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Which Fingers Should We Perform Two-Finger Chest Compression Technique with When Performing Cardiopulmonary Resuscitation on an Infant in Cardiac Arrest?

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This study compared the effectiveness two-finger chest compression technique (TFCC) performed using the right vs. left hand and the index-middle vs. middle-ring fingers. Four different finger/hand combinations were tested randomly in 30 healthcare providers performing TFCC (Test 1: the right index-middle fingers; Test 2: the left index-middle fingers; Test 3: the right middle-ring fingers; Test 4: the left middle-ring fingers) using two cross-over trials. The "patient" was a 3-month-old-infant-sized manikin. Each experiment consisted of cardiopulmonary resuscitation (CPR) consisting of 2 minutes of 30:2 compression: ventilation performed by one rescuer on a manikin lying on the floor as if in cardiac arrest. Ventilations were performed using the mouth-to-mouth method. Compression and ventilation data were collected during the tests. The mean compression depth (MCD) was significantly greater in TFCC performed with the index-middle fingers than with the middle-ring fingers regardless of the hand (95% confidence intervals; right hand: 37.8-40.2 vs. 35.2-38.6 mm, $P = 0.002$; left hand: 36.9-39.2 vs. 35.5-38.1 mm, $P = 0.003$). A deeper MCD was achieved with the index-middle fingers of the right versus the left hand ($P = 0.004$). The ratio of sufficiently deep compressions showed the same patterns. There were no significant differences in the other data. The best performance of TFCC in simulated 30:2 compression: ventilation CPR performed by one rescuer on an infant in cardiac arrest lying on the floor was obtained using the index-middle fingers of the right hand. Clinical Trial Registry at the Clinical Research Information Service (KCT0001515).

Keywords: Cardiopulmonary Resuscitation; Infant; Fingers; Hand

INTRODUCTION

The 2015 cardiopulmonary resuscitation (CPR) guideline recommends that the lone healthcare provider should use the two-finger chest compression technique (TFCC) instead of the two-thumb encircling hands technique (TTHT) when performing CPR on an infant in cardiac arrest (1). However, the guideline does not describe the exact method to be used during TFCC, i.e., which fingers and which hand.

In case of two-handed chest compression technique, the chest compression force is proportional to the rescuer's upper body mass (2). In TFCC, however, the full mass of the upper body is not loaded onto the compression point. Therefore, the quality of TFCC might be influenced by other factors, such as finger or hand strength.

We hypothesised that the quality of TFCC could be improved by using two fingers of the right hand, because the hand grip power of the right hand is typically greater than that of the left hand regardless of handedness (3-5) and that TFCC performance would be better with the use of two fingers of similar lengths because the rescuer might not be able to maintain a stable finger posture with two fingers of greatly differing lengths.

MATERIALS AND METHODS

Study design

The study was a prospective randomised cross-over trial. Two cross-over trials based on four different experiments were conducted randomly (Fig. 1). The participants were randomised three times throughout the trials using randomisation lists created by assigning random-number sequences obtained by a web-based program to six permuted blocks with the initial of each group, "A" or "B" (6). Five-minute rests were provided between the tests.

Study setting and population

This study was conducted in the emergency department of a university hospital using a model of infant cardiac arrest in which

