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ORIGINAL RESEARCH

Effectiveness of real-time chest compression feedback devices for individuals experienced in cardiopulmonary resuscitation: a randomized controlled simulation study

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Abstract

The present study aims to evaluate the impact of a new feedback device with the algorithm measuring the chest compression (CC) depth during a simulation of adult cardiac arrest. We designed a randomized controlled study and included participants who were healthcare providers over 18 years old, had undergone at least one basic life support training program, and had experience conducting cardiopulmonary resuscitation (CPR) in real-life situations. We used the CPR manikin, and the feedback system of a light-weight portable feedback device which was developed and validated. Feedback device can connect wirelessly to an application installed on a general-purpose device. Primary outcome was the mean of CC depth and secondary outcomes were the accuracy of CC depth, the proportion of accurate CC depth, the CC rate, and the proportion of complete chest decompression. In a study with 45 participants randomized into two groups, no significant difference in mean CC depth was observed between the groups (5.0 ± 0.7 and 5.3 ± 1.0, $p = 0.098$). However, the group using the CPR feedback device demonstrated significantly higher accuracy in CC depth (66.7%) compared to the control group (24.4%, $p < 0.001$). Multivariate analyses identified the feedback device improving CC depth accuracy, highlighting its potential to enhance CPR quality by ensuring compressions meet the guideline-recommended depths (adjusted odds ratio 7.08, 95% confidential intervals 2.67–18.75). The study reveals that the feedback device was effective in enhancing the accuracy of CC depth during CPR by experienced healthcare providers.

Keywords

Cardiopulmonary resuscitation; Chest compression; Device; Feedback; Simulation

1. Introduction

Cardiopulmonary resuscitation (CPR) guidelines are revised and published every 5 years by the American Heart Association, the European Resuscitation Council, and the Korean Association of Cardiopulmonary Resuscitation [1–3]. In the realm of basic life support, there is strong emphasis on CPR quality, particularly focusing on the appropriate depth and rate of chest compressions (CCs). The guidelines recommend a compression depth of 5–6 cm and a rate of 100–120 compressions per minute, recommendations that have remained consistent in recent years [1–3]. Excessive compression can result in complications such as rib fractures, hemothorax, or other complications, and may even compromise effective diastolic arterial pressure [4, 5]. These guidelines highlight the potential benefits of using feedback devices [1–3] and several meta-analyses have also highlighted their efficacy [6–8].

Previous feedback devices, often were cumbersome, heavy, had limited portability. Recent studies have utilized feedback applications developed for mobile devices, such as smartphones and smartwatches, to provide CPR feedback [9–11]. However, the accuracy of versatile devices that are worn on the body may not be as high as those used on the victim's chest surface. In response, our research team developed a lightweight and portable dedicated CPR feedback device that improves stability and adds ergonomic elements to existing cardholder-type products [12]. The portable device, weighing 130 g, can be wirelessly connected to versatile devices outfitted with monitors, and is designed for use with patients in hospital and non-hospital settings. To demonstrate the clinical use of the developed device, we conducted simulations of adult cardiac arrest and evaluated whether the device improved the CPR indicators. We sought to determine whether this could help improve CC quality.

2. Methods

2.1 Study design

We designed a prospective, randomized, controlled crossover study to evaluate the impact of a new feedback device with an algorithm that measures CC depth with real-time feedback during adult cardiac arrest simulations. This study was performed at the emergency department of a tertiary hospital (Seoul, Republic of Korea) in August 2023.

2.2 Participants

The inclusion criteria were (1) healthy persons over 18 years old and (2) healthcare providers who had undertaken at least one basic life support training program and had experienced CPR in real-life situations. Participants with wrist or back pain, or lung or heart diseases were excluded. The participants approved the content of this study and provided written informed consent.

To measure the sample size for this experiment, we referred to a previous study on a ring-shaped feedback device to investigate the CC depth values based on the presence or absence of feedback [13]. The sample size was determined by utilizing the results of CC depth from 20 individuals in the group without CC feedback (mean 50.5, standard deviation (SD) 6.1) and 20 individuals in the group with real-time feedback (mean 44.4, SD 9.4). The sample size was calculated using the *t*-test and the "pwr" package in the statistical analysis program R (version 4.2.3). The α-error value was set at 0.05 and power $(1 - \beta)$ at 0.9, and with an effect size of 0.8, the minimum sample size was 36 individuals. Considering a drop rate of 10%, the required sample size was 40 participants. Finally, 45 participants were included in this study.

