



Clinical Paper

Measuring and improving cardiopulmonary resuscitation quality inside the emergency department^{☆,☆☆}



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ABSTRACT

Aim of study: To evaluate CPR quality during cardiac resuscitation attempts in an urban emergency department (ED) and determine the influence of the combination of scenario-based training, real-time audiovisual feedback (RTAVF), and post-event debriefing on CPR quality.

Methods: CPR quality was recorded using an R Series monitor-defibrillator (ZOLL Medical) during the treatment of adult cardiac arrest patients. Phase 1 (P1; 11/01/2010–11/15/2012) was an observation period of CPR quality. Phase 2 (P2; 11/15/2012–11/08/2013) was after a 60-min psychomotor skills CPR training and included RTAVF and post-event debriefing.

Results: A total of 52 cardiac arrest patients were treated in P1 (median age 56 yrs, 63.5% male) and 49 in P2 (age 60 yrs, 83.7% male). Chest compression (CC) depth increased from 46.7 ± 3.8 mm in P1 to 61.6 ± 2.8 mm in P2 ($p < 0.001$), with the percentage of $CC \geq 51$ mm increasing from 30.6% in P1 to 87.4% in P2 ($p < 0.001$). CC release velocity increased from 314 ± 25 mm/s in P1 to 442 ± 20 mm/s in P2 ($p < 0.001$). No significant differences were identified in CC fraction (84.3% P1 vs. 88.4% P2, $p = 0.1$), CC rate (125 ± 3 cpm P1 vs. 125 ± 3 cpm P2, $p = 0.7$), or pre-shock pause (9.7 s P1 vs. 5.9 s P2, $p = 0.5$), though CC fraction and pre-shock pause were within guideline recommendations.

Conclusion: Implementation of the bundle of scenario-based training, real-time audiovisual CPR feedback, and post-event debriefing was associated with improved CPR quality and compliance with CPR guidelines in this urban teaching emergency department.

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1. Introduction

Each year, there are approximately 424,000 out-of-hospital cardiac arrests (OHCA) in the United States and 275,000 in Europe.^{1,2} There are an additional 209,000 in-hospital cardiac arrests (IHCA) in the United States alone.³ Since emergency physicians practice in the unique environment connecting prehospital and in-hospital care, they commonly perform cardiac resuscitations in both realms and must be both current with resuscitation knowledge and proficient with resuscitation skills. In its 2013 Cardiopulmonary Resuscitation (CPR) Quality Consensus Statement, the American Heart Association (AHA) recommended specific CPR quality metrics and the measurement of CPR quality during every resuscitation attempt both inside and outside the hospital.⁴ There is mounting

clinical evidence that adherence to these CPR quality metrics results in significant increases in survival and favorable neurologic function after both OHCA and IHCA.^{5–8} Unfortunately, despite regular guideline updates and significant training efforts, healthcare providers frequently perform suboptimal CPR. Chest compression (CC) rates are highly variable and of insufficient depth, and interruptions in compressions are too frequent and too long.^{9–13} Specific to the emergency department (ED) setting, Losert et al. reported better overall CPR performance in highly trained staff compared to cohorts in prior studies. With training alone, however, providers still did not achieve all of the CPR quality recommendations.¹⁴ One possible explanation for suboptimal CPR delivery is the lack of both concurrent and retrospective CPR quality monitoring and CPR performance feedback to providers.

In 2013, Bobrow et al. demonstrated that an emergency medical services (EMS) bundled approach of scenario-based training and real-time audiovisual feedback (RTAVF) was associated with a significant improvement in both CPR quality metric compliance and survival from OHCA.⁵ Edelson et al. showed increased rates of return of spontaneous circulation (ROSC) for IHCA patients when CPR quality was improved through RTAVF and performance debriefing.¹⁵ Although these studies showed novel approaches to improving CPR quality, neither was performed in the ED. The purpose of this study was to analyze the impact of a bundled approach to improving CPR quality through a combination of scenario-based training, RTAVF, and post-event debriefing in the ED setting.

2. Methods

2.1. Setting

Data were obtained from a large urban teaching ED located in Phoenix, Arizona. This ED averages 56,000 adult visits per year and is a cardiac care center with 24/7 cardiac catheterization lab capabilities. It is also a public teaching hospital with an accredited emergency medicine residency program.

