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Pediatrics

Could One-Hand Compression for a Small Child Cause Intra-abdominal Injuries?

Department of Emergency Medicine, College of Medicine, Chungnam National University Hospital, Daejeon, Korea, Ajou University School of Medicine, Suwon, Korea[1], College of Medicine, Chungbuk National University Hospital, Cheongju, Korea[2], College of Medicine, Konyang University Hospital, Daejeon, Korea[3], Emergency Medical Technology, Chungbuk Health & Science University, Cheongwon, Korea[4]

Dong A Kim, M.D., Yeon Ho You, M.D., Yong Chul Cho, M.D., Seung Ryu, M.D., Jin Woong Lee, M.D., Seung Whan Kim, M.D., In Sool Yoo, M.D., Won Joon Jeong, M.D., Jungsang Min, M.D., Ji Sook Lee, M.D.[1], Jin Hong Min, M.D.[2], Seong Soo Park, M.D.[3], Byoung Gil Yoon[4]

Purpose: We examined the question of whether one-hand chest compression for a small child could compress intra-abdominal organs.

Methods: We retrospectively examined medical charts and multidirectional computed tomography (MDCT) images obtained from children aged 1 to 18 years who presented to the hospital from March 2002 to March 2012. We measured the length of the sternum (S_{total}) and the length of the lower half of the sternum ($S_{total/2\sim X}$). We also measured the distance from the diaphragm to the midpoint of the sternum ($S_{total/2\sim D}$) and half the width of an adult hand ($W_{total/2}$). Finally, we counted the number of instances at each age in which $S_{total/2\sim X}$ and $S_{total/2\sim D}$ were less than $W_{total/2}$.

Results: This study included records and MDCT images for 301 children with a mean age of 12.05±5.59 years. We also enrolled 47 adult rescuers (25 men, 53.2%) with a mean age of 23.20±2.13 years. The mean $W_{total/2}$ was 4.62±0.46 cm. All 1-year-old children had $S_{total/2\sim X}$ and $S_{total/2\sim D}$ less than $W_{total/2}$. Among children aged 2 years, six (60.0%) had $S_{total/2\sim X}$ and $S_{total/2\sim D}$ less than $W_{total/2}$. Among children aged 3 years, four (26.7%) had $S_{total/2\sim X}$ and $S_{total/2\sim D}$ less than $W_{total/2}$, and among those aged 4 years, two (13.3%) had $S_{total/2\sim X}$ and $S_{total/2\sim D}$ less than $W_{total/2}$. However, $S_{total/2\sim X}$ and $S_{total/2\sim D}$ were greater than $W_{total/2}$ in children aged 5 years or more.

Conclusion: Our measurements indicate that one-hand chest compression for a small child could cause intra-abdominal organ injury.

Key Words: Child, Cardiopulmonary resuscitation, Compression

책임저자: 유 연 호
대전광역시 중구 대사동 640
충남대학교병원 응급의학과
Tel: 042) 280-8081, Fax: 042) 280-8082
E-mail: yyo1003@naver.com

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Article Summary

What is already known in the previous study

In accordance with the 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care, compressing the lower part of the sternum might cause complications such as liver injury.

What is new in the current study

Rescuers who practice one-hand chest compression should bear in mind that the risk of intra-abdominal organ injury may be more prevalent in children aged 1 to 4 years.

Introduction

High quality paediatric cardiopulmonary resuscitation (CPR) is critical when reviving a collapsed child in order to reduce the risk of neurologic sequelae after cardiopulmonary arrest[1-4]. To perform high quality CPR, the optimal chest compression site, rate, and depth are necessary[5-7]. In accordance with the 2010 American Heart Association guidelines for cardiopulmonary resuscitation and emergency cardiovascular care, paediatric CPR in small children involves compression of the lower half of the sternum[8].

However, compressing the lower part of the sternum might cause complications such as cardiac contusion, liver injury, and musculoskeletal injury[9,10]. Nonetheless, the risk of injury to abdominal organs after one-hand chest compression has not been reported. Here, we address the possibility of compression of intra-abdominal organs during if one-hand chest compression in small children.

