# Chest Compression Depth Targets in Critically Ill Infants and Children Measured With a Laser Distance Meter: Single-Center Retrospective Study From Japan, 2019–2022*

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**OBJECTIVES:** Current resuscitation guidelines recommend target chest compression depth (CCd) of approximately 4cm for infants and 5cm for children. Previous reports based on chest CT suggest these recommended CCd targets might be too deep for younger children. Our aim was to examine measurements of anterior-posterior chest diameter (APd) with a laser distance meter and calculate CCd targets in critically ill infants and children.

**DESIGN:** A retrospective descriptive study.

**SETTING:** Single-center PICU, using data from May 2019 to May 2022.

**PATIENTS:** All critically ill children admitted to PICU and under 8 years old were eligible to be included in the retrospective cohort.

**INTERVENTIONS:** None.

**MEASUREMENTS AND MAIN RESULTS:** The chest APd measurements using a laser distance meter are part of our usual practice on the PICU. Target CCd and the over-compression threshold CCd for each age group was calculated as 1/3 and 1/2 of APd, respectively. In 555 patients, the median (interquartile range) of the calculated target CCd for each age group was: 2.7 cm (2.5–2.9 cm), 2.9 cm (2.7–3.2 cm), 3.2 cm (3–3.5 cm), 3.4 cm (3.2–3.6 cm), 3.4 cm (3.2–3.6 cm), 3.6 cm (3.4–3.8 cm), 3.6 cm (3.4–4 cm), and 4 cm (3.5–4.2 cm), for 0, 2, 3–5, 6–8, 9–11, 12–17, 18–23, 24 to less than 60, and 60 to less than 96 months, respectively. Using guideline-recommended absolute CCd targets, 4 cm for infants and 5 cm for children, 49% of infants between 0 and 2 months, and 45.5% of children between 12 and 17 months would be over-compressed during cardiopulmonary resuscitation.

**CONCLUSIONS:** In our cohort, the 1/3 CCd targets calculated from APd measured by laser meter were shallower than the guideline-recommended CCd. Further studies including evaluating hemodynamics during cardiopulmonary resuscitation with these shallower CCd targets are needed.

**KEYWORDS:** cardiac arrest; cardiopulmonary resuscitation; chest compression depth; pediatric; pediatric critical care

In Japan, over the period 2014–2019, each year over 1500 children under the age of 18 years suffer an out-of-hospital cardiac arrest (1). The 2020 and 2022 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care recommends high-quality cardiopulmonary resuscitation (CPR) with rescuers compressing an infant or child's chest to at least one third of the anterior-posterior diameter (APd), or approximately 4 cm for infants and 5 cm for children (2, 3). However, CT imaging studies of children carried out 2005–2017 suggested that targeting chest compression depth

*See also p. 767.



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## RESEARCH IN CONTEXT

- High-quality cardiopulmonary resuscitation (CPR) is necessary for good neurologic outcome and CPR feedback-devices are sometimes used to monitor chest compression quality (e.g. rate and depth).
- Current recommended chest compression depths (CCds) may be too deep for infants and young children.
- We sought to evaluate the one-third CCd target used in critically ill infants and children, with measurement made by laser distance meter.

(CCd) at approximately 4 cm for infants and approximately 5 cm for young children could result in "overcompression" (4).

Therefore, to better determine the meaning of one-third (1/3) of relative chest depth, we undertook a laser distance meter study in critically ill infants and children under 8 years old. Our aims were: 1) to measure APd and calculate target CCd and 2) to compare our measurements with current recommended target depths.

## METHODS

The local institutional review board approved this research project called "Anterior-posterior chest diameter measurement and estimation of appropriate chest compression depth in a PICU" (2022095) on March 27, 2023. The need for informed consent was waived due to its minimal risk to the patients. All research procedures followed were in accordance with the ethical standards of the institutional ethical committee on human experimentation and with the Helsinki Declaration of 1975.

