely identified CPR quality errors of ventilation that were not confirmed by quantitative analysis. It remains unclear why code leaders were able to recall the occurrence of excessive ventilation more sensitively, yet less specifically, than CC quality errors. It is possible that current code leader focus during a pediatric resuscitation of presumed respiratory etiology continues to prioritize rescue breathing. This approach persists despite the recent national guideline recommendations that prioritize early high quality CCs over ventilations, even for pediatric arrest victims (i.e., CAB over ABC).²⁹

This study has several limitations. First, due to practical constraints and clinical responsibilities, code leaders were not interviewed and did not complete questionnaires immediately after the resuscitation event. Instead interviews and questionnaires were completed within 24 h of each resuscitation event, introducing the possibility of *recall bias*. However, since many interviews were conducted immediately after the event, and most within 12 h, this bias is likely small. Second, at the time of data collection, clinical providers requested no link, de-identified or otherwise, to the actual resuscitation quality. Surveys were therefore completed anonymously. While it is possible that a single code leader may have completed more than one survey, the pool of possible code leaders is comprised of nearly 80 providers, making it unlikely that a single code leader completed more than three questionnaires. Third, we analyzed average CPR quality measures over the duration of an entire resuscitation event. While it is possible that this measure may not capture variation of CPR quality within an individual event, it is consistent with previous publications on CPR quality.^{3-5,7,8,11} Fourth, we lack detailed (audio or video recorded) information on the precise clinical circumstances that led to the CPR quality errors. In a typical code response, the screen displaying real time CPR quality would be directed toward the code leader. However, it is conceivable that in the crowded environment of a cardiac arrest event, this screen may be out of view of the code leader. Similarly, in the noisy environment of a code, the audio feedback prompts may not have been heard by the code leader. Code leaders may have been tailoring resuscitation therapy to more direct measures of CPR quality (e.g., invasive arterial blood pressure and end-tidal CO₂) that were not captured by the quantitative analysis on the monitor defibrillator, which may have appropriately superseded and guided the code leader to over-ride the generic standard AHA recommended rate, depth, interruption, and ventilation targets. Finally and importantly, this investigation was underpowered to assess whether code leader perception of CPR quality errors was affected by other possible confounding variables (e.g., length of resuscitation, time during resuscitation, location of event) or related to short and long-term clinical outcomes.

5. Conclusion

Despite CPR audiovisual feedback alerts during real pediatric CPR events, code leaders consistently failed to recall important CPR quality errors for CC rate <95/min, CC depth <38 mm, and CC interruptions >10 s. Code leaders reliably recalled ventilation CPR quality errors exceeding AHA recommended rates (>10/min). In the future, resuscitation programs should train code leaders to actively monitor for and correct quantitative CPR quality errors.

Abbreviations

CC	chest compression
AHA	American Heart Association
CPR	cardiopulmonary resuscitation
CWI	chest wall impedance
bpm	breaths per minute
ICU	Intensive Care Unit
ED	Emergency Department
ROSC	Return of Spontaneous Circulation
ETCO₂	end-tidal carbon dioxide

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Code Leader Post-Event Recall of CPR Quality Data Sheet

1. Was Q-CPR Technology used to monitor chest compressions?
2. Was continuous end tidal CO₂ monitoring used to monitor quality of CPR?
If yes, was an end tidal CO₂ value of >10 mm Hg achieved during chest compressions?
3. Was an arterial catheter pressure tracing used to monitor compression quality?
☐ *Not Applicable (Arterial Line not in place)*
If yes, was a diastolic blood pressure of >15 mm Hg achieved during chest compressions?
4. Were compressions interrupted (hands off period) for >10 seconds at any time?
If yes, what was the reason (indicate all that apply):
 - ☐ Pulse Check
 - ☐ Vascular Access Attempt
 - ☐ Tracheal Intubation Attempt
 - ☐ Rhythm Check
 - ☐ Defibrillation Attempt
 - ☐ Other
5. Did you perceive a compression rate of approximately 100 during each minute of CPR?
6. Did you perceive number of delivered compressions to be >80 during each minute of CPR?
7. Did you perceive the depth of compressions to be adequate?
8. Did ventilation rate exceed 10 breaths/minute? *Excluding the initial confirmation of tracheal tube placement*

Fig. 1.

Code Leader Post-Event Recall of CPR Quality Data Sheet.

Fig. 2. Code leader explanation for CPR interruption. *Other: chest tube placement (3); ECMO cannulation (1); attempt to pace (1); chest radiograph (1); change compressor (1); suction (1); respiratory adequacy check (1).

Table 1

Patient demographics, PEA-pulseless electrical activity, VT-ventricular tachycardia, VF-ventricular fibrillation, and ROSC-return of spontaneous circulation. Percentages not equal to 100% due to rounding.

Total patients, <i>n</i>	44
Mean age, yrs [SD]	14.8 [4.0]
Gender, <i>n</i> male [%]	21 [48]
Mean weight, kg [SD]	49.4 [17]
Location, <i>n</i> PICU [%]	27 [61]
Arrest rhythm, <i>n</i> [%]	
PEA/asystole	20 [45]
Bradycardia	12 [27]
VT/VF	11 [25]
Unknown	1 [2]
ROSC, <i>n</i> [%]	12 [27]