ORIGINAL RESEARCH

Retrospective Study Using Computed Tomography to Compare Sufficient Chest Compression Depth for Cardiopulmonary Resuscitation in Obese Patients

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Background—This study aimed to investigate the relationship between body mass index (BMI) and sufficient chest compression depth (CCD) in obese patients by a mathematical model.

Methods and Results—This retrospective analysis was performed with chest computed tomography images conducted between 2006 and 2018. We classified the selected individuals into underweight (<18.5), normal weight (≥18.5, <25), overweight (≥25, <30), and obese (≥30) groups according to BMI (kg/m^2). We defined heart compression fraction (HCF) as $\frac{\text{[heart anteroposterior diameter - (internal chest anteroposterior diameter - proposed CCD)]}}{\text{heart anteroposterior diameter}} \times 100$ and estimated under-HCF (the value of HCF <20%), and over-HCF (the residual depth <2 cm after simulation with chest compression depth 5 and 6 cm). We compared these outcomes between BMI groups. Of 30 342 individuals, 8856 were selected and classified into 4 BMI groups from a database. We randomly selected 100 individuals in each group and analyzed a total of 400 individuals' cases. Higher BMI groups had a significantly decreased HCF with both 5 and 6 cm depth (P<0.001). The proportion of under-HCF with both depths increased according to BMI group, whereas the proportion of over-HCF decreased except for the 5 cm depth (P<0.001). The adjusted odds ratio of under-HCF, according to BMI group after adjustment of age and sex, was 7.325 (95% CI, 3.412–15.726; P<0.001), with 5 cm and 10.517 (95% CI, 2.353–47.001; P=0.002) with 6 cm depth, respectively.

Conclusions—The recommended chest compression depth of 5 to 6 cm in the current international guideline is unlikely to provide sufficient ejection fraction during cardiopulmonary resuscitation in obese patients. **(*J Am Heart Assoc*. 2019;8:e013948. DOI: 10.1161/JAHA.119.013948.)**

Key Words: body mass index • cardiopulmonary resuscitation • chest compression resuscitation • obesity

Chest compression depth (CCD) is an important factor of high-quality chest compression. An increase in this depth is related to shock success in resuscitations, and sufficient CCD relies linearly on the perfusion of vital organs during cardiopulmonary resuscitation (CPR).[1–3] This depth is about 5 cm, not exceeding 6 cm in the current guidelines in adult and cardiac arrest patients.[4,5] It corresponds to approximately one fourth to one fifth of the external anteroposterior chest diameter and produces ≈25% to 33% of the normal cardiac output.[6,7] However, CCD was significantly different between hemodynamic-directed and standard CPR groups in several animal studies.[7,8] There is a lack of studies, suggesting that unique and specific depth supplies adequate myocardial and cerebral blood flow.

The number of obese patients continues to be high, exceeding 30% to 40% in most sex and age groups in the United States.[9,10] They have an increased risk of out-of-hospital cardiac arrest and changes to the thorax in them may make resuscitative efforts more demanding.[11–16] In obese patients, the depth of subcutaneous adipose tissue in the chest was deeper and anteroposterior diameter of the chest was longer than in others.[17,18] Wang et al reported that higher body mass index

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Clinical Perspective

What Is New?

- In this retrospective study, greater chest and heart anteroposterior diameters were measured by chest computer tomography in individuals with higher body mass index. The calculated heart compression fraction, a surrogate for ejection fraction, was decreased with chest compressions at 5 cm and 6 cm depth and worsened with higher body mass index.

What Are the Clinical Implications?

- The recommended chest compression depth of 5 cm to 6 cm recommended in the current international guideline may not provide adequate chest compression depth during cardiopulmonary resuscitation in obese patients.
- Healthcare providers should consider deeper chest compression depth during cardiopulmonary resuscitation in obese patients and perform chest compression with a maximum of 6 cm depth using a feedback device if available.

