Clinical Trial/Experimental Study

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Is there any alternative to standard chest compression techniques in infants? A randomized manikin trial of the new "2-thumb-fist" option

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Abstract

Background: Pediatric cardiac arrest is a fatal emergent condition that is associated with high mortality, permanent neurological injury, and is a socioeconomic burden at both the individual and national levels. The aim of this study was to test in an infant manikin a new chest compression (CC) technique ("2 thumbs-fist" or nTTT) in comparison with standard 2-finger (TFT) and 2-thumb-encircling hands techniques (TTEHT).

Methods: This was prospective, randomized, crossover manikin study. Sixty-three nurses who performed a randomized sequence of 2-minute continuous CC with the 3 techniques in random order. Simulated systolic (SBP), diastolic (DBP), mean arterial pressure (MAP), and pulse pressures (PP, SBP–DBP) in mm Hg were measured.

Results: The nTTT resulted in a higher median SBP value (69 [IQR, 63–74] mm Hg) than TTEHT (41.5 [IQR, 39–42] mm Hg), ($P<.001$) and TFT (26.5 [IQR, 25.5–29] mm Hg), ($P<.001$). The simulated median value of DBP was 20 (IQR, 19–20) mm Hg with nTTT, 18 (IQR, 17–19) mm Hg with TTEHT and 23.5 (IQR, 22–25.5) mm Hg with TFT. DBP was significantly higher with TFT than with TTEHT ($P<.001$), as well as with TTEHT than nTTT ($P<.001$). Median values of simulated MAP were 37 (IQR, 34.5–38) mm Hg with nTTT, 26 (IQR, 25–26) mm Hg with TTEHT and 24.5 (IQR,23.5–26.5) mm Hg with TFT. A statistically significant difference was noticed between nTTT and TFT ($P<.001$), nTTT and TTEHT ($P<.001$), and between TTEHT and TFT ($P<.001$). Sixty-one subjects (96.8%) preferred the nTTT over the 2 standard methods.

Conclusions: The new nTTT technique achieved higher SBP and MAP compared to the standard CC techniques in our infant manikin model. nTTT appears to be a suitable alternative or complementary to the TFT and TTEHT.

Abbreviations: AHA = American Heart Association, CC = chest compression, CPR = cardiopulmonary resuscitation, DBP = diastolic blood pressure, IQR = interquartile range, MAP = mean arterial pressure, nTTT = 2-thumb-fist technique, OHCA = out-of-hospital cardiac arrest, PALS = pediatric advanced life support, RMANOVA = 2-way repeated-measures analysis of variance, SBP = systolic blood pressure, PP = pulse pressure, TFT = 2-finger technique, TTEHT = 2-thumb-encircling hands technique.

Keywords: cardiopulmonary resuscitation, chest compression, infant, quality

1. Introduction

Pediatric cardiac arrest (CA) is a fatal emergent condition that is associated with high mortality, permanent neurological injury, and is a socioeconomic burden at both the individual and national levels.[1] With about 16,000 pediatric CAs in the USA annually,[2] it is an important public health concern. Pediatric CA is associated with low survival rates and those who survive to hospital discharge often have severe neurological damage.[1,3] Many advances in resuscitation have been made since the first pediatric advanced life support (PALS) by American Heart Association (AHA) was developed in 1988, such as emphasis on early bystander resuscitation and public access to automated external defibrillators, survival rates for pediatric out-of-hospital

Editor: Abdelouahab Bellou.

Ethical approval: Approval was granted by the Institutional Review Board of the Polish Society of Disaster Medicine (approval no.: 21.11.2016.IRB)

Informed consent: Informed consent was obtained from all individual participants included in the study.

The authors have no conflict of interest to disclose.

