Original Article

Adequacy of hand positioning by medical personnel during chest compression in a simulation study

Yasuaki Koyama,[1] Tasuku Matsuyama,[2] Takako Kainoh,[1] Tetsuya Hoshino,[1] Junzo Nakao,[1] Nobutake Shimojo,[1] and Yoshiaki Inoue[1]

[1]*Department of Emergency and Critical Care Medicine, University of Tsukuba Hospital, Tsukuba, Ibaraki, Japan, and* [2]*Department of Emergency Medicine, Kyoto Prefectural University of Medicine, Kyoto, Japan*

Aim: During chest compressions (CCs), the hand position at the lower half of the sternum is not strictly maintained, unlike depth or rate. This study was conducted to determine whether medical staff could adequately push at a marked location on the lower half of the sternum, identify where the inappropriate hand position was shifted to, and correct the inappropriate hand position.

Methods: This simulation-based, prospective single-center study enrolled 44 medical personnel. Pressure and hand position during CC were ascertained using a flexible pressure sensor. The participants were divided into four groups by standing position and the hand in contact with the sternum: right–left (R–*l*), right–right (R–*r*), left–right (L–*r*), and left–left (L–*l*). We compared the groups and the methods: the manual method (MM), the thenar method, and the hypothenar method (HM).

Results: Among participants using the MM, 80% did not push adequately at the marked location on the lower half of the sternum; 60%–90% of the inadequate positions were shifted to the hypothenar side. CCs with the HM facilitated stronger pressure, and the position was minimally shifted to the hypothenar side.

Conclusion: Medical staff could not push at an appropriate position during CCs. Resuscitation courses should be designed to educate personnel on the appropriate position for application of maximal pressure while also evaluating the position during CCs.

Key words: Cardiopulmonary resuscitation, chest compressions, hand position, manikins, standing position

INTRODUCTION

THE INTERNATIONAL CONSENSUS on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care (CoSTR) emphasizes the importance of chest compressions (CCs) quality, especially depth, rate, recoil, hand position, and minimizing interruptions.[1] However, they do not specify hand positioning during CC.[1] In 2000, the European Resuscitation Council Guidelines recommended a strict landmark-based technique to slide from the lower rib[2] that is difficult for a layperson. According to the CoSTR in 2005, to reduce hands-off time, the heel of the dominant hand should be in the center of the chest with the nondominant hand on top.[3] Further revisions in the guidelines were made to facilitate CCs by rescuers; the recommended hand position was the lower half of the sternum.[1,4] This guideline is ambiguous and the evidence on the appropriate hand-placement position for CCs in cardiopulmonary resuscitation (CPR) is insufficient. Moreover, whether CCs on the lower half of the sternum can be adequately undertaken in real-life situations remains unclear. Further, real-time feedback devices in the clinical setting cannot evaluate hand position, but only CC depth, rate, and recoil.

Previous research conducted on manikins reported that approximately 65% of emergency medical services personnel could not undertake CCs at the appropriate location.[5] Moreover, in scenarios where rescuers compress the incorrect region, the direction in which the hand position was shifted remains unknown.

This study was conducted to assess the following: (i) whether medical staff could adequately push the marked location on the specified half of the sternum; (ii) the position to which the inadequate hand position was shifted; and (iii)

Corresponding: *Yasuaki Koyama, MD, Department of Emergency and Critical Care Medicine, University of Tsukuba Hospital, 2-1-1 Amakubo, Tsukuba, Ibaraki, Japan. E-mail: yasukoya@md.tsukuba.ac.jp.*

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whether it is possible to correct inadequate hand position with simple verbal instructions.

METHODS

Study design and participants

THIS SIMULATION-BASED, prospective, single-center study enrolled medical personnel, including 10 doctors and 20 nurses at our hospital and 14 paramedics. This study was approved by the Ethics Committee of the University of Tsukuba Hospital, Japan.

