Systematic Review and Meta-Analysis

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Comparison of two-thumb encircling and two-finger technique during infant cardiopulmonary resuscitation with single rescuer in simulation studies

A systematic review and meta-analysis

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Abstract

Background: The recommended chest compression technique for a single rescuer performing infant cardiopulmonary resuscitation is the two-finger technique. For 2 rescuers, a two-thumb-encircling hands technique is recommended. Several recent studies have reported that the two-thumb-encircling hands technique is more effective for high-quality chest compression than the two-finger technique for a single rescuer performing infant cardiopulmonary resuscitation. We undertook a systematic review and meta-analysis of infant manikin studies to compare two-thumb-encircling hands technique with two-finger technique for a single rescuer.

Methods: We searched MEDLINE, EMBASE, and the Cochrane Library for eligible randomized controlled trials published prior to December 2017, including cross-over design studies. The primary outcome was the mean difference in chest compression depth (mm). The secondary outcome was the mean difference in chest compression rate (counts/min). A meta-analysis was performed using Review Manager (version 5.3. Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2014).

Results: Six studies that had reported data concerning both chest compression depth and chest compression rate were included. The two-thumb-encircling hands technique was associated with deeper chest compressions compared with two-finger technique for mean chest compression depth (mean difference, 5.50 mm; 95% confidence interval, 0.32–10.69 mm; $P=.04$), but no significant difference in the mean chest compression rate (mean difference, 7.89 counts/min; 95% confidence interval, to 0.99, 16.77 counts/min; $P=.08$) was noted.

Conclusion: This study indicates that the two-thumb-encircling hands technique is a more appropriate technique for a single rescuer to perform high-quality chest compression in consideration of chest compression depth than the two-finger technique in infant manikin studies.

Abbreviations: AHA = American Heart Association, BLS = basic life support, CCD = chest compression depth, CCR = chest compression rate, Cis = confidence intervals, CPR = cardiopulmonary resuscitation, CV ratio = compression and ventilation ratio, IHCA = In-hospital cardiac arrests, ILCOR = International Liaison Committee on Resuscitation, MD = mean difference, OHCA = out-of-hospital cardiac arrests, RCTs = randomized controlled trials, SD = standard deviation, TFT = two-finger technique, TTT = two-thumb encircling technique.

Keywords: chest compression method, infant cardiopulmonary resuscitation, manikins

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1. Introduction

There are approximately 16,000 pediatric cardiac arrests in the United States annually.[1] The data in previous studies indicated that >25% of children treated for in-hospital cardiac arrests (IHCA) survive to discharge and >10% of children treated for out-of-hospital cardiac arrests (OHCA) survive to discharge.[2] The survival rate following pediatric cardiac arrest is higher than that following adult cardiac arrest.[3] However, the neurologic outcome for pediatric post-cardiac arrest patients with a return to spontaneous circulation is poorer than that for adults.[4] Even among pediatric cardiac arrest events, the survival rate and the neurologic prognosis for infants are poorer than for children and adolescents.[4]

In recent International Liaison Committee on Resuscitation (ILCOR) cardiopulmonary resuscitation (CPR) guidelines, the survival rate and favorable neurologic outcome are reported to be closely related to the quality of the CPR.[5,6] Chest compression depth (CCD) and rate (CCR), decompression, and minimization of hands-off time during CPR are important factors affecting the delivery of high-quality chest compression.[5]

According to the 2015 American Heart Association (AHA) guidelines, the recommended chest compression technique for infant cardiac arrest is the two-finger technique (TFT) for a single rescuer and the two-thumb encircling technique (TTT) for 2 rescuers.[5] To minimize the hands-off time for a single rescuer, it has been suggested that switching from chest compressions to ventilation using the TFT would be easier to perform. In addition, rescuers should provide chest compressions with a depth that is at least one-third the anterior–posterior diameter of the chest, approximately 1.5 in. (4 cm) in infants.[5] The recommendation for the CCR is 100 to 120 counts per minute.[5]

Some of previous studies reported that duration of external CPR is the best indicator associated with survival.[7,8] When resuscitation is started soon, survival is increased.[7] In addition, several studies have reported on approaches to providing high-quality chest compressions. According to Sandeep et al,[9] 2 pediatric studies reported good outcomes when the arrests were witnessed and prompt and presumably excellent CPR was provided. For example, there are studies to improve the quality of chest compressions using feedback devices,[10,11] or to develop and compare new chest compression methods for infant CPR that have not been previously available.[12–16] In addition, some studies have compared the effects of providing TFT and TTT for single rescuers.[17–20] These studies reported that, for a single rescuer, TTT is a more effective technique than TFT to perform high-quality chest compression. However, to our knowledge, no study has analyzed and synthesized the results of these studies.

