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ORIGINAL ARTICLE

Comparison between modified and conventional one-handed chest compression techniques for child cardiopulmonary resuscitation: A randomised, non-blind, cross-over simulation trial†

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Aim: Chest compression depth (CCD) decreases significantly when performing one-handed chest compression (OHCC). We modified OHCC posture to increase CCD as follows: first, the axis of the compression hand was adjusted to the compression area; second, the opposite hand was wrapped around the elbow of the compression arm. This study compared modified OHCC with conventional OHCC for child cardiopulmonary resuscitation.

Methods: A total of 46 health-care providers performed 2 min of continuous chest compression using conventional OHCC (trial 1) and modified OHCC (trial 2) in a random order on a 5-year-old-sized child manikin lying on a bed. Chest compression parameters were assessed with an accelerometer and analysed by comparing the mean values of 30-s segments.

Results: The average CCD decreased significantly in all segments in both trials (trial 1 (segments 1–4): 40.9 ± 5.6 mm, 39.4 ± 6.6 mm, 38.0 ± 6.9 mm, 36.7 ± 7.3 mm, $P < 0.001$; trial 2 (segments 1–4): 42.3 ± 5.4 mm, 41.2 ± 6.2 mm, 40.1 ± 6.8 mm, 39.0 ± 6.9 mm, $P < 0.001$). However, the average CCD in trial 2 was significantly greater in all segments than that in trial 1 (segments 1–4: $P = 0.016$; $P = 0.009$; $P = 0.004$; $P = 0.001$). The average chest compression rates were comparable in all segments in both trials.

Conclusion: By modifying OHCC posture, a deeper mean CCD could be maintained for 2 min than by using conventional OHCC.

Key words: cardiac arrest; cardiopulmonary resuscitation; child.

What is already known on this topic

1. Recent cardiopulmonary resuscitation guidelines recommend chest compression with one or two hands for cardiac arrest in children.
2. The chest compression depth (CCD) decreased significantly after 30 s when using one hand.

What this paper adds

1. By modifying the posture of the one-handed chest compression (OHCC) technique, a deeper mean CCD could be maintained for 2 min than by using the conventional OHCC technique.

Recent cardiopulmonary resuscitation (CPR) guidelines recommend chest compression with one or two hands for cardiac arrest in children.[1,2] The one-handed chest compression technique (OHCC) can be used when the child is small because the chest compression pressure and depth of OHCC are lower than those in the two-handed chest compression technique (THCC).[3,4] However, OHCCs have several advantages. First, a single rescuer can maintain airway stability and minimise hand-off time by easy transition from chest compression to ventilation using OHCCs. Second, a rescuer can reduce leaning on the chest wall at the end of each chest compression by using OHCCs. The primary disadvantage of OHCCs is fatigability. The chest compression depth (CCD) with OHCC decreased faster than with THCC.[5,6] In THCC, the CCD is maintained for approximately 90 s under conditions of continuous chest compression (CCC).[6] However, the CCD decreased significantly after 30 s when using OHCC.[5] Therefore, chest compression providers should be rotated more frequently than every 2 min when OHCC is used.[2,7] If chest compression providers are rotated more frequently, the hand-off time will increase. As a result, high-quality CPR will not be maintained. To overcome this weakness, the quality of OHCC must be enhanced, or the strategies for CPR for cardiac arrest in children must be changed. We used two different approaches because the CPR environment varies according to the location of the event, that is, out-of-hospital or in-hospital. In the out-of-hospital

