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ORIGINAL RESEARCH

Impact of elbow supports use on chest compression quality: a crossover simulation study

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Abstract

During chest compressions, a downward force is generated by the rescuer's body through straightened arms to the patient's chest. If the elbows are not straight, the depth of chest compressions could be reduced. Such a situation could occur during prolonged chest compressions or when the rescuer must wear protective equipment, such as during the coronavirus disease 2019 (COVID-19) pandemic, and can lead to reduced chest compression quality. This study aimed to compare the quality of chest compressions performed using elbow supports to limit the elbows' range of motion with that of standard chest compression (SCC). This prospective, randomized controlled, crossover simulation trial was conducted from October to December 2018. It included 34 participants who were certified in Basic Life Support with an overall compression score of $\geq$80% in the preliminary evaluation. They were randomly assigned to the immediate intervention (elbow support chest compression (ESCC)) or wait-list control (SCC) groups, and were asked to perform hands-only cardiopulmonary resuscitation for 8 minutes with and without elbow supports, respectively. After 1 week, the participants were made to switch groups, and the quality of chest compressions between the two groups was compared. The study findings showed that the ESCC group had a significantly higher overall compression score than the SCC group (82.85 $\pm$ 13.73% *vs.* 76.11 $\pm$ 19.19%, respectively, p = 0.044). No difference was observed in the chest compression depth between men and women in the ESCC group (53.12 $\pm$ 6.14 mm *vs.* 49.13 $\pm$ 3.23 mm, respectively, p = 0.053), but a significant difference was observed between those of the SCC group (53.18 $\pm$ 6.58 mm *vs.* 47.87 $\pm$ 5.23 mm, respectively, p = 0.026). Thus, elbow supports could assist rescuers in performing more effective chest compressions, especially for females or in situations where compression quality could be affected.

Keywords

Out-of-hospital cardiac arrest; Cardiopulmonary resuscitation; Cardiac massage; Elbow joint

1. Introduction

The American Heart Association (AHA) guidelines for cardiopulmonary resuscitation (CPR) are updated every 5 years based on the recent scientific evidence [1–3]. The revised guidelines emphasize high-quality chest compression in adults by maintaining a chest compression depth of at least 5 cm and a rate of at least 100–120 compressions per minute [1–3]. Additionally, it is recommended that complete recoil must be achieved after each compression with minimal interruption in chest compressions [1–3]. To prevent delays in chest compression during the early stages of cardiac arrest, the CPR sequence was changed from airway, breathing and circulation (A-B-C) to circulation, airway and breathing (C-A-B) [1] and the importance of chest compressions over artificial respiration is emphasized with the introduction of the hands-only CPR [2].

Providing high-quality chest compressions to patients with cardiac arrest is paramount to improving their chance of survival and neurological recovery [4–6]. However, maintaining an optimal chest compression depth and rate ultimately causes physical fatigue in rescuers, which compromises the quality of chest compressions [7]. Therefore, it is important to find novel strategies to reduce rescuers' fatigue while still maintaining effective compressions.

Several studies have evaluated potential strategies to enhance the effectiveness of chest compressions by reducing rescuers' fatigue. However, most of them have emphasized on a switching position time for chest compressions, suggesting that rescuers should switch positions every 2 minutes or when fatigue increases [7, 8]. However, such measures can be difficult to implement in situations like one-rescuer CPR or during the coronavirus disease 2019 (COVID-19) pandemic where rescuers have to wear level D protective equipment that minimizes their participation in CPR due to concerns of infection.

Chest compressions are given *via* repetitive upper-body movement by bending at the waist with the arms kept straight to allow optimal delivery of the downward vertical force from the arms to the recipient's chest. However, long durations of chest compressions cause the elbows to be overworked, which tends to increase the elbow joints' range of motion (ROM), thereby reducing the force delivered by the arms and leading to a decrease in chest compression depth and ineffective chest compressions [9].

Hattori *et al*. [10] reported that the use of elbow supports could help reduce the space in the medial elbow joint, decrease the mechanical stress on the elbows and protect the elbows when performing repetitive motions. Thus, based on these reported findings, we performed this present study to investigate the effects of elbow supports on chest compression quality and injury prevention in rescuers during CPR.

2. Materials and Methods

2.1 Study design and settings

This prospective, randomized controlled, crossover simulation trial was conducted between October and December 2018 (Fig. 1). A randomizer program (www.randomizer.org) was used to generate random numbers to assign the participants to an immediate intervention (elbow support chest compression (ESCC)) or a wait-list control (standard chest compression (SCC)) group. All participants provided informed consent forms (ICFs). A pre-test questionnaire survey, including questions on the participants' sex, age, height, weight, basic resuscitation education and disease, was conducted by a research assistant before the crossover experiment.

In the first crossover experiment, the immediate intervention and control groups performed chest compressions for 8 minutes with and without elbow supports, respectively. The elbow supports HV-004 from Posung (Busan, Republic of Korea) was used in the intervention group (Fig. 2). It was adjusted using Velcro straps to firmly secure them on the participants' elbows. After 1 week, the second crossover experiment was conducted, in which the participants in the ESCC and SCC groups were made to switch groups. The researchers assessed the effectiveness of chest compressions by instructing the participants to perform hands-only CPR without artificial respiration for 8 minutes, which is the median time required for Korean emergency medical personnel to arrive at an emergency scene [11]. To assess the quality of chest compressions performed by the participants, the chest compression depth, chest compression rates, accurate chest compression recoil, accurate hand position during chest compressions, and overall compression score (OCS) were determined.