Therefore, the aim of the present study was to analyze the results of previously published randomized controlled trials (RCTs), and to perform a systematic review and meta-analysis to evaluate the comparison of TTT and TFT during infant CPR performed by a single rescuer.

2. Methods

Ethics committee is not applicable in this meta-analysis.

2.1. Data sources and search strategy

To avoid duplication of records, we searched data using PROSPERO records. Then where the protocol has not been published and is not available anywhere other than PROSPERO. The research question was based on the PICO (Population, Intervention, Comparison, and Outcome) guideline was as follows: "The BLS (Basic Life Support) provider (P), Two-thumb encircling method (I), Two-finger method (C), The Quality of CPR (O)." Our study included articles written in English only and RCTs published prior to 2017. We selected infant manikin studies that perform TTT and TFT. All the included studies were cross-over design studies. We searched, using the following keywords "two thumb," "two-thumb," "two thumbs," "two-thumbs," "mannequin," "mannequins," "manikin," "manikins," and "patient simulation" on MEDLINE, EMBASE, and in the Cochrane library database.

A total of 69 studies were retrieved from the research databases then we excluded 32 of duplication studies. We then included manikin studies that had compared single rescuer chest compression methods in CPR simulation. After title and abstract screening, we excluded the 20 of non-relevant articles with our purpose. We reviewed the full-text articles and then excluded for the following reasons: review articles (n = 1), study design (n = 9), study protocol (n = 1). Finally, 6 studies were included, according to our study inclusion criteria, shown in Fig. 1.

2.2. Data extraction

We extracted the data from 6 RCTs. For analysis of study characteristics, we confirmed data such as name of the first author, year of publication, study design, number of participants, manikin materials, the compression and ventilation ratio (CV ratio), compression duration, and outcome data. Our primary outcome was the mean value of CCD, which was measured in mm. The median values in 2 studies were converted to mean values. Our secondary outcome was the CCR, which was evaluated as counts/min and extracted using the same method. In addition, we used subgroup data from 1 study for meta-analysis.[20]

2.3. Risk of bias assessment

We evaluated the risk of bias through applying the Cochrane collaboration tool. The risk of bias was assessed using the bias of selection, performance, detection, attrition, reporting, and other sources of bias and was divided into "low risk," "high risk," and "unclear." [21]

2.4. Statistical analysis

The analyses were conducted using Review Manager (version 5.3), and a statistical significance level was defined as $\alpha = 0.05$. A P-value <.05 was considered to be statistically significant. The CCD and CCR were presented as means, standard deviation (SD) values, and 95% confidence intervals (CIs). First, we applied the fixed-effect model for identification of heterogeneity, and conducted a Q test and a chi-squared test, and then considered the heterogeneity through presented data of I^2 and P-values. The heterogeneity of effect size was defined as low (25%), intermediate (50%), or high (75%).[22] In addition, a P-value of <.01 using a chi-squared test indicated the presence of heterogeneity, and we applied a random-effect model instead of a fixed-effect model accordingly.

3. Results

3.1. Eligible studies and study characteristics

Through searching the database, we identified and included 6 studies that had compared TTT and TFT. The characteristics of