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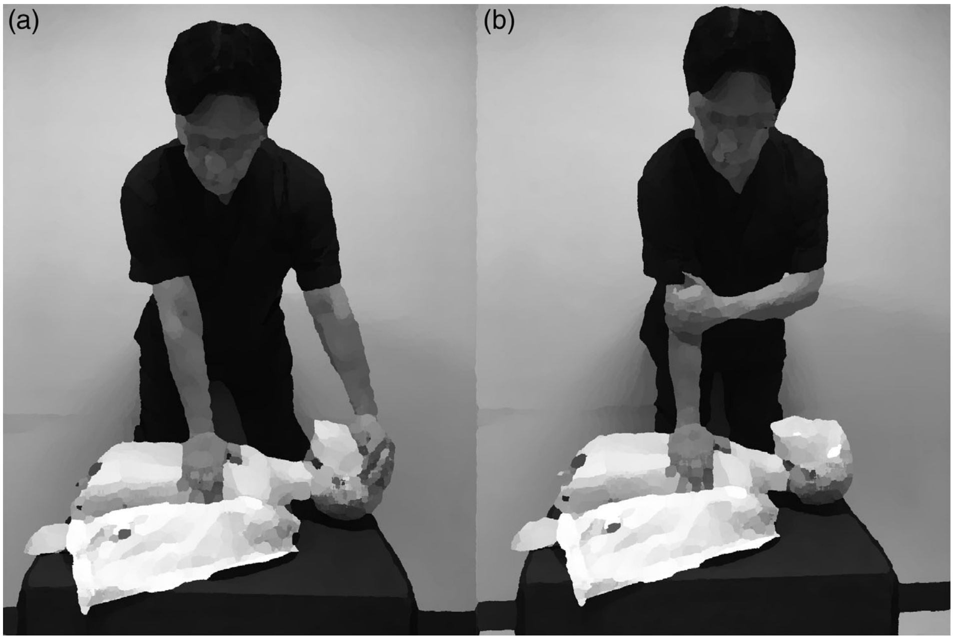

Fig. 1 Postures in chest compression technique. (a) Conventional one-handed chest compression technique. (b) Modified one-handed chest compression technique.

environment, CPR for a child in cardiac arrest should be performed at a compression-to-ventilation ratio of 15:2 irrespective of the number of rescuers.[2] A greater CCD can be maintained with OHCC by alternating the compression hand every other CPR cycle.[8] In an in-hospital environment, chest compressions should be performed continuously because an advanced airway is usually inserted. Although the same strategy (alternating chest compression hands) could be used at a specified time interval, the hand-off time would increase.[9] To enhance the quality of in-hospital OHCC, we modified OHCC posture using two steps. First, the axis of the chest compression arm was adjusted to the chest compression area to maximise rescuer weight load by compressing the sternum vertically. Second, the opposite hand was wrapped around the elbow of the compression arm to stabilise the OHCC posture during vertical movement caused by chest compression (Fig. 1). These posture modifications can eliminate the advantage of OHCCs (e.g. maintaining airway stability during single-rescuer CPR or easy transition from chest compression to ventilation). However, if there are two or more rescuers, those who are in charge of chest compression can concentrate on the chest compression because other rescuers can provide ventilation by using an advanced airway. A pilot trial to evaluate the quality of OHCC with posture modification showed that the decay of CCD decreased.[10] The present study was conducted to compare the quality of modified OHCC with that of conventional OHCC.

Methods

Study design

This was a prospective, randomised, cross-over trial. Participants were assigned to Groups A or B by using randomisation lists created with random-number sequences obtained with a web-based programme (http://www.random.org/sequences/; accessed 9 January 2016), to obtain six permuted blocks with the initials of each group: 'A' or 'B'. Participants assigned to Group A performed trial 1 (conventional OHCC), followed by trial 2 (modified OHCC). Participants assigned to Group B performed trial 2, followed by trial 1. A 30-min rest was provided between trials (Fig. 2).

Study setting and population

This study was conducted in the emergency department of a university hospital using a simulated in-hospital paediatric cardiac arrest model between March 2016 and October 2017. The model was previously developed for the purpose of simulation study and included a 70-cm-high bed, a 25-cm-high step stool and a Resusci Junior Basic and SkillGuide paediatric manikin (Laerdal Medical, Stavanger, Norway).[9] The manikin was the size of a 5-year-old child. The bed was specially manufactured with a plywood plate to prevent bed frame deflection from external impact, such as chest compression.[11,12] The bed was 50 cm wide, 60 cm long and 70 cm high. Chest compression parameters, such as CCD or chest compression rate (CCR), were recorded with an accelerometer (CPRmeter; Laerdal Medical). Data were extracted as mean values of 30-s segments by using Q-CPR review software (version 3.1; Laerdal Medical). Certified basic life support health-care providers participated in the study after providing written informed consent. The exclusion criteria were inability to perform CPR because of a recent hand or arm injury and refusal to participate in the study. Ultimately, 51 health-care providers were recruited.

