

Effect of a feedback system on the quality of 2-minute chest compression-only cardiopulmonary resuscitation: a randomised crossover simulation study

Chunshuang Wu*, Jingyu You*, Shaoyun Liu, Lan Ying, Yuzhi Gao, Yulin Li, Xiao Lu, Anyu Qian, Mao Zhang  and Guangju Zhou 

Abstract

Objective: We evaluated the quality of 2-minute continuous chest compressions (CCCs) performed by emergency staff in 30-second intervals to determine the effect of a feedback system on maintaining the quality of CCCs.

Methods: Two hundred three physicians and nurses were randomised into two groups. Each participant performed 2-minute CCCs both with and without feedback. Group A performed CCCs under the guidance of a feedback device followed by performance without feedback, and Group B performed these tasks in reverse order. The primary outcome was the proportion of optimal compressions; i.e., compressions at both the correct rate (100–120 beats/minute) and correct depth (5–6 cm).

Results: During 2-minute CCCs, the proportion of optimal compressions was poor in personnel without feedback. The proportion of optimal compressions was unchanged and low from 2.4% (interquartile range, 0.0%–32.8%) in the first 30 seconds to 3.3% (0.0%–47.7%) in the last 30 seconds of the 2-minute period. Use of the feedback device significantly improved and maintained the quality of compressions from the first 30 seconds (53.3%; 29.2%–70.4%) to the last 30 seconds (82.8%; 50.8%–96.2%).

Conclusion: Use of the feedback device was helpful for maintaining the quality of CCCs.

Department of Emergency Medicine, Second Affiliated Hospital, Zhejiang University School of Medicine & Institute of Emergency Medicine, Zhejiang University, Hangzhou, China

*These authors contributed equally to this work.

Corresponding author:

Guangju Zhou, Department of Emergency Medicine, Second Affiliated Hospital, Zhejiang University School of Medicine, Institute of Emergency Medicine, Zhejiang University, No. 88 Jiefang Road, Hangzhou 310009, China. Email: 2308026@zju.edu.cn



Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative

Commons Attribution-NonCommercial 4.0 License (<https://creativecommons.org/licenses/by-nc/4.0/>) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (<https://us.sagepub.com/en-us/nam/open-access-at-sage>).

Keywords

Cardiopulmonary resuscitation (CPR), continuous chest compression, cardiac arrest, feedback device, compression quality, emergency

Date received: 7 August 2019; accepted: 21 November 2019

Introduction

The compression rate and depth are important parameters affecting the overall quality of chest compressions (CCs) during cardiopulmonary resuscitation (CPR). These parameters are responsible for maintaining blood flow and oxygen delivery to the heart and brain; therefore, they play a key role in increasing the rate of restoration of spontaneous circulation and neurologically intact survival at hospital discharge.^{1,2} However, it is difficult to reach and maintain the optimal CC rate and depth, even for well-trained health care professionals.^{3,4} Rescuers are generally unaware of the quality of CCs being delivered or the time at which the quality of CCs begins to decrease.

To ensure high-quality CCs, the 2005 American Heart Association (AHA) guidelines for CPR and emergency cardiovascular care recommended that rescuers rotate the compressor role every 2 minutes to prevent compressor fatigue and deterioration in the quality of CCs.⁵ Nishiyama et al.⁶ subsequently reported that the CPR quality decreased significantly faster when performing continuous CCs (CCCs) than when performing CCs in a 30:2 ratio and recommended that CPR providers change their roles every 1 minute during compression-only CPR. However, their study did not provide sufficient evidence to warrant changes in standard practices because of the limited experimental conditions.

Feedback devices can track compression metrics in real time as a means of evaluating the CC quality in real CPR or CPR training

courses; moreover, they can help to close the gap between current CPR metrics and established guidelines and increase the likelihood of high-quality CPR in terms of minimal interruptions and no-flow time.⁷⁻¹⁸ Although the positive effects of audiovisual feedback during CPR or CPR training have already been confirmed by numerous studies, the results remain controversial because of differences in the individual participants, research designs, outcome metrics, or CC criteria.⁷⁻¹⁸

In this study, we investigated the quality of 2-minute CCCs performed by healthcare professionals according to the 2015 AHA guidelines. The aim of this study was to determine the effect of a feedback system on maintaining the quality of CCCs.