2.3 Hardware system of the developed devices

We developed a lightweight portable device to provide feedback on the depth and rate of CC, as shown in Figs. 1,2, respectively. The device is designed to ensure user comfort while performing CPR. The overall device dimensions were $99.5 \times 75.0 \times 16.7$ mm^3 (length, width, depth) with a weight of 130 g (Fig. 2).

The device includes a battery (3.7 V, 300 mAh), a nine-axis (three-axis accelerometer, three-axis gyroscope, three-axis magnetometer) inertial measurement unit sensor (ICM-20948, InvenSense, San Jose, CA, USA), force sensitive receptor sensor (RA30P), and an integrated module (NRF52832, Nordic Semiconductor, Trondheim, Norway) that combines a microprocessor (ARM M4 Cortex) with a bluetooth module. The algorithm for measuring CC depth was based on a previous study and optimized for this device [11, 13].

This device can connect wirelessly to an application installed on all purpose device, including a tablet computer or smartphone, and displays information regarding the real-time pressure depth and rate on the screen. Fig. 3 showcases the method received the real-time CPR information for participants and the interaction between devices. Prior to the simulation, participants were thoroughly oriented on the proper use of the device to ensure effective interaction.

2.4 Experimental materials used for simulation

We used the BT-CPTA-PLUS™ manikin (BT Inc., Goyang, Korea), and a dedicated recording program was operated on a laptop during the simulation (Fig. 4). The program estimated the CC depth, decompression depth, and compression rate using a mounted sensor, indicating adequate or inadequate compression of the central chest of the manikin. The experiment was conducted on a flat, firm floor. With CC feedback device, the participants performed CCs on the feedback device placed on the chest of the manikin while watching the mobile application display for CPR feedback information. The information included CC depth, rate, and decompression in real time. Without feedback device, the participants performed CCs on the manikin's chest directly.

2.5 Intervention and control

In the intervention experiment, participants initiated CC with real-time feedback from the developed device. Conversely, participants in the control experiment performed CC without any feedback.

All the participants were randomly allocated to two groups in a 1:1 ratio (groups A and B). Group A underwent the intervention experiment, followed by a control experiment 1 h later. Group B underwent the control experiment, followed by the intervention experiment 1 h later. The intervention experiment involved the participants initiating CCs while using the feedback system. Compression was continued for 2 min, without rescue breathing, while the participant was in a kneeling position next to the manikin. The control experiment was conducted using the same parameters, except that no feedback system was used. A partition was placed on the floor between the investigators and participants so that the investigators could not recognize the participant group during the experiment. Additionally, before the participants joined the experiment, only the experiment coordinator knew the participants' identities, and personal information was anonymized. Our experimental data were anonymized and assigned sequential numbers to further maintain blinding. When analyzing the data, the investigator could not recognize the participant group or any individual participant. Participant characteristics, such as age, height, weight, number of CPR training sessions, length from the last training session, and number of real-life CPR sessions, were evaluated. Data were downloaded and collected directly from the manikin recording system by an author blinded to the participants' group allocation.

2.6 Primary and secondary outcomes

The primary outcome was the mean of CC depth, which was calculated as the average of CC depth over a 2 min period. Secondary outcomes that were examined included the accuracy of CC depth, the proportion of accurate CC depth, the CC rate, and the proportion of complete chest decompression. The categorical outcome of CC depth accuracy was established as the mean value of CC depth falling within the range of 5 to 6 cm. Furthermore, the accurate CC depth proportion was calculated by dividing the count of CC with a depth ranging

FIGURE 1. The cardiopulmonary resuscitation simulation manikin and the developed feedback device.