Sample size calculation

Sample size was calculated based on CCD as a primary outcome variable. The two-sided significance level was set at 0.05, and the power of the test was set at 80%. The average CCD with conventional OHCC was 41.6 $\pm$ 4.8 mm based on published results.[13] The average decrease in CCD during 2 min of CCC with conventional OHCC was 5.6 mm in a previous study.[5] In contrast, the average decrease in CCD during 2 min of CCC with modified OHCC was 2.9 mm.[10] We set the allowable difference in conventional and modified OHCC as the average decrease in CCD during 2 min of CCC (5.6–2.9 = 2.7). The minimum number of participants in each group was calculated using a web programme (sample size calculator: two cross-over sample means) and was determined to be 13.[14]

Study protocol

After recruiting the participants, we collected basic information (gender, age, staff position and handedness) and anthropometric data (height, weight, knee height) before the experiments. The child manikin was placed on the bed in a supine position. A mattress was not used because mattress deflection during chest compression could cause overestimation of the CCD measured with the accelerometer.[15] The visual feedback screen of the accelerometer was covered to prevent participants from receiving feedback signals during experiments. Although no difference was reported in chest compression quality between OHCC performed with the dominant and non-dominant hand, chest compression was randomly assigned to the right or left hand before the experiment using a randomisation list.[3,13] The participants only performed OHCC with the assigned hand in both trials. In addition, the positions of the participants and manikin were standardised. Participants assigned to use the right hand were located on the right side of the manikin. Participants assigned to use the left hand were located on the left side of the manikin. Participants were educated in detail on the modified OHCC method by the researchers in charge of collecting data immediately before the experiments. The participants performed 2 min of CPR while standing on the step stool beside the bed. Mouth-to-mouth ventilation was not performed because the experimental setting was an in-hospital environment. We assumed that the child manikin had an advanced airway. Therefore, the participants only performed CCC in each trial.

Outcome variables

The primary outcome variables were average CCD (mm). The mean CCR (/min) and the ratio of complete recoil were the secondary outcome variables.

Statistical analysis

All statistical analyses were performed using IBM SPSS version 20.0 (IBM, Armonk, NY, USA). The data are presented as mean ± standard deviation. Data were analysed using the Shapiro–

