American Journal of Emergency Medicine 66 (2023) 67–72

Contents lists available at ScienceDirect

American Journal of Emergency Medicine

journal homepage: www.elsevier.com/locate/ajem

Efficacy of distance training program for cardiopulmonary resuscitation utilizing smartphone application and home delivery system

Stephen Gyung Won Lee, MD [a,b], Ki Jeong Hong, MD, PhD [b,c,d,*], Sun Young Lee, MD [b,d,e], Sang Do Shin, MD, PhD [b,c,d], Kyoung Jun Song, MD, PhD [a,b,d], Jeong Ho Park, MD, PhD [b,c,d], Seulki Choi, MD [b,c], Gyeongmin Lee, MD [b,c], Jieun Pak, MD [a,b], Yong Joo Park, MD [b,c]

[a] *Department of Emergency Medicine, Seoul National University Boramae Medical Center, Seoul, Republic of Korea*
[b] *Laboratory of Emergency Medical Services, Seoul National University Hospital Biomedical Research Institute, Seoul, Republic of Korea*
[c] *Department of Emergency Medicine, Seoul National University Hospital, Seoul, Republic of Korea*
[d] *Department of Emergency Medicine, Seoul National University College of Medicine, Seoul, Republic of Korea*
[e] *Public Health Center, Seoul National University Hospital, Seoul, Republic of Korea*

ARTICLE INFO

Article history:
Received 2 December 2022
Received in revised form 7 January 2023
Accepted 9 January 2023

Keywords:
Cardiopulmonary resuscitation
Basic life support
Distance learning
Smartphone application
Delivery
COVID-19

ABSTRACT

Aim of the study: Community cardiopulmonary resuscitation (CPR) education is important for laypersons. However, during the COVID-19 pandemic, with social distancing, conventional face-to-face CPR training was unavailable. We developed a distance learning CPR training course (HEROS-Remote) using a smartphone application that monitors real-time chest compression quality and a home delivery collection system for mannikins. This study aimed to evaluate the efficacy of the HEROS-Remote course by comparing chest compression quality with that of conventional CPR training.
Methods: We applied layperson CPR education with HEROS-Remote and conventional education in Seoul during the COVID-19 pandemic. Both groups underwent a 2-min post-training chest compression test, and we tested non-inferiority. Chest compression depth, rate, complete recoil, and composite chest compression score was measured. Trainees completed a satisfaction survey on CPR education and delivery. The primary outcome was the mean chest compression depth.
Results: A total of 180 trainees were enrolled, with 90 assigned to each training group. Chest compression depth of HEROS-Remote training showed non-inferiority to that of conventional training (67.4 vs. 67.8, $p = 0.78$), as well as composite chest compression score (92.7 vs. 95.5, $p = 0.16$). The proportions of adequate chest compression depth, chest compression rate, and chest compressions with complete chest recoil were similar in both training sessions. In the HEROS-Remote training, 90% of the trainees were satisfied with CPR training, and 96% were satisfied with the delivery and found it convenient.
Conclusion: HEROS-Remote training was non-inferior to conventional CPR training in terms of chest compression quality. Distance learning CPR training using a smartphone application and mannikin delivery had high user satisfaction and was logistically feasible.

1. Introduction

High-quality bystander cardiopulmonary resuscitation (CPR) is crucial for the survival of patients with out-of-hospital cardiac arrest (OHCA) [1]. CPR guidelines emphasise the importance of effective CPR training for laypersons to improve the outcome of OHCA [2]. Digital healthcare technologies have recently enabled to implement new methods of CPR training such as self-led online courses, distance learning, and virtual reality training [3,4]. However, face-to-face instructor-led CPR training with chest compression practice using mannikins remains the standard method of CPR training [2].

However, the COVID-19 pandemic has hindered face-to-face CPR training owing to lockdown and social distancing measures to regulate the spread of infection [5]. To minimise the risk of COVID-19 transmission during CPR training, the European Resuscitation Council COVID-19 guidelines recommend that distance learning, self-directed learning, and augmented and virtual learning be used for CPR training [6].