2.2 Participants

The study participants were students aged ≥20 years who were enrolled at the Department of Emergency Medical Services at "H" University. They were given detailed explanations of the objective and methods of the study. They were also informed that no participation or withdrawal from the study at any time would not have any negative consequences on their studies. To reduce deviations in OCS, only those with Basic Life Support (BLS) certification and a pre-experiment OCS of ≥80% were included. Students with any medical disorder, currently receiving medication, or had been treated or were being treated for musculoskeletal disorders were excluded. G*power 3.0.10 (Heinrich-Heine-Universität, Düsseldorf, Germany) was used to calculate the sample size needed for the paired *t*-test (two-tailed test) with a significance level of 0.05, an effect size of 0.50, and statistical power of 0.80. The minimum sample size needed for the study was estimated to be 34, and considering a drop-out rate of 10%, a total of 38 participants were recruited for this study. Of them, 34 participants voluntarily submitted the ICF, and all participated until the end of the study (Fig. 1).

2.3 Manikin and data collection system

The SimPad Skillreporter device (SimPad PLUS SkillR IE 202-30033, Laerdal Medical, Stavanger, Norway) was used to measure the quality of the chest compressions, which were performed on a simulator manikin (Resusci Anne QCPR 172-01260, Laerdal Medical, Stavanger, Norway). Chest compression depth (mm), chest compression rate (times/minute), accurate chest compression recoil (%), accurate hand position during chest compressions (%) and OCS (%) were determined using the data recorded in the chest compression measuring equipment. Based on the 2020 CPR guidelines, an adequate compression depth and rate were defined as at least 50.00 mm and 100–120 times per minute, respectively [3, 12]. In this study, a chest compression depth exceeding 60.00 mm was observed in 4 cases (11.76%). To calculate the percentage of compressions with an adequate depth per minute (%), the number of compressions with an adequate depth in 1 minute was divided by the total number of compressions in that minute [13]. The percentage of compressions with an adequate rate per minute (%) was expressed as the number of compressions with an adequate rate in 1 minute divided by the total number of compressions.

2.4 Statistical analysis

The SPSS software for Windows, version 25.0 (IBM Corp., Armonk, NY, USA) was used for data analysis. The general characteristics of the participants were expressed as frequency, percentage (%), mean and standard deviation. The data had a normal distribution, and a parametric test was performed. The paired *t*-test was used to analyze the differences in chest compression depth (mm), chest compression rate (times/minute), accurate chest compression recoil (%), accurate hand position during chest compressions (%), and OCS (%) between the ESCC and SCC groups. A two-sided Student's *t*-test was used to compare the chest compression depth (mm), chest compression rate (times/minute), accurate chest compression recoil (%), accurate hand position during chest compressions (%), and OCS (%) between male and female participants. The percentage of compressions with adequate depth per minute (%) and percentage of compressions with an adequate rate per minute (%) in the ESCC and SCC groups were expressed as mean and standard error (SE) and compared using the paired

TABLE 1. General characteristics of the participants (n = 34).

Characteristics	Value
Sex	
Male, n (%)	23 (67.6)
Female, n (%)	11 (32.4)
Age (in years), mean ± SD	23.21 ± 1.64
Height (in cm), mean ± SD	170.23 ± 8.65
Weight (in kg), mean ± SD	68.08 ± 10.77
BMI, mean ± SD	23.40 ± 2.62
Received BLS education?	
Yes, n (%)	34 (100)
Do you have any previously diagnosed diseases?	
No, n (%)	34 (100)
Do you have any musculoskeletal disease?	
No, n (%)	34 (100)
Are you on any regular medication?	
No, n (%)	34 (100)

Data are presented as number (%) or mean and standard deviation. n: number of participants the indicated characteristics; SD: standard deviation; BMI: body mass index; BLS: basic life support.

TABLE 2. Quality of chest compression (n = 34).

Variable	ESCC	SCC
Overall compression score (%)	82.85 ± 13.73	76.11 ± 19.19
Correct hand position during compression (%)	98.26 ± 13.73	94.94 ± 18.00
Depth of compression (mm)	51.83 ± 5.65	51.46 ± 6.60
Extent of complete recoil (%)	77.50 ± 29.29	84.17 ± 25.10
Frequency of compression (times/minute)	102.05 ± 11.30	106.85 ± 14.64

ESCC: elbow support chest compression; SCC: standard chest compression.

t-test. $p < 0.05$ was used to determine significance level in all tests.

3. Results

3.1 Participant characteristics

This study consisted of 34 participants, of whom 23 were males (67.6%) and 11 were females (32.4%). Their mean age, height, body weight and body mass index (BMI) were 23.21 ± 1.64 years, 170.23 ± 8.65 cm, 68.08 ± 10.77 kg, and 23.40 ± 2.62 kg/m^2, respectively (Table 1).