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Medicine (2018) 97:5(e9386)

Received: 1 June 2017 / Received in final form: 13 November 2017 / Accepted: 29 November 2017

http://dx.doi.org/10.1097/MD.0000000000009386

cardiac arrests (OHCA) remains low. A study based on the Cardiac Arrest Registry to Enhance Survival national registry shows that there has not been improvement outcomes in pediatric OHCA that occurred over the 9-year period of 2005 to 2013, with only 1 of 12 children who suffered OHCA survived.[4] Infants are less likely to survive from OHCA than older children and adolescents,[4] with a survival rate of only 3.3%.[1] In-hospital pediatric CA have better outcomes compared to OHCA with a survival to hospital discharge rate of 48%, likely due to early recognition and availability of skilled providers.[5]

Quality cardiopulmonary resuscitation (CPR) is the single most determinant of survival rates[6,7] and postarrest neurological outcomes.[8] CPR generates forward blood flow to vital organs, such as the heart and brain, to maximize chance of return of spontaneous circulation (ROSC) and prevent anoxic brain damage.[9] Two decades of resuscitation research has brought little change in terms of chest compression (CC) techniques in infants. The 2010 PALS recommended the 2-finger technique (TFT) for the lone rescuer or layperson and 2-thumb-encircling hands technique (TTEHT) for 2 rescuers.[10,11] The TTEHT technique generates higher arterial and coronary perfusion pressure and more consistent compression force and depth, while TFT allows for faster transition between compressions and ventilation for a single rescuer situations at the expense of less effective compression.[12] Standard techniques also have their drawbacks such as rescuer fatigue that leads to deterioration of CC quality.[13] Another concern is that pediatric CC is often suboptimal even under experienced healthcare providers with real-time feedback devices.[14] This highlights the need for improvement on how CC is delivered. Accordingly, there is increased interest in new emerging CC alternatives in resuscitation.[15–19]

We devised a “novel 2-thumb technique” (nTTT) which consists of 2 thumbs directed perpendicular to the chest while closing the fingers of both hands in a fist (Fig. 1). Compared with the standard techniques, which relied primarily on finger and hand strength, nTTT uses large upper body muscles to transfer downward force on the infant’s chest, which generates more force and less prone to fatigue.

Figure 1. The new two thumbs-fist CC technique, applied in an infant manikin. Both thumbs are applied together at the lower third of the sternum, while the fingers are closed in a fist. CC = chest compression.

Previously in a manikin study where we compared the quality of CC of the 3 techniques, nTTT achieved superior CC depth compared to TFT and similar CC depth compared with TTEHT.[19] Both nTTT and TTEHT met the 4-cm CC depth recommended for an infant by AHA.[20] One major advantage of nTTT over TTEHT was it allowed consistent and complete thoracic recoil in all cases.[19] Complete chest recoil is important in CPR because incomplete recoil impedes venous return to the heart and decrease cardiac output. These promising results led to a follow-up study using experienced paramedics and hemodynamic parameters as endpoints, which showed that nTTT generated significantly higher systolic (SBP), diastolic (DBP), pulse, and mean arterial pressures (MAP) compared to the current recommended CC techniques for infant CPR.[21] Equally important is that in contrast with the other techniques, there was no decline in CPR performance in nTTT with sustained blood pressures over a prolonged period.[21] However, whether similar results could be replicated in care providers with less CPR experience, for example, nurses, are not known.

We therefore conducted this study to compare the quality of CC of the new nTTT method with the standards recommended by PALS, TFT and TTEHT. Quality of CC is defined as quantitative measurements of hemodynamic parameters: SBP, DBP, MAP, and pulse pressure (PP, SBP–DBP). We hypothesized that nTTT in our infant manikin model will result in higher blood pressures compared with both TFT and TTEHT.

2. Material and methods

This was a randomized, crossover manikin study, approved by the IRB of the Polish Society of Disaster Medicine (approval no. 21.11.2016.IRB).

Subjects were 63 nurses from Emergency Medical Service with a work experience of >1 year and >10 human adult CPR performed. The nurses all had CPR training according to PALS but no prior clinical experience in infant CPR.

The participants received a 30-minute training session on basic life support in infants.[2] ALS-baby trainer-modified manikin (Laerdal Medical, Stavanger, Norway) simulating a 3-month old infant was used; it was fitted with a fixed-volume arterial system attached to a clinical monitor (Draeger Infinity Delta; Draegerwerk AG & Co. KGaA, Luebeck, Germany) via an arterial pressure transducer. The arterial circuit was attached to the manikin chest plate and connected to the transducer (Edward Lifesciences: TruWave Disposable Pressure Transducer; Irvine, CA). During the tests, the manikin was placed on backboard on an adjustable hospital stretcher, leveled to the iliac crest of each rescuer. The nurses were asked to perform uninterrupted CC for 2-minute period using 3 techniques:

1. TFT: The rescuer compresses the lower half of the sternum with 2 fingers of 1 hand.
2. TTEHT: Two thumbs are placed over the lower third of the sternum, with the fingers encircling the torso and supporting the back.
3. nTTT: It consists in using 2 thumbs opposed and directed at the angle of 90° to the chest (at the lower third of the sternum) while closing the fingers of both hands in a fist (Fig. 1).

