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Body Measurements for Designing Hip Dislocation Prevention Garment in Children with Cerebral Palsy

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Abstract

This study aims to provide basic size data for the development of a hip dislocation prevention garment for cerebral palsy (CP) children and useful information for the design of garment products for CP children through identifying differences in body shape between CP and non-CP children and reviewing the tibial-stature prediction formulas of previous studies. Forty-seven Korean children with CP aged 2 to 14 years were measured for body size from October 2019 to August 2020. Body measurements of 18 sites, including greater trochanter length, which is an important site for a hip dislocation prevention garment, were collected and analyzed. Data of non-CP children were taken from same age of Size Korea and compared. Tibial-stature prediction formulas suggested in four previous studies were also reviewed. CP children had significantly lower stature as well as circumferential dimensions when compared to non-CP children. Greater trochanter length is difficult to predict through other body dimensions. Thus, direct measurement is required. Of the general key dimensions used in the clothing industry, only hip circumference could explain the body shape of CP children. Tibial-stature prediction formulas cannot always but tend to largely predict the actual stature of CP children.

Key words: Cerebral palsy, Hip dislocation, Prevention garment, Medial wear, Anthropometric data

I. Introduction

Cerebral palsy (CP) is a non-progressive disorder that occurs in the brain of a fetus or child and appears as a symptom of motor and posture development (Sadowska et al., 2020). The onset of cerebral palsy is due to a combination of factors that occur before or/and after childbirth (Chung et al., 2016). The types of symptoms that appear in children with CP include stiffness, involuntary movement, ataxia, and hypotonia, of which more than one type may appear at the same time (National Institute of Special Education [NISE], 2016). Since there is no ultimate treatment, it is important to manage most of the functions available after diagnosis of an outbreak and to prevent complications of the musculoskeletal system.

One of the most frequent disorders in children with CP is hip dislocation, including subluxation and dislocation, which is a symptom in which the ball-shaped femoral head is separated from the socket-shaped pelvic acetabulum. Hip dislocation occurs frequently in children with gait impairment among children with spastic paralysis CP, and has been reported to occur mainly around the age of 5 to 7. Opinions on the surgical treatment of hip dislocation differ from researchers. However, if the femoral head is dislocated more than 30%, surgical treatment is needed. However, since surgical treatment causes severe pain to the pa-

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tient and burdens the caregiver with a rehabilitation period and cost, it is important to perform preventive treatment such as wearing treatment tools, medication, and exercise therapy before proceeding to dislocation that requires surgical treatment (Chung et al., 2016).

Previous studies on the prophylactic treatment of hip dislocation in children with CP suggested that hip compression bandages significantly reduce adductor spasticity and thus, could be used as a non-invasive dislocation treatment method (Kim et al., 2019). The bandage-type tools have the advantage of providing a significant treatment effect with small pain on the patient, but has the disadvantage that a medical professional should treat it to apply pressure to the correct position. To provide continuous stimulation for effective preventive treatment, it is necessary to develop medical wear that can apply a pressure stimulus to the correct location only by wearing it so that patients and caregivers can extend the treatment themselves at home without the help of experts.

One of the physical therapy methods that can help the development of children with CP, suit therapy, is a therapy that improves body cognition, bone and joint development, and postural stability by wearing a clothing-type treatment aid tool (NISE, 2016). The result of improving the motor skills of children with CP when applying Adeli suit therapy, one of the representative suit treatments, has already been verified through several studies (Mahani et al., 2011; Martins et al., 2016). Since such a suit treatment is portable, it can continuously provide non-invasive stimulation that is helpful for treatment. Thus, suit therapy can be said to be a very suitable treatment for CP children with the non-progressive permanent disorder.

