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Simulation and education

The effect of hand and body position on chest compression quality and rescuer fatigue in prone cardiopulmonary resuscitation

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ABSTRACT

Aim: This study aimed to compare the quality of compressions in supine cardiopulmonary resuscitation (CPR) and prone CPR by performing chest compressions on a manikin. Evaluating the effect of prone CPR using different hand and body position on the quality of manual chest compressions and fatigue of participants.

Methods: After completing 2 min of chest compression in the supine position (Supine Group), 25 participants randomly performed three sets of 2-minutes chest compressions on a prone position manikin. Stand + hands overlapped Group: participants stood beside the patient bed with their hands overlapped and placed on the posterior segment of the thoracic spine between the scapulae, Straddle + hands separated Group: participants straddled the patient bed with their hands placed above the scapulae on both sides at the mid-chest level, and Straddle + hands overlapped Group: participants straddled the patient bed with their hands overlapping on the posterior segment of the thoracic spine between the scapulae. Subsequently, the quality of chest compressions and participants fatigue were assessed.

Results: Chest compression depth ratio and mean chest compression depth (MCCD) were worse in the three prone CPR groups (Stand + hands overlapped Group: 0.0(0.0,15.6) %, 39.8 ± 1.3 mm; Straddle + hands separated Group: 1.4(0.0,11.7) %, 42.4 ± 1.2 mm; Straddle + hands overlapped Group: 0.0(0.0,9.2) %, 40.9 ± 1.2 mm) than in the Supine group (87.1(68.1,94.0) %; $p < 0.001$, 52.4 ± 0.4 mm; $p < 0.001$). In the three prone CPR groups, Straddle + hands separated Group had the greatest MCCD, lowest changes in heart rate ($p = 0.018$) and lowest changes in RPE scores ($p < 0.001$). There were no significant differences between the four groups in terms of mean chest compression rate, accurate chest compression rate ratio, or correct recoil ratio.

Conclusion: This simulation-based study showed that the quality of chest compressions was worse in the prone position than in the supine position. When prone chest compressions were performed using different hand and body position, prone CPR performed by a participant straddling a hospital bed with hands placed above the scapula on either side at the mid-chest level provided higher-quality chest compressions and lower rescuer fatigue.

Introduction

High-quality chest compressions are crucial for cardiopulmonary resuscitation (CPR); adequate compression depth, correct compression rate, and minimal interruptions are key considerations.[1,2]. Fatigue is an important factor in the quality of chest compressions. Depth of chest compressions became progressively shallower as fatigue increased. The Borg rating of perceived exertion (RPE) scale is a commonly used fatigue rating scale.[3]. Decreased compression depth is associated with lower resuscitation success and a poor prognosis, with survival rates being significantly worse when compression depth is < 40 mm.[1,4]. When in-hospital cardiac arrest (IHCA) occurs, clinicians usually perform

Abbreviations: (CPR), cardiopulmonary resuscitation; (IHCA), In-hospital cardiac arrest; (MCCD), Mean chest compression depth; (RPE), Borg rating of perceived exertion; (MAP), mean arterial pressure; (MCCR), mean chest compression rate; (ACCRR), accurate chest compression rate ratio; (ACCDR), accurate chest compression depth ratio.

