

Does Accelerometer Use Lead to Higher Quality CPR for Advanced Cardiac Life Support Providers? A Prospective Randomized Study

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Abstract

Aim: High-quality cardiopulmonary resuscitation (CPR) is the cornerstone to improved outcomes for patients with cardiac arrest. The aim of this prospective randomized study was to evaluate whether audio-visual feedback use affects the critical components of high-quality CPR compared with CPR without feedback.

Materials and Methods: One hundred in-hospital Advanced Cardiac Life Support (ACLS) providers volunteered as participants. Participants were tested on a high-fidelity manikin in a simulated cardiac arrest scenario performing 2 min of single-rescuer CPR. The control group completed the scenario with conventional CPR, whereas the intervention group adjusted CPR as instructed by the Philips MRx accelerometer. The primary outcome was mean compression rate, whereas the secondary outcomes included percent appropriate compression rate, mean compression depth, percent appropriate compression depth, percent complete chest recoil, percent chest compression fraction (CCF%), mean ventilations per minute.

Results: The intervention arm had a higher median percent of compressions with an appropriate rate (between 100 and 120 min⁻¹, 92.5% vs. 46.0%; p<0.001) and CCF% (mean 68.9% vs. 66.9%; p=0.029). Twenty percent of the control arm had zero chest compressions within the American Heart Association-recommended compression rate range. The intervention arm also had a significantly lower mean compression rate (110.3 min⁻¹ vs. 117.3 min⁻¹; p=0.004). A trend toward decreased compression depth with the intervention group was found (44.2 mm vs. 47.5 mm; p=0.062).

Conclusion: In-hospital cardiac arrest providers provided a slower but more appropriate compression rate and a higher CCF% using the Philips MRx accelerometer than providers without the device. The intervention group trended toward a decreased compression depth.

Keywords: Adult cardiac arrest, CPR feedback, high quality CPR

Introduction

Despite dramatic advances in resuscitative medicine, survival rates for adult cardiac arrest remain poor ranging from 6% to 24% (1). One of the keys to improved survival rates is prompt and high-quality cardiopulmonary resuscitation (CPR). Despite the importance of CPR, studies continue to demonstrate low-quality CPR by properly trained healthcare providers (2-4). When CPR is delivered exactly as recommended by the American Heart Association (AHA) guidelines, it is still inherently inefficient with only 20% of normal blood flow to the heart and at best 30%-40% of normal blood flow to the brain (5-8).

Prior observational studies have helped define high-quality CPR (HQ-CPR) by identifying five critical components of CPR associated with improved survival rates. These components include minimizing

interruptions in chest compressions, compression rates between 100 and 120 compressions min⁻¹, compression depth of 2-2.4 in., complete chest recoil, and appropriate ventilation rate and volume (3, 9). However, monitoring of these parameters remains inconsistent and is often completely absent, prohibiting real-time opportunities for improvements in CPR quality and possibly survival rates. With the advent of audio-visual feedback devices and high-fidelity training manikins, it is now possible to measure CPR parameters during active resuscitations and training simulation scenarios. Although small out-of-hospital studies have demonstrated improved performance with regard to chest compression rate and depth through the use of audio-visual feedback devices (10-13), other studies have demonstrated a possible overestimation of chest compression depth with these devices (14-17). The potential benefit of real-time feedback during CPR remains unclear, and less work has been done to evaluate such



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methods among cardiac arrest resuscitations in the emergency department (ED).

In this prospective study, we randomized providers to provide conventional provider-driven CPR or CPR guided by an audio-visual feedback accelerometer to determine if there is a difference in the quality of the five critical components of CPR (chest compression depth, chest compression rate, chest recoil, excessive ventilation, and percent chest compression fraction (CCF%)) when applied in simulated cardiac arrest with in-hospital providers in the ED.

Materials and Methods

Study design and randomization

This randomized controlled trial was conducted in the ED at a single academic institution between March 2015 and November 2015. One hundred AHA Advanced Cardiac Life Support (ACLS)-certified providers were enrolled in the study. All providers were current ED employees who volunteered. Written consent was obtained to participate in the study. Providers were randomized to either the control group or the intervention group. Using a random number generator, each participant was assigned a private, random number between 1 and 1000. Participants were assigned to the control group if they have an odd number and to the intervention group if even number. The control group was defined as CPR performed according to the provider's best practices, and the intervention group was defined as audio-visual feedback-guided CPR. Participants were not compensated for study participation. This study was granted approval by the IRB and Ethics committee at the institution prior to enrolling participants (Approval Date 8/8/14; Approval No.: IRB00010880).

