



Original Article

Correlation between the Gait Deviation Index and skeletal muscle mass in children with spastic cerebral palsy

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Abstract. [Purpose] This study aimed to identify a simple and useful muscle parameter for use with the Gait Deviation Index in assessment of ambulatory children with unilateral and bilateral spastic cerebral palsy. [Participants and Methods] Twenty-eight patients (aged 6 to 18 years; 16 females and 12 males) participated in this cross-sectional study. Outcome measurements included the Gait Deviation Index, grip strength, 5-repetition chair stand test, upper limb skeletal muscle mass index, and lower limb skeletal muscle mass index. [Results] By multiple regression analysis, significant independent correlations were observed between the Gait Deviation Index and 5-repetition chair stand test and the Gait Deviation Index and lower limb skeletal muscle mass index, but not between the Gait Deviation Index and grip strength or upper limb skeletal muscle mass index. [Conclusion] The Gait Deviation Index was correlated with lower limb muscle mass in children with spastic cerebral palsy. Determination of lower limb muscle mass may be useful gait evaluation.

Key words: Cerebral palsy, Gait Deviation Index, Skeletal muscle mass index

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INTRODUCTION

Three-dimensional gait analysis (3DGA) is a well-known assessment tool used in children with cerebral palsy (CP) to support decision making before lower limb orthopedic surgery and to assess surgical outcomes¹⁾. 3DGA provides a large amount of data in the form of graphs that express joint motions (kinematics), as well as moment and power (kinetics) of the pelvis, hip, knee, and ankle joints in three planes (sagittal, frontal, and transverse)²⁾. However, results of 3DGA are complex and require a skilled interpreter.

Schwartz and Rozumalski developed a new comprehensive index of gait pathology named the Gait Deviation Index (GDI) in 2008. The GDI is derived from 3DGA and provides numerical values indicating overall gait pathology (0–100; ≥ 100 indicates absence of gait pathology). Every 10-point decrease in the GDI corresponds to one standard deviation from

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the mean of healthy controls³).

Muscle weakness⁴ and reduced muscle mass^{5–12} in children with CP have been well documented. A previous study reported that muscle mass could be used to select, and assess the outcomes of, interventions in clinical settings^{13, 14}. Meanwhile, lower muscle strength has been shown to predict independent ambulation in children with CP¹⁵, and an association with the GDI has been suggested¹⁶. To our knowledge, no studies have examined the relationship between the GDI and skeletal muscle mass index (SMI) in children with CP.

This study aimed to investigate correlations among the GDI, upper limb SMI (USMI), lower limb SMI (LSMI), and muscle strength (i.e., grip strength [GS] and 5-repetition chair stand test [5-CS]) in ambulatory children with unilateral and bilateral spastic CP.

PARTICIPANTS AND METHODS

This study was carried out over a 24-month period (April 2016 through March 2018) in general practice. Twenty-eight patients (16 females and 12 males; body weight, 32.8 ± 10.7 kg; height, 134.9 ± 16.1 cm) aged between 6–18 years (mean age, 10.5 ± 3.8 years) were recruited based on 3DGA data, which is conducted before orthopedic surgery. All children aged 6 to 18 years who had unilateral and bilateral spastic CP at Gross Motor Function Classification System (GMFCS) level I–II and had undergone a clinically indicated 3DGA were included in this study. Exclusion criteria were children with significant illness, injury, or surgery within one year that might have affected the usual activity levels in the community; those who were unable to complete 3DGA; and those who were unable to complete a physical test. This study was conducted with the approval of the Ethical Review Committee at Aichi Prefecture Mikawa Aoitori Medical and Rehabilitation Center for Developmental Disabilities (approval number: 29002). Written consent was obtained from each child's guardian.