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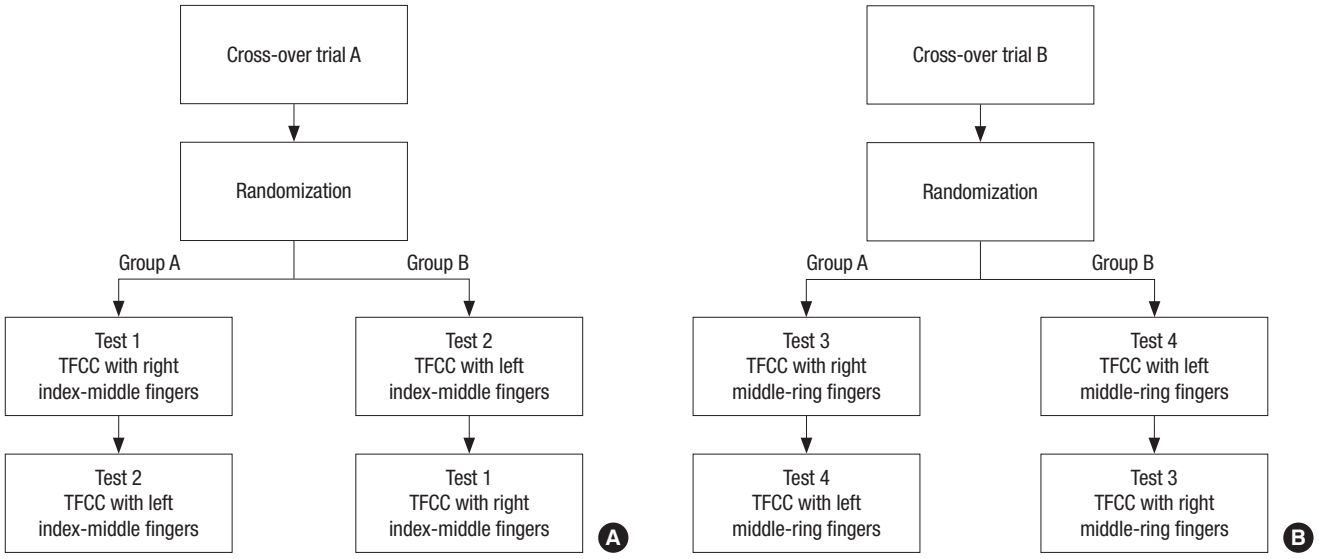

Fig. 1. Study flow diagram. Two cross-over trials (**A** and **B**) including four tests (1 to 4) were conducted with random order.
TFCC, Two-finger chest compression technique.

the "patient" was a 3-month-old-infant-sized manikin (Resusci Baby QCPR, Laerdal Medical, Stavanger, Norway) between June 2015 and July 2015. Healthcare providers who were certified basic-life-support providers participated in the study after providing written informed consent. The exclusion criteria were an inability to perform CPR because of a recent finger or hand injury and refusal to participate in the study. Ultimately, 30 healthcare providers were recruited.

Sample size was calculated based on chest compression depth as the primary outcome variable. The two-sided significance level was set at 0.05, and the power of the test at 80%. The standard deviation of the mean compression depth (MCD) was 5 mm, based on published results (7). The allowable difference in MCD between TFCC with the right vs. left hand was 10% (2.6 mm) of the MCD. The minimum number of participants in each group was calculated using a web program (sample size calculator: two cross-over sample means) and determined to be 15 (8).

Study protocol

The infant manikin was placed on a hard floor in the supine position. The participants performed single-rescuer CPR with 30:2 compression: ventilation using TFCC for 2 minutes. Ventilations were performed using the mouth-to-mouth method and a Manikin Face Shield (Laerdal Medical).

The fingers used in the TFCC were limited to the index-middle fingers and the middle-ring fingers because the thumb and little finger are very different in length. Therefore, the participants performed TFCC with the index-middle fingers of the right hand (Test 1), index-middle fingers of the left hand (Test 2), middle-ring fingers of the right hand (Test 3), or middle-ring fingers of the left hand (Test 4) (Fig. 2). Before the experiments, the lengths of the index, middle, and ring fingers of both hands were mea-

Fig. 2. Postures of the two-finger chest compression in the tests.
Test 1: Two-finger chest compression with the index-middle fingers of the right hand.
Test 2: Two-finger chest compression with the index-middle fingers of the left hand.
Test 3: Two-finger chest compression with the middle-ring fingers of the right hand.
Test 4: Two-finger chest compression with the middle-ring fingers of the left hand.
The test 1 and 3 were conducted on the right side of the manikin and the test 2 and 4 were conducted on the left side of the manikin.