Methods

Study setting and population

This study was conducted on 5 June 2018. The participants were physicians and nurses from a major academic conference on resuscitation and hypothermia therapy attended by national emergency health staff in Hangzhou, China. Upon enrolment, the participants were randomised into two groups. Each group performed 2 minutes of CPR with and without guidance from a feedback device. We excluded medical staff with health problems (e.g., spine or wrist injury), pregnancy, or other conditions that may have prevented proper performance of CPR as well as staff who did not complete the study.

Feedback system

We used an R Series Monitor/Defibrillator (ZOLL Medical Corporation, Chelmsford, MA, USA), which is an all-in-one electrode with an integrated accelerometer and a sternal back mode that can detect sternal movement. The instrument provides visual feedback (displaying the current compression depth and rate and the compression recoil) and verbal feedback (prompts of ‘press deeper’ and ‘chest compressions are better’) according to the 2015 AHA guidelines (correct depth: 5–6 cm; correct rate: 100–120 beats/minute). The participants were instructed to perform continuous CPR (no rescue breathing) on an adult bust manikin (Little Anne manikin; Laerdal Medical, Stavanger, Norway). A chest pad was positioned on the manikin to provide information on the compression depth and rate. The manikin was placed on a hard floor, and the participants conducted CCs on the right side of the manikin in a

kneeling position. When performing CPR without feedback, the participant received no verbal or visual feedback. This feedback device is compatible with defibrillators and can be kept on the patient during defibrillation.

Monitor-generated data from every participant were accessible via an SD card and measured using RescueNet Code Review software (ZOLL Medical Corporation). During the preliminary analysis, two researchers tested three different intervals (10-, 20-, and 30-second intervals) on the RescueNet Code Review software. Considering the accuracy and feasibility of these data, we chose the 30-second interval to evaluate the chronological change in the quality of CCs.

Study protocol

This was a phase 2b, crossover, randomised, active-controlled study. The flow chart is shown in Figure 1. After receiving

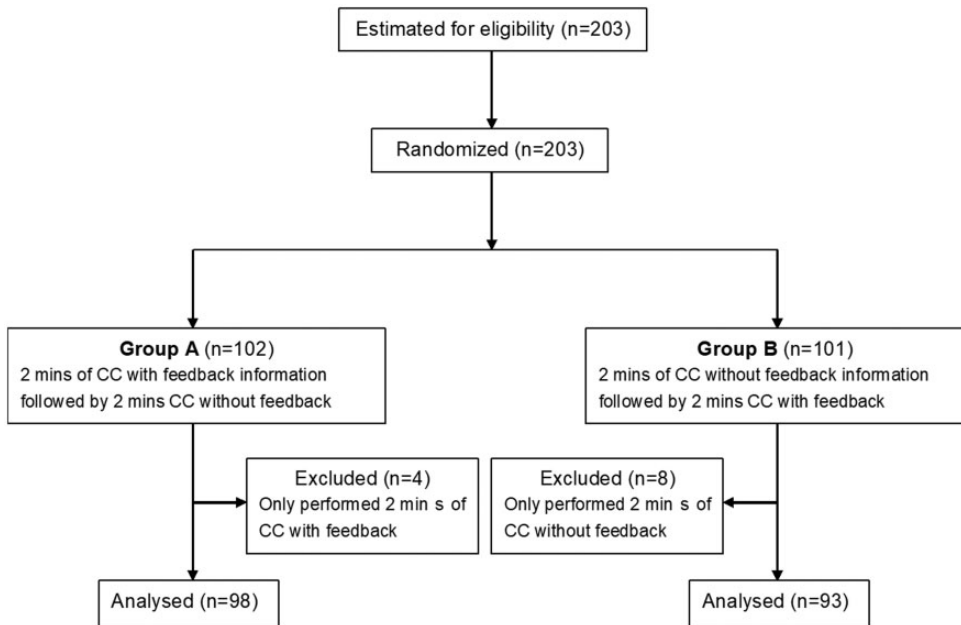


Figure 1. Flow chart of study design and participant recruitment. CC = chest compressions.