3DGA data were collected using the Vicon Motion Systems with eight MX-T cameras sampling at 100 Hz and eight AMTI OPT force plates (Advanced Mechanical Technology, Inc., Watertown, MA, USA). The data were processed with Plug-in-Gait software for Workstation and NEXUS (Vicon Motion Systems, Oxford, UK). Reflective markers were placed according to the Plug-in-Gait Lower Body-Ai model (Vicon Motion Systems). Markers of 14 mm were placed on the bilateral anterior superior iliac spine, posterior superior iliac spine, lateral femoral, lateral condyle of femur, lateral lower leg, lateral malleolus of ankle joint, head of the second metatarsal, and calcaneus. The GDI was calculated for each participant from a representative gait cycle for both the left- and right-hand sides. The mean of three trials was used for the analysis as previously reported^{17–19}.

Outcome measurements including GS, 5-CS, USMI, and LSMI were obtained on the 3DGA day. GS was collected using TKK5401 (Takei, Inc., Japan) in a sitting position. 5-CS was measured according to a report by Nakazono et al²⁰. The SMI was measured using the method of bioelectrical impedance analysis (MC-780; TANITA, Inc., Japan) and was divided by the square of the height.

Levels of associations between the GDI and GS, 5-CS, USMI, and LSMI were tested using Pearson correlation coefficients. A multiple linear regression analysis was performed to examine correlations between the GDI and 5CS and the GDI and LSMI. The analysis was adjusted for confounding variables including GMFCS level and gender using a stepwise procedure. All analyses were performed with SPSS (Version 24.0; IBM Corp., Armonk, NY, USA). $P < 0.05$ was considered statistically significant.

RESULTS

A total of 28 patients were recruited in this study. The mean GDI was 77.3 ± 12.1 , indicating a decrease of more than 2 SD compared to normal gait (Table 1). A moderate association was observed between the GDI and 5-CS ($r = -0.43$, $p < 0.05$), and between the GDI and LSMI ($r = 0.41$, $p < 0.05$). No correlation was observed between the GDI and GS or USMI (Table 2).

The multiple linear regression analysis adjusted for potentially confounding variables including GMFCS level and gender revealed significant independent correlations between the GDI and 5-CS and the GDI and LSMI (Table 3).

DISCUSSION

To our knowledge, this is the first study to show the association between the GDI and lower muscle mass in children with spastic CP. Moderate independent correlations were observed between the GDI and 5-CS, and between the GDI and LSMI (Adjusted $R^2 = 0.247$). These results suggest that medical workers should evaluate both lower muscle strength and lower muscle mass when assessing gait in children with spastic CP.

In this study, the associations between the GDI and 5-CS and the GDI and LSMI were not affected by gender, GMFCS level. Although a correlation between the GDI and GMFCS level (I–III) has been reported²¹, LSMI was more strongly associated with the GDI than with GMFCS level in children with spastic CP (GMFCS level I–II). This finding suggests that a reduced LSMI may reflect reduced gait ability in children with CP.

The present study also showed an independent association between the GDI and lower muscle strength. However, muscle strength is sometimes difficult to measure in children with spastic CP due to restricted range of motion and spasm. Thus,

Table 1. Demographic characteristics of patients

Characteristics	n=28
Age (years)	10.5 ± 3.8
Gender: F/M	16/12
GMFCS level: I/II	13/15
Bilateral/unilateral CP	21/7
GDI (scores)	77.3 ± 12.1
GS (kg)	15.8 ± 8.8
5-CS (seconds)	9.3 ± 3.5
USMI (kg/m ²)	1.2 ± 0.2
LSMI (kg/m ²)	4.7 ± 0.7

Mean ± SD. GMFCS: Gross motor function classification system; CP: Cerebral palsy; GDI: Gait deviation index; GS: Grip force; 5-CS: 5-repetition chair stand test; USMI: Upper limbs skeletal muscle mass index; LSMI: Lower limbs skeletal muscle mass index.