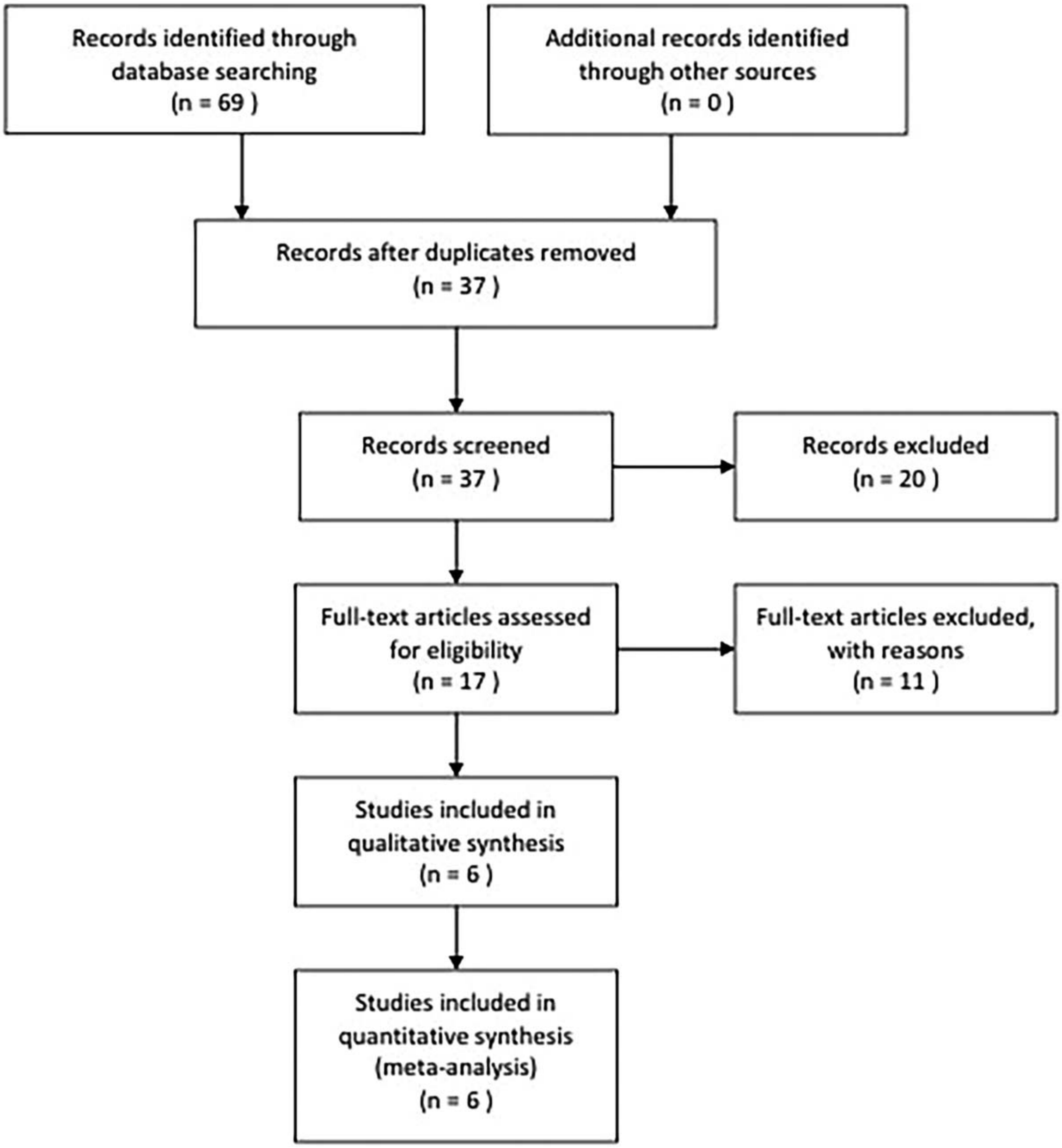

Figure 1. Flow diagram for identification of relevant studies.

the 6 studies included are shown in Table 1. All the included studies were manikin studies undertaken between 2012 and 2017. In each study, the participant numbers differed from between 20 and 120. A total of 278 participants were included in our research. In 2 studies, the chest compression and ventilation ratio was 15:2,[13,18] and in 2 other studies the compression and ventilation ratio was 30:2.[17,20] In 2 further studies, only chest compressions had been performed.[12,19] In 5 studies, chest compressions were performed for 2 minutes.[12,13,18–20] Only 1 study offered chest compressions for 5 minutes.[17] In 2 studies, the hands-off time (seconds) was evaluated,[13,18] and 2 studies reported chest recoil (%) in their results.[12,13,18]

3.2. Risk of bias assessment

The risk of bias assessment is shown in Fig. 2. Five of the randomized cross-over design studies controlled for selection bias (e.g., random sequence generation, allocation concealment),[12,13,18,19] but 2 studies considered that the allocation concealment was unclear.[17,20] There was attrition bias (e.g., incomplete outcome data) in cases where the number of participants was not in accordance with the N value of the outcome[20] and when the outcome was not indicated in the study results.[17]

All of the included studies were controlled for detection bias using electronic devices and, consequently, were graded as low risk for blinded outcome assessment. In addition, studies were graded as unclear when bias assessment was not reported.