a short instruction regarding the use of the feedback system, the participants were randomly assigned to Group A or B. Group assignment was performed as a simple (complete) randomisation. A research staff member (JY) at the study site opened the next sequentially numbered opaque envelope that contained the assignment. Another individual (AQ) unassociated with the clinical portion of the study prepared the envelopes. The randomisation sequence was created using IBM SPSS version 22.0 statistical software (IBM Corp., Armonk, NY, USA) and was stratified by centre with a 1:1 allocation. In the first part of this study, the participants Group A performed 2 minutes of CCCs with the feedback device (display visible and alert turned on). The participants could adjust the compression rate and depth according to the audiovisual information. After a 1-hour rest (washout period), the second session was conducted, and CCCs were performed without the feedback device (display covered and alert muted). The participants in Group B performed the same tasks in the reverse order.

Sample size calculation

The sample size was calculated based on published data with the percentage of optimal CCs (relative to all CCs) as the primary outcome.¹⁹ According to previous data,¹⁰ the percentage of optimal CCs in the group blinded to feedback was estimated to be 40%. The hypothesised margin of superiority for those performing CCs with versus without the feedback device was set at 15%. These parameters were found to achieve a 5% significance level at 80% power in a sample size of 170 subjects per group, as a result of the online program (<http://www.powerandsamplesize.com>) for the two compared proportions. Considering the possibility of data loss and the substantial bias caused by the

simple (complete) randomisation,²⁰ we enrolled 203 participants.

Statistical analysis

Statistical analyses were performed using IBM SPSS version 22.0 for Windows software (IBM Corp.). Continuous variables are presented as mean \pm standard deviation for normally distributed data and as median (interquartile range [IQR]) for non-normally distributed data. The normality of the data was tested using the Kolmogorov–Smirnov test. The normally distributed data were analysed by a *t*-test, and the non-normally distributed data were analysed by the Wilcoxon signed-rank test. The categorical variables were analysed by the χ^2 test or Fisher's exact test. Changes in the percentage of optimal compressions, the percentage of compressions at the target depth, the percentage of compressions at the target rate, and the mean compression depth and rate over time were compared using repeated-measures analysis. Statistical significance was set at $p < 0.05$.

Primary and secondary endpoints

The primary endpoint was the absolute percentage of optimal compressions (compressions at a rate of 100–120 beats/minute and depth of 5–6 cm, simultaneously) per person. The secondary endpoint was the percentage of compressions with the target depth (5–6 cm), percentage of compressions with the target frequency (100–120 beats/min), number of 'effective' trials, mean compression depth, and mean rate. All performances with a mean rate of 100 to 120 beats/minute and $>80\%$ of compressions with a depth 5 to 6 cm were classified as 'effective' trials according to the published literature.⁹ All performances were done under the direct supervision of two researchers (CW and SL). At the end of the study, the data were input into

Microsoft Office Excel (Microsoft Corp., Redmond, WA, USA) by another researcher (LY) for further analysis.

Results

Study population

This study included 203 subjects who were randomly divided into Group A (n = 102) and Group B (n = 101). Four participants in Group A and eight in Group B did not complete the second part of the study; therefore, the analysis was performed on

data from 191 subjects. There were no differences in sex, profession, professional title, department, last training time, or estimated frequency of CPR provision between Groups A and B (Table 1).

Compression quality during whole 2-minute performance

Without feedback, the proportion of optimal CCs was 6.9% (IQR, 0.4%–39.6%), the proportion of CCs at the target depth was 42.9% (IQR, 13.1%–66.5%), the proportion of CCs at the target rate was 55.2%

Table 1. Participant demographics in Groups A and B.