To provide an effective suit treatment, pressure or stimulation must act accurately on the body part of the subject. Thus, understanding of the body shape of the suit wearer must be preceded. In general, the growth rate of children with CP is lower than that of children of the same age due to movement disorders and impaired oral-motor function (Tomoum et al., 2010). Since it is difficult to evaluate the growth of children with CP using the growth indicator of children without CP, many studies have been conducted to suggest a new growth chart that considers the development characteristics of children with CP (Araújo & Silva, 2013; Brooks et al., 2011; Duran et al., 2019; Wright et al., 2017). The growth chart for children with CP developed in the previous study mainly uses anthropometric measurements such as stature, age, and weight. These measurements help to assess the nutritional and developmental status of CP children, but it is insufficient to grasp body shape for garment development.

It is difficult for CP children to obtain body measurements when compared to non-CP children. CP children find it difficult to maintain a standing posture due to motor disorder caused by nervous system abnormalities. For example, when checking a growth chart or designing the size of a garment product, the most generally used measurement is stature. Stature is one of the easiest measurements to collect from a standing subject, and at the same time, it is one of the most difficult measurements for CP children who are unable to walk or have difficulty standing upright. To overcome the limitation of measuring the stature of children with CP, regression equations that can predict stature through easily measured segmental measurements, have been proposed (Gauld et al., 2004; Kihara et al., 2015; Smith, 2007; Stevenson, 1995). However, the list of segmental dimensions used in this regression equation is different from the list of body dimensions required for garment product design, and the population of collected data is also different. Thus, there is a limitation in the application. To apply the regression equation suggested in previous studies to the development of medical wear for children with CP in South Korea (hereafter, Korea), the process of verifying the equations from the aspect of garment design must be preceded.

Therefore, this study aims to analyze body measurements for children with CP and to provide basic anthropometric data for designing hip dislocation prevention garments. We compare body measurements of CP children with the SK children to understand the body shape difference between the two groups and we verify segmental-stature regression equations proposed in previous studies to examine the applicability as garment size data.

II. Methods

The subjects of this study were children between the age of 1 to 15 who were diagnosed with cerebral palsy and who had hip dislocation but had never undergone surgical operation. Body dimensions were measured for 49 subjects who visited three designated hospitals in Korea from October 2019 to August 2020 with voluntary consent from their parents. After testing the Gross Motor Function Classification System (GMFCS) level of the subjects, only children with levels IV and V were filtered to analyze the target for motor function similarity of the study subjects. Finally, 47 CP children, consisting of 30 boys and 17 girls between the age of 2 to 14, were chosen as the study subjects (Table 1). The entire process of data collection and analysis was conducted under prior approval from the Chungbuk National University Bioethics Review Committee (IRB. No. CBNU-202004-SBETC-0063).

Table 1. Demographic information of CP children subject to anthropometrics *N* = 47

	Type	*N*
Sex	Male	30
	Female	17
GMFCS level	IV	18
	V	29

CP: Cerebral Palsy, GMFCS: Gross Motor Function Classification System

The anthropometrics were measured in 18 measurements consisting of 7 items of length, 9 items of circumference, and 2 other items such as weight and Body Mass Index (BMI) (Table 2). The measurements were listed through discussions of four experts in rehabilitation treatment and clothing construction, and were consisted of body measurements that seemed ne-

Table 2. Anthropometrics and anthropometer methods for CP children

Measurement		Anthropometer method
Length	Stature	Straight length from sole to vertex of head
	Leg length	Length from lateral waist to lateral malleolus through lateral patella
	Greater trochanter length	Length from lateral waist to greater trochanter
	Knee length (Tibial)	Length from lateral patella to lateral malleolus
	Crotch length	Length from anterior waist to posterior waist through crotch
	Waist to hip length	Length from lateral waist to buttock protrusion level
	Thigh vertical length	Straight length from gluteal fold to posterior juncture of calf and thigh
Circumference	Chest circ.	Horizontal circumference through mesosternum
	Hip circ.	Horizontal circumference through buttock protrusion
	Waist circ.	Horizontal circumference through waist
	Thigh circ.	Horizontal circumference through gluteal fold
	Midthigh circ.	Horizontal circumference through midthigh
	Knee circ.	Horizontal circumference through midpatella
	Calf circ.	Horizontal circumference through calf protrusion
	Waist circ. (O.)	Horizontal circumference through omphalion
	Minimum leg circ.	Horizontal circumference through inferior leg
Others	Weight	Body weight
	BMI (kg/m^2)	Weight (kg) divided by square of the stature (m)

