

Original Article

Kinetic Relationships between the Hip and Ankle Joints during Gait in Children with Cerebral Palsy: A Pilot Study

MISAKO ISHIHARA, MS^{1, 2}*, YUMI HIGUCHI, PhD¹

¹) Graduate School of Comprehensive Rehabilitation, Osaka Prefecture University: 3-7-30, Habikino, Habikino-shi, Osaka 583-8555, Japan

²) Department of Rehabilitation, Iseikai Gakkentoshi Hospital, Japan

Abstract. [Purpose] The purpose of this study was to evaluate kinetic relationships between the ankle and hip joints during gait, in the late stance, in children with spastic cerebral palsy (CP). [Subjects] The subjects were 3 ambulant children with spastic hemiplegic CP (aged 10, 13, and 14: CP group) and 3 typically developing children with the same ages (control). [Methods] A three-dimensional gait analysis including force data was performed to compare the peak moment, power, and ankle/hip power ratio between the hemiplegic (uninvolved and hemiplegic) and the control groups. In the statistical analysis, mean values from 5 gait cycles for each of 3 conditions (uninvolved, hemiplegic and control) were used. The three conditions were compared by performing a Kruskal-Wallis test and Steel-Dwass multiple comparisons. [Results] The peak moments of ankle plantar flexors in the 10-year-old case, were significantly lower on the uninvolved and hemiplegic sides compared with the control group, respectively. The peak flexion moments of the hip on the hemiplegic side were significantly higher compared with the control in the 14- and 13-year-old cases. The peak of ankle power generation (A2) in the 13- and 10-year-old cases were significantly lower on the uninvolved and hemiplegic sides, respectively, compared with the control. The peaks of hip flexor power generation (H3) in the 14- and 13-year-old cases were significantly higher on the uninvolved and hemiplegic sides, respectively. The A2/H3 ratios were significantly lower on the uninvolved and hemiplegic sides compared with the control, and the ratio for the hemiplegic side was lower than that for the uninvolved side. [Conclusion] This study shows that propulsion of walking is generated by hip, rather than the ankle, on both the hemiplegic and involved sides.

Key words: Children with cerebral palsy, Gait, Ankle

(This article was submitted Oct. 17, 2013, and was accepted Dec. 14, 2013)

INTRODUCTION

Children with spastic cerebral palsy (CP) have weakness of the muscles in their lower limbs¹. In even ambulant children with spastic CP, the distal lower limb muscles are weaker and proportionally smaller than proximal muscles, and these children also have difficulties in selective and voluntary movement¹⁻³. The ankle in children with CP is frequently involved in both pathological and developmental problems. Therefore, children with spastic CP walk at a reduced speed, with increased energy expenditure, compared with children with typical developing⁴. Even though children with spastic CP walk independently, most have an easily recognized disorder of gait that may include deviations such as jump gait or crouch gait⁵.

Lewis et al. demonstrated that for healthy children,

instruction to increase ankle push-off during walking results in lower hip flexion and extension moment as well as decreased hip power in the late stance, and also the interchange between the hip and ankle kinetics in human walking. There was a trade-off between the hip and ankle during walking⁶. This suggested that walking with increased ankle push-off may help to compensate for hip muscle weakness or injury and hip joint force.

Osteoarthritis of the hip frequently occurs in CP as a deuteropathy due to the misuse or overuse of this joint and is one of the causes of deterioration in walking^{7, 8}. If walking with increased push-off in children with spastic CP could reduce burdens on their hip joint, it could be beneficial to maintain walking ability. Relationships of the trade-off between the hip joint and ankle, in healthy individuals and individuals with total hip arthroplasty, have been previously studied^{5, 8}. However, the relationship in children with spastic CP have not been reported. The purpose of this study was to clarify kinetic relationship between the ankle and hip during gait, especially in late stance, in children with spastic CP.

