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Thoracic Deformity in the Transverse Plane among Adults with Severe Cerebral Palsy

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Abstract. [Purpose] Thoracic deformity (TD) secondary to severe kyphoscoliosis occurs frequently in adults with severe cerebral palsy (CP) and can eventually result in pneumonia. To determine the severity of TD, we used two protocols to examine and compare the anteroposterior (AP) and laterolateral (LL) diameters of the thorax in the transverse plane among adults with severe CP. [Subjects and Method] The study examined 20 adults with severe CP. Computed tomographic scans were acquired at the level of the xiphisternal junction in each patient, and two protocols were used to measure the AP and LL diameters. The largest AP diameters were measured along the gravity line (protocol 1) and along the line where the middle point of the sternum connects with the spinous process of the vertebra (protocol 2). The largest LL diameters were measured along the lines perpendicular to each AP diameter. The ratios of the AP to LL diameters were calculated. [Results] The AP diameter of protocol 1 was significantly shorter than that of protocol 2, and the LL diameter of protocol 1 was significantly longer than that of protocol 2. There was a significant difference in the ratio of AP to LL between the protocols. [Conclusions] Our results suggest that differences between protocols in the AP and LL diameters show the severity of TD.
Key words: Cerebral palsy, Thorax, Deformity

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INTRODUCTION

Thoracic deformity (TD) secondary to severe kyphoscoliosis occurs frequently in adults with severe cerebral palsy (CP) who are classified as Gross Motor Function Classification System (GMFCS) level V, are bedridden, and have an intelligence quotient lower than 35. This deformity restricts lung function by reducing both chest wall compliance and the mechanical advantage of respiratory muscles, and can eventually result in pneumonia[1)]. The quantitative measurement of TD is important for assessing lung function; however, there have been few studies of it.

Anteroposterior (AP) view chest X-rays have been used to measure the severity of TD in individuals with severe CP[2)]. Because it is a three-dimensional feature, TD must be measured in the transverse plane; however, this method is limited to assessment of the deformity in the coronal plane. Computed tomography (CT) has been used to measure TD in the transverse plane of children with pectus excavatum[3)] and with congenital scoliosis and fused ribs[4)]. CT allows a more accurate assessment of relevant deformation indices, evaluation of chest shape, and asymmetry in the transverse plane[4)].

Previous studies have not measured thoracic dimensions in the transverse plane in the assessment of TD in individuals with severe CP. We recently devised two protocols to measure TD, and demonstrated that they are highly reliable[7)]. The purpose of this study was to use these protocols to measure and compare the AP and LL diameters of the thorax in the transverse plane of adults with severe CP.

SUBJECTS AND METHODS

Twenty adults with severe CP (16 males and 4 females, GMFCS level V), who were recruited from Nishiotaru Hospital, participated in this study. Patients were included if they had previously undergone chest CT scans (Asteion TSX-021B, Toshiba, Japan) for the diagnosis of pneumonia. The mean age of the patients was 42.8 years (SD = 17.6 years; range, 20–70 years). Ethical approval was granted by Nishiotaru Hospital, and informed consent was obtained from the parents or guardians of all the participants.

Printed CT scan films of the thorax in the transverse plane at the level of the xiphisternal junction were scanned (CanoScan LiDE 90; Canon, Japan) and saved on a personal

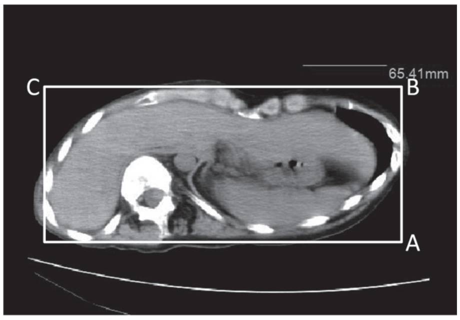

Fig. 1. Protocol 1 for measuring anteroposterior (A–B) and laterolateral (B–C) diameter