(BMI) and anteroposterior chest diameter were correlated with worse outcomes following in-hospital cardiac arrest.[19] The 5 to 6 cm depth of chest compression applied uniformly in all adults could not be optimal, and sufficient CCD for high-quality CPR may need to be deeper in obese cardiac arrest patients.

Meyer et al reported that the proper CCD in neonate CPR was one third the depth of anteroposterior chest diameter, using mathematical modeling based on neonatal chest computed tomography (CT).[20] Braga et al reported the optimal CCD in children aged <8 years is one third external anteroposterior chest depth.[21] However, no study has reported about the proper CCD in a high-BMI group, using mathematical methods. To the best of our knowledge, this is the first paper to report whether the CCD, according to the guidelines, is sufficient for obese patients during CPR, using a mathematical model based on the direct cardiac compression theory. We hypothesized that the chest anteroposterior diameter in obese patients is longer than that in other patients and that the proportion of the heart compressed by chest compression with a 5 to 6 cm depth is insufficient in obese patients. We aimed to verify and compare the proportion of the heart compressed by chest compression according to BMI group, based on ejection fraction, using mathematical modeling methods with chest CT.

Materials and Methods

The data, analytic methods, and study materials that support the findings of this study are available from the corresponding author upon reasonable request.

Study Design

We conducted a retrospective study to evaluate the differences in compression proportion of the heart by chest compression with 5 cm and 6 cm depths at the level of maximal heart diameter on the lower half of the sternum, using chest CT. This study was performed at 1 academic tertiary hospital (Seoul, Republic of Korea) from February to March 2019 and was approved by the Institutional Review Board of Hanyang University Hospital (HYUH [Seoul, Republic of Korea]. 2019-01-025). The study was waived for informed consent by the Institutional Review Board.

Study Individuals

We extracted the medical records of individuals who underwent chest CT in the health check-up center, between January 2006 and December 2018. We excluded individuals aged <18 years and those whose weight or height were not recorded. Individuals with anatomical abnormalities in the chest, trauma-induced deformities, pulmonary/heart structural deformities, or any kind of pathological lesion interpreted by radiology specialists were excluded. We classified the selected individuals into underweight (<18.5 kg/m^2), normal weight (≥18.5 kg/m^2, <25 kg/m^2), overweight (≥25 kg/m^2, <30 kg/m^2), and obese (≥30 kg/m^2) groups according to BMI with World Health Organization criteria. After that, we randomly selected 10 individuals in each group through the Random Integer Set Generator on the website (https//www.random.org) to extract the numbers randomly for a pilot study, which we conducted with 40 individuals who were not included in this study. We obtained the compression proportion (%) of the heart by chest compression with a 5 cm depth in each group (mean; 51.10, 44.20, 35.00, and 27.50 according to BMI group, respectively) and the 2 covariates (age, and sex) have a combined R_2 of 0.364. The common standard deviation within a group was 36.20. The total sample of 184 subjects achieves 95% power to detect differences among the means versus the alternative of equal means using an F test with a 0.05 significance level using the PASS 16.0.4 software package power analysis and sample size software (NCSS, LLC; Kaysville, UT, USA). We considered that a minimum sample size of 46 individuals in each group was required (Figure 1). According to the sample size of the pilot study, we randomly selected 100 individuals in each BMI category for a total of 400 individuals. We avoided selection with matched age and sex, because the total number of underweight individuals was relatively smaller, and they are younger and more frequently women than other groups. We used randomly selection and adjusted variables to avoid selection bias by matching age and sex.