Study procedure

The Little Anne CPR training manikin (Laerdal Medical Corporation, Stavanger, Norway) and a flexible pressure sensor (Shinnosuke-kun; Sumitomo Riko Co., Ltd., Komaki-shi, Aichi, Japan) were used. The center mark of the sensor was placed on the lower half of the manikin's sternum (Fig. 1A). A total of 25 pressure sensors (1 cm^2) were placed 5 × 5 cm^2 apart, and the pressure applied to each sensor was measured. When CCs were applied within a 3 × 3 cm^2 area centered around the gray dot (Fig. 1B), the hand position was deemed adequate.

Participants were randomly divided into four study protocols by standing position and methods (namely the CC-order protocols). During this protocol, participants could choose either hand to place in contact with the sternum during CCs. The CCs included a series of the manual method (MM), the thenar method (TM), and the hypothenar method (HM) (Fig. 2A). The order of these methods and standing positions varied among the four CC-order protocols (Fig. 2B). In Order 1, participants conducted CCs for 1 min with the usual hand position targeting the gray dot (MM; Fig. 2A) when the standing position was on the right side and the left side of the manikin. Next, they were given a brief instruction and the hand in contact with the sternum was shifted and the thenar part of the hand was placed on the gray dot (TM; Fig. 2A). Then, the participants performed 10 CCs when the standing position was on the right side and the left side of the manikin. Finally, they were given another instruction and the hypothenar part of the hand was placed on the gray dot (HM; Fig. 2A) and they conducted 10 CCs when the standing position was on the right side and the left side of the manikin; implementation of each method was separated by an interval of more than 1 min. In Order 2, we reversed the order of the TM and the HM. Order 3 began from the left side, which was the reverse of Order 1, and in Order 4, we reversed the order of the TM and the HM undertaken in Order 3 (Fig. 2B). The manikin was placed on a stretcher to simulate real-life clinical situations. No feedback was provided to participants during the CC procedure.

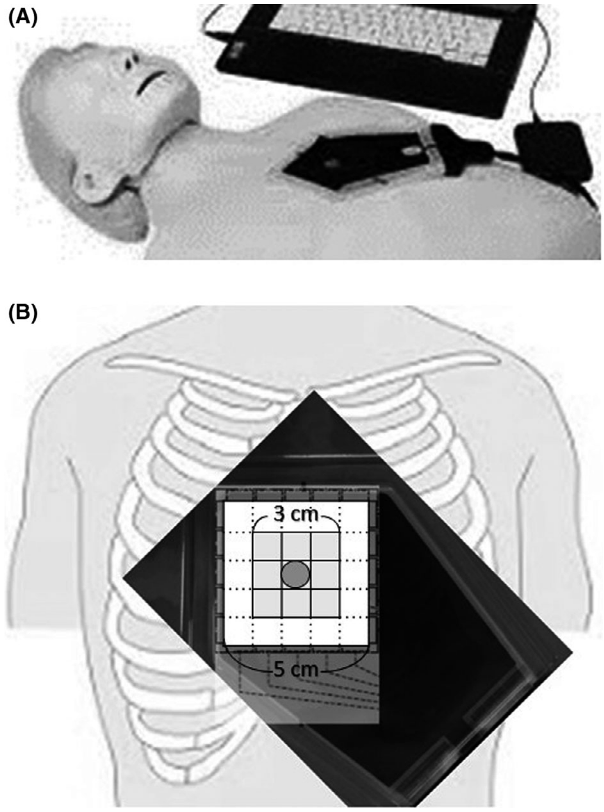


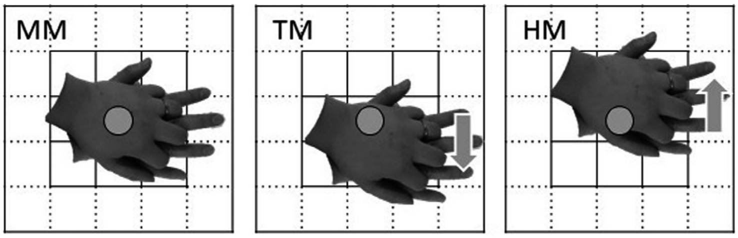
Fig. 1. Pressure sensor placement and specifications. (A) The pressure sensor (Shinnosuke-kun) was set up on the lower half of the sternum in a CPR training manikin. (B) The white square is representative of the measured area (5 × 5 cm^2); the gray dot marks the center; the pearl gray area shows the appropriate position during chest compression.