In line with these guidelines, previous studies have evaluated the efficacy of online CPR training and distance learning [7-10] using tablet PCs, mannikins, audiovisual feedback devices, and videoconferencing

* Corresponding author at: Department of Emergency Medicine, Seoul National University Hospital, 101, Daehak-ro, Jongno-gu, Seoul 03080, Republic of Korea.
E-mail addresses: ssberg@snu.ac.kr, emkjhong@gmail.com (K.J. Hong).

https://doi.org/10.1016/j.ajem.2023.01.026
0735-6757/

systems. However, previous studies have limitations in that the intervention groups were all performed at the study site in a controlled environment where the training apparatus was set up in advance and thus could not assess the real-life and logistic feasibility of the education courses. If the trainee should be gathered in a dense classroom space for online distance learning, the effect of distance learning on infection prevention would decrease.

To overcome these limitations, we developed a distance learning CPR training course called Home Education and Resuscitation Outcomes Study Remote (HEROS-Remote). The course used a smartphone application in which the instructor could provide real-time objective feedback on trainees' CPR quality, in addition to videoconferencing features. The training course implemented a home delivery system that delivered mannikins to each trainee's doorstep at home before education. The delivery system enabled all trainees to participate in CPR training at home without having to visit a training centre. Using this platform, CPR education could be made available during the COVID-19 period with a social distancing policy.

This study aimed to evaluate the efficacy of the HEROS-Remote course for chest compression quality by comparing trainees participating in the conventional CPR training course and those participating in the HEROS-Remote training course. We hypothesised that chest compression quality after HEROS-Remote training would be non-inferior to that after conventional CPR education.

2. Methods

2.1. Study design and setting

This prospective observational study compared the chest compression quality between HEROS-Remote training and conventional CPR training for laypersons in Seoul, South Korea, from August 2021 to December 2021. The Seoul Metropolitan Government operated a CPR education program for Seoul citizens using the Home Education and Resuscitation Outcome Study (HEROS) CPR training course based on conventional education methods. During the COVID-19 period, the Seoul Metropolitan Government supported the development of a distance education program for CPR named HEROS-Remote and operated the course for Seoul citizens.

South Korea has the highest internet access rate among Organisation for Economic Co-operation and Development (OECD) member countries [11], and approximately 95% of the population use smartphones [12]. South Korea has an active courier service market in which the economically active population utilises courier services an average of 122 times annually [13] and same-day delivery and collection services are regularly provided. The smartphone-friendly population and efficient delivery service allowed Seoul to be an appropriate testing bed for the new CPR training course that utilised a smartphone application and a home delivery system.

2.2. Population

The study population was recruited from among adult non-healthcare providers who received CPR training via Seoul Metropolitan Government-operated community health centres. Although the original study design was to perform cluster randomisation for study group allocation, convenience sampling was performed because the investigators had to intermittently suspend the conventional CPR training courses during the COVID-19 outbreak to abide by the government's social distancing policies, whereas the HEROS-Remote training could be operated continuously throughout the study period regardless of social distancing. Eight to ten trainees were allocated to each training course.

Trainees who did not provide written consent or those younger than 19 years or older than 65 years were excluded. Trainees who had received CPR training within 6 months were excluded. For the final analysis using post-training CPR quality, trainees with missing chest compression data, those who did not participate in the hands-on chest compression sessions, and those who failed to connect the simulation mannikin to the application were excluded.

2.3. Conventional CPR training: HEROS

After enrolment, the participants assigned to the conventional CPR training group visited a CPR training centre and completed a face-to-face CPR training course. In 2016, the Seoul Metropolitan Government implemented the HEROS CPR training course. It was a standardised 1-h CPR training course that focused on chest compression-only CPR and dispatcher-assisted CPR (DACPR). This standard training consisted of a 30-min video-based training using a Little Anne QCPR mannikin (Laerdal, Stavanger, Norway), followed by a 30-min instructor-led practice session in which course trainees were provided objective measurement and feedback on chest compression performance [14]. The course utilised the QCPR Classroom (Laerdal, Stavanger, Norway) to provide objective real-time feedback for each trainee during training [15].