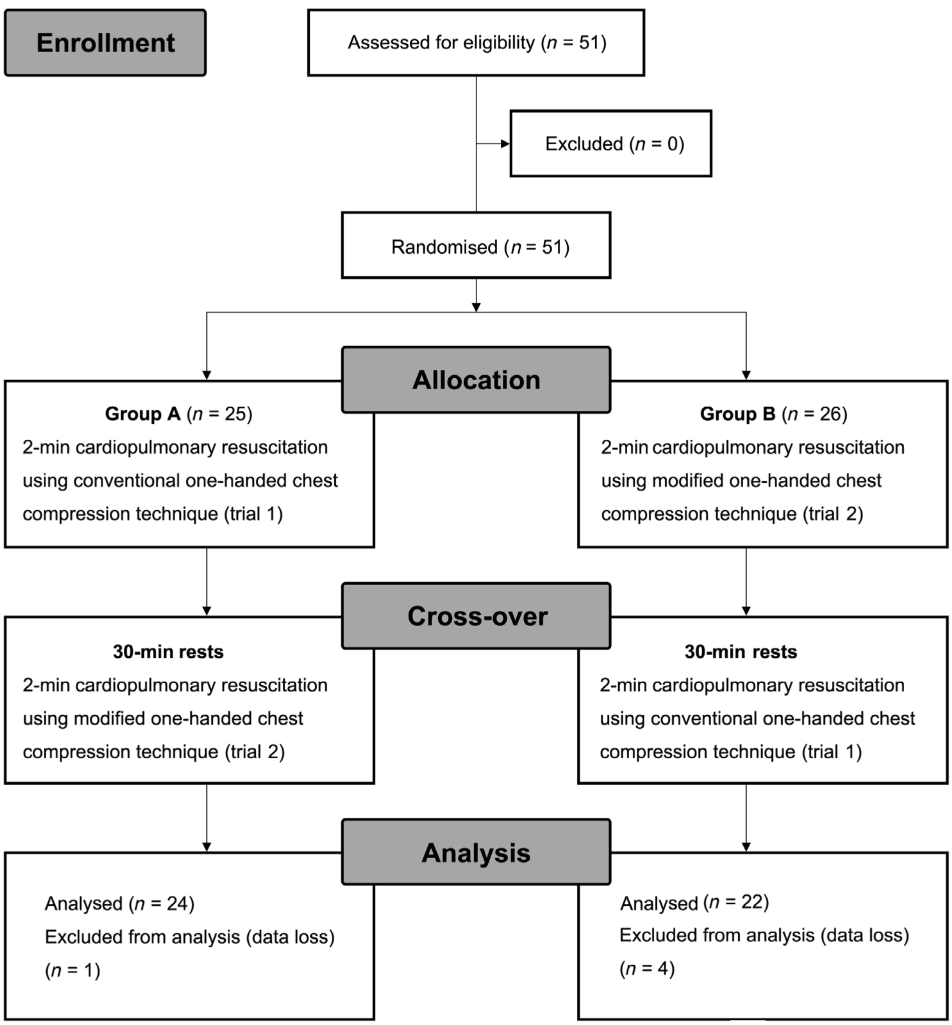

Fig. 2 Study design.

Table 1 Baseline characteristics of the study participants

Characteristics	Data
Gender, *n* (%)	
Male	30 (65)
Female	16 (35)
Age, years, mean ± SD	28.5 ± 3.4
Height, cm, mean ± SD	171.3 ± 8.2
Weight, kg, mean ± SD	67.3 ± 13.8
Knee height, cm, mean ± SD	44.8 ± 3.1
Handedness, *n* (%)	
Right	45 (98)
Left	1 (2)
Position, *n* (%)	
Attending physician	1 (2)
Resident physician	7 (15)
Intern physician	38 (83)

SD, standard deviation.

Wilk test to verify the normality of distribution. For normally distributed data, repeated-measures analysis of variance with multiple comparisons using Bonferroni correction was performed to evaluate differences in the mean values of 30-s segments of the outcome variables in each trial, and a two-sided paired *t*-test was used to compare outcome variables between trials 1 and 2; otherwise, the Friedman test was conducted to evaluate differences in the mean values of 30-s segments of the outcome variables in each trial, and the Wilcoxon signed-rank test was used to compare outcome variables between trials 1 and 2. If the Friedman test was used, multiple comparisons were conducted with the Wilcoxon signed-rank test between the mean values of 30-s segments of outcome variables. A P value of <0.05 was considered to indicate statistical significance.

Ethics statement

The present study protocol was reviewed and approved by the Institutional Review Board of our hospital (approval no. C2016006(1750)). Informed consent was submitted by all subjects when they were enrolled. This study is registered at the Clinical Research Information Service (CRIS, http://cris.nih.go.kr), number KCT0001833.

Results

A total of 51 health-care providers were recruited and assigned randomly to the two groups (Fig. 2). None of the participants was excluded; however, data of one Group A participant and four Group B participants were missing due to a data storage problem (n = 5).

Participant characteristics

The baseline characteristics are shown in Table 1. Most of the study participants were right handed (45/46, 97.8%); 24 performed OHCC with the right hand and 22 with the left hand.

Changes in chest compression parameters during a 2-min period

Average CCD decreased significantly in all segments in both trials (trial 1, conventional OHCC (segment 1–4): 40.9 ± 5.6 mm, 39.4 ± 6.6 mm, 38.0 ± 6.9 mm, 36.7 ± 7.3 mm, $P < 0.001$; trial 2, modified OHCC (segment 1–4): 42.3 ± 5.4 mm, 41.2 ± 6.2 mm, 40.1 ± 6.8 mm, 39.0 ± 6.9 mm, $P < 0.001$) (Table 2). The average CCR did not change significantly in both trials (Table 3).

Comparison of chest compression parameters in conventional and modified OHCC

The average CCD in trial 2 was significantly greater in all segments than in trial 1 (segment 1: 40.9 ± 5.6 mm vs. 42.3 ± 5.4 mm, P = 0.016; segment 2: 39.4 ± 6.6 mm vs. 41.2 ± 6.2 mm, P = 0.009; segment 3: 38.0 ± 6.9 mm vs. 40.1 ± 6.8 mm, P = 0.004; segment 4: 36.7 ± 7.3 mm vs. 39.0 ± 6.9 mm, P = 0.001) (Fig. 3). The ratio of complete recoil in all the segments were not significantly different between trials 1 and 2 (segment 1: 92.8 ± 15.4% vs. 93.1 ± 23.1%, P = 0.760; segment 2: 97.3 ± 13.2% vs. 93.7 ± 23.1%, P = 0.514; segment 3: 97.2 ± 11.5% vs. 95.2 ± 19.4%, P = 0.138; segment 4: 97.6 ± 12.0% vs. 96.2 ± 17.3%, P = 0.916). The mean CCR was not different significantly between trials 1 and 2, except for segment