Data collection

The data collected were age, sex, occupation, years of occupation, dominant hand, CPR training within 2 years, and CPR experience within 2 years of the study.

Each sensor was a capacitive pressure sensor; the pressure was expressed in pico farad. We identified the sensor position where the average pressure applied to each of the 25 sensors by each participant during CC was at a maximum. We also identified the sensor position where the pressure applied to each sensor was maximal for each CC. Furthermore, collected data were divided into four groups according to standing position and the freely selected hand in contact with the sternum. The participants in the right–*left* (R–*l*) group undertook CC from the right side and used the left

(A)



(B)

Compressions	Order 1	Order 2	Order 3	Order 4
For 1 minute ↓	MM (Right)	MM (Right)	MM (Left)	MM (Left)
For 1 minute ↓	MM (Left)	MM (Left)	MM (Right)	MM (Right)
10 compressions ↓	TM (Right)	HM (Right)	TM (Left)	HM (Left)
10 compressions ↓	TM (Left)	HM (Left)	TM (Right)	HM (Right)
10 compressions ↓	HM (Right)	TM (Right)	HM (Left)	TM (Left)
10 compressions (Standing position)	HM (Left)	TM (Left)	HM (Right)	TM (Right)

Fig. 2. Chest compression methods. (A) These figures illustrate the standing position (right side of the manikin) and the contact side of the hand (right). Left: manual method, the usual hand position targets the gray dot. Middle: thenar method, where the lower hand shifts to the hypothenar side and the thenar part of the hand is placed on the gray dot. Right: hypothenar method, where the lower hand shifts to the thenar side and the hypothenar part of the hand is placed on the gray dot. (B) Order of chest compressions for the four groups (the CC-order protocols). Right or left in the parenthesis is the standing position. HM, hypothenar method; MM, manual method; TM, thenar method.

hand for contact with the sternum; the right–*right* (R–*r*) group used the right hand; the left–*right* (L–*r*) group undertook CC from the left side and used the right hand for contact with the sternum; the left–*left* (L–*l*) group used the left hand (Table 2).

Outcome measures

Primary outcomes were the ratio of participants in an adequate position where the average maximal pressure was applied to each sensor or each CC with the MM, where the inadequate position was shifted, and the ratio of participants in each inadequate position. Secondary outcomes were the ratio of participants in an adequate position where the average maximal pressure was applied to each sensor with the MM, TM, and HM; the ratio of participants in each inadequate position with each method; the maximum average pressure applied to each sensor with each method; and the average rhythm with each method.

Statistical analysis

Data are presented as median and interquartile range or proportions, as appropriate. The chi-square and Kruskal–Wallis *H*-tests were used for categorical and continuous variables, respectively. The Mann–Whitney *U*-test with Bonferroni correction was applied if there was a significant difference. We conducted intergroup comparisons by standing position and hand in contact with the sternum. Moreover, we undertook comparisons between the methods. All *P*-values were two-sided and values of 0.05 or less were considered statistically significant. All statistical analyses were conducted with

EZR (Saitama Medical Centre, Jichi Medical University, Saitama, Japan), which is a graphical user interface for R (The R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Adequate position with the manual method

THE AVERAGE AGE and work experience of participants were 32 and 7.8 years, respectively. Overall, 29 and 37 participants had CPR training and CPR experience in the preceding 2 years, respectively. The CC-order protocols did not differ significantly in characteristics (Table 1). The ratio of participants in an adequate position was 25%, 13%, 22%, and 10% in the R–*l*, R–*r*, L–*r*, and L–*l* groups, respectively (Table 2), without significant intergroup differences. Inadequate position was shifted 61–90% to the hypothenar side and 29–50% to the front side (Table 2).