Materials and Methods

The medical records including multidirectional computed tomography (MDCT) scans of children who presented to one of 3 hospitals (Chungnam National University Hospital, Ajou University Hospital, Chungbuk National University Hospital) from March 2002 to March 2012 were reviewed retrospectively. Our institutional review board approved the study protocol and deemed it appropriate for exemption from informed consent. Children who were not within normal percentile height and body weight were excluded, as were children who had diseases that could shift mediastinal organs (such as atelectasis, cardiac abnormality, space-occupying mediastinal mass, spinal deformity, ascites, pneumothorax, or haemothorax), those who had had previous chest or abdominal surgery, those who had MDCT scans with raised hands, and those whose nipples were not in the same transverse section on the MDCT scan (Fig. 1). The MDCT scanners used in this study were the Somatom plus 4 (Siemens, Erlangen, Germany), the Sensation Cardiac 64 (Siemens, Forchheim, Germany), the Hispeed/I (GE Medical Systems, Milwaukee, MN, USA) and the Brilliance 64 (Phillips, Eindhoven, The Netherlands). S_{total} (the length of the sternum), $S_{total/2\sim X}$ (the length of the lower half of the sternum), and $S_{total/2\sim D}$ (the distance from the diaphragm to the midpoint of the sternum) were measured from the MDCT images by one researcher (Fig. 2A).

Demographic data and half the width of the rescue workers' hands ($W_{total/2}$) were recorded as they participated in a pediatric CPR simulation on a child manikin covered with paper, in accordance with the 2010 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular care[8]. The rescue workers practiced one-handed CPR, alternating between the dominant and non-dominant hands, after their hands were covered with ink, and we calculated the mean width of the hand using the stain on the paper. We assumed that the rescue workers placed the mid-line of their hand on the inter-nipple line of the sternum during

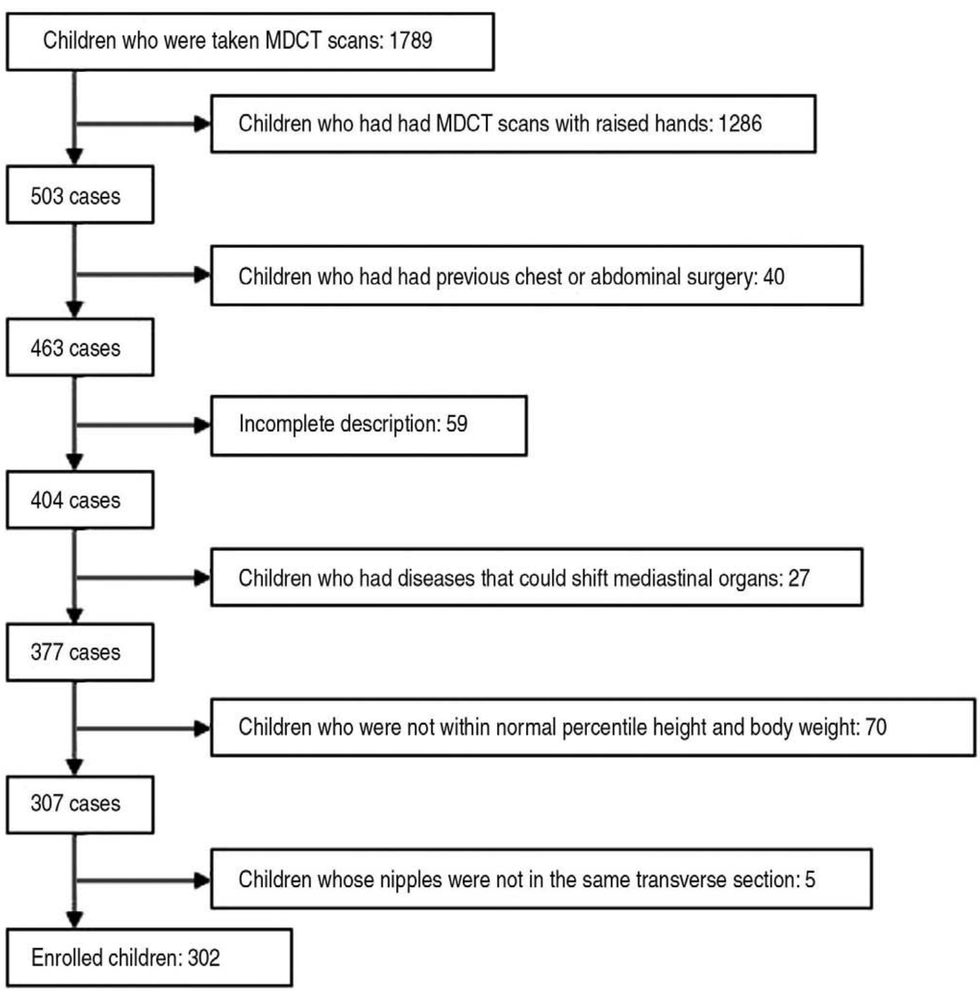

Fig. 1. Enrolment flow diagram of children with MDCT scans.