Equipment

A Resusci Anne QCPR AED Airway manikin with SimPad technology (Laerdal Medical, Memphis, TN, USA) weighing 60 kg was used during all simulations. The SimPad BLS learner (Laerdal Medical) functioning in the assessment mode was used during the study. The 2010 and 2015 AHA guidelines were used as comparison settings for baseline metrics. The SimPad technology automatically recorded and stored both the primary and the secondary outcomes of interest, including chest compression rate, percentage of appropriate chest compression rate, chest compression depth, percentage of appropriate chest compression depth, percentage of complete chest recoil, ventilation volume, ventilations per minute, and CCF%. Data were downloaded to a secure, password protected Excel spreadsheet only accessible by the primary investigator.

A Philips MRx portable monitor defibrillator (Philips, Andover, MA, USA) with Q-CPR capability was used for each simulation. The Symbio CS1201 Simulator (Symbio Corporation, Beaverton, OR, USA) was used as a rhythm generator, and asystole was the rhythm provided for each simulation. For the intervention group, the Philips Q-CPR accelerometer (Laerdal Medical, Stavanger, Norway) was used to provide audio-visual feedback during simulated CPR. This feedback device provides audio and visual cues informing the rescuer of appropriate chest compression rate and depth, complete chest recoil, and audio cues at 10-second intervals when chest compressions are not being performed. This device was selected as this is the monitor-defibrillator deployed during all resuscitations at the study site.

Experiments

After randomization, each participant underwent 2 min of single-rescuer-simulated cardiac arrest resuscitation. The single-rescuer scenario was selected as this is often the setting during the initial phases of a cardiac arrest event. This scenario also better illustrates the integration of both the cardiac and the pulmonary components of resuscitation. Participants in the control arm were instructed to perform the AHA ACLS single-rescuer resuscitation comprised cycles of 30 chest compressions to 2 ventilations. All participants were allowed 1 min to familiarize themselves with the manikin, including practice compressions and ventilations before the 2-minute scenario started. Participants were allowed to modify the resuscitation environment prior to beginning by using a stool, changing the height of the bed, or using gloves based on their preference. A standard chest compression backboard was used for each simulation. Ventilations were provided using a standard bag-valve mask (Ambu SPUR II) without an oral or nasal airway adjunct. During the 2-minute simulation scenarios, participants were encouraged not to change any of the resuscitation environments and to focus on maintaining the 30:2 ratio for each cycle of CPR. A research assistant started, stopped, and timed each scenario, and the SimPad technology assessment mode automatically stopped collecting data at the end of the 2-minute period. At the completion of the 2-minute scenario, outcome data were downloaded from the SimPad to the Excel data set, and demographic information was collected from each participant.

The intervention arm underwent the same simulated cardiac arrest scenario as the control group with the addition of the audio-visual feedback accelerometer. Participants in the intervention arm were provided with a short voiceover PowerPoint presentation prior to the simulation explaining the appropriate placement and appropriate use of the feedback accelerometer. They were specifically instructed to adjust their resuscitation metrics based on feedback provided by the accelerometer.

Statistical analysis

A previous study found that the use of the device improved correct chest compression depth from 45% to 73% of the participants, and a power calculation based on this found that a sample size of 45 subjects in each group would result in 80% power to find a difference at a 5% two-tailed significance level (10). Based on this estimation, 50 participants were enrolled in each group.

Participant demographic characteristics included current medical position (nurse, resident physician, physician, student, and emergency medicine technician), date of the most recent ACLS training, and previous experience with a CPR feedback device. Participant characteristics were compared between the control and the intervention groups using the chi-square or Fisher's exact tests where appropriate to determine whether or not randomization was successful at balancing the potential confounders between the groups. The quality of CPR metrics included average compression rate, compression depth (mm), ventilation volume (mL) and ventilation rate, participant percentage of appropriate (as defined by the 2010 and 2015 AHA guidelines) compression rate, compression depth, complete chest recoil, and CCF%. The median values were used for comparison of non-normally distributed continuous variables.