2.4. HEROS-Remote training

For the participants in the HEROS-Remote training group, we delivered a package containing a Little Anne QCPR mannikin, tripod, and course instructions to their homes 1 day before distance training (Fig. S1). On arrival of the packages, the participants were instructed to instal the HEROS-Remote smartphone application on their smartphones and how to set up the smartphone on the tripod and position the mannikin during training (Fig. S2). The application provided access to an online platform developed for the HEROS-Remote training course, on which instructors could play a condensed version of the training video (25 min) used in the conventional CPR training group and monitor the trainee's CPR performance using two-way videoconferencing. In addition, the application provides Bluetooth linkage between the Little Anne QCPR mannikin and the trainee's smartphone, which enables real-time measurement and display of each participant's objective CPR performance on both the participant's and instructor's smartphone screen. This may be equivalent to the QCPR Classroom used in the conventional CPR training group (Fig. S3).

Upon accessing the online classroom via the HEROS-Remote application, the trainees in the HEROS-Remote training group watched the condensed training video followed by a 35-min chest compression practice session in which course instructors provided real-time feedback using the smartphone application.

The HEROS-Remote training group was asked to put the equipment back in the delivery box and leave the box in front of their doorstep after the course was finished. The boxes were collected by a courier service on the same day and delivered to the investigator's office for disinfection and repackaging for the next education.

2.5. Data collection

After completion of the training courses, participants were asked to perform a post-training test in which they performed chest compression on the Little Anne QCPR mannikin for 2 min without instructor feedback. The chest compression quality generated by the mannikin during the conventional course and the HEROS-Remote course was automatically transmitted to an online cloud after course completion. Post-training test data were extracted for analysis.

After the post-training test, each trainee of both courses completed a survey on information regarding trainee demographics, user satisfaction, and course feasibility using a 5-point Likert scale (1 = strongly agree; 5 = strongly disagree). Responses of 1–2 on a Likert scale were categorised as positive responses for analysis.

2.6. Outcomes

The primary outcome was the mean chest compression depth measured during the 2-min post-training test. The proportion of chest compressions with adequate depth (chest compression depth ≥ 50 mm), mean chest compression rate, proportion of chest compressions with complete chest recoil (absence of leaning), and total chest compression score were also measured. The total chest compression score is an individual's overall measure of CPR performance, scored from 0% to 100%, generated by the QCPR Classroom [15].

2.7. Sample size

To estimate the appropriate sample size for the non-inferiority trial, the non-inferiority margin for depth was set at 5 mm, with an expected standard deviation of 10 mm, based on a previous randomised clinical trial [3]. Assuming a two-sided alpha of 0.05 and power of 90%, the estimated minimal sample size was 69 participants per group. Considering data transmission failure, mechanical error, and dropout rate, the sample size was increased by 30%, resulting in 90 participants per group being adequately powered.

2.8. Statistical analysis

Continuous variables were reported as mean with standard deviation or median with interquartile range. Categorical variables are reported as numbers with percentages. Comparisons between groups were performed using Student's *t*-test, Mann-Whitney *U* test, or $\chi 2$ test, as appropriate. A paired t-test was used to compare course initiation and post-training test chest compression quality. Statistical analyses were performed using Stata, Version 16 (StataCorp, College Station, TX, USA).

3. Results

In total, 324 participants underwent CPR training during the study period. After excluding patients who did not meet the inclusion criteria, a total of 180 trainees were enrolled, with 90 trainees assigned to each training group (Fig. 1). The demographics of the study population are summarised in Table 1. Of the study population, 91.1% had previous CPR training. Of these, 85.0% had participated in face-to-face CPR training with hands-on practices. The time interval from the last CPR training was 33.7 months in the total population. There was no statistically significant difference in previous CPR training experience between the HEROS-Remote and conventional CPR training groups.

