Intra-Rater Reliability, Standard Error of Measurement, and Minimal Detectable Change of Smartphone-Based Thoracic Kyphotic Curve in Children with Cerebral Palsy

Do-Hyun Kim*

Department of Physical Therapy, Uiduk University, Gyeongju, Republic of Korea

Abstract

Objective: The purpose of this study was investigating the validity and reliability of smartphone application and inclinometer for measuring thoracic kyphotic curve in children with cerebral palsy (CP) and typically developing (TD) children.

Methods: Ten children with CP (five boys and five girls; mean age, 9.00±2.05 years; mean height, 126.60±6.60 cm; mean weight, 25.30±7.93 kg; GMFCS levels I-III) and ten TD children (five boys and five girls; mean age, 8.90±0.99 years; mean height, 124.30±7.54 cm; mean weight, 25.30±5.77 kg) were recruited in this study. We measured thoracic kyphotic curve with iHandy Level smartphone application and inclinometer in the sitting position. Intra-rater reliability was determined by the ICC (3,k) model. Pearson’s correlation was utilized to explore the relationships between smartphone application and inclinometer data. The differences between the CP and TD groups were established by the Mann-Whitney U test.

Results: The intra-rater reliability of thoracic kyphotic curve with smartphone application was 0.96 (p<0.001). The standard error of measurement (SEM) was 1.92 and the minimal detectable change (MDC) at 90% CI was 4.48. The correlational relationship between thoracic kyphotic curves measured using the smartphone application and the inclinometer was strong in CP group (r=0.838, p=0.002). The Mann-Whitney U test confirmed that the CP group showed greater thoracic kyphotic curves than the TD group (p=0.001).

Conclusions: We found that the thoracic kyphotic curve was significantly greater in children with CP than TD children. Additionally, we confirmed that measuring thoracic kyphotic curvature using a smartphone application is valid and reliable in ambulant children with CP.

*Corresponding author:
Dr. Do-Hyun Kim, PT, PhD,
Department of Physical Therapy,
Uiduk University: Gangdong-myeon, 261 Donghae-daero,
Gyeongju-si, Gyeongsangbuk-do, Republic of Korea, 38004;
Tel: +82-54-760-1792; E-mail: kimdh@uu.ac.kr

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Introduction

Postural control is defined as maintaining trunk position in space to achieve stability while static or during dynamic movement (1); it requires interaction between the sensory, musculoskeletal, and central nervous systems, and is associated with functional activities in daily life (2). Children with cerebral palsy (CP) have decreased postural stability than typically developing (TD) children. Saxena et al. (3) compared postural control in standing position between children with spastic CP and TD children and they found the anteroposterior and mediolateral sway, velocity moment in CP children was significantly higher than TD children.

Children with CP is well defined as a group of permanent movement deficit that causes restriction of activities due to nonprogressive newborn brain lesions (4). Most children with CP encounter postural control problems due to sensation and motor deficits (5). Poor postural control in children with CP causes excessive posterior tilt of pelvis and hunched back in the sitting position (6). Additionally, it is believed to be linked to not only development and movement skill acquisition delays but also to interference with goal-directed movement, activities of daily living, and social participation in children with CP (7).

Postural control is frequently evaluated by means of body sway measurement (8), postural muscle activity evaluation (9), and clinical tool assessment (10). These approaches have the advantage of being able to measure postural control accurately. However, given that children with CP are often accompanied by cognition problem, there is a need for a simple tool to measure postural control (11). Measurement of spinal curvature with an inclinometer in the sagittal plane is simple and has excellent reliability in participants without CP (12,13). Additionally, previous studies report that excessive thoracic kyphosis (14) and lumbar lordosis (15) can result in musculoskeletal pain, breathing difficulties, and digestive problems (16).

The development of smartphone sensors has led to a great deal of interest among clinicians and researchers in using associated applications as alternative postural evaluation tools (17). This approach has the advantage of portability, meaning anyone can implement it in both clinical and naturalistic settings (12). Additionally, lumbar lordotic curve assessment with a smartphone application has already provided good intra- and inter-rater reliability in healthy subjects (12). However, measuring thoracic kyphotic curves in children with CP has received little attention; such knowledge is necessary for developing clinical evaluation techniques and successful therapeutic interventions.

