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Review

Effect of smart devices on the quality of CPR training: A systematic review

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Abstract

Aim of the review: Use of smart devices to provide real-time cardiopulmonary resuscitation (CPR) feedback in the context of out-of-hospital cardiac arrest (OHCA) has considerable potential for improving survival. However, the findings of previous studies evaluating the effectiveness of these devices have been conflicting. Therefore, we conducted a systematic review of the literature to assess the utility of smart devices for improving the quality of CPR during CPR training.

Data sources: Thirteen electronic databases were searched. The articles were reviewed according to the eligibility criteria. CPR quality was evaluated based on the rates and depths of chest compression, and the proportion of adequate depth of chest compressions.

Results: Ultimately, 11 studies (5 randomised controlled trials, 1 randomised trial, and 5 randomised cross-over trials) were selected for this systematic review. Eight of these studies used smartphones and three used smartwatches. This review did not find an apparent benefit from smart device use during CPR in terms of maintaining the recommended compression rates and depths of chest compressions. However, all three smartwatch studies reported that the proportion of chest compressions of adequate depth was significantly improved with smartwatch use (smartwatch group vs. non-smartwatch group in the three studies: 65.01% vs. 45.15%, $p = 0.01$; 64.6% vs. 43.1%, $p = 0.049$; 98.7% vs. 79.3%, $p = 0.002$).

Conclusion: This review does not find durable evidence for usefulness of smart devices in CPR training. However, the smartwatches may improve the accuracy of chest compression depth. Future studies with larger sample sizes might be necessary before reaching a firm conclusion.

Keywords: Cardiopulmonary resuscitation (CPR), CPR training, Smart devices, CPR quality

Introduction

Cardiac arrest is defined by a loss of cardiac function and systemic circulation.[1] About 350,000 out-of-hospital cardiac arrest (OHCA) incidents occur each year among adults in the U.S.[2] Survival after OHCA remains low and less than 10% of patients with OHCA survive.[3–5] Successful outcomes of OHCA are dependent on efficient collaboration between public bystanders, emergency medical services and hospital professionals; thus, providing immediate and adequate cardiopulmonary resuscitation (CPR) by public bystander is a key link in the chain of survival. However, it is well-documented that even well-trained persons can have difficulty performing high quality CPR in real-life CPR situations because of fear and anxiety.[6] Thus, several real-time CPR feedback devices have been developed to provide adequate visual or auditory feedback with respect to compression depth, speed, and

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accuracy during CPR.[7–11] Basically, the various applications (apps) used in the smart devices detect chest compressions using the built-in accelerometers and display both compression rate and count. A visual feedback of compression quality is also on the frequency display (Fig. 1). According to some studies, the use of professional CPR feedback devices prevents low-quality CPR resulting from rescuer fatigue during chest compressions.[12,13] However, these professional CPR feedback devices are not available to public bystanders in emergency OHCA situations.

The number of smartphone users worldwide is expected to grow from 2.1 billion in 2016 to about 2.5 billion in 2019 and the use of smart device apps have become somewhat of a necessity in modern society.[14] They have also rapidly penetrated the global healthcare field, therefore, it is encouraging that apps for CPR feedback, such as iCPR® or PocketCPR®, that are compatible with smart devices such as smartphones or smartwatches, have been developed and are already being used. There have been various studies conducted to show the usefulness of smart devices as CPR feedback devices, but the results have been conflicting thus far.[9,10,15–23] This systematic review aimed to examine randomised trials to determine if smart devices used during CPR training could improve the quality of CPR. Additionally, we investigated what type of smart device, phone or watch, was more effective at improving CPR quality.

Methods

Design

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement guidelines.[24,25]

Eligibility criteria

The PICOS (participants, intervention, comparison, outcomes, and study design) framework was used to identify eligible studies. We included studies with participants (P) who were adult (≥18 years old) medical personnel, students, and/or laypeople. The intervention (I) was defined as CPR training using smart devices including smartphones and smartwatches. The comparisons (C) were defined as routine CPR training sessions conducted without smart devices. The outcomes (O) included CPR quality measures, such as chest compression rate, depth of compression, and number of adequate compressions during CPR as determined by the concordant guidelines from American Heart Association (AHA), European Resuscitation Council (ERC) and International Liaison Committee on Resuscitation (ILCOR).[26–28] The study designs (S) included interventional studies including randomised controlled trials (RCTs), randomised trials (RTs), and randomised cross-over trials (RCOTs). The articles were restricted to those written in English or Korean.

Because the ILCOR/AHA/ERC for CPR were substantially revised in 2010, this systematic review only included available peer-reviewed articles published between January 2010 and February 2018.[27] All literature searches were conducted by a university librarian with formal training. The following electronic databases were searched between February 1st, 2018 and February 13th, 2018: PubMed, Embase, Cochrane Central Register of Controlled Trials (CENTRAL), CINAHL, Web of Science, SCOPUS, ProQuest Dissertations & Theses Global (PQDT Global), Google Scholar, KoreaMed, KMBASE, KISS, DBPia and NDSL. Search keywords included: 'Arrest', 'Cardiac arrest', 'Heart arrest', 'CPR', 'Cardiopulmonary resuscitation', 'Resuscitation', 'Chest compression', 'Cardiac compression', 'Heart compression', 'CPR feedback device', 'CPR quality', 'Chest compression', 'Heart compression', 'Cardiac compression', 'Basic life Support', 'Smart device', 'Smart Watch', 'Smartphone', 'Wearable device', 'Wearable technology', 'Apple watch', 'Samsung Galaxy', 'iPhone', 'mobile health application'. One of the study authors independently confirmed the search findings.