*Corresponding author. Misako Ishihara (E-mail: Artemis1023misa@gmail.com)

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Table 1. Subjects

Age	14		13		10	
	Control	CP	Control	CP	Control	CP
Gender	Male	Male	Male	Male	Female	Male
Weight (cm)	36.0	46.0	46.0	51.0	35	28.1
Height (kg)	150.0	176.0	165.0	168.3	146.0	135.9
Speed (m/s)	1.33	1.43	1.08	1.49	1.54	1.31
A/S*1		Rt		Rt		Rt
GMFCS*2		I		II		I
Limitation of ROM in the ankle joint (°)	Rt	Dorsiflexion-5°		Dorsiflexion-15°		Dorsiflexion-5°
Limitation of ROM in the Ankle joint(°)	Lt	-		-		-
Brace		-		KFO		-
History of operation*3		-		+		-

*1: Affected side: hemiplegic side

*2: Gross Motor Functional Classification System

*3: Rt hamstrings and tendon-Achilles lengthening before 3 years

SUBJECTS AND METHODS

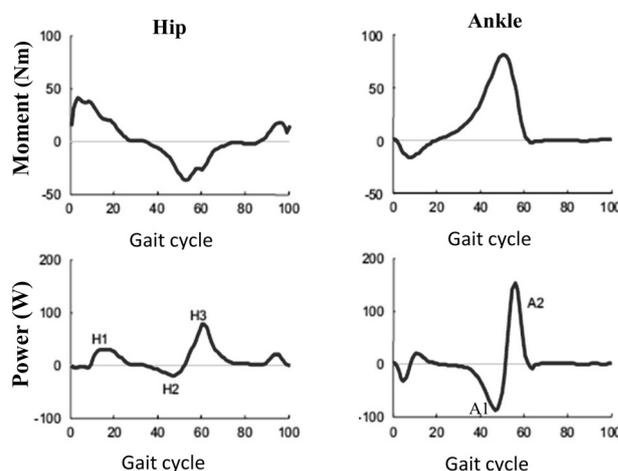
Subjects

The subject in this study were 3 male children with spastic hemiplegic CP (aged 10, 13, and 14: CP group), who attended general school classes in the community, were able to continuously walk 10 m or more without assistive devices, and had not had a surgical intervention or botulinum toxin injection within the last year (Table 1). Typically developing children with the same ages were recruited by a local paper (control). The details of the study were explained to the children and their parents to obtain their written consent. This study was conducted with the approval of the Research Ethics Committee of the Faculty of Rehabilitation, Osaka Prefecture University (2011P02).

Methods

Measurement was performed using a 3-dimensional motion analysis device, Motion Capture (Motion Analysis Corporation), with 2 force plates (AMTI) and 10 infrared cameras (at a sampling frequency of 200 HZ). Reflective markers were attached to the body, according to the Helen Hayes marker set. After sufficiently practicing gait on the force plates, each subject's barefoot gait pattern at a self-selected speed was recorded. We used the commercially available OrthoTrac software (ver. 6.5.3) to calculate the moment and power in each joint from kinetic data and the force data. One gait cycle was normalized from initial contact (0%) to initial contact (100%) on the same side.

Peak values of moment and power in the hip and ankle were calculated in the sagittal plane for each subject. Peak moments and powers were calculated for specific phases of gait cycle. The power values were labeled according to the protocol of Eng et al¹⁰. H1 was the hip extensors' power generation during the early stance phase; H2 was the hip joint's power absorption; H3 was the hip flexors' power generation; A1 was the ankle plantar-flexor power absorption; and A2 was the ankle plantar-flexor power generation. The ankle/hip power ratio (A2/H3 ratio⁹) characterizes the relative power of the ankle to the hip in the late stance. The

**Fig. 1.** Moment and power data for a gait cycle

All major moment and power peaks were calculated for the prescribed phase of the gait cycle in line with previously reported convention (Eng, 1995). Ankle plantar flexion and hip extension moment are positive. A1 and A2 represent ankle plantar flexion power, both absorption (negative) and generation (positive), during the mid and late stance phases, respectively. H1 represents hip extension power, while H2 and H3 represent hip flexion power.

values for moment (Nm) and power (W) were normalized with respect to the individual's body weight (kg) (Fig. 1).