3.2 Comparison of the quality of chest compressions according to the chest compression method

The quality of chest compressions of the ESCC and SCC groups are shown in Fig. 3. The ESCC group had a significantly higher OCS than the SCC group (82.85 ± 13.73% *vs.* 76.11 ± 19.19%, respectively, p = 0.044). Despite that participants in both the ESCC and SCC groups performed adequate compression rates (102.05 ± 11.30 times/minute *vs.* 106.85 ± 14.64 times/minute, respectively, p = 0.029), a significant difference in chest compression rate were still observed between them. No difference was observed in chest compression depth between the ESCC and SCC groups (51.83 ± 5.65 mm *vs.* 51.46 ± 6.60 mm, respectively, p = 0.557). Further, no significant difference was observed between them in terms of accurate chest compression recoil (p = 0.094) and accurate hand position during chest compressions (p = 0.314) (Table 2).

3.3 Comparison of chest compression depth and rate according to sex

The age (p = 0.107) and BMI (p = 0.092) of the participants, based on sex, were well-balanced, indicating a homogeneous study cohort (Table 3). Analysis of OCS according to sex showed no difference between male and female participants in the ESCC group (83.69 ± 14.93% *vs.* 81.09 ± 11.24%, respectively, p = 0.612) and the SCC group (76.56 ± 20.28% *vs.* 75.18 ± 17.56%, respectively, p = 0.848). Also, there was no significant difference in chest compression rate between male and female participants in the ESCC (p = 0.181) and SCC (p = 0.583) groups. For chest compression depth, although no difference was observed between male and female participants in the ESCC group (53.12 ± 6.14 mm *vs.* 49.13 ± 3.23 mm, respectively, p = 0.053), our study findings showed that

TABLE 3. Comparison of chest compression depth and rate according to sex (n = 34).

Variable	Male (n = 23)	Female (n = 11)	t	p value
Age	23.52 ± 1.75	22.55 ± 1.21	0.261	0.107
BMI	23.92 ± 2.51	22.30 ± 2.61	1.738	0.092
ESCC				
Overall compression score (%)	83.69 ± 14.93	81.09 ± 11.24	0.512	0.612
Depth of compression (mm)	53.12 ± 6.14	49.13 ± 3.23	2.010	0.053
Frequency of compression (times/minute)	103.86 ± 12.53	98.27 ± 7.28	1.368	0.181
Extent of complete recoil (%)	77.52 ± 28.56	77.45 ± 32.20	0.006	0.995
SCC				
Overall compression score (%)	76.56 ± 20.28	75.18 ± 17.56	0.194	0.848
Depth of compression (mm)	53.18 ± 6.58	47.87 ± 5.23	2.339	0.026*
Frequency of compression (times/minute)	107.81 ± 11.16	103.86 ± 12.53	0.554	0.583
Extent of complete recoil (%)	78.56 ± 28.78	95.90 ± 5.68	−1.965	0.058

*BMI: body mass index; ESCC: elbow support chest compression; SCC: standard chest compression. Data are presented as mean ± standard deviation. *p < 0.05, analyzed using the t-tests.*

the female participants of the SCC group performed significantly shallower compressions compared with male participants (53.18 ± 6.58 mm *vs.* 47.87 ± 5.23 mm, respectively, p = 0.026).

3.4 Comparison of percentage of compressions with an adequate depth per minute

There was no significant difference in the accuracy of chest compression depth between the ESCC and SCC groups for each of the 8 minutes of compression. However, the ESCC group maintained a higher percentage of adequate chest compressions than the SCC group (Fig. 4). The percentages (± SE) of compressions with an adequate depth per minute for the ESCC and SCC groups after 1 minute were similar at 83.41 ± 4.83% and 82.01 ± 5.43% (p = 0.794), respectively. Further, the percentages (± SE) of compressions with an adequate depth per minute at 2, 4 and 8 minutes for the ESCC and SCC groups were also similar, with values of 72.18 ± 6.45% *vs.* 67.61 ± 7.29% (p = 0.338), 61.75 ± 7.00% *vs.* 58.03% ± 7.40 (p = 0.456), and 45.65% ± 6.41% *vs.* 44.55% ± 7.59% (p = 0.829), respectively (Fig. 4).

3.5 Comparison of percentage of compressions with an adequate rate per minute

Analysis of the accuracy of the chest compression rate showed no significant difference between the groups in each of the 8 minutes of compression. The percentage (± SE) of chest compressions with an accurate rate for the ESCC and SCC groups was 46.87 ± 6.50% and 47.84 ± 6.60% after 1 minute (p = 0.909) and 32.87 ± 6.23% and 38.14 ± 5.98% after 3 minutes, respectively (p = 0.513). After 4 and 8 minutes, there was still no statistically significant difference between the groups in the percentage of compressions with an adequate rate (4 minutes: ESCC: 43.19 ± 7.11% *vs.* SCC: 36.73 ± 6.39%, p = 0.497; 8 minutes: 50.88 ± 6.92% *vs.* 41.70 ± 6.76%, p = 0.350; Fig. 5).

4. Discussion

In this study, we assessed the efficacy of elbow supports in reducing rescuers' fatigue and maintaining an adequate quality of chest compressions when performed for a long period of time (8 minutes; median time required for Korean emergency medical personnel to arrive at an emergency scene) by comparing the rescuers' quality of chest compressions with and without elbow supports. Based on the OCS of the ESCC and SCC groups, our results indicated that elbow supports were effective in maintaining chest compression quality for a long time and allowed both male and female rescuers to maintain relatively adequate chest compression depths.