Search data extraction

All articles extracted from the 13 databases were reviewed by two reviewers independently (MA and YK). After excluding duplicated studies, the reviewers chose studies based on the titles and abstracts according to pre-defined selection criteria. Studies without available full text were excluded. Finally, a total of three reviewers (MA, YK, and WC) reviewed the full articles again. The study extraction processes were reviewed and confirmed by all reviewers.

Risk of bias assessment

The quality of the selected studies was assessed using the Cochrane risk of bias tool, RoB 2.0. Bias was evaluated according to five components: (1) bias arising from the randomisation process, (2) bias

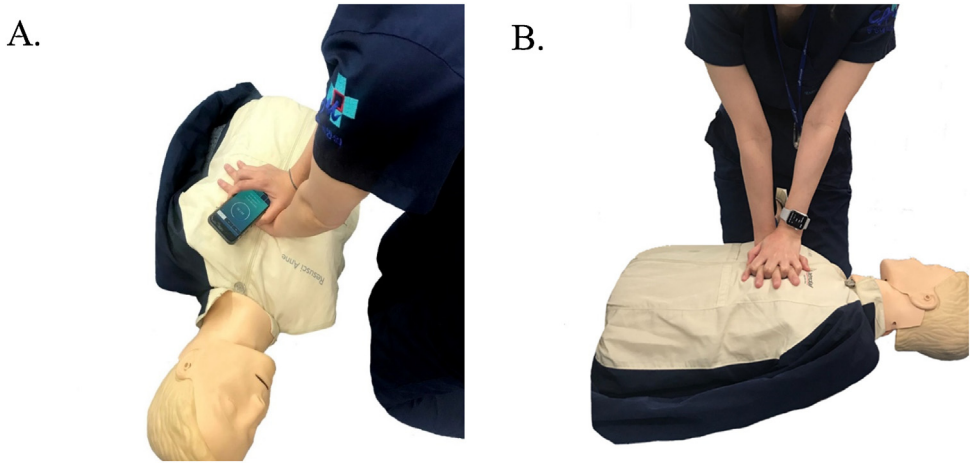


Fig. 1 – Performing CPR using a smart device with pre-installed app on the manikin. A. Smartphone; B. Smartwatch.

due to deviation from the intended intervention, (3) bias due to missing outcomes, (4) bias in outcome measurement, and (5) bias in selection of the reported results. The risk of bias for each study was rated as high, low, or of some concern. The initial assessments of bias risk were conducted by three investigators independently (MA, WC, and YK,). Subsequently, the assessments were compared and discrepancies identified among the investigators were resolved after discussion.

Outcomes

Several outcomes were analysed in the individual and integrated reviews of the included studies. The primary outcomes were based on CPR quality measurements: chest compression rate, mean chest compression depth, and proportion of adequate depth of chest compressions. Secondary outcomes comprised characteristics of the included studies such as study design, including intervention method and evaluation tools used; participant demographics and sample size; and type of smart device (smartphone or smartwatch) used for the CPR training. Six out of eleven studies performed post-training survey and the survey results were analysed as well.

Results

Search results

The PRISMA flow diagram in Fig. 2 depicts the selection process. The literature search initially yielded 131 articles from 13 electronic databases and reference reviews. Thirty-eight duplicated articles were excluded. The titles and abstracts of the remaining 93 studies were reviewed according to the eligibility criteria. Finally, a total of eleven studies were selected for inclusion in this systematic review.[9,10,15–23]

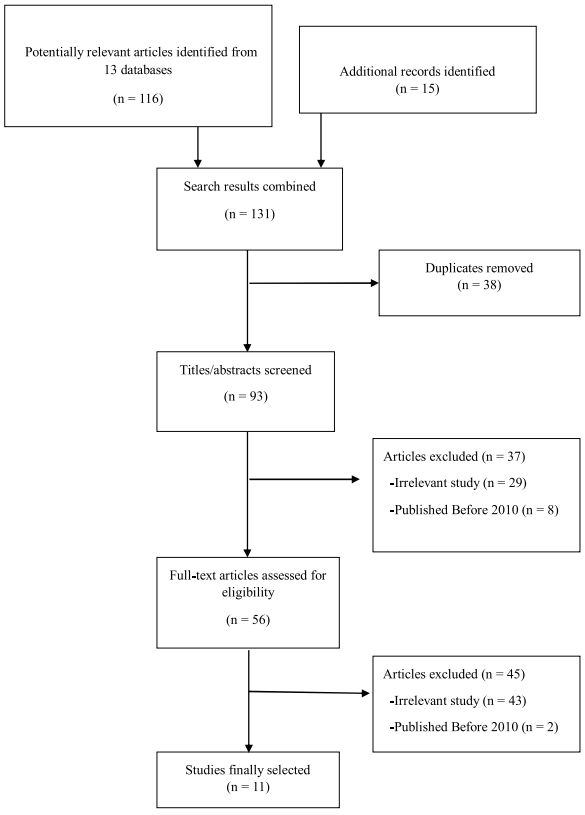


Fig. 2 – PRISMA flow diagram of study selection process.

Study characteristics

Table 1 shows the characteristics of the selected studies. The studies included five RCTs (45%),[9,16,19,22,23] five RCOTs (45%),[10,15,18,20,21] and an RT (9%).[17] Eight of 11 studies (73%) used smartphones[9,10,15–20] and 3 studies (27%)[21–23] used smartwatches for their CPR training intervention. All selected studies were written in English, although the literature search language selection included both English and Korean.