Participants were randomized into 1 of 3 groups (TFT, TTEHT, and nTTT) with ResearchRandomized software (www.randomizer.org). The first group started CC using TFT, second using the TTEHT, and third using the nTTT. After finishing a 2-minute CC with the first CC technique, they had a 20-minute

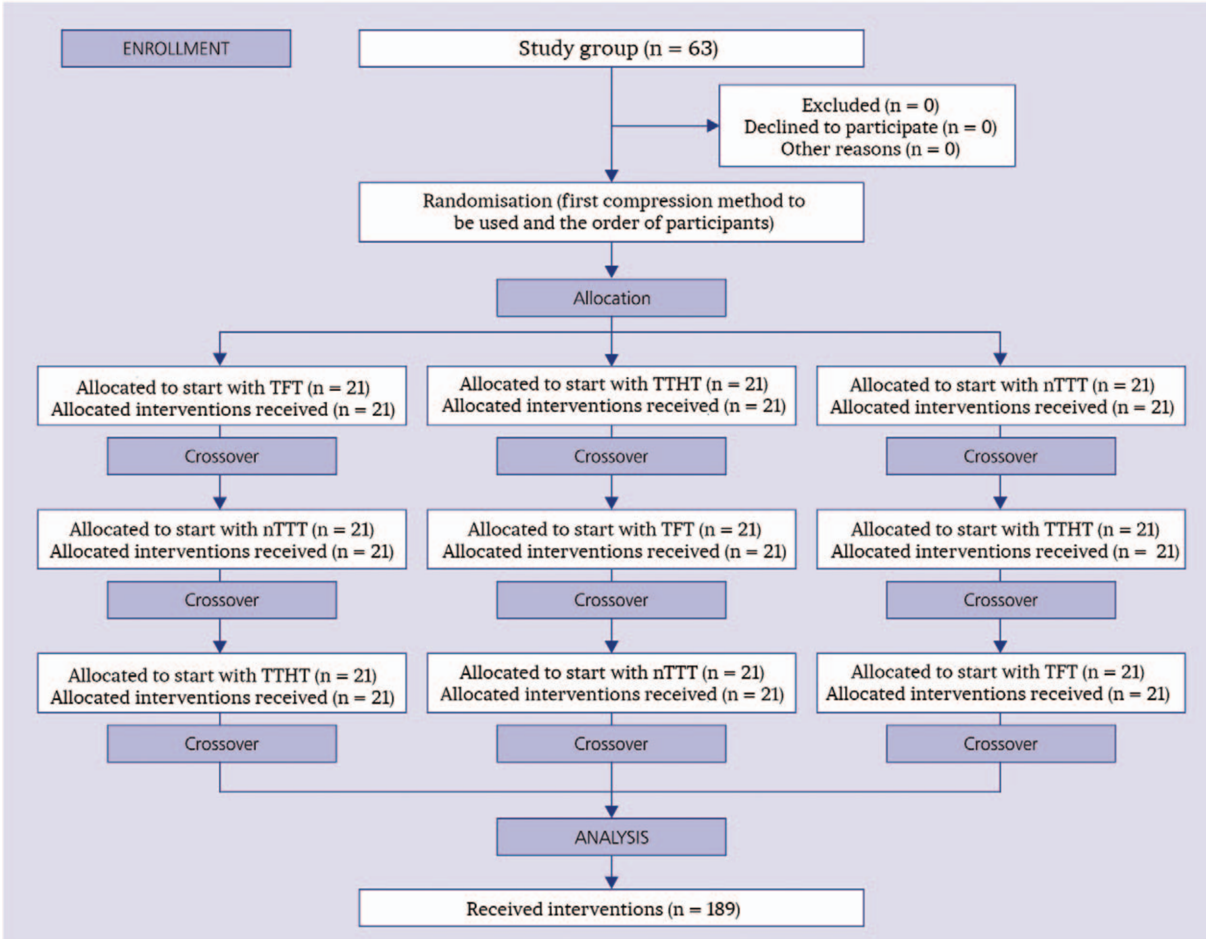

Figure 2. CONSORT flow chart.

break, and then re-started CC with the next randomly assigned CC technique. After another 20-minute break, the nurses performed the remaining CC technique. Randomization flow chart is shown in Figure 2. Participants were blinded to the arterial pressure tracing.