Table 1

Characteristics of studies included in the review.

Study and year	Study design	Participants	Manikin	Compression: ventilation ratio	Duration	Compression method		Guideline	Compression height	Outcome
						Experimental group	Control group			
Smereka et al 2017[13]	Prospective randomized crossover trial	52, Novice physicians	ALS baby trainer manikin	15:2	2 min	Two-thumb encircling technique	Two-finger technique	2015	High adjustable hospital stretcher, Iliac crest of each rescuer	Chest compression depth (mm), chest compression rate (/min), recoil (%), hands-off time (s)
Smereka et al 2017[12]	Prospective randomized crossover trial	120, paramedics	ALS baby trainer manikin	Compression only	2 min	Two-thumb encircling technique	Two-finger technique	2015	High adjustable hospital stretcher, Iliac crest of each rescuer	Chest compression depth (mm), chest compression rate (/min), recoil (%)
Lee et al 2017[18]	Prospective randomized crossover trial	37, physician, BLS-provider	Resusci baby QCPR manikin	15:2	2 min	Two-thumb encircling technique	Two-finger technique	2010	On the floor	Chest compression depth (mm), chest compression rate (/min), recoil (%), hands-off time (s)
Jiang et al 2015[17]	Prospective randomized crossover trial	27, physicians or ED residents, BLS-provider	Resusci baby QCPR manikin	30:2	5 min	Two-thumb encircling technique	Two-finger technique	2010	Iliac crest of each rescuer	Chest compression depth (cm)
Martin et al 2013[19]	Randomized crossover experimental study	22, PALS-instructor	ALS baby manikin	Compression only	2 min	Two-thumb encircling technique	Two-finger technique	2010	On a flat table	Chest compression depth (mm), chest compression rate (/min)
Huynh et al 2012[20]	Randomized crossover observational study	20, medical personnel	Laerdal heart code BLS manikin	30:2	2 min	Two-thumb encircling technique	Two-finger technique	2010	On the floor, On a table (30 in.), radiant warmer (45 in.)	Chest compression depth (mm)

