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Effect of Strength Training of Ankle Plantarflexors on Selective Voluntary Motor Control, Gait Parameters, and Gross Motor Function of Children with Cerebral Palsy

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Abstract. [Purpose] The purpose of this study was to investigate the effect of ankle plantarflexor strength training on selective voluntary motor control, gait parameters, and gross motor function of children with cerebral palsy (CP), focusing on changes in the strength and muscle activity of the ankle plantarflexors. [Methods] Six children aged between 4 and 10 years with CP participated in a 6 week strengthening program. The subjects were evaluated before and after the intervention in terms of ankle plantarflexor strength, muscle activity, gait velocity, cadence, step length, and D (standing) and E (walking, running, and jumping) dimensions of the Gross Motor Function Measure (GMFM). The data were analyzed using the non-parametric Wilcoxon signed-rank test. [Results] The strength of the plantarflexors increased in the majority of subjects. Significant and clinically meaningful post-intervention improvements in subject's gait velocity, cadence, and step length were found. [Conclusion] The controlled ankle plantarflexor strengthening program may lead to improvements in strength and spatiotemporal gait parameters of children with CP.

Key words: Ankle plantarflexor, Strengthening exercise, Gait parameter

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INTRODUCTION

Children with cerebral palsy (CP) have neurodevelopment disorders, such as spasticity, contracture, reduced coordination, selective voluntary motor control, and muscle weakness[1)]. Among these, muscle weakness is a major motor problem for children with cerebral palsy[2–7)]. As with muscle weakness, poor selective voluntary motor control (SVMC) is also a prominent characteristic of children with CP. SVMC is defined as the performance of isolated movement while performing a functional task such as walking[8)], and the ability to activate muscles independently in response to voluntary motor requirements in amounts appropriate for recruitment and activation of muscles. Compared with normal children, children with CP have various muscle recruitment patterns and magnitudes[9)], and these differences can affect voluntary muscle recruitment leading to impairments in motor ability.

Although children with spastic CP can walk independently, they have 52% or less maximum contractile force in the main lower extremity muscles compared to same-aged normally developing children in ankle flexion and extension[5)]. In particular, the plantarflexor, which is the weakest muscle in children with spastic CP, has 36% of the muscle strength of normal children[10)].

Muscle strength and resistance training have been widely used as a therapeutic interventions for increasing muscle strength and functional improvement[3, 11–13)]. In the past, muscle strength training for children with CP was not considered viable because it required much effort by the children and led to increased muscle spasticity[14)]. However, some studies have reported that children with spastic CP do not show an increase in muscle spasticity after they performing muscle strength training[15, 16)].

The effect of muscle strengthening exercise depends on which muscles are targeted. A study of 10 children with spastic CP who performed knee extensor, ankle extensor, and closed chain exercises showed that the positive effect was maintained for six weeks[13)]. The same study also reported functional improvements in walking, running, and jumping as assessed by the Gross Motor Function Measure (GMFM)[13)]. In another study of ankle plantarflexor muscle strengthening exercises for children with CP, stride length and gait velocity increased[11)].

In spastic CP, the distal muscles of the lower limbs are weaker and may be proportionally smaller than the proximal muscles. The plantarflexor is one of the key muscles of the lower extremities in children with CP[10)]. In normal gait,

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the plantarflexors provide much of the force required to support the body and advance the lower limb, particularly in midstance and late stance[17]).

The purpose of this investigation was to determine whether increasing ankle strength improves the gait parameters and gross motor function of children with CP. We also investigated its effect on the electromyogram (EMG) activities of the ankle plantarflexor and dorsiflexor muscles.

SUBJECTS AND METHODS

The subjects were a convenience sample of six children diagnosed with spastic CP (1 boy and 5 girls) who were attending a CP clinic in South Korea. They were aged between 4 and 10 years (mean age: 5.8 ± 2.5 years), 110.7 ± 11.5 cm tall, and weighed 20.4 ± 4.3 kg. This study complied with the ethical standards of the Declaration of Helsinki, and all the subjects and parents received explanations regarding the purpose and procedure of the study before voluntarily agreeing to take part. All parents signed an informed consent statement before the start of the measurements. All the subjects were assessed by Gross Motor Function Classification Scale (GMFCS) as level I. They could follow verbal commands and walk independently without orthotics or assistive devices. They had not received nerve block injections or orthopedic surgery, and they had hypertonicity lower than grade +1 of the plantarflexors as evaluated by the Modified Ashworth Scale.