the CPR practice. Therefore, we used that as the indicator for the half width of the hand. Data were compiled using SPSS for Windows (version 15.0; SPSS, Inc., Chicago, IL, U.S.A.) and are presented as means and standard deviations or percentages. Data were analysed with Mann-Whitney or chi square tests and results were considered significant if the *p*-value was less than 0.05.

Results

1. General characteristics of patients and rescuers

This study enrolled 301 children with a mean age of 12.1±5.6 years. Of the studied children, 199 were boys (66.1%). The mean height and body weight were 146.7±30.8 cm and 47.1±22.5 kg, respectively. The mean S_{total} was 14.4±3.5 cm and $S_{total/2\sim X}$ and $S_{total/2\sim D}$ were 7.2±1.8 cm and 7.1±2.1 cm, respectively. The study also enrolled 47 adult rescuers with a mean age of 23.2±2.1 years, of whom 25 were men (53.2%). The mean height and body weight of the rescuers were 170.5±8.4 cm and 62.3±11.3 kg, respectively, and the mean $W_{total/2}$ was 4.6±0.5 cm (Fig. 2B).

The diagnoses of the enrolled children included pneumonia (31.6%), lung contusion (23.6%), viral infection (16.3%), pulmonary tuberculosis (14.6%), leukaemia (6.6%), asthma (3.0%), foreign body in the oesophagus (2.3%), brain haemorrhage (1.0%), lupus nephritis (0.7%), and urinary tract infection (0.3%).

2. Comparison of $S_{total/2\sim X}$ and $S_{total/2\sim D}$ among children

The height, body weight, $S_{total/2\sim X}$, and $S_{total/2\sim D}$ of the children at each age, from 1 year to 18 years, are summarized in Table 1. There were no differences in the height, body weight, $S_{total/2\sim X}$, and $S_{total/2\sim D}$ between boy and girl subjects aged 15 years or less, but $S_{total/2\sim X}$ and $S_{total/2\sim D}$ were greater in boy subjects aged 17 and 18 years.

3. Comparison of $W_{total/2}$ with $S_{total/2\sim X}$, and $S_{total/2\sim D}$

The mean subtraction of $W_{total/2}$ from $S_{total/2\sim X}$ and $S_{total/2\sim D}$ in 1-year-old children was -1.3±0.4 and -0.1±0.7 cm, respectively. The mean subtraction of $W_{total/2}$ from $S_{total/2\sim X}$ and $S_{total/2\sim D}$ in 2-year-old children was -0.5±0.7 and -0.5±0.7 cm, respectively. Among the 1-year-old children, 9 (100.0%) of $S_{total/2\sim X}$ and 6 (66.7%) of