A previous study found a high OCS of 93% 1 minute after starting chest compressions, but it decreased to 67% in the second minute [14]. After 3 minutes, the OCS decreased sharply to 39%, which further reduced to 18% after 5 minutes [14]. Rescuer fatigue has been reported to increase after 1.5 to 3 minutes of starting chest compressions; therefore, it could be difficult to expect high-quality chest compressions when performed by a single rescuer for a long time [8, 14]. In another study that investigated the performance of hands-only CPR for 8 minutes, the percentage of compressions with an adequate depth was maintained at 60% for the first minute but decreased to 41% after 2 minutes [13]. After 4 minutes, it decreased sharply to 25%, and after 8 minutes, the adequate chest compression depth was decreased to 18% [13]. Even in this present study, we observed that the percentage of compressions with an adequate depth performed using standard hands-only CPR without elbow supports decreased from 82.01% to 67.61% after 2 minutes, and after 6 minutes, it further decreased to 45.81%, indicating a drop in accuracy of chest compression depth by 40%. However, the ESCC group demonstrated a significantly higher OCS than the SCC group, while the per-

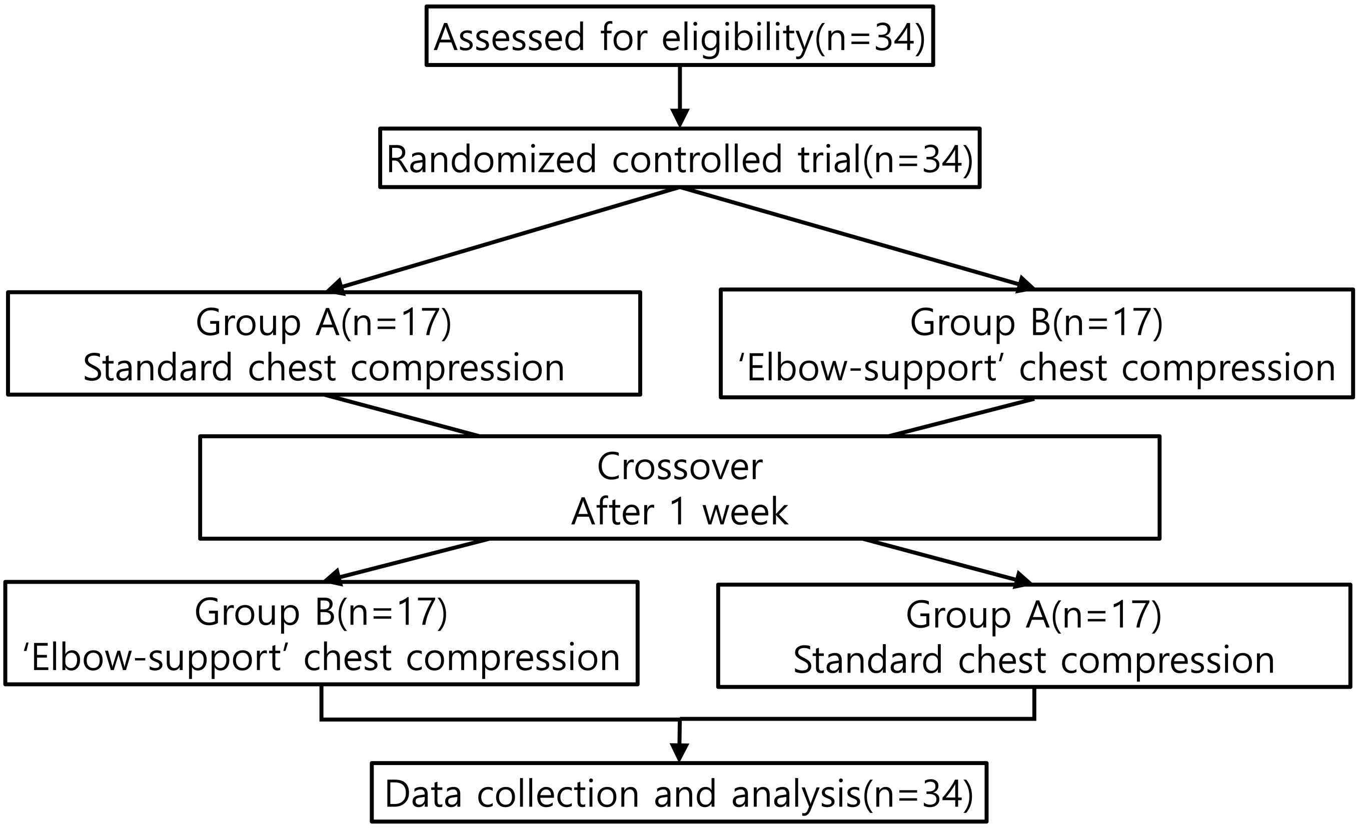

FIGURE 1. Flow Chart of the Study Design and Recruitment of Participants based on the CONSORT Guidelines. n: Number of participants the indicated characteristics.

