Safety of the inter-nipple line hand position landmark for chest compression

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Summary

Background: No previous study has investigated the safety of hand position during chest compression determined by the inter-nipple line, in which the heel of one hand is positioned on the centre of the chest between the nipples, from the standpoint of prevention of organ injury.

Methods: We measured the distance from the xiphisternal junction to the inter-nipple line (dN) in 1000 surgical patients and the heel length (H) of hands in 100 healthy volunteers, then used the formula H/2-dN to determine the amount of deviation when the heel of the rescuer's hand extended to the xiphoid process (D). Next, 100 surgical patients were randomly assigned to 18 anaesthesiologists, who placed the heels of their hands on the sternum for validation.

Results: The D value was positive in 551 patients, indicating that the heel may extend to the xiphoid process during chest compression in those individuals. Multivariate logistic-regression analyses showed that deviations beyond the xiphoid process to the epigastric region were more likely to occur in female (OR 3.52), elderly (OR 2.00), and short-statured (OR 2.09) patients, and with male rescuers (OR 2.81). During actual positioning, deviation occurred in 51 patients and extended to the epigastric region in 5 females.

Conclusions: Simulation of hand position determined by the inter-nipple line resulted in placement of the rescuer's hands over the xiphoid process in nearly half of the patients. Hand deviation to the epigastric region may occur when the patient is a short-statured or elderly female, and when the rescuer is male.

Key words

Cardiopulmonary resuscitation (CPR); Chest compression; Hand position; Anatomical landmark; Inter-nipple line; Complication; Visceral injury

1. Introduction

Chest compressions for cardiopulmonary resuscitation (CPR) consist of rhythmic applications of pressure over the lower half of the sternum,[1, 2] with proper hand placement essential to avoid injury.[3, 4] In previous guidelines, the index and middle fingers running along the rib margin to the base of the sternum were used to help the rescuer identify the lower half of the sternum of the victim, and thus avoid compressing the xiphoid process or abdomen.[5, 6] However, it can be difficult for laypersons and even healthcare professionals to identify such anatomical landmarks,[7] which was shown to delay the first chest compression after ventilation, resulting in fewer compressions delivered per minute.[8-11] In contrast, manikin studies with healthcare professionals indicated improved quality of chest compressions when the dominant hand was in contact with the sternum,[12] and shorter pauses between ventilations and compressions when the hands were simply positioned 'in the centre of the chest'.[8]

In response, the International Liaison Committee on Resuscitation (ILCOR) stated in the 2005 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science with Treatment Recommendations (CoSTR) that teaching hand placement for chest compression should be simplified, with less attention to anatomical landmarks, and emphasized the importance of minimizing interruption of chest compressions and performing an adequate number per minute.[4] The ILCOR CoSTR statement also notes that it is reasonable for laypeople and healthcare professionals to be taught to position the heel of their dominant hand in the centre of the chest of an adult victim, with the nondominant hand on top.[13]

In 2005, various worldwide organizations involved in CPR education revised their guidelines in accordance with the ILCOR CoSTR statement.[1, 13, 14] The American Heart Association (AHA) guidelines state that the rescuer should place the heel of the hand on the sternum in the centre (middle) of the victim's chest between the nipples.[1] Such hand placement using the inter-nipple line (INL) has been used for teaching laypersons chest compression techniques, and also found successful in dispatcher-assisted CPR and other settings.[5, 15, 16] The INL has also been adopted in guidelines published in Japan. However, concern has emerged regarding improper placement of the rescuer's hand on the chest, which may cause compression of the xiphoid process and subsequent organ injuries, when the INL is applied as the landmark.

No previous study has examined the safety of hand position determined by the INL from standpoint of preventing potential organ injury. Herein, we investigated whether use of the INL as a landmark can lead to improper hand position on the sternum during chest compression.

2. Methods

We designed a two-step approach for our study, i.e., a preliminary simulation study regarding hand position determined by the INL and subsequent validation study. After receiving approval for the study protocol from our institutional review board (Ethics Committee of Hiroshima University Hospital), written informed consent was obtained prior to the study from all subjects. This study was then done in an operating theatre.

2.1. Simulation study

First, we simulated the hand position determined with the INL by measuring the anatomical structure of surgical patients and hand heels of volunteers, in order to ascertain whether such hand positioning could result in pressure being applied over the xiphoid process. We prospectively enrolled 1000 consecutive elective surgical patients aged at least 8 years old as candidates for this simulation study. They were placed in a supine position with both arms parallel to the body on the operating table. Twenty-three anaesthesiologists, randomly assigned to the patients and blinded to the study hypothesis, measured the length of the sternum body (S) and distance from the base of the xiphoid process to the INL (dN) in each patient with accurate paper rulers, using the jugular notch of the sternum, nipples, and xiphisternal junction as landmarks (Fig. a). Furthermore, to obtain an average measurement for the xiphoid process (dX), its length was measured in the same fashion (Fig. a) in randomly selected patients whose xiphoid process was specifically identified through palpation.