The chest compression quality of the 2-min post-training test was compared between the HEROS-Remote training and conventional CPR training groups (Table 2). There was no statistically significant difference in mean chest compression depth between the HEROS-Remote training and conventional CPR training groups (67.4 vs. 67.8, $p = 0.78$). The proportion of adequate chest compression depth, chest compression rate, proportion of chest compressions with complete chest recoil, and chest compression score also did not differ between the two groups. The total compression time was shorter, and the total number of compressions was lower in the HEROS-Remote training group than in the conventional CPR training group.

The mean difference between HEROS-Remote training and conventional CPR training group for chest compression depth was −0.4 (95% CI, −3.5 to 2.7) mm (Fig. 2). The chest compression depth of the HEROS-Remote training was not inferior to that of conventional CPR training. Other chest compression metrics after HEROS remote training were also non-inferior to those after conventional CPR training.

We conducted a post-training survey of trainees after both courses (Table 3). Of the participants, 90.0% of those who underwent HEROS-Remote training and 97.8% of those who underwent conventional CPR training were satisfied with the course. There was no difference in questions regarding chest compression performance and sufficient feedback from the instructor.

In total, 87.8% and 100.0% of the participants in the HEROS-Remote training and conventional training groups, respectively, answered that they would recommend the course to others. A total of 14.4% of the participants in the HEROS-Remote training group experienced difficulty asking questions during the course. Confidence in CPR skills and performing bystander CPR was also lower in the HEROS-Remote training group than in the conventional training group.

In the HEROS-Remote training group, 86 (95.5%) participants responded that the delivery system was satisfactory and convenient. In addition, 83 trainees (92.2%) answered that the HEROS-Remote

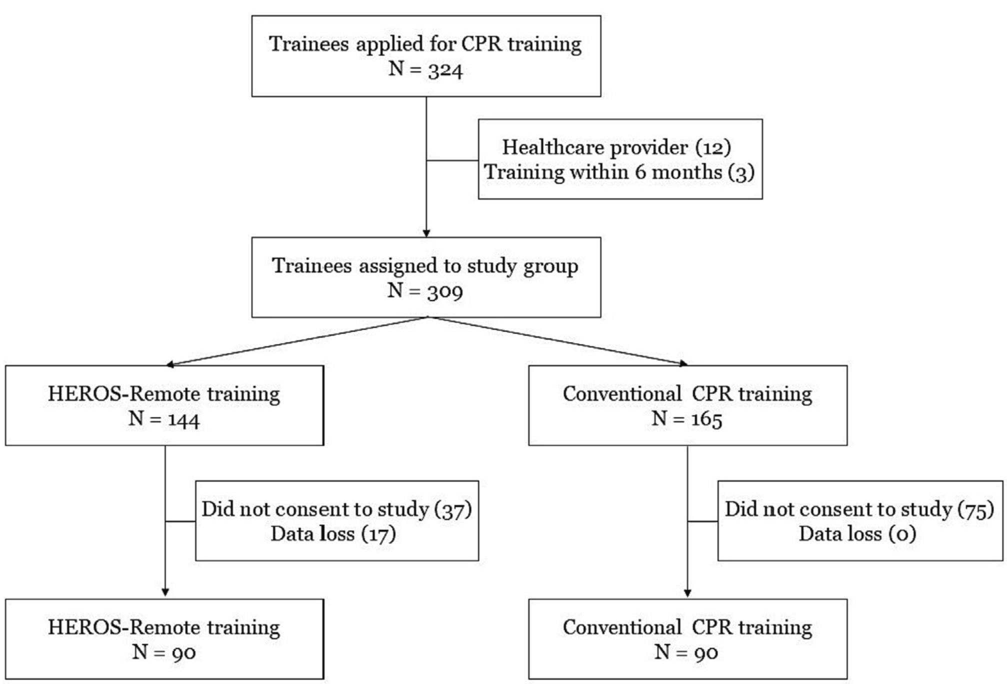

Fig. 1. Study flowchart.
CPR, cardiopulmonary resuscitation.

Table 1
Population demographics.