	Group A (n = 98)	Group B (n = 93)	p*
Sex			0.683
Male	31 (31.6)	32 (34.4)	
Female	67 (68.4)	61 (65.6)	
Profession			0.764
Physician	35 (35.7)	38 (40.9)	
Nurse	60 (61.2)	51 (54.8)	
Other	3 (3.1)	4 (4.3)	
Professional title			0.258
Senior	3 (3.1)	6 (6.5)	
Semi-senior	23 (23.5)	19 (20.4)	
Junior	61 (62.2)	50 (53.8)	
Other	11 (11.2)	18 (19.4)	
Department			0.373
Emergency	59 (60.2)	57 (61.3)	
Intensive care unit	23 (23.5)	18 (19.4)	
Prehospital	3 (3.1)	0 (0.0)	
Other	13 (13.3)	18 (19.4)	
Last training time			0.273
<0.5 years	55 (56.1)	46 (49.5)	
0.5–1.0 year	33 (33.7)	34 (36.5)	
<2 years	8 (8.2)	6 (6.5)	
≥2 years	2 (2.0)	7 (7.5)	
Frequency of CPR provision			0.296
Once per week	17 (17.3)	10 (10.8)	
Once per month	26 (26.5)	34 (36.6)	
Once per 3 months	30 (30.6)	23 (24.7)	
Less than once per 3 months	25 (25.5)	26 (28.0)	

Data are presented as n (%). Professional title: Senior, associate chief or chief/associate chief of nursing or head nurse; Semi-senior, attending doctor/nurse-in-charge; Junior, resident doctor/nurse; Other: intern/nursing assistant. CPR, cardiopulmonary resuscitation. *Chi-square χ^2 .

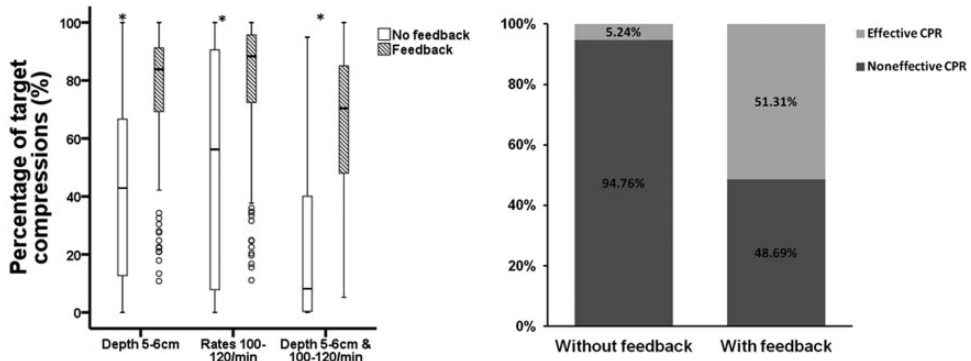


Figure 2. Percentages of adequate depth, adequate frequency, and optimal compressions per person in chest compressions with and without feedback and the percentages of effective CPR with and without feedback. Effective CPR: CPR with a mean rate of 100 to 120 compressions/minute and >80% of compressions of adequate depth. CPR = cardiopulmonary resuscitation.

(IQR, 7.3%–89.9%), and the proportion of effective CPR trials was 5.2%. While under the guidance of the feedback device, these proportions were 70.4% (IQR, 47.9%–85.1%), 83.8% (IQR, 68.7%–91.4%), 88.3% (IQR, 72.2%–95.8%), and 51.3%, respectively (all $p < 0.001$ compared with no feedback) (Figure 2). The mean CC depth and rate without the feedback device were 5.7 ± 0.8 cm and 118.0 ± 14.1 beats/minute, respectively, and those with the feedback device were 5.5 ± 0.3 cm and 112.6 ± 6.3 beats/minute, respectively.