2.2. Study design

This was a prospective, before-after study of consecutive adult patients who experienced cardiac arrest, either out-of-hospital or in the ED and had CPR performed in the ED. Traumatic cardiac arrests and patients under the age of 18 years were excluded from the study.

CPR quality was monitored using a Food and Drug Administration approved monitor-defibrillator (R-series; ZOLL Medical, Chelmsford, MA). The monitor provides RTAVF. The defibrillator pads incorporate accelerometer-based technology to measure CPR metrics including: CC depth, rate, fraction, release velocity and pre-shock pause. During resuscitation attempts, a numerical display on the monitor provides dynamic compression-to-compression depth and rate measurements. When compression depth falls below 51 millimeters per compression or the rate falls below 80 compressions per minute (cpm), the respective numeric display changes from a solid purple to a highlighted red and an audio prompt instructs the compressor to “push harder” or a metronome is enabled at 100 cpm. To remind the compressor to allow complete chest recoil, the words “fully release” intermittently appear on the display. When adequate compression depth and rate are consistently achieved, a diamond icon on the display, the perfusion performance indicator, slowly fills in to represent the perfusion pressure. When compression depth or rate is inadequate, or compressions are stopped, the perfusion performance indicator begins to slowly empty. Additionally, when compressions stop for 10s,

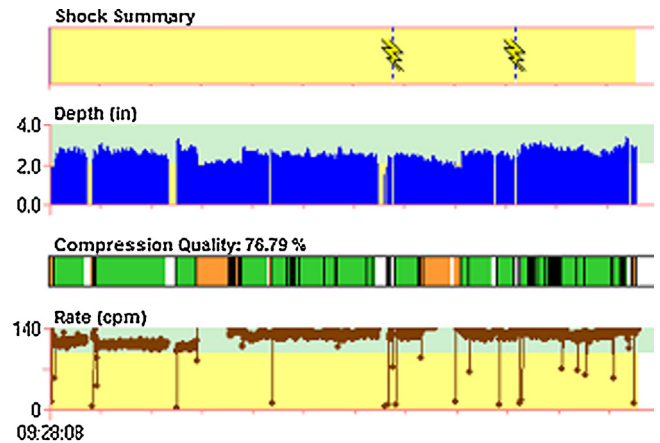


Fig. 1. Code review software graphic used for data analysis and post-event debriefing.

the visual display starts a timer to alert the resuscitation team to the amount of time passed since the last compression. The timer disappears when compressions resume.

During phase 1 (P1; 11/01/2010–11/15/2012), RTAVF features on the monitor were intentionally disabled to obtain baseline CPR quality data. On the day Phase 2 (P2; 11/15/2012–11/08/2013) was implemented, clinicians, including attending physicians, residents, and nursing staff, underwent a 60 min didactic/psychomotor skill CPR training. This included several cardiac arrest scenarios emphasizing high-quality CPR and the optimal utilization of RTAVF. For those unable to attend the initial training session, focused training was provided to ensure all medical personnel were familiar with proper application and utilization of the study monitor-defibrillator. During P2, RTAVF was enabled and providers were given an in-person debriefing session immediately following resuscitation events. If an immediate post-event debriefing session was not feasible, the session was conducted within 5 days. Debriefing sessions were conducted with all available participants of the event in a group setting, but occasionally on an individual basis in order to debrief as many of the participants as possible. Details of the resuscitation, including specific CPR quality data and opportunities for improvement, were discussed during the debriefing sessions in a free-form format that encouraged open dialog among members of the resuscitation team. Visual CPR metric data were created using Code Review (ZOLL Medical, Chelmsford, MA) software as shown in Fig. 1. This study was part of the Arizona Department of Health Services sanctioned statewide cardiac resuscitation quality improvement program, which is HIPAA exempt, and was also approved by the Maricopa Integrated Health Services Institutional Review Board.

2.3. Data collection and processing

Research staff downloaded defibrillator data to a memory card and subsequently to a password protected secured hard drive on a daily basis. The monitor automatically time stamped each individual resuscitation event allowing code files to be linked to patient EMS and hospital care reports by matching the time stamp of each CPR data file with the ED arrival date and time. Most cardiac arrest patients were readily identified by staff for submission to the statewide Save Hearts in Arizona Registry and Education (SHARE) OHCA database. Additionally, patients were identified by providers who submitted the patient medical record number and date of service to the investigators for review. Information from the nursing resuscitation flow sheets was used to annotate the code

files (e.g. to identify periods when a patient obtained ROSC which is required to determine the CC fraction).