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supine CPR.[5]. However, cardiac arrest also occurs in patients in the prone position. Clinical data suggest that prone positioning improves prognosis in patients with severe hypoxemia.[6]. The prone position is a crucial posture for mechanically ventilated patients with severe pneumonia in intensive care units as well as for many important surgeries in the operating room.[5,7]. How to perform prone CPR is also becoming increasingly important. Previously, multiple societies recommended prioritizing repositioning patients to the supine position for optimal CPR, when cardiac arrest occurs in the prone position.[8]. However, repositioning the patient in the supine position may require collaboration from multiple team members and takes approximately 3 min to complete.[9]. Additionally, changes in position have the potential to disconnect the patient from life-sustaining equipment, such as a ventilator, and rapid change in position may cause hemodynamic instability and exacerbate hypoxemia.[7]. According to the data, for every minute of delay during CPR, the chances of survival of a patient decrease by approximately 10 %.[10]. To minimize unnecessary compression interruptions, prone CPR has been increasingly used over the past few years and is also recognized by the American Heart Association (AHA).[10]. However, the guidelines are not specific about how it should be performed. Most of the available evidence to guide prone CPR hand and body position comes from clinical case reports; one recommendation is to place the hands interlocked on the posterior thoracic vertebrae between the shoulder blades, while another suggests placing the hands apart above the shoulder blades of the patient at the mid-thoracic level.[11–15]. No trials have evaluated the effect of different hand and body position during prone CPR on the quality of CPR. The aim of this study was to assess the quality of chest compressions in the prone position and the traditional supine position by performing chest compressions on a manikin, as well as to assess the effect of performing prone CPR using different hand and body position on the quality of chest compressions and participant fatigue.

Methods

Study design

This was a simulation-based randomized controlled crossover trial. The flowchart is shown in Fig. 1. After the participants completed the enrollment training, researchers recorded data on 2-minutes traditional supine CPR chest compressions completed at the time of the participant assessment (Supine Group). Participants who passed the assessment subsequently performed prone chest compressions in three different scenarios: Stand + hands overlapped Group, participants stood next to the hospital bed with their hands folded on the posterior thoracic vertebrae between the scapulae; Straddle + hands separated Group, participants straddled the hospital bed with their hands placed above the scapulae on either side at the mid-thoracic level, and Straddle + hands overlapped Group, participants straddled the hospital bed with their hands folded and placed on the posterior thoracic vertebrae between the scapulae (Fig. 2). The researchers divided the prone CPR scenarios into six groups in different orders and randomly numbered them 1–6. Participants were randomly given an envelope containing a number representing the order of compressions, and the three scenarios were separated by 30 min. All three scenarios used a manikin (JW3201-AIDMAN® Pro, YIMO KEJI, Beijing, China) placed in the prone position on a standard hospital bed (PP Double Swing Bed, 012843, 2130 × 950 × 500 mm) for CPR. To ensure sufficient depth of compression in the prone position, it is common in clinical practice for the fist of the rescuer or a saline bag to be placed under the sternum of the patient for support.[15,16]. Placing the hand under the chest of the manikin and applying pressure may cause a hand injury to the rescuer. We also tried using saline bags; however, as the manikin does not have the spinal mobility of a real human body and has poor overall compliance, the use of saline bags destabilized the manikin position during compression, making it difficult to perform chest compressions. As a result, salt bags were used as replacements. During chest compressions, participants were allowed to properly observe the AIDMAN® Pro AID® II − CPR training assessment system display screen to adjust compression depth, compression rate and thoracic recoil in real-time.

