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ORIGINAL RESEARCH

Analysis of the adequacy of infant cardiopulmonary resuscitation according to chest compression technique based on the 2020 AHA guidelines

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Abstract

The quantitative and qualitative differences between the two-finger (TF) and two-thumb-encircling hands (TT) techniques were not sufficiently investigated to determine which is more effective for single-rescuer infant cardiopulmonary resuscitation (CPR). As the type of chest compression (CC) technique can impact survival rates and prognoses of patients, this study aimed to compare the adequacy of single-rescuer infant CPR CC techniques and explore participants' CPR experiences using an exploratory sequential mixed methods design. To assess the adequacy of CC and ventilation according to technique, 70 students who completed basic life support provider certification among students from emergency medical services and nursing departments of a single college performed CC using the TF and TT techniques (4 sets of 5 cycles with a ratio of 30:2) in simulation. Meanwhile, a numeric rating scale was used to measure fatigue. SPSS (v. 25.0, IBM Corp, Armonk, NY, USA) was used to analyze the collected data by frequency analysis, descriptive statistics, paired *t*-test, and repeated measures analysis of variance (ANOVA). We conducted focus group interviews and analyzed CPR experiences. There were statistically significant differences between the TF and TT techniques in fatigue score (6.09 *vs.* 4.23 points, $p < 0.001$), average hands-off time (6.77 *vs.* 7.43 s, $p = 0.001$), mean ventilation volume (41.40 *vs.* 35.51 ml, $p = 0.002$), CC accuracy rate (65.89% *vs.* 77.11%, $p = 0.011$), mean CC rate (104.37 *vs.* 107.11 beats/min, $p = 0.020$), overall CPR score (78.26 *vs.* 84.37 points, $p = 0.005$), and overall compression score (82.60 *vs.* 92.54 points, $p < 0.001$). Furthermore, we found significant differences over time in mean CC count ($p = 0.030$), mean ventilation volume ($p = 0.042$), and mean hands-off time ($p = 0.029$). Two categories (ambivalent attitudes and perception of pain) and five sub-categories were derived based on the results. In conclusion, as stated in the 2020 American Heart Association (AHA) guidelines, both TF and TT techniques are useful for single-rescuer infant CPR. Overall, TT technique provides higher quality of compressions at the cost of fewer ventilations. We recommend future studies of more diverse groups and techniques.

Keywords

Infant; Chest compression; Two fingers; Two thumbs; Cardiopulmonary resuscitation

1. Introduction

1.1 Necessity of research

Regardless of age, bystander cardiopulmonary resuscitation (CPR) is crucial for saving a patient's life. Timely delivery of high-quality CPR by a bystander can significantly impact the survival and neurological prognoses of adults, children, and infants [1, 2]. Moreover, effective CPR during cardiac arrest can increase brain and coronary artery perfusion pressure, favoring the return of spontaneous circulation, and effective chest compression (CC) and ventilation are key factors to successful CPR [3]. Accordingly, the guidelines of the American Heart Association (AHA) and Korean Association of Cardiopulmonary Resuscitation (KACPR) emphasize the delivery of high-quality bystander CPR [4].

For high-quality infant CPR, 2020 AHA and KACPR guidelines recommend a compression depth of at least one-third the depth of the chest or 4 cm, and a CC rate of 100–120 compressions per min, with sufficient chest recoil after CC and minimal interruption of CC of $\leq$ 10 s. Furthermore, the guidelines recommend prevention of hyperventilation when performing two ventilations [5]. In addition, the 2020 AHA guidelines for single-rescuer infant CPR recommend using both CC techniques: the two-finger CC (TF) and the two-

thumb encircling hands CC (TT). However, previous studies have indicated that the TT technique provided greater CC depth than the TF technique and no difference in CC count and hands-off time in single-rescuer infant CPR cases [2, 6–9]. Despite such findings, the KACPR guidelines differ from the 2020 AHA guidelines by still recommending the TF technique for single-rescuer infant CPR, considering hands-off time and difficulty with rescuer's posture [5, 6, 10].

Increased rescuer fatigue during CPR could affect the adequacy of CC, and as a result, the rescuer may experience difficulties in delivering effective CPR over time, which could affect the survival and neurological prognosis of the infant [11]. A comparison of single-rescuer infant CPR according to CC technique for 2 min showed that TF CC resulted in higher pain and fatigue, with no difference in hands-off time [2]. However, previous research has not sufficiently investigated the qualitative differences between TT and TF techniques to determine which CC technique is more effective for single-rescuer infant CPR, thus requiring further studies. Additionally, mixed methods studies testing the adequacy of the compression-ventilation ratio (C:V ratio; 30:2) over time using focus group interviews (FGIs) were even scarcer.