2.4. Statistical analysis

Summary data are presented as medians with interquartile range for continuous data or as percentages with 95% confidence intervals (CIs) for categorical data. Fisher's exact test and the Kruskal–Wallis test were used for univariate comparisons between P1 and P2 for categorical and continuous data, respectively. To quantify the difference for the various CPR quality metrics from P1 to P2, we used either linear regression for continuous data with normally distributed residuals or median regression for continuous data that did not meet the assumptions of linear regression. Differences are reported as mean or median differences, along with 95% CIs and IQRs respectively. We included several potential confounders or risk factors in our regression analyses if they were either significantly associated with the outcomes ($p \leq 0.05$) or they were judged significant confounders by changing the coefficients for P1 vs. P2 by 10% or more compared to the model without them. For linear regression we ran model diagnostics to check for non-linear residuals and the presence of heteroscedasticity. For median regression we used robust standard errors. All analyses were performed using Stata v12.1 (Stata Corp LP, College Station, TX).

3. Results

There were a total of 166 (76 P1, 90 P2) resuscitation attempts during the study period. In P1 there were 61 adult non-traumatic cardiac arrest cases of which 6 were excluded for insufficient CPR quality data and 3 were excluded due to missing patient data. The remaining 52 cases were included in P1 (Fig. 2). In P2, there were 54 adult non-traumatic cardiac arrest cases of which 5 were excluded for missing CPR data, leaving 49 cases for analysis. Patient characteristics of the 101 cases included for analysis are presented in Table 1, along with univariate comparisons between study periods. Initial presenting rhythm, as documented by EMS in OHCA and by the ED in ED cardiac arrests, was asystole in 33 patients (32%), pulseless electrical activity in 22 patients (22%), and ventricular fibrillation/ventricular tachycardia in 18 patients (18%). Initial rhythm was not documented in 22 (22%) cases and was documented as “other” in 6 (6%) cases. The suspected etiology of cardiac arrest was cardiac in 78 cases (77%), respiratory in 9 cases (9%), drug overdose in 7 cases (7%), and gastrointestinal bleed in 1 case (1%). There was no documented suspected etiology in 6 cases (6%). There were no differences in rates of ROSC or survival to hospital discharge between P1 and P2, though the study was not powered to detect significant differences in outcomes between the two groups.

CPR quality data are presented in Table 2. CC depth significantly increased from 46.7 ± 3.8 mm in P1 to 61.6 ± 2.8 mm in P2

