Assessment of the Quality of Manual Chest Compressions and Rescuer Fatigue in Different Cardiopulmonary Resuscitation Positions

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Keywords: head-up cardiopulmonary resuscitation; manikin; manual chest compressions; supine cardiopulmonary resuscitation

Abbreviations:
ACCDR: accurate chest compression depth ratio
ACCRR: accurate chest compression rate ratio
ACD: active compression-decompression
CA: cardiac arrest
CPR: cardiopulmonary resuscitation
HUP-CPR: head-up cardiopulmonary resuscitation
ITD: impedance threshold device
MAP: mean arterial pressure
MCCD: mean chest compression depth
MCCR: mean chest compression rate
OCHA: out-of-hospital cardiac arrest
ROSC: rate of spontaneous circulation
RPE: rating of perceived exertion
SUP-CRP: supine cardiopulmonary resuscitation

Abstract

Objective: Following the 2020 cardiopulmonary resuscitation (CPR) guidelines, this study compared participant's fatigue with the quality of manual chest compressions performed in the head-up CPR (HUP-CPR) and supine CPR (SUP-CPR) positions for two minutes on a manikin.

Methods: Both HUP-CPR and SUP-CPR were performed in a randomized order determined by a lottery-style draw. Manual chest compressions were then performed continuously on a realistic manikin for two minutes in each position, with a 30-minute break between each condition. Data were collected on heart rate, blood pressure, and Borg rating of perceived exertion (RPE) scale scores from the participants before and after the compressions.

Results: Mean chest compression depth (MCCD), mean chest compression rate (MCCR), accurate chest compression depth ratio (ACCDR), and correct hand position ratio were significantly lower in the HUP group than that in the SUP group. However, there were no significant differences in accurate chest compression rate ratio (ACCRR), correct recoil ratio, or mean arterial pressure (MAP) before and after chest compressions between the two groups. Changes in heart rate and RPE scores were greater in the HUP group.

Conclusion: High-quality manual chest compressions can still be performed when the CPR manikin is placed in the HUP position. However, the quality of chest compressions in the HUP position was poorer than those in the SUP position, and rescuer fatigue was increased.

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Introduction

Rapidly recognizing a cardic arrest (CA) event and performing high-quality cardiopulmonary resuscitation (CPR) can save a patient's life.[1] In 2018, there were approximately 74.3 out-of-hospital cardiac arrest (OHCA) patients per 100,000 population in the United States. Among this patient group, the rate of survival to hospital discharge was approximately 10.4% in this patient group, and the rate of survival with good neurological prognoses was approximately 8.2%.[2] Inadequate cerebral perfusion is a significant factor contributing to poor neurological prognoses; however, optimal supine CPR (SUP-CPR) results in normal cerebral perfusion in only 30% of cases.[3,4] Therefore, although the rate of spontaneous circulation (ROSC) in OHCA patients has improved with enhancements in the Emergency Medical Services system,

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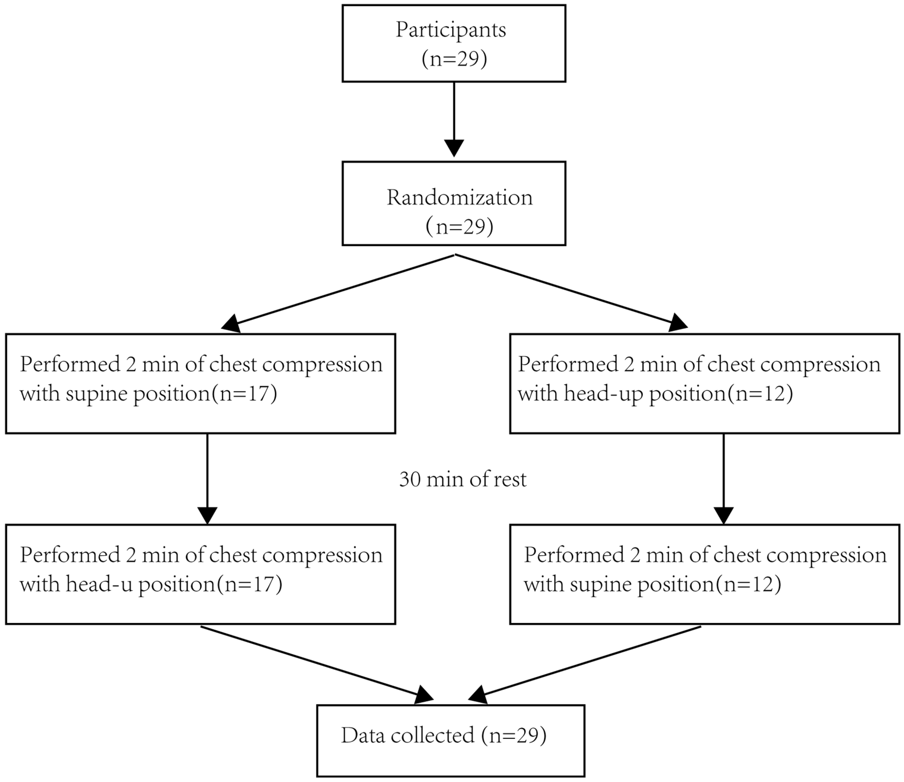