Therefore, the current study applied a mixed methods design to identify the adequacy and experience of using the TF or TT technique for single-rescuer infant CPR, and to establish essential data to improve the quality of infant CPR.

1.2 Objectives

The primary objective of the present study was to test the adequacy of infant CPR according to CC technique based on the 2020 AHA guidelines. Specific objectives were as follows:

① Identify the level of fatigue and adequacy of CC using the TF or TT technique during single-rescuer infant CPR.

② Identify the adequacy of CC using the TF or TT technique over time (about 5 cycles of 4, total 8 min of CPR) during single-rescuer infant CPR.

③ Describe the experience of performing ventilation and CC using the TF or TT technique during single-rescuer infant CPR, and how it affected the CPR process.

2. Methods

2.1 Study design

The present study was conducted using an exploratory sequential mixed methods design. The quantitative research used a one-group pretest-posttest design to identify the quality and adequacy of CC using either the TF or TT technique for infant CPR. The qualitative research consisted of content analysis on data collected through FGIs conducted with the study participants upon completion of the quantitative research (Fig. 1).

2.2 Study population

The target population of the present study consisted of students enrolled in the emergency medical service and nursing departments in a single college in Korea. Of these students, those who had completed the basic life support (BLS) provider certification and consented to participate in the study were selected.

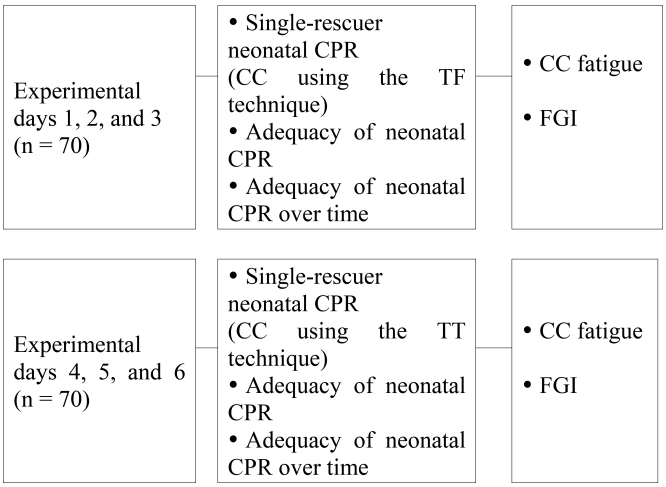

FIGURE 1. Flowchart of simulations. Abbreviations: CPR, cardiopulmonary resuscitation; CC, chest compression; FGI, focus group interview; TF, two-finger; TT, two-thumb-encircling hands.

2.2.1 Inclusion and Exclusion Criteria

Participants: The study subjects received AHA BLS provider education at the same time. We included studies with current students participants with recent BLS training (<1 year previously).

Exclusion criteria: Those who have never received AHA BLS provider education in 2020.

2.2.2 Sample size

The number of study subjects was calculated using G*Power 3.1.9 (Heinrich-Heine-University, Düsseldorf, Germany), with an effect size of 0.30, significance level of 0.05, and power of 0.80. The estimated sample size required for the study was 64; therefore, 70 subjects were included in consideration of subjects who would not participate in the study, drop out, or provide insufficient answers to the questionnaire questions.

2.3 Setting

The study was conducted in a location with adequate lighting that was isolated from outside noise. The participants took part in the experiment as single-rescuers, meaning first responders, to a simulated situation involving out-of-hospital cardiac arrest of an infant.

To assess the quality and adequacy of CC using the TF and TT techniques for single-rescuer infant CPR, the participants performed 4 sets of 5 cycles of 30 CCs and 2 ventilations (8 min each), using the TF technique on day 1 and the TT technique on day 2. All CPR procedures were assessed and recorded using Laerdal Resusci Baby QCPR® manikin (Laerdal Medical, Stavanger, Norway). We recorded the biometrics of the participants, including sex, age, height, and weight, and the certified year of BLS status and provider. The level of fatigue after completion of CPR was measured based on self-

assessment using a numeric rating scale (NRS) as follows: 0 (least fatigue) to 10 (most fatigue) points. Quality of CPR was assessed based on total CC count, total ventilation count, total hands-off time, mean ventilation volume, CC accuracy rate, mean CC count, overall CPR score, and overall compression score. Adequacy of CPR over time was assessed based on mean CC depth, mean CC count, mean ventilation volume, and mean hands-off time.