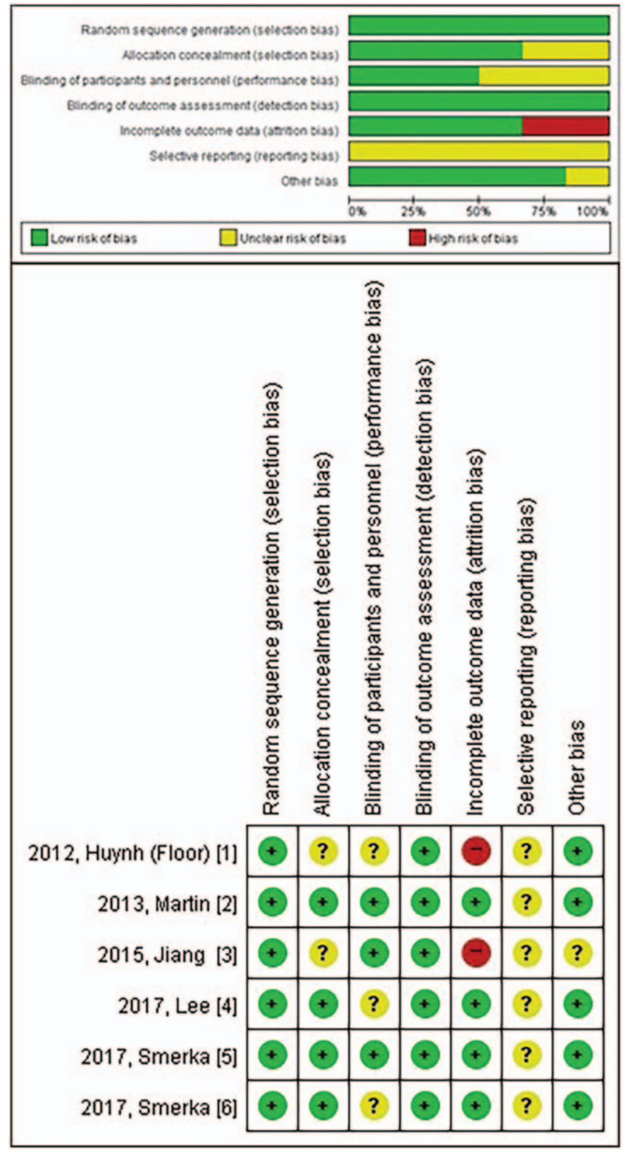

Figure 2. Risk of bias graph: review of authors' judgements regarding each risk of bias item presented as percentages across all included studies.

3.3. Meta-analysis of primary outcome measures

Electronic devices were used to automatically evaluate all of the study outcomes. Four studies evaluated the mean CCD according to the mean value,[17–20] but 1 study used the median value.[13] All data were converted to mean values and we then performed the analysis. We extracted subgroup data from 1 study using the 7 samples of CCD in the analysis.

Our results showed that TTT offered significantly deeper CCD than TFT (mean difference [MD], 5.50; 95% CI 0.32–10.69; $P=.04$) (Fig. 3A).

3.4. Meta-analysis of secondary outcome measures

Six samples extracted from 5 studies were used for analysis to compare the mean CCRs, and 3 studies reported the outcome as a mean value whereas 2 studies reported median values. Our study only used mean values and we converted median values to means.