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sured from the palmar digital crease to the fingertips on the palmar sides of the hands. To standardise the positions of the participants and manikin, the participants performed TFCC on the right side of the manikin when they used two fingers of the right hand (Tests 1 and 3) and on the left side of the manikin when they used two fingers of the left hand (Tests 2 and 4). The sequences of the tests were randomly allocated.

Performance data were collected using the SimPad SkillReporter (Laerdal Medical). The data included MCD (mm), total compressions (TCs, number), ratio of deep-enough compressions (DEC, %), ratio of compressions fully released (CFR, %), mean compression rate (MCR, numbers/min), hands-off time (HOT, s), total ventilations (TVs, numbers), and mean volume (MV, mL).

Outcome variables

The primary outcome variables were MCD and DEC. The other variables (TC, CFR, MCR, HOT, TV, and MV) served as secondary outcome variables.

Statistical analysis

All statistical analyses were performed using IBM SPSS v.20.0 (IBM, Armonk, New York, NY, USA). The data are presented as the means ± standard deviations. Data were analysed using the Shapiro-Wilk test to verify the normality of distribution. For normally distributed data, a two-sided paired *t*-test was used; otherwise, the Wilcoxon signed-rank test was used. A *P* value of < 0.05 was considered to indicate statistical significance.

Ethics statement

Chung-Ang University Hospital institutional review board reviewed and approved this study protocol, #C2015076(1534). Written informed consents were obtained before the study enrollment. This study was registered at the Clinical Research In-

Table 1. Comparisons of the length differences between the adjacent two-fingers

Parameters	Right index and middle fingers (n = 30) (95% CI)	Left index and middle fingers (n = 30) (95% CI)	95% CI of the difference		*P* value*
			Lower limit	Upper limit	
Length difference (mm)	7.8 ± 2.1 (7.0 to 8.5)	7.6 ± 2.2 (6.8 to 8.4)	-0.716	1.050	0.702
	Right middle and ring fingers	Left middle and ring fingers			
Length difference (mm)	5.9 ± 1.9 (5.2 to 6.6)	5.9 ± 2.7 (4.9 to 6.9)	-0.964	1.031	0.946
	Right index and middle fingers	Right middle and ring fingers			
Length difference (mm)	7.8 ± 2.1 (7.0 to 8.5)	5.9 ± 1.9 (5.2 to 6.6)	1.102	2.631	< 0.001†
	Left index and middle fingers	Left middle and ring fingers			
Length difference (mm)	7.6 ± 2.2 (6.8 to 8.4)	5.9 ± 2.7 (4.9 to 6.9)	0.773	2.694	0.001†

Data are presented as mean ± SD (95% CI).
*Statistical significances were tested by two-sided paired *t*-tests; †Significant by *P* value < 0.05.

Table 2. Comparisons of two-finger chest compression techniques: right vs. left hand