Chronological quality of compressions with and without feedback

Table 2 shows the chronological change in the quality of CCs with and without feedback guidance. The mean CC depth and rate gradually decreased over time ($p < 0.001$) both with and without feedback guidance. The proportion of optimal CCs was 2.4% (IQR, 0.0%–32.8%) to 3.3% (IQR, 0.0%–47.7%) from 0–30 to 90–120 seconds without feedback guidance. The proportion of optimal CCs in the fourth 30-second interval was significantly higher than that in the first 30-second interval under guidance from the feedback

device: 82.8% (IQR, 50.8%–96.2%) vs. 53.3% (IQR, 29.2%–70.4%) ($p < 0.001$). Without feedback guidance, the proportions of CCs at the target depth and rate were also stable and low. The corresponding parameters under feedback guidance were 71.2% (IQR, 50.0%–84.9%) to 91.3% (IQR, 66.2%–98.2%) ($p < 0.001$) and 75.9% (IQR, 53.3%–92.6%) from the first 30-second interval to 96.0% (IQR, 79.1%–100.0%) for the fourth 30-second interval ($p < 0.001$).

Discussion

In a sample of Chinese physicians and nurses, the overall CPR performance of medical workers was poor within the recommended 2-minute CC scenario in adults. When analysed in 30-second intervals, the feedback device significantly improved the endpoints and maintained the quality of compressions during 2-minute CCCs.

The Institute of Medicine, AHA, and International Liaison Committee on Resuscitation have all emphasised that high-quality CPR plays a key role in increasing the likelihood of survival. It is especially important to meet specific compression depth and rate targets. In adults,

Table 2. Chronological change in quality of chest compressions.

	0–30 seconds	30–60 seconds	60–90 seconds	90–120 seconds	P
Percentage of optimal compressions (%)					
Feedback	53.3 (29.2–70.4)	79.6 (44.6–93.6)	83.3 (44.1–95.9)	82.8 (50.8–96.2)	<0.001 [#]
No feedback	2.4 (0.0–32.8)	3.2 (0.0–50.8)	3.6 (0.0–43.4)	3.3 (0.0–47.7)	0.515
P	<0.001*	<0.001*	<0.001*	<0.001*	
Percentage at the target depth (%)					
Feedback	71.2 (50.0–84.9)	90.4 (69.4–98.1)	93.0 (72.1–100.0)	91.3 (66.1–98.2)	<0.001 [#]
No feedback	35.4 (2.9–72.3)	48.7 (1.8–86.0)	34.6 (0.0–89.6)	30.77 (0.0–80.9)	0.630
P	<0.001*	<0.001*	<0.001*	<0.001*	
Percentage at the target rate (%)					
Feedback	75.9 (53.3–92.6)	92.9 (77.6–98.4)	96.1 (80.7–98.3)	96.0 (79.1–100.0)	<0.001 [#]
No feedback	44.9 (2.9–87.7)	52.1 (2.9–96.6)	59.0 (3.6–96.2)	64.6 (4.5–96.3)	0.330
P	<0.001*	<0.001*	<0.001*	<0.001*	
Mean compression depth (cm)					
Feedback	5.6 ± 0.5	5.5 ± 0.4	5.4 ± 0.4	5.4 ± 0.4	<0.001 [#]
No feedback	6.0 ± 0.8	5.7 ± 0.8	5.5 ± 0.9	5.4 ± 0.9	<0.001 [#]
P	<0.001*	0.001*	0.225*	0.811*	
Mean compression rate (beats/minute)					
Feedback	113.9 ± 9.4	112.1 ± 7.3	111.8 ± 6.5	111.8 ± 6.49	<0.001 [#]
No feedback	120.5 ± 14.3	118.1 ± 14.6	117.2 ± 14.3	116.3 ± 14.2	<0.001 [#]
P	<0.001*	<0.001*	<0.001*	<0.001*	

Values are presented as median (interquartile range) or mean ± standard deviation.

*p < 0.05 versus no feedback; [#]p < 0.05 with time effect.