	Total	HEROS-Remote training *N* = 90	Conventional CPR training N = 90	*P*-value
	N (%)	N (%)	N (%)	
Age, years, mean (SD)	47.5 (10.9)	45.9 (11.5)	49.1 (10.0)	<0.05
Male	111 (61.7)	51 (56.7)	60 (66.7)	0.17
Previous CPR training	164 (91.1)	83 (92.2)	81 (90.0)	0.60
Previous CPR training method				0.31
Face-to-face CPR training with hands-on practice	153 (93.3)	80 (96.3)	73 (90.1)	
Face-to-face CPR training without hands-on practice	7 (4.3)	2 (2.4)	5 (6.2)	
Non-face-to-face CPR training with hands-on practice	2 (1.2)	1 (1.2)	1 (1.2)	
Non-face-to-face CPR training without hands-on practice	2 (1.2)	0 (0.0)	2 (2.5)	
Time since last CPR training, months, mean (SD)	33.7 (28.7)	34.7 (25.5)	32.7 (32.1)	0.71

CPR, cardiopulmonary resuscitation; SD, standard deviation.

training course was effective in preventing the spread of infectious diseases. Trainees in the HEROS-Remote training group saved a travel distance of 21.6 (±9.9) km per trainee using the home delivery system instead of visiting the training centre.

4. Discussion

This investigation developed and operated a HEROS-Remote training program composed of a distance training program with real-time chest compression quality feedback using a smartphone application and home delivery service for layperson CPR education in Seoul during the COVID-19 period. Home delivery and smartphone-based distance education were available during the COVID-19 outbreak along with social distancing regulations. In addition, real-time individual chest compression quality measurements and feedback from the instructor were also applicable during education. In the pilot trial in Seoul, the chest compression quality of the HEROS-Remote group was not inferior to that of the conventional education group. In addition, the HEROS-Remote course was logistically feasible and had a high user satisfaction.

Although DACPR could increase bystander CPR rates, layperson CPR training remains crucial for high-quality bystander CPR provision [2,16,17]. Community CPR training for laypersons has been conventionally conducted using an instructor-led, face-to-face method. It utilises a deliberate practice and mastery learning model using CPR feedback devices and mannikins [2]. However, during the COVID-19 outbreak, traditional face-to-face education has become a barrier to opening the education course [5]. Trainees also fear the spread of infection during training, and the risk of course-related infection could occur [18]. During the pandemic, the public need for CPR training remains [19], and distance learning for CPR training could be an alternative solution of CPR training [6].

Previous studies have tested the feasibility of non-contact CPR training courses, such as video self-instruction courses and kiosks [4,20-23]. Other studies have introduced online meeting platforms for real-time participation using audiovisual feedback devices led by instructors [8,9]. These studies reported the non-inferiority of non-contact education to traditional face-to-face training. However, previous studies have been performed in controlled simulation environments where the trainee visits a training facility where multiple tablet PCs, audiovisual feedback devices, mannikins, and cameras are set up in advance for distance learning training [8-10]. Thus, previous studies could not evaluate the feasibility of distance learning courses by considering real field implementation as a community CPR education program. In the real education process, trainees have to go through multiple steps to participate in a training session: receive the equipment, set the equipment for education, log in to the class, participate in the class, and send the equipment back to the instructor. These processes could affect accessibility and satisfaction with education and are related to the sustainability of educational course operations. Our study is the first to evaluate the logistic feasibility of a distance learning course. In addition, we compared chest compression quality after education. We sought to overcome the limitation of inaccurate chest compression quality measurement [24], which could have occurred if only the videoconferencing function was used to monitor trainees. We connected the mannikin of each trainee to the smartphone application. The instructor can monitor and provide objective feedback on the chest compression performance.

The overall course satisfaction rate for HEROS-Remote training was reported to be 90.0%. However, the overall course satisfaction and willingness to recommend the course to others were lower than those of the conventional CPR training group. Confidence in the ability to activate EMS, CPR skills, and willingness to perform bystander CPR was also lower in the HEROS-Remote training group. A detailed assessment of trainees' requests and further refinement of the course are warranted.