2.4 Data collection

The participants did not receive any training prior to the experiment to minimize differences between experiments when collecting quantitative data. Furthermore, the experiments were conducted one by one at an unspecified time to minimize participant contamination and errors that may have affected the results due to exchange of information between participants or acquisition of prior knowledge.

In addition, semi-structured FGIs were conducted with all 70 participants (7 groups with 10 members each) for qualitative data collection using open-ended questions. We conducted interviews in a quiet, comfortable seminar room, with participant consent for participation and recording of the interviews.

2.5 Data analysis methods

2.5.1 Quantitative data analysis

Collected data were analyzed using SPSS for Windows version 25.0 statistics package. Specific analysis methods used were as follows:

First, we derived the mean and standard deviation values of the biometric data, the adequacy of single-rescuer infant CPR using the TF or TT technique, and participants' fatigue.

Second, we analyzed differences in the adequacy of single-rescuer infant CPR using the TF and TT technique, and fatigue using paired *t*-test.

Third, we analyzed the adequacy of single-rescuer infant CPR using the TF or TT technique over time using repeated measures ANOVA.

2.5.2 Qualitative data analysis

The interviews for qualitative research were conducted using open-ended questions. The participants' statements were transcribed verbatim from the recording, and a member verification process was used to ensure that the analyzed results were described without any distortion. The FGIs were conducted with the participants divided into 7 groups to ensure transferability. Data were collected up to the saturation point when no new information about the research topic could be derived. We used the content analysis method by Elo and Kyngäs [12] to analyze the FGI content. The data collected during interviews was repeatedly read, underlining relevant words and phrases, and adding annotations to the margins. When reading the responses several times, sentences or phrases considered meaningful were marked by underlining. Subsequently, meaningful statements were categorized and described as universal and abstract concepts. Finally, we comprehensively organized categories to ensure they represented the phenomena experienced from the participants' perspective. The researchers reviewed relevant precedent studies and continued to examine the data to ensure their subjectivity was not introduced. Analyzed data were peer reviewed by one researcher and one nursing professor with valuable experience in qualitative research.

2.6 Study tools

2.6.1 Adequacy of CC

We assessed CPR using a manikin (Resusci Baby®, QCPR®, Laerdal, Norway) and a connected laptop PC installed with CPR quality assessment programs (Sim Pad Skill Reporter and Resusci Anne® Wireless Skill Reporter software, Laerdal, Norway). The scores automatically saved in Sim Pad Skill Reporter were used. Records used to assess the quality of CPR included CPR score (%), compression score (%), CC count (times), compression depth (mm), chest recoil percentage (%), CC percentage (%), hand position accuracy (%), compression rate (times/min), hands-off time (s), ventilation score (%), total number of breaths (times), tidal volume (mL), adequate tidal volume (%), and respiratory rate (times/min). The scores for CPR score (%), compression score (%), chest recoil rate (%), CC percentage (%), hand position accuracy (%), ventilation score (%), and adequate tidal volume (%) ranged between 0 and 100 points with higher scores indicating higher performance. The overall CPR score for final assessment of the quality of CPR was automatically obtained after adding the scores for each item. For CC rates of 100–120 times/min, adequate CC depth of at least one-third the depth of the chest (anteroposterior diameter of the chest) or 40 mm, and hands-off time of $\leq$ 10 s [5], the results automatically obtained from the manikin were used. These values were based on the 2020 AHA guidelines. We assessed the adequacy of ventilation using the Manikin Face Shield (Laerdal, Norway) (Fig. 2).

FIGURE 2. Simpad SkillReporter and Resusci Baby® QCPR®.

2.6.2 Adequacy of CC over time

We found the mean CC time to be 7.28 min from a call to the 119 Emergency Service to arrival at the scene, and 10.86 min from the scene to arrival at the hospital [6, 13]. Based on this information, the criteria for adequate CC in the current study were 4 cm, 5 cycles, and 8 min (2020 AHA guidelines). We assessed adequate CC using the TF or TT technique for a single-rescuer infant CPR as the total number of breaths and adequate CC according to a mean CC depth, 4 cm CC count, incomplete recoil count, total compression count, and elapsed

time (8 min) during 5 cycles of 4 sets. These were measured using a manikin-connected Sim Pad Skill Reporter.

2.6.3 CC fatigue

The level of fatigue after completion of CPR was measured based on self-assessment using the following NRS: 0 (least fatigue) to 10 (most fatigue) points.

2.6.4 General characteristics

We recorded participants' biometric data on sex, age, height, weight, and the year of BLS provider certification.