Table 2 Changes in the average chest compression depth during a 2-min period

Trials	Segment 1 (0–30 s)	Segment 2 (30–60 s)	Segment 3 (60–90 s)	Segment 4 (90–120 s)	*P* value
Conventional one-handed chest compression technique, mm, mean ± SD	40.9 ± 5.6	39.4 ± 6.6	38.0 ± 6.9	36.7 ± 7.3	<0.001†
Multiple comparison tests‡	a	b	c	d	
Modified one-handed chest compression technique, mm, mean ± SD	42.3 ± 5.4	41.2 ± 6.2	40.1 ± 6.8	39.0 ± 6.9	<0.001§
Multiple comparison tests¶	a	b	c	d	

†Repeated-measures analysis of variance was used to determine statistical significance. ‡Same letters indicate non-significant differences between time segments based on multiple comparison tests using the Bonferroni correction. §The Friedman test was used to determine statistical significance. ¶Same letters indicate non-significant differences between time segments based on multiple comparison tests with the Wilcoxon signed-rank test. SD, standard deviation.

Table 3 Changes in the average chest compression rate during a 2-min period

Trials	Segment 1 (0–30 s)	Segment 2 (30–60 s)	Segment 3 (60–90 s)	Segment 4 (90–120 s)	*P* value
Conventional one-handed chest compression technique, /min, mean ± SD	109.8 ± 11.2	110.0 ± 12.5	109.7 ± 13.0	109.4 ± 13.6	0.776†
Multiple comparison tests‡	a	a	a	a	
Modified one-handed chest compression technique, /min, mean ± SD	109.0 ± 10.2	108.3 ± 11.6	107.7 ± 11.1	107.3 ± 11.3	0.073†
Multiple comparison tests‡	a	a	a	a	

†Repeated-measures analysis of variance was used to determine statistical significance. ‡Same letters indicate non-significant differences between time segments based on multiple comparison tests using the Bonferroni correction. SD, standard deviation.

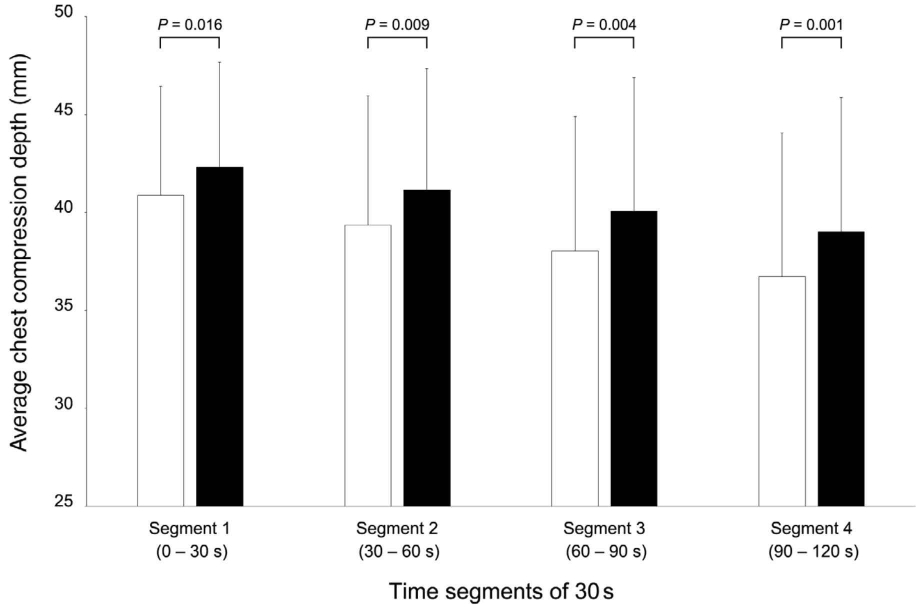

Fig. 3 Comparison of average chest compression depth (CCD) using conventional (white bar, trial 1) and modified (black bar, trial 2) one-handed chest compression techniques. Each bar represents the average CCD in a 30-s segment, and the error bars indicate ± standard deviation.