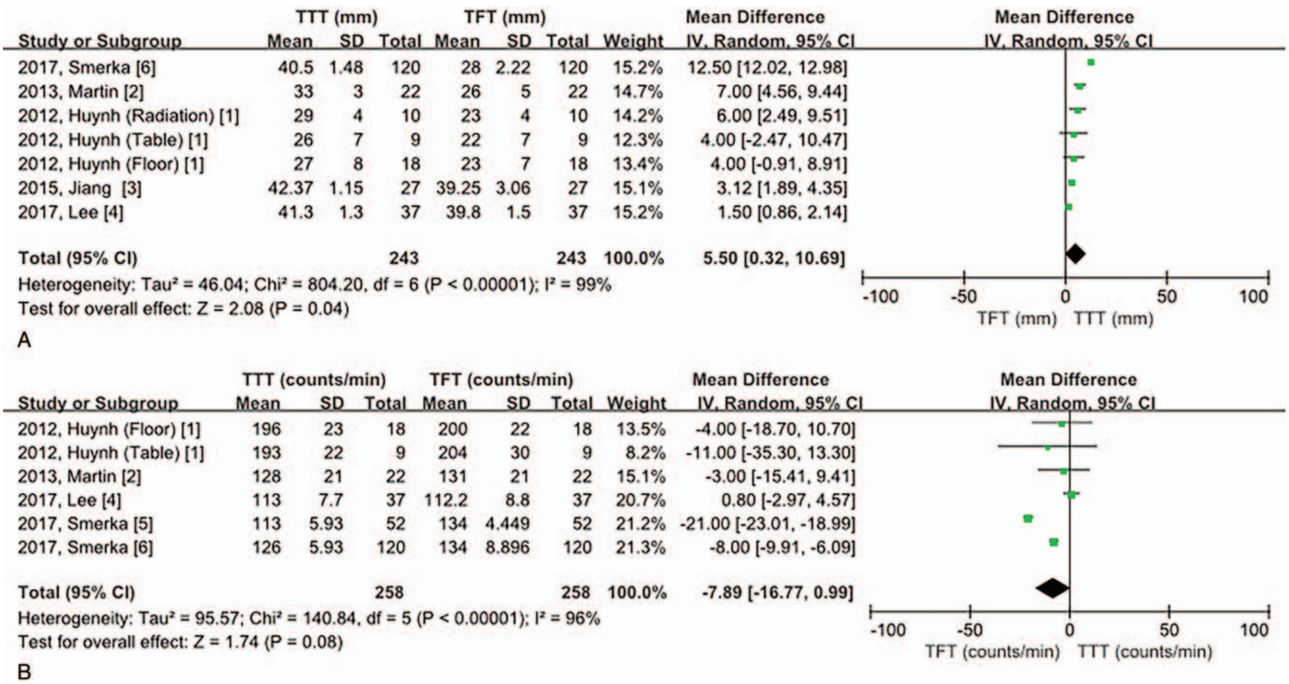

Figure 3. A: Forest plot of chest compression depth between two-thumb-encircling hands technique and two-finger technique in meta-analysis. B: Forest plot of chest compression rate between two-thumb-encircling hands technique and two-finger technique in meta-analysis.

TFT was relatively faster than TTT; however, this was not statistically significant (MD, 7.89; 95% CI, 0.99–16.77; $P=.08$) (Fig. 3B).

4. Discussion

Children have limited compensatory mechanisms to deal with severe illness or injury. The illnesses and pathophysiological responses of pediatric patients often differ from those seen in adults.[5] Pediatric cardiac arrest is not a single problem. Although the anatomical structure and the common cause of cardiac arrest in children differ from those in adults, the recent CPR guideline emphasize the importance of chest compression in all ages.[5,6] One of the most important factors in CPR is the delivery of high-quality chest compression.[9] CCD, chest decompression, CCR, and hands-off time are all factors relating to high-quality chest compression.

All RCTs included in this study reported that TTT provided deeper CCDs than TFT.[12,13,17–20] We conducted a meta-analysis based on 6 relevant studies. Based on the results of these 6 studies, our analyses indicated that TTT provided significantly deeper chest compression than TFT ($P=.04$). In addition, there were no significant differences for CCRs between the 2 methods in 2 studies,[18,19] while several studies reported that TFT provided a faster CCR than TTT.[12,13,20] However, there was no statistically significant difference between the 2 methods in this meta-analysis ($P=.08$).

The reasons why TTT provided higher quality chest compressions are complex. One previous study suggested that effective chest compressions could not be achieved using TFT over a long duration because the rescuer performing TFT would become more easily fatigued.[17] In addition, Jo et al[14] analyzed differences in the strength of each finger and reported that the finger strength when performing the TTT was significantly higher than that of the other two-finger combinations.

Based on our study results, we cannot conclude that changing the guidelines recommended for TFT to TTT for a single rescuer would lead to a higher survival rate and a favorable neurologic prognosis. However, based on previous research results, we were able to conduct the first comparative meta-analysis concerning these techniques and provide more objective evidence. Several studies have reported that high-quality chest compressions had not been provided for actual adult patients or in cases of pediatric cardiac arrest.[23–26] In addition, Jang et al[27] reported that the compression methods, including TTT, could not provide the required CCD as per the current guidelines in an infant in-hospital cardiac arrest situation. Because it is difficult to perform effective chest compressions, many studies have been conducted using varying approaches to ensure high-quality chest compressions, and the techniques for high-quality chest compressions have been revised in the guidelines accordingly.[8,9,28,29] Since the guideline for CCD has changed, several studies comparing TTT and TFT could not be included in this meta-analysis. However, significant differences have been reported concerning these techniques.[30–32]

Hands-off time is also an important factor in assessing the quality of chest compressions.[8,9] An increase in the hands-off time during CPR is associated with a decrease in the survival rate of out-of-hospital cardiac arrest.[33] Although these results pertain only to adults, the basic principles of pediatric CPR do not differ from adults. For this reason, several studies reported that TTT is not recommended for a single rescuer due to concerns of increased hands-off time because of difficulties in shifting between chest compression and ventilation.[12,13,17] However, Udassi et al[30] reported a statistically significant difference in hands-off time between TTT and TFT, but the difference was only 0.6 seconds and there was no difference in the effective ventilation between the 2 methods. In addition, Lee et al[18] reported that the difference in total hands-off time for 2 minutes of CPR between the 2 methods was only approximately 2 seconds. The hands-off time is an important parameter related to the survival rate for cardiac arrest. However, it is not known whether this small difference would affect the survival rate. Further study concerning hands-off time is likely to help improve the current chest compression method.