This retrospective observational study used measurements of APd in critically ill children admitted to PICU at a tertiary children's hospital (Aichi Children's Health and Medical Center, Japan) between May 01, 2019, and May 31, 2022.

The PICU at our center has 14 beds and approximately 500 medical and surgical patients admitted annually. All children admitted to the PICU and younger than 8 years were included. Patients who were unable to be placed supine or were discharged before the study team could obtain measurements were excluded. Infants who had been enrolled in this study within the past month, and children who were enrolled in this study within the past 6 months were excluded.

### Measurements

The chest measurement system consists of the laser distance meter (Suaoki P7 40m, Shenzhen, China) and an IV pole with casters (**Supplemental Fig. S1**, http://links.lww.com/PCC/C510). The laser distance meter has an accuracy of ±2 mm in distance and ±0.3° in angle. The system was designed to measure multiple points by moving the IV pole, without changing the meter's height from the ground. The measurements were performed by intensivists who completed training consisting of an introduction and orientation to the measurement system and at least one measurement supervised by the first author (T.I.).

Patient demographics including age, weight, height, previous history of chest compression (CC), and illness category were collected on all eligible patients. After placing a hard board (CPR backboard or portable x-ray cassette) under the patient's back, we measured and recorded two distances to calculate APd: one from the center of the chest, between the nipples of the patient to the distance meter (D1); another from the surface of the backboard to the meter (D2). During the measurement, the measurement angle was maintained within 5° to vertical. This is because Cosine 5° is 0.996 and the difference between true distance and measured distance is less than 0.4% and can be ignored. APd was calculated by subtracting the distance recorded between the backboard and meter (D2) from the distance recorded between the center of the patient's chest to the meter (D1) (**Supplemental Fig. S2**, http://links.lww.com/PCC/C510). All measurements were recorded at the end of expiration.

### Statistical Analysis

Standard descriptive statistics were used to summarize patient demographics. APd was expressed as median and interquartile range (IQR). The target CCd was calculated as 1/3 APd in each age category: infants at 0–2 months, 3–5 months, 6–8 months, and 9–11 months; children 12–17 months, 18–23 months, 2 to younger than 5 years, and 5 to younger than 8 years. The median of the target CCd in each age category was compared

against the corresponding recommended absolute CCd target (4 cm for infants and 5 cm for children) by one-sided one-sample Wilcoxon test. Over-compression threshold (OCT) CCd was defined as 1/2 APd, based on the previous study (5) and the proportion of the patients whose 1/2 APd were smaller than the recommended absolute CCd target (4 cm for < 1 yr, 5 cm for children) was calculated in each group. We also evaluated the number of patients in each group that were under-compressed, which was defined as when 1/3 APd was greater than the recommended absolute CCd target. chi-square test was conducted to examine whether the proportions of patients with the OCT CCd, among age groups by each recommended CCd (i.e., 4 cm infants, 5 cm for children), were differed. STATA, Version 16.1 (StataCorp, College Station, TX) was used for statistical analysis. A $p$ value of less than 0.05 was considered significant.

## RESULTS

There were 1434 PICU admissions during the study period, and 1302 patients younger than 8 years. APd was measured in 555 patients (**Supplemental Fig. S3**, http://links.lww.com/PCC/C510).

**Tables 1** and **2** show the demographic data. Most of the patients were Asian (98%) and post-cardiac surgery (60%). A history of CCs before APd measurement was present in 5% of the cohort.

**Tables 3** and **4** show measured APd, calculated CCd target (1/3 of APd), calculated OCT CCd (1/2 of APd), and proportion of patients that would receive over-compression using guideline-recommended CCd for each age group. **Figure 1** shows relationship between age in months and calculated CCd, such as target CCd and OCT. For all age groups, the median calculated CCd target was less than the recommended absolute CCd (Tables 3 and 4; $p < 0.001$ for all).

