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Original Contribution

# A new chest compression depth indicator would increase compression depth without increasing overcompression risk☆,☆☆,★

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ABSTRACT

*Purpose:* Adequate chest compression (CC) depth is critical for effective cardiopulmonary resuscitation. Pediatric resuscitation guidelines recommend that CC be at least one-third of the anterior-posterior (AP) chest diameter or approximately 4 cm in infants and 5 cm in children. We aimed to find a better indicator of CC depth that maximizes CC depth while also minimizing injury.

*Basic procedures:* Chest computed tomographic images of patients aged 8 years and younger were measured for external diameter (ED) (AP distance from skin to skin) and internal diameter (AP distance between internal surface of anterior chest wall and anterior surface of vertebral body) at the midway of the lower half of the sternum. *Compressible depth* was defined as 1 cm short of internal diameter. We determined that up to a 10% estimated risk of overcompression is acceptable and approximated a quantile regression line for the 10th percentile of compressible depth on ED. After rounding coefficients, we used its equation as a new indicator.

*Main findings:* A total of 426 images were analyzed. The new indicator had a slope of 0.5 and an intercept of −1.9 cm (1 fingerbreadth). Compared to one-third ED, the new indicator would provide deeper CC with average difference of 1.9 mm (95% confidence interval, 1.6-2.2 mm) without increasing the risk of overcompression (both 4.9%). Chest compression of 4/5 cm would provide deeper CC compared to the new indicator (difference, 3.5 mm; 95% confidence interval, 2.7-4.1 mm); however, its overcompression risk was too high (31.5%).

*Principal conclusion:* Chest compression of one-half ED minus 1 fingerbreadth maximizes CC depth without increasing overcompression in pediatric population.



## 1. Introduction

Adequate chest compression (CC) is critical in both adult and pediatric cardiopulmonary resuscitation (CPR) [1-3]. To achieve the goal, maximizing CC depth without increasing the risk of overcompression would be important. However, it is unclear whether current guidelines are the best ones to facilitate the goal. They recommend that compressions be at least one-third of the anterior-posterior (AP) chest diameter or approximately 4 cm in infants and 5 cm in children [4,5]. Their scientific background is based on the result of recent studies where the safety of previous CC depth, one-third to one-half AP chest diameter, was tested using anthropometric measurement of pediatric population [6-8]. However, even the studies did not try to develop a new optimized CC indicator using their data. Although we now know that one-third AP diameter is safe target, we are not still sure about whether it is the best option for providing adequate CC depth in pediatric population where patients' body sizes are hugely varied.

Our main study question was whether there would be any room for improvement in current depth indicators. We postulated that, by more closely approximating the anthropometric data, we may find a new indicator of depth goal that will help us to maximize CC depth while minimizing the potential injury from overzealous CC. Therefore, the primary goal of this study was to find a better indicator for minimum CC depth in a young (≤8 years old) pediatric population. The secondary goal was to provide comparative analysis data about the potential harm and benefit (increase in CC depth) of different CC depth indicators in the population.

## 2. Materials and methods

This was a retrospective study that analyzed chest computed tomographic (CT) scans of infants and young children (≤8 years old) that had been taken at an academic teaching hospital. The institutional review

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**Table 1**
Patient characteristics

| Age | n | Male (%) | Height (cm, IQR) | Weight (kg, IQR) | ED (cm, IQR) | ID (cm, IQR) |
|---|---|---|---|---|---|---|
| <3 mo | 31 | 17 (54.8) | 53.0 (50.5-57.3) | 4.4 (3.1-5.4) | 9.0 (8.5-10.0) | 4.9 (4.4-5.1) |
| 3 mo to 1 y | 45 | 26 (57.8) | 69.0 (66.0-73.0) | 8.3 (7.0-9.6) | 10.7 (10.1-11.5) | 5.4 (4.8-5.8) |
| 1 | 68 | 47 (69.1) | 82.0 (78.6-86.0) | 11.0 (9.8-12.3) | 11.5 (11.0-11.9) | 6.0 (5.5-6.4) |
| 2 | 44 | 21 (47.7) | 89.9 (88.0-91.8) | 12.5 (11.8-13.6) | 11.9 (11.5-12.5) | 6.0 (5.5-6.5) |
| 3 | 46 | 26 (56.5) | 98.1 (95.0-104.0) | 15.6 (13.5-17.0) | 12.7 (11.8-13.2) | 6.5 (5.8-6.9) |
| 4 | 49 | 27 (55.1) | 105.9 (101.1-110.3) | 17.8 (15.4-19.5) | 13.3 (12.7-14.2) | 6.5 (6.2-7.4) |
| 5 | 43 | 21 (48.8) | 113.5 (110.0-119.9) | 19.3 (17.0-22.6) | 13.5 (12.5-14.5) | 6.8 (6.3-7.1) |
| 6 | 43 | 25 (58.1) | 118.4 (115.1-123.4) | 22.0 (18.7-24.0) | 14.3 (13.3-14.7) | 7.3 (6.5-7.8) |
| 7 | 30 | 17 (56.7) | 125.0 (118.6-131.6) | 26.3 (22.4-30.5) | 14.7 (13.9-15.6) | 7.6 (6.9-8.2) |
| 8 | 27 | 16 (59.3) | 127.3 (123.7-132.9) | 25.0 (23.4-31.0) | 14.8 (13.6-16.4) | 7.9 (7.1-8.5) |

board at the study hospital approved the analysis and provided a waiver of consent.