Table 2. Correlation between GDI, GS, 5CS, USMI, and LSMI

Property	Coefficient of correlation				
	GDI	GS	5CS	USMI	LSMI
GDI					
GS	0.34				
5-CS	-0.43*	-0.15			
USMI	0.30	0.87**	-0.04		
LSMI	0.41*	0.79**	-0.14	0.86**	

**Significant at the 0.01 level. *Significant at the 0.05 level. GDI: Gait deviation index; GS: Grip force; 5-CS: 5-repetition chair stand test; USMI: Upper limbs skeletal muscle mass index; LSMI: Lower limbs skeletal muscle mass index.

Table 3. Results of a multiple linear regression analysis

Predictors	Adjusted R ² , 0.247	β	95% confidence interval		p-value
			Lower bound	Upper bound	
5-CS		-0.37	-2.5	-0.09	0.036
LSMI		0.35	0.08	12.31	0.047

The analysis was adjusted for gender and GMFCS level. 5-CS: 5-repetition chair stand test; LSMI: Lower limbs skeletal muscle mass index.

a decrease in LSMI may indicate a reduction in the GDI due to gait instability. The results of the present study have some clinical implications for gait analysis in patients with CP, and suggest that variables derived from LSMI can be used as predictive factors of gait function.

There are some limitations worth noting. First, muscle activity was not measured in this study. Since spasm is affected by degeneration of peripheral muscle tissue²², the association between the GDI and lower muscle mass might be affected by spasm. Second, the average GDI was used, instead of calculating the GDI for individual legs, as both bilateral and unilateral CP patients were included in this study. However, 5-CS and SMI were measured for both limbs. Yet, the average GDI was used, because in patients with unilateral CP, the unaffected side may show compensatory changes, whereas in patients with bilateral CP, involvement can be asymmetric²³.

In conclusion, a significant association was observed between the GDI and lower muscle mass in children with spastic CP. This finding suggests that lower muscle mass may provide a useful tool for gait evaluation. A further study will be necessary to explore this possibility.

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Conflict of interest

The authors have no other financial disclosures and conflict of interest to report.