Among the four groups, participants used the most adequate position in the R–*l* group (33%), followed by the L–*r* (26%), R–*r* (14%), and L–*l* (10%) groups (Table 2). Pairwise comparisons (R–*l* vs R–*r*, L–r vs L–*l*, L–*r* vs R–*r*, R–*l* vs L–*l*) between the groups showed statistically significant differences ($P < 0.001$).

Adequate position in each group

In each group, the ratio of participants in an adequate position with the HM was better than that with the MM or the TM (R–*r*; $P = 0.003$, L–*r*; $P = 0.040$, L–*l*; $P = 0.047$), except for the R–*l* group ($P = 0.089$). When the participants undertook CC with the HM in all groups, the pressure position was minimally shifted to the hypothenar side. Compared by each CC, the ratio with the HM was better than that with the MM or the TM in all groups ($P < 0.001$; Table 3).

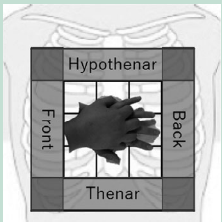
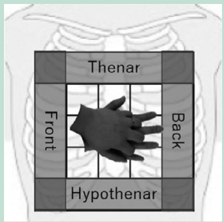
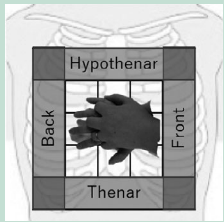
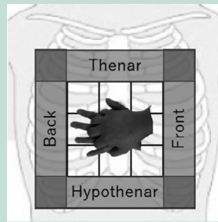
Maximal value of average pressure and average compression rate

The maximal value of the average pressure applied to each sensor and the average compression rate with the MM, TM, and HM showed no significant difference between each group (the maximal value: MM, $P = 0.396$; TM, $P = 0.302$; HM, $P = 0.158$; the average compression: MM, $P = 0.330$; TM, $P = 0.632$; HM, $P = 0.524$). The maximum value of average pressure with the HM was better than that with the MM or TM in all groups (R–*l*, $P < 0.001$; R–*r*, $P < 0.001$; L–*r*, $P = 0.005$; L–*l*, $P < 0.001$). The average compression rate with the MM was greater than with the TM or HM in all

Table 1. Participant demographics

	Order 1	Order 2	Order 3	Order 4	*P*-value
Participants, *n*	12	10	10	12	
Ages (years), mean ± SD	33 ± 6	30 ± 6	31 ± 7	34 ± 6	0.21
Sex, *n*					
Male	8	6	9	7	0.763
Female	4	4	1	5	
Profession, *n*					
Doctor	3	2	2	3	1
Nurse	5	5	5	5	
Ambulance crew	4	3	3	4	
Work experience (years), mean ± SD	8.1 ± 1.4	6.7 ± 1.9	6.2 ± 1.8	9.9 ± 1.8	0.279
Dominant hand, *n*					
Right	11	10	10	10	0.87
Left	1	0	0	2	
CPR training within 2 years, *n*					
Yes	9	8	6	6	0.74
No	3	2	4	6	
CPR experience within 2 years, *n*					
Yes	11	9	8	9	0.95
No	1	1	2	3	

Table 2. Primary outcome with the manual method

					
Standing position: hand in contact with the sternum	Right–left (R–*l*)	Right–right (R–*r*)	Left–right (L–*r*)	Left–left (L–*l*)	
Total participants, *n*	20	24	23	21	
Adequate, *n* (%)	5 (25)	3 (13)	5 (22)	2 (10)	0.797
Inadequate, *n* (%)	15 (75)	21 (87)	18 (78)	19 (90)	
Thenar, *n* (%)	0 (0)	0 (0)	1 (4)	0 (0)	
Hypothenar, *n* (%)	13 (65)	19 (79)	14 (61)	19 (90)	
Back, *n* (%)	0 (0)	2 (8)	2 (9)	0 (0)	
Front, *n* (%)	9 (45)	12 (50)	10 (43)	6 (29)	
Total compressions, *n*	2,130	2,494	2,616	2,188	
Adequate, *n* (%)	700 (33)	357 (14)	674 (26)	209 (10)	<0.001
Inadequate, *n* (%)	1,430 (67)	2,137 (86)	1,942 (74)	1,979 (90)	
Thenar, *n* (%)	0 (0)	0 (0)	99 (4)	0 (0)	
Hypothenar, *n* (%)	1,093 (51)	1,911 (77)	1,333 (51)	1,974 (90)	
Back, *n* (%)	1 (0)	108 (4)	210 (8)	5 (0)	
Front, *n* (%)	1,076 (51)	970 (39)	1,078 (41)	656 (30)	