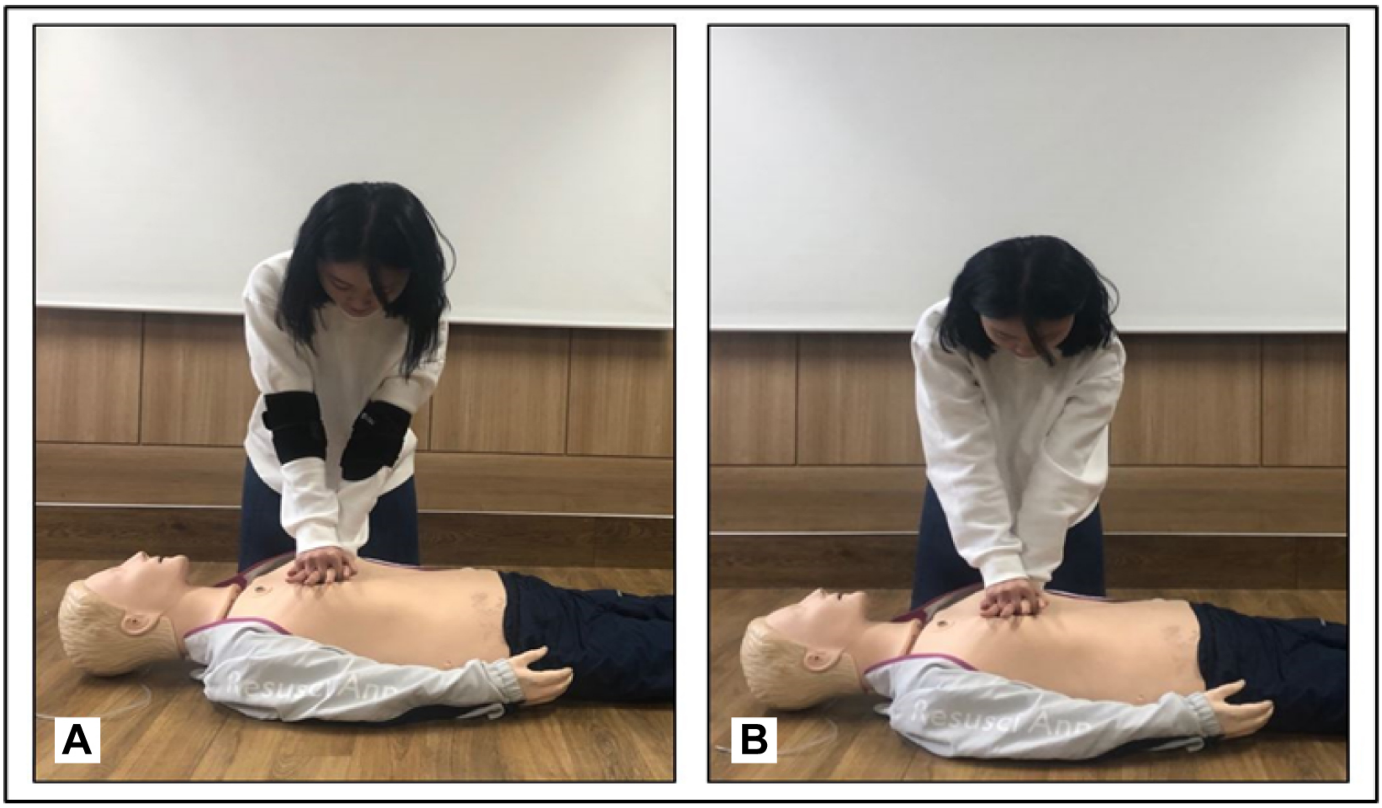

FIGURE 2. "Elbow-support" and Standard Chest Compression Methods. A: "Elbow-support" chest compression method. B: Standard chest compression method.