Risk of bias and methodological study quality assessment

Table 2 displays the summary assessment of risk of bias and methodological quality of the included studies using the Cochrane risk of bias tool, RoB 2.0. The randomisation process was assessed first. Five studies (45%) were rated as 'of some concern' or 'high' for this domain due to the lack of detailed information on the actual randomisation process used.[10,15,17,18,21] Second, 'bias due to deviation from intended intervention' was evaluated. Five RCTs/RTs (45%) were rated as 'of some concern' since they did not clearly comment on blinding to intervention.[9,16,17,19,22] Five RCOTs were rated as 'high' for this domain either due to insufficient rest time between experimental sessions[10,15,18,20] or due to lack of information on the resting period between experimental sessions.[21] Third, the 'bias due to missing outcome data' was measured. One study (9%) was rated as 'of some concerns' because detailed information on dropout cases was lacking.[21] Fourth, 'bias in measurement of the outcome' was assessed. All eleven studies (100%) were rated as 'low' for this domain as outcomes were evaluated with the use of manikins designed to measure CPR compression quality in accordance with pre-existing protocols.[9,10,15–23] Fifth, 'bias in section of the reported results' was evaluated. Five RCOTs were rated as 'of some concern' in this domain since there was not enough information on how potential carry-over effects were addressed.[10,15,18,20,21] Considering the significant between-study heterogeneity, a meta-analysis was not performed. The I^2s of chest compression rate, depth and proportion of adequate chest compressions between the studies were 66%, 81% and 63%, respectively.

Descriptions of intervention, outcome measurement, and evaluation tools

Table 3 shows the nature of the CPR training, the outcomemeasurements, and the evaluation tools. As a method of CPR training, the studies by Zapletal et al. and Truszewski et al. utilized the single rescuer CPR, using a 30:2 compression–ventilation ratio for a total of 8 min.[9,10] The studies by Chan et al., Park, and Gruenerbl et al. used 5 cycles of CPR at a 30:2 compression-ventilation ratio as well, but without actual mouth breathing.[16,17,21] The remaining studies used chest compression without ventilation for a total of 2 min[15,17,19,22,23] or 4 min.[18] In all studies, the outcomes recorded by the training manikins were linked to computer programs after the CPR training sessions. In seven out of eleven studies, the analysis of the results was conducted using Laerdal 's Resuscitation SkillReporter.[15,17–21,23]

Results of CPR training and effects on CPR quality

Table 4 and Fig. 3 show the results of the selected studies.

Rates of chest compression: All eleven studies evaluated the rates of chest compressions in their studies. In six out of eight

Table 1 – Characteristics of the included studies (*N* = 11).

Author (year published)	Country study conducted	Type of study	Participants	Numbers of participants	Participant pre-assessment			Smart devices used for CPR training	Apps used for CPR training
					Gender/ Age	BMI	Previous training		
Semeraro et al. (2011)	Italy	RCOT	Healthcare professionals, administrative staff	50	Yes/Yes	Yes	Yes	iPhone	iCPR®
Chan et al. (2012)	China	RCT	Personnel with auxiliary medical service first-aid certificate	50	Yes/Yes	Yes	Yes	iPhone	PocketCPR®
Park (2014)	Korea	RT	Personnel who completed CPR course	64	Yes/NI	NI	NI	iPhone and Galaxy	PocketCPR®
Park et al. (2014)	Korea	RCOT	Medical students	21	Yes/Yes	Yes	NI	iPhone	PocketCPR®
Zapletal et al. (2014)	Austria	RCT	Medical students	240	Yes/Yes	Yes	Yes	Zoll PocketCPR®, Laderal CPRmeter®, and iPhone	Zoll PocketCPR® Laderal CPRmeter®, iPhone app Zoll PocketCPR®
Sakai et al. (2015)	Japan	RCT	Laypersons with or without previous CPR training	87	Yes/Yes	NI	Yes	iPhone	Self-developed app compatible with iPhone to teach people how to respond to medical emergency.
Truszewski et al. (2016)	Poland	RCOT	Nurses	140	Yes/Yes	Yes	Yes	TrueCPR® (Physio-Control, Inc, Redmond, WA, USA) CPR-Ezy® (Health Affairs Ltd., Hertfordshire, US) iPhone	TrueCPR®, CPR-Ezy ® iCPR®
Eaton et al. (2018)	United Kingdom	RCOT	Laypeople who had not attended a CPR training course in the last 6 months	118	Yes/Yes	NI	NI	iPod touch	PocketCPR®
Gruenerbl, et al. (2015)	Japan	RCOT	Laypeople who received a single episode of CPR training previously	1st, 2nd & 3rd experiments: 40, 35 & 41, respectively	Yes/NI	NI	Yes	LG G-Watch R smartwatch with Android Wear OS	Self-developed app
Ahn et al. (2017)	Korea	RCT	Medical students	40	Yes/Yes	Yes	Yes	Samsung Galaxy Gear smartwatch	NI
Lee et al. (2018)	Korea	RCT	Medical students	30	Yes/Yes	Yes	Yes	Samsung Galaxy Gear smartwatch	NI

Abbreviations: RCT, randomised controlled trial; RT, randomised trial; RCOT, randomised cross-over trial; CPR, cardiopulmonary resuscitation; NI, no information. BMI, body mass index or height and weight.

Table 2 – Risk of bias and quality assessment of the included studies (*N* = 11).