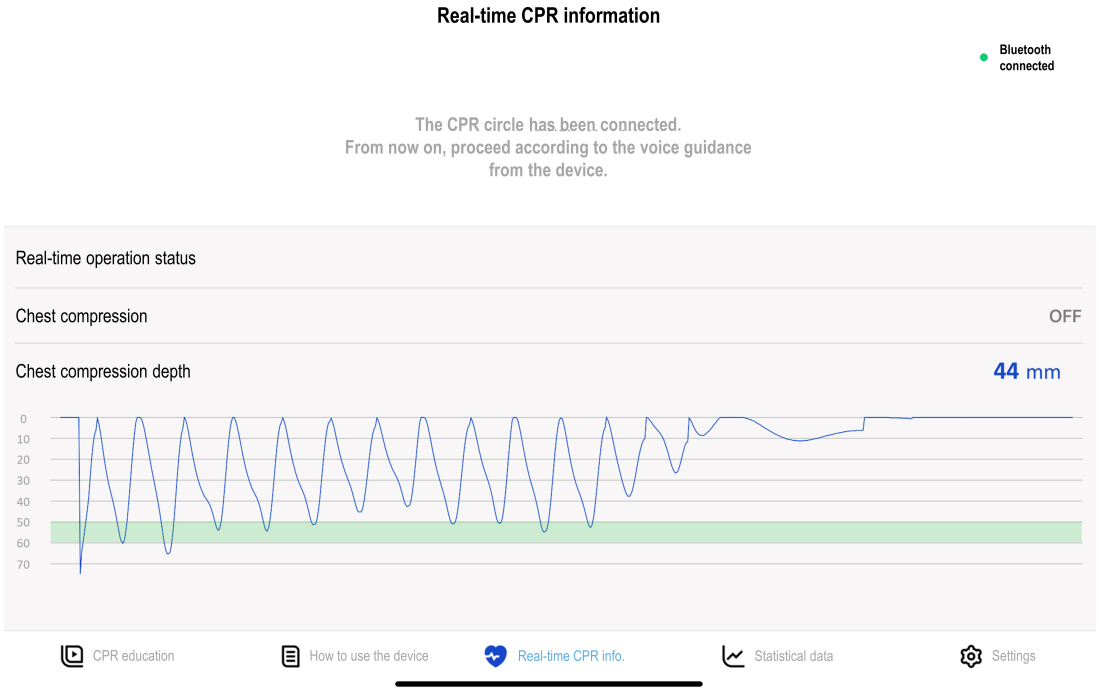

FIGURE 2. Information regarding the cardiopulmonary resuscitation as shown in the application.