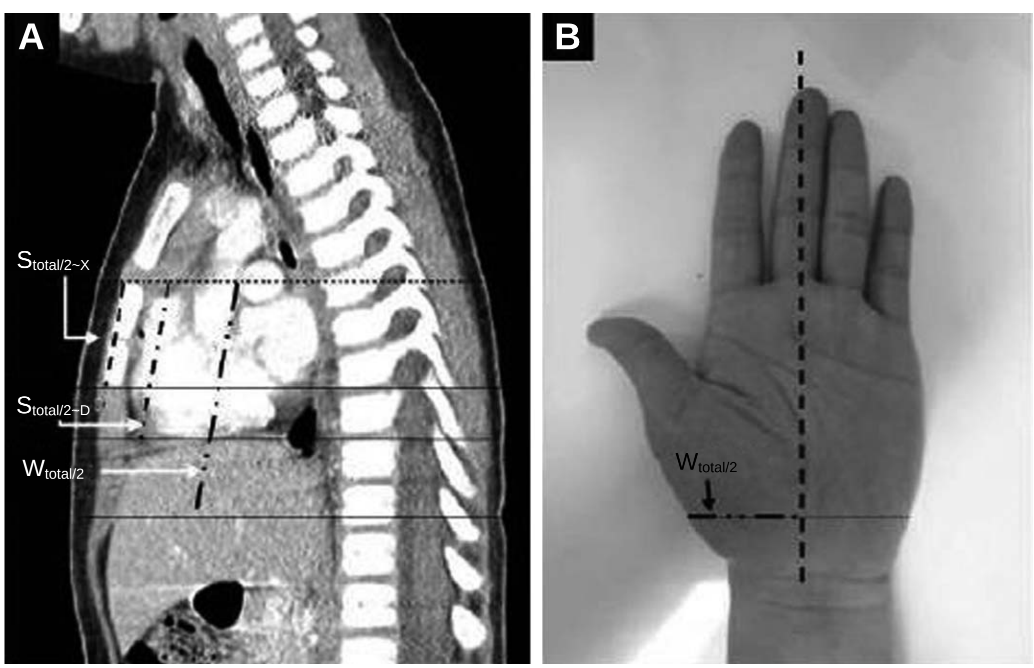

Fig. 2. These images show $S_{total/2\sim X}$, $S_{total/2\sim D}$, and $W_{total/2}$. (**A**) The mid-point of the sternum (······), $S_{total/2\sim X}$ (-----), $S_{total/2\sim D}$ (-·-·-), and $W_{total/2}$ (-··-·). (**B**) A representative image for the half line of the hand (-----) and $W_{total/2}$ (-··-·).
* $S_{total/2\sim X}$: The length from the midpoint of the sternum to the xiphoid process.
† $S_{total/2\sim D}$: The length from the midpoint of the sternum to the diaphragm.
‡ $W_{total/2}$: Half the width of an adult hand.

$S_{total/2\sim D}$ were less than $W_{total/2}$, and liver was located underneath of an adult hand. Among those aged 2 years, 6 (60.0%) of $S_{total/2\sim X}$ and 8 (80.0%) of $S_{total/2\sim D}$ were less than $W_{total/2}$, and liver was located underneath of an adult hand. Among those aged 3 years, 4 (26.7%) of $S_{total/2\sim X}$ and 7 (46.7%) of $S_{total/2\sim D}$ were less than $W_{total/2}$, and liver

Table 1. Height, body weight, and chest measurements by age.

Age	Number (%)	Height	Body weight	$S_{total/2\sim X}$	$S_{total/2\sim D}$
1	9 (3.0)	79.3±3.2	10.1±0.9	3.4±0.4	4.5±0.7
2	10 (3.3)	89.9±4.5	13.9±2.8	4.2±0.7	4.1±0.7
3	15 (5.0)	97.5±2.3	14.8±1.9	5.1±1.0	4.7±0.8
4	15 (5.0)	101.3±6.3	16.3±2.4	5.4±0.9	5.0±0.7
5	9 (3.0)	108.0±7.3	20.5±2.6	6.0±0.7	5.4±0.5
6	9 (3.0)	117.3±8.7	21.9±3.6	5.8±0.4	5.5±0.9
7	11 (3.7)	124.9±6.3	27.0±3.2	6.2±0.5	5.7±0.8
8	16 (5.3)	128.1±7.1	29. 5±6.7	6.0±0.5	6.0±1.2
9	10 (3.3)	133.0±3.7	31.0±5.0	6.5±0.4	5.6±0.5
10	9 (3.0)	138.9±15.1	34.3±8.2	6.5±0.5	6.0±1.3
11	4 (1.3)	139.9±13.6	43.6±1.4	6.5±0.6	6.1±1.2
12	11 (3.7)	156.1±4.0	54.6±6.6	6.6±0.8	7.8±1.6
13	11 (3.7)	153.8±11.6	49.5±11.7	7.7±1.1	7.7±1.4
14	14 (4.7)	163.8±6.1	49.4±11.1	8.2±0.8	8.2±1.5
15	18 (6.0)	171.3±7.5	63.9±8.3	8.2±1.2	9.1±1.7
16	36 (12.0)	168.6±10.7	63.7±10.5	8.2±1.2	8.0±2.0
17	45 (15.0)	171.2±7.6	66.4±10.9	8.6±1.2	8.0±1.7
18	49 (16.3)	171.9±5.9	67.3±10.4	8.4±1.0	8.4±2.0

(Mean±S.D.) cm

* $S_{total/2\sim X}$: The length from the midpoint of the sternum to the xiphoid process.
† $S_{total/2\sim D}$: The length from the midpoint of the sternum to the diaphragm.