Domain	Degrees of bias risk	*n* (%)
Randomisation	Low	6 (55)
	Some concerns	4 (36)
	High	1 (9)
Deviations from intended intervention	Low	1 (9)
	Some concerns	5 (45)
	High	5 (45)
Missing outcome data	Low	10 (91)
	Some concerns	1 (9)
	High	0 (0)
Measurement of the outcome	Low	11 (100)
	Some concerns	0 (0)
	High	0 (0)
Selection of reported overall results	Low	6 (55)
	Some concerns	5 (45)
	High	0 (0)

smartphone studies and all three smartwatch studies, all participants performed compressions within the recommended rates (100–120 compressions/min) according to the guidelines regardless of smart device use.[9,10,15–23] The mean compression rates of the control groups were faster in the study by Truszewski et al. and slower in the study by Sakai et al., than the current guidelines but the smartphone groups in both studies performed compressions within the recommended rates.[10,19]

Mean depth of chest compressions and proportion of adequate chest compressions: All studies evaluated the depth of chest compressions by investigating the average depth (mm or cm) of chest compressions and/or the proportion (%) of adequate depth of chest compressions. Seven out of eight smartphone studies reported the depth of chest compressions.[9,10,15–19] Among them, three studies by Park et al., Sakai et al., and Semeraro et al. did not find any significant difference between the smartphone groups and control groups.[15,18,19] Additionally, no studies apart from Zapletal et al. and Chan et al. were able to reach acceptable compression depth with smartphone use based on the current guidelines.[9,16] Two studies by Park and Truszewski et al. reported a significantly lower mean depth of chest compression with smartphone use.[10,18] Only one study by Chan et al. reported a significant improvement in chest compression depth leading to acceptable depths with smartphone use.[16] All three smartwatch studies evaluated the depth of chest compressions and the study by Lee et al. reported that chest compressions were significantly deeper in the smartwatch group when compared to the non-smartwatch use group, but still were not deep enough according to the ILCOR/AHA/ERC guidelines.[23] The other two smartwatch studies by Ahn et al. and Gruenerbl et al. reported that adequate chest compression depth was achieved by both study groups regardless of smartwatch use.[21,22]

Five out of eight smartphone studies reported the proportion of achieving adequate chest compression depth during CPR.[9,10,17–20] Among those, only one study by Eaton et al. reported a significantly higher proportion of individuals performed compressions of adequate depth while using smartphones when compared to controls.[20] However, all three studies that used smartwatches found that the proportion of chest compressions of adequate depth improved significantly with the use of a smartwatch.[21–23]

Post-training survey

Six of the eleven studies performed post-training surveys about the use of feedback devices during CPR (Table 4).[10,15–18,21] Apart from one study by Semeraro et al., the survey results showed that participants perception of smartphones as CPR aids tended to be negative.[15] For example, in a study by Chan et al., on a 1–5 Likert scale where 1 = completely disagree and 5 = strongly agree, participants' average response to the question of whether it was "easy to hold a smartphone during use" was 1.96; while Park et al. reported that participants' average response to whether it was "bothersome to compress chest while holding a smartphone" was 3.3.[16,18] In another study by Park, the most common complaint about the smartphone use during CPR training was that participants experienced pain in the back of the hand when administering compressions while also holding a smartphone.[17] Truszewski et al. survey participants on the ease of use of two different professional CPR devices, such as TrueCPR® and CPR-Ezy, and smartphone, the participants rated 3.9, 3.5 and 2.5, respectively, on a 1–5 Likert scale, where 1 = extremely difficult and 5 = extremely easy.[10] Only one study that used a smartwatch did a post-study survey and 93% of the participants were positive about using a smartwatch during CPR; participants noted that using a smartwatch as a CPR aid could help remove fear of doing damage while performing CPR.[21]

Discussion

To the best of our knowledge, this systematic review is the first to evaluate methodological quality and the effects of smart device use during CPR training. A total of eleven studies were finally selected for this systematic review.[9,10,15–23] Of the eleven full-text articles included in the qualitative analysis, we found that four studies (36%) were conducted in Korea.[17,18,22,23] The healthcare backgrounds of study participants in the eleven studies were diverse, including medical personnel such as doctors and nurses, medical students, and laypeople who had already completed basic CPR training or who had no previous knowledge of CPR. In this review, three studies (27% of the included studies) recruited laypeople as the only participants.[19–21] The sample sizes of the included studies were varied, but most studies (6 of 11, 55%) included ≤50 participants,[15,16,18,21–23] two studies (18%) included 51 to 100 participants,[17,19] and three studies (27%) included ≥100 participants.[9,10,20] In the methodological study quality assessment, most studies except that of Lee et al. had some bias due to deviation from the intended intervention.[23] This seems to be the nature of interventions using smart devices during CPR training, as strict blinding between researchers and participants is difficult. There also seemed to be carry-over effects because of insufficient rest time (2 min to 1 h) in five of the RCOT studies.[10,15,18,20,21]

To assess the effectiveness of smart device in CPR training, chest compression rate, mean chest compression depth and proportion of compressions of adequate depth were evaluated as the primary outcomes in this review. All eleven studies evaluated the chest compression rates during CPR.[9,10,15–23]

All eleven studies evaluated the rates of chest compressions in their studies. Other than two studies that reported either faster or slower mean compression rates of the control groups, based on the current recommended guideline, all other studies observed the acceptable chest compression rates in their study groups regardless

Table 3 – Descriptions of interventions, outcome measurements, and evaluation tools.