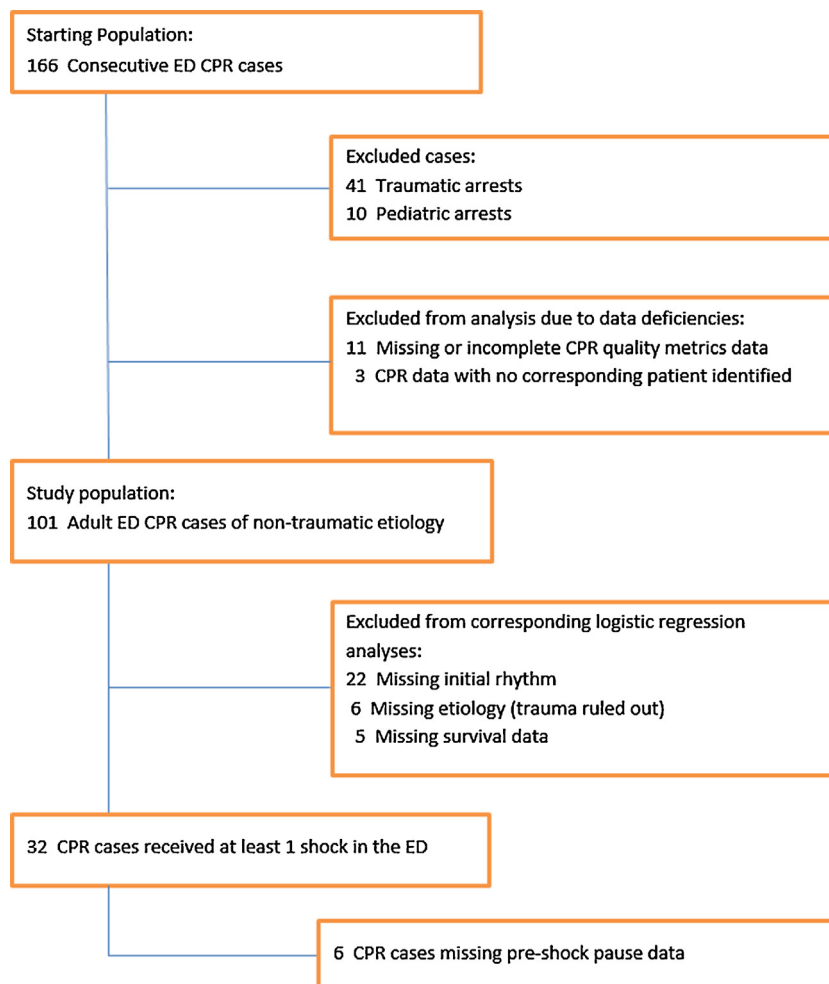


Fig. 2. Study population inclusion/exclusion flow chart.

Table 1
Population characteristics by study period (P1 vs. P2).

Characteristic	Overall	P1	P2	p-value
Total, no. (%)	101 (100)	52 (51.5)	49 (48.5)	
Age – years, median (IQR)	58 (45–70)	56 (47–72)	60 (45–68)	0.58
Male sex, no. (%)	74 (73.3)	33 (63.5)	41 (83.7)	0.03
Initial rhythm, no. (%)				0.84
Asystole	33 (41.8)	16 (42.1)	17 (41.5)	
PEA	22 (27.9)	10 (26.3)	12 (29.3)	
VF/VT	18 (22.8)	8 (21.1)	10 (24.4)	
Other	6 (7.6)	4 (10.5)	2 (4.9)	
Missing, no.	22	14	8	
Presumed etiology, no. (%)				0.43
Cardiac	78 (82.1)	44 (86.3)	34 (77.3)	
Overdose	7 (1.1)	4 (7.8)	3 (6.8)	
Respiratory	9 (7.4)	3 (5.9)	6 (13.6)	
GI Bleed	1 (9.5)	0 (0.0)	1 (2.3)	
Missing, no.	6	1	5	
Defibrillated, no. (%)	32 (31.7)	18 (34.6)	14 (28.6)	0.53
ROSC, no. (%)	42 (41.6)	20 (38.5)	22 (44.9)	0.55
Hospital outcome, no. (%)				0.42
Survived to hospital DC	6 (6.3)	2 (4.0)	4 (8.7)	
Died before hospital DC	90 (93.8)	48 (96.0)	42 (91.3)	
Missing, no.	5	2	3	

Abbreviations: IQR, interquartile range; PEA, pulseless electrical activity; VF, ventricular fibrillation; VT, ventricular tachycardia; GI, gastrointestinal; ROSC, return of spontaneous circulation; DC, discharge.

($p < 0.001$), with the percentage of $CC \geq 51$ mm increasing from 30.6% in P1 to 87.4% in P2 ($p < 0.001$). CC release velocity (CCRV) significantly increased from 314 ± 25 mm/s in P1 to 442 ± 20 mm/s in P2 ($p < 0.001$). No significant differences were identified in CC fraction (84.3% P1 vs. 88.4% P2, $p = 0.1$), CC rate (125 ± 3 cpm P1 vs. 125 ± 3 cpm P2, $p = 0.7$), or pre-shock pause (9.7 s P1 vs. 5.9 s P2, $p = 0.5$).

4. Discussion

The objective of CPR is to generate forward blood flow in order to reestablish and maintain adequate coronary and cerebral perfusion pressures until spontaneous circulation is achieved.¹⁶ High-quality CPR results in higher coronary perfusion pressures and is associated with improved survival and neurologic outcomes.^{5–8,17} Currently, the metrics defining high-quality CPR include CC fraction of at least 80%, CC depth at least 51 mm, CC rate between 100 and 120 cpm, allowing complete chest recoil, and ventilation rate less than 12 min^{-1} with tidal volume just to see the chest rise.⁴ Although CPR quality is closely linked to outcomes, healthcare providers generally perform suboptimal quality CPR and few routinely measure CPR performance.^{5,9–12,18,19} The quality of CPR has also been shown to decline after care is transferred from prehospital personnel to ED providers during an ongoing resuscitation.²⁰ We found that during the pre-intervention phase, CC depth and rate did not meet published metrics. The European Resuscitation Council (ERC) suggests

that CPR feedback devices can assist rescuers in achieving high-quality CPR targets.²¹ Several previous studies have evaluated CPR quality after incorporating some combination of training, RTAVF and debriefing, but none were investigated in the ED, a unique setting linking EMS and in-hospital care.^{5,15,19,22–24} These studies showed closer adherence to CPR quality metrics in both the prehospital and in-hospital settings after implementing their interventions designed to improved CPR quality.^{5,15,22–24}