Potential subjects were excluded if they had ankle plantarflexion contracture greater than 15 degrees, or had knee or hip fixed flexion deformity greater than 10 degrees.

Two normally developing children (1 boy and 1 girl with a mean age of 5.6 ± 2.1 years, a mean height of 113.5 ± 0.7 cm, and a mean weight of 21.5 ± 0.7 kg) served as the control group, providing comparative strength, muscle activity, and gait parameter data. The subjects and control children showed no significant differences in age, height, or weight.

Ankle dorsiflexor selective control was graded on a 3-point scale using the Trost SMC test protocol (a higher score indicates greater strength). In the test, a score of 0 = no ability to isolate movement, a score of 1 = partially isolated movement, and a score of 2 = complete isolation of movement[18]). Electromyograms of the ankle plantarflexor and tibialis anterior muscles were obtained using surface EMG (QEMG-4, LAXTHA Inc., Korea). Medi-Trace Mini Electrodes (Ludlow Technical Products Ltd., Canada) were used. The quantification of the collected signals during the contraction of each muscle was achieved by the root mean square method. The degree of muscle vitalization was analyzed by measuring the muscle activity in the SMC test (ankle dorsiflexion) and in the heel raise.

Gait parameters were measured using an electrical walkway system (GAITRite, CIR System Inc., USA). The system captures temporal and spatial gait parameters through the serial port of a personal computer. It consists of an 810 × 89 × 0.625 cm (length × width × height) instrumented mat with 27,648 embedded pressure-sensitive sensors, which are spaced at 1.27 cm and arranged in a 48 × 576 grid. The sampling rate was 80 Hz, and the obtained data were analyzed using gait analysis software (GAITRite GOLD, version 3.2b). The subjects walked at a gait speed with which they were comfortable in three trials. The subjects initiated and terminated walking a minimum of 3 m from the start and end of the walkway to maintain the gait speed on the mat. The gait velocity, cadence, and step length for both legs were measured.

The GMFM is a standardized, criterion-referenced test designed to assess changes in gross motor function in children with CP[19]). GMFM-88 has been shown to have high levels of validity, reliability, and responsiveness in evaluations of motor function and intervention effects in children with CP[19, 20]). Dimension D (13 items), which measures motor activities while standing on the GMFM-88, and dimension E (24 items), which measures motor activities while walking, running, and jumping, were chosen as the outcome measures. These represent areas with which many children with mild spastic diplegia have difficulty[21]), and they are activities that are more likely to be improved by a lower limb functional strength training program.

Maximal voluntary isometric contraction (MVIC) was measured using a handheld dynamometer (Power Track II, JTECH medical, UAS). The handheld dynamometer has been shown to have good reliability in the assessment of isometric strength of children with CP[22, 23]). The ankle plantarflexor muscles were tested bilaterally in a random order in the standardized positions described in Table 1[5]). The dynamometer was positioned against a solid, immovable object for measurement of the ankle plantarflexor strength to ensure that there was no measureable force exerted by the examiner. The dynamometer was held perpendicular to the long axis of the body segment, and force was applied at right angles. The subject was instructed to hold the appropriate position for 5 s while pushing maximally against the plate of the handheld dynamometer. Each muscle was tested three times, with a rest period of 30 s between each test. The results were then averaged.

The subjects in the intervention group did a heel raise exercise, which included progressive resistance ankle plantarflexor training for 6 weeks, 3 times a week, with each

Table 1. Positioning for testing of lower extremity muscles

Muscle	Body position	Limb position	Stabilization	Dynamometer placement
Ankle plantarflexor	Supine, plantar surface of foot against wall	Knee extend, ankle at 0 degrees (neutral)	Push into plantar flexion against dynamometer stabilized on wall Additional stabilization at shoulders to keep participant from sliding up	Resistance given across metatarsal heads

session lasting 30 min.