2.6.5 Focus group instrument

1. Introductory questions: Basic information (BLS-provider certification status, actual CPR experience, *etc.*).

2. Key questions: Experience related to ventilation and CC using the TF or TT technique for single-rescuer infant CPR ("How was the experience of performing CC using the TF or TT technique?" and "How did CC using the TF or TT technique affect the CPR process?").

3. Closing questions: Additional statements and understanding about CC using the TF or TT technique.

3. Results

3.1 General characteristics of the participants

The mean (±standard deviation (SD)) age, weight, and height of the participants were 22.40 (±1.75) years, 66.13 (±12.23) kg, and 168.4 (±7.22) cm, respectively. The study population included 38 men (54.7%), and the majority of participants (n = 42, 60.0%) had completed BLS provider certification in 2021 (Table 1).

TABLE 1. General characteristics of the participants (n = 70).

Variable	N (%) or mean ± SD
Sex	
Male	38 (54.30)
Female	32 (45.70)
Age (year)	22.40 ± 1.75
Weight (kg)	66.13 ± 12.23
Height (cm)	168.4 ± 7.22
BLS completion year	
2019	2 (2.90)
2020	26 (37.10)
2021	42 (60.0)

Abbreviations: BLS, basic life support; SD, standard deviation.

3.2 Differences in CPR according to CC technique

Analysis of CC using the TF or TT technique for infant CPR showed statistically significant differences in fatigue (6.09 *vs.* 4.23 points, $p < 0.001$), total hands-off time (132.77 *vs.* 142.37 s, $p < 0.001$), average hands-off time (6.77 *vs.* 7.43 s, $p = 0.001$), chest compression fraction (72.33 *vs.* 70.34%, $p < 0.001$), mean ventilation volume (41.40 *vs.* 35.51 mL, $p = 0.002$), CC accuracy rate (65.89 *vs.* 77.11%, $p = 0.011$), mean CC rate (104.37 *vs.* 107.11 beats/min, $p = 0.020$), overall CPR score (78.26 *vs.* 84.37 points, $p = 0.005$), and overall compression score (82.60 *vs.* 92.54 points, $p < 0.001$). However, there were no significant differences in total CC count (62169.70 *vs.* 63563.80 times, $p = 0.330$) and total ventilation count (1429.06 *vs.* 1517.23 times, $p = 0.324$) (Table 2).

3.3 Differences in CPR according to CC technique over time

Analysis of the adequacy of infant CPR over time according to technique showed significant differences in mean CC count ($p = 0.030$), mean ventilation volume ($p = 0.042$), and mean hands-off time ($p = 0.029$). Moreover, although there was no significant difference in mean CC depth over time ($p = 0.191$), the TT technique showed a greater CC depth (Table 3 and Fig. 3).

3.4 Qualitative content analysis results

From the content analysis of responses given by the participants, 5 sub-categories were derived, based on which 2 categories were derived (Table 4).

A. Ambivalent

This category included two sub-categories of "relative comfort" and "contradictory attitude."

(1) Relative comfort

The participants stated that the TT technique was more effective and stable than the TF technique.

"I realized that the two-thumb-encircling hands technique is better than the two-finger chest compression technique." (Participant 7)

"It was more useful since my fingers didn't hurt as much as with the two-finger chest compression technique." (Participant 41)

"I think I can perform chest compression without burden on the hands due to better grip when holding the infant with both hands." (Participant 69)

(2) Contradictions

Most participants stated that the TF technique exhausted them more than the TT technique, but it was easier for ventilation.

"It was uncomfortable, but the posture was very good for ventilation." (Participant 1)

"Fatigue was definitely more severe during chest compression as compared to using two thumbs, but it was easier during ventilation." (Participant 33)

In some cases, the participants stated that CC using the TT technique was easier and simpler, causing no problem during

TABLE 2. Differences in CPR according to CC technique (n = 70).

Variable	TF mean ± SD	TT mean ± SD	*t*	*p*
Fatigue NRS (points)	6.09 ± 1.73	4.23 ± 1.67	8.463	<0.001*
Total compression mean depth (mm)	43.03 ± 3.76	43.77 ± 2.84	−1.408	0.164
Total compression count (n)	62169.70 ± 12560.01	63563.80 ± 12764.71	−0.980	0.330
Total ventilation count (times)	1429.06 ± 782.89	1517.23 ± 803.72	−0.994	0.324
Total hands-off time (s)	132.77 ± 22.96	142.37 ± 24.79	−3.732	<0.001*
Average hands-off time (s)	6.77 ± 1.58	7.43 ± 1.77	−3.526	0.001*
Chest compression fraction (%)	72.33 ± 4.78	70.34 ± 5.17	3.732	<0.001*
Mean Ventilation volume (mL)	41.40 ± 20.43	34.51 ± 21.45	11.221	0.002*
Compression accuracy rate percentage (%)	65.89 ± 38.10	77.11 ± 32.94	−2.688	0.011*
Mean Compression rate (beats/min)	104.37 ± 11.38	107.11 ± 8.15	−2.375	0.020*
Overall CPR score (points)	78.26 ± 12.64	84.37 ± 11.13	−2.926	0.005*
Overall compression score (points)	82.60 ± 16.40	92.54 ± 10.07	−4.082	<0.001*