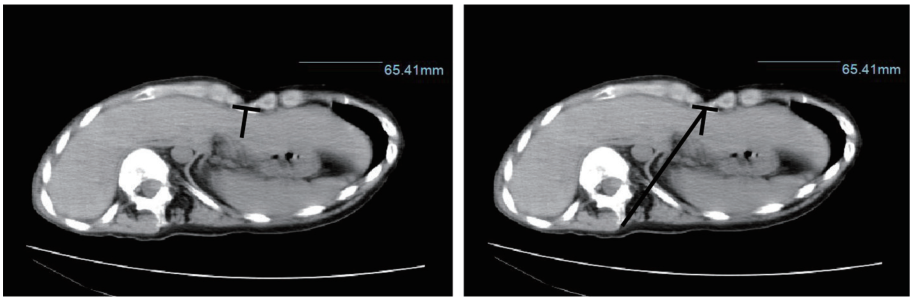

Fig. 2. Protocol 2: The perpendicular bisector was matched to inclination and the size of sternum to indicate the midpoint of the sternum (A). A line connecting the midpoint of the sternum with the spinous process of the vertebra was drawn (B).

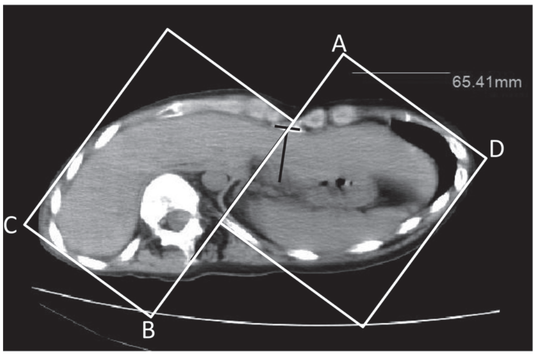

Fig. 3. Protocol 2 for measuring anteroposterior (A–B) and laterolateral (A–D plus B–C) diameter

computer as digital images of each patient. Two protocols were used to measure both the AP and laterolateral LL diameters.

In protocol 1, Microsoft PowerPoint 2003® (PP) was used to insert a digital image of the thorax in the transverse plane onto a slide, and a rectangle was drawn on the image. The rectangular length was matched to the largest AP diameter, and the width was matched to the largest LL diameter (Fig. 1). The digital image and rectangle were grouped and saved as a picture in the JPEG image file format. The public domain image processing program ImageJ® was used to measure the rectangular length and width of the AP and LL diameters.

In protocol 2, PP was used to insert a digital image of the thorax in the transverse plane onto a slide. After a grid was superimposed on the slide, vertical and horizontal lines were drawn along the grid lines. These lines were grouped as the perpendicular bisector, which was matched to the inclination and size of the sternum to indicate the midpoint of the sternum (Fig. 2-A). A line was drawn connecting the midpoint of the sternum with the tip of the spinous process of a vertebra (Fig. 2-B). After drawing two rectangles, the right side of one rectangle length and the left side of the other were matched to the connecting line. The rectangular length of each side was determined as the largest AP diameter of the side, and the rectangular width of each side was deter-

Table 1. Data of the two protocols for measuring the chest wall in the transverse plane (mm)

	Protocol 1		Protocol 2		difference between protocols 1 and 2		
	Mean (SD)	Range	Mean (SD)	Range	difference	95% CI	effect size
AP diameter	152.9 (32.9)	99.3–22.2	197.7 (42.8)	122.9–294.7	44.8**	23.7–66.0	1.18
LL diameter	260.6 (37.9)	195.7–333.1	242.3 (36.3)	189.7–314.4	18.4**	5.4–31.3	0.50
The ratio of AP and LL	0.60 (0.14)	0.34–0.89	0.82 (0.20)	0.53–1.19	0.22**	0.11–0.33	1.28

AP; anteroposterior LL; laterolateral SD; standard deviation CI; confidence level **; significant difference between protocols 1 and 2

mined as the largest LL diameter of the side (Fig. 3). The digital image, perpendicular bisector, and rectangles were grouped and saved in the JPEG format. ImageJ was used to measure the AP and LL diameters. The length between A and B in Figure 3 was measured as the AP diameter. The length obtained by adding the right rectangular side to the left was measured as the LL diameter (Fig. 3).

The ratio of AP to LL in each protocol was subsequently calculated.

The Shapiro-Wilk test was used to confirm the normality of the data. If the data were normally distributed, the paired t test was used to compare the data between the two protocols. If the data were not normally distributed, the Mann-Whitney test was used for the comparison. In addition, the effect size was calculated from these data[6]. Significance level was accepted for values of $p \leq 0.05$. The statistical program R version 2.8.1 (R Foundation for Statistical Computing, http://www.r-project.org/) was used to perform using all statistical analyses.

RESULTS

The results are shown in Table 1.