Simulated SBP, DBP, MAP, and PP (SBP–DBP) were measured in mm Hg. Data were entered in 10-second intervals to a spreadsheet and tests were recorded with a video camera to permit detailed review. Participants were asked about their preferred CC technique (in terms of being easy to apply, advantages vs drawbacks, fatigue, and effectiveness feeling).

Based on pilot data, the calculated number of required subjects was 40. Results are shown as a numbers (percentages), means and standard deviation (±SD), or medians and interquartile range (IQR). We used 2-way repeated-measures analysis of variance (RMANOVA) using a generalized linear model. A *P*-value of <.05 was considered significant.

3. Results

Sixty-three nurses (39 females, 61.9%) participated. The mean age was 29.5 ± 5.5 years, and mean work experience time was 6.5 ± 2.7 years.

The simulated SBP, DBP, MAP, and PP obtained with the 3 CC techniques are presented in Table 1. The use of the nTTT resulted in a higher median SBP value (69 [IQR, 63–74] mm Hg) compared with the TTEHT (41.5 [IQR, 39–42] mm Hg), (*P* <.001) and the TFT (26.5 [IQR, 25.5–29] mm Hg), (*P* <.001). The statistical significance for the difference in SBP was also observed between TFT and TTEHT (*P* <.001) (Fig. 3).

The simulated median value of DBP was 20 (IQR, 19–20) mm Hg with nTTT, 18 (IQR, 17–19) mm Hg with TTEHT, and 23.5 (IQR, 22–25.5) mm Hg with TFT. DBP was significantly higher with TFT than with TTEHT (*P* <.001), as well as with TTEHT than nTTT (*P* <.001), but no significant differences between TFT and nTTT were observed (*P* = .09) (Fig. 2).

The median values of simulated MAP were 37 [IQR, 34.5–38] mm Hg with nTTT, 26 (IQR, 25–26) mm Hg with TTEHT, and 24.5 (IQR, 23.5–26.5) mm Hg with TFT. A statistically significant difference was noticed between nTTT and TFT (*P* <.001), nTTT and TTEHT (*P* <.001), and between TTEHT and TFT (*P* <.001) (Fig. 2).

In consequence, the median PP values were 51 (IQR, 44–54) mm Hg with nTTT, 22.5 (IQR, 20–24.5) mm Hg with TTEHT, and 3 (IQR, 3–5) mm Hg with TFT. The differences were statistically significant for all comparisons (*P* <.001) (Fig. 2).

When asked before the study, 53 participants (84.1%) preferred the TFT over the TTEHT. After the trial, 61 subjects (96.8%) declared to prefer the nTTT over the 2 standard methods. The only complaint about the 3 CC techniques was sore at the fingers with TFT (21 participants, 33.3%) and burning within the ball of the thumb with TTEHT (48 participants,

Table 1

Median values with IQR for all participants (all values in mm Hg).