### *2.1. Patients and data collection*

The inclusion criterion was chest CT scan images of patients aged 8 years and younger that had been taken at the study hospital from its opening in May 2003 until August 2013. Exclusion criteria were as follows: (1) any documented chest wall deformity, including both pectus excavatum and carinatum; (2) any other congenital anomaly syndrome, regardless of known chest wall deformity; and (3) significant chest wall trauma. The patients' age at the timing of the CT scan, sex, height, and body weight were gathered from chart reviews.

### *2.2. Computed tomographic measurements and definition of depth-related variables*

All chest CT scans of the eligible patients were reviewed using the picture archiving and communication system. External diameter (ED) (AP distance from skin to skin) and internal diameter (ID) (AP distance between internal surface of anterior chest wall and anterior surface of vertebral body) were measured at the midway of the lower half of the sternum by drawing a perpendicular line. The measuring method was the same as that of the previous study by Braga et al [7], except that the axial level of the measurement was the midsternum in the previous study. Secondary variables derived from the measurements were as follows: (1) compressible depth, 1 cm short of ID, as previously adopted in other studies [7,8]; (2) presence of the risk of overcompression, positive if CC depth suggested by an indicator of interest exceeds compressible depth; and (3) remaining depth, depth of potentially remaining space if a chest is compressed to the point as indicated by an indicator of interest.

### *2.3. Statistical analysis*

We determined that up to a 10% risk of overcompression is acceptable and approximated a quantile regression line for the 10th percentile of the compressible depth on ED. After rounding coefficients of the fitted regression line, we used its equation as a new indicator of CC depth. To evaluate its potential implication for the resuscitation of infants and young children, we compared it with the conventional indicators in terms of the aspects of estimated risk of overcompression, remaining depth, and overall depth of CC.

Continuous variables are reported using mean and SD, unless there was significant nonnormality when the median and interquartile range (IQR) were used. Paired *t* test or Wilcoxon signed rank test were used as appropriate to test the significance of the difference of various depth-related measurements. $\chi^2$ Test was performed to test the significance of the difference of the proportion of patients who were at risk for overcompression. The association between age category and relative frequency of patients at risk for overcompression was tested with the Cochrane-Armitage trend test, whereas the association between age category and various depth-related measurements was tested with Spearman $\rho$. All analyses were performed using R package version 3.1.1 (R Foundation for Statistical Computing, Vienna, Austria).

## 3. Results

Nine hundred thirty-one chest CT scans were initially identified as meeting the inclusion criteria. After excluding 475 scans based on the exclusion criteria, 453 CT scans underwent the measurement process. During the process, 30 scans were additionally excluded, and a total of 426 scans were ultimately eligible for analysis. Table 1 summarizes the height; body weight; and measurements of ED, ID, and compressible depth.

Fig. 1 illustrates the linear relationship between ED and compressible depth. Simple linear regression analysis showed that the predicted compressible depth was found to be $0.526 \times \text{ED} - 1.257$ cm ($R^2 = 0.758$; $P < .001$, not shown in the figure). To develop a CC depth indicator with a 10% risk of overcompression, we approximated a quantile regression line for the 10th percentile of compressible depth on ED. The regression line had a slope of 0.523 and an ED intercept of −1.928 cm. As for the 25th, 50th, and 75th percentile lines, the slopes were 0.529, 0.532, and 0.538, respectively, and the intercepts were −1.599, −1.295, and −1.040 cm, respectively.

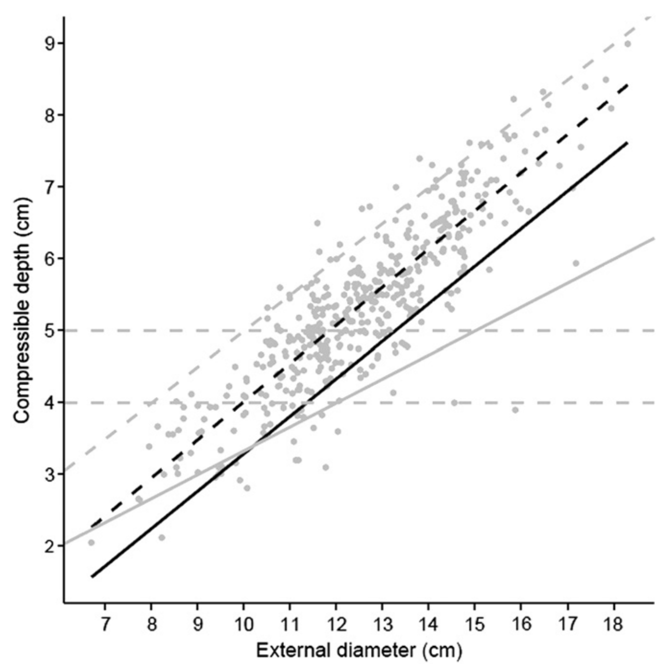


**Fig. 1.** Scatterplot demonstrating the relationship between ED and compressible depth. Black solid line: 10% quantile regression line; black dashed line: 50% quantile regression line; gray solid line: one-third of ED; gray dashed line (oblique): one-half of ED; gray dashed lines (horizontal): 4 cm and 5 cm absolute compression depth.