Circ.: Circumference, O.: Omphalion level, BMI: Body Mass Index cessary to develop a prevention garment for hip dislocation. The measurement method was based on the report about dynamic and static anthropometric guides for CP patients (Korean Agency for Technology and Standards [KATS], 2016). Since CP children cannot stand upright, they were measured while lying on a bed. Measurements were taken undressed, except for diapers, as CP children always wear diapers. Greater trochanter position is an important position because it serves as a stimulation point for preventing hip dislocation <Fig. 1>, but it has not been defined anthropometrically. Therefore, to specify the location of the greater trochanter in a form that can be used in designing medical wear, the tape measured length along the body surface from the waist lateral point to the greater trochanter location was defined as the greater trochanter length (Table 2).

Correlation coefficients were calculated for each body measurement and age to look at the measurements that can represent the body shape of CP children. We focused on the correlation in stature, chest circumference, waist circumference (omphalion level), and hip circumference, which are mainly used body measurements when manufacturing garment products, and greater trochanter length, which is very important in the development of hip dislocation prevention garment for CP children. The correlation coefficients for each variable were sorted in descending order, and only the top 10 anthropometrics were presented.

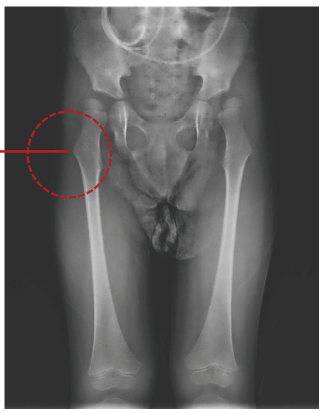


Fig. 1. Radiology image of greater trochanter position.

As a control group to compare the body shape of CP children and non-CP children, the measurements of children between the age of 2 to 14 of the 5th Size Korea (SK) were analyzed (KATS, 2004). The 5th SK data is the latest data that provides Korean body dimensions from 2 to 14 years old. First, the body dimensions of 47 CP children and 6,425 SK children in the same age group were compared. Second, we extracted 1,739 data points from 6,425 SK children referring to 47 CP children data points using the stratified random sampling method since the gender distribution of CP children data was uneven. The stature quartile level of CP children was considered, not chronological age, to compare body measurements in the same stature group since the stature growth rate of CP children is significantly lower than non-CP children (Wright et al., 2017). The overall process of filtering CP and SK children data is shown in <Fig. 2>. There were no tape measurements of leg length and knee length in the SK data, which were calculated by subtracting lateral malleolus height from outside leg length and knee height, respectively. Considering that some of the SK children data were measured only for children aged 7 years or older, each measurement was analyzed using mean, standard deviation, and two-sample *t*-test.

To examine the possibility of using the segment-stature prediction formula when developing medical wear, the stature of each child of CP and SK was predicted with 4 tibial-stature prediction formulas, which are relatively accurate. The prediction formulas used in this study and the group of subjects used to derive the formulas are shown in <Table 3>. Predicted stature was compared with measured stature using paired *t*-test.

All data were entered in csv file format and analyzed with R Statistics (R Core Team, 2021).

III. Results

The distribution of stature measurements by the chronological age of CP and SK children between the