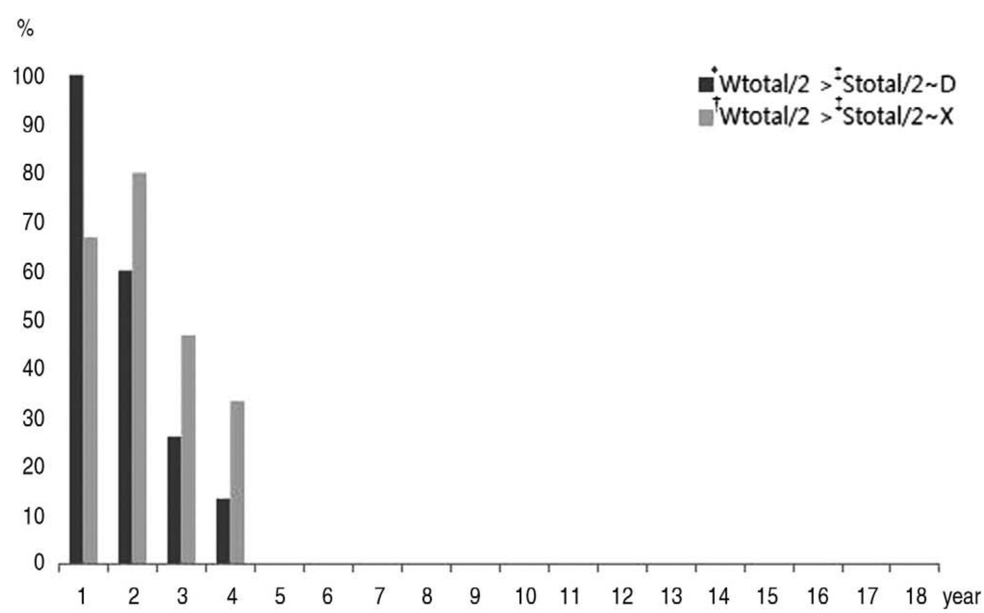

Fig. 3. This graph shows that the ratio of $W_{total/2}$ was bigger than $S_{total/2\sim X}$, and $W_{total/2}$ was bigger than $S_{total/2\sim D}$ for each age. $W_{total/2}$ was greater than $S_{total/2\sim X}$ and $S_{total/2\sim D}$ in some children aged up to 4 years.
* $S_{total/2\sim X}$: The length from the midpoint of the sternum to the xiphoid process.
† $S_{total/2\sim D}$: The length from the midpoint of the sternum to the diaphragm.
‡ $W_{total/2}$: Half the width of an adult hand.

was located underneath of an adult hand. Among those aged 4 years, 2 (13.3%) of $S_{total/2\sim X}$ and 5 (33.3%) of $S_{total/2\sim D}$ were less than $W_{total/2}$, and liver was located underneath of an adult hand. However, $S_{total/2\sim X}$ and $S_{total/2\sim D}$ were greater than $W_{total/2}$ in children aged 5 years or more (Fig. 3).

Discussion

In this study, we evaluated the risk of intra-abdominal organ injuries associated with CPR at each age and found that $S_{total/2\sim X}$ and $S_{total/2\sim D}$ were less than $W_{total/2}$ in children aged ≤4 years. Although there were some differences in data between boys and girls aged ≥15 years, we believe that those differences would not have affected our results because there were no cases where $S_{total/2\sim X}$ and $S_{total/2\sim D}$ were less than $W_{total/2}$ in children aged ≥5 years. Therefore, based on our measurements, we can recommend that rescuers who perform one-handed chest compression should bear in mind that the risk of intra-abdominal organ injuries may be more likely in children aged 1 to 4 years.