Optimal compressions: compressions with both correct rate of 100 to 120 beats/minute and depth of 5 to 6 cm.

the greatest benefit is attained when the compression depth is 5 to 6 cm and the rate is 100 to 120 beats/minute in accordance with the 2015 AHA guidelines. The rates of restoration of spontaneous circulation and survival decline at values above or below these ranges.²¹ In the present study, CPR performance without the feedback device was suboptimal, which is consistent with a previous study.²² Although health practitioners are familiar with current AHA guidelines, the performance of CPR in clinical settings was poor.

Various outcome indexes have been used in different studies to evaluate the compression quality. Metrics such as the mean compression rate and depth are common endpoints; however, such a measurement cannot accurately determine whether compression falls within the target depth or target rate at any time of the CC trial. In other words, if 50% of CCs are above the target range and 50% of CCs are below the target range, the mean value is still within the recommendations. In the present study, the mean compression rate and depth with or without feedback were within the normal range. This distinction is important because guidelines have emphasised the need for CCs at both the correct rate and depth simultaneously. Therefore, the percentage of CCs with the correct rate and depth ('optimal compressions' in this study) and the percentages of CCs at the target depth and within the target rate are more appropriate for the evaluation of CC quality. In the present study, the intergroup differences in the proportion of optimal compressions, compressions at the target depth, and compressions at the target rate were statistically significant across all CPR periods. In addition, as an endpoint for evaluation of the entire 2-minute performance, the number of effective CPR trials was also used in our study to evaluate the quality of CPR.

Based on the analyses of 30-second intervals during 2-minute CCCs, we wanted to obtain detailed information regarding the chronological changes of CCs with and without feedback devices. In the present study, the quality of CCs without feedback was poor, which is similar to the findings of previous studies.^{23,24} However, the difference is that the proportion of optimal compressions at the target depth and rate remained steady over time in our 2-minute CPR trial; further studies are needed for a proper evaluation of this finding. The compression quality with feedback increased over the first 30 seconds and was maintained at a high level thereafter, rather than exhibiting a decline.²⁵ Buléon et al.¹⁰ analysed 10-minute continuous CCs minute by minute and found that the compression quality with feedback improved significantly every minute and remained stable over time, consistent with our results. A subsequent study²⁶ showed that CPR with real-time feedback was independently associated with improved CPR quality, increased survival, and more favourable functional outcomes after out-of-hospital cardiac arrest. A final study²⁷ revealed that the use of feedback not only improves the rate and depth of CCs but also allows for correct chest relaxation. Other researchers have confirmed the effects of a feedback system on CC skills and suggested that feedback systems may allow practitioners to continue delivering high-quality CPR after passing the recommended 2-minute window.^{17,28} The use of a real-time audiovisual feedback device improved the quality of CCs; however, one remaining challenge is how to choose between, or unify, currently available devices, which differ in precision. Further studies will be necessary to properly evaluate such parameters.

This study had several limitations. First, selection bias might have been present during the recruitment of participants in the regional healthcare-related conference.

To reduce the potential for such bias, we recruited more participants than deemed necessary based on the sample size calculations. Second, the crossover study design may have affected the results. To reduce the potential for learning effects, we implemented a 1-hour rest before the CCs in the next phase, which is longer than in previous studies.^{11,29,30} Third, providing CPR to a dummy lying down on a hard floor is inconsistent with patient interactions in most clinical settings. Fourth, the compression quality may be reduced by other important interventions (e.g., intubation, defibrillation) during stressful real-life cardiac arrest situations. Finally, incomplete chest wall recoil leads to ineffective CPR, which was not assessed in our study.

Conclusion

During a recommended 2-minute CCC scenario in adults, although the mean CC rate and depth were maintained over time, the overall CC quality was poor when feedback devices were not used. Use of a real-time audiovisual feedback device is helpful for maintaining a high quality of CCs.