Time (min:sec)	00:10	00:20	00:30	00:40	00:50	01:00	01:10	01:20	01:30	01:40	01:50	02:00
TFT SBP	35 (32–36)	33 [32–35)	31 (29–32)	30 (28–32)	30 (28–31)	31 (28–33)	31 (29–33)	31 (29–32)	31 (29–32)	30 (29–31)	31 (29–32)	30.5 (29–32)
TTHT SBP	44.5 (41–53)	55.0 (51–61)	53.5 (49–56)	52.5 (48–56	49.5 (48–56)	45.0 (39–54)	51.5 (40–53)	49.5 (42–51)	45.5 (40–53)	44.0 (42–52)	45.5 (34–48)	48.7 (44.1–50.8)
nTTT SBP	82.0 (76–85)	85.0 (81–92)	85.0 (76–92)	89.0 (81–98)	87.0 (80–92)	92.0 (80–95)	89.0 (79–97)	92.0 (80–92)	88.0 (78–92)	83.0 (78–90)	87.0 (79–93)	89.0 (84–98)
TFT DBP	30.0 (27–31)	28.0 (27–30)	27.0 (24–28)	25.0 (23–27)	25.0 (23–26)	26.0 (23–28)	26.0 (24–28)	26.0 (24–27)	26.0 (24–26)	25.5 (24–26)	25.0 (24–27)	25.0 (23–27)
TTHT DBP	18.5 (16–22)	17.5 (15–27)	16.0 (13–25)	17.5 (16–19)	17.0 (15–21)	15.5 (12–18)	16.5 (15–20)	17.5 (15–19)	17.5 (15–20)	17.5 (15–19)	14.5 (13–17)	14.0 (12–16)
nTTT DBP	23.0 (19–31)	22.0 (20–27)	21.0 (19–27)	21.0 (19–28)	20.0 (18–28)	20.0 (19–29)	21.0 (18–29)	20.0 (19–27)	20.0 (19–29)	20.0 (18–26)	20.0 (19–28)	21.0 (19–29)
TFT MAP	33.0 (31–34)	31.0 (29–33)	28.5 (27–30)	28.0 (26–30)	27.0 (25–29)	28 (26–31)	28.0 (27–31)	29.0 (27–29)	29.0 (27–29)	28.0 (27–29)	28.5 (27–30)	27.5 (25–30)
TTHT MAP	32.0 (30–34)	33.5 (32–44)	33.5 (32–38)	34.0 (33–36)	34.0 (33–36)	33.0 (31–34)	30.0 (28–34)	32.5 (30–34)	31.5 (29–33)	32.0 (28–33)	30.0 (25–31)	28.5 (25–31)
nTTT MAP	49.0 (39–54)	47.0 (43–51)	47.0 (43–48)	49.0 (44–50)	48.0 (44–50)	45.0 (44–52)	48.0 (44–51)	45.0 (43–51)	43.0 (43–52)	44.0 (41–51)	45.0 (42–52)	45.0 (44–53)
TFT PP	5.0 (5–6)	5.0 (5–5)	5.0 (5–6)	5.0 (5–6)	5.0 (5–5)	5.0 (5–5)	5.0 (5–5)	5.0 (5–5)	5.0 (5–6)	5.0 (5–5)	5.0 (5–5)	6.0 (5–6)
THTT PP	27.5 (23–36)	33.5 (27–39)	37.5 (28–39)	34.5 (33–39)	35.5 (27–37)	33.0 (20–36)	35.0 (23–38)	32.0 (24–36)	28.0 (23–36)	32.5 (27–36)	30.0 (25–36)	30.5 (22–35)
nTTT PP	57.0 (50–66)	65.0 (61–68)	61.0 (58–72)	65.0 (55–74)	63.0 (59–70)	64.0 (60–76)	62.0 (57–77)	64.0 (59–71)	63.0 (59–71)	63.0 (58–66)	67.0 (59–73)	64.0 (59–77)

DBP = diastolic blood pressure, IQR = interquartile range, MAP = mean arterial pressure, nTTT = new 2-thumb technique, PP = pulse pressure (all in mm Hg), SBP = systolic blood pressure, TFT = 2-finger technique, TTHT = 2-thumb-encircling hand technique.

76.2%). No specific complaint was reported with the no significant fatigue was referred with any of the CC techniques during the 2-minute trials.

4. Discussion

The basis of our study stems from the belief that current CC techniques for infants' CPR have flaws that merits improvement.[13,16] The main findings were that our new nTTT method substantially outperforms the current standards of CC for infants, TFT and TTEHT, in generation of blood flow in our infant manikin crossover study. Statistically significant higher values of SBP, MAP, and PP were obtained with nTTT compared with TFT or TTEHT during the 2-minute CPR simulation trial. DBP was highest with the TFT method but was not statistically different from nTTT. nTTT is also the overwhelming choice among the 3 techniques by our participants with no reports of rescuer fatigue or discomfort.