In the statistical analysis, mean values from 5 gait cycles for each of the control and uninvolved and hemiplegic sides were used. For the control and the uninvolved and hemiplegic sides, age-matched comparisons were made with each other by performing a Kruskal-Wallis test and Steel-Dwass multiple comparisons. The significance level was set at less than 5%.

RESULTS

In comparisons between the control and uninvolved and

Table 2. Peak values in the late stance phase

		Control	Uninvolved side	Hemiplegic side	
Moment (Nm/kg)	Ankle	14 Yr	1.52±0.03	1.58±0.24	1.61±0.65
		13 Yr	1.19±0.09	1.19±0.07	1.16±0.08
	PF	10 Yr	1.8±0.15	1.23±0.01*	1.06±0.03*
		14 Yr	-0.13±0.02	-0.62±0.06*	-1.09±0.41*
	Hip flex	13 Yr	-0.49±0.04	-0.35±0.07	-0.71±0.08* **
		10 Yr	-0.47±0.04	-0.42±0.06	-0.56±0.07
Power (W/kg)	A2	14 Yr	3.03±0.6	3.22±0.7	3.16±1.6
		13 Yr	2.82±0.47	2.61±0.17	0.34±0.13*
	H3	10 Yr	5.16±1.07	2.73±0.25*	1.74±0.27* **
		14 Yr	0.35±0.04	0.72±0.11*	0.98±0.18*
	H3	13 Yr	0.45±0.18	0.8±0.15	2.02±0.46* **
		10 Yr	1.02±0.15	1.08±0.13	0.94±0.16

A2 represents ankle plantar flexion power generation during late stance.

H3 represents hip flexion power generation.

*: vs control

** : vs uninvolved side

p<0.05

Table 3. A2/H3 power ratio

		Control	Uninvolved side	Hemiplegic side
A2/H3 power ratio	14 Yr	8.75±1.87	4.49±0.62*	3.58±2.6*
	13 Yr	6.77±2.16	3.36±0.73*	0.18±0.09* **
	10 Yr	5.19±1.33	2.56±0.37*	1.9±0.46*

A2 represents ankle plantar flexion power generation during late stance.

H3 represents hip flexion power generation.

A2/H3 power ratio represents the ratio of A2 to H3.

*: vs control

** : vs uninvolved side

p<0.05

hemiplegic sides in children with the same ages, the peak moments of ankle plantar flexors did not differ significantly in the 14- and 13-year-old cases. In the 10-year-old case, however, the peak moments of ankle plantar flexors were significantly lower on the uninvolved and hemiplegic sides compared with the control, respectively. The peak flexion moments of the hip on the hemiplegic side were significantly higher compared with the control in the 14- and 13-year-old cases. In the 10-year-old case, no significant differences were observed; the values were high on the hemiplegic side (Table 2).

The peak of ankle power generation (A2) showed no significant differences in the 14-year-old case. On the other hand, in the 13- and 10-year-old cases, the A2 peaks were significantly lower on the uninvolved and the hemiplegic sides, respectively, compared with the control. The peaks of hip flexor power generation (H3) in the 14- and 13-year-old cases were significantly higher on the uninvolved and hemiplegic sides, respectively, compared with the control. In the 10-year-old case, no significant differences were observed (Table 2).

The A2/H3 ratios were significantly lower on the uninvolved and hemiplegic sides compared with the control, and the hemiplegic side showed lower values than the uninvolved side (Table 3).

involved side (Table 3).