Author (year published)	Intervention description	Outcome measurement	Evaluation tool (brand name, name of company, country made)
Semeraro et al. (2011)	Group 1: CC with a smartphone for 2 min, 10 minute rest, followed by CC without a device for 2 min ($n=25$). Group 2: CC without a device for 2 min, 10 minute rest, followed by CC with a smartphone for 2 min ($n=25$)	Rate and depth of CC	Recording results using resuscitation manikin (Q-CPR Review, Laerdal Medical, Country unknown)
Chan et al. (2012)	Both smartphone ($n=25$) and non-smartphone ($n=25$) groups underwent 2 CPR scenarios as below. 1st Scenario: 2 sets of 5 cycles of 30:2 single rescuer CPR without actual mouth breathing (2 minutes' rest between each set) followed by 1 hour's rest; then 2nd Scenario: 2 sets of 200 CC with 2-minute rest between each set	Rate and depth of CC	Recording results using resuscitation manikin (AmbuSmartMan®, Amnu Inc, Country unknown)
Park (2014)	Smartphone group: 5 cycles of 30: 2 single rescuer CPR but without actual mouth breathing ($n=33$) Non-smartphone group: same CPR training ($n=31$)	Rate, depth and proportion of adequate depth of CC	Recording resuscitation manikin (Resusci Anne SkillReporter System®, Laerdal Medical, Norway)
Park et al. (2014)	Group 1: CC using a smartphone for 4 min, 1 hour's rest then followed by CC without a smartphone for 4 min ($n=21$) Group 2: Same training but in a reverse order ($n=21$)	Rate, depth and proportion of adequate depth of CC	Recording resuscitation manikin (Resusci Anne SkillReporter System®, Laerdal Medical, Norway)
Zapletal et al. (2014)	Single-rescuer CPR with mouth-to mouth ventilation at 30:2 ratio for 8 min using the PocketCPR® in three different devices or without any device ($n=60$ in each group)	(1) Rate, Depth and Proportion of adequate depth of CC (2) Absolute hands-off time and time till first CC (3) Ventilation parameters: Ventilation volume & time	Recording resuscitation manikin (Ambu® CPR software, Ballerup, Denmark)
Sakai et al. (2015)	Evaluated in a format of case scenario. Smartphone group: CC using the smartphone for 2 min ($n=43$) Non-smartphone group: CC for 2 min ($n=41$)	(1) % of participants who initiated CC adequately (2) Rate, Depth and numbers of adequate CC (3) Hands-off time during CPR	Recording resuscitation manikin (Resusci Anne SkillReporter System®, Laerdal Medical, Norway)
Truszewski et al. (2016)	All participants ($n=140$) performed single-rescuer CPR with mouth-to mouth ventilation using 3 different CPR feedbacks devices (TrueCPR®, CPR-Ezy®, and Smartphone-iCPR®) and without a feedback device in a randomised sequence: 8 min CPR, then twenty minutes' rest before switching the device	Rate, Depth and Proportion of adequate depth of CC as well as % of incorrect decompression	Recording resuscitation manikin (METIman Prehospital, CAE HealthCare, Saint-Laurent, Quebec, Canada)
Eaton et al. (2018)	Group 1: CC using the smartphone for 2 min, followed by another CC without the device for 2 minute 2 ($n=118$) Group 2: Same training but in an opposite sequence ($n=118$).	Rate and proportion of adequate depth of CC	Recording resuscitation manikin (Resusci Anne Skils Station®, Laerdal Medical, UK)
Gruenerbl et al. (2015)	1st training: Performed 5 cycles of CPR at 30:2 ratio (no actual ventilation) without the smartwatch and any education about current CPR regulations ($n=40$). 2nd training: Performed 5 cycles of CPR with the smartwatch and education about current CPR regulations ($n=41$) 3rd training: Performed 5 cycles of CPR without the smartwatch but with education about current CPR regulations 2 weeks later ($n=35$ after 6 people	Rate, depth and proportion of adequate depth of CC	Recording resuscitation manikin (Q-CPR Review, Laerdal Medical, Country unknown)

Table 3 *(continued)*

Author (year published)	Intervention description	Outcome measurement	Evaluation tool (brand name, name of company, country made)
	dropped out) This is to address whether to improve the performance by simply giving additional info on CPR		
Ahn et al. (2017)	Smartwatch group: CC for 2 min (n = 20) Non-smartwatch group: CC for 2 min (n = 20)	Rate, depth, proportions of adequate depth and complete decompression of CC	Recording resuscitation manikin (Resusci Anne SkillReporterTM System, Laerdal Medical, Norway)
Lee et al. (2018)	Smartwatch group: CC for 2 min (n = 15) Non-smartwatch group: CC for 2 min (n = 15)	Rate, depth, proportion of adequate depth of CC	Recording resuscitation manikin (Resusci Baby QCPR, Laerdal, Norway)

Abbreviations: CPR, cardiopulmonary resuscitation; CC, chest compression.

of smart device use (Table 4 and Fig. 3). This means that maintaining chest compressions within the recommended rates may not need additional assistance from smart device during CPR training. Next, seven out of eight smartphone studies and all three smartwatch studies evaluated the mean depth of chest compression. Among them, only the study by Chan et al. reported a significant improvement in compression depth to the point that compressions met the current guideline criteria with a smart device.[16] Of the remaining studies, recommended depth of compression was not reached by smart device or no significant differences in compression depth were identified between smart device and non-smart device groups (Table 4 and Fig. 3). These findings suggest that using smart device during CPR training might not be helpful for reaching or maintaining adequate depth of chest compressions during CPR training. Regarding proportion of compressions of adequate depth, five out of eight smartphone studies and all three smartwatch studies assessed this outcome. Among them, only one study by Eaton et al. reported a significantly higher proportion of compressions of adequate depth performed in the smartphone studies.[18] However, all three smartwatch studies reported that the proportion of chest compressions of adequate depth was significantly improved with smartwatch use.[21–23] Taken together, the use of smartwatches seems to aid the participants in performing more chest compressions of adequate depth (Table 4 and Fig. 3).