There were several limitations to this study. First, the RCTs included in this analysis were simulation studies using a manikin rather than clinical studies and therefore could not completely reflect the clinical scenario. Second, the studies included in the meta-analysis were experimental studies of the medical technique, and the results would differ depending on the experience or proficiency of the participants in the experiment. Third, we found significant heterogeneity in the main analysis due to several factors including the study methods involved and the participants included in the studies. The results of the meta-analysis should be interpreted in consideration of this heterogeneity. Finally, parameters such as ventilations and hands-off time for high-quality CPR were not available because the measurement standards differed in each study and the results were insufficient quantity to draw informed conclusions. Further studies are required in relation to further relevant parameters.

5. Conclusion

In our meta-analysis based on previous simulation studies, the TTT provided deeper CCD than the TFT for a single rescuer. However, there was no statistically significant difference between the TTT and the TFT in terms of the CCR. These results provide evidence that the TTT is a suitable compression method to offer high-quality CPR for a single rescuer. For infant cardiac arrest, however, additional studies are necessary to confirm whether the TTT is an appropriate method.

Author contributions

Conceptualization: Ji Eun Lee, Hyunggoo Kang, Tae Ho Lim, Kyung Hun Yoo.
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Visualization: Hyunggoo Kang, Tae Ho Lim.
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Writing – review & editing: Ji Eun Lee, Juncheol Lee, Jaehoon Oh, Hyunggoo Kang, Tae Ho Lim, Kyung Hun Yoo.

References

[1] Topjian AA, Berg RA, Nadkarni VM. Pediatric cardiopulmonary resuscitation: advances in science, techniques, and outcomes. Pediatrics 2008;122:1086–98.
[2] Alexis AT, Vinay MN, Robert AB. Cardiopulmonary resuscitation in children. Curr Opin Crit Care 2009;15:203–8.
[3] Nadkarni VM, Larkin GL, Peberdy MA, et al. First documented rhythm and clinical outcome from in-hospital cardiac arrest among children and adults. JAMA 2006;295:50–7.
[4] Atkins DL, Everson-Stewart S, Sears GK, et al. Epidemiology and outcomes from out-of-hospital cardiac arrest in children. The resuscitation outcomes consortium epistry–cardiac arrest. Circulation 2009;119:1484–91.
[5] Atkins DL, Berger S, Duff JP, et al. Part 11: Pediatric basic life support and cardiopulmonary resuscitation quality: 2015 American Heart Association Guidelines update for cardiopulmonary resuscitation and emergency cardiovascular care. Circulation 2015;132:S519–25.
[6] Maconochie IK, Bingham R, Eich C, et al. European resuscitation council guidelines for resuscitation 2015: Section 6. Paediatric life support. Resuscitation 2015;95:223–48.
[7] López-Herce J, Carcia C, Dominguez P, et al. Outcome of out-of-hospital cardiorespiratory arrest in children. Pediatr Emerg Care 2005;21:807–15.
[8] Suominen P, Olkkola KT, Voipio V, et al. Utstein style reporting of in-hospital paediatric cardiopulmonary resuscitation. Resuscitation 2000;45:17–25.
[9] Sandeep S, Kamal K, Indu L. Better outcome after pediatric resuscitation is still a dilemma. J Emerg Trauma Shock 2010;3:243–50.
[10] Martin P, Theobald P, Kemp A, et al. Real-time feedback can improve infant manikin cardiopulmonary resuscitation by up to 79%–a randomised controlled trial. Resuscitation 2013;84:1125–30.
[11] Ahn C, Lee J, Oh J, et al. Effectiveness of feedback with a smartwatch for high-quality chest compressions during adult cardiac arrest: a randomized controlled simulation study. PLoS One 2017;12:e0169046.
[12] Smereka J, Kasiński M, Smereka A, et al. The quality of a newly developed infant chest compression method applied by paramedics: a randomised crossover manikin trial. Kardiol Pol 2017;75:589–95.
[13] Smereka J, Szarpak L, Smereka A, et al. Evaluation of new two-thumb chest compression technique for infant CPR performed by novice physicians. A randomized, crossover, manikin trial. Am J Emerg Med 2017;35:604–9.
[14] Jo CH, Cho GC, Lee CH. Two-Thumb encircling technique over the head of patients in the setting of lone rescuer infant CPR occurred during ambulance transfer: a crossover simulation study. Pediatr Emerg Care 2017;33:462–6.
[15] Jo CH, Jung HS, Cho GC, et al. Over-the-head two-thumb encircling technique as an alternative to the two-finger technique in the in-hospital infant cardiac arrest setting: a randomised crossover simulation study. Emerg Med J 2015;32:703–7.
[16] Fakhraddin BZ, Shimizu N, Kurosawa S, et al. New method of chest compression for infants in a single rescuer situation: thumb-index finger technique. J Med Dent Sci 2011;58:15–22.
[17] Jiang J, Zou Y, Shi W, et al. Two-thumb-encircling hands technique is more advisable than 2-finger technique when lone rescuer performs cardiopulmonary resuscitation on infant manikin. Am J Emerg Med 2015;33:531–4.
[18] Lee SY, Hong JY, Oh JH, et al. The superiority of the two-thumb over the two-finger technique for single-rescuer infant cardiopulmonary resuscitation. Eur J Emerg Med 2018;25:372–6.
[19] Martin PS, Kemp AM, Theobald PS, et al. Do chest compressions during simulated infant CPR comply with international recommendations? Arch Dis Child 2013;98:576–81.
[20] Huynh TK, Hemway RJ, Perlman JM. The two-thumb technique using an elevated surface is preferable for teaching infant cardiopulmonary resuscitation. J Pediatr 2012;161:658–61.
[21] Higgins JP, Altman DG, Gøtzsche PC, et al. The Cochrane Collaboration's tool for assessing risk of bias in randomised trials. BMJ 2011;343:d5928.
[22] Hedges LV, Olkin I, Hedges LV. Statistical Methods for Meta-Analysis. 1st edNew York: Academic Press; 1985.
[23] Kramer-Johansen J, Myklebust H, Wik L, et al. Quality of out-of-hospital cardiopulmonary resuscitation with real time automated feedback: a prospective interventional study. Resuscitation 2006;71:283–92.