Figure 1. Study Protocol.

the overall rate of positive neurological recovery remains unsatisfactory.[5,6] To improve neurological prognoses following CPR, researchers have developed a novel resuscitation method, head-up CPR (HUP-CPR), which combines controlled head-thorax elevation with active compression-decompression (ACD) CPR, and incorporates the use of an impedance threshold device (ITD). Animal studies have demonstrated that HUP-CPR reduces intracranial pressure, increases cerebral perfusion pressure, and improves neurological prognoses when compared to SUP-CPR.[7–12] Moore, et al developed and clinically validated a positioning device capable of automatically controlling head-thorax elevation. Their research indicated that the rapid implementation of the device was significantly associated with a higher probability of ROSC and positive neurological prognosis following OHCA.[13] The majority of patients with OHCA who are treated by SUP-CPR have a disappointing prognosis, and the aggressive application of HUP-CPR may be beneficial for these patients.[2,13] The International Liaison Committee on Resuscitation (ILCOR) 2023 stated that although the routine use of HUP-CPR was not recommended due to insufficient clinical evidence, it was still important to evaluate the utility of HUP-CPR in future research programs.[14] When HUP-CPR is performed outside the hospital, it is unclear whether manual chest compressions can be used in combination with ITD if an ACD cannot be obtained in time. During HUP-CPR, the thorax is tilted due to elevation of the head and thorax, which may affect the quality of chest compressions. Notably, no relevant studies have been conducted to evaluate the quality of manual chest compressions in the HUP position. Therefore, the aim of this study was to use a manikin to assess whether manual HUP-CPR results in high-quality chest compressions.

Methods

Participants

Twenty-nine participants from Wuhan Union Hospital (Wuhan, China) were included in this study, including 19 females and 10 males. Participants were all physicians and had good exercise habits to keep them physically active.[15] All participants were in good health with no underlying diseases of the musculoskeletal system or cardiovascular system, had recently received Basic Life Support training, and had successfully completed the assessment tasks. After obtaining informed consent from each participant, their height and weight were measured and their corresponding body mass index was calculated.

Protocol

This was a simulation-based, randomized controlled crossover trial. The flow of the experiment is shown in Figure 1. The researcher prepared two envelopes containing chest compression scenarios. Participants were randomly given an envelope to determine the order of chest compressions. The participants performed chest compressions on manikins in different positions (SUP and HUP), with a 30-minute break between the two positions. Researchers collected data regarding the participants' systolic and diastolic blood pressure, heart rate, and Borg rating of perceived exertion (RPE) scale scores (Figure S1; available online only)[16] one minute before performing chest compressions. As recommended by the 2020 CPR guidelines, participants placed the palm root at the intersection of the line joining the two nipples

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Figure 2. Hand Positions for the Chest Compressions in the HUP-CPR (left) and SUP-CPR (right) Positions.
Abbreviations: HUP-CPR, cardiopulmonary resuscitation in head-up position; SUP-CPR, cardiopulmonary resuscitation in the supine position.

and the midline of the sternum. They performed two minutes of uninterrupted chest compressions according to the rate set by a metronome (110 beats/minute; the guidelines recommend 100-120 beats/minute for chest compressions) while maintaining a compression depth of five-to-six centimeters and ensuring complete thoracic recoil at the end of each compression.[1] After completing the compressions, the researchers once again measured the participants' systolic and diastolic blood pressure, heart rate, and RPE scale scores. Following the data collection, the participants rested quietly for 30 minutes to recover.