Parameters	Right index-middle fingers (n = 30) (95% CI)	Left index-middle fingers (n = 30) (95% CI)	95% CI of the difference		*P* value
			Lower limit	Upper limit	
Mean compression depth (mm)	39.0 ± 3.3 (37.8 to 40.2)	38.1 ± 3.1 (36.9 to 39.2)	NA	NA	0.004*,‡
Deep enough compressions (%)	78.5 ± 27.5 (68.3 to 88.8)	69.6 ± 32.1 (57.6 to 81.6)	NA	NA	0.007*,‡
Total compressions (No.)	169.6 ± 23.3 (160.9 to 178.3)	167.2 ± 23.0 (158.6 to 175.8)	-0.183	5.049	0.067†
Compressions fully released (%)	82.2 ± 24.0 (73.2 to 91.1)	85.7 ± 19.3 (78.5 to 92.9)	NA	NA	0.319*
Mean compression rate (/min)	119.9 ± 17.3 (113.5 to 126.4)	118.7 ± 17.2 (112.3 to 125.2)	-0.893	3.293	0.250†
Hands-off time (sec)	34.9 ± 5.5 (32.8 to 36.9)	35.0 ± 5.2 (33.1 to 36.9)	-1.655	1.388	0.859†
Total ventilations (No.)	10.2 ± 1.7 (9.6 to 10.9)	10.1 ± 1.6 (9.5 to 10.7)	NA	NA	0.412*
Mean volume (mL)	66.6 ± 31.3 (54.9 to 78.3)	70.8 ± 42.0 (55.1 to 86.5)	NA	NA	0.367*
	Right middle-ring fingers (n = 30) (95% CI)	Left middle-ring fingers (n = 30) (95% CI)			
Mean compression depth (mm)	36.9 ± 4.5 (35.2 to 38.6)	36.8 ± 3.5 (35.5 to 38.1)	NA	NA	0.559*
Deep enough compressions (%)	62.8 ± 36.4 (49.2 to 76.4)	56.3 ± 33.8 (43.7 to 68.9)	NA	NA	0.166*
Total compressions (No.)	169.9 ± 26.3 (160.1 to 179.7)	166.0 ± 23.4 (157.3 to 174.8)	0.421	7.312	0.029†,‡
Compressions fully released (%)	83.8 ± 27.1 (73.7 to 93.9)	79.0 ± 31.1 (67.4 to 90.6)	NA	NA	0.520*
Mean compression rate (/min)	119.2 ± 19.0 (112.1 to 126.3)	117.9 ± 18.3 (111.0 to 124.7)	-0.405	3.139	0.126†
Hands-off time (sec)	34.1 ± 5.6 (32.0 to 36.2)	33.9 ± 4.8 (32.1 to 35.7)	-1.539	2.006	0.790†
Total ventilations (No.)	10.1 ± 1.6 (9.5 to 10.7)	9.6 ± 1.8 (8.9 to 10.3)	NA	NA	0.074*
Mean volume (mL)	65.5 ± 36.9 (51.7 to 79.3)	71.4 ± 41.7 (55.8 to 86.9)	NA	NA	0.141*

Data are presented as mean ± SD (95% CI).
N/A, not applicable.
*Statistical significances were tested by Wilcoxon signed rank tests; †Statistical significances were tested by two-sided paired *t*-tests; ‡Significant *P* value < 0.05.

formation Service (KCT0001515).

RESULTS

Participants' characteristics

Thirty healthcare providers (19 males, 11 females; 22 medical doctors, 8 nurses) participated in the experiment. Their mean age was 28.4 ± 3.6 years (males 29.0 ± 3.8; females 27.5 ± 3.1 years). Twenty-eight participants were right-handed and two were left-handed. The respective mean lengths of the index, middle, and ring fingers were 69.7 ± 3.5, 77.5 ± 4.3, and 71.6 ± 3.9 mm on the right hand and 70.0 ± 4.0, 77.6 ± 4.3, and 71.8 ± 4.1 mm on the left. For both hands, the length differences between the index and middle fingers were significantly greater than those between the middle and ring fingers ($P < 0.01$, Table 1).

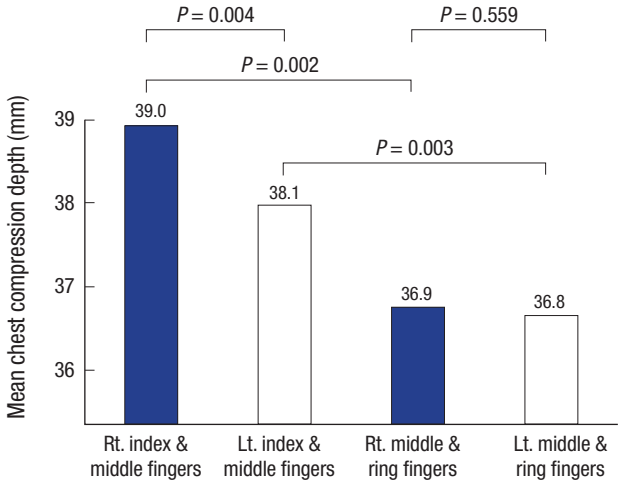

Fig. 3. Comparisons of mean chest compression depths. The compression depths of the two-finger chest compression techniques were deepest with right index-middle fingers.