[24] Abella BS, Alvarado JP, Myklebust H, et al. Quality of cardiopulmonary resuscitation during in-hospital cardiac arrest. JAMA 2005;293: 305–10.
[25] Wik L, Kramer-Johansen J, Myklebust H, et al. Quality of cardiopulmonary resuscitation during out-of-hospital cardiac arrest. JAMA 2005;293:299–304.
[26] Sutton RM, Niles D, Nysaether J, et al. Quantitative analysis of CPR quality during in-hospital resuscitation of older children and adolescents. Pediatrics 2009;124:494–9.
[27] Jang HY, Wolfe H, Hsieh TC, et al. Infant chest compression quality: a video-based comparison of two-thumb versus one-hand technique in the emergency department. Resuscitation 2018;122:36–40.
[28] American Heart Association2005 American Heart Association (AHA) guidelines for cardiopulmonary resuscitation (CPR) and emergency cardiovascular care (ECC) of pediatric and neonatal patients: pediatric basic life support. Pediatrics 2006;117:e989–1004.
[29] Spencer B, Chacko J, Sallee D. American Heart AssociationThe 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiac care: an overview of the changes to pediatric basic and advanced life support. Crit Care Nurs Clin North Am 2011;23:303–10.
[30] Udassi S, Udassi JP, Lamb MA, et al. Two-thumb technique is superior to two-finger technique during lone rescuer infant manikin CPR. Resuscitation 2010;81:712–7.
[31] Udassi JP, Udassi S, Theriaque DW, et al. Effect of alternative chest compression techniques in infant and child on rescuer performance. Pediatr Crit Care Med 2009;10:328–33.
[32] Haque IU, Udassi JP, Udassi S, et al. Chest compression quality and rescuer fatigue with increased compression to ventilation ratio during single rescuer pediatric CPR. Resuscitation 2008;79:82–9.
[33] Bobrow BJ, Clark LL, Ewy GA, et al. Minimally interrupted cardiac resuscitation by emergency medical services for out-of-hospital cardiac arrest. JAMA 2008;299:1158–65.