TTEHT is considered the most effective technique because its circumferential squeezing of the thorax generates higher coronary, systolic, and diastolic pressures compared to TFT.[12,22–25] Our finding is novel and striking, because for the first time, we showed that our nTTT outperformed TTEHT in SBP, MAP, and PP. Arterial blood pressure generated during CPR is a quality metric of CPR and higher pressure has been correlated with improved survival,[26] ROSC,[6] and more favorable neurological outcomes.[27] In general, of children who survive a CA, only 24% to 47% have a favorable neurological outcome.[28] Higher cerebral perfusion pressure during CPR has been reported to improve neurological outcomes in animal models and the main contributor is MAP, assuming a minimal intracranial pressure in the absence of brain injuries.[27,29] In our study, nTTT had a significantly higher median MAP (37 [IQR, 34.5–38] mm Hg) versus TTEHT (26 [IQR, 25–26] mm Hg) and TFT (24.5 [IQR, 23.5–26.5] mm Hg), thus indicating improved cerebral perfusion with nTTT. Optimal cerebral perfusion pressure comes from traumatic brain injury research and there is no evidence at to the target pressure for infant CAs, but it is reasonable to speculate that higher MAP, as seen with nTTT technique, will lead to improved neurological outcomes falling CA. Coronary perfusion pressure is a predictor of ROSC and is mainly determined by DBP.[30] In our study, the nTTT trails behind TFT, which had the highest DBP of all 3 techniques (TFT 23.5 [IQR, 22–25.5] mm Hg versus nTTT 20 [IQR, 19–20] mm Hg), although there was no statistical significant difference. A plausible explanation for the higher DBP in TFT is the incomplete decompression with TFT. A coronary perfusion pressure of ≥15 mm Hg is associated with higher chance of ROSC.[31] From DBP alone, it appears that all 3 techniques achieved the minimum needed suggested for ROSC. Whether the small difference in DBP between the TFT and nTTT groups translates to any clinical differences is unclear and warrants further study in the clinical setting.

CC is physically demanding task, especially for females and smaller individuals. One concern regarding CC in CPR is rescuer fatigue. It has been shown in real in-hospital resuscitations that CC quality deteriorates after as short as 90 seconds of CPR delivery.[32] In our study, we did not measure performer vitals as a sign of fatigue but anecdotally they appear to be less fatigued with nTTT. Within the 2-minute CPR session, MAP for THT and TTEHT had a time-dependent decline, with the most dramatic drop of pressure in TFT group (28.5 mm Hg at 00:10 minutes to 24.0 mm Hg at 02:00 minutes) and a similar decline with TTEHT. THT has been reported to cause fatigue.[13] While TTEHT relies on a good hand grip strength to squeeze the thorax and grip strength is affected by gender and size of the individual.[33] Rescuers with small hands or large infants might hinder full coverage of fingers around the thorax, thus affecting quality of CPR. The new nTTT facilitates CC it uses the upper body weight to compress the thorax without need of hand muscles contraction which should avoid fatigue and permit consistent quality CC over long periods. The thumbs in nTTT are placed in a comfortable way in the infant thorax, avoiding the finger and hand fatigue associated with TFT.

An important parameter when any new device or technique is implanted in the clinical setting is users' evaluation of ease-of-use and preference. Before the study, a vast majority of nurses preferred TFT. A post-hoc survey to our participants showed that almost all (96.8%) nurses preferred the nTTT over the 2 standard techniques. There was no finger or hand discomfort with nTTT which was an expected and common occurrence with TFT and TTEHT. This indicates that nTTT could be well accepted by practitioners or maybe even laypersons.