Abbreviations: CPR, cardiopulmonary resuscitation; CC, chest compression; NRS, numerical rating scale; TF, two-finger; TT, two-thumb-encircling hands; SD, standard deviation.
**Indicates statistically significant differences.*

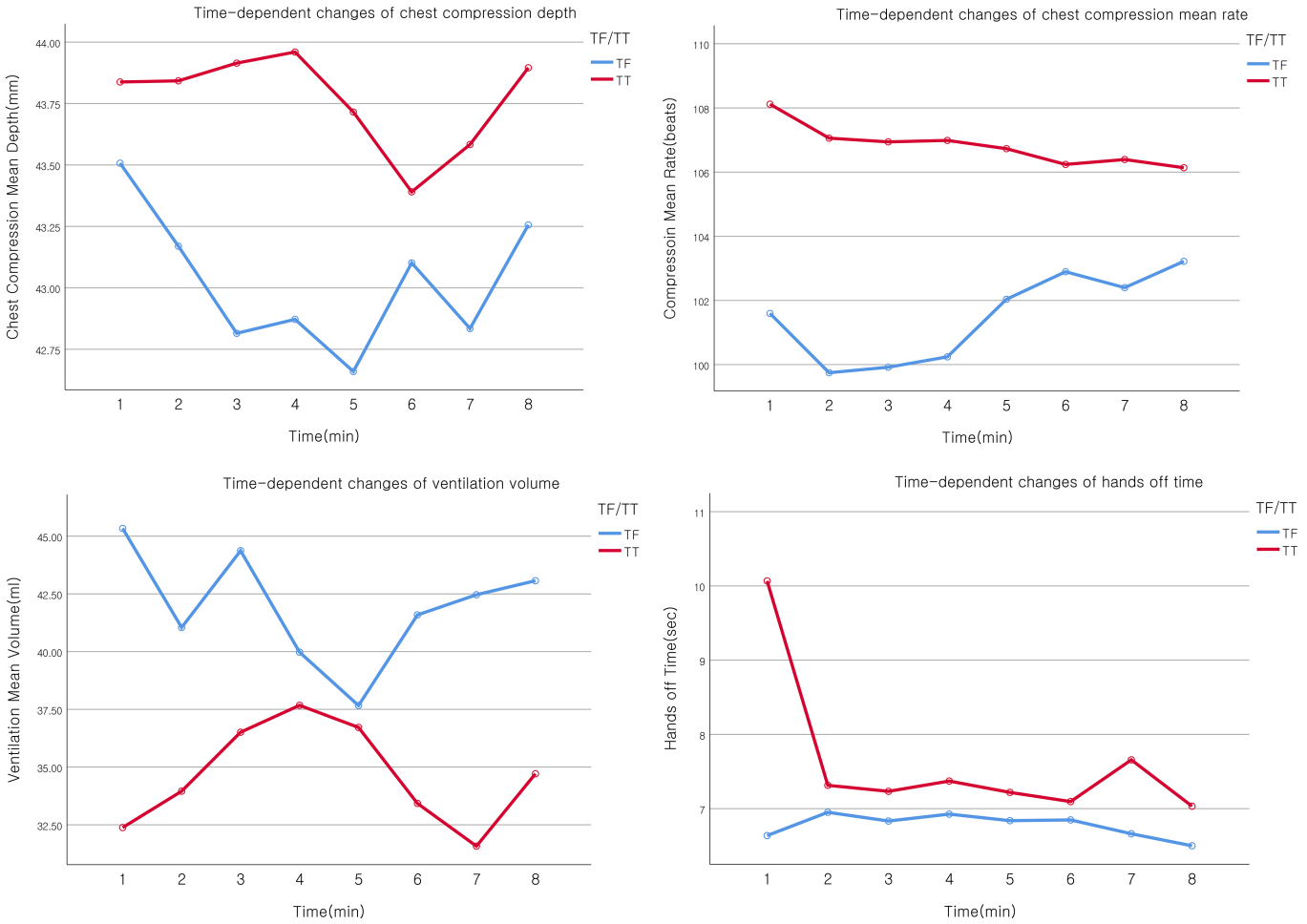

FIGURE 3. Assessment of adequate infant CPR over time (n = 70). Abbreviations: TF, two-finger; TT, two-thumb-encircling hands.