The heel raise exercise is a training method for the ankle plantarflexor. It involves stretching the hip adductor, ankle plantarflexor, and hamstring muscles for 3–5 min as a warm-up to increase excitation of the motor unit and activate the range of motion before the training. The main exercise, the heel raise, was performed by applying a load with a weighted vest of 20% of 1 repetition maximum (RM) for the first and second sets. When the child was able to perform the complete set of the exercises, the exercise was performed iteratively by applying a load with a weighted vest of 50% of 1RM[24]. The exercise was finished with a cool-down period of 3–5 min to reduce damage and increase relaxation and flexibility of the body. The subjects were allowed to rest for 1 min between the sets to maintain the exercise performance. They repeated the exercise 8 to 12 times, with three to five sets performed per session. The 1RM of the heel raise exercise started at 30% of the child's weight. It was then increased up to a weight where the child could still perform one set completely without losing balance[24]. Weight was added or removed by using a weighted vest in which a 0.5 kg weight can be placed in the pocket. The exercise time for one session took approximately 30 min. The resulting data were analyzed using SPSS version 18.0 for Windows. The Wilcoxon signed-rank test was used to identify differences between the pre- and post-test data for each of the dependent measures. A p value less than 0.05 was considered statistically significant.

RESULTS

The characteristics of the subjects are presented in Table 2. The results show that the muscle strength of the ankle plantarflexor significantly increased ($p < 0.05$) (Table 3) in all six children. The subjects showed no statistically significant electromyogram changes while performing the ankle dorsiflexion and heel raise exercises.

The average scores of the standing, walking, running, and jumping dimensions of the GMFM showed changes, but they were not statistically significant (Table 4). The analysis of the spatiotemporal gait parameters showed that the velocity, cadence, and step length of all six children with CP were significantly increased ($p < 0.05$) (Table 5).

DISCUSSION

This study aimed to determine the effect of ankle plantarflexor training for children with CP on muscle strength, muscle activation, gait parameters, and gross motor function. The results show that the muscle strength of the ankle plantarflexor showed a significant improvement and that the subjects' gait velocity, cadence, and step length increased.

Engsberg et al.[11] reported that the muscle strengths of the ankle dorsiflexors and plantarflexors of children with

Table 2. General characteristics of subjects

	Subjects	Sex	Age (months)	Weight (kg)	Height (cm)	MAS	GMFCS	type
CP	1	F	39	15.6	95	1	1	Bilateral
	2	M	122	25	128	1	1	Unilateral
	3	F	42	18	105	1+	1	Bilateral
	4	F	60	17.5	107	1	1	Bilateral
	5	F	84	20	118	1	1	unilateral
	6	F	72	26.3	111	1	1	Bilateral
ND	1	M	66	22	114			
	2	F	69	21	113			

CP: cerebral palsy, ND: normally-developing children, MAS: Modified Ashworth Scale, GMFCS: Gross Motor Functional Classification Scale

Table 3. Comparison of ankle plantarflexor strength between the CP and ND

		Rt		Lt	
	Subjects	Pre-test	Post-test	Pre-test	Post-test
CP	1	19.5	22.0	17.6	24.9
	2	36.6	36.6	4.4	12.2
	3	24.2	28.6	22.7	24.9
	4	22.0	27.1	22.7	19.8
	5	22.0	24.9	16.1	24.2
	6	10.1	11.4	10.0	10.9
	Mean ± SD	22.4 ± 8.5	25.1 ± 8.3*	15.5 ± 7.2	24.9 ± 6.4
ND		35.3 ± 1.1		34.3 ± 0.2	

CP: cerebral palsy, ND: normally-developing children, MVIC: maximal voluntary isometric contraction (N),
* = significant difference, $p < 0.05$

CP were about 50% and 35%, respectively, compared with the strength of these muscles in children with typical development, suggesting that children with CP require muscle strength training.

The results of the ankle plantarflexor strength exercise in this study are similar to findings reported by Engsberg et al[11]. Their subjects showed muscle strength increases after ankle muscle strength training using an isokinetic dynamometer for 12 weeks. Engsberg et al.[11] also conducted ankle dorsiflexor as well as plantarflexor training using an isokinetic dynamometer. However only ankle plantarflexor training was performed in the present study using a protocol, which was familiar to the children. Crompton et al.[22] reported that results obtained with an isokinetic dynamometer or a similar machine are not reliable when used for children with CP and that training using an isokinetic machine can be difficult for children with CP.

Based on our review of strength training programs, it appears that a training program for a minimum of six weeks may be sufficient to improve lower extremity muscle performance. Dodd et al. have demonstrated that a six week strengthening program can increase the ability to generate muscle force in children with CP[13, 25]. Our present study also demonstrated a change in the muscle strength after six weeks of training.