CCs delivered at guideline recommended absolute CCd targets, 4 cm for infants and 5 cm for children, would result in over-compression in 49% of infants between 0 and 2 months, and 45.5% of children between 12 and 17 months. The younger the age group, the more patients would have over-compression by each guideline-recommended CC target ($p < 0.005$ for both of infant and children age groups). Only three patients in 9–11 months old age group had under-compression. Under-compression was not found in any other age group.

**TABLE 1.**
**Patient Demographics by Age Category: Infant**

| Demographics | Total[a] | 0–2 mo | 3–5 mo | 6–8 mo | 9–11 mo |
|---|---|---|---|---|---|
| *n* (%) | 555 (100) | 157 (28) | 73 (13) | 50 (9) | 50 (9) |
| Age, mo, median (IQR) | 8 (2–20) | 1 (0–2) | 4 (3–4) | 7 (6–8) | 10 (9–11) |
| Gender, male, *n* (%) | 286 (52) | 83 (53) | 45 (62) | 26 (52) | 19 (38) |
| Weight, kg, median (IQR) | 6.6 (3.7–9.5) | 3.1 (2.7–3.6) | 4.5 (3.8–5.4) | 6.4 (5.6–7) | 7.1 (6.2–7.7) |
| Race, *n* (%) | | | | | |
| Asian | 544 (98) | 153 (97) | 71 (98) | 50 (100) | 47 (94) |
| Multiracial | 10 (1.8) | 4 (3) | 1 (1) | 0 | 3 (6) |
| White | 1 (0.2) | 0 | 1 (1) | 0 | 0 |
| Illness category, *n* (%) | | | | | |
| Medical cardiac | 73 (13) | 16 (10) | 17 (23) | 10 (20) | 8 (16) |
| Medical noncardiac | 78 (14) | 19 (12) | 10 (14) | 3 (6) | 4 (8) |
| Surgical cardiac | 331 (60) | 108 (69) | 43 (59) | 36 (62) | 31 (62) |
| Surgical noncardiac | 71 (13) | 13 (8) | 3 (4) | 1 (2) | 7 (14) |
| Trauma | 2 (0.4) | 1 (0.6) | 0 | 0 | 0 |
| History of chest compression, *n* (%) | 25 (5) | 3 (2) | 4 (5) | 4 (8) | 2 (4) |

IQR = interquartile range.
[a]Includes infants and children.

**TABLE 2.**
**Patient Demographics by Age Category: Child**

| Demographics | 12–17 mo | 18–23 mo | 2 to < 5 yr | 5 to < 8 yr |
|---|---|---|---|---|
| *n* (%) | 66 (12) | 46 (8) | 82 (15) | 31 (6) |
| Age, mo, median (IQR) | 14 (13–15) | 20 (18–21) | 36 (31–43) | 73 (66–82) |
| Gender, male, *n* (%) | 35 (53) | 24 (52) | 38 (46) | 17 (52) |
| Weight, kg, median (IQR) | 8.4 (7.6–9.4) | 9.1 (8.4–10) | 12.2 (10.3–13.2) | 18.4 (16.2–20.3) |
| Race, *n* (%) | | | | |
| Asian | 66 (100) | 45 (98) | 82 (100) | 30 (97) |
| Multiracial | 0 | 1 (2) | 0 | 1 (3) |
| White | 0 | 0 | 0 | 0 |
| Illness category, *n* (%) | | | | |
| Medical cardiac | 9 (14) | 3 (7) | 8 (10) | 2 (6) |
| Medical noncardiac | 10 (15) | 5 (11) | 20 (24) | 7 (23) |
| Surgical cardiac | 39 (59) | 29 (62) | 29 (36) | 16 (52) |
| Surgical noncardiac | 8 (12) | 9 (20) | 25 (30) | 5 (16) |
| Trauma | 0 | 0 | 0 | 1 (3) |
| History of chest compression, *n* (%) | 5 (8) | 1 (2) | 4 (5) | 1 (3) |

IQR = interquartile range.