Our study has notable strengths stemming from its novelty and addressing of a clinically relevant topic. Previous studies on CC techniques compared parameters such as hands-off time,

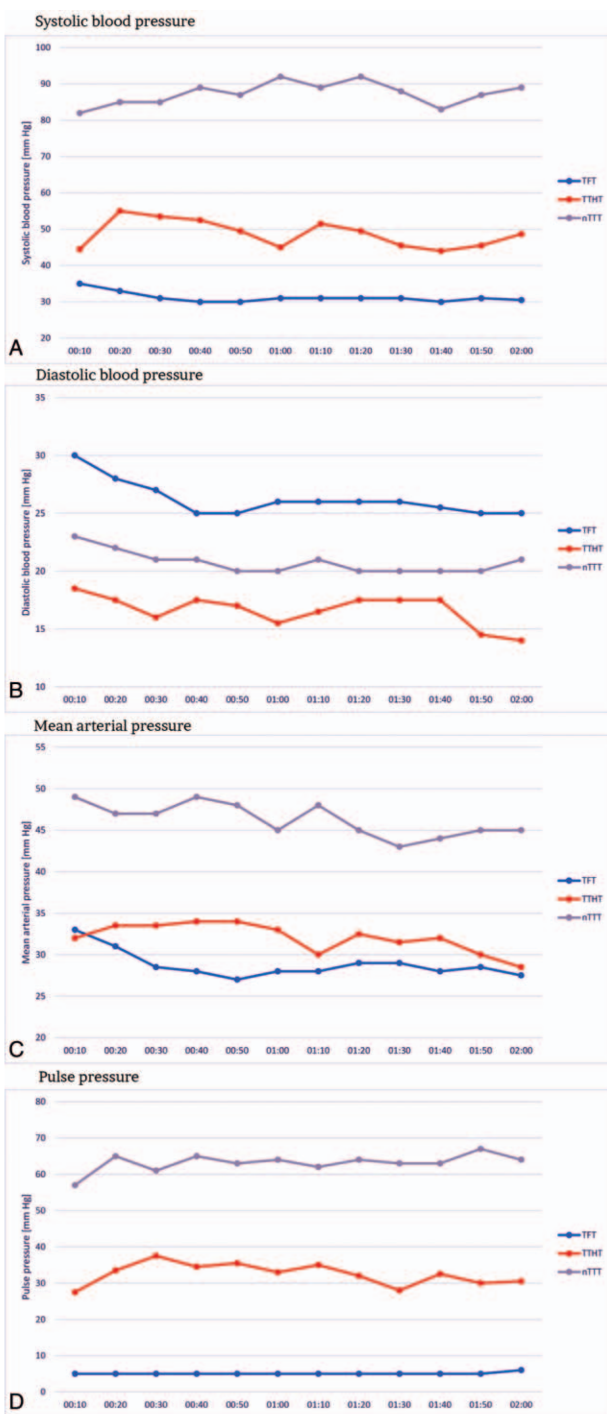

Figure 3. Simulated systolic (A), diastolic (B), mean (C) blood pressure, and pulse pressure (D) in mmHg recorded during the 2-minute period with the 3 CC tested techniques. CC = chest compression.

compression depth, and pressure. Our ability to electronically capture blood pressure at 10-second intervals allowed us to characterize multiple arterial blood pressure measurements in detail. Use of manikin also allows us to achieve statistical power via a cross-over design. The population recruited in this study included emergency room nurses with no prior clinical experience in infant CPR. Our positive results demonstrate that in rescuers no experience with infant CPR, THT, and TTEHT proves to be suboptimal and difficult, while nTTT is easy to learn and master after a brief demonstration. The results demonstrated in our manikin study, if replicated in human infants, may have relevance internationally in countries with similar resuscitation practices.

There are several limitations in our study. Firstly, the use of a manikin cannot fully replicate the properties of a human body, such as elasticity of blood vessels and rib recoil, thus the hemodynamics may not truly represent human infants. Further studies may use baby swine to confirm our findings. Use of animal model also allow us to induce CA, intervene with different CC techniques ,and measure clinical outcomes, such as ROSC, survival rates, and complications of CC. Another limitation is that we did not have information regarding the depth, frequency, and chest recoil of CC in our participants, which are some of the components of a quality CPR. Our participants received basic CPR training in infants and instructed to perform CC according to AHA guidelines to maximize the quality of CC. Finally, we did not incorporate ventilation into our study. Mask ventilation will interrupt CC which will compromise blood flow during CPR and thus survival. A follow-up study may examine the hemodynamics and hands-off time of different CC techniques with incorporation of ventilation.

5. Conclusions

In conclusion, the new nTTT technique achieved higher SBP and MAP compared to the standard CC techniques in our infant manikin model. nTTT appears to be a suitable alternative or complementary to the TFT and TTEHT.

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