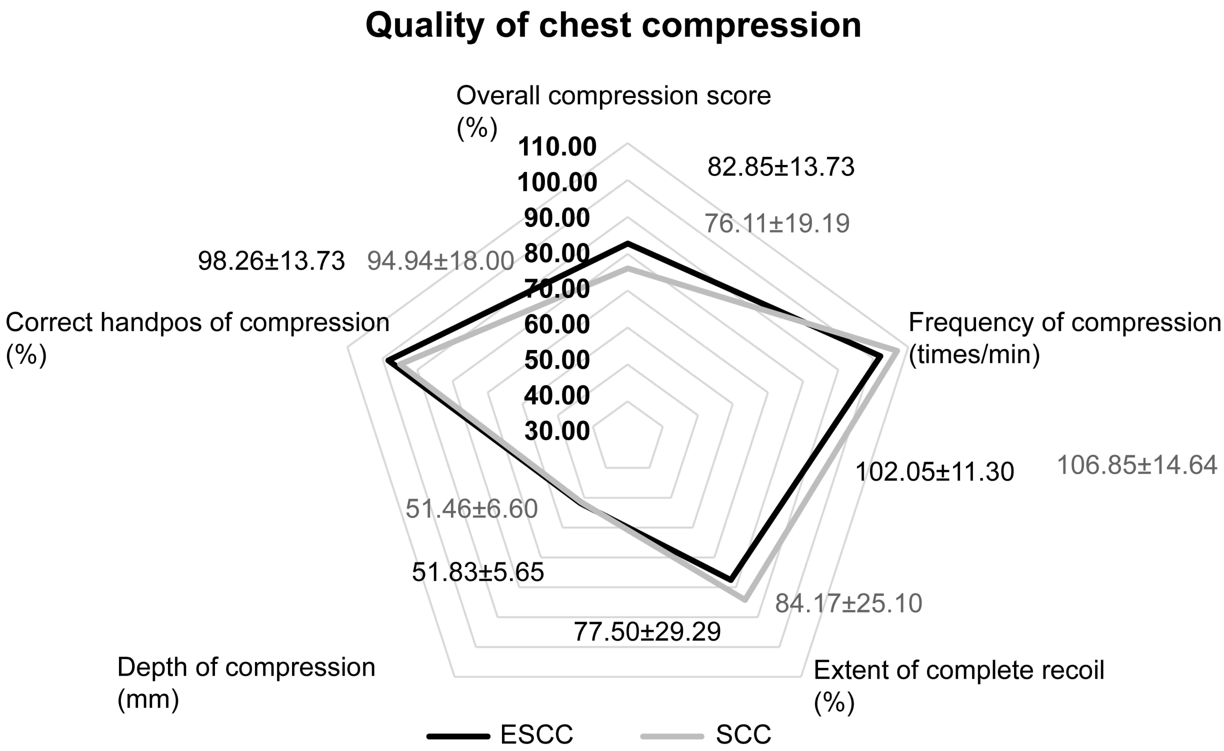

FIGURE 3. Comparison of the Quality of Chest Compression according to the Compression Method. ESCC: elbow support chest compression; SCC: standard chest compression. Data are presented as mean ± standard deviation. *$p < 0.05$, analyzed using paired t-tests.

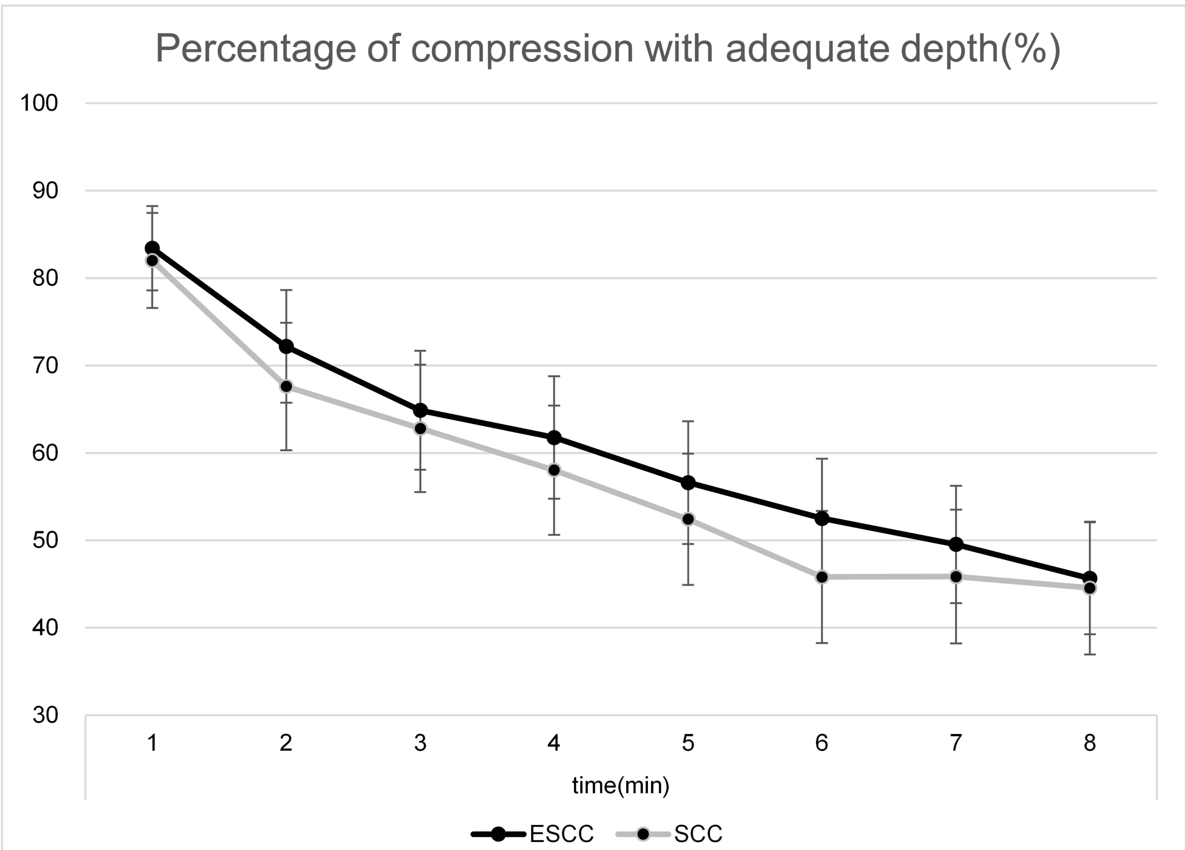

FIGURE 4. Comparison of the Percentage of Compressions with an Adequate Depth per Minute. ESCC: elbow support chest compression; SCC: standard chest compression. Data presented as mean ± standard error. *$p < 0.05$, analyzed using the paired t-tests.