Comparisons of TFCC performances: right vs. left hand

The MCDs and DECs were significantly greater when TFCC was performed with the right index-middle fingers than with the left index-middle fingers ($P < 0.01$, Table 2, Fig. 3). Although the MCD and DEC did not differ significantly in the TFCC performed with the middle-ring fingers, TC was significantly greater using the right than the left hand ($P = 0.029$, Table 2). The other variables were not significantly different.

Comparisons of TFCC performances: index-middle vs. middle-ring fingers

For both hands, the MCDs and DECs were significantly greater when TFCC was performed with the index-middle fingers than with the middle-ring fingers ($P < 0.01$, Table 3, Fig. 3). The other variables were not significantly different.

DISCUSSION

Studies of TFCC have focused on comparisons with TTHT (7,9-20) and the results consistently showed the superiority of the latter technique. Although several studies have recommended TTHT, even in lone-rescuer infant CPR (15,20), in one study the HOT of TTHT was significantly greater than that of TFCC (15). Another study used the over-the-head two-thumb encircling

Table 3. Comparisons of two-finger chest compression techniques: index-middle vs. middle-ring fingers

Parameters	Right index-middle fingers (n = 30) (95% CI)	Right middle-ring fingers (n = 30) (95% CI)	95% CI of the difference		*P* value
			Lower limit	Upper limit	
Mean compression depth (mm)	39.0 ± 3.3 (37.8 to 40.2)	36.9 ± 4.5 (35.2 to 38.6)	NA	NA	0.002*,‡
Deep enough compressions (%)	78.5 ± 27.5 (68.3 to 88.8)	62.8 ± 36.4 (49.2 to 76.4)	NA	NA	0.001*,‡
Total compressions (No.)	169.6 ± 23.3 (160.9 to 178.3)	169.9 ± 26.3 (160.1 to 179.7)	-4.742	4.209	0.904†
Compressions fully released (%)	82.2 ± 24.0 (73.2 to 91.1)	83.8 ± 27.1 (73.7 to 93.9)	NA	NA	0.543*
Mean compression rate (/min)	119.9 ± 17.3 (113.5 to 126.4)	119.2 ± 19.0 (112.1 to 126.3)	-2.988	4.388	0.701†
Hands-off time (sec)	34.9 ± 5.5 (32.8 to 36.9)	34.1 ± 5.6 (32.0 to 36.2)	-0.876	2.410	0.348†
Total ventilations (No.)	10.2 ± 1.7 (9.6 to 10.9)	10.1 ± 1.6 (9.5 to 10.7)	NA	NA	0.692*
Mean volume (mL)	66.6 ± 31.3 (54.9 to 78.3)	65.5 ± 36.9 (51.7 to 79.3)	NA	NA	0.905*
	Left index-middle fingers (n = 30) (95% CI)	Left middle-ring fingers (n = 30) (95% CI)			
Mean compression depth (mm)	38.1 ± 3.1 (36.9 to 39.2)	36.8 ± 3.5 (35.5 to 38.1)	NA	NA	0.003*,‡
Deep enough compressions (%)	69.6 ± 32.1 (57.6 to 81.6)	56.3 ± 33.8 (43.7 to 68.9)	NA	NA	0.008*,‡
Total compressions (No.)	167.2 ± 23.0 (158.6 to 175.8)	166.0 ± 23.4 (157.3 to 174.8)	-1.567	3.900	0.390†
Compressions fully released (%)	85.7 ± 19.3 (78.5 to 92.9)	79.0 ± 31.1 (67.4 to 90.6)	NA	NA	0.281*
Mean compression rate (/min)	118.7 ± 17.2 (112.3 to 125.2)	117.9 ± 18.3 (111.0 to 124.7)	-1.762	3.496	0.505†
Hands-off time (sec)	35.0 ± 5.2 (33.1 to 36.9)	33.9 ± 4.8 (32.1 to 35.7)	-0.181	2.448	0.088†
Total ventilations (No.)	10.1 ± 1.6 (9.5 to 10.7)	9.6 ± 1.8 (8.9 to 10.3)	NA	NA	0.227*
Mean volume (mL)	70.8 ± 42.0 (55.1 to 86.5)	71.4 ± 41.7 (55.8 to 86.9)	NA	NA	0.649*