Upper: Figure is in the standing position, hand in contact with the sternum, and definition of inadequate position. Front label was the position in front of the hand in contact with the sternum, back label was the position behind the hand, thenar label was the thenar side of the hand, and hypothenar label was the hypothenar side of the hand.
Middle: Table showing the corresponding primary outcome.
Lower: The percentage of adequate positioning where the pressure applied to each sensor was maximum by each chest compression using the manual method.

groups (R–*l*, $P < 0.001$; R–*r*, $P < 0.001$; L–*r*, $P < 0.001$; L–*l*, $P < 0.001$; Fig. 3).

DISCUSSION

IN OUR STUDY, most participants could not push the marked location on the specified half of the sternum. This finding highlights the difficulty in achieving an adequate position in every CC using only visual assessment.

In previous studies, 70–90% of students could compress at an adequate position.[6,7] However, these studies used the Resusci Anne Skill Reporter manikin (Laerdal Medical Corporation, Stavanger, Norway). This manikin has wider margins than the manikin used in our study; therefore, the proportion of participants pushing on the correct area in the previous studies was higher than in our study. Another study reported that only 32% of ambulance crew compressed the appropriate position with Shinnosuke-kun, even after more than 2,000 h of emergency service experience.[5] Similarly, in our study, although over one-half of participants were doctors and nurses with recent CPR experience or education, they could not compress at the adequate position. The observed low proportion of correct position is attributable to the inadequacy of CPR training rather than lack of training itself. Therefore, further studies should establish training methods for correct positions during CC.

Our study revealed that in over 60% of participants the pushing position was inadequately shifted to the hypothenar side (in the middle of Table 2). A previous study found that the maximal pressure point during CC was shifted from an arbitrary line (middle finger–carpus line) to the hypothenar side. When the hand is in dorsiflexion (as in the CC position), the *os scaphoideum* protrudes and the rescuer experiences periosteal pain; to compensate for this, the pressure is

Table 3. Analysis of hand position during chest compressions

Position	Right–*left* MM	TM	HM	*P*	Right–*right* MM	TM	HM	*P*	Left–*right* MM	TM	HM	*P*	Left–*left* MM	TM	HM	*P*
Percentage of adequate positioning, where the average pressure applied to each sensor was at a maximum and shifted by each participant																
Total participants, *n*	20	22	21		24	22	23		23	22	22		21	22	22	
Adequate, frequenc y, *n* (%)	5 (25)	14 (64)	10 (48)	0.089	3 (13)	8 (37)	15 (65)	0.003	5 (22)	10 (45)	14 (64)	0.040	2 (10)	4 (18)	10 (45)	0.047
Inadequate, frequency, *n* (%)	15 (75)	8 (36)	11 (52)		21 (87)	14 (63)	8 (35)		18 (78)	12 (55)	8 (36)		19 (90)	18 (82)	12 (55)	
Thenar, *n*	0	2	0		0	4	0		1	1	0		0	0	0	
Hypothenar, *n*	13	6	0		19	9	0		14	8	0		19	17	1	
Back, *n*	0	0	1		2	5	0		2	2	0		0	0	0	
Front, *n*	9	1	10		12	1	8		10	8	8		6	4	12	
Percentage of adequate positioning, where the pressure applied to each sensor was at a maximum by each chest compression																
Total compressions, *n*	2,130	218	207		2,494	222	226		2,616	224	216		2,188	215	215	
Adequate, frequency, *n* (%)	700 (33)	110 (50)	110 (53)	<0.001	357 (14)	61 (27)	117 (52)	<0.001	674 (26)	122 (54)	125 (58)	<0.001	209 (10)	28 (13)	91 (42)	<0.001
Inadequate, frequency, *n* (%)	1,430 (67)	108 (50)	97 (47)		2,137 (86)	161 (73)	109 (48)		1,942 (74)	102 (46)	91 (42)		1,979 (90)	187 (87)	124 (58)	
Thenar, *n*	0	17	0		0	22	0		99	2	8		0	6	0	
Hypothenar, *n*	1,093	58	0		1,911	120	2		1,333	76	0		1,974	159	10	
Back, *n*	1	0	3		108	26	0		210	2	0		5	0	0	
Front, *n*	1,076	38	94		970	19	109		1,078	82	87		656	52	124	