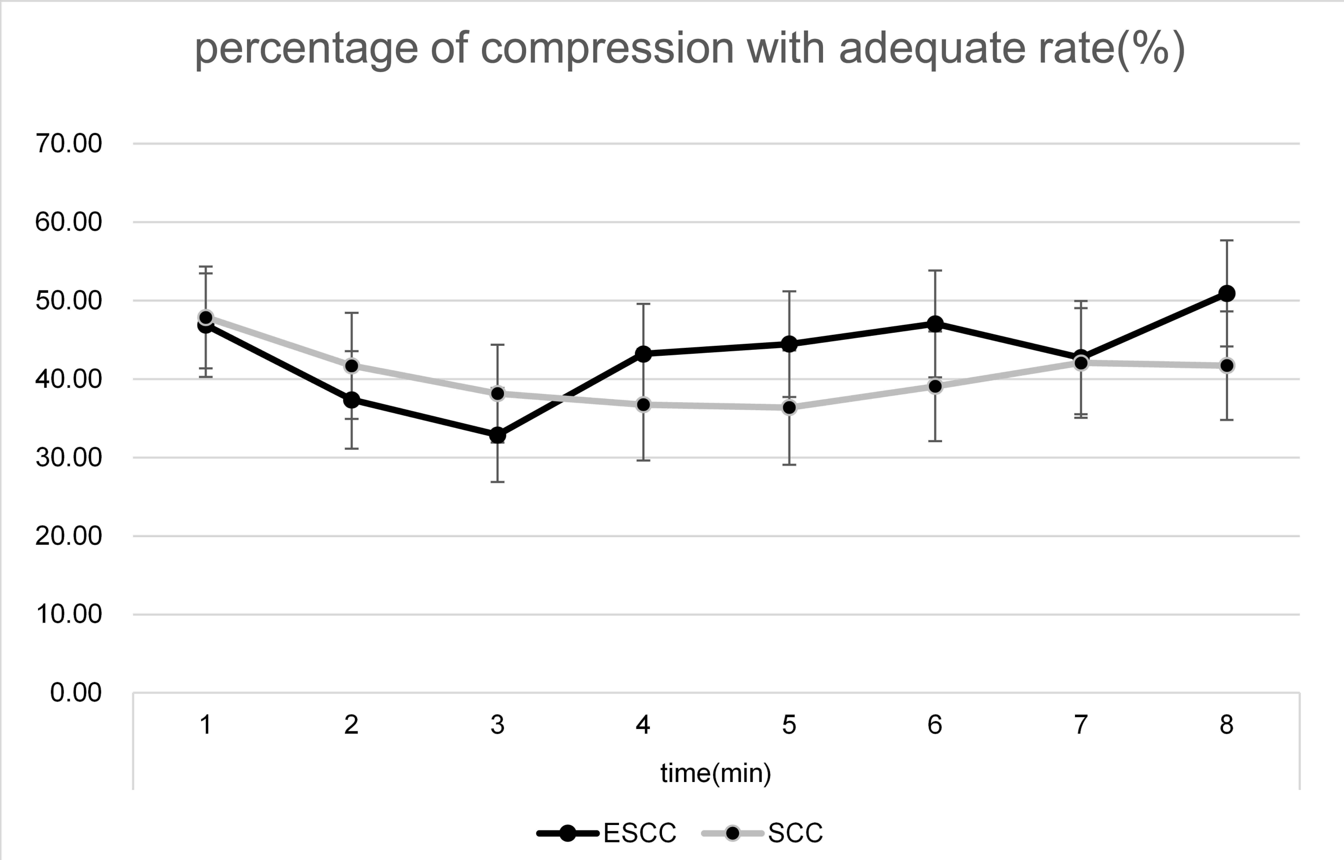

FIGURE 5. Comparison of the Percentage of Compressions with an Adequate Rate per Minute. ESCC: elbow support chest compression; SCC: standard chest compression. Data presented as mean ± standard error. $*p < 0.05$, analyzed using the paired *t*-tests.

centage of compressions with an adequate depth was 83.41% after 1 minute and was maintained at 72.18% after 2 minutes. Even after 6 minutes of compressions, the percentage was 52.61%, indicating that an adequate chest compression depth was maintained for over 50% of the time for up to 6 minutes. Even after 8 minutes, the ESCC group maintained a higher percentage of compressions with an adequate depth than the SCC group.

It is believed that the chest compression quality can be effectively maintained with elbow supports, which limits the elbows' ROM. According to a study that assessed the kinematics of the rescuer's body after hands-only CPR for 10 minutes, the authors found that chest compression depth was associated with the angle of the rescuer's elbow [15]. Appropriate elbow flexion can absorb an overload applied to the chest compression kinematic system, but excessive elbow flexion can result in a shallow chest compression depth of <50 mm [15]. To perform high-quality chest compressions, the rescuer must flex their knees by at least 90° and flex their left and right elbows by at least 14.1° and 3.7°, respectively [15]. Maintaining an appropriate joint ROM can reduce fatigue by minimizing muscle activity in the upper body, thereby enabling high-quality chest compression [15]. When performing pediatric CPR, the use of the elbow-lock chest compression method, which involves rotating to allow the elbow to fix the direction of the hand, also enables the maintenance of an adequate chest compression depth and a high OCS [16]. The findings of this present study were consistent with those from previous studies, which showed that preventing elbow flexion is indeed effective in allowing high-quality chest compression [16].