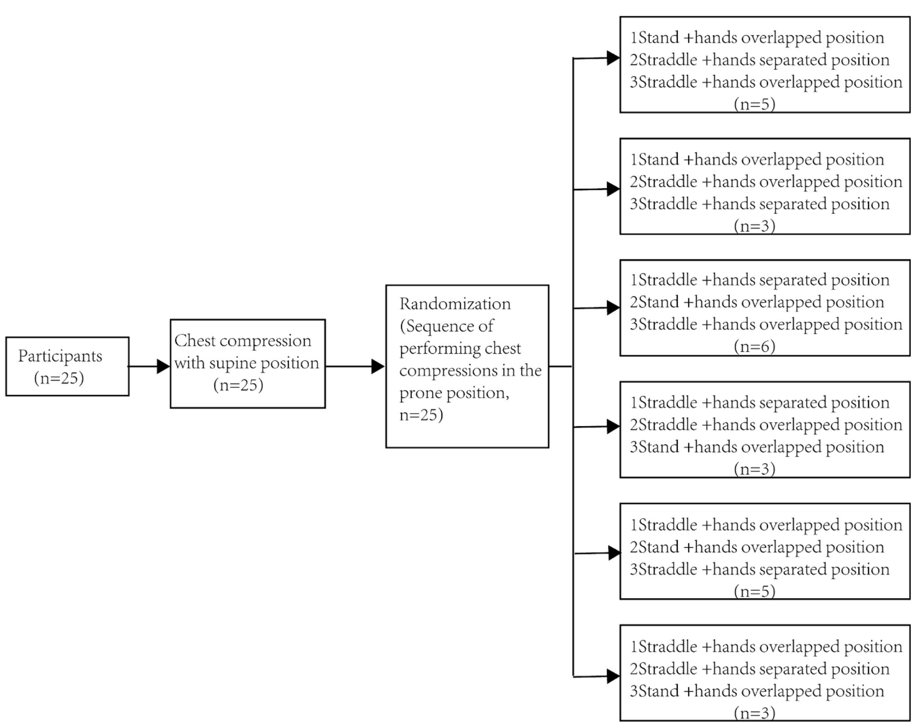

Fig. 1. Flow diagram.