In both scenarios, a manikin (JW3201-AIDMAN Pro; YIMO KEJI; Beijing, China) was placed on a standard hospital bed (PP Double Swing Bed 012843; 2130 × 950 × 500 mm) for CPR. In the SUP group, the manikin was positioned on a flat, standard hospital bed. In the HUP group, the upper half of the standard hospital bed (head and chest of the manikin) was raised by approximately 30° (Figure 2).[8,17] During chest compressions, participants were allowed to properly observe the AIDMAN Pro AID II – CPR training assessment system display screen to adjust compression depth, hand position, and thoracic recoil in real time. The quality of chest compressions was also investigated, along with participants' fatigue, during manual chest compressions in the HUP position by observing and monitoring their performances using the audiovisual feedback described above.

Data Collection

As each participant performed the compressions, the researchers recorded compression depth, compression rate, total number of compressions, hand position, and thoracic recoil, as displayed by the AIDMAN Pro AID II - CPR training assessment system. Further, the researchers measured and recorded the participants' systolic and diastolic blood pressure using a sphygmomanometer (YUWELL, GB3053-93; Jiangsu YUWELL Medical Equipment Incorporated Company; Jiangsu, China) and measured heart rate using a wrist-type electronic sphygmomanometer (electronic blood pressure monitor, EW-BW10; Panasonic; Beijing, China) before and after the participants performed the chest compressions. The researchers then recorded the participants' RPE scale scores to assess subjective fatigue, with higher scores indicating greater physical exertion.

The quality indicators of chest compressions collected in this study included the following: mean chest compression depth (MCCD), mean chest compression rate (MCCR), accurate chest compression depth ratio (ACCDR; the ratio of the number of compressions with accurate depth to the total number of compressions), accurate chest compression rate ratio (ACCRR; the ratio of compressions with accurate rate to the total number of compressions), correct recoil ratio, correct hand position ratio, changes in heart rate, changes in mean arterial pressure (MAP), and changes in RPE scores.

Statistical Analysis

SPSS Statistics for Windows, version 25.0 (IBM Corp.; Armonk, New York USA) was used for statistical analysis. Visualization (histograms and probability plots) and analytical methods (the Shapiro–Wilk test) were used to test the normal distribution of the data in both groups. Categorical variables are expressed as counts and percentages. Normally distributed variables are expressed as means and standard deviations (SD) and were assessed using Paired Sample t-tests. Skewed distribution variables are expressed as medians and interquartile ranges (IQR) and were assessed using Wilcoxon signed-rank tests. The significance level was set at $P < .05$.

Results

Participants

Twenty-nine participants were enrolled in this study and their baseline characteristics are outlined in Table 1.

Outcomes

The differences in the quality of chest compressions were compared, as well as measurements of fatigue among the participants in the two positions (Table 2). The results indicated that there were significant differences in MCCD in the two positions (SUP: 52.8 [SD = 1.5] mm, HUP: 51.6 [SD = 1.9] mm; 0.35 [95%CI, −1.99 to −0.55]; P

	Mean	Range
Age (years)	24.6	23.0–29.0
Height (cm)	165.7	155.0–180.0
Weight (kg)	59.0	46.0–73.0
BMI (kg/m^2)	21.4	17.7–25.5

Table 1. Demographics of the Study Participants
Abbreviation: BMI, body mass index.