Therefore, the primary purpose of this study was to investigate the intra-rater reliability, standard error of measurement (SEM), and minimal detectable change (MDC) of thoracic kyphotic curve using a smartphone application in children with CP and TD children. The secondary purpose was to examine concurrent validity by calculating the correlational relationship between smartphone application and inclinometer data in children with CP and TD children. The third purpose was to compare the thoracic kyphotic curve in the sagittal plane between children with CP and TD children. Clinically, this study provides important information about postural control in children with CP and will allow clinicians to make better clinical decisions.
Methods

Subjects

Ten children with CP and ten TD children were recruited from the paediatric physiotherapy clinic in Gyeongsangbuk-do. The target sample size was estimated by power analysis with G-Power version 3.1 software (University of Dusseldorf, Dusseldorf, Germany) based on an effect size of 4.36, a 1-β error (power) of 0.8 (80%), and an α error of 0.05. This power analysis showed that the total target sample size was seven per group, and ten children were therefore recruited in each group to account for dropout. The inclusion criteria were an age of 6–15 years; a score of I (walk and climb stairs without hands support) to III (walks with assistive devices) on the Gross Motor Function Classification System (18); the ability to independently maintain sitting and standing positions; and the ability to understand and follow the researcher’s instructions. The exclusion criteria were botulinum A toxin injections to the lower extremities within the previous six months and sufficient visual or auditory impairment to interfere with performing the experimental tasks. All children received information on the research protocol and signed the consent form approved by the Inje University Institutional Review Board (2018-02-008-002).

Rater

All measurements were evaluated by a single rater with eight years’ experience in paediatric physiotherapy. The rater completed training relating to the evaluation procedures used in the study for two weeks, delivered by a senior researcher with 25 years’ experience in paediatric physiotherapy.

Apparatus

The free iHandy Level application (iHandy Ltd., Cheung Sha Wan, Kowloon, Hong Kong) featuring a visual display and digital inclinometer was used to determine the angle of thoracic kyphotic curvature. This application has already provided good inter- and intra-rater reliability (ICCs of 0.90 and 0.85, respectively) and good validity (Pearson coefficient correlation r of 0.86) for measuring spinal angles in participants without CP (12). The Acuangle Inclinometer (Isomed, Portland, OR, USA) was also used to measure the angle of thoracic kyphotic curvature. This equipment is 93 mm long × 100 mm wide × 15 mm high with an accuracy of 0.083°. When the device is tilted, the pole in the hydraulic oil is quantified.

Procedure

All children contributed on two occasions (test occasion and retest occasion), two weeks apart. Thoracic kyphotic curvature was assessed in the sitting position for which the children were required to sit comfortably and properly on an adjustable stool without back support. The smartphone and Acuangle Inclinometer were placed on the seventh cervical spinous process (C7) and the first thoracic spinous process (T1), and the twelfth thoracic spinous process (T12) and the first lumbar spinous process (L1). The anterior superior iliac spine and the twelfth rib were used as landmarks for T12, while C7 was found to determine the location of T1. C7 and T12 were dotted with a marker. The smartphone was placed on a flat floor and then calibrated to obtain stable values prior to data collection; each measurement was collected three times and the mean value was used for analysis (Figure 1).
Figure 1: Measurement of thoracic kyphotic curve

Statistical analysis

All data were analyzed with PASW Statistics Version 18 (Norusis/SPSS Inc., Chicago, IL, USA). Descriptive data are represented as means with standard deviations. Intra-rater reliability was determined by the ICC (3, k) model. Generally, intra-rater reliability is considered that ICC below 0.50 reflects a poor, between 0.50 and 0.75 represents moderate, between 0.60 and 0.90 means good, and above 0.90 represents excellent. A Pearson correlation analysis was used to estimate correlational relationship between measuring by smartphone application and by inclinometer. The differences between the CP and TD groups were established by the Mann-Whitney U test. Statistical significance was described by a $p$-value <0.05.

Results

Ten children with CP (five boys and five girls; mean age, 9.00±2.05 years; mean height, 126.60±6.60 cm; mean weight, 25.30±7.93 kg) and ten TD children (five boys and five girls; mean age, 8.90±0.99 years; mean height, 124.30±7.54 cm; mean weight, 25.30±5.77 kg) were recruited in Gyeongsangbuk-do, Republic of Korea (Table 1).
Table 1: Clinical characteristics of the children

<table>
<thead>
<tr>
<th>Variables</th>
<th>CP group</th>
<th>TD group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>9.00±2.05 a</td>
<td>8.90±0.99</td>
</tr>
<tr>
<td>Sex (B/G)</td>
<td>5/5</td>
<td>5/5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>126.60±6.60</td>
<td>124.30±7.54</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>25.30±7.93</td>
<td>25.30±5.77</td>
</tr>
<tr>
<td>Type of CP (Hemiplegia/diplegia)</td>
<td>5/5</td>
<td>-</td>
</tr>
</tbody>
</table>

aMean ± standard deviation  
bCerebral palsy  
cTypical development

The intra-rater reliability of thoracic kyphotic curve with smartphone application was 0.96 (p<0.001). The SEM was 1.92 and the MDC at 90% CI was 4.48 (Table 2). In children with CP, the angle of thoracic kyphotic curve was 42.45±6.05° (smartphone application) and 45.30±6.81° (inclinometer). The correlational relationship between thoracic kyphotic curves measured using the smartphone application and the inclinometer was strong in CP group (r=0.838, p=0.002). In TD children, the thoracic kyphotic curve was 31.05±4.64° (smartphone application) and 33.05±5.33° (inclinometer). Strong correlation was also observed between thoracic kyphotic curves measured by the smartphone application and the inclinometer (r=0.953, p<0.001). The Mann-Whitney U test confirmed that the CP group showed significantly greater thoracic kyphotic curves than the TD group (U=7.00, p=0.001) (Table 3).