Data are presented as mean ± SD (95% CI).
N/A, not applicable.
*Statistical significances were tested by Wilcoxon signed rank tests; †Statistical significances were tested by two-sided paired *t*-tests; ‡Significant *P* value < 0.05.

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technique (OTTT) in an attempt to reduce the HOT (19), with the rescuer positioned over the head of the manikin during CPR. While the HOT did not differ significantly between OTTT and TFCC, the proportion of complete recoil was significantly lower in OTTT. These results support the use of TFCC first when a lone rescuer performs CPR for infant cardiac arrest, as stated in the recent guideline (1).

This raises the question of the proper fingers to use for TFCC. Neither the optimal finger combination nor the optimal hand for performing TFCC has been studied. In addition, recent guidelines do not include any recommendations regarding finger and hand use in TFCC (1). In the illustration of TFCC included in the 2010 American Heart Association guidelines, the rescuer used the middle and ring fingers of the right hand for TFCC (21), but this choice was neither described nor justified.

We predicted that the mechanisms of chest compression force generation would differ completely between TFCC and two-handed chest compression techniques. During TFCC, the interphalangeal joints of the two fingers should be fully extended to transfer the compression force to the fingertips. This implies that the performance of TFCC is influenced by the amount of finger strength. This study paid attention to hand grip power because stronger hand grip power might be associated with greater finger strength. Several studies have shown that the hand grip power of the right hand is greater than that of the left hand in both right- and left-handed individuals (3-5). We also noted that some rescuers could not perform adequately TFCC because of a much shorter index finger. This suggested that if the two adjacent fingers differ greatly in length, the performance of TFCC will be compromised.

Our study found that while the best TFCC performance was obtained using the two fingers of the right hand, TFCC performance was better with the index-middle fingers than with the middle-ring fingers, although the length difference between the index and middle fingers was greater than that between the middle and ring fingers of the participants. This might reflect the fact that the index finger is used more frequently than the ring finger. In addition, the contribution of the radial side to hand grip power is much greater than that of the ulnar side (approximately 60% and 40%, respectively) (22).

This study asked the question, "Which fingers do we perform two-finger chest compression with?" The answer is the index-middle fingers of the right hand. Although TTHT is superior to TFCC, if the latter is performed using the index-middle fingers of the right hand, it may meet the requirements of the current guidelines.

Our study had several limitations. First, the results were obtained using a mechanical model and may not be representative of real-life situations. A human clinical trial is needed to confirm our results. Second, the experiment was conducted with the manikin on the floor, because this was considered to reproduce the conditions faced by a single-rescuer performing CPR in an out-of-hospital environment. It remains to be determined whether different results would be obtained in an in-hospital environment, i.e., with the infant lying on a bed. Third, although the grip power of the right hand is stronger, even in left-handed individuals (4,5), the majority of the participants in our study were right handed and the results must still be confirmed in left-handed rescuers.

The best performance of TFCC in a simulation of 30:2 compression: ventilation CPR performed by one-rescuer on an infant in cardiac arrest lying on the floor was obtained with rescuers using the index-middle fingers of the right hand.

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DISCLOSURE

The authors have no potential conflicts of interest to disclose.

AUTHOR CONTRIBUTION

Conception and design: Oh JH. Acquisition of data: Kim YS. Analysis and interpretation of data: Kim YS, Oh JH, Kim CW, Kim SE, Lee DH, Hong JY. Writing of the manuscript: Kim YS, Oh JH. Study supervision: Oh JH. Approval of final manuscript: all authors.

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