HM, hypothenar method; MM, manual method; TM, thenar method.

shifted to the hypothenar side.[8] A recent study suggested that rescuers damaged the scapholunate ligament during CCs when the pushing position was fitted to the mid-line.[9] Therefore, the maximum pressure point is usually the hypothenar side. However, if standing position and hand in contact with the sternum are both right, or both left, the hand position is shifted to the hypothenar side, which may compress closer to the xiphoid and increase the risk of blunt upper abdominal trauma.[10] Therefore, the hand position must not shift to the hypothenar side.

When we evaluated each CC, the rescuer position at the right side of the patient with the left hand in contact with the sternum, or vice versa, was better, as specified in the 2000 guidelines.[2] With the right-side standing position and left hand in contact with the sternum (and CC with interlaced fingers), the thenar side of the lower hand and xiphoid can be visually identified; therefore, compression of the xiphoid can be avoided, despite the hand position shifting to the hypothenar side. If both standing position and the hand in contact with the sternum are right, the xiphoid is hidden by the thumb of the upper left hand and we cannot identify whether the xiphoid is compressed with the hypothenar side of the lower right hand.

Further, approximately 30–50% of the pushing position was shifted to the front side in our study because the heel of the hand may be in front of the sensor if the center of the palm is on the gray dot, or it may be impossible to push the center of the sensor from directly above on the stretcher even with the footrest. A study reported that 30% of patients with return of spontaneous circulation had rib fractures.[11] Patients may sustain rib fractures when a rescuer's hand position shifts forward.

The HM had a simple verbal instruction. We found that the pressure position with the HM was minimally shifted to the hypothenar side without pressure changes in all groups. The xiphoid was visually identifiable with the HM, which significantly contributed to more adequate positioning with the HM than with the TM. The maximal value of average pressure for depth with the HM is higher than that with the MM or the TM. The maximal value of average pressure can produce the deepest CC. Thus, the HM has greater depth than the MM or the TM. However, the HM did not affect forward shifting.

To summarize the findings, we recommend that the hand in contact with the sternum should be the left if the standing position is on the right and vice versa, and the TM should be used for CCs. In a clinical setting, a real-time feedback device focusing on the hand position should be developed. During resuscitation courses, inability to push the marked location should be corrected by instructors through knowledge of adequate hand positioning.