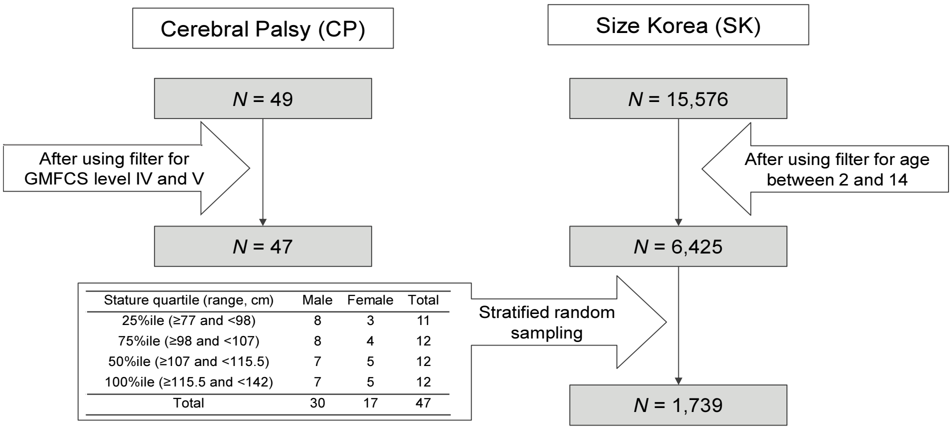


Fig. 2. Data filtering.

Table 3. Tibial-Stature prediction formulars of four references

References	Subject			Stature (cm) prediction formula
	Clinical status	Age	n (% of male)	
Stevenson (1995)	CP	2-12	172 (56.5)	3.260 (TL) + 30.800
Gauld et al. (2004)	Normal	5-19	2,343 (48.8)	Male: 2.758 (TL) + 1.717 (Age) + 21.818
				Female: 2.771 (TL) + 1.457 (Age) + 3 7.748
Smith (2007)	CP	3-10	67 (46.3)	3.519 (TL) + 38.614
Kihara et al. (2015)	CP	3-12	50 (54.0)	3.250 (TL) – 2.630 + 0.170 (TL) + 34.450
	Normal	3-12	38 (60.5)	3.250 (TL) + 34.450

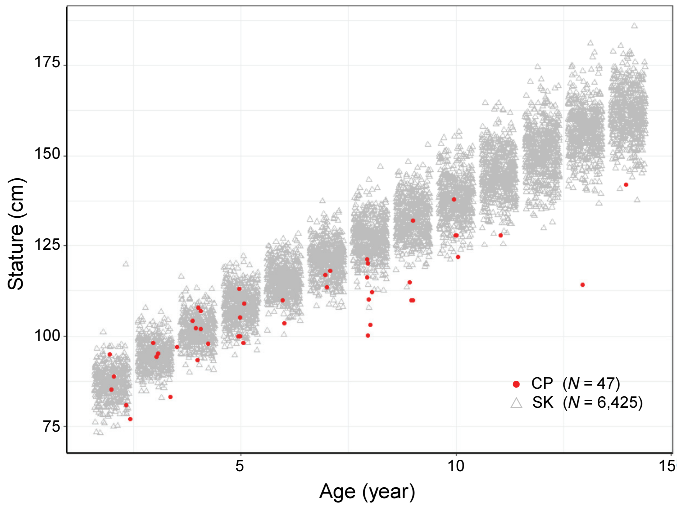
TL: Tibial, CP: Cerebral Palsy

age of 2 to 14 is shown in <Fig. 3>. In the case of children under 5 years of age, the difference between CP and SK children was not evident. However, from 6 years of age, the stature of CP children was smaller than that of SK children of the same age.

<Table 4> shows the correlation between each body measurement and age in CP children data. Many measurements with a high correlation coefficient of 0.700 or more were observed with hip circumference. Stature was found to have a high correlation with length measurements such as leg length, as well as weight, knee circumference, chest circumference, and hip circumference. The measurements highly correlated with the greater trochanter length, appeared in the order of weight, stature, and leg length. However, the correlation coefficients were relatively low values.

<Table 5> shows the mean, standard deviation, and *t*-test results of the data of 47 CP children and 1,739 SK children who were stratified random sampled based on gender and stature distributions of CP children data. Even with the data of SK children with the same stature distribution as those of CP children, significant mean differences were found in all comparable measurements except stature and chest circumference. The age of CP children was significantly higher (p<.05) than that of SK children, which means that CP children are shorter than non-CP children of the same age. Hip circumference, thigh circumference, calf circumference, waist circumference (omphalion level), weight, and BMI were significantly smaller (p<.001) for CP children than SK children.