The HEROS-Remote training course saved travel time and distance to the training centre for trainees and instructors. Regardless of the COVID-19 outbreak, this benefit may improve the accessibility of CPR training. The distance learning course could be utilised not only during the pandemic but also in situations where accessibility to CPR training is limited, such as in rural areas or for workers who cannot visit training centres during office hours.

Table 2
Chest compression metrics.

	HEROS-Remote training N = 90	Conventional CPR training N = 90	P-value
	Mean (SD)	Mean (SD)	
Compression time, seconds	105.8 (29.6)	122.6 (4.8)	<0.01
Total number of compressions, n	195.5 (45.8)	221.0 (19.6)	<0.01
Compression depth, mm	67.4 (10.1)	67.8 (10.9)	0.78
Proportion of compressions with adequate depth, %	90.8 (22.1)	92.1 (20.6)	0.69
Compression rate, /min	110.8 (7.1)	110.4 (4.2)	0.60
Proportion of compressions with complete chest recoil, %	89.8 (21.0)	94.7 (11.7)	0.05
Chest compression score	92.7 (15.0)	95.5 (11.8)	0.16

CPR, cardiopulmonary resuscitation; SD, standard deviation.

5. Limitations

This study has several limitations. First, the majority of the study population had previous CPR training experience. Although the study only included trainees without previous CPR training within CPR 6 months regarding the previous literature [25], there could be difficulties in applying the distance learning course to first-time learners. Second, smartphone applications and wireless connections with mannikins in the HEROS-Remote course could induce digital literacy in the elderly population. As our study did not include trainees over 65 years of age, we could not measure the feasibility of the course in the geriatric population. Third, the outcome was the 2-min post-training chest

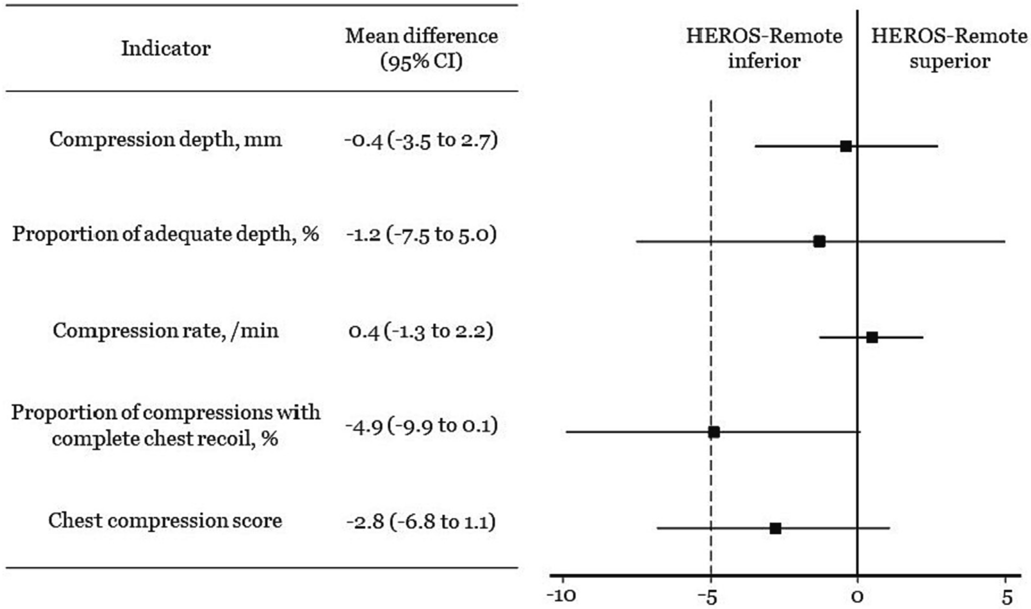

Fig. 2. Mean difference of chest compression metrics between study groups.
CI, confidence intervals.

compression depth. Long-term skill retention could not be measured. Further studies are warranted to evaluate the long-term effects of distance learning on retention. Fourth, we could not perform a randomised trial as planned in the original study design because conventional CPR training courses had to be cancelled or postponed during the COVID-19 outbreak. Regular random assignment during the study period was