To achieve successful, high quality CPR, certain conditions are essential to reduce organ injuries from chest compression and to generate a higher cardiac output. Several factors are associated with complications of chest compression. First, the total duration of chest compression during CPR is one factor. The quality of chest compression deteriorates critically over time with increasing fatigue and decreasing attention of the rescuer. From this point of view, complications may be more likely with prolonged chest compression, and increasing stiffness in the ischemic tissue might also contribute[10]. Second, the depth of chest compression is associated with complications. An increase in the number of iatrogenic injuries has been associated with chest compressions that exceeded 6 cm in depth during cardiopulmonary resuscitation[11]. Finally, the position of the chest compression is important to reduce organ injuries. It has been reported that chest compression should be performed at the middle one-third of the sternum to reduce liver injury and that complications such as cardiac contusion, liver injury, and musculoskeletal injuries occur when the lower part of the sternum is compressed[9,10].

A prospective study of cardiac resuscitation complications reported that thoracic complications were observed in 42.7 percent of the cases, and abdominal visceral complications were noted in 30.8% of the cases[12]. Intra-abdominal bleeding due to a spleen rupture following rib fractures with dislocation was experienced by 2.6 percent[13]. Another study has reported stomach lacerations without bleeding, ruptured spleens, mediastinal hemorrhage, and pneumothoraxes as complications of chest compression[11]. In contrast, another study has shown that there were no significant hollow or solid thoracoabdominal organ injuries and no rib fractures during child-CPR[14].

Although complications are more common in adults than in children because of the reduced pliability of the rib cage in adults compared to that in children, children can also be at risk of severe organ injuries from chest compressions, including hepatic rupture, chest wall contusion, retroperitoneal hematoma, epicardial hematoma, pneumothorax, pulmonary interstitial hemorrhage, rib fractures, splenic contusion, stomach perforation, and haemoperitoneum[15-17]. Betz’s series included a 2-month-old case and a 5-year-old drowning case, both with multiple rib fractures in the mid-clavicular line[18]. In another study, the most frequent structure beneath the lower third of the sternum was the left ventricle, but the liver was located in that position in 28.7%[19].

The risk of blunt upper abdominal trauma, including injuries to the liver, increases if the compression area includes the sternoxiphoid junction, although the optimal chest compression site to generate a high cardiac output is at the maximum diameter of the left ventricle[20,21]. Therefore, the safety issues should be resolved before the use of chest compression at the sternoxiphoid junction in clinical practice. Several studies have been performed to determine the proper position and optimal depth of chest compression, but no study has indicated that a greater compression area increases the risk of intra-abdominal injuries. The relative compression area is larger in a small child; however, chest compression with a consistent compression area is typically used. In this study, the length from the midpoint of the sternum to the xiphoid process and the length from the midpoint of the sternum to the diaphragm were less than half the width of an adult hand in children aged ≤4 years. This implies an increased risk of intra-abdominal organ injuries in children aged ≤4 years, because the relative compression area is larger.

There are several limitations to this study. First, owing to the retrospective nature of the study, we were unable to determine whether the data were based on guardians' statements rather than clinical findings. Further studies are needed to validate the findings of the present study. Second, the mode of measurement was only via MDCT images. Therefore, we were unaware of any intra-abdominal injuries that occurred as a result of chest compression. However, we determined which intra-abdominal organs are beneath the chest compression area at each age, and the results implied a risk of intra-abdominal organ injuries with chest compression. Third, we did not consider the curve of the children's sternums. However, children's sternums fuse during puberty, and the curve of the sternum is not as pronounced; therefore, we feel as if this would not have affected the results[22]. Fourth, this study did not consider the difference in sizes between adult dominant and non-dominant hands. The rescue workers alternated practicing one-handed CPR with their dominant and non-dominant hands after their hands were covered with ink, and we calculated the mean width of their hands based on the stain on the paper. Therefore, the difference in sizes between the dominant and non-dominant hands likely did not affect the results. Sixth, the sample size was small for some ages. However, the risk of intra-abdominal injuries was present in a small sample of children aged ≤4 years. This implies that intra-abdominal organ injuries might occur in a small child. Finally, we enrolled children with MDCT scans. This might have resulted in selection bias; children with lung diseases might have been over-represented. However, because children with atelectasis, which could shift mediastinal organs, were excluded, selection bias may not have been a concern.

Conclusion

The length from the midpoint of the sternum to the xiphoid process and length from the midpoint of the sternum to the diaphragm were less than half the width of an adult hand in children aged 4 years or less. This result implies that one-hand chest compressions for small children might cause intra-abdominal organ injuries. However, further studies examining the risk of organ injuries after one-hand chest compression in paediatric CPR are needed.

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