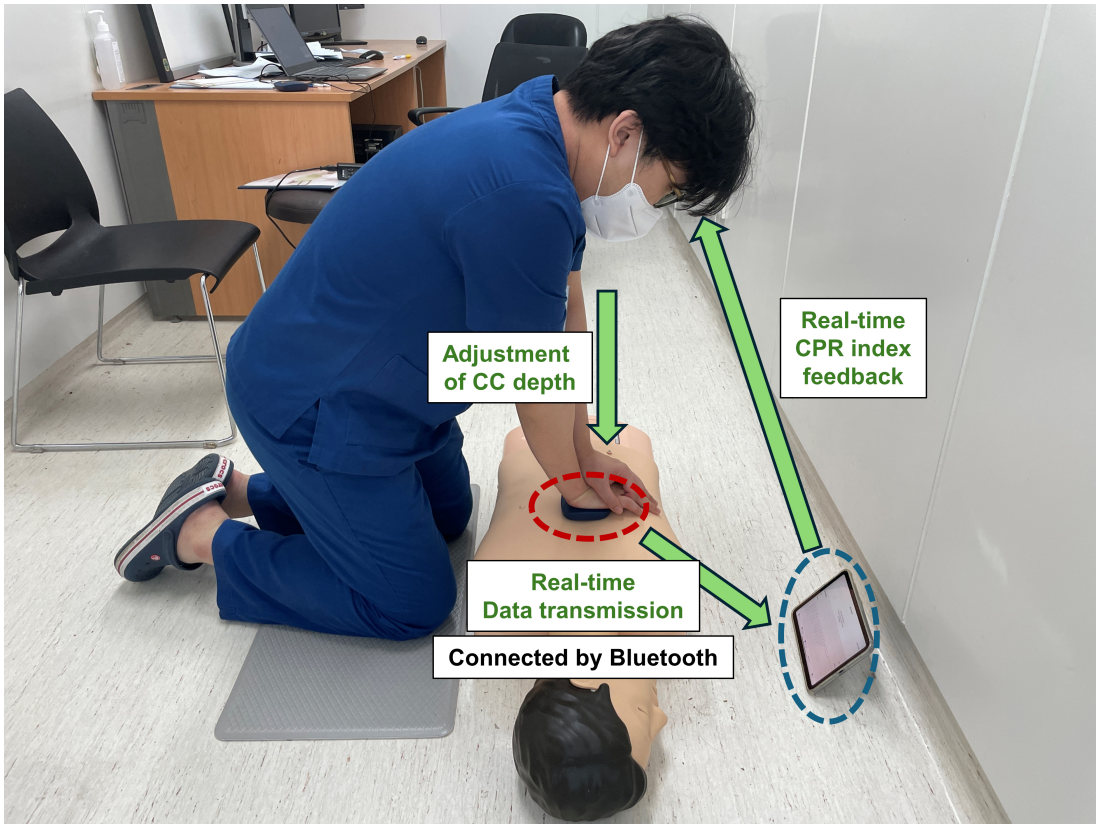

FIGURE 3. A schematic diagram depicting the interaction of feedback provided to rescuers during cardiopulmonary simulation.

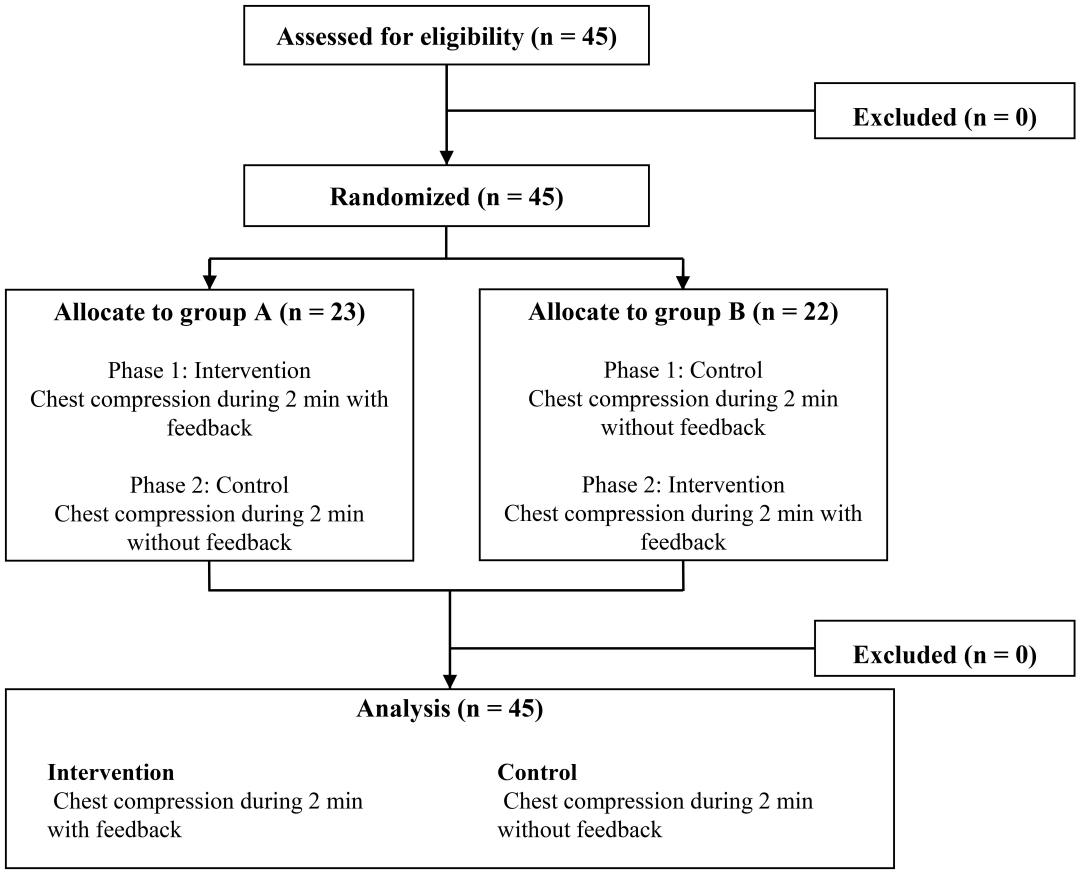

FIGURE 4. A flowchart of the participant enrollment process.