Next, 100 healthy volunteers (physicians, nurses, medical students, clinical engineers, ambulance crew members, and clerks) placed the heel of one hand on a plastic ruler approximately the same size as the sternum with intent to perform chest compression as a rescuer. We measured the length of the ruler portion covered with the hand and determined the average width of the heel (H) (Fig. b). Using a simulated hand positioned between the nipples, we speculated that if half of H was greater than the dN value of a patient, the hand position may result in pressure being applied over the xiphoid process (Fig. c). Therefore, we defined the difference between H/2 and the dN value using the following formula: H/2 - dN, to determine the amount of heel deviation extending to the xiphoid process (D), and calculated the D value in each patient. The D value was considered positive when the caudal end of the heel of the rescuer’s hand extended to the xiphoid process (Fig. d, e). We considered that if the D value is larger than the dX value, the heel of the hand may extend beyond the xiphoid process to reach the epigastric region (Fig. f).

We divided the patients into 8 subgroups according to gender and age (8-12, 13-17, 18-64, >64 years old), and 2 subgroups based on height (<150, ≥150 cm) and compared the D values among them. From those results, we determined relationships among hand heel deviations and gender, age, and height of the patients, and gender of the rescuers, in order to determine situations in which use of the INL may lead to improper hand position on the sternum.

2.2. Validation study

We verified the findings obtained in the simulation study by testing actual positioning of the hand heel between the nipples. We prospectively enrolled 100 consecutive elective surgical patients aged at least 8 years old, while 18 anaesthesiologists blinded to the study hypothesis were enrolled as rescuers. The patients were placed in a supine position with their arms parallel to their body in the same manner as in the simulation study. The rescuers were randomly assigned and instructed to place the heel of one hand on the sternum in the centre of the chest of the patient between the nipples. Next, rescuers measured the distance between the caudal end of the heel of their hand and the base of the xiphoid process, and we defined the value as D (Fig. d, e). The measurement was considered to be a positive value when the caudal end of the heel of the rescuer's hand extended to the xiphoid process (Fig. d). The rescuers and patients were divided into 4 groups based on gender (M/M, M/F, F/M, F/F), and the D values were compared among them.

2.3. Statistical analysis

The sample size in the simulation study was calculated after assuming that the mean percentage of correct hand positions would decrease by at least 1.5% when employing the INL as the landmark from results obtained in a preliminary study. With an alpha error of 0.05 and beta error of 0.1, we estimated that 694 subjects would be required. Thus, we enrolled 1000 patients to compensate for estimation error and possible dropouts. In the validation study, the sample size was calculated based on the same error values, while we used the percentage of hand positions that resulted in abdominal compression demonstrated in the simulation study. The resulting minimal number of patients was 89, which we rounded up to 100.

All values are presented as the mean ± standard deviation. An unpaired *t* test, Mann-Whitney's U test, and Fisher's exact probability test were used for comparisons between genders. Comparisons among the subgroups were performed with a one-way analysis of variance, followed by Tukey-Kramer's method and a Kruskal-Wallis rank test. Pearson's correlation coefficient was used for simple regression analysis. To verify the relationships between hand heel deviation and gender, age, and height of the subjects in the simulation study, we performed univariate logistic regression, and odds ratio (OR) and 95% confidence interval (CI) values were obtained. In addition, we included those factors in the model at the same time and performed multivariate logistic regression to adjust for potential confounding factors. Statistical testing was carried out with the StatView 5.0 software package (SAS Institute Inc., Cary, NC, USA). Statistical significance was accepted when P was less than 0.05. An OR for which the 95% CI value did not include 1.0 was considered statistically significant.