Table 2: The intra-rater reliability, standard error of measurement (SEM), and minimal detectable change (MDC) of smartphone-based thoracic kyphotic curve

<table>
<thead>
<tr>
<th>Intra-rater reliability</th>
<th>r</th>
<th>SEM a (degree)</th>
<th>MDC b (degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.96</td>
<td>0.90</td>
<td>1.92</td>
<td>4.48</td>
</tr>
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</table>

aStandard error of measurement  
bMinimal detectable change
Table 3: Comparison of thoracic kyphotic curve data between smartphone application and the inclinometer

<table>
<thead>
<tr>
<th></th>
<th>Smartphone application (degree)</th>
<th>Inclinometer (degree)</th>
<th>U</th>
<th>p</th>
<th>Pearson’s correlation</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>CP (^b) group</td>
<td>42.45±6.05(^a)</td>
<td>45.30±6.81</td>
<td>7.000</td>
<td>0.001</td>
<td>0.838</td>
<td>0.002</td>
</tr>
<tr>
<td>TD (^c) group</td>
<td>31.05±4.64</td>
<td>33.05±5.33</td>
<td>8.000</td>
<td>0.001</td>
<td>0.953</td>
<td>(p&lt;0.001)</td>
</tr>
</tbody>
</table>

\(^{a}\) Mean±standard deviation  
\(^{b}\) Cerebral palsy  
\(^{c}\) Typical development

Discussion

The intra-rater reliability of the measurement of thoracic kyphotic curve with a smartphone application was excellent. In addition, our results showed a strong correlation between smartphone application and inclinometer data in both children with CP and TD children. Additionally, children with CP had a significantly larger thoracic kyphotic curve compared to TD children.

The angle of thoracic kyphotic curve measured by smartphone application in the sitting position showed 42.45±6.05° in children with CP and 31.05±4.64° in TD children. These results are consistent with Barrett et al. (13) who measured an approximately 33.30° thoracic kyphotic curve by inclinometer in thirty healthy adults. Additionally, further previous studies suggest that normal thoracic kyphotic curves range from 20° to 50°. Suh et al. (19) compared this particular curve in adults with CP with healthy volunteers using lateral radiographs. They found that the angle of thoracic kyphotic curve in CP adults (39.10°) was greater than that in the healthy volunteers (33.40°). However, no statistically significant difference was observed between the two groups. In the Suh’s study, thoracic kyphotic curve was measured with lateral radiography in a standing position. In our study, thoracic kyphotic curve was measured in the sitting position. Thoracic kyphotic curve in the sitting position increased more than the standing position. For this reason, there may have been a difference from the results of Suh’s study.

In terms of intra-rater reliability, measurements made using the smartphone application had excellent reliability in children with CP (ICC=0.81-0.98). Was et al. (20) also found that thoracic kyphotic curve assessment with a smartphone application exhibited excellent reliability (ICC=0.80) in 40 healthy adults. Similarly, Furness et al. (21) demonstrated that measuring thoracic rotation range of motion with a smartphone application had excellent intra- (ICC=0.94-0.98) and inter-rater reliability (ICC=0.72-0.89). In agreement with this previous research, our study shows that measuring the angle of thoracic kyphotic curve in CP children using a smartphone application has excellent reliability.

In the present study, the MDC at 90% CI was 4.48 in children with CP, indicating that if the thoracic kyphotic curve changes by more than 4.5° following intervention, clinicians would be able to interpret this as a clinically meaningful change beyond measurement error (22). Additionally, statistically significant correlations were observed between the curve measured by smartphone application and assessed by
inclinometer ($r=0.838$, $p=0.002$). Similarly, Was et al. (20) report no statistical difference when comparing the angles measured by digital inclinometer and smartphone application in both sitting and standing positions.

Overall, the angle of thoracic kyphotic curve was significantly greater in children with CP than in TD children. Measuring the curve using the smartphone application had strong correlations with the traditional inclinometer data and excellent intra-rater reliability. Clinically, the smartphone application might be used as an alternative measurement method for assessing the thoracic kyphotic curve in children with CP. However, since the results of this study were measured in the sitting position, it could not be generalized with the measurement in standing and one-leg standing.

The present study has some limitations. First, this is a short-term study, long-term studies with the minimal important difference will be required in the future. Second, our study did not show inter-rater reliability, it will be needed for clinical application. Finally, in our study, thoracic kyphotic curve was measured in the sitting position. Comprehensive understanding of sagittal spinal curvature will require measuring various postures such as standing and one-leg standing in this population.

**Conclusion**

We found that the thoracic kyphotic curve was significantly greater in children with CP than TD children. Additionally, we confirmed that measuring thoracic kyphotic curvature using a smartphone application is valid and reliable in ambulant children with CP.

**Acknowledgment**

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**Conflict of Interest**

The authors have no conflict of interest to report.

**References**