With the recent AHA consensus statement calling for routine CPR monitoring and continuous quality improvement for all resuscitation attempts, it is important to identify effective strategies to operationalize the CPR quality improvement process.⁴ There is a growing gap between the science of cardiac resuscitation and the care delivered during resuscitation attempts.⁴ In order to maximize survival and neurologic outcomes, it is imperative that healthcare providers understand both the cognitive aspects of high-quality CPR and the psychomotor skills and team dynamics required to provide this therapy to cardiac arrest patients. The central purpose of this study was achieved in measuring and improving the CPR quality delivered inside this urban teaching ED.

The CPR metric of chest compression depth has been linked to coronary and cerebral perfusion, and survival from cardiac arrest.^{6,24,25} Edelson et al. demonstrated increased defibrillation success with deeper chest compressions and Vadeboncoeur et al. showed that chest compressions greater than 51 mm were linked to improved survival and neurologic outcomes after OHCA.^{6,25} Clinical studies suggest that the majority of compressions provided during prehospital resuscitations do not meet guideline recommendations for depth.^{13,19} In our analysis, mean CC depth increased significantly from 46.7 ± 3.8 mm to 61.6 ± 2.8 mm between P1 and P2, and the number of compressions meeting the AHA guideline recommendation of at least 51 mm increased substantially from 30.6% to 87.4%.

Inadequate chest recoil critically hinders coronary and cerebral perfusion pressures in animal studies.^{26,27} Additionally, two human studies have implicated incomplete chest wall recoil as negatively impacting hemodynamics, but were not performed on cardiac arrest patients.^{28,29} The available cardiac arrest literature describes a lack of chest wall recoil during resuscitation from both OHCA and IHCA.^{19,30–32} CCRV measures the maximum velocity of the compression upstroke.³³ In this study, CCRV increased significantly from P1 to P2 (314 ± 25 mm/s in P1 to 442 ± 20 mm/s in P2; $p < 0.001$). Importantly, CCRV and complete chest recoil are not synonymous. CCRV measures the velocity of decompression rather than the completeness of decompression. Theoretically, achieving faster chest recoil would augment the negative intrathoracic suction and thus improve venous return to the heart.³⁴ Although complete chest recoil is a recommended goal in CPR, specific CCRV targets have not yet been defined. Based on the available literature it is likely that faster CCRV is desirable. Further investigation into CCRV and its effect on outcomes is needed.

Table 2
CPR quality metrics by study period (P1 vs. P2).

CPR metrics	Phase 1	Phase 2	Difference, P1 to P2 (95% CI)	p-value
Mean CC Depth – mm, mean (95% CI) ^{†,***}	46.7 (42.9, 50.5)	61.6 (58.7, 64.4)	14.2 (9.4, 19.1)	<0.001
Percent of CCs ≥ 51 mm, median (95% CI) ^{***}	30.6 (18.3, 42.9)	87.4 (74.6, 100.1)	56.7 (39.0, 74.4)	<0.001
Mean CCRV (mm/s), mean (95% CI) ^{†,***}	314 (289, 338)	442 (422, 462)	129 (97, 160)	<0.001
CC Fraction – %, median (95% CI) ^{***}	84.3 (80.8, 87.7)	88.4 (84.8, 91.9)	4.1 (–0.9, 9.1)	0.1
Mean CC rate – CCs/min., mean (95% CI) [†]	125 (122, 128)	125 (122, 127)	–1 (–6, 4) ^{****}	0.65
Pre-shock pause – sec., median (95% CI) ^{***}	9.7 (3.0, 16.3)	5.9 (0, 13.9)	–3.8 (–14.2, 6.7)	0.5

Abbreviations: CC, chest compression; CCRV, chest compression release velocity; CI, confidence interval; CPR, cardiopulmonary resuscitation; IQR, interquartile range; P1, phase 1; P2, phase 2; min., minute; mm, millimeters; sec., seconds.

[†] Linear regression.