	SUP-CPR	HUP-CPR	t/z	P
Mean Chest Compression Depth (mm)	52.8 [SD = 1.5]	51.6 [SD = 1.9]	–3.614	.001
Mean Chest Compression Rate (beats/min) (P_{25}, P_{75})	109.5 (105, 113.3)	102.5 (99.8, 106.0)	4.135	<.001
Accurate Chest Compression Depth Ratio (%) (P_{25}, P_{75})	87.2 (84.3, 90.6)	81.4 (66.2, 87.6)	3.881	<.001
Accurate Chest Compression Rate Ratio (%) (P_{25}, P_{75})	95.4 (78.2, 97.7)	88.3 (72.7, 94.9)	1.438	.150
Correct Recoil Ratio (%), median (P_{25}, P_{75})	100 (100, 100)	100 (100, 100)	1.826	.068
Correct Hand Position Ratio (%), median (P_{25}, P_{75})	100 (100, 100)	100 (99.0, 100)	2.903	.004
Change in Heart Rate (beats/min)	14.5 [SD = 9.5]	20.9 [SD = 10.0]	–6.768	<.001
Change in MAP (mmHg)	4.7 [SD = 5.0]	4.3 [SD = 4.4]	0.392	.698
Change in RPE Scores	5.8 [SD = 2.2]	8.8 [SD = 1.9]	–10.823	<.001

Table 2. Performances of the Research Participants in the Two Positions
Note: Continuous data are presented as means [standard deviations] or medians (25th, 75th percentile), depending on the data distribution.
Abbreviations: SUP-CPR, cardiopulmonary resuscitation in the supine position; HUP-CPR, cardiopulmonary resuscitation in head-up position; MAP, mean arterial pressure; RPE, rating of perceived exertion.

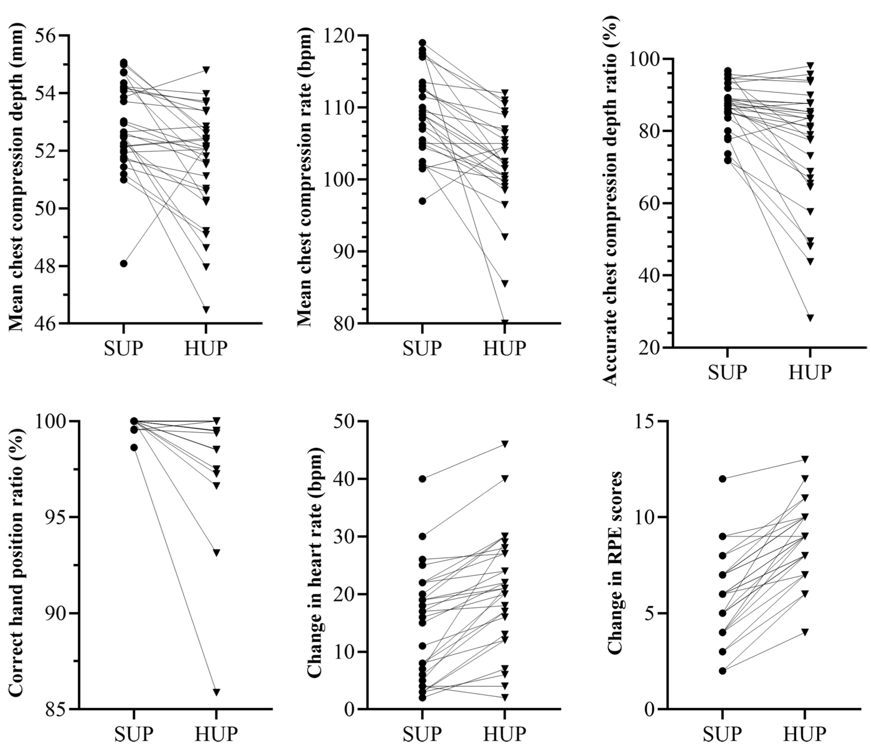

Figure 3. Performance of Each Participant in Terms of Changes in Mean Compression Depth, Mean Chest Compression Rate, Accurate Compression Depth Ratio, Correct Hand Position Ratio, Change in Heart Rate, and Change in RPE Score.
Abbreviations: HUP-CPR, cardiopulmonary resuscitation in head-up position; SUP-CPR, cardiopulmonary resuscitation in the supine position; RPE, rating of perceived exertion.