3. Results

3.1. Simulation study

We studied 1000 Japanese patients (8 to 93 years old), while 50 male and 50 female healthy adult volunteers participated as rescuers. The S and dN values were significantly greater in the male patients (Table 1). The length of the xiphoid process could be measured in 70 patients (M/F, 35/35) and dX values (M, 2.8±1.3 cm; F, 2.5±0.9 cm, P = 0.220) were not significantly different between the genders. The dN values were negative in 3 patients (M/F, 0/3; 61-76 years; 140-146 cm), indicating that the INL was not on the sternum body and deviated toward the xiphoid process or abdomen. In 20 patients (M/F, 7/13), the dN values were greater than S/2, thus, with the INL as the landmark, the hand position would be on the upper half of the sternum. The H value for all rescuers was 10.6±1.1 cm, while those for males and females individually were 11.5±0.5 cm and 9.8±0.8 cm, respectively. The D value was positive in 551 patients, indicating that the caudal end of the heel may extend to the xiphoid process in those, and both the D values and percentage of positive D values were significantly greater in female patients (Table 2). The percentage with a large D value (D>dX), in whom the heel of the hand may extend beyond the xiphoid process and reach the epigastric region (Fig. f), was also significantly higher in female patients

(Table 2). There were no correlations between D value and patient age, height, weight, and body mass index (BMI). In comparisons among the patient subgroups, the D value and frequency of large D value (D>dX) were the greatest in the oldest female group, and also greater in short-statured patients (<150 cm) as compared to taller patients (Table 2).

The OR and 95% CI values obtained from logistic-regression analyses are shown in Table 3. The hand of the rescuer was more likely to be placed over the xiphoid process (D>0) in females, older children, adolescents, patients older than 64 years old, and short-statured patients. In addition, male rescuer hands were more likely to be placed over the xiphoid process in all patients, and extended beyond the xiphoid process to the epigastric region (D>dX) in female, older, and short-statured patients.

3.2. Validation study

One hundred Japanese patients (10 to 85 years old) were analyzed, and 12 male and 6 female anaesthesiologists participated as rescuers. The D value was positive in 51 patients (Table 4), with no significant difference between the genders (P = 0.135) or for the percentage of positive D values (P = 0.230). Among female patients, there were 5 (10%) in whom the heel of the rescuer extended beyond the xiphoid process to the epigastric region, while there were no male patients with that characteristic (Table 4). There were no significant correlations between D value and patient age, height, weight, and BMI. Furthermore, there were no significant differences for the D value ($P = 0.425$), percentage of positive D values ($P = 0.416$), and percentage of hand deviation to the epigastric region ($P = 0.100$) among the 4 subgroups (Table 4).

4. Discussion

In the present study, use of the INL as the landmark for CPR resulted in rescuer hand placement over the xiphoid process in nearly half of the patients, regardless of patient gender, age, height, and other physical conditions. Also, an extreme deviation beyond the xiphoid process to the epigastric region was found likely to occur when a male rescuer resuscitates an older or short-statured female patient, which may lead to organ injuries from improper hand placement when the INL is applied in those scenarios.

From the earliest days of CPR,[2] it has been recognized that chest compression is a traumatic procedure that carries an intrinsic risk of injury, with skeletal injuries the most frequently reported.[17-19] Furthermore, potential lethal complications include visceral injuries, such as lacerations of the atria, ventricles, large vessels, stomach, liver, and spleen,[5, 17, 20-23] with the risks increased when less experienced rescuers assume unconventional positions, compress at unconventional sites, or apply excessive force, especially with elderly victims.[17, 22, 23] Although the exact mechanisms of these visceral injuries require elucidation, they may be related to improper rescuer hand placement during compression, thereby applying pressure to the xiphoid process or abdomen.[17, 21, 24-26]

There is insufficient clinical evidence regarding the best method to determine the optimal hand position for chest compression during adult CPR.[3, 13, 14] In contrast, manikin studies have found that the likelihood of achieving an acceptable hand position is no different between subjects who received detailed instructions on anatomical landmarks and those instructed to simply compress the centre of the chest.[8-11] The European Resuscitation Council guidelines[14] state that the rescuer should place the hands without delay 'in the centre of the chest,' which is in reference to a report by Handley et al.[8] In contrast, the AHA guidelines[1] adopt the INL as the hand position landmark based on the same report, though the authors did not investigate hand placement using the INL.[8] Recently, Shin et al.[27] investigated the spatial relationship between the INL and heart using computed tomography imaging, and reported that compressing the sternum more caudally than the INL might be more effective in adult CPR when viewed from the cardiac pump theory. However, the possibility of complications such as visceral injuries was not examined.

We consider it better to instruct the rescuer to place their hands simply 'in the centre of the chest' as compared to 'between the nipples,' as it has been recommended that hand placement instructions be simplified with less attention to anatomical landmarks.[4] Furthermore, use of the INL can lead to improper hand position, as indicated in our findings. Moreover, with Japanese victims, male rescuers or experienced providers should be advised to locate the lower end of the sternum using their fingers either at the beginning or during chest compression, to avoid compressing the xiphoid process or epigastric region, particularly with short-statured or older female victims.