List of abbreviations

CC: chest compression; CCC: continuous chest compression; CPR: cardiopulmonary resuscitation; AHA: American Heart Association

Author contributions

MZ, GZ, CW, and JY contributed substantially to the conception and design of the work. CW, LS, JY, GZ, and AQ conducted the experiments and acquired the data. CW, JY, YG, LS, and YL contributed to the data analysis and interpretation. CW, LS, JY, and YL drafted the original manuscript, and MZ, GZ, YG, and XL revised the manuscript. All authors have contributed to this work and approved this submission.

Availability of data and materials

The datasets used and/or analysed during the present study are available from the corresponding author on reasonable request.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

Ethics approval and consent to participate

Because this was a simulation study involving an adult bust manikin, we did not obtain an Institutional Review Board number. However, participation in this study was performed on a voluntary basis. The study protocol was approved by the Human Research Ethics Committee of the Second Hospital Affiliated to Zhejiang University School of Medicine. All participants received a verbal and written introduction to the protocol and provided informed consent for participation before enrolling in the study.

Funding

This work was supported by a grant from the 2015 Welfare Scientific Research Project from the Chinese Ministry of Health [No. 2015SQ 00050], the 2012 Chinese National Key Clinical Discipline Developing Project [emergency medicine], Zhejiang Provincial Welfare Scientific Research Project of China (LGD19H150003), and Zhejiang Provincial Medical Science Foundation (2017KY389).

Patient consent for publication

Not applicable.

ORCID iDs

Mao Zhang  <https://orcid.org/0000-0001-7919-8213>

Guangju Zhou  <https://orcid.org/0000-0002-2110-2263>

References

1. Kleinman ME, Brennan EE, Goldberger ZD, et al. Part 5: adult basic life support and cardiopulmonary resuscitation quality: 2015 American Heart Association guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation* 2015; 132: S414–S435.
2. Nolan JP. High-quality cardiopulmonary resuscitation. *Curr Opin Crit Care* 2014; 20: 227–233.
3. Abella BS, Alvarado JP, Myklebust H, et al. Quality of cardiopulmonary resuscitation during in-hospital cardiac arrest. *JAMA* 2005; 293: 305–310. Epub 2005/01/20.
4. Wik L, Kramer-Johansen J, Myklebust H, et al. Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. *JAMA* 2005; 293: 299–304. Epub 2005/01/20.
5. ECC Committee, Subcommittees and Task Forces of the American Heart Association. 2005 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care. *Circulation* 2005; 112(24 Suppl): IV1–203. Epub 2005/11/30.
6. Nishiyama C, Iwami T, Kawamura T, et al. Quality of chest compressions during continuous CPR; comparison between chest compression-only CPR and conventional CPR. *Resuscitation* 2010; 81: 1152–1155. Epub 2010/08/25.
7. Peberdy MA, Silver A and Ornato JP. Effect of caregiver gender, age, and feedback prompts on chest compression rate and depth. *Resuscitation* 2009; 80: 1169–1174.
8. Vahedian-Azimi A, Hajiesmaeili M, Amirsavadkouhi A, et al. Effect of the Cardio First Angel device on CPR indices: a randomized controlled clinical trial. *Crit Care* 2016; 20: 147.
9. Wutzler A, Bannehr M, von Ulmenstein S, et al. Performance of chest compressions with the use of a new audio-visual feedback device: a randomized manikin study in health care professionals. *Resuscitation* 2015; 87: 81–85.
10. Buléon C, Delaunay J, Parienti JJ, et al. Impact of a feedback device on chest compression quality during extended manikin CPR: a randomized crossover study. *Am J Emerg Med* 2016; 34: 1754–1760. Epub 2016/06/29.
11. Eaton G, Renshaw J, Gregory P, et al. Can the British Heart Foundation PocketCPR application improve the performance of chest compressions during bystander resuscitation: a randomised crossover manikin study. *Health Informatics J* 2018; 24: 14–23.
12. Kirkbright S, Finn J, Tohira H, et al. Audiovisual feedback device use by health care professionals during CPR: a systematic review and meta-analysis of randomised and non-randomised trials. *Resuscitation* 2014; 85: 460–471.
13. Krasteva V, Jekova I and 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: 687–699.
14. Haagsma JA, Graetz N, Bolliger I, et al. The global burden of injury: incidence, mortality, disability-adjusted life years and time trends from the Global Burden of Disease study 2013. *Inj Prev* 2016; 22: 3–18. Epub 2015/12/05.
15. Kramer-Johansen J, Myklebust H, Wik L, et al. Quality of out-of-hospital cardiopulmonary resuscitation with real time automated feedback: a prospective interventional study. *Resuscitation* 2006; 71: 283–292. Epub 2006/10/31.
16. Cortegiani A, Russotto V, Montalto F, et al. Use of a Real-Time Training Software (Laerdal QCPR(R)) compared to instructor-based feedback for high-quality chest compressions acquisition in secondary school students: a randomized trial. *PLoS One* 2017; 12: e0169591. Epub 2017/01/06.
17. Cortegiani A, Russotto V, Baldi E, et al. Is it time to consider visual feedback systems the gold standard for chest compression skill acquisition? *Crit Care* 2017; 21: 166. Epub 2017/07/05.
18. Yeung J, Meeks R, Edelson D, et al. The use of CPR feedback/prompt devices during training and CPR performance: a systematic review. *Resuscitation* 2009; 80: 743–751. Epub 2009/05/30.