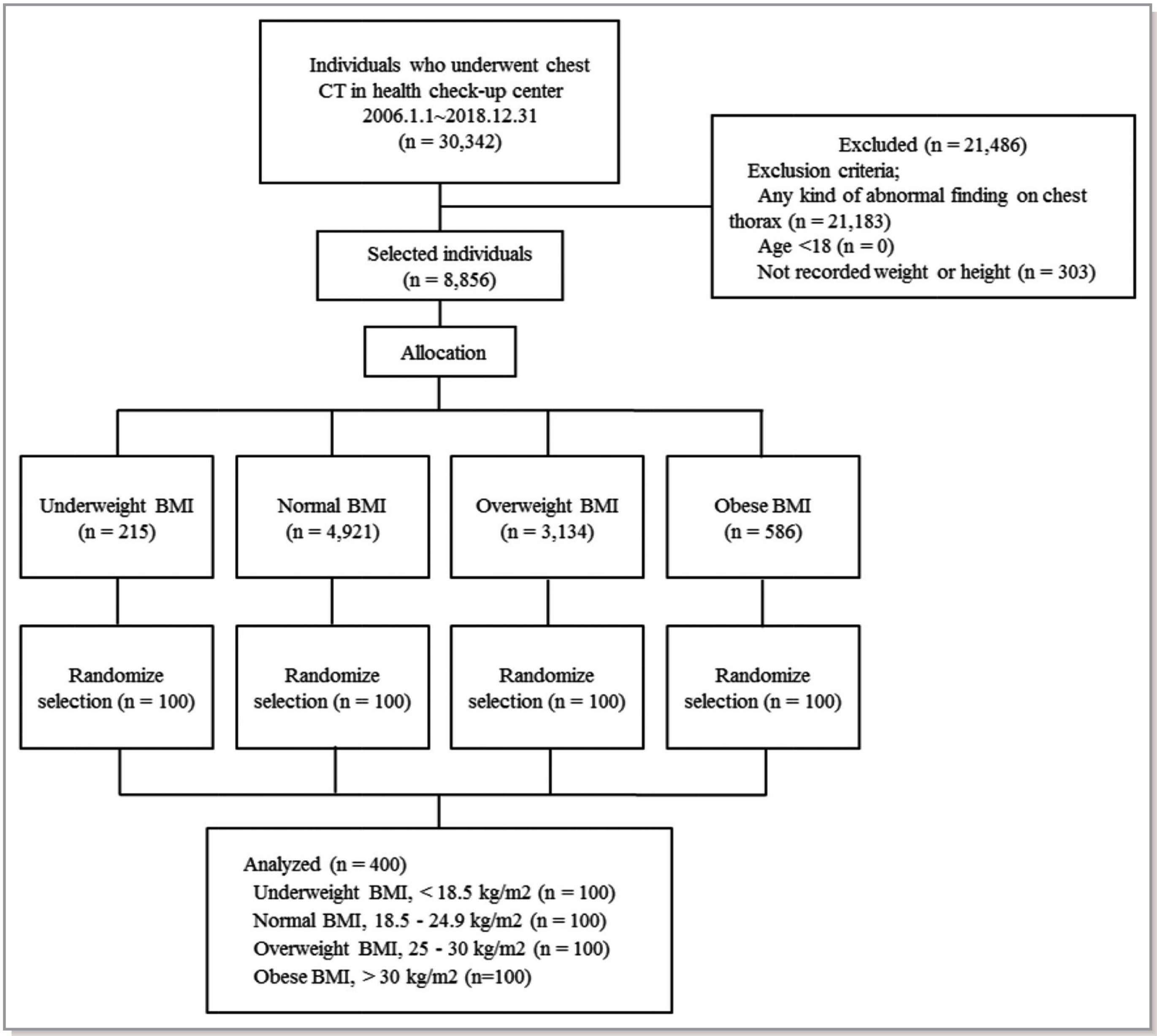

Figure 1. Flowchart of the study. BMI indicates body mass index; CT, computed tomography.