The quality of CPR measures was plotted using box-and-whisker plots and compared between the control and the intervention groups using t-tests or Wilcoxon two-sample tests where appropriate. We used the chi-square and Fisher's exact tests for comparison of categorical measures. All statistical analyzes were made using SAS 9.4 (SAS Institute Inc., Cary, NC, USA). All reported p-values are two-sided. A $p < 0.05$ was considered statistically significant.

Results

A total of 100 trial participants, with 50 randomized to standard CPR and 50 randomized to feedback-guided CPR, were included in the study. Participants were predominantly nurses, and the majority

had received ACLS training within the last year. The majority of the participants (60%) had prior experience with a CPR feedback device (Table 1). There were no differences between the control and the intervention groups with regard to their position, most recent ACLS training, or previous experience with a CPR feedback device; thus, all outcome analyzes were performed via bivariate, two-sample tests.

Participants performing CPR with the feedback device had a statistically significantly higher median percent of compressions with an appropriate rate (between 100 and 120 min^{-1} , 92.5% vs. 46.0%; $p < 0.001$) and a statistically significantly lower mean compression rate (110.3 min^{-1} vs. 117.3 min^{-1} ; $p = 0.004$) than participants not using the device. Of note, 20% of the control arm had zero chest compressions within the guideline-recommended chest compression rate range, all with a mean rate exceeding the currently recommended upper rate. Participants in the intervention arm also had significantly higher mean CCF% (68.9% vs. 66.9%; $p = 0.029$) than participants without the feedback device (Table 2, Figure 1).

There was a trend ($p < 0.1$) for participants using the accelerometer to have a lower average compression depth (44.2 mm vs. 47.5 mm; $p = 0.062$) and lower median percent of compressions with appropriate depth (34.0% vs. 86.5%; $p = 0.065$) than participants not using the device (Table 2, Figure 1).

There was no difference found between the intervention and the control groups with regard to percent appropriate recoil (99% vs. 99%; $p = 0.3$), average ventilation volume (510 mL vs. 486 mL; $p = 0.3$), or average ventilation rate (4.1 min^{-1} vs. 4.2 min^{-1} ; $p = 0.5$).

Discussion

With well-established evidence of the importance of HQ-CPR leading to improved outcomes in adult cardiac arrest, methods to continually measure and monitor CPR metrics in real time are of great value. According to the 2015 AHA guidelines, the definition for HQ-CPR has expanded to include upper limits for both compression rate (120 min^{-1}) and compression depth (60 mm) (9). These changes further emphasize

Table 1. Baseline characteristics of the study participants

| Participant Characteristics | Control (n=50) | Intervention (n=50) | p |
|---|----------------|---------------------|-------|
| Medical provider type, n (%) | | | |
| Physician | 7 (14) | 9 (18) | 0.191 |
| Nurse | 27 (54) | 27 (54) | |
| Resident physician | 13 (26) | 6 (12) | |
| EMT | 3 (6) | 5 (10) | |
| Student | 0 (0) | 3 (6) | |
| Last ACLS training, n (%) | | | |
| <1 year | 30 (60) | 31 (62) | 0.838 |
| 1-2 years | 20 (40) | 19 (38) | |
| >2 years | 0 (0) | 0 (0) | |
| Previous CPR feedback device experience, n (%) | 30 (60) | 30 (60) | 1.000 |
| ACLS: advanced cardiac life support; CPR: cardiopulmonary resuscitation | | | |

Table 2. Quality of CPR metrics

| Quality of CPR Measures | Control (n=50) | Intervention (n=50) | p |
|--|-------------------|---------------------|--------|
| Average compression rate (compressions min^{-1}), mean (SD) | 117.3 (15.0) | 110.3 (6.2) | 0.004 |
| Percent appropriate compression rate, median (IQR) | 46.0 (2.0-85.0) | 92.5 (80.0-99.0) | <0.001 |
| Average compression depth (mm), mean (SD) | 47.5 (10.0) | 44.2 (7.1) | 0.062 |
| Percent appropriate compression depth, median (IQR) | 86.5 (8.0-100.0) | 34.0 (1.0-98.0) | 0.065 |
| Percent appropriate recoil, median (IQR) | 99.0 (86.0-100.0) | 99.0 (92.0-100.0) | 0.341 |
| Average ventilation volume (mL), mean (SD) | 510.2 (118.9) | 486.4 (132.4) | 0.348 |
| Average ventilation rate (ventilations min^{-1}), mean (SD) | 4.2 (1.1) | 4.1 (1.0) | 0.569 |
| CCF%, mean (SD) | 66.9 (4.7) | 68.9 (4.3) | 0.029 |
| Tests used: t-tests for unequal variances for average compression rate and depth; t-tests for equal variances for average ventilation volume, ventilation rate, and CCF%; Wilcoxon two-sample test for percent appropriate compression rate, percent appropriate compression depth, and percent appropriate recoil; SD: standard deviation; IQR: interquartile range; CPR: cardiopulmonary resuscitation | | | |