19. Chow SC, Shao J and Wang H. A note on sample size calculation for mean comparisons based on noncentral t-statistics. *J Biopharm Stat* 2002; 12: 441–456. Epub 2002/12/13.
20. Nguyen TL, Collins GS, Lamy A, et al. Simple randomization did not protect against bias in smaller trials. *J Clin Epidemiol* 2017; 84: 105–113. Epub 2017/03/05.
21. Nassar BS and Kerber R. Improving CPR performance. *Chest* 2017; 152: 1061–1069. Epub 2017/05/14.
22. Neubrand T, Cabrera N, Coss S, et al. Pushing hard: the mandate to improve care of pediatric cardiopulmonary arrest. *Acad Emerg Med* 2019; 26: 117–119. Epub 2018/07/20.
23. Sugeran NT, Edelson DP, Leary M, et al. Rescuer fatigue during actual in-hospital cardiopulmonary resuscitation with audiovisual feedback: a prospective multicenter study. *Resuscitation* 2009; 80: 981–984. Epub 2009/07/08.
24. Liu Y, Huang Z, Li H, et al. CPR feedback/prompt device improves the quality of hands-only CPR performed in manikin by laypersons following the 2015 AHA guidelines. *Am J Emerg Med* 2018; 36: 1980–1985. Epub 2018/03/12.
25. Poole K, Couper K, Smyth MA, et al. Mechanical CPR: who? when? how? *Crit Care* 2018; 22: 140. Epub 2018/05/31.
26. Bobrow BJ, Vadeboncoeur TF, Stolz U, et al. The influence of scenario-based training and real-time audiovisual feedback on out-of-hospital cardiopulmonary resuscitation quality and survival from out-of-hospital cardiac arrest. *Ann Emerg Med* 2013; 62: 47–56 e1. Epub 2013/03/08.
27. Majer J, Jaguszewski MJ, Frass M, et al. Does the use of cardiopulmonary resuscitation feedback devices improve the quality of chest compressions performed by doctors? A prospective, randomized, cross-over simulation study. *Cardiol J* 2019; 26: 529–535. Epub 2018/08/30.
28. Sutton RM, Maltese MR, Niles D, et al. Quantitative analysis of chest compression interruptions during in-hospital resuscitation of older children and adolescents. *Resuscitation* 2009; 80: 1259–1263. Epub 2009/09/08.
29. Skorning M, Derwall M, Brokmann JC, et al. External chest compressions using a mechanical feedback device: cross-over simulation study. *Anaesthetist* 2011; 60: 717–722. Epub 2011/03/26.
30. Semeraro F, Taggi F, Tammaro G, et al. iCPR: a new application of high-quality cardiopulmonary resuscitation training. *Resuscitation* 2011; 82: 436–441. Epub 2011/01/14.