Equipment and Materials

The 3 types of CT equipment used in this study were the Brilliance 64 multi-detector CT scanner (Philips Healthcare, Best, The Netherlands), the Somatom Sensation 16 (Siemens Healthcare, Forchheim, Germany), and the Definition Flash scanner (Siemens Healthcare, Forchheim, Germany). The setting for the examination was as follows: 120 kVp, 50 to 80 mAs, 1.15-mm/s table feed, 0.5-s rotation time, 5-mm slice thickness, and 5-mm intervals. All CT images were stored as Digital Imaging and Communication in Medicine format in the Picture Archiving and Communication System (Centricity, GE Healthcare, Milwaukee, WI, USA).

Data Collection

We collected basic characteristics, such as the sex, age, height, and weight of all individuals. The value of BMI was calculated as kg/m^2. All CT images for each subject were reconstructed and shown as transverse, sagittal, and coronal views, using Picture Archiving and Communication System. Each image was simultaneously cross-linked to the images with other settings. Two emergency physicians reconstructed all images of each subject. They measured parameters on images, which were simultaneously cross-linked to transverse, and sagittal views, using a 3-dimensional image solution program (Rapidia, version 2.8, INFINITT, Seoul, Korea).[22] with consensus (Figure 2). We selected the image at which the maximal diameter of the heart on the lower half of the sternum was shown in the transverse and sagittal views, and then we measured several parameters on it for all individuals: (1) external chest anteroposterior diameter (mm), perpendicular from the skin anteriorly on the sternum to the skin posteriorly on the back; (2) internal chest anteroposterior diameter (mm), from the posterior surface on the sternum vertically to the anterior vertebral body; (3) heart anteroposterior diameter (mm), anterior to posterior diameter of the heart in-line of external and internal anteroposterior diameter.[20] We assumed heart diameter as the end-diastolic volume and internal chest anteroposterior minus proposed CCD as the end-systolic volume. Therefore, the mathematical formula of [heart anteroposterior diameter—(internal chest anteroposterior diameter–proposed CCD)] means stroke volume. We calculated heart compression fraction (HCF), which is the proportion of the heart compressed by chest compression with proper CCD, using the following ejection fraction formula:

$$\frac{[\text{heart anteroposterior diameter} - (\text{internal chest anteroposterior diameter} - \text{proposed CCD})]}{\text{heart anteroposterior diameter}} \times 100$$

We also calculated the proportion of 5 cm and 6 cm to external anteroposterior diameter of each individual.

Primary and Secondary Outcomes

The primary outcome was heart compression fraction (HCF), which is the proportion of the heart compressed by chest compression at 5 cm and 6 cm depths. The number of individuals under- and over-compressed by chest compression at 5 cm and 6 cm depths was investigated as secondary outcomes. We prospectively defined under-HCF as estimated to result in <20%, which is to multiply 25% to 33% of the normal cardiac output created by chest compression during CPR and 67% of normal ejection fraction value in a healthy 70 kg man together.[6,23] Over-HCF was defined as <20 mm residual depth, which was the residual internal chest depth after simulated chest compression was calculated as end-systolic volume (internal anteroposterior diameter−proposed CCD).[17]

Statistical Analysis

Data were compiled using a standard spreadsheet application (Excel 2016; Microsoft, Redmond, WA, USA). Kolmogorov–Smirnov tests were performed for normality assumption for all data sets. Descriptive statistics were used to describe the baseline characteristics of the individuals and to present categorical variables as frequencies, percentages, and continuous variables as the mean±SD. One-way ANOVA was used to compare groups with respect to normally distributed continuous variables, and the Kruskal-Wallis test was used for other continuous variables. The Chi-squared test or Fisher exact test was used to analyze categorical variables. We performed post-hoc analysis with Bonferroni correction to compare each group, also. ANCOVA was performed to adjust for influencing factors and to investigate the main factor influencing the outcomes such as age and sex. Two-tailed $P<0.05$ was considered statistically significantly different. Univariate and multivariate analyses (adjusted for age and sex) were performed to determine the relationships between the BMI group and under-HCF/over-HCF. A logistic regression was used for the multivariate analyses and assessed by the Hosmer-Lemeshow test. Data analyses were performed using SPSS statistical software (version 21.0 KO, SPSS Inc, Chicago, IL, USA).