DISCUSSION

The purpose of this study was to evaluate kinetic relationships between the ankle and the hip during the late stance in children with spastic CP. This study found that the A2/H3 ratios of children with spastic CP on both the hemiplegic and uninvolved sides were lower than those of the control and that the children showed decreased moments and power generation at the ankle, while generating power at the hip was increased. This indicated that propulsion of walking was generated by the hip rather than the ankle; in other words, it was a hip-dependent walking. This may lead to increased hip joint forces, overuse injury of the hip musculature, and deterioration in walking, which results from the ankle not producing a sufficient propulsive force during walking in children with spastic CP. Therefore, it is necessary to use of ankle power rather than hip power to improve walking ability for children with CP. Raid et al.¹¹⁾ pointed out that a major power generation shift from the ankle to the hip on both sides occurs in children with spastic hemiplegic CP. Our findings concerning the A2/H3 ratio are consistent with this previous study.

This study had some limitations: It involved only 3 subjects, and the gait of the control group was also characteristic. In order to generalize the results as the common characteristics of children with spastic CP, it may be necessary to study an increased number of subjects. Furthermore, it is desirable to perform measurement at a fixed gait speed, as moments and power have been reported to be associated with the gait speed.

In conclusion, this study shows that propulsion during walking is generated by the hip, rather than the ankle, on both the hemiplegic and involved sides in children with spastic CP. We consider that training of the ankle plantar flexor is essential to maintenance of walking ability for children with spastic CP. Maintenance of walking ability is not merely maintenance of motor functions but is also an important approach for children with spastic CP to be able to enhance their quality of life.

REFERENCES

- 1) 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](#)]
- 2) Wiley ME, Damiano DL: Lower-extremity strength profiles in spastic cerebral palsy. *Dev Med Child Neurol*, 1998, 40: 100–107. [[Medline](#)] [[CrossRef](#)]
- 3) 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](#)]
- 4) Novacheck TF, Stout JL, Tervo R: Reliability and validity of the Gillette Functional Assessment Questionnaire as an outcome measure in children with walking disabilities. *J Pediatr Orthop*, 2000, 20: 75–81. [[Medline](#)] [[CrossRef](#)]
- 5) Rodda JM, Graham HK, Carson L, et al.: Sagittal gait patterns in spastic diplegia. *J Bone Joint Surg Br*, 2004, 86: 251–258. [[Medline](#)] [[CrossRef](#)]
- 6) Lewis CL, Ferris DP: Walking with increased ankle pushoff decreases hip muscle moments. *J Biomech*, 2008, 41: 2082–2089. [[Medline](#)] [[CrossRef](#)]
- 7) Bottos M, Feliciangeli A, Sciuto L, et al.: Functional status of adults with cerebral palsy and implications for treatment of children. *Dev Med Child Neurol*, 2001, 43: 516–528. [[Medline](#)] [[CrossRef](#)]
- 8) Andersson C, Mattsson E: Adults with cerebral palsy: a survey describing problems, needs, and resources, with special emphasis on locomotion. *Dev Med Child Neurol*, 2001, 43: 76–82. [[Medline](#)] [[CrossRef](#)]
- 9) Tateuchi H, Tsukagoshi R, Fukumoto Y, et al.: Immediate effects of different ankle pushoff instructions during walking exercise on hip kinematics and kinetics in individuals with total hip arthroplasty. *Gait Posture*, 2011, 33: 609–614. [[Medline](#)] [[CrossRef](#)]
- 10) Eng JJ, Winter DA: Kinetic analysis of the lower limbs during walking: what information can be gained from a three-dimensional model? *J Biomech*, 1995, 28: 753–758. [[Medline](#)] [[CrossRef](#)]
- 11) Riad J, Haglund-Akerlind Y, Miller F: Power generation in children with spastic hemiplegic cerebral palsy. *Gait Posture*, 2008, 27: 641–647. [[Medline](#)] [[CrossRef](#)]