In <Fig. 4>, the difference between the estimated



CP: Cerebral Palsy, SK: Size Korea

Fig. 3. Relation between stature and age for CP (*N* = 47) and SK (*N* = 6,425).

Table 4. Correlation coefficient of 5 key body dimensions of CP children

N = 47 (Top 10 dimensions in descending order)

Rank	Stature	*r*	Chest circ.	*r*	Waist Circ. (O.)	*r*	Hip circ.	*r*	Greater trochanter length	*r*
1	Leg length	0.961	Hip circ.	0.842	Waist circ.	0.947	Thigh circ.	0.891	Weight	0.578
2	Weight	0.900	Weight	0.815	Hip circ.	0.742	Knee circ.	0.856	Stature	0.547
3	Age	0.868	Knee circ.	0.797	Chest circ.	0.717	Midthigh circ.	0.845	Leg length	0.547
4	Knee length	0.785	Midthigh circ.	0.773	Knee circ.	0.665	Chest circ.	0.842	Midthigh circ.	0.469
5	Knee circ.	0.752	Leg length	0.747	Thigh circ.	0.641	Weight	0.825	Calf circ.	0.463
6	Chest circ.	0.729	Thigh circ.	0.732	Midthigh circ.	0.616	Calf circ.	0.772	Crotch length	0.461
7	Hip circ.	0.705	Stature	0.729	Weight	0.579	Waist circ. (O.)	0.742	Knee circ.	0.448
8	Crotch length	0.605	Waist circ. (O.)	0.717	Crotch length	0.558	Waist circ.	0.742	Waist to hip length	0.426
9	Thigh circ.	0.560	Waist circ.	0.657	Minimum leg circ.	0.512	Leg length	0.733	Hip circ.	0.420
10	Midthigh circ.	0.550	Calf circ.	0.634	Calf circ.	0.486	Stature	0.705	Knee length	0.417

CP: Cerebral Palsy, Circ.: Circumference, O.: Omphalion level

stature calculated by four tibial-stature prediction formulas from preceding studies and measured stature is presented as a box plot. Except for Gauld et al. (2004), all previous studies showed that the stature of CP children were predicted significantly ($p<.001$) larger than the actual stature. When predicting the stature of SK children with the same prediction formulas, Smith (2007) predicted significantly ($p<.001$) larger than the actual stature and the other three prediction formulas from Stevenson (1995), Gauld et al. (2004) and Kihara et al. (2015).

Ⅳ. Discussion

This study identified the body shape characteristics of CP children through comparison with those of SK children and examined whether the segment-stature prediction formula presented in previous studies can

Table 5. Differences between CP and SK children on body dimensions Unit: cm

	CP			SK			*t*-value
	N	Mean	(S.D.)	*N*	Mean	(S.D.)	
Age (year)	47	6.2	(3.1)	1,739	5.2	(2.4)	2.7*
Stature	47	107.0	(14.7)	1,739	109.0	(14.7)	–.8
Leg length†	47	58.1	(10.7)	437	73.9	(6.0)	-
Greater trochanter††	34	11.4	(3.0)	-	-	-	-
Knee length (Tibial)†	45	26.6	(5.9)	437	27.7	(2.7)	-
Crotch length†	47	45.5	(7.3)	438	55.7	(5.4)	-
Waist to hip length†	47	11.1	(2.7)	438	16.3	(2.3)	-
Thigh vertical length†	45	21.3	(6.8)	438	21.7	(2.5)	-
Chest circ.	47	57.4	(6.2)	1,739	57.2	(6.3)	.2
Hip circ.	47	54.8	(7.6)	1,734	58.7	(7.5)	–3.6***
Waist circ.†	46	47.5	(5.2)	438	57.5	(6.4)	-
Thigh circ.	47	29.4	(5.8)	1,736	34.4	(5.3)	–6.4***
Midthigh circ.†	47	24.8	(4.7)	438	36.5	(4.2)	-
Knee circ.†	47	21.8	(2.9)	438	28.4	(2.7)	-
Calf circ.	47	18.8	(2.7)	1,738	23.3	(3.0)	–10.4***
Waist circ. (O.)	46	47.3	(5.2)	1,737	53.1	(6.1)	–6.4
Minimum leg circ.†	47	13.8	(1.6)	437	17.8	(1.5)	-
Weight (kg)	47	16.3	(4.3)	1,737	19.8	(6.5)	–3.7***
BMI	47	14.2	(2.7)	1,737	16.4	(1.8)	–8.0***