Results

A total of 30 342 individuals who underwent chest CT in this study period were eligible; 21 486 individuals were excluded because of exclusion criteria; 21 183 individuals had any kind of positive finding on chest thorax; and 303 had a missing value of weight or height. We classified and selected 8856 individuals by World Health Organization BMI classification and randomly selected 100 individuals in each group, based on sample size analysis of a minimum of 46 individuals in each group (Figure 1).

Patients' Characteristics

The baseline characteristics of the individuals and chest anatomy parameters are summarized in Tables 1 and 2, respectively. Significant differences were observed among the 4 groups in age, sex, height, weight, and all parameters we measured and calculated, such as external and internal heart anteroposterior diameters and proportion of 5 cm and 6 cm to external diameter. Underweight individuals were younger and more frequently women than in other groups and of lower height than in the overweight and obese groups, significantly. The weight, external anteroposterior diameter, internal anteroposterior diameter, and heart anteroposterior diameter of each group significantly increased in order.

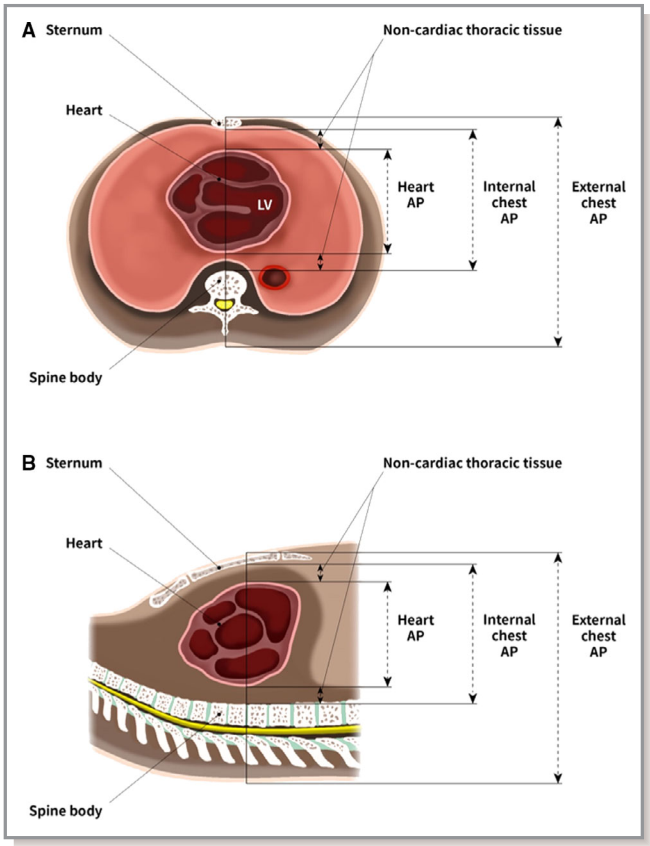

Figure 2. Image of chest anatomy and measurements for chest parameters. **A**, Axial image of chest anatomy. External chest, internal chest, and heart anteroposterior diameter were measured at the level of maximal heart anteroposterior diameter at midsagittal and lower half of sternum. External chest anteroposterior was measured vertically from anterior skin on sternum to posterior skin on spinal process of spine. The internal chest anteroposterior was measured from posterior of the sternum to anterior of the spine body. Heart anteroposterior was measured anterior to posterior of the heart in an external and internal anteroposterior line. LV indicates left ventricle; AP, anteroposterior. **B**, Midsagittal image of chest anatomy, cross-linked with the axial image to observed maximal diameter of heart.

Primary and Secondary Outcomes

The results for primary outcome with univariate and multivariate analysis are summarized in Table 2. HCF by 5 cm and 6 cm significantly decreased across BMI categories. We adjusted for the influencing factors that could affect the results of chest anatomy parameters and primary outcomes, using ANCOVA. A significant difference was observed in all chest anatomy parameters and primary outcomes among the 4 groups, with adjustment for factors such as age and sex ($P<0.001$) (Table 2).