## AT THE BEDSIDE

- The CCd targets calculated from APd measured by a laser distance meter were shallower than the guideline-recommended CCd.
- Younger infants (0–2 mo) and children (12–17 mo) may be at risk of over-compression using recommended guidelines for absolute CCd targets.
- Further studies including evaluating hemodynamics during CPR with shallower CCd targets are needed.

## DISCUSSION

In this study, we describe chest APd in critically ill infants and children, and target CCd calculated by an APd measured with a laser distance meter. Our laser measurement system can be easily applied to nearly all critically ill infants and children, which would result in more APd measurements than other existing CT-based studies. In our cohort, calculated target CCd was less than the recommended absolute CCd and compression at guideline-recommended depths may result in overly deep compressions in many infants and children.

There are several studies examining pediatric chest APd using computer tomography (4, 6–9). A retrospective (pre-2009 data) CT study from the United States used measurements of APd at mid-sternum in infants, and reported that during a 38-mm simulated CC, 86% of 3–12 months old would have greater than 10 mm of residual internal chest depth (RICD), meaning within safety margin (6). However, a retrospective (2005–2017) CT study from Singapore found that APd at the lower half of sternum with 4 cm simulated CCs led to 18% (95% CI, 13–24%) of infants with potential over-compression (4). In our cohort, 40% of infants between 0 and 5 months would be over-compressed using a 4 cm CCd. However, body weight of the patients was not described in the other studies; thus, it is difficult to compare our cohort with the previous cohorts.

For children, the CT study from United States (6) reported that 55% of 1–3 years old, and 98% of 3–8 years old would have greater than 10 mm of RICD, with a 51 mm CCd. Although, the CT study from Singapore (5) reported that 8% (95% CI, 4–12%) of

## TABLE 3.

**Measured Anterior-Posterior Diameter, Calculated Target Chest Compression Depth, Recommended Absolute Chest Compression Depth, and Percentage of Patients That Would Receive Over-Compression by Age Category: Infant**

| | Infant | | | |
|---|---|---|---|---|
| **Age Category** | **0–2 mo** | **3–5 mo** | **6–8 mo** | **9–11 mo** |
| Measured anterior-posterior diameter (cm), median (IQR) | 8.1 (7.5–8.8) | 8.8 (8.2–9.7) | 9.7 (9.1–10.4) | 10.1 (9.5–10.7) |
| tCCd (cm), median (IQR) | 2.7 (2.5–2.9) | 2.9 (2.7–3.2) | 3.2 (3–3.5) | 3.4 (3.2–3.6) |
| rCCd (cm) | | | 4 | |
| *p* for tCCd vs. rCCd[a] | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ |
| Over-compression threshold[b] (cm), median (IQR) | 4.1 (3.8–4.4) | 4.4 (4.1–4.9) | 4.9 (4.6–5.2) | 5.1 (4.8–5.4) |
| Over-compression using guideline recommended tCCd, *n* (%) | 77 (49) | 14 (19.2) | 4 (8) | 0 |

IQR = interquartile range, rCCd = recommended absolute chest compression depth, tCCd = target chest compression depth.
[a]One-sided one-sample Wilcoxon test comparing tCCd to rCCd.
[b]Over-compression threshold was defined as 1/2 anterior-posterior diameter.

## TABLE 4.

**Measured Anterior-Posterior Diameter, Calculated Target Chest Compression Depth, Recommended Absolute Chest Compression Depth, and Percentage of Patients That Would Receive Over-Compression by Age Category: Child**

| | Child | | | |
|---|---|---|---|---|
| **Age Category** | **12–17 mo** | **18–23 mo** | **2 to < 5 yr** | **5 to < 8 yr** |
| Measured anterior-posterior diameter (cm), median (IQR) | 10.1 (9.7–10.8) | 10.7 (10.1–11.3) | 10.9 (10.3–12) | 11.8 (10.6–12.6) |
| tCCd (cm), median (IQR) | 3.4 (3.2–3.6) | 3.6 (3.4–3.8) | 3.6 (3.4–4) | 3.9 (3.5–4.2) |
| rCCd (cm) | | | 5 | |
| *p* for tCCd vs. rCCd[a] | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ | $p < 0.001$ |
| Over-compression threshold[b] (cm), median (IQR) | 5.1 (4.9–5.4) | 5.3 (5.1–5.7) | 5.5 (5.2–6) | 5.9 (5.3–6.3) |
| Over-compression using guideline recommended tCCd, *n* (%) | 30 (45.5) | 11 (23.9) | 19 (23.2) | 3 (9.7) |