TABLE 3. Differences in CPR according to CC technique over time (n = 70).

Variable		TF	TT	T(p)	*p*
Mean CC depth (mm)	1 min	43.50 ± 2.51	43.84 ± 2.94	−0.746 (0.458)	0.191
	2 min	43.17 ± 2.45	43.84 ± 2.99	−1.628 (0.108)	
	3 min	42.81 ± 2.57	43.91 ± 2.70	−2.758 (0.007)	
	4 min	42.87 ± 3.02	43.96 ± 2.87	−2.373 (0.020)	
	5 min	42.65 ± 5.34	43.72 ± 3.37	−1.440 (0.154)	
	6 min	43.10 ± 5.30	43.39 ± 3.78	−0.388 (0.699)	
	7 min	42.83 ± 6.64	43.58 ± 3.50	−0.863 (0.391)	
	8 min	43.26 ± 7.87	43.90 ± 2.76	−0.654 (0.515)	
Mean CC count (times)	1 min	101.59 ± 19.03	108.12 ± 6.70	−2.851 (0.006)	0.030*
	2 min	99.75 ± 19.77	107.05 ± 7.12	−3.108 (0.003)	
	3 min	99.92 ± 19.95	106.94 ± 7.99	−2.987 (0.004)	
	4 min	100.24 ± 20.52	106.99 ± 8.50	−2.904 (0.005)	
	5 min	102.04 ± 18.85	106.73 ± 8.72	−2.195 (0.032)	
	6 min	102.89 ± 17.49	106.24 ± 8.69	−1.754 (0.084)	
	7 min	102.40 ± 17.30	106.39 ± 9.46	−2.037 (0.045)	
	8 min	103.22 ± 18.63	106.14 ± 8.93	−1.474 (0.145)	
Mean ventilation volume (mL)	1 min	45.38 ± 30.58	32.69 ± 24.37	3.872 (0.000)	0.042
	2 min	40.66 ± 26.09	33.76 ± 21.14	1.797 (0.077)	
	3 min	44.30 ± 27.65	36.58 ± 22.64	2.308 (0.024)	
	4 min	39.54 ± 24.81	37.69 ± 22.97	0.570 (0.571)	
	5 min	37.36 ± 22.89	36.56 ± 25.10	0.305 (0.761)	
	6 min	41.16 ± 28.93	32.75 ± 26.07	2.320 (0.024)	
	7 min	42.43 ± 31.76	31.35 ± 21.49	3.804 (0.000)	
	8 min	42.94 ± 25.57	34.21 ± 26.99	2.459 (0.017)	
Mean hands-off time (s)	1 min	6.84 ± 2.05	10.07 ± 17.69	−1.514 (0.135)	0.029*
	2 min	7.33 ± 2.87	7.31 ± 2.05	0.041 (0.968)	
	3 min	7.20 ± 2.78	7.23 ± 1.87	−0.101 (0.920)	
	4 min	7.45 ± 3.57	7.37 ± 1.93	0.175 (0.862)	
	5 min	7.27 ± 3.08	7.22 ± 1.86	0.133 (0.894)	
	6 min	7.29 ± 3.07	7.10 ± 1.76	0.476 (0.636)	
	7 min	6.66 ± 1.63	7.75 ± 2.36	−3.996 (0.000)	
	8 min	6.49 ± 1.51	7.13 ± 1.94	−3.233 (0.002)	

Abbreviations: CPR, cardiopulmonary resuscitation; CC, chest compression; TF, two-finger; TT, two-thumb-encircling hands.
**Indicates statistically significant differences.*

TABLE 4. Qualitative content analysis results (N = 70).

Category	Sub-category	N (%)
Ambivalence	Relative comfort (CC was comfortable, but ventilation was uncomfortable)	33 (47.14)
	Contradictions (in relation to ventilation, CC was difficult, but ventilation was comfortable)	8 (11.43)
Pain perception	Finger discomfort (when using the TF technique)	31 (44.29)
	Lower back pain (when using the TT technique)	12 (17.14)
	Burden over time	11 (15.71)

Abbreviations: CC, chest compression; TF, two-finger; TT, two-thumb-encircling hands.

compression. However, there was discomfort when changing posture for ventilation.