from 5 to 6 cm by the total count of CC in two-minute period. CC rate was specified as the quantity of CC in 1 min. The ratio of decompressions with recoil depths of less than 1 cm to the total number of decompressions performed in two-minute period was utilized to calculate the proportion of complete chest decompression.

2.7 Statistical analysis

The R (version 4.2.3, The R Foundation for Statistical Computing) and Excel 2019 (Microsoft, Redmond, WA, USA) programs were used to analyze the experimental records. The overall characteristics were expressed through the utilization of descriptive statistics. Normal distribution of data was assessed using the Shapiro-Wilk test. Non-normally distributed variables were represented as medians with interquartile ranges (IQR) and 95% confidence intervals (CI), while normally distributed variables were expressed as mean ± SD with 95% CI. In order to analyze normally distributed variables, the paired *t*-test was applied. A nonparametric method known as the Wilcoxon signed rank sum test was implemented in order to compare continuous variables. A Friedman test was employed to evaluate the mean CC depth values of the two groups throughout the duration of compression. By identifying factors that influenced the outcomes and comparing effect sizes, both linear and multiple logistic regression analyses were conducted. Logistic regression using the "enter" method was independently performed. Age, sex (male), body mass index, number of CPR training received, length from the last training received, number of real CPR intervention, feedback in simulation were adjusted for. *p*-values less than 0.05 were regarded as indicators of findings that were statistically significant.

3. Results

3.1 Group allocation and participant characteristics

The experiment included 45 participants, including group A (n = 23) and group B (n = 22) (Table 1). The median number CPR training programs undertaken per participant was 2 (2–3), the median number of months since the last training session was 21 (17–31), and the median number of real-life CPR interventions provided by the participants was 20 (10–50). Fig. 3 shows the group allocation.

3.2 Outcomes of CC

There was no significant difference observed in the mean CC depth between the participants who received feedback (5.0 ± 0.7 cm) and those who did not (5.3 ± 1.0 cm, $p = 0.098$). The participants who received feedback achieved a considerably higher accuracy of CC depth (30/45, 66.7%) compared to the control (11/45, 24.4%) ($p < 0.001$). In the feedback condition, the percentage of accurate CC depth was considerably higher compared with in the control (49.6 ± 36.8% *vs.* 29.6 ± 30.6%, $p = 0.006$) (Table 2).

The multivariable linear regression analysis showed significant association between feedback and the mean of CC depth, after adjusting for all other variables, with an adjusted R-squared value of 5% (Table 3). All values had a variance inflation factor of less than 2.6 and there was no multicollinearity [14]. In multivariate logistic regression, feedback was the only factor influencing the accuracy of CC depth after adjusting variables (adjusted OR 7.08, 95% CI 2.67–18.75, $p < 0.001$) (Table 4).

4. Discussion

This study aimed to evaluate the efficacy and usability of a newly designed light-weight CPR feedback device to ensure conformity with CPR guideline recommendations [1–3]. The feedback device enhanced the accuracy of CC depth in this study, indicating its value in eliminating insufficient compression depth and lowering the hazards of over-depth compression, such as rib fractures, hemothorax, sternal fracture, retrosternal and mediastinal hematoma, lung injury, or cardiac injury [4, 5, 15, 16]. In addition, as this study was conducted by experienced medical personnel who performed real-life CPR interventions, the significance of these findings is heightened by their potential implications for the quality of CPR administered, thereby influencing patient outcomes in CPR scenarios. In light of previous investigations, this finding might be viewed as another research that supports the significance of feedback devices. Around 40% of rescuers, including professional healthcare personnel, did CC with inadequate depth [2, 17, 18].