IQR = interquartile range, rCCd = recommended absolute chest compression depth, tCCd = target chest compression depth.
[a]One-sided one-sample Wilcoxon test comparing tCCd to rCCd.
[b]Over-compression threshold was defined as 1/2 anterior-posterior diameter.

children 1–8 years old with 5 cm simulated compressions had the potential for over-compression (RICD < 10 mm). Furthermore, a retrospective (2005–2015) study from Korea (7) found that children 1–3 years old (36.4%, $n = 143$) were affected more than children 4–9 years old (0.9%, $n = 108$) ($p < 0.001$). Another retrospective (2006–2018) study from Korea showed compression to 5 cm was deeper than 1/3 the APd among children 1–7 years old (8). And, the CCd target at 5 cm did not leave a residual depth of 1 cm among children 1–5 years, potentially causing intrathoracic injury (8). In our cohort, 5 cm CCd would lead to over-compression in 35% of children between 1 and 2 years, and 17% of children between 3 and 4

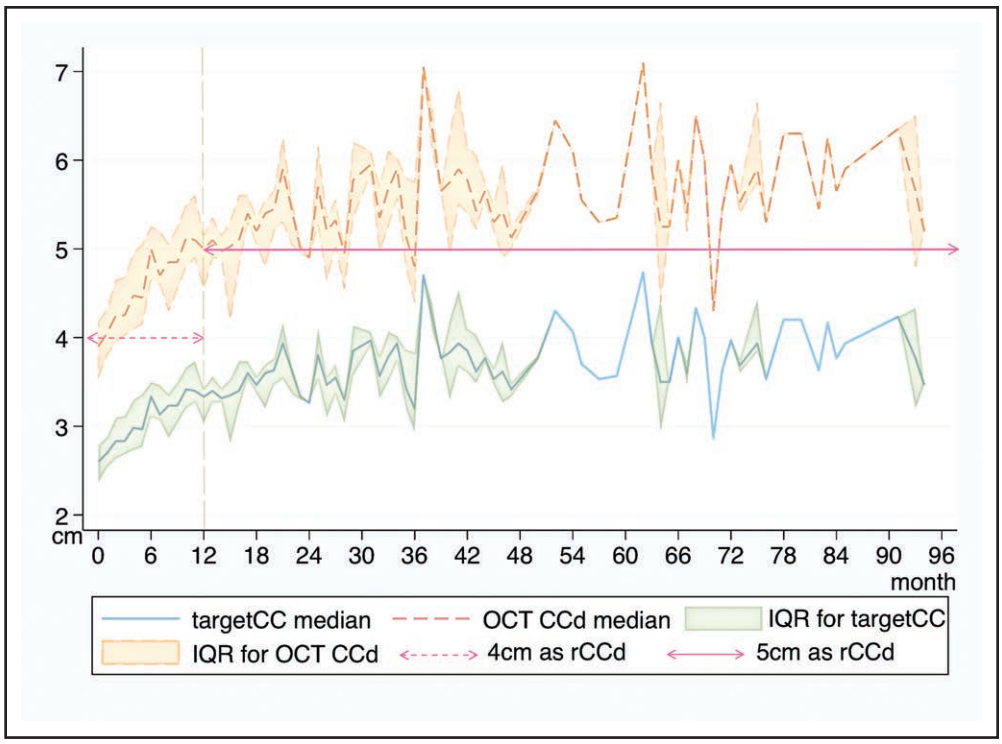


**Figure 1.** Relationship between age (mo) and calculated chest compression depth (CCd), such as target CCd (tCCd) and over-compression threshold (OCT). IQR = interquartile range, rCCd = recommended absolute chest compression depth.