The number of individuals under-HCF by proposed depth increased sequentially through BMI categories ($P<0.001$). On the other hand, over-HCF by proposed depth decreased in order. However, it was not statistically significant in assuming 5 cm depth compression ($P=0.060$) (Table 3).

Multivariate analysis of factors associated with under-HCF by proposed compression depth was performed to adjust age and sex, using logistic regression. When chest compression was at a 5 cm depth, the adjusted odds ratio of obese to normal weight group was 7.325 (95% CI, 3.412–15.726; $P<0.001$) and male-to-female sex was 3.744 (95% CI, 1.958–7.160; $P<0.001$). At 6-cm depth compression, they were 10.517 (95% CI, 2.353–47.001; $P=0.002$) and 5.074 (95% CI, 1.412–18.236; $P=0.013$). Age was significant at the 5 cm depth, with adjusted odds ratio of 1.037 (95% CI, 1.006–1.068; $P=0.018$) per year but insignificant at the 6-cm depth (Table 4).

Discussion

In our retrospective study, we demonstrated that HCF using a mathematical formula decreased, and the proportion of under-compression increased according to the level of the BMI group, regardless of CCD. BMI is a surrogate marker for obesity, as risk factors for various cardiovascular diseases and out-of-hospital cardiac arrest.[11–14,24] Several studies reported that patients at each stage of the BMI spectrum demonstrated different survival rates and neurologic outcomes after cardiac arrest.[25–27] We thought that these insufficient chest compressions for the obese patient with cardiac arrest could influence stroke volume during manual external chest compression and result in a lower return of spontaneous circulation and survival rate.

The increased volume of abdominal fat tissue in obese individuals raises intra-abdominal pressure and repositions the diaphragm in the cranial direction. However, the effective size of the lungs tends to be preserved, or is slightly decreased in the morbidly obese.[28–30] For these reasons, the anatomy of obese individuals tends to offer a bigger thorax cavity and longer chest anteroposterior diameter than that of normal BMI individuals.[17,19,31] The increased anteroposterior diameter and circumference of the upper abdomen in obese individuals could also increase the chest anteroposterior diameter of the lower half of the sternum. These changes make sufficient CCD in obese patients difficult. In the former study, we found that the HCF by CCD with depths of 5 cm and 6 cm was significantly lower in the geriatrics group than in others. Changes in the structure of skeletal muscle and the lungs with increasing age are attributed to an increase of the anteroposterior diameter of the chest in geriatrics.[32] In the present study, BMI was a significant factor in HCF after adjustment for age and sex. A high BMI index, men, and older age could receive insufficient chest compressions during CPR

Table 1. Baseline Characteristics and Univariate Analysis

Characteristics	Underweight BMI <18.5 kg/m^2 (n=100)	Normal BMI 18.5 to 24.9 kg/m^2 (n=100)	Overweight BMI 25 to 30 kg/m^2 (n=100)	Obese BMI >30 kg/m^2 (n=100)	*P* Value*
Age, y	38.5±10.4	45.1±9.9	46.9±9.7	46.5±9.1	<0.001†
Sex, male	14 (14%)	53 (53%)	70 (70%)	65 (65%)	<0.001†
Height, cm	164.2±6.3	165.6±8.8	168.2±9.0	169.6±9.5	<0.001‡
Weight, kg	47.4±4.2	62.2±8.5	76.5±9.1	95.1±14.7	<0.001§

Values are presented as number (%) or mean±SD. Categorical variable was tested by chi-square test, and continuous variables were calculated with the Kruskal-Wallis test. Post hoc was performed with Bonferroni correction. BMI indicates body mass index.
**P*<0.05 is significant.
†Underweight BMI group was significantly younger and more frequently women than in the other groups. No differences between other groups.
‡Underweight BMI group had lower height than overweight and obese group. Normal BMI group had lower height than obese group.
§There was a difference between every single group.

at a 5-cm depth chest compression without hemodynamically directed feedback.