the importance of using real-time CPR feedback mechanisms to help guide CPR metrics, as it can be very challenging to determine the appropriate compression rate and compression depth in real time.

In the present study, we observed an overall slower chest compression rate with a statistically higher percentage of compressions within the

appropriate range when an audio-visual feedback device was used to guide CPR. In the control arm, <50% of all the chest compressions were delivered at an appropriate rate, the majority of which were at rates exceeding the AHA upper limit recommendation of 120 compressions min^{-1} . Furthermore, we found that 20% of the participants in the control arm were never within the AHA-recommended compression range at

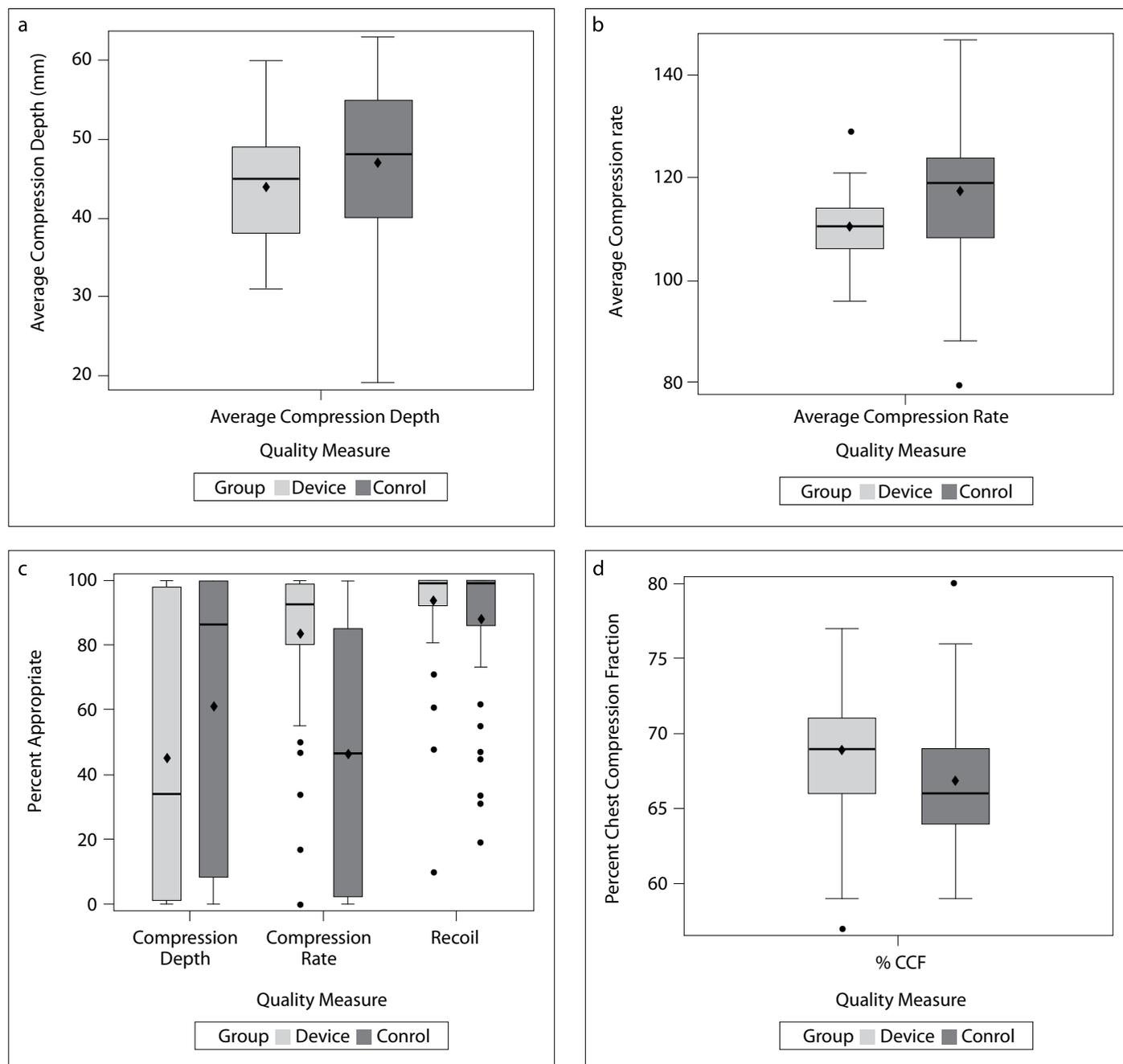


Figure 1. a-d. Boxplot CPR metrics for best practice-driven CPR and audio-visual-driven CPR in simulated in-hospital cardiac arrest. Average compression depth (a), average compression rate (b), appropriate percentage depth, rate, and recoil (c), and chest compression fraction percent (d)

- Box Limits indicate the intra-quartile range (IQR; 25th and 75th percentiles)
- Box Line represents the median
- ◆ Black Diamonds indicate the means
- I Upper and lower fences indicate the highest and lowest values that are not outliers
- Outliers indicated by filled dots, and are values that are greater than 1.5 times the IQR.

any point during their simulation scenario. This finding supports the need for real-time guidance and feedback during CPR to achieve the recommended CPR rate metrics. Idris et al. (18) reported that return of spontaneous circulation rates peak with a compression rate of 125 min^{-1} but then decline at rates greater than this, suggesting that faster may not be better. Faster compression rates have been associated with inadequate compression depth, inappropriate chest recoil, decreased cardiac preload, and possibly increased rescuer fatigue, all of which compromise cardiac output. Our findings demonstrate that the use of a feedback accelerometer may be helpful in achieving a much greater percentage of compressions within the recommended rate range.

The CCF% was also statistically higher when CPR was guided by the accelerometer. While the device studied does not provide continuous audio or visual feedback on CCF%, it does prompt the provider if 10 s lapses without signs of chest compressions. This is important since time can be difficult to track during resuscitation. Additionally, our simulation scenario only examined one 2-minute period of resuscitation, and it is possible that in longer arrests, the use of the audio-visual device could be associated with even greater improvements in CCF%. Despite the improved CCF% in the feedback arm, both the control arm (66.9%) and the feedback arm (68.9%) performance measures were below the AHA-recommended CCF% of 