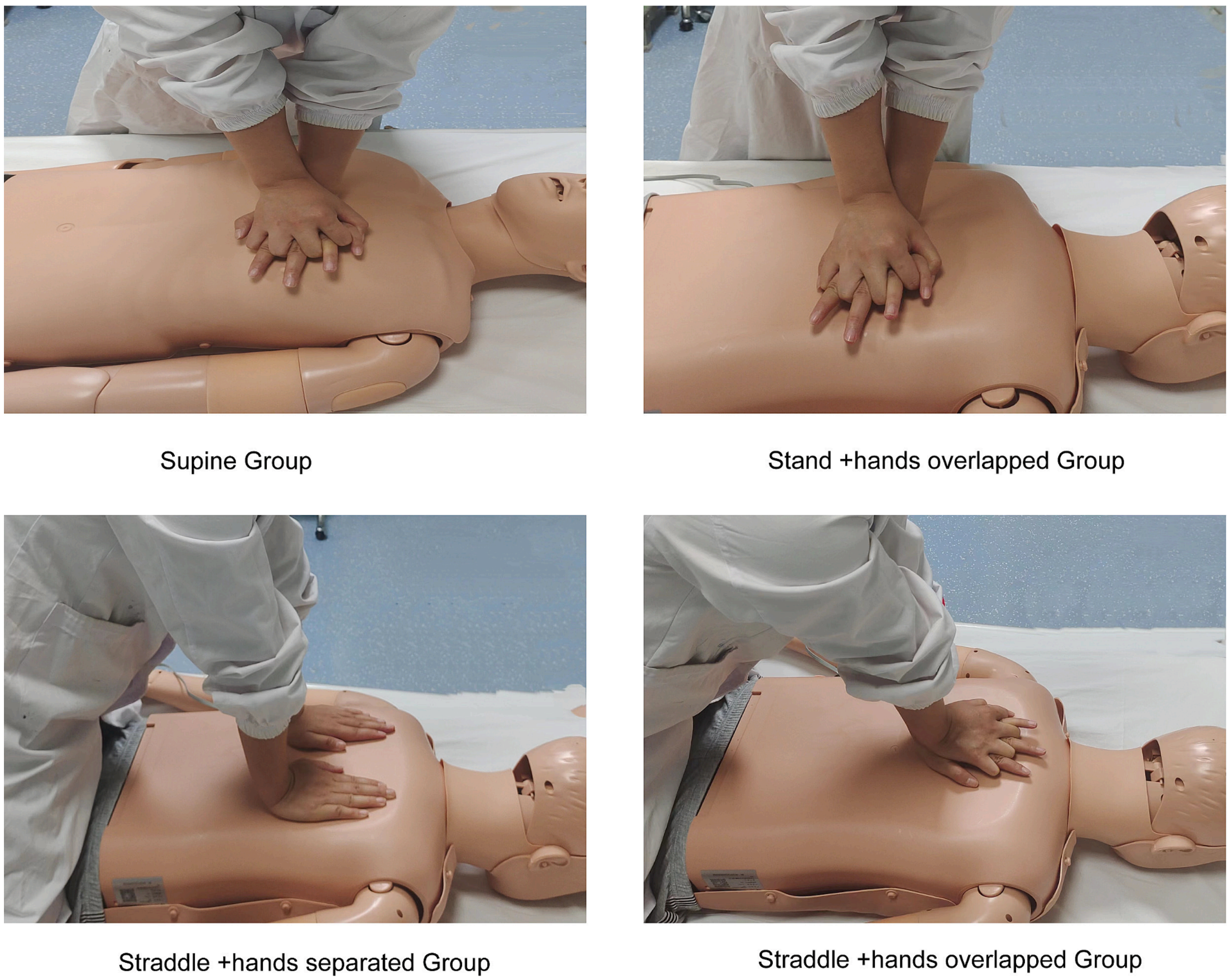

Fig. 2. Hand and body position for the chest compressions in the prone-CPR and supine-CPR positions.

Data on the systolic and diastolic blood pressure of the participant was collected using a mercury sphygmomanometer (YUWELL, GB3053-93, Jiangsu YUWELL Medical Equipment Incorporated Company, Jiangsu, China), and heart rate was measured using a wrist-mounted electronic sphygmomanometer (electronic blood pressure monitor, EW-BW10, Panasonic®, Beijing, China) before and after performing compressions. RPE scale scores (Figure S1).[3] were collected in the 1-minute period before the start of chest compressions, with higher scores indicating greater physical exertion. As each participant performed the compressions, compression depth, compression rate, total number of compressions, and thoracic recoil as displayed by the AIDMAN® Pro AID® II – CPR training assessment system were recorded.

Based on the recommendations of the 2020 CPR guidelines, participants performed uninterrupted chest compressions for 2 min at a rate of 100–120 compressions/minute, maintaining a compression depth of 50–60 mm, ensuring that the chest completely recoiled at the end of each compression. After this, heart rate, blood pressure, and RPE scale scores of the participants were recorded. All data collection was completed quickly within 1 min to ensure high quality investigation of compression quality and changes in participant fatigue. Subsequently, participants rested quietly for 30minutesfor recovery.

Ethics approval and consent to participate

This study was performed using a manikin and had no ethical implications. All participants provided written informed consent.

Participants

Twenty-five participants, including eight males and 17 females, were selected from the medical staff of Wuhan Union Hospital (Wuhan, China). All participants were in good health and had recently undergone Basic Life Support training and successfully passed the assessment. Each participant completed an informed consent form. ***Data collection***

The primary outcome indicator of CPR quality was the mean chest compression depth (MCCD). The secondary outcome indicators included mean chest compression rate (MCCR), accurate chest compression depth ratio (ACCDR; ratio of the number of compressions with accurate depth to the total number of compressions), accurate chest compression rate ratio (ACCRR; ratio of compressions with accurate rate to the total number of compressions), correct recoil ratio. The indicators used to assess participant fatigue were changes in mean arterial pressure (MAP), changes in heart rate, and changes in RPE scores.

Statistical analysis

The data were analyzed using SPSS Statistics for Windows (version 25.0; IBM Corp., Armonk, NY, USA). Visualization (histograms and probability plots) and analytical methods (Shapiro–Wilk test) were used to test for normality in groups. For comparisons between groups, normally distributed variables were assessed using paired sample Student's t-tests. Variables with skewed distributions were assessed using Wilcoxon signed-rank tests. Multiple groups were compared using repeated measures analysis of variance and Friedman's test. The significance level was set at $p < 0.05$.