The results of the GMFM showed that 4 of the 6 children had increased scores in the standing dimension although this result was not statistically significant. Three children had increased scores in the walking, running, and jumping dimension, and this was also not statistically significant. Wiley and Damiano[5] investigated lower extremity muscle training for 6 weeks with 11 children with CP. Six of the children with CP were diagnosed with spastic diplegia, and five with hemiplegia. One child who performed only ankle plantarflexor exercise showed an increase in muscle strength, as well as an increase in scores of the GMFM E dimension. Another study reported that the GMFM E dimension score of children with CP increased to 4.4, on average, after lower extremity muscle strength training for 6 weeks[13]. The present study also showed increased in the average scores of 2.3 of the GMFM E dimension.

The results of the spatiotemporal gait analysis showed that gait velocity increased by an average of 7.3 cm/s. Although this speed was still slower than that of two children with normal development, this result is similar to that of another study, which reported an increase of about 6 cm/s after knee extensor strength training for six weeks[4]. In our present study, an increase of about 11 steps/min in cadence and increases of about 2 cm for the right and left sides in step length were realized. In comparison, Engsberg et al.[11] reported a 8.0 cm/s increase in gait velocity and a 2.4 steps/min increase in cadence following ankle plantarflexor strength training, similar to the results of this study. The subjects in the present study were young and had small

Table 4. Changes in gross motor function measure

	Subjects	GMFM; D		GMFM; E	
		Pre-test	Post-test	Pre-test	Post-test
CP	1	90	94	83	83
	2	59	62	36	36
	3	87	90	76	80
	4	95	98	83	87
	5	100	100	93	99
	6	100	100	97	97
	Mean ± SD	88.5 ± 15	90.6 ± 14.5	78.0 ± 21.9	80.3 ± 22.9

CP: cerebral palsy, GMFM: Gross Motor Function Measure (%), D: standing, E: walking, running, and jumping

Table 5. Comparison of temporal gait parameters in CP and ND children

	Subjects	Velocity (cm/s)		Cadence (steps/m)		Step length (cm)			
						Rt		Lt	
		Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test	Pretest	Post-test
CP	1	63.4	67.2	114.6	138.9	29.4	31.5	28.7	30.6
	2	90.8	103.5	106.8	124.7	48.3	52.0	53.3	55.5
	3	62.4	68.1	109.9	121.3	48.0	51.3	38.4	48.6
	4	71.5	80.2	115.7	125.3	38.1	40.1	35.5	36.3
	5	111.1	111.2	136.6	137.4	50.3	50.3	47.0	47.0
	6	89.2	102.0	122.6	130.1	42.5	45.1	44.9	45.0
	Mean ± SD	81.4 ± 19.0	88.7 ± 19.2*	117.7 ± 10.7	129.6 ± 7.1*	42.7 ± 7.9	45.1 ± 8.0*	41.3 ± 8.0	43.8 ± 8.9*
ND		117.3 ± 24.6		159.7 ± 17.4		56.0 ± 12.8		55.8 ± 12.7	

CP: cerebral palsy, ND: normally-developing children, * = significant difference, $p < 0.05$

body sizes. The study by Engsberg et al.[11] included subjects categorized as level I, II and III, which is relatively wide.

Measurement of the activity pattern of the plantarflexor using EMG revealed a variety of patterns, and no significant results were found. The activity of the motor unit, muscle fiber type, muscle length, and physiological state of the muscles influence the magnitude of EMG signals[26]. Although the children with CP in the present study had the same functional level, the length and physiological state of their muscles were different due to individual gait patterns. Thus, the children with CP showed various patterns of muscle activity compared to children with normal development. In particular, if the prime movement involves a distal muscle, accurate activity is more difficult due to antagonist muscle co-contraction. Tedroff et al.[9] found that children with CP experienced greater difficulty in recruiting the lateral gastrocnemius, which is an agonist muscle, during ankle plantarflexion.

A limitation of this study is that only a small number of subjects participated in this study. Further studies are required with larger sample numbers, and with the inclusion of children aged more than 10 years old, and subjects with GMFCS levels of I, II, and III who have mobility, with and without limitation.

In conclusion, preservation of function and mobility is one of the primary aims in the management of children with CP, and intervention is often directed at the plantarflexors[11, 27]. The heel raise exercise is a valid training method for children with CP because it improves the strength of the plantarflexor, thereby increasing their mobility. This exercise can be performed without any equipment, which might be difficult to handle, and children with CP can perform it themselves as part of a muscle strength training program.

Increases in muscle strength resulted in maintenance of function in the present CP group. Plantarflexor strengthening may turn out to be one of the most important interventions available for ambulant children with CP.

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