80% (3). The single-rescuer model in our study design likely contributed to the observed lower CCF% given that the provider had to change positions to provide rescue breaths; however, this is often the case during the initial phases of a cardiac arrest event. Prior studies have shown that providers can take up to 16 s to deliver two ventilations (19). This further emphasizes the importance of team dynamics and care coordination to maximize this clinically important metric of CPR when multiple rescuers are present and possibly suggests a lower goal of CCF% as a reasonable achievable metric for single-rescuer resuscitations.

Despite improved chest compression rate and CCF% with the use of the accelerometer feedback device, we observed a trend toward lower compression depth in the intervention arm than in the control group. This finding is consistent with findings from prior studies suggesting that the accelerometer device may overestimate chest compression depth when chest compressions are performed on a soft surface, such as a mattress, even with the use of a CPR backboard, as was done in our study (14-17). While our finding was not statistically significant and only a trend, it does suggest that future investigations should focus on strategies to accurately detect chest compression depth, particularly with a narrower recommendation window of a depth between 50 and 60 mm (9). Oh et al. (15) described a dual accelerometer method that was better at detecting true sternal-spine compression depth. Perkins et al. (20) have published on the development of a "smart backboard," a novel device that helps subtract mattress compression for improved accuracy of feedback information with regard to depth. An anterior-posterior approach in determining chest compression depth, as demonstrated in both of these techniques, could also lead to a more patient-specific appropriate compression depth, such as $>1/3$ of the anterior-posterior chest diameter instead of the "one-size-fits-all" recommendation of 50-60 mm for all patients regardless of body habitus. While the 2015 AHA guidelines do define an upper

limit for chest compression depth to help avoid injury (21), most studies, including ours, continue to demonstrate that compressions are more often too shallow rather than too deep (9, 22). Future studies searching for novel ways to overcome the overestimation of compression depth and other limitations of currently available CPR feedback devices are needed to continue to improve CPR metrics. Resuscitation leaders should be aware of these limitations when using feedback devices and should take corrective steps, such as ensuring the use of a backboard, to help improve compression depth measurement. Education platforms, such as ACLS training programs, should also take into account these device limitations when teaching resuscitation science to healthcare providers.