Results

Twenty-five participants were enrolled; Table 1 shows their basic characteristics.

Table 2 shows the overall differences in the quality of chest compressions and participant fatigue in the four different scenarios. There were significant differences between the four groups in terms of MCCD and ACCDR (Table S2). The MCCD was significantly different between Stand + hands overlapped Group and Straddle + hands separated Group, Stand + hands overlapped Group and Supine Group, Straddle + hands separated Group and Supine Group, as well as Straddle + hands overlapped Group and Supine Group ($p = 0.005$, < 0.001, < 0.001, and < 0.001, respectively), but no significant differences between the remaining groups. The ACCDR was significantly different between Stand + hands overlapped Group and the Supine Group, Straddle + hands separated Group and the Supine Group, and Straddle + hands overlapped Group and the Supine Group ($p < 0.001$); however, no such significant differences were noted between the remaining groups. There were significant differences in changes in heart rate between Stand + hands overlapped Group and Straddle + hands separated Group as well as between Straddle + hands separated Group and Straddle + hands overlapped Group ($p = 0.013$ and 0.046, respectively), but no such difference was observed between the remaining groups. Changes in RPE scores were significantly different between Stand + hands overlapped Group and Straddle + hands separated Group, as well as between Straddle + hands separated Group and Straddle + hands overlapped Group ($p < 0.001$), but not between the remaining groups. The MCCR, ACCRR, and correct recoil ratio were not significantly different between the four groups. Additionally, there were no differences in the changes in MAP between the three prone positions.

We divided the 2-minutes manual chest compressions into four 30-s cycles, and the Supine Group showed significantly greater MCCD, compared to the three prone position groups in all four cycles ($p < 0.01$). The compression depth of all four groups deteriorated over time (Fig. 3). The MCCD for each 30-s cycle in each of the three groups in the prone position was also compared (Table S1). For the 0–30 s interval, Stand + hands overlapped Group and Straddle + hands separated Group were significantly different ($p = 0.006$), with no significant differences between the remaining groups. For the 30–60 s interval, there were no significant differences between the groups in the prone position. For 60–90 s, Stand + hands overlapped Group and Straddle + hands separated Group were significantly different ($p = 0.004$), whereas no significant differences were observed between the remaining groups. For the 90–120 s interval, Stand + hands overlapped Group and Straddle + hands separated Group were significantly different ($p = 0.003$); however, no significant differences were observed between the remaining groups.

Discussion

Multiple studies have shown that prone position ventilation can improve the prognosis of patients with respiratory failure. With the increasing application of prone position.[7,17–18], improving the quality of CPR to patients experiencing cardiac arrest in this position is a key determinant of patient survival and prognosis. This study compared the effects of different rescuer hand and body position on the quality of prone CPR and rescuer fatigue.

Compared to the Supine Group, the compression depth of the three prone position groups was poorer, both overall and for each 30-s period. This may be due to better mobility of the sternum compared to the back. It is easier to achieve the target compression depth by performing supine compressions. The MCCDs of the three prone position groups were all below the recommendations by the 2020 AHA Guidelines for CPR.[10] (Stand + hands overlapped Group: 39.8 ± 1.3 mm; Straddle + hands separated Group: 42.4 ± 1.2 mm; Straddle + hands overlapped Group: 40.9 ± 1.2 mm). Straddle + hands separated Group had the greatest compression depth. This may be because the force applied during prone position compression is distributed over a larger area compared with that during the direct compression of the sternum, which has greater mobility. Participants must exert a greater force to achieve sufficient compression depth in the prone position. Placing the hands apart on the back makes it easier for the participant to press down on the back and squeeze the chest cavity. Compression depths > 38 mm are still beneficial for patient survival and prognosis.[4]. With an increase in compression depth, return of spontaneous circulation rate and discharge survival rate also increase until depth reaches the 50–60 mm recommended by the guidelines.[1,4].