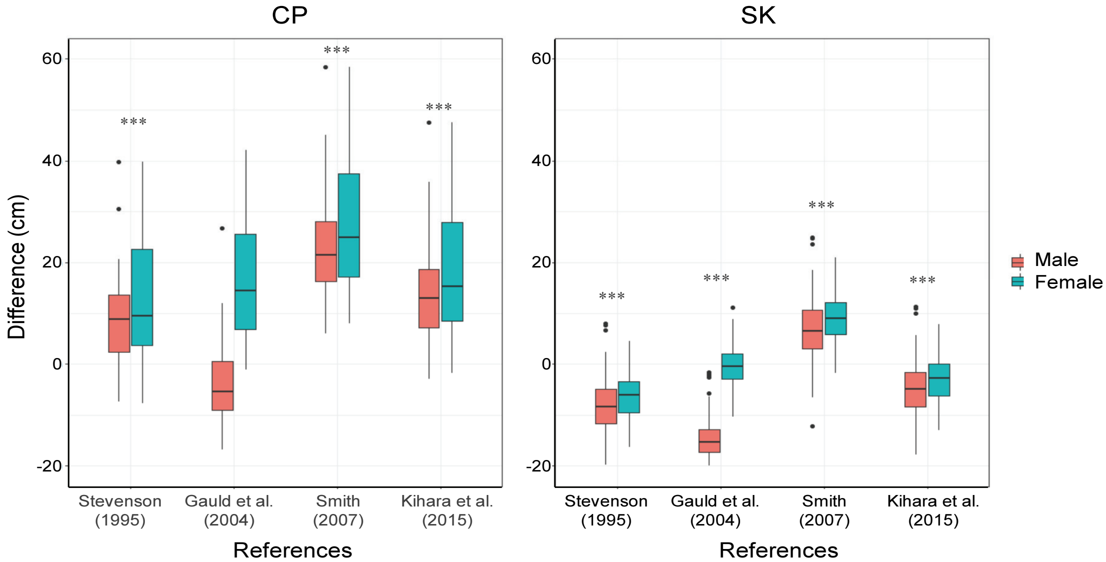
*p<.05, ***p<.001
CP: Cerebral Palsy, SK: Size Korea, BMI: Body Mass Index, Circ.: Circumference, O.: Omphalion level
†: There is no data for age 1 to 6 in Size Korea.
††: There is no data in Size Korea.

utilize clothing product size information for CP children.

The stature growth rate of CP children is similar to that of SK children until the age of 5. However, from the age of 6, growth is significantly slower than that of SK children. When compared with the data sampled by the same sex and height distribution as those of CP children among SK children data, CP children's hip circumference, thigh circumference, calf circumference, waist circumference (omphalion level), weight, and BMI were smaller than that of SK children. In other words, CP children have a lower vertical growth rate than non-CP children of the same age, and their circumference and weight growth rates are lower than those of similar height groups. Many previous studies have also reported that the growth rate of CP children is lower than non-CP children.

It should be noted that although the hip circumference of CP children was measured wearing a diaper, the hip circumference was smaller than that of non-CP children of the same stature. The reason for the growth failure of CP children is insufficient nutrition intake due to various disorders. Kim (2007) reported that only 15% of children with CP had the self-eating ability. Sullivan (1997) reported that poor dentition, early satiety, behavioral disorders, and communicational disorders in CP children cause difficulty in nutritional intake, and oral-motor dysfunctions were the most negative influencing factors. Tomoum et al. (2010) also reported that in the severity of disability in CP children, both growth and nutritional status decrease.