"The process of going from chest compression to ventilation was not very smooth." (Participant 52)

"Compression was easy and simple, so there was no problem during compression. However, there was discomfort when changing the posture for ventilation." (Participant 66)

B. Pain perception

This category included the sub-categories of "finger discomfort," "lower back pain," and "burden over time.".

(1) Finger discomfort

Most participants stated that the TF technique was more uncomfortable and caused their fingers to hurt.

"My fingers hurt more and more as I performed the two-finger compression." (Participant 11)

"I thought my fingers were breaking." (Participant 27)

"I thought my fingers were gone after the 4-min mark." (Participant 49)

(2) Lower back pain

The participants stated that they felt less pain with the TT technique, but they felt burden and pain in the lower back, not the fingers, when performing the TT technique.

"I felt pain in the neck and lower back." (Participant 9)

"My lower back hurt." (Participant 63)

(3) Burden over time

The participants stated that they faced difficulties accurately performing CPR due to pain over time.

"After about 4 to 5 min, I felt loss of strength in my hands and the rhythm being broken." (Participant 15)

"I was fine up to 2 and 3 min, but my fingers hurt too much after that." (Participant 24)

"My fingers hurt, I lost strength, and had trouble concentrating as time went on." (Participant 54)

4. Discussion

The objective of the current study was to quantify the adequacy of ventilation and CC techniques (TF and TT), rescuer fatigue, and CPR experience in single-rescuer infant CPR cases.

The chest compression depth of TT (43.77 mm) was greater than that of TF (43.03 mm), but there was no statistically significant difference (p = 0.164), which was different from previous studies [2, 6, 7, 14]. The chest compression count of TT (63536.80 times) was greater than that of TF (62169.70 times), but there was no statistically significant difference (p = 0.330), which is consistent with the results of the study by Kim & Lee [6]. These findings also support the results of previous studies reporting that using TF or TT as a CC technique in single-rescuer infant CPR would not matter, because the CC depth is maintained at 4 cm in both techniques, as recommended by the 2020 AHA and KACPR guidelines [2, 6, 7, 14]. There was a significant difference in CC accuracy rate between TF (65.89%) and TT (77.11%; p = 0.011), while CC accuracy score was higher with TT (92.54 points) than TF (82.60 points). However, TF provided significantly shorter interruption time of chest compressions (p = 0.001) and significantly higher chest compression fraction ($p < 0.001$) than TT. This result is different from that of previous studies [2, 6, 14], which found no difference between the chest compression rate and the chest compression stop time between techniques. Therefore, since the TT technique recommends interruption time of chest compressions $\leq$ 10 s and maintaining the chest compression ratio at 60–80%, and the accurate chest compression ratio and chest compression accuracy score were higher than those of the TF, more emphasis should be put on the training of the TT technique in the infant CPR education conducted by the single rescuer.

There was no difference in total ventilation count between TF and TT techniques (p = 0.324), which was consistent with the results of another study of 78 medical students [2]. The total ventilation volume was higher with TF (41.40 mL) than TT (34.51 mL), which was consistent with the results from another study of physicians [15]. However, there were difficulties in analyzing the causes due to the lack of previous studies that used the C:V ratio of 30:2 in single-rescuer infant CPR. Ventilation for infants is essential, as out-of-hospital cardiac arrest often progresses from respiratory problems, such as suffocation [16, 17]. Replication studies comparing the two techniques with a C:V ratio of 30:2 are needed. Meanwhile, the CPR score was higher with the TT (84.37 points) than the TF technique (78.26 points). If the TT technique is effective based on higher CC accuracy and overall CPR score, while showing no differences in CC depth and count compared to the TF technique, then KACPR should also consider using both the TF and TT technique for single-rescuer infant CPR, as recommended by the 2020 AHA guidelines.

Comparisons of the adequacy and difference in single-rescuer infant CPR between the TF and TT techniques over time showed no difference in mean CC depth between TF and TT (p = 0.191), higher mean CC count in TT than TF (p = 0.030), and shorter hands-off time in TF than TT (p = 0.029). However, it was maintained $\leq$ 10 s except for 1 min elapsed in the TT technique. Kim and Lee [6] investigated CC depth and count over time (8 min) in emergency medical service students and found no difference in mean CC count and hands-off time. There was the slight difference from this study because TT technique was found related to greater CC depth. While these results are inconsistent with the findings of the current study, a CC depth of 4 cm, a CC rate of 100–120 times/min, and a hands-off time within 10 s, as recommended by the 2020 AHA and KACPR guidelines, were maintained. These results support previous studies and the 2020 AHA guidelines that recommend using both TF and TT techniques for single-rescuer infant CPR [2, 6, 7, 14]. Thus, the KACPR should also consider using the TT technique for single-rescuer infant CPR, as mentioned earlier. Furthermore, minimizing hands-off time can increase the CC count to increase brain and coronary artery perfusion pressure, improving the survival rate [3]. Therefore, an assessment of the adequacy of various CC techniques over time for single-rescuer infant CPR adequacy is needed. In infant cardiopulmonary resuscitation performed by a single rescuer, the fact that chest compression interruption time is longer than that of TF for 1 min using the TT technique is interpreted as requiring time to adapt. Moreover, since the TT technique provided better result values of the average chest compression depth and number of chest compressions than the TF technique, it is necessary to emphasize and recommend the TT technique training for single rescuer infant CPR in