REFERENCES

- 1) Wilson NC, Chong J, Mackey AH, et al.: Reported outcomes of lower limb orthopaedic surgery in children and adolescents with cerebral palsy: a mapping review. *Dev Med Child Neurol*, 2014, 56: 808–814. [[Medline](#)] [[CrossRef](#)]
- 2) Gage JR: *Gait analysis in cerebral palsy*, vol xv. New York: Cambridge University Press, 2012, p 206.
- 3) Schwartz MH, Rozumalski A: The Gait Deviation Index: a new comprehensive index of gait pathology. *Gait Posture*, 2008, 28: 351–357. [[Medline](#)] [[CrossRef](#)]
- 4) Wiley ME, Damiano DL: Lower-extremity strength profiles in spastic cerebral palsy. *Dev Med Child Neurol*, 1998, 40: 100–107. [[Medline](#)] [[CrossRef](#)]
- 5) Fry NR, Gough M, McNee AE, et al.: Changes in the volume and length of the medial gastrocnemius after surgical recession in children with spastic diplegic cerebral palsy. *J Pediatr Orthop*, 2007, 27: 769–774. [[Medline](#)] [[CrossRef](#)]
- 6) Oberhofer K, Stott NS, Mithraratne K, et al.: Subject-specific modelling of lower limb muscles in children with cerebral palsy. *Clin Biomech (Bristol, Avon)*, 2010, 25: 88–94. [[Medline](#)] [[CrossRef](#)]
- 7) Elder GC, Kirk J, Stewart G, et al.: Contributing factors to muscle weakness in children with cerebral palsy. *Dev Med Child Neurol*, 2003, 45: 542–550. [[Medline](#)] [[CrossRef](#)]
- 8) Barber L, Hastings-Ison T, Baker R, et al.: Medial gastrocnemius muscle volume and fascicle length in children aged 2 to 5 years with cerebral palsy. *Dev Med Child Neurol*, 2011, 53: 543–548. [[Medline](#)] [[CrossRef](#)]
- 9) Barrett RS, Lichtwark GA: Gross muscle morphology and structure in spastic cerebral palsy: a systematic review. *Dev Med Child Neurol*, 2010, 52: 794–804. [[Medline](#)] [[CrossRef](#)]
- 10) Malaiya R, McNee AE, Fry NR, et al.: The morphology of the medial gastrocnemius in typically developing children and children with spastic hemiplegic cerebral palsy. *J Electromyogr Kinesiol*, 2007, 17: 657–663. [[Medline](#)] [[CrossRef](#)]
- 11) Shortland A: Muscle deficits in cerebral palsy and early loss of mobility: can we learn something from our elders? *Dev Med Child Neurol*, 2009, 51: 59–63. [[Medline](#)] [[CrossRef](#)]
- 12) Noble JJ, Fry NR, Lewis AP, et al.: Lower limb muscle volumes in bilateral spastic cerebral palsy. *Brain Dev*, 2014, 36: 294–300. [[Medline](#)] [[CrossRef](#)]
- 13) McNee AE, Gough M, Morrissey MC, et al.: Increases in muscle volume after plantarflexor strength training in children with spastic cerebral palsy. *Dev Med Child Neurol*, 2009, 51: 429–435. [[Medline](#)] [[CrossRef](#)]
- 14) Tok F, Ozçakar L, Safaz I, et al.: Effects of botulinum toxin-A on the muscle architecture of stroke patients: the first ultrasonographic study. *J Rehabil Med*, 2011, 43: 1016–1019. [[Medline](#)] [[CrossRef](#)]
- 15) Davids JR, Oeffinger DJ, Bagley AM, et al.: Relationship of strength, weight, age, and function in ambulatory children with cerebral palsy. *J Pediatr Orthop*, 2015, 35: 523–529. [[Medline](#)] [[CrossRef](#)]
- 16) Sagawa Y Jr, Watelain E, De Coulon G, et al.: Are clinical measurements linked to the gait deviation index in cerebral palsy patients? *Gait Posture*, 2013, 38: 276–280. [[Medline](#)] [[CrossRef](#)]
- 17) Desloovere K, Molenaers G, Feys H, et al.: Do dynamic and static clinical measurements correlate with gait analysis parameters in children with cerebral palsy? *Gait Posture*, 2006, 24: 302–313. [[Medline](#)] [[CrossRef](#)]
- 18) Öunpuu S, Gorton G, Bagley A, et al.: Variation in kinematic and spatiotemporal gait parameters by Gross Motor Function Classification System level in children and adolescents with cerebral palsy. *Dev Med Child Neurol*, 2015, 57: 955–962. [[Medline](#)] [[CrossRef](#)]
- 19) Pool D, Valentine J, Bear N, et al.: The orthotic and therapeutic effects following daily community applied functional electrical stimulation in children with unilateral spastic cerebral palsy: a randomised controlled trial. *BMC Pediatr*, 2015, 15: 154. [[Medline](#)] [[CrossRef](#)]
- 20) Nakazono T, Kamide N, Ando M: The reference values for the chair stand test in healthy Japanese older people: determination by meta-analysis. *J Phys Ther Sci*, 2014, 26: 1729–1731. [[Medline](#)] [[CrossRef](#)]
- 21) Malt MA, Aarli Å, Bogen B, et al.: Correlation between the gait deviation Index and gross motor function (GMFCS level) in children with cerebral palsy. *J Child Orthop*, 2016, 10: 261–266. [[Medline](#)] [[CrossRef](#)]
- 22) Sheean G: The pathophysiology of spasticity. *Eur J Neurol*, 2002, 9: 3–9, 53–61. [[Medline](#)] [[CrossRef](#)]
- 23) Sangeux M, Wolfe R, Graham HK: One side or two? *Dev Med Child Neurol*, 2013, 55: 786–787. [[Medline](#)] [[CrossRef](#)]