5. Limitations

This study has several limitations. First, all subjects were Japanese, thus the results may only be applicable to a Japanese population and worldwide investigations are necessary to generalize the results. Second, this simulation study was performed in an operating theatre setting. It is unclear if any of our findings are applicable to an actual rescuer and victim situation, since questions regarding the relationship between hand position and internal organ injuries were not addressed. In addition, simulated experiences are also not always predictive of real settings, where emotional and other factors can affect CPR technique as well as hand position. For example, the rescuer may exert force to an excessive depth and with inadequate recoil, along with improper rate. Third, the number of subjects was relatively small. Notably, the length of the xiphoid process was determined in only 70 patients, as we found it difficult to measure from the body surface. However, we later performed a verification study including measurement of the xiphoid process with a larger number of Japanese subjects, which revealed that the results were reproducible. Finally, we only measured the surface structures of the human body, while the force distribution across the heel of the hand and anatomical structures underneath the sternum were not investigated.[28, 29] Additional clinical studies are required to elucidate the incidence of organ injuries and relationships of such injuries with the method used to determine hand position for chest compression.

6. Conclusion

In the present study, use of the INL as the hand position landmark for chest compression resulted in rescuer hand placement over the xiphoid process in nearly half of the patients, regardless of gender, age, height, and other physical conditions. In addition, the degree of hand heel deviation to the caudal side increased in short-statured and older female patients, and with male rescuers. Although our study was performed with a Japanese population, it is noteworthy that use of the INL for CPR may result in improper hand position, possibly leading to organ injuries.

7. Conflicts of interest

There are no conflicts of interest in this study.

8. Acknowledgments

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10. Figure legend

In the simulation study, we measured the length of the sternum body (S), distance from the base of the xiphoid process to the inter-nipple line (dN), and length of the xiphoid process (dX) in the patients, and determined the average width of the heel of the hand (H) of the rescuers (a, b). We then calculated the differences between the values for H/2 and dN (H/2-dN) in each patient, and defined the result as the degree of hand heel deviation to the caudal side of the patient (D value) (c, d, e). The rescuer's heel deviated beyond the xiphoid process to the epigastric region when the D value was greater than the dX value (f).

In the validation study, the heel of the hand of the rescuer was placed in the centre of the patient's chest between the nipples (d, e). We measured the distance between the caudal end of the heel and base of the xiphoid process (D). The resultant D value was considered positive if the caudal end extended to the xiphoid process.

Table 1. Measured variables in patients and comparisons between genders

	Patients			*P*-value
	Total (n = 1000)	Male (n = 494)	Female (n = 506)	
Age, years	52 ± 20	52 ± 22	51 ± 19	0.282
Height, cm	159 ± 10	164 ± 9	154 ± 7	<0.001
Weight, kg	57 ± 12	61 ± 13	53 ± 10	<0.001
BMI, kg/m^2	22 ± 4	23 ± 4	22 ± 4	0.764
S, cm	16.8 ± 2.3	17.5 ± 2.3	16.1 ± 2.1	<0.001
dN, cm	5.1 ± 2.2	5.5 ± 2.1	4.6 ± 2.2	<0.001

Values are shown as the mean ± S.D.

BMI = body mass index; S = length of the sternum body; dN = distance from the base of the xiphoid process to the inter-nipple line.

Table 2. Comparisons of D values, frequencies of positive D value, and hand deviation beyond the xiphoid process among patient subgroups

		D value, cm	D > 0, n (%)	D > dX, n (%)
Total patients	(n = 1000)	0.2 ± 2.2	551 (55)	111 (11)
Males	(n = 494)	-0.2 ± 2.1	232 (47)	29 (6)
Females	(n = 506)	0.7 ± 2.2 †	319 (63) †	82 (16) †
Gender and age subgroups				
Males				
8-12 yrs	(n = 18)	1.3 ± 1.6 *	14 (78)	4 (22)
13-17 yrs	(n = 26)	0.2 ± 1.6	14 (54)	1 (4)
18-64 yrs	(n = 274)	-0.3 ± 2.0	116 (42)	13 (5)
≥ 65 yrs	(n = 176)	-0.2 ± 2.2	88 (50)	11 (6)
Females				
8-12 yrs	(n = 11)	1.1 ± 1.5	8 (73)	1 (9)
13-17 yrs	(n = 20)	0.9 ± 1.9	16 (80) *	3 (15)
18-64 yrs	(n = 321)	0.3 ± 2.2 *	182 (57) *	37 (12)
≥ 65 yrs	(n = 154)	1.3 ± 2.2 **	113 (73) **	41 (27) ***
Height subgroups				
< 150 cm	(n = 149)	1.3 ± 2.2 §	105 (71) §	39 (26) §
≥ 150 cm	(n = 851)	0.0 ± 2.1	446 (52)	72 (9)