KACPR.

Rescuer fatigue was higher with TF (6.09 points) than TT (4.23 points; $p < 0.001$). A previous study of medical students also reported greater finger pain and fatigue with the TF technique, while the quality of infant CPR was superior with the TT technique [2]. Rescuer fatigue during CPR can degrade the quality of CC [11], while the survival rate of patients with out-of-hospital cardiac arrest is proportional to the timely initiation of bystander CPR [18]. Therefore, we determined that there should be no problem including the TT technique for high-quality single-rescuer infant CPR, as recommended by the 2020 AHA guidelines.

Based on the FGI response analysis to identify the single-rescuer infant CPR experiences of the participants, 2 categories and 5 sub-categories were derived. Firstly, ambivalence in using the TF or TT technique for single-rescuer infant CPR included the relative comfort of CC, but ventilation being uncomfortable, along with the contradictory attitude of CC being difficult and ventilation being comfortable. The participants stated that they felt the TT technique was more effective and stable when performing CPR. Compared to the TT technique, the TF technique made it easier to perform ventilation despite increased fatigue. Such findings support the results of the quantitative research in the present study as well as the results in previous studies [2, 6, 7, 11, 14, 15]. Therefore, we need studies on various techniques for reducing fatigue and improving infant CPR quality. Secondly, the participants had perceived pain while using the TF and TT techniques for single-rescuer infant CPR. They felt finger pain when using the TF technique, whereas they felt lower back pain, but less finger pain, when using the TT technique. Also, the participants complained about the burden of accurately performing CPR over time due to pain from midway and beyond when using the two techniques. These findings were consistent with another study that reported no difference in convenience of ventilation with both techniques, but severe finger pain with the TF technique and more severe lower back pain with the TT technique [6]. A study was conducted on the TT technique with the rescuer above the head of the casualty, in an attempt to overcome the shortcomings of the TF and TT techniques; the results showed similar effects as the conventional TT technique [8]. Therefore, we need accurate analysis over time and various techniques to address the shortcomings of the TF and TT techniques for improving patients' survival rate and neurological prognosis through high-quality single-rescuer infant CPR. In addition, we need follow-up studies with qualitative research on the accuracy of the CC position, including rescuers' capabilities.

5. Conclusions and recommendations

The current study applied a mixed methods design to analyze the accuracy of single-rescuer infant CPR over time using the TF and TT techniques, and to describe the experience of performing CPR. The results showed that the TT technique could be used for high-quality infant CPR, and it maintained the adequacy of CC over time, while causing less fatigue. Furthermore, the participants showed ambivalence toward the TF and TT techniques, while also communicating the burden of performing CPR over time due to finger discomfort or lower back pain. The significance of the current study is that it assessed not only the accuracy of the TF and TT techniques for single-rescuer infant CPR, but also the quality of CPR over time and the usefulness of the TT technique through FGIs. However, the study is limited by deriving the results from a single-group simulation.

Based on the findings of this study, both techniques can be applied for single-rescuer infant CPR. Overall, TT technique provided higher quality of compressions at the cost of fewer ventilations. In addition, follow-up studies with analysis of the accuracy and position of CC in various postures and inquiry into rescuers' experiences are recommended for preventing rescuer fatigue, and thus a decline in the quality of CPR.

AVAILABILITY OF DATA AND MATERIALS

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

AUTHOR CONTRIBUTIONS

HJK, JHK and DP—designed the research study. JHK, DP—performed the research. HJK—provided help and advice on the experiments. DP—analyzed the data. HJK and DP—wrote 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

Data were collected after obtaining approval from the Institutional Review Board (IRB; Approval No: DWU-2021-03-003-03). A researcher with no conflict of interest explained the objectives, methods, expected outcomes, and handling of unexpected problems to the participants, along with confidentiality and voluntary participation. We conducted assessments and interviews after obtaining written informed consent from the participants.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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