According to the 2015 International Liaison Committee on Resuscitation systematic review and one observational study, increased compression depth is associated with iatrogenic injury such as rib fracture, sternal fracture, and heart or lung injury.[33,34] For this reason, the CCD recommended by the American Heart Association guidelines was modified in 2015 from "at least 5 cm to at least 5 cm but should not exceed 6 cm".[5] In the present study, almost no individual was over-compressed at a 6-cm depth in the overweight and obese groups. Chest compressions with maximum of 6 cm in overweight or obese patients may improve the cardiac output during CPR without increasing the risk of the over-compression related injuries.

Previous studies assessed the depth of chest compressions only from thoracic anatomic landmarks.[17,18] In this study, external and internal diameters of the thorax in chest CT increased in the higher BMI groups. Furthermore, the maximal diameter of heart anteroposterior was longer in the higher BMI group, which could be explained by obesity cardiomyopathy clinically presenting left ventricular dilation and hypertrophy because of increasing total blood volume and cardiac output.[35,36] This phenomenon may be another reason that deeper chest compressions are needed for obese patients to maintain enough cardiac output in a cardiac arrest situation.

Table 2. Chest Anatomy Parameters and Primary Outcome With Univariate and Multivariate Analysis, Adjustment for Age and Sex

	Underweight BMI <18.5 kg/m^2 (n=100)	Normal BMI 18.5 to 24.9 kg/m^2 (n=100)	Overweight BMI 25 to 30 kg/m^2 (n=100)	Obese BMI >30 kg/m^2 (n=100)	*P* Value*	Adjusted *P* Value*
Chest anatomy parameters						
External anteroposterior diameter, mm	180.1±12.2	212.1±18.4	237.4±16.2	267.7±21.0	<0.001†	<0.001
Internal anteroposterior diameter, mm	88.4±11.2	104.0±15.1	117.4±14.9	131.9±16.4	<0.001†	<0.001
Heart anteroposterior diameter, mm	72.8±7.2	81.7±10.4	91.9±11.0	102.2±10.1	<0.001†	<0.001
Proportion of 5 cm to external anteroposterior diameter, %	27.9±1.9	23.8±2.2	21.2±1.5	18.8±1.4	<0.001‡	...
Proportion of 6 cm to external anteroposterior diameter, %	33.5±2.3	28.5±2.6	25.4±1.8	22.6±1.7	<0.001‡	...
Primary outcome						
Heart compression fraction by 5 cm depth, %	48.0±11.9	35.0±12.5	27.2±11.2	20.4±10.4	<0.001†	<0.001
Heart compression fraction by 6 cm depth, %	61.9±12.9	47.3±14.0	38.2±12.0	30.3±11.1	<0.001†	<0.001

Values are presented as mean±SD. BMI indicates body mass index.
**P*<0.05 is significant. All univariate analyses were calculated by ANOVA† or Kruskal-Wallis,‡ and ANCOVA was performed for all multivariate analyses as appropriate. All variables were significantly different in each group by post hoc.

Table 3. Secondary Outcome With Univariate Analysis

Outcome	Underweight BMI <18.5 kg/m^2 (n=100)	Normal BMI 18.5 to 24.9 kg/m^2 (n=100)	Overweight BMI 25 to 30 kg/m^2 (n=100)	Obese BMI >30 kg/m^2 (n=100)	*P* Value
Under-compression† by 5 cm depth, n	1 (1.0%)	11 (11.0%)	30 (30.0%)	48 (48.0%)	<0.01*
Under-compression† by 6 cm depth, n	0 (0%)	2 (2.0%)	6 (6.0%)	19 (19.0%)	<0.01*
Over-compression‡ by 5 cm depth, n	4 (4.0%)	1 (1.0%)	0 (0%)	0 (0%)	0.060
Over-compression‡ by 6 cm depth, n	21 (21.0%)	6 (6.0%)	1 (1.0%)	0 (0%)	<0.01*

Values are presented as number (%). All variables were tested by Fisher exact test. BMI indicates body mass index; CCD, chest compression depth
*P<0.05 is significant.
†If heart compression fraction was <20%.
‡If residual depth (internal anteroposterior diameter—proposed CCD) is <20 mm.