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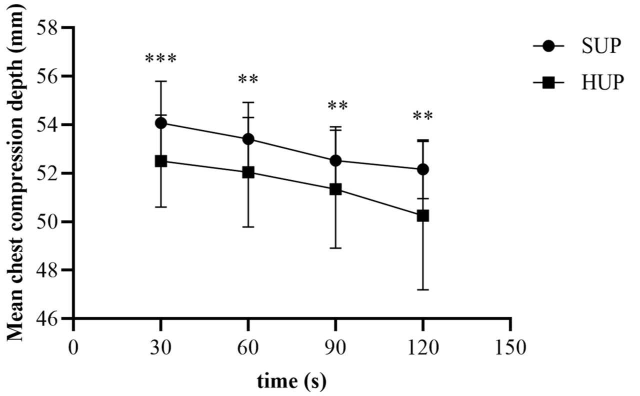

Figure 4. Mean Chest Compression Depths in the Two Positions for each 30-Second Block.
Note: *P <.05, **P <.01, ***P <.001.

= .001); MCCR (SUP: 109.5 [P_{25}, P_{75} 105.0, 113.3] beats/min, HUP: 102.5 [P_{25}, P_{75} 99.8, 106.0] beats/min; P <.001); ACCDR (SUP: 87.2 [P_{25}, P_{75} 84.3, 90.6]%, HUP: 81.4 [P_{25}, P_{75} 66.2, 87.6]%; P <.001); correct hand position ratio (SUP: 100 [P_{25}, P_{75} 100, 100]%, HUP: 100 [P_{25}, P_{75} 99.0, 100]%; P = .004); change in heart rate (SUP: 14.5 [SD = 9.5] beats/min, HUP: 20.9 [SD = 10.0] beats/min; 0.95 [95% CI, −8.40 to −4.50]; P <.001); and change in RPE score (SUP: 5.8 [SD = 2.2], HUP: 8.8 [SD = 1.9]; 0.27 [95% CI, −3.53 to −2.40]; P <.001). Participants' heart rates and RPE scores at the end of compression were statistically different in both groups (SUP: 95.0 [84.5, 102.0] beats/min, HUP: 99.0 [89.0, 108.0] beats/min; P = .004; SUP: 13.0 [12.0, 14.5], HUP: 16.0 [15.0, 17.0]; P <.001); (Figure S2, Figure S3; available online only). Figure 3 shows the performance changes in each participant with regard to MCCD, MCCR, ACCDR, correct hand position ratio, change in heart rate, and change in RPE score during the compressions. There were no significant differences in ACCRR (SUP: 95.4 [P_{25}, P_{75} 78.2, 97.7]%, HUP: 88.3 [P_{25}, P_{75} 72.7, 94.9]%; P = .150), correct recoil ratio (SUP: 100 [P_{25}, P_{75} 100, 100]%, HUP: 100 [P_{25}, P_{75} 100, 100]%; P = .068), and change in MAP (SUP: 4.7 [SD = 5.0] mmHg, HUP: 4.3 [SD = 4.4] mmHg; 1.12 [95%CI, −1.8 to 2.7]; P = .698). As shown in Figure 4, the two-minute manual chest compressions were divided into four 30-second cycles. The SUP group showed a greater mean chest compression depth than the HUP group in all four cycles. The compression depth decreased over time in both scenarios. The mean compression depth of each 30-second cycle in the two scenarios were significantly different from zero to 30 seconds (SUP: 54.1 [SD = 1.7] mm, HUP: 52.5 [SD = 1.9] mm; 0.36 [95%CI, 0.84 to 2.30]; P <.001); 30-60 seconds (SUP: 53.4 [SD = 1.5] mm, HUP: 52.0 [SD = 2.2] mm; 0.40 [95%CI, 0.56 to 2.19]; P = .002); 60-90 seconds (SUP: 52.5 [SD = 1.4] mm, HUP: 51.3 [SD = 2.4] mm; 0.39 [95%CI, 0.39 to 1.97]; P = .005); and 90-120 seconds (SUP: 52.2 [SD = 1.2] mm, HUP: 50.3 [SD = 3.1] mm; 0.54 [95%CI, 0.80 to 3.02]; P = .001).