The average chest compression rate, correct chest compression rate ratio, and correct recoil ratio of the prone position groups showed no significant deterioration compared to the Supine group, possibly related to the use of audiovisual feedback devices. As devices providing audiovisual feedback have become more prevalent, the quality of chest compressions has improved, enabling timely corrections to chest recoil and compression rate.[20–22].

The fatigue of the participants in Straddle + hands separated Group was also lower than in Stand + hands overlapped Group and Straddle + hands overlapped Group. Some studies have confirmed that an increase in heart rate is positively correlated with rescuer fatigue.[23,24]. Our study showed that Straddle + hands separated Group participants had the lowest increase in heart rate after compressions, which was consistent with their subjective fatigue perception; The participants placed their hands separately on both sides of the spine of the manikin, resulting in a larger and more uniform compression area compared with those of Stand + hands overlapped Group and Straddle + hands overlapped Group; this made it easier to push the entire back downwards to create compressive deformation, achieving a greater compression depth. Manikin back compliance has not been compared with that of the human body, but considering that the back has a well-developed musculature with lesser overall mobility than that of the sternum, the manikin stiffness reflects this to some extent.

The depth of chest compressions became shallower with time, similar to observations in previous manikin studies.[23,25]. The same phenomenon was also observed in human study.[26]. The average depth of compression for each 30-s period during the 2-minutes resuscitation cycle was higher in Straddle + hands separated Group than in Stand + hands overlapped Group and Straddle + hands overlapped Group, suggesting that the effect of compression in Straddle + hands separated Group was more stable.

Our study has several limitations. As an audiovisual feedback device was used, our results may have underestimated the deterioration in the quality of compressions performed by the participants. Additionally, manikins are not fully representative of the human body. Therefore, our results need to be validated in humans. We did not use CPR pads, which may be more in line with CPR performed under realistic conditions. The participants performed chest compressions for only 2 min, which is much shorter than the typical duration of chest compressions performed in a real CA event. However, the 2 min compression duration does

Table 1
Demographics of participants.

Age (years)	24.8 ± 1.9
Height (cm)	166.1 ± 7.2
Weight (kg)	60.8 ± 14.0
BMI (kg/m^2)	21.8 ± 3.7
Sex	8 male (32 %), 17 female (68 %)

Continuous data are presented as the mean ± standard deviation, depending on the data distribution. Categorical data are presented as the number (%).
BMI = body mass index.

Table 2
The performances of the participants in four scenarios.

	Stand + hands overlappedGroup	Straddle + hands separatedGroup	Straddle + hands overlappedGroup	Supine Group	F/H value	P value
Mean chest compression depth (mm)	39.8 ± 1.3	42.4 ± 1.2	40.9 ± 1.2	52.4 ± 0.4	40.3	P < 0.001
Mean chest compression rate (compressions/min)	108.6 ± 1.7	108.0 ± 1.6	112.1 ± 1.6	108.8 ± 1.6	2.3	P = 0.09
Accurate chest compression depth ratio (%)	0.0(0.0,15.6)	1.4(0.0,11.7)	0.0(0.0,9.2)	87.1 (68.1,94.0)	48.6	P < 0.001
Accurate chest compression rate ratio (%) (P_{25}, P_{75})	76.9(49.8,95.8)	83.0(68.2,92.1)	74.8(59.0,88.7)	85.0 (68.1,94.0)	3.1	P = 0.34
Correct recoil rate (%), median (P_{25}, P_{75})	100(100,100)	100(100,100)	100(100,100)	100(100,100)	3.7	P = 0.16
Change in heart rate (beats/min)	18.1 ± 2.6	10.0 ± 1.7	17.7 ± 3.1	–	4.8	P = 0.018
Change in MAP (mm Hg)	−1.3 ± 1.8	−1.8 ± 1.1	1,1 ± 1.0	–	1.3	P = 0.29
Change in RPE scores	7.4 ± 0.5	4.6 ± 0.3	7.3 ± 0.5	–	32.3	P < 0.001