Table 3
Survey results for course satisfaction, confidence, and willingness to perform CPR and course feasibility

	HEROS-Remote training N = 90	Conventional CPR training N = 90	P-value
	N (%)	N (%)	
Common survey for both groups			
Are you satisfied with the CPR training course?	81 (90.0)	88 (97.8)	0.03
Would you recommend the course to others?	79 (87.8)	90 (100.0)	<0.01
Did you perform enough chest compressions during the practice session?	86 (95.6)	89 (98.9)	0.17
Did the instructor provide enough feedback during the practice session?	82 (91.1)	89 (98.9)	0.03
Was instructor feedback during the practice sessions helpful?	85 (94.4)	89 (98.9)	0.17
Was it hard to ask questions during the course?	13 (14.4)	2 (2.2)	<0.01
Do you feel confident in activating EMS upon recognition of cardiac arrest?	81 (90.0)	89 (98.9)	0.02
Do you feel confident in your CPR skills?	80 (88.9)	90 (100.0)	<0.01
Would you be willing to perform bystander CPR upon recognition of cardiac arrest?	80 (88.9)	90 (100.0)	<0.01
Additional survey for HEROS-Remote training group			
Is the HEROS-Remote training course superior to conventional CPR training?*	26 (32.5)		
Is the HEROS-Remote training course superior or equal to conventional training?*	65 (81.3)		
Was it easy to use the smartphone application?	73 (81.1)		
Was it easy to access the classroom via smartphone application?	69 (76.6)		
Did you have to access the classroom multiple times?	37 (41.1)		
How many times did you have to access the classroom?, mean (SD)	1.97 (1.0)		
Why did you have to access the classroom multiple times?**			
Audio error	14 (37.8)		
Video error	10 (27.0)		
Mannikin connection error	3 (8.1)		
Unstable Internet connection	7 (18.9)		
App turned off spontaneously	4 (10.8)		
App frozen	8 (21.6)		
Other	2 (5.4)		
Was it easy to connect the mannikin to the smartphone application?	83 (92.2)		
Mannikin connection successful on first attempt	77 (85.6)		
Was the video quality of the course optimal?	74 (82.2)		
Was the audio quality of the course optimal?	71 (78.9)		
Are you satisfied with the delivery system?	86 (95.5)		
Was the delivery system convenient?	86 (95.5)		
Was the HEROS-Remote training effective to prevent spread of infectious diseases?	83 (92.2)		

EMS, emergency medical services; CPR, cardiopulmonary resuscitation; SD, standard deviation.
* Survey question for trainees who have previously completed conventional CPR training course ($N = 80$).
** Survey question for trainees who needed to re-access the classroom ($N = 37$).

not possible. Fifth, because non-inferiority was measured based on mean compression depth, there is limitation in evaluating the efficacy of overall CPR performance other than chest compression quality.

6. Conclusions

The HEROS-Remote training course was not inferior to conventional CPR training in terms of chest compression quality after education. The distance learning CPR training method utilizing a smartphone application and mannikin delivery collection system had high user satisfaction and was logistically feasible for community CPR education.

Ethics statement

The study was approved by the institutional review board of the investigators' institution (IRB No. 1906–021-1038).

Trial registration

This trial was registered at ClinicalTrials.gov and the identifier was NCT05023616.

Funding

This study was supported from the Seoul National University Hospital Research Fund (Grant number: 04–2021-2270).

CRediT authorship contribution statement

Stephen Gyung Won Lee: Writing – original draft, Formal analysis. **Ki Jeong Hong:** Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Sun Young Lee:** Funding acquisition, Formal analysis, Data curation. **Sang Do Shin:** Supervision, Investigation, Data curation. **Kyoung Jun Song:** Supervision, Investigation, Data curation. **Jeong Ho Park:** Validation, Methodology, Investigation. **Seulki Choi:** Investigation, Data curation. **Gyeongmin Lee:** Investigation, Data curation. **Jieun Pak:** Investigation, Data curation. **Yong Joo Park:** Validation, Methodology, Investigation.

Declaration of Competing Interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ajem.2023.01.026.

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