^{***} Adjusted for age.

^{****} Median regression.

^{*****} Difference due to rounding.

Although our intervention was associated with significant improvements in two critical CPR metrics, not all CPR metrics improved. Specifically the CC rate, fraction and the pre-shock pause were unchanged in our study. Compressions were performed at an average rate of 125 cpm in both phases. While the optimal compression rate remains unknown, 125 falls outside of the AHA recommended 100–120 cpm.⁴ Idris et al. has shown that ROSC rates peaked at 125 cpm and then rapidly decreased at higher rates.³⁵ One explanation for our excessive compression rates is that the majority of our study was performed under the AHA/ERC 2010 Guidelines' recommended rate of greater than 100 cpm.^{21,36} Maintaining a rate under 120 was not an established metric in P1 and a rate ceiling of 120 cpm was not introduced until late in P2. Additionally, while the study monitor-defibrillator enabled a metronome when CC rates fell below 100 cpm, there was no upper limit of CC rate that would induce the defibrillator to prompt the compressor to slow down. This highlights the need for technologies to be continuously updated to match current recommendations.

Christenson et al. determined that CC fraction is an independent predictor of survival from OHCA with an initial rhythm of ventricular fibrillation or ventricular tachycardia.⁸ The importance of CC fraction is further described by Berg et al. showing decreased coronary perfusion pressure with frequent CC interruptions.¹⁶ Although our baseline CC fraction of 84.3% met recommendations (CC fraction target >80%), there was a small increase to 88.4% in P2 which was not statistically significant.

Median pre-shock pause duration in our study was 9.7 s (IQR 4.9–18.8) in P1 and 5.9 s (IQR 3.0–13.0) in P2 ($p=0.5$). While there was not a statistical improvement from P1 to P2, the pre-shock pause for P1 was already less than the recommended 10 s. Although a timer on the defibrillator appears when compressions are stopped, it is not visible until 10 s after the last compression, making it ineffective in helping to achieve a pre-shock pause of less than 10 s. It may be worth investigating successful strategies for further decreasing the pre-shock pause such as filtered rhythm analysis and charging during compressions.^{7,25}

While we are unable to determine the relative impact of each aspect of our CPR quality bundle, the authors believe that the comprehensive approach is necessary. From our experience, the initial training is critical to team dynamics and the optimal utilization of RTAVF. Debriefing sessions provide an opportunity to learn from deficiencies and act as training refreshers.

4.1. Limitations

There were several limitations of this study. It was necessary to eliminate 11 study participants because event data was not captured during the resuscitations. However, we have no reason to believe these patients differed significantly from our study subjects. Ventilation rate and tidal volume were not measured in this analysis. While the current recommendations for ventilation rate less than 12 breaths/min and tidal volume enough to see chest rise were part of the training, we did not have RTAVF or debriefing on ventilation.

Additional study limitations include being a single-center, non-randomized, non-blinded, study. We acknowledge the Hawthorne effect may be, in part, responsible for our results. However, ED providers knew their CPR was being measured in both P1 and P2. There were also variations in the level of training and proficiency of individual providers which we did not account for and may have affected our results. This study was underpowered to assess for outcomes such as survival to discharge and neurologic function of survivors.

4.2. Future study

Areas of potential future investigation include studies powered to determine the impact of improved ED CPR quality on survival and neurologic outcomes. Future studies could also include a feedback component for the upper limit of recommended CC rate and technologies or techniques designed to impact the pre-shock pause. Additionally, studies that include ventilation rate and tidal volume monitoring with corresponding feedback to keep ventilations rates below 12 breaths per minute and tidal volumes to minimal chest rise would be worth pursuing for evaluation of comprehensive CPR performance.

We used RTAVF devices to improve ED CPR quality in our study. An alternative approach may be the use of mechanical CPR devices, particularly for prolonged resuscitation attempts. However, even with this approach, high-quality manual CPR is necessary prior to the application of a mechanical device.

5. Conclusions

We found that implementation of a CPR quality bundle of care including scenario-based training, real-time audiovisual feedback, and post-event debriefing was associated with improvements in CPR quality in a large urban teaching emergency department during adult cardiac resuscitations.

Conflicts of interest statement

Annemarie Silver, PhD, is an employee of Zoll Medical Corporation. Drs. Bobrow and Spaite disclose that the University of Arizona receives support from the Medtronic Foundation involving community-based translation of resuscitation science.

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