Continuous data are presented as the mean ± standard deviation or median (25th,75th percentile), depending on the data distribution. Friedman's test (F/H value).
Stand + hands overlapped Group: Participants stood next to the hospital bed with their hands folded and placed on the posterior thoracic vertebrae between the scapulae;
Straddle + hands separated Group: Participants rode across the hospital bed with their hands placed above the scapulae on either side at mid-thoracic level;
Straddle + hands overlapped Group: Participants rode across the hospital bed with their hands folded and placed on the posterior thoracic vertebrae between the scapulae. The order was randomized by drawing lots.
Supine Group: cardiopulmonary resuscitation in the supine position.
MAP, mean arterial pressure.
RPE, rating of perceived exertion.

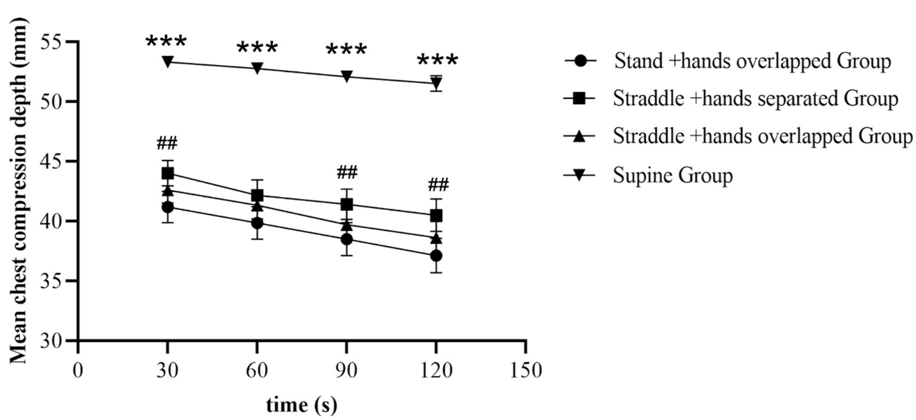

Fig. 3. The mean chest compression depths of four scenario are compared for each 30 sec. Supine Group VS. Prone groups ***P < 0.001 Stand + hands overlapped Group VS. Straddle + hands separated Group ##P < 0.01.

represent one CPR cycle, and other studies examining the quality of chest compressions have also used this compression duration.[25,27].

Conclusion

This simulation-based study showed that the quality of chest compressions was worse in the prone position than in the supine position. When conditions do not support the transfer of a patient with cardiac arrest from the prone position to the supine position for traditional CPR, our results from a manikin study suggest prone compressions with the rescuer straddling the bed and placing the hands above the scapula on either side at the mid-chest level results in greatest efficacy and lowest rescuer fatigue.

Declarations.

Ethics approval and consent to participate.

This study was performed using a manikin and had no ethical implications. All participants provided written informed consent.

Consent for publication

Not applicable.

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Author contributions

Peng Sun provided the idea and design of the study. Qian Liu, Beibei Li implemented the experiments, analyzed the data, and drafted the manuscript; Siyi Zhou,Lulu Gu, Letian Xue, Ruyue Lu and Li Xu critically revised the manuscript for important intellectual content. All authors gave final approval of the submitted version.

CRediT authorship contribution statement

Qian Liu: Writing – review & editing. **Beibei Li:** Writing – original draft, Investigation, Data curation. **Siyi Zhou:** Writing – review & editing. **Lulu Gu:** Writing – review & editing. **Letian Xue:** Writing – review & editing. **Ruyue Lu:** Writing – review & editing. **Li Xu:** Writing – review & editing. **Peng Sun:** Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resplu.2024.100787.

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