Overall, this review finds the lack of durable evidence about a beneficial role of using smart device in CPR training in terms of maintaining the recommended rates and depths of chest compressions during CPR according to the ILCOR/AHA/ERC guidelines. The similar CPR performance in terms of maintaining chest compression rates and depths between groups regardless of smart device use might be related to the study design as participants such as medical students were likely to be young and healthy and the training duration was relatively short. It has been reported that the number of appropriate chest compressions decreases in a prolonged cardiac arrest situation due to rescuer fatigue.[29,30] Perhaps, in this kind of traditional training setting, it would be difficult to address the fatigue factor that could be a critical determinant of clinical outcome at OHCA, which often require a prolonged CPR by a single rescuer. Of note, in the study of Park et al., the participants performed two rounds of 4 min chest compressions and the proportion of adequate depth of chest compression became significantly higher in the smartphone group after performing chest compressions for 2 min, suggesting the use of smart device might become more beneficial in the setting of prolonged CPR.[18] Given that smart device apps are directly aimed at guiding the administration of CPR in the context of OHCA, a study designed to simulate a real-time OHCA among diverse lay participants in terms of age, gender, etc. that, in particular, addresses fatigue from prolonged CPR could help us better understand the potential role of these devices for lay response to OHCA emergencies.

Although smart device use did not help significantly from the standpoint of mean compression rate or depth, the smartwatch as a real-time feedback device shows some promise in aiding users to administer more chest compressions of adequate depth as all the smartwatch studies reported a significant improvement in this regard. However, we cannot conclude that smartwatch is better than smartphone in this regard since there were only three smartphone studies included in this review and was no direct comparison study between devices. The major drawback of using a smartphone is the difficulty of holding it while performing chest compressions, which can lead to the redistribution of force while holding the device or sliding during chest compressions, preventing the execution of effective chest compressions. This might be the reason why two studies by Park and Truszewski et al. reported a significantly lower mean depth of chest compression with smartphone use.[10,18] Therefore, it is not surprising that the most common complaint about using a smartphone during chest compression was that it was bothersome to compress chest while holding a smartphone although the apps were easy to use in post-training surveys. One study by Semeraro et al. used arm band to avoid these challenges, but it will not be easy to wear arm band in a real-time CPR situation from practicality standpoint.[15] Unlike smartphones, smartwatches do not need to be placed on the chest of patients during CPR and can be easily worn. Thus, it is quite possible that holding vs. wearing a device could have made a difference in study outcomes with respect to accuracy of chest compression.

There are a few more things worth to mention. In the study by Park et al., males performed more adequate chest compressions regardless of smartphone use.[18] Interestingly, Zapletal et al. reported that the absolute hands-off time during CPR was shorter in the smartphone group than in the non-smartphone group, which can be another potential advantage of using a device.[9] The study by Sakai et al. found that a smartphone with a self-developed app designed to teach laypeople how to respond to medical emergency helped initiation and appropriate maintenance of CPR when used in a real case scenario, which suggests that such apps and smart devices may also play beneficial role in initiating CPR during OHCA

Table 4 – Major Study Results.

Author (year published)	Major results (smart device group's vs. non-smart-device group's)	Authors' conclusion
Semeraro et al. (2011)	(1) Mean CC rate: 101.1 min^{-1} in the smartphone group vs. 107.8 min^{-1} in the non-smartphone group ($p < 0.01$) (2) Mean CC depth: 37.2 mm in the smartphone group vs. 41.1 mm in the non-smartphone group ($p = 0.28$)	(1) Smartphone use was useful to maintain CC. (2) "The smartphone was useful to maintain CC": 6.3 on a seven-point Likert scale (1 = completely disagree and 7 completely agree).
Chan et al. (2012)	(1) Mean CC rate ($p < 0.05$): Smartphone group vs. Non-smartphone group 105.19 min^{-1} vs. 118.58 min^{-1} at 1st set scenario 1 ($p < 0.0001$); 105.23 min^{-1} vs. 119.36 min^{-1} at 2nd set of scenario 1($p < 0.0001$); 106.10 min^{-1} vs. 121.08 min^{-1} at 1st set of scenario 2 ($p < 0.0001$); 106.61 min^{-1} vs. 117.42 min^{-1} at 2nd set of scenario 2 ($p < 0.0001$). (2) Mean depth of CC: Smartphone group vs. Non-smartphone group 5.22 cm vs. 4.56 cm at 1st set of scenario 1 ($p = 0.002$); 5.30 cm vs. 4.56 cm at 2nd set of scenario 1 ($p = 0.001$); 5.34 cm vs. 4.56 cm at 1st set of scenario 2 ($p < 0.0001$); 5.35 cm vs. 4.49 cm at 2nd set of scenario 2 ($p < 0.0001$)	(1) Smartphone use improved the quality of CC in terms of depth. (2) "Pocket CPR is easy to hold during use": 1.96 on a five point Likert scale (1 = strongly disagree and 5 = strongly agree).
Park (2014)	(1) Mean CC rate: 108.09 min^{-1} in the smartphone group vs. 114.25 min^{-1} in the non-smartphone group ($p = 0.007$) (2) Mean depth of CC: 48.35 mm in the smartphone group vs. 53.77 mm in the non-smartphone group ($p < 0.002$) (3) Proportion of adequate CC: 60.51% in the smartphone group vs. 73.96% in the non-smartphone group ($p^* = 0.13924$) Males were more adequate in CC in both groups ($p < 0.05$)	(1) Smartphone use did not improve the quality of CPR. (2) Most common complaint of using a smartphone: Pain in the back of the hand with the device (48.5%).
Park et al. (2014)	(1) Mean CC rate: 103.30 min^{-1} in the smartphone group vs. 107.12 min^{-1} in the non-smartphone group ($p = 0.133$) (2) Mean depth of CC: 47.6 mm in the smartphone group vs. 45.3 mm in the non-smartphone group ($p = 0.085$) (3) Proportion of adequate CC depth: 45.7% in the smartphone group vs. 27.0% in the non-smartphone group ($p^* = 0.3012$) (4) After 2 min, the proportion of adequate depth of CC was significantly higher in the smartphone group ($p < 0.05$).	(1) Smartphone use improved accuracy of CC during prolonged (4 min) CPR. (2) The participants answered: easy to use (4.1) but bothersome to compress chest while holding a smartphone (3.3) on a 5-point Likert scale (1 = completely disagree and 5 = completely agree).
Zapletal et al. (2014)	(1) Mean CC rate: 105 min^{-1}, 112 min^{-1}, 107 min^{-1} and 113 min^{-1} in PocketCPR®, CPRmeter®, Smartphone and standard CPR, respectively. (Smartphone vs. standard CPR, $p = 0.002$; others non-significant) (2) Mean depth of CC: 5.8 cm, 5.9 cm, 5.9 cm and 5.5 cm in PocketCPR®, CPRmeter®, Smartphone and standard BLS, respectively. (Smartphone vs. standard CPR, $p = 0.004$; others non-significant) (3) Proportion of adequate depth increased by 9% with use of Zoll PocketCPR®, 5% with CPRmeter®, but decreased by 3% with the smartphone and 1% with standard CPR ($p < 0.001$ for Zoll PocketCPR® vs. standard CPR; others non-significant) (4) Absolute hands-off time was 99, 99, 88, 103 s with the PocketCPR®, CPRmeter®, smartphone and standard CPR, respectively (smartphone vs. standard CPR, $p = 0.013$; others non-significant) (5) Time to first CC: 15 s, 5 s, 6 s, and 0 s in Zoll PocketCPR® group, CPRmeter®, smartphone, and standard CPR, respectively	Overall CPR performance using CPR feedback devices were suboptimal. All feedback devices caused substantial delay in starting CPR, which may worsen outcome.
Sakai et al. (2015)	(1) % of participants who initiated CC adequately: 100% in the smartphone group vs. 75.6% in the non-smartphone group (2) Mean CC rate for 2 min: 211.6 in the smartphone group vs. 77.0 in the non-smartphone group ($p < 0.001$) (3) Mean depth of CC: 3.5 cm in the smartphone group vs. 3.67 cm in the non-smartphone group ($p = 0.492$) (4) Time without CC: 4.4 s in the smartphone group vs.	Smartphone use with newly-developed CPR support app helped initiation of CPR adequately and to maintain appropriate rate of CC. Time without CC was significantly reduced with the smartphone use.