The chest compression depth was similar in the ESCC group irrespective of sex, whereas a significant difference was found in the SCC group, with women having a shallower chest compression depth (47.87 ± 5.23 mm) than men. A study by López-González *et al.* [17] compared sex differences in the rate of movement during 20 minutes of CPR and found that women had a higher rate of movement than men. Another study that compared the percentage of compressions with an adequate depth (at least 50 mm) during hands-only CPR for 8 minutes also reported that men had a decrease in the percentage of compressions to <70% after 2 minutes but could still maintain a relatively adequate chest compression depth, whereas women showed a rapid decrease in the percentage of compressions to <20% after just 1 minute, indicating that fatigue occurred within a relatively short time in women [13]. The rate of movement during CPR has also been found to differ according to the BMI and fitness of the rescuer [17]. However, we observed no significant difference in BMI in this study according to the participants' sex. Even in previous studies where no difference in the BMI of the participants was observed, maintaining chest compression depth resulted in a potentially high rate of movement, and women were found to perform chest compressions at shallower depths than men [18]. In this study, there was no difference between men and women when chest compressions were performed for 8 minutes while wearing elbow supports, but a difference was found when chest compressions were performed without elbow supports. Thus, based on previous literature and our experience, we believe that this could result from women having a higher rate of movement than men. Although direct comparison is difficult because this study did not analyze the percentage of physical movements, our findings showed that when women wore elbow supports, they had adequate chest compression depth, suggesting that their rate of movement could have been indeed reduced.

In the 2020 AHA CPR guidelines, the target chest compression rate is set at 100–120 times per minute [3]. However, the chest compression rate increases as chest compressions are continued [19]. In a previous study, the average compression rate after starting hands-only CPR was found to be 120.97 times/minute in the beginning, increased to 123.69 times/minute after 6 minutes and was 128.06 times/minute after 10 minutes [19]. In this present study, the percentage of compressions with an adequate rate per minute was 47.84% in the SCC group and 46.87% in the ESCC group. After 8 minutes, the percentage of compressions with an adequate rate decreased to 41.70% in the SCC group, but it increased to 50.88% in the ESCC group. In addition, the ESCC group showed a low percentage of compressions with an adequate rate in the first 3 minutes, which is believed to be the result of discomfort from adapting to the elbow supports because they are not usually worn. Thus, after 4 minutes, when the participants had adapted to wearing the elbow supports, the ESCC group showed a higher accuracy of chest compression rate than the SCC group. However, additional studies are needed to confirm why the accuracy of chest compression rate was low for the first few minutes in the ESCC group.

This study also identified measures to reduce fatigue when a layperson needs to perform hands-only CPR for a long time before the pre-hospital provider arrives. Elbow supports effectively limited elbow ROM, significantly increased the OCS and percentage of compressions with an adequate depth, and enabled rescuers to maintain these parameters for longer than they could without elbow supports. In particular, increased fatigue in female rescuers performing chest compressions for a long time caused the chest compression depth to become shallower, but using elbow supports was associated with an adequate compression depth maintained.

During the COVID-19 pandemic, wearing an N-95 mask can increase rescuers' fatigue and affects the quality of chest compressions during CPR [20]. Therefore, when wearing an N-95 mask, frequently switching rescuers could be an effective strategy [20]. In cases when an N-95 mask must be worn or in only one-rescuer situations, frequently switching rescuers could be practically difficult, indicating the importance of new measures for higher-quality chest compression and prevention of fatigue, especially for female rescuers. In these cases, using elbow supports could be an effective measure.

This study had the following limitations. First, the mean age of the participants was 23.21 $\pm$ 1.64 years; thus, the study findings cannot be generalized to all age groups. Second, after 3 minutes, the percentage of compressions with an adequate rate decreased in the ESCC group, and the associated cause should be further investigated to improve CPR effectivity. Third, although it is difficult to directly compare CPR between the SCC and ESCC groups with 11 female participants, the data between the two groups were very similar, and the *p*-value was very close to 0.05 (p = 0.053). Fourth, in this study, the population selected was quite specific (pre-experimental OCS of more than 80%), and the study was conducted on young certified BLS providers. Therefore, different results could be obtained for bystanders (laypersons). Fifth, the sample size was relatively small, and more participants should be investigated in future trials to validate our findings.

5. Conclusions

This study found that elbow supports enabled the rescuers to effectively maintain their OCS throughout 8 minutes of chest compressions while also enabling female rescuers to maintain a relatively adequate chest compression depth. Thus, the use of elbow supports could assist rescuers in giving higher quality chest compressions in one-rescuer situations, especially for female rescuers or when switching turns is not possible.

AVAILABILITY OF DATA AND MATERIALS

The data that support the findings of this study are openly available in Zenodo.org at http://doi.org/10.5281/zenodo.7860902, reference number md5:52df21a8ffe076f8a49c3325951750ae.

AUTHOR CONTRIBUTIONS

JHK—conceived and designed the study. EKJ—analyzed and interpreted the data and drafted the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The present study was approved by the Institutional Review Board (IRB) of "H" University (approval no.: 1041223-201806-HR-11). The research assistant provided explanation about the study before obtaining voluntary consent from the participants.

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Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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