Study limitations

Our study has several limitations. While this was a prospective randomized study, it was performed at a single academic institution and only evaluated a single-rescuer model. It is possible that we would have detected greater difference in certain CPR metrics if we were to evaluate a two-rescuer model that did not require the CPR provider to transition from the chest compression position to the airway. While our sample size was sufficient to detect statistical differences in compression rate and CCF%, with a larger sample size, there may have been detectable differences in other metrics, including chest compression depth. CPR performance metrics may have also been different with a longer resuscitation scenario as opposed to the 2-minute scenario in the present study. Additionally, we only looked at one audio-visual feedback device; therefore, the present study is not generalizable to other feedback devices that are available and used in other EDs. In the present study, we sought to only evaluate selected CPR metrics that could be measured directly from the manikin and, thus, the choice of an asystole scenario during the simulation. Other contributing factors to CPR quality, such as pre-shock and post-shock pauses, were not assessed in the present study but are also important measures of CPR quality. As the majority of providers in the present study were emergency medicine nurses, these results may not be generalizable to other provider populations, such as physicians or emergency medicine technicians. The providers in our study were also all volunteers, which can introduce volunteer bias with an inherent difference in providers who choose to participate in the present study compared with those who did not. Finally, in this scenario, the patient did not have an advanced airway, and the placement of an advanced airway may affect ventilation volumes, as well as chest compression quality.

Conclusion

For ED-based cardiac arrest resuscitation, providers provided a slower but more appropriate chest compression rate with a higher CCF% when using the Philips MRx audio-visual accelerometer to guide CPR than providers not using this device. The audio-visual feedback device, however, trended toward a lower chest compression depth in this same provider population. There was no difference detected in the other critical components of CPR, including appropriate chest recoil and ventilation rate and volume.

Ethics Committee Approval: Ethics committee approval was received for this study from the Ethics Committee of Oregon Health and Science University (Approval Date 8/8/14; Approval No.: IRB00010880).

Informed Consent: Written informed consent was obtained from patients who participated in this study.