Discussion

In this simulation-based, randomized controlled crossover trial, the quality of manual chest compressions was investigated, along with participant's fatigue in the HUP position compared with conventional SUP-CPR. The results showed that both groups met the 2020 American Heart Association (AHA; Dallas, Texas USA) requirements for CPR,[1] both in terms of the overall mean depth of chest compressions and mean rate of chest compressions. But HUP-CPR was inferior to SUP-CPR both in terms of the overall mean depth of chest compressions and mean rate of chest compressions. Faster chest compression rates are associated with shallower depths and increased fatigue.[18,19] However, the current results showed that, although the MCCR was significantly higher in the SUP group than in the HUP group, the quality indicators of chest compressions did not worsen in the SUP group. This could be attributed to the utilization of audiovisual feedback devices during the experiment. In the absence of audiovisual feedback conditions for chest compressions, participants often prioritize maintaining the rate of chest compressions and may fail to promptly notice decreases in compression indicators, such as chest compression depth and thoracic recoil.[18,20] With the increasing recognition and wide-spread adoption of devices that provide real-time feedback on CPR quality, the overall quality of chest compressions has improved, particularly in terms of timely corrections of indicators such as chest compression depth, adequate thoracic recoil, and proper hand positioning.[21–23]

The position of chest compressions is another important indicator of their quality.[1] The current results showed that the HUP group had a lower proportion of correct hand positioning. This may be attributed to the instability of the compressions resulting from the tilted thorax in the HUP position, which makes it easier for the hand to slide out of position. It may also be due to participants' unfamiliarity with performing chest compressions in the HUP position. The depth of chest compressions became progressively shallower as fatigue increased in participants with longer compression times, similar to that observed in previous studies.[24,25] These results indicated that the MCCD during each 30-second segment of a two-minute resuscitation cycle was shallower for HUP-CPR than for SUP-CPR.

Several studies have confirmed that the level of fatigue of the participants affects the quality of chest compressions and that an increase in heart rate can somewhat reflect increased fatigue of the participants.[25–27] Although the increase in heart rate and the increase in RPE scores were modest in the HUP group compared with the SUP group, the aggravation of fatigue among participants also explained, to a certain extent, why the quality of chest compressions under the HUP position was poorer. On the one hand, it may be that the participants were still in the compression position recommended by the guideline,[1] with their shoulders positioned above the pressure point, arms perpendicular to the floor, and relying on their upper body weight to apply the force vertically downward. However, when vertically downward pressure is applied to a thorax that is tilted due to elevation, two sets of component forces are generated on the thorax, as follows: those horizontal to the thorax and those perpendicular to the thorax. Participants were required to apply greater force to achieve sufficient compression depth, which led to increased fatigue. On the other hand, it is also possible that the participants were not familiar with performing chest compressions in the HUP position.

Limitations

On the one hand, each chest compression was performed using real-time audiovisual feedback. Audiovisual feedback can improve CPR quality.[21–23] Therefore, these results may have underestimated deteriorations in the actual quality of compressions in the participants. Additionally, the participants performed chest

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compressions for only two minutes, which is much shorter than the typical duration of chest compressions performed in a real CA event. However, the two-minute compression duration does represent one CPR cycle, and other studies examining the quality of chest compressions have also used this compression duration.[24,28]

Considering that manikin do not have human physiology conditions, the researchers did not jointly use devices such as ACD and ITD, but only assessed the quality of manual chest compressions and participants fatigue in the HUP position.

Conclusion

This study showed that manual chest compressions can be performed effectively when a CPR manikin is placed in the HUP position. Although participant fatigue increased, the changes observed in the rescuers over a two-minute compression cycle remained within acceptable limits.

Supplementary Materials

To view supplementary material for this article, please visit https://doi.org/10.1017/S1049023X25000032

Author Contributions

Peng Sun provided the idea and design of the study. Beibei Li and Pan Zhang implemented the experiments, analyzed the data, and drafted the manuscript; Shuang Xu, Qian Liu, Yannan Ma, Siyi Zhou, and Li Xu critically revised the manuscript for important intellectual content. All authors gave final approval of the submitted version.

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