The results of this study illustrate a notable increase in the accuracy of CC depth when a feedback device was used. This emphasizes its effectiveness in conforming to the CPR guidelines and reducing the risks associated with improper

TABLE 1. Baseline characteristics of the participants.

Characteristic	Population			*p* value
	Total (n = 45)	Group A (n = 23)	Group B (n = 22)	
Sex, male	24 (53%)	15 (63%)	9 (38%)	0.102
Age, yr	28.0 (26.0–30.0)	27.0 (26.0–28.5)	28.0 (25.8–30.8)	0.526
Body mass index	23.0 ± 3.5	23.9 ± 3.4	22.4 ± 3.4	0.943
No. of CPR training	2.0 (2.0–3.0)	2.0 (2.0–3.5)	2.0 (1.3–3.0)	0.807
Length from the last training, mon	21.0 (17.0–31.0)	21.5 (8.2–31.8)	27.6 (17.2–44.8)	0.519
No. of real CPR intervention	20.0 (10.0–50.0)	30.0 (10.0–50.0)	15.0 (1.3–100.0)	0.077

Values are presented as mean ± SD or median (IQR). BMI, body mass index; CPR, cardiopulmonary resuscitation.

TABLE 2. Outcomes of chest compression according to feedback.

Outcomes	No Feedback (N = 45)	Feedback (N = 45)	*p*
CC depth	5.3 ± 1.0 cm	5.0 ± 0.7 cm	0.098
Accuracy of CC depth	11 (24.4%)	30 (66.7%)	<0.001
Proportion of accurate CC depth	29.6 ± 30.6%	49.6 ± 36.8%	0.006
CC rate, per min	108.4 ± 15.8	108.5 ± 11.2	0.988
Proportion of complete chest decompression	99.5 ± 2.2%	98.4 ± 6.3%	0.239

Values are presented as mean ± SD or number (proportion). CC, chest compression.

TABLE 3. Multivariate linear regression analysis for the mean of CC depth.

Variable	β	*t*	*p*
Intercept	−0.40	−0.01	0.993
Age	0.17	0.12	0.906
Sex, male	−0.87	−0.08	0.939
BMI	1.21	0.76	0.449
No. of CPR training	1.40	0.49	0.628
Length from the last training	−0.27	−0.85	0.399
No. of real CPR intervention	0.01	0.12	0.906
Feedback	19.98	2.77	0.007

R^2 = 0.125, $_{adj}R^2$ = 0.05, D-W = 1.91. BMI, body mass index; CPR, cardiopulmonary resuscitation.

TABLE 4. Multivariate logistic regression analysis for the accuracy of CC depth.

Variable	Adjusted OR (95% CI)	*p*
Intercept	1.16 (0.00–731.78)	0.964
Age	0.93 (0.77–1.13)	0.469
Sex, male	0.41 (0.09–1.87)	0.250
BMI	1.03 (0.83–1.26)	0.801
No. of CPR training	1.28 (0.87–1.88)	0.206
Length from the last training	0.99 (0.94–1.03)	0.510
No. of real CPR intervention	1.00 (0.99–1.01)	0.914
Feedback	7.08 (2.67–18.75)	<0.001

Nagelkerke R^2 = 0.295. BMI, body mass index; CI, confidence intervals; CPR, cardiopulmonary resuscitation; OR, odds ratio.

compression depth. Notably, while both groups achieved an average CC depth within the recommended 5–6 cm range, the control group displayed higher variability, leading to reduced accuracy. This underscores the role of the device in ensuring a consistent CC depth. The utilization of the feedback device not only enhances the precision of chest compressions but also serves as an educational tool for healthcare professionals, reinforcing the critical aspects of effective CPR [7, 19–23]. By providing real-time feedback, the device assists in correcting technique on the spot, thereby ingraining the proper depth and rhythm required for high-quality CPR [7]. Therefore, this technology could help narrow the gap between theoretical knowledge and practical application, aiding medical personnel not only in understanding the guidelines but also in improving their ability to apply them in critical situations.