Values are shown as the mean ± S.D or number (%).
D = degree of hand heel deviation to the caudal side; dX = length of xiphoid process. The D value was considered positive when the caudal end of the heel extended to the xiphoid process. The rescuer's heel deviated beyond the xiphoid process to the epigastric region when the D value was greater than the dX value.
In female and short-statured patients, the D value, and frequencies of positive D value and large D value (D>dX) were greater than in the male and taller patients, respectively. In comparisons among age and gender subgroups, the D value, and frequencies of positive D value and large D value (D>dX) were the greatest in the oldest female group.

† $P < 0.001$ vs. Males
* $P < 0.001$ vs. Males 18-64 yrs
** $P < 0.001$, vs. Males 18-64 yrs, Males ≥ 65 yrs, Females 18-64 yrs
*** $P < 0.001$, vs. Males 13-17 yrs, Males 18-64 yrs, Males ≥ 65 yrs, Females 18-64 yrs
§ $P < 0.001$ vs. Height ≥ 150 cm

Table 3. Relationships between hand heel deviation and subject gender, age, and height

	Univariate analysis		Multivariate analysis	
	D > 0	D > dX	D > 0	D > dX
Patient gender				
Male	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Female	2.03 (1.70-2.43)	3.80 (2.77-5.20)	2.06 (1.70-2.51)	3.52 (2.50-4.95)
Patient age (years)				
8-12 yrs	3.13 (1.70-5.78)	2.07 (1.02-4.20)	2.87 (1.47-5.61)	1.68 (0.77-3.68)
13-17 yrs	1.70 (1.10-2.64)	0.95 (0.45-2.00)	1.86 (1.18-2.93)	0.97 (0.44-2.12)
18-64 yrs	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
≥ 65 yrs	1.49 (1.23-1.80)	2.05 (1.54-2.72)	1.53 (1.25-1.88)	2.00 (1.47-2.73)
Patient height (cm)				
< 150 cm	2.34 (1.79-3.06)	3.62 (2.68-4.90)	1.44 (1.06-1.97)	2.09 (1.47-2.97)
≥ 150 cm	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Rescuer gender				
Male	1.00 (reference)	1.00 (reference)	1.00 (reference)	1.00 (reference)
Female	0.49 (0.41-0.58)	0.38 (0.29-0.51)	0.47 (0.39-0.56)	0.36 (0.26-0.48)

Values are shown as odds ratios, with 95% confidence intervals in parentheses.
D = degree of hand heel deviation to the caudal side; dX = length of xiphoid process. The D value was considered positive when the caudal end of the heel extended to the xiphoid process. The rescuer's heel deviated beyond the xiphoid process to the epigastric region when the D value was greater than the dX value.

Table 4. Comparisons of patient characteristics, D values, frequencies of positive D value, and hand deviation to the epigastric region among patient subgroups in the Validation study

		Age (years)	Height (cm)	D value (cm)	D >0 [n (%)]	HDER [n (%)]
Total patients	(n = 100)	52 ± 20	160 ± 9	0.1 ± 1.8	51 (51)	5 (5) [a]
Males	(n = 48)	52 ± 21	166 ± 9	-0.2 ± 2.0	21 (44)	0 (0)
Females	(n = 52)	53 ± 19	155 ± 7 †	0.3 ± 1.5	30 (58)	5 (10) [a]
Rescuer/Patient gender subgroups						
M/M	(n = 29)	50 ± 21	166 ± 9	-0.2 ± 2.0	12 (41)	0 (0)
M/F	(n = 32)	52 ± 17	155 ± 5 *	0.5 ± 1.6	20 (63)	4 (13) [b]
F/M	(n = 19)	55 ± 22	165 ± 8	-0.2 ± 2.0	9 (47)	0 (0)
F/F	(n = 20)	54 ± 24	155 ± 8 *	0.1 ± 1.3	10 (50)	1 (5) [b]

Values are shown as the mean ± S.D or number (%).

D = degree of hand heel deviation to the caudal side; HDER = hand deviation to the epigastric region.

[a]The mean age, height, and weight of these 5 female patients were 54±21 years old (range 19-73 years), 153±8 cm (range 149-167 cm), and 53±13 kg (range 39-69 kg), respectively.

[b]The rescuers for 4 of these patients were male, with a 19-year-old patient the exception.

† *P* <0.001 vs. males

* *P* <0.001 vs. M/M, F/M

Figure. Methods used for measurements and simulation of hand positions.