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References

- Mozaffarian D, Benjamin EJ, Go AS, Arnett DK, Blaha MJ, Cushman M, de Ferranti S, et al. Heart Disease and Stroke Statistics-2015 Update: A Report from the American Heart Association. *Circulation*. 2015; 131: 29-322. [\[CrossRef\]](#)
- Wik L, Kramer-Johansen J, Myklebust H, Sorebo H, Svensson L, Fellows B, et al. Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. *JAMA*. 2005; 293: 299-304. [\[CrossRef\]](#)
- Meaney PA, Bobrow BJ, Mancini ME, Christenson J, de Caen AR, Bhanji F, et al. Cardiopulmonary Resuscitation Quality: Improving Cardiac Resuscitation Outcomes both Inside and Outside the Hospital: A consensus Statement from the American Heart Association. *Circulation*. 2013; 128: 417-35. [\[CrossRef\]](#)
- Abella BS, Sandbo N, Vassilatos P, Alvarado JP, O'Hearn N, Wigder HN, et al. Chest compression rates during cardiopulmonary resuscitation are suboptimal: a prospective study during in-hospital cardiac arrest. *Circulation*. 2005; 111: 428-34. [\[CrossRef\]](#)
- Halperin HR, Tsitlik JE, Guerci AD, Mellits ED, Levin HR, Shi AY, et al. Determinants of blood flow to vital organs during cardiopulmonary resuscitation in dogs. *Circulation*. 1986; 73: 539-50. [\[CrossRef\]](#)
- Niemann JT, Rosborough JP, Ung S, Criley JM. Coronary perfusion pressure during experimental cardiopulmonary resuscitation. *Ann Emerg Med*. 1982; 11: 127-31. [\[CrossRef\]](#)
- Paradis NA, Martin GB, Rivers EP, Goetting MG, Appleton TJ, Feingold M, et al. Coronary perfusion pressure and the return of spontaneous circulation in human cardiopulmonary resuscitation. *JAMA*. 1990; 263: 1106-13. [\[CrossRef\]](#)
- Sanders AB, Ogle M, Ewy GA. Coronary perfusion pressure during cardiopulmonary resuscitation. *Am J Emerg Med*. 1985; 3: 11-4. [\[CrossRef\]](#)
- Neumar RW, Shuster M, Callaway CW, Gent LM, Atkins DL, Bhanji F, et al. Part 1: Executive Summary: 2015 American Heart Association Guidelines Update for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. *Circulation*. 2015; 132: 315-67. [\[CrossRef\]](#)
- Skorning M, Beckers SK, Brokmann JC, Rortgen D, Bergrath S, Veiser T, et al. New visual feedback device improves performance of chest compressions by professionals in simulated cardiac arrest. *Resuscitation*. 2010; 81: 53-8. [\[CrossRef\]](#)
- Havel C, Schreiber W, Trimmel H, Malzer R, Haugk M, Richling N, et al. Quality of closed chest compression on a manikin in ambulance vehicles and flying helicopters with a real time automated feedback. *Resuscitation*. 2010; 81: 59-64. [\[CrossRef\]](#)
- Krasteval V, Jekova I, Didon JP. An audiovisual feedback device for compression depth, rate and complete chest recoil can improve the CPR performance of lay persons during self-training on a manikin. *Physiol Meas*. 2011; 32: 687-99. [\[CrossRef\]](#)
- Yeung J, Davies R, Gao F, Perkins GD. A randomized control trial of prompt and feedback devices and their impact on quality of chest compressions-A Simulation Study. *Resuscitation*. 2014; 85: 553-9. [\[CrossRef\]](#)
- Soar J, Edelson DP, Perkins GD. Delivering high-quality cardiopulmonary resuscitation in-hospital. *Curr Opin Crit Care*. 2011; 17: 225-30. [\[CrossRef\]](#)
- Oh J, Song Y, Kang B, Kang H, Lim T, Suh Y, et al. The use of dual accelerometers improves measurement of chest compression depth. *Resuscitation*. 2012; 83: 500-4. [\[CrossRef\]](#)
- Perkins GD, Kocierz L, Smith SCL, McCulloch RA, Davies RP. Compression feedback devices over estimate chest compression depth when performed on a bed. *Resuscitation*. 2009; 80: 79-82. [\[CrossRef\]](#)
- Dixon M, Montgomery A, Howard J. Do mechanical CPR feedback devices improve the quality of chest compressions on simulated patients in a hospital bed. *Resuscitation*. 2010; 81 (Suppl): 11. [\[CrossRef\]](#)
- Idris A, Guffey D, Aufderheide TP, Brown S, Morrison LJ, Nichols P, et al. The relationship between chest compression rates and outcomes from cardiac arrest. *Circulation*. 2012; 125: 3004-12. [\[CrossRef\]](#)
- Sayre MR, Berg RA, Cave DM, Page RL, Potts J, White RD, et al. Hands-Only (Compression-Only) Cardiopulmonary Resuscitation: A Call to Action for Bystander Response to Adults Who Experience Out-of-Hospital Sudden Cardiac Arrest. A Science Advisory for the Public From the American Heart Association Emergency Cardiovascular Care Committee. *Circulation*. 2008; 117: 2162-7. [\[CrossRef\]](#)
- Perkins GD, Fossan H, Field R, Akhtar N, Davies R, Fullerton J. Novel smart backboard improves CPR performance. *Resuscitation* 2010; 81 (Suppl): 11. [\[CrossRef\]](#)
- Hellevo H, Sainio M, Nevalainen R, Huhtala H, Olkkola KT, Tenhunen J, et al. Deeper chest compression - More complications for cardiac arrest patients? *Resuscitation*. 2013; 84: 760-5. [\[CrossRef\]](#)
- Steill IG, Brown SP, Christenson J, Cheskes S, Nichol G, Powell J, et al. What is the role of chest compression depth during out-of-hospital cardiac arrest resuscitation? *Crit Care Med*. 2012; 40: 1192-8. [\[CrossRef\]](#)