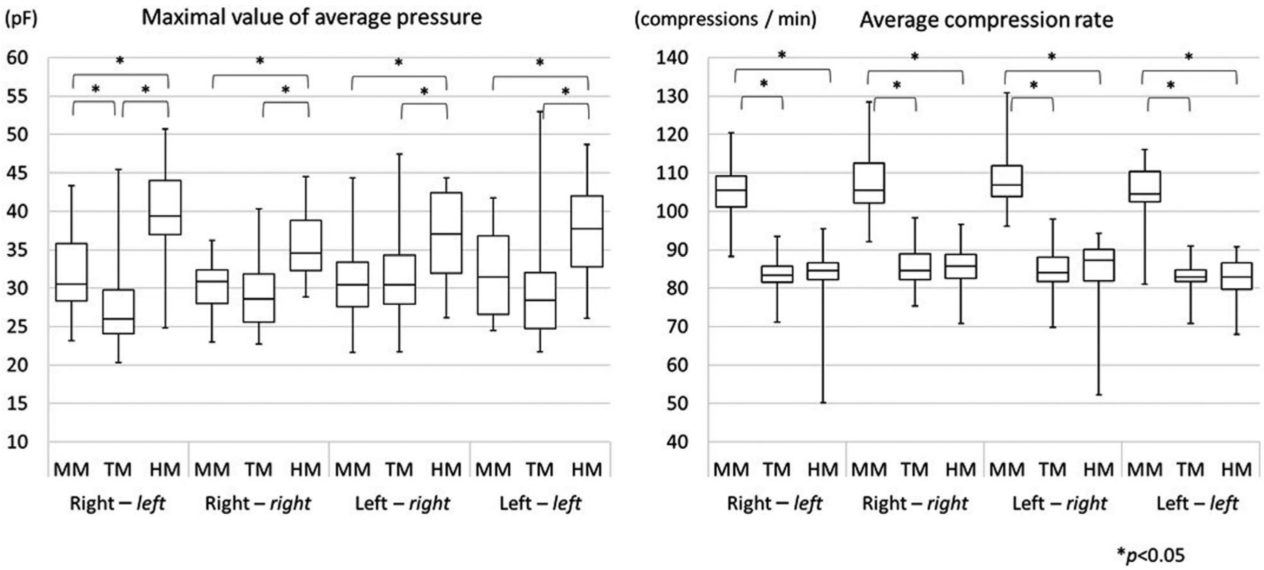


Fig. 3. Maximal value of average pressure and average compression rate. The maximal value of average pressure applied to each sensor and the average compression rate with each method in all groups. HM, hypothenar method; MM, manual method; TM, thenar method.

Our study has some limitations. First, the participants undertook CCs with the MM with a 1-min interval to account for fatigue. However, a more adequate position may not have been possible with CC every 2 min, as per guidelines. Second, participants undertook only 10 compressions with the TM or the HM. The first technique performed by participants was the MM, which may have influenced the lower average compression rate with the TM or the HM. Further research is needed to validate our findings. Third, we did not compare differences by hand dominance because only 3 of 44 participants had left-hand dominance. A previous study found fewer errors when the dominant hand of the rescuer was placed in contact with the sternum,[12] and no significant difference was observed between the dominant and the nondominant hand.[13] Our study had many right-hand-dominant participants who pushed at a more adequate position in R–*l* or L–*r*, indicating no relationship between hand dominance and adequate positioning. Finally, the number of CCs differed significantly despite the number of participants in the study groups not differing significantly. This could be because of the small number of participants included in this study.

In conclusion, 80% of the medical staff could not undertake compression at the adequate position in the lower half of the sternum; 60–90% and 30–50% of inadequate positions were shifted to the hypothenar and forward sides, respectively. CPR instructors should educate on adequate position with the HM during training and evaluation.

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DISCLOSURES

Approval of Research Protocol: The Ethics Committee of the University of Tsukuba Hospital, Japan (H30-355).
Informed consent: All participants provided written informed consent.
Registry and the registration no. of the study/trial: N/A.
Animal studies: N/A.
Conflict of interest: None declared.

AUTHOR CONTRIBUTIONS

YK, TK, TH, and JN collected the data. YK wrote the manuscript. TM, NS, and YI revised and edited the manuscript. All authors read and approved the manuscript.

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APPENDIX I

STUDY INSTRUMENTS

THE ADULT STERNAL width was 7.8 cm on average,[14] and the heel of the hand measured to be approximately 2 cm.[15] Thus, a 3-cm width was considered adequate. The lower half of the adult sternum measures approximately 10 cm and the width of the wrist on the sternum during chest compression is approximately 7 cm.[15] The strongest point of the force applied to the wrist from the arbitrary line (middle finger–carpus line) is 1.3 cm on the hypothenar side with the right hand facing downward and 1.0 cm on the hypothenar side with the left hand facing downward. The distance between these two strongest points is 2.2 cm.[8] Thus, a length of 3 cm was considered adequate.