years. A previous CT study done in Japan described APd at nipple line in children: mean APd was 11.4 cm for 1 to younger than 2 years, 12.6 cm for 3 to younger than 5 years, and 13.5 cm for 5 to younger than 8 years (9). In our cohort, median APd in children were shallower by roughly 1 cm: 10.5 cm (9.8–11.1 cm) for 1 to younger than 3 years, 11.1 cm (10.6–12.2 cm) for 3 to younger than 5 years, and 11.8 cm (10.6–12.6 cm) for 5 to younger than 8 years. However, descriptive methods were different (mean vs. median), and our study used directly measuring pediatric APd with the laser distance meter.

In the adult population, more CC-related injuries have been reported when deeper (> 6 cm) CCs were given (10). A pediatric animal model also demonstrated similar dose-dependency of CCd in CC-related injuries (11). However, injuries secondary to CPR in children, and particularly infants, are infrequent. Compared with an adult, the rib cage of a child has greater compliance due to incomplete bone development and studies have reported rib fractures following CPR to be lower in infants and children (0–11%) (12, 13) compared with adults (39.8–97%) (14, 15). Nonetheless, the clinical impact of over-compression in infants and children are still unclear and need to be investigated further.

Conversely, CC shallower than guideline recommendations have been reported. A multicenter retrospective (2015–2017) study of pediatric resuscitation quality showed that CCd recorded by dual accelerometer sensors were shallower than guideline recommendations: median (IQR) CCd were 2.3 cm (1.9–3.0 cm) for infants younger than 1 year and 3.8 cm (2.9–4.6 cm) for children 1–8 years old (16). However, there was no description whether the resuscitation teams had used hemodynamic targets, such as diastolic pressure via arterial lines (17), or simply failed to achieve adequate CCd target even with availability of real-time feedback on CCd. APd and CCd targets were available from this multicenter study and like our findings although all APds were measured by tape measure (5), which might have relatively low inter-rater reliability. Given the relatively large sample size, our findings, and those from other retrospective studies, may have an impact on changing CCd recommendations for infants and children to shallower target depths, particularly in the presence of dual accelerometer sensors, which can offset mattress decompression during CPR.

Our study has several limitations. First, our study did not address hemodynamic effect of CPR or patient outcome. Both 1/3 APd or absolute CCd target, such as 4 or 5 cm, are based on few retrospective studies (6, 18, 19) and optimal CCd can vary among patients. We measured the pediatric APd only in static conditions, while the patient was at rest, not during resuscitation. The chest is noted to deform over time during CC, and it might be important to measure target CCd over time during CPR and its associated hemodynamic output measures, such as blood pressure. Second, the use of 1/2 APd as the OCT lacks clinical validity in

infants and children, although studies in adult studies (10) have data validating 6 cm as over-compression. Third, we chose not to examine inter-rater reliability. We believe that inter-rater reliability largely depends on the accuracy of laser-measurements as long as the measurement angle is maintained within 5° to vertical axis and APd was measured at mid-nipple line. Yet when there is uncertainty about the mid-nipple line position, such as in open sternum cases, results may vary. Last, our study was conducted in Japan, using a cohort of critically ill infants and children admitted to the PICU, more than half of whom were post-cardiac surgery patients. We do not know if our findings can be generalized to other PICU populations or other countries.

In conclusion, the CCd targets calculated from APd measured by a laser distance meter were shallower than the guideline recommended CCd in our cohort. Furthermore, younger infants (0–2 mo) and children (12–17 mo) were more likely to have received over-compression using recommended guidelines for absolute CCd target. Further studies including evaluating hemodynamics during CPR with shallower CCd targets are needed.

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*The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.*

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