Multivariate logistic regression confirmed the impact of the use of the feedback device, indicating that it was the significant factor influencing CC depth accuracy. Unlike prior studies in which novices frequently failed to meet the recommended compression depth [11, 14] our findings indicate that even seasoned medical professionals can benefit from feedback devices to enhance the CC accuracy. This finding suggests a critical need to incorporate these devices into CPR procedures to ensure high-quality outcomes. Moreover, the adaptability of the feedback device to connect wirelessly with commonly used smart devices makes it an indispensable tool for both inhospital and prehospital settings. By leveraging technology that is already integral to our daily lives, the device ensures that high-quality CPR is not confined to the walls of a hospital but is accessible anywhere, at any time. This accessibility may increase the chances of survival in emergency situations by empowering more people to perform effective CPR with

confidence.

Feedback devices for CPR are longstanding and exist in various forms [19]. These CPR feedback devices are placed directly on the patient's chest and provide feedback via sound and light emitting diode, whereas others are wired to provide CPR feedback [24, 25]. Such medical devices may be heavy, with reduced portability [19, 21, 26], and pose challenges when used outside hospital settings. In addition, it is difficult to use these feedback devices in CPR situations when cardiac arrest occurs unexpectedly inside or outside the hospital [20, 27]. CPR performed without feedback relies on well-trained rescuers, and it is difficult to verify adherence to guidelines regarding CC depth and rate in real-time [28]. The device developed for this study has the potential to overcome these limitations as it is lightweight, portable, and can wirelessly connect to general-purpose devices, such as tablets or smartphones. This approach is user-friendly and easily accessible, which increases the likelihood of its widespread adoption among healthcare providers and, as a result, can contribute to overall improvements in the efficacy of CPR in various settings.

Although promising, the present data were derived from controlled simulations, necessitating additional research in various real-world settings to validate the effectiveness of the feedback device. This is due to the fact that actual CPR situations cannot be predicted and do not occur in a controlled setting. Furthermore, it is important to take into account the potential disruption that may occur when utilizing a feedback device during mandatory CPR performance. Moreover, it is essential to evaluate the response time of the device, its user-friendliness, and its compatibility with other emergency settings in real-life CPR situations. Therefore, its efficacy in real-life CPR scenarios remains a crucial metric before its widespread adoption in medical practice.

The present study has some limitations. First, the participant pool was restricted to experienced healthcare providers, suggesting the need for more diverse studies to validate the broader applicability of the device. A controlled environment utilizing a manikin does not replicate the complexities of real-life scenarios, highlighting the necessity for research in actual clinical settings. For example, in the situation of in-hospital cardiac arrest, the CC is performed on bed, not on a flat and firm surface. Therefore, because of the mattress effect, the accelerometer of the device overestimates the CC depth, so the accuracy of CC depth can be decreased. Additionally, it is necessary to verify the effectiveness of feedback after considering various potential variables that affect the outcomes. Second, the study could not assess long-term clinical effects on patient outcomes. Third, technological aspects, such as reliance on wireless connectivity, present potential challenges, especially in settings with limited or unreliable connectivity, necessitating assurance of the device's functionality across diverse environments. Fourth, practical considerations regarding the device's durability, battery life, and maintenance were not investigated and are crucial for its usage, especially in out-of-hospital scenarios. Finally, because of the convenience of experimental test, the participants performed second CC 1 hour after performing the first CC. So, the result may be influenced by a learning effect and an insufficient wash-out period.

5. Conclusions

In controlled simulations, the newly developed lightweight CPR feedback device exhibited enhanced CC accuracy. Its portability suggests that it has potential for wider beneficial applications. However, its effectiveness in real-world situations and impact on patient outcomes warrant additional research.

AVAILABILITY OF DATA AND MATERIALS

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

AUTHOR CONTRIBUTIONS

CA, SYL and YO—designed the research. MW and JHK—performed the experiment. MW, CA and YO— analyzed the data. MW, JHK and CA—wrote the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

This study was approved by the Institutional Review Board of Chung-Ang University Hospital (2305-011-554) and conducted in accordance with the Declaration of Helsinki. The study protocol was registered with the Clinical Research Information Service (KCT0008794, available at https://cris.nih.go.kr/cris/search/detailSearch.do?seq=25574&search_page=L).
Informed consent was obtained from all subjects involved in the study.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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