This study has several limitations. First, the individuals selected in this study were different from the actual cardiac arrest patient population. The study population was younger and healthier, because we collected individual data from the health check-up center and excluded people who had pathologic lesions in the thoracic cavity. Second, the mathematical formula used to calculate the HCF may not directly reflect the actual cardiac output or ejection fraction. However, several previous studies have also used this method, and we explained theoretically how it reflects actual ejection fraction indirectly.[20,22] Third, chest CT was performed with both arms in a raised position and maintained the inspiratory state during the scan. It could be different from the neutral position of the arms and positive pressure ventilation during a CPR situation. These things affected the chest anteroposterior diameters and parameters we calculated. Fourth, minor errors in measurement could have occurred, because we selected images of maximal heart anteroposterior diameter on the line of the external anteroposterior diameter and did not consider the entire structure of the heart. Fifth, although significant statistical differences were found in the results, the wide 95% CI of the adjusted odds ratio in multivariate analysis (Table 4; Under-compression with 6 cm CCD) and low numbers in the exposure group are not enough to have strong statistical power. Finally, follow-up prospective studies are needed to investigate the relationship between CCD and survival outcomes in cardiac arrest obese patients.

Conclusions

In this study, we found that individuals with higher BMI were associated with a lower heart compression fraction by the proposed compression depth, using chest CT and a mathematical model. The recommended CC depth of 5 to 6 cm in the current international guideline is unlikely to provide sufficient ejection fraction during CPR in obese patients. Chest compression maximum of 6 cm with a feedback device is needed for obese patients to provide maximum capacity without iatrogenic injury.

Acknowledgments

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Table 4. Multivariate Analysis of Factors Associated With Under-Compression With 5 and 6 cm Depth of Chest Compression

	Under-Compression With 5 cm CCD			Under-Compression With 6 cm CCD		
Variables	Adjusted Odds Ratio	95% CI	*P* Value	Adjusted Odds Ratio	95% CI	*P* Value
Age, per y	1.037	1.006, 1.068	0.018*	0.997	0.950, 1.046	0.905
Sex, male	3.744	1.958, 7.160	<0.001*	5.074	1.412, 18.236	0.013*
BMI, kg/m2			<0.001*			0.002*
18.5 to 24.9 (n=100)	Reference	. . .	. . .	Reference	. . .	. . .
<18.5 (n=100)	0.175	0.021, 1.441	0.105	0.000	0.000	0.997
25.0 to 29.9 (n=100)	2.987	1.372, 6.505	0.006*	2.583	0.503, 13.260	0.256
>30.0 (n=100)	7.325	3.412, 15.726	<0.001*	10.517	2.353, 47.001	0.002*

BMI indicates body mass index; CCD, chest compression depth. Multivariate logistic regression was used for adjusted odds ratio. Hosmer-Lemeshow test; P-value: 0.507 (5 cm CCD), 0.957 (6 cm CCD).
*P<0.05 is significant.

Author contributions: H. Lee contributed to this study as the first author and Oh contributed as a corresponding author. H. Lee and Oh conceived the study and designed the trial. J. Lee, Kang, Lim, Ko, supervised the trial procedure and data collection. Song, and Cho analyzed all images and data. H. Lee and Oh drafted the manuscript, and all authors contributed substantially to its revision. Oh takes responsibility for the paper.

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Disclosures

None.

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