4 (segment 1: 109.8 ± 11.3/min vs. 109.0 ± 10.4/min, $P = 0.447$; segment 2: 110.0 ± 12.6/min vs. 108.3 ± 11.6/min, $P = 0.101$; segment 3: 109.7 ± 13.1/min vs. 107.7 ± 12.1/min, $P = 0.064$; segment 4: 109.4 ± 13.8/min vs. 107.3 ± 12.3/min, $P = 0.048$).

Subgroup analysis according to handedness

Of the participants, 25 performed OHCC with the dominant hand and 21 with the non-dominant hand. The mean CCD decreased significantly in all the segments in both trials irrespective of handedness (Tables S1 and S2, Supporting Information). However, no significant differences were found in the mean CCD in all the segments in both trials between the dominant and non-dominant hands (Table S3, Supporting Information).

Discussion

Although we modified the OHCC posture, the average CCD decreased rapidly over 2 min, in a pattern similar to that in conventional OHCC. However, a greater average CCD was maintained with the modified OHCC for 2 min than when using conventional OHCC. Several findings in this study are significant. First, posture modification could achieve deeper CCD compared with conventional OHCC starting in time segment 1. This means that the advantage of modified OHCC is not the result of decreased rescuer fatigue but, instead, the increase in power transition. This may have been the result of axis adjustment. By adjusting the axis of the compression arm, the patient's thorax can be moved vertically. When performing conventional OHCC, the axis of the compression arm is slightly inclined. We could not move the patient's thorax vertically with an inclined posture. Actually, the standard posture for conventional OHCC remains unclear. The choice of posture for conventional OHCC in this study was guided by a picture in the European Resuscitation Council guidelines for 2015.[2] No resuscitation guidelines described the posture for OHCC in detail. Therefore, our results might provide evidence for standardisation of OHCC posture. Much power is needed to achieve effective CCD. In adult victims, approximately 500 N is required to depress a sternum by 5 cm.[16] Because the chest compression force transferred to the patient's thorax is proportional to the mass of the rescuer, upper body weight should be loaded onto the patient's sternum.[17] Therefore, axis adjustment might increase the power transmitted in the vertical direction. However, the amount of power needed to achieve high-quality CPR in child cardiac arrest is unknown. There are limited data on resuscitation results in child cardiac arrest. In addition, the size and stiffness of a child's thorax vary according to age. Therefore, it is difficult to standardise the chest compression technique in all age groups of children because of the lack of data. Second, the advantage of modified OHCC is rapidly lost with time. This means that posture modification is ineffective in decreasing rescuer fatigue. Based on previous studies, alternating chest compression hands or changing chest compression technique is the only verified solution for relieving rescuer fatigue.[8,9] The application of a mixed strategy with simultaneous posture modification and alternating compression hands might achieve greater CCD for a longer time. Further study will be needed to develop an ideal chest compression technique for child cardiac arrest.

The ratio of complete recoil in all the segments was not significantly different between the trials. These results mean that the posture modification did not increase leaning.

We conducted subgroup analyses to confirm the effect of handedness on the fatigability of the two trials. The results were not changed according to the handedness. The handedness did not affect the posture modification. These results showed the same findings as those of previous studies.[3,13]

Our study had several limitations. First, although we recruited trained medical doctors, the average CCD did not reach the depth recommended by the resuscitation guidelines. The manikin's anterior–posterior diameter was approximately 15 cm. Therefore, the average CCD should have reached 5 cm. Second, the results were obtained using a mechanical simulation model and may not be representative of real-life situations. A human clinical trial is needed to confirm our results. Third, our study setting did not include a mattress and used a specially manufactured plywood bed because we used an accelerometer for measurements. Therefore, our setting was different from a real-life resuscitation environment. Although our study had limitations, we believe that the results might contribute to posture standardisation for OHCC in child cardiac arrest scenarios.

Conclusion

By modifying the OHCC posture, a deeper mean CCD could be maintained for 2 min than that on using conventional OHCC.

Acknowledgement

We thank all health-care providers for their contributions to this study.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Table S1. Changes in the average chest compression depth during a 2-min period with a dominant hand (n = 25).
Table S2. Changes in the average chest compression depth during a 2-min period with a non-dominant hand (n = 21).
Table S3. Comparisons of average chest compression depths according to the handedness.