The systemic motor dysfunction of CP children al-



***p<.001
CP: Cerebral Palsy, SK: Size Korea

Fig. 4. Mean difference between estimated stature from the tibial-stature prediction formula and the measured stature.

so interferes with muscle development, which seems to affect the growth of their circumferential dimensions. Duran et al. (2019) stated that the more severe the degree of motor dysfunction, the higher the body fat rate. Thus, the evaluation of children's nutritional status should not be based solely on weight and stature. Considering the fact that the severity of the disability affects food intake and body composition, including body fat of CP children, the degree of disability is an essential factor in developing their garments.

Custom-made might be required in the medical wear development since the body shape of CP children does not appear in age-proportional size like the existing sizing system. However, custom-made cannot be recommended in terms of product availability because CP children and their caregivers can be forced to afford extremely high costs and extra time for it. Therefore, it would be effective to develop a sizing system for CP children and introduce a combined pattern drafting method that applies only a few custom measurements of the key dimensions to medical wears such as a grater trochanter length.

In this study, the correlation between the stature and age of CP children was relatively high. However, when considering the fact that circumferential measurements including chest circumference showed a low correlation with age, the representativeness of age as body size indices is very low. The measurement showing a high correlation in common among the key dimensions mainly used in the manufacture of garments was hip circumference, which can be interpreted that the hip circumference has greater representativeness for explaining the body size of CP children when compared to other dimensions. The current Korean sizing system standard for infant's garments (KATS, 2019a) sets stature and age for boy's and girl's garments (KATS, 2019b, 2019c) and sets chest circumference, waist circumference, and hip circumference as basic body dimensions. However, in the case of CP children, since all these dimensions except the hip circumference do not have the representativeness of the CP children's body size, the hip circumference can be considered as a new key dimension in the sizing system for CP children.

In order to prevent hip dislocation that occurs frequently in children with CP, it is necessary to support the hip joint head in the acetabular, and for this purpose, compression centered on the greater trochanter is required (Kim et al., 2019). As such, the greater trochanter is a very important part of the design of hip dislocation prevention garments for CP children. Thus, it is necessary to find a way to specify the exact location of this part on their body surface. We defined the greater trochanter length measurement method and collected CP children's data to determine the location of the greater trochanter that can be used in the garment. However, we did not find a strong correlation between this dimension and other dimensions. Therefore, the location of the greater trochanter should be determined through direct tape measurement for each wearer. CP children's hip dislocation prevention garment should have a different size from typical development children's trousers as they apply the custom measured greater trochanter length.

The tibial-stature prediction formulas of preceding studies could not predict the actual children's height in both CP and SK. The reason for this result appears to be that the ethnicity of the data for which the regression equation was calculated is different from that of the subjects of this study. Although it was confirmed that there is a limitation on directly applying the prediction formulas of the preceding studies to the data of CP children in Korea, the tendency that formulas predict stature larger than the actual stature, was observed. The stature formula using a segmental dimension is very useful when acquiring the stature information of the CP children who have difficulty standing up. However, there are insufficient reports for Korean CP children (Han et al., 2001). This study has only been able to grasp the problem tendency of the existing prediction formulas. If the segment-stature prediction formula for Korean CP children is developed based on this result, it will be possible to provide good data not only for the design of CP children's garment products but also in the areas related to nutritional status evaluation.

This study is meaningful in that it provides size information of CP children from the aspect of garment product development. However, this study has limitations in the analyses and results interpretation due to the wide range of age groups and gender inequality. It is also meaningful that we use a novel methodology for random sampling comparison data using stratified layers in consideration of the characteristics of the study objects. This has an academic value in that the existing stature prediction formula was verified with data of CP and non-CP children in Korea, and the possibility of its use was discussed. The results of this study are basic data for developing hip dislocation prevention garments for CP children. Based on this study, the development of clothing sizes and patterns that reflect changes in body type due to the severity and various factors on growth stage (e.g., feeding method, treatment, or GMFCS level changes) should be developed in a follow-up study. It is expected that the results and methodology of this study can be an important reference for various types of medical wear and devices for CP children.

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