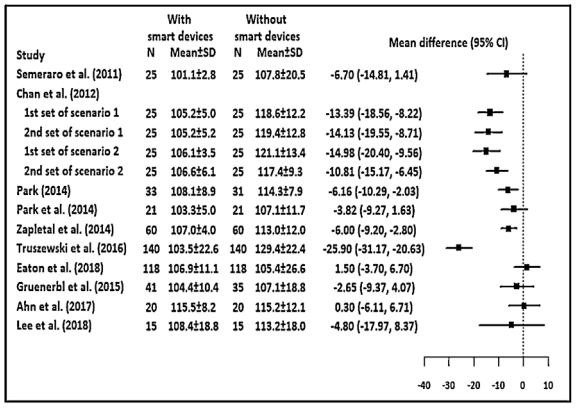
Table 4 *(continued)*

Author (year published)	Major results (smart device group's vs. non-smart-device group's)	Authors' conclusion
	63.8 s in the non-smartphone group ($p < 0.001$) (5) Above findings are still valid irrespective of previous CPR training history	
Truszewski et al. (2016)	(1) Mean CC rate: 129.4 min^{-1}, 110.2 min^{-1}, 101.5 min^{-1} vs. 103.5 min^{-1} in the group of standard CPR, TrueCPR®, CPR-Ezy®, and smartphone (Standard CPR vs. TrueCPR® $p < 0.001$, Standard CPR vs. CPR-Ezy® $p < 0.001$, Standard CPR vs. smartphone $p < 0.001$; TrueCPR® vs. CPR-Ezy® $p < 0.001$; TrueCPR® vs. smartphone $p < 0.001$; others non-significant). (2) Mean depth of CC: 44.6 mm, 54.5 mm, 45.6 mm, 39.6 mm in the groups of standard CPR, TrueCPR®, CPR-Ezy®, and smartphone (Standard CPR vs. TrueCPR $p < 0.001$, standard CPR vs. smartphone $p = 0.031$, TrueCPR® vs. CPR-Ezy® $p < 0.001$, TrueCPR® vs. smartphone $p < 0.001$, CPR-Ezy® vs. smartphone $p = 0.023$; others non-significant) (3) Proportion of adequate depth: 37.5%, 85.6%, 39.5% vs. 33.4% in the group of standard CPR, TrueCPR®, CPR-Ezy® and smartphone, respectively (TrueCPR® vs. standard CPR $p < 0.001$, TrueCPR® vs. CPR-Ezy® $p < 0.001$, TrueCPR® vs. smartphone $p < 0.001$; others non-significant). (4) TrueCPR® showed the highest level of proper CC over time (total 8 min)	(1) Only TrueCPR® significantly improved the portion of effective CC compared to standard CPR. (2) The smartphone was significantly worse compared to standard CPR with regard to compression depth. (3) The smartphone was the worst rated device in terms of "easy of use": 2.5 points on a 1–5 Likert scale (5: extremely easy & 1: extremely difficult) compared to 3.9 and 3.5 for TrueCPR® and CPR-Ezy®, respectively.
Eaton et al. (2018)	(1) Mean CC rate: 106.87 min^{-1} in the smartphone group vs. 105.37 min^{-1} in the non-smartphone group ($p = 0.858$) (2) Proportion of adequate CC depth: 90.86% in the smartphone group vs. 66.24% in the non-smartphone group ($p = 0.001$)	Smartphone use improved the CPR quality in terms of proportion of adequate depth.
Gruenerbl et al. (2015)	(1) Mean CC rate: 102.12 min^{-1}, 104.4 min^{-1} vs. 107.05 min^{-1} in the groups without a smartwatch and CPR education, the group with smartwatch, and the group without a smartwatch but with CPR education, respectively ($p = 0.44$) (2) Mean depth of CC: 60.49 mm, 59.76 mm vs. 61.66 mm in the above-mentioned three groups, respectively ($p = 0.30$) (3) Proportion of adequate CC depth: 48.31%, 65.01% vs. 45.15% in the above-mentioned three groups, respectively ($p = 0.01$)	Smartwatch use could maintain the rate and depth of CC, and improved proportion of adequate depth of CC. 93% participants were positive about using the smartwatch during CPR.
Ahn et al. (2017)	(1) Mean CC rate: 115.5 min^{-1} in the smartwatch group vs. 115.2 min^{-1} in the non-smartwatch group ($p = 0.555$) (2) Mean depth of CC: 53.1 mm in the smartwatch group vs. 51.1 mm in the non-smartwatch group ($p = 0.927$) (3) Proportion of adequate depth: 64.6% in the smartwatch group vs. 43.1% in the non-smartwatch group ($p = 0.049$) (4) Proportion of complete chest decompression: 100% in both groups	Use of the smartwatch could improve the quality of CPR with regard to proportion of adequate depth of CC.
Lee et al. (2018)	(1) Mean CC rate: 108.4 min^{-1} in the smartwatch group vs. 113.2 min^{-1} in the non-smartwatch group ($p = 0.482$) (2) Mean depth of CC: 40.9 mm in the smartwatch group vs. 38.1 mm in the non-smartwatch group ($p = 0.004$). (3) Proportion of correct depth: 98.7% in the smartwatch group vs. 79.3% in the non-smartwatch group ($p = 0.002$)	The smartwatch device could improve the quality of CPR with regard to the accuracy of CC.