The AP diameter, LL diameters and the ratios of AP to LL were confirmed to be normally distributed.

The mean AP diameter of protocol 1 was significantly shorter than that of protocol 2, and the effect size was Large.

The mean LL diameter of protocol 1 was significantly longer than that of protocol 2, and the effect size was Medium.

The mean ratio of AP to LL of protocol 1 was significantly smaller than that of protocol 2, and the effect size was Large.

DISCUSSION

In this study, we used two protocols to measure and compare the AP and LL diameters of the thorax in the transverse plane of adults with severe CP. The results show that the AP diameter obtained using protocol 1 was significantly shorter and the LL diameter significantly longer than those obtained using protocol 2.

Individuals with severe CP present with TD secondary to severe kyphoscoliosis early in life[7], both of which affect thoracic function and growth, and have an adverse effect on the function and growth of the lungs[4]. TD restricts lung function by reducing both chest wall compliance and the mechanical advantage of respiratory muscles, and can eventually result in pneumonia[1]. The most common cause of death among the Japanese with severe CP is pneumonia/bronchitis (25.9%), followed by respiratory diseases (16.0%)[8]. Kyphoscoliosis and TD are not congenital deformities in individuals with CP. These deformities develop with age, especially in individuals with severe CP[7]. Therefore, it is necessary to measure their severity quantitatively. AP view chest X-rays have been used to measure the severity of kyphoscoliosis and TD in individuals with severe CP[2, 7]. Because TD is a three-dimensional thoracic deformity, it must also be measured in the transverse plane[5]. Previous studies have not measured thoracic dimensions in the transverse plane in the assessment of TD in individuals with severe CP.

We recently devised two protocols to measure TD and showed that they are highly reliable[5]. In this study, we used these two protocols to measure and compare the AP and LL diameters of the thorax in the transverse plane of adults with severe CP, because normal thoracic volume depends on adequate thoracic width and depth[4]. Protocol 1 was designed with reference to the Japanese Body Dimension Data for Ergonomic Design, edited by the National Institute of Bioscience and Human-Technology[9], and was used to measure the thoracic width and depth in individuals without deformities. Protocol 2 was a modified version of protocol 1 because TD in the transverse plane of individuals with severe CP shows thoracic rotation and a lateral deviation of the spine or sternum or both[5]. If the two protocols were used to measure thoracic width and depth in individuals without deformities, there would be no differences in the AP and LL diameters between them. In this study, the AP diameter of protocol 1 was significantly shorter and the LL diameter significantly longer than those of protocol 2. These results suggest that differences in the AP and LL diameters between the two protocols show the severity of TD.

Yamamoto et al.[10] used a method of measurement similar to protocol 1, without CT, to evaluate the ratio of the depth to width at the level of the xiphisternal junction in Japanese with and without severe CP (GMFCS level V). Their results show that the ratio in individuals with CP was 0.53 and in those without CP was 0.72, which suggests that in individuals with severe CP, the thoracic width will become wider and the depth narrower than in those without severe CP[10]. However, their results for TD did not take into account thoracic rotation and the lateral deviation of the spine or sternum, or both[5]. In our study, the ratio of the AP to LL diameters of protocol 1 was 0.60 and that of protocol 2 was 0.82, which suggests that the thoracic width in individuals with severe CP becomes narrower and the depth wider than in individuals without severe CP. These results suggest that protocols 1 and 2 are needed to measure thoracic width and depth in individuals with severe CP who have TD.

A limitation of this study is that it did not measure the thoracic dimensions of healthy individuals. However, in individuals with severe CP, our protocol 1 results were similar to those of Yamamoto et al.[10], and they can be referenced to the results for healthy individuals reported in their study[10]. Another limitation of this study is that the risk of radiation is cumulative. Further study of TD deformity measurements in individuals with severe CP may be needed to avoid excessive exposure to radiation.

In conclusion, two CT protocols were used to measure and compare the AP and LL diameters of the thorax in the transverse plane of adults with severe CP. Protocol 2 was a modified version of protocol 1 that allows measurement of TD in the transverse plane, which is necessary because individuals with severe CP show thoracic rotation and lateral deviation of the spine or sternum, or both[5]. In this study, the AP diameter of protocol 1 was significantly shorter and the LL diameter significantly longer than those of protocol 2. These results suggest that differences in the AP and LL diameters between the two protocols show the severity of TD.

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