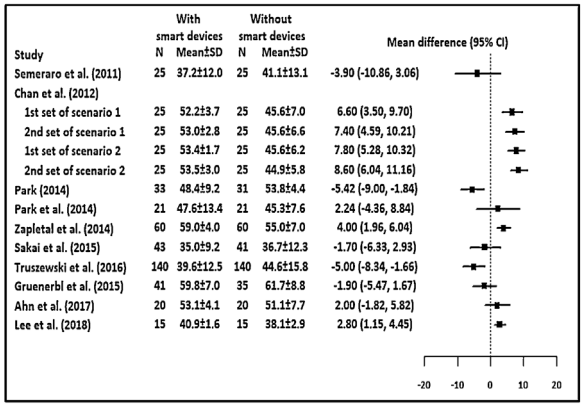
Abbreviations: CPR, cardiopulmonary resuscitation; CC, chest compression. *Note*: The *p* values are described as written in their studies; Some *p* values were not reported in the manuscripts of Semeraro et al. (2011), Chan et al. (2012), and Gruenerbl et al. (2015), and therefore, they had to be calculated using Review Manager Version 5.3. *P**: Recalculated *p* values by *t*-test.

emergencies.[19] In the study of Gruenerbl et al., 93% of participants reported that a smartwatch could remove fear of doing damage while performing CPR,[21] which could be a huge benefit to a public bystander during an OHCA emergency. There are some limitations. This review included the studies written in English, and therefore there may be a possibility of selective reporting. In addition, it is possible that publication bias if studies with non-significant results were not published. Further, many of the studies included in this systematic

A.



B. .



C.

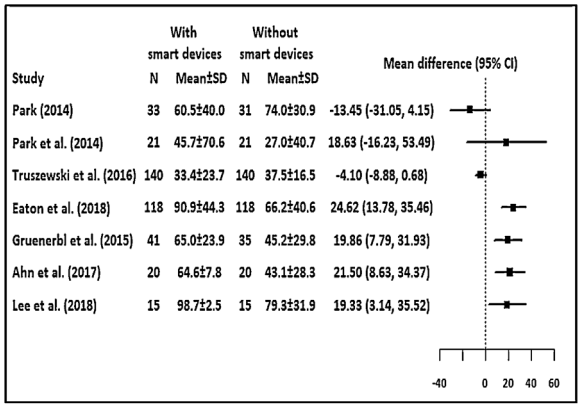


Fig. 3 – Forest plot of rates of chest compression (A), mean depths of chest compressions (B), and proportions of chest compressions of adequate depth (C). CC rate of the study by Sakai et al. is not presented because only the CC rate over 2 min was available (A). In the studies by Zapletal et al., Truszewski et al. and Gruenerbl et al., data from control and smartphone groups are only shown (A–C). In the study of Gruenerbl et al., data from the control group with education and smartwatch group are only presented (A–C). The study by Zapletal et al. only provided the relative changes of proportion, so their data are not shown (C). The study by Park presents the proportion of adequate CC (not adequate depth) (C).

review had a small number of subjects in their studies. Thus future studies with larger sample sizes might be necessary before reaching a firm conclusion.

Conclusions and implications

To the best of our knowledge, this systematic review is the first to examine the methodological quality of the involved studies and to identify the effectiveness of smart devices at improving CPR quality during CPR training. Overall, this review does not find durable evidence of a beneficial role from using smart devices in CPR training in terms of maintaining the recommended chest compression rate and depth during CPR according to the ILCOR/AHA/ERC guidelines. However, smartwatches may improve the proportion of chest compressions of adequate depth during CPR. Overall, research with these devices is still in its infancy and further studies are required to determine whether the use of smart device can improve the quality of CPR. Given that many of the studies included in this systematic review had a small number of subjects in their studies, future studies with larger sample sizes might be necessary before reaching a solid conclusion. Further, a study that compares smartphones and smartwatches as CPR aids may be needed as well.

Conflicts of interest

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