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Effect of weight around ankle on decreasing hip flexion excursion during gait in children with diplegia

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Abstract

Introduction. Children with diplegia have considerably larger hip flexion excursion during the gait cycle than normal developing children. There have been few studies that look at the effect of ankle loading on gait in children with hemiparesis, but none that look at the effect of ankle loading on hip flexion angles during gait in children with diplegia, to our knowledge. The purpose of the study is to evaluate the effect of using a weight around the ankle on the degree of hip flexion excursion in children with diplegia.

Methods. Fifty children with spastic diplegia were assigned into 2 groups at random (A, B). Both groups received the same prescribed exercise program with gait training for group A and gait training while using a weight around the ankle for group B. Treatment was conducted for 1 hour 3 sessions/week for 3 successive months. Two-dimensional (2D) gait analysis was used to evaluate hip excursion throughout the gait cycle before and after the 3 months of therapy.

Results. Mixed design MANOVA was used to study the effect within each group and between the 2 groups. A comparison of both groups after treatment demonstrated a significant decrease in right and left hip flexion excursion in the initial swing, mid-swing, terminal swing, initial contact, mid-stance, and pre-swing ($p > 0.01$). There was no significant difference in loading response between groups after treatment ($p = 0.3$).

Conclusions. Using weight around the ankle during gait helped to decrease the degree of excessive hip flexion excursion during gait in children with diplegia.

Key words: cerebral palsy, gait analysis, ankle weight loading

Introduction

Cerebral palsy (CP) is a collection of persistent defects of posture and mobility that cause activity restriction and are caused by nonprogressive problems in the developing foetus or newborn brain [1]. Neurologic system damage usually leads to impaired motor control, late onset of walking, and an irregular walking pattern [2].

Description of walking disorders in CP divides the gait cycle into swing and stance phases to achieve the functional goals of load tolerance, one-limb support, and limb progression [3, 4] The sagittal plane kinematics-based categorisation for children with spastic cerebral palsy identified that apparent equines, true equines, crouch gait, and jumping gait were recognised as the four major groups [5, 6].

According to the ankle, knee, pelvis, hip posture throughout stance, Rodda et al. established 5 forms of gait in spastic diplegic individuals, ranging from true equines to crouch gait, that includes fewer equines and more hip and knee flexion [7]. Among the most widespread walking patterns in mobile children with CP is the crouch gait [8]. Regardless of the position of the ankle joints during stance, persistent knee flexion during locomotion is sometimes referred to as a crouch gait. The calf is long and feeble during crouch gait, whereas the hamstrings and iliopsoas are dominant and spastic or tight. The ultimate gait pattern is greatly influenced by muscle weakening. Children may exhibit crouch gait as a result of weakness or as a result of tightened hamstrings and hip flexors pulling them into a crouch gait. Most children's general gait patterns are influenced by weakness and contracture [9]. In the crouch gait, there is an inefficient plantar flexion-knee extension pair. The direction of the ground reaction force when walking in a crouch gait is behind the knee [7].

Various studies have examined weight loading on the lower limbs in adults. According to two studies, weighting the ankle during walking with an amount equal to 1% of the body weight has a positive influence on the gait characteristics [10, 11]. The study by Hwang et al. [12] suggested that adding load during gait can be useful in the walking capabilities of symptom-free people. Another study, this time by Park et al. [13], discovered that gait training with a sandbag weighing 3–5% of body weight attached to the ankle improves hemiplegic stroke patients' balance ability.

Few studies were found to study the effect of load around the ankle on gait in children with hemiparetic CP. A study by Simão et al. [14] examined the effects of gait training with various loadings on gait kinematic parameters using a case report on three children. Immediately following training, Simão et al. [14] noticed higher joint angles in the knee and hip and better propulsion during the swing phase, particularly with a 60% loading of the weight of the lower limb. Another study by Simão et al. [15], applied to 20 children, concluded that gait training while adding weights to the lower limbs helped to enhance the clearance of the foot during the swing phase. A study by El-Negmy et al. [16] on 30 hemiparetic children assessed the effect of using 0.5 kg weight attached to the ankle of the hemiparetic side during gait training. The study found that the muscle strength of the ankle dorsiflexors was increased significantly and the dorsiflexion angle on initial contact was decreased significantly.

Children with spastic diplegia had considerably larger angles of the left and right pelvic and hip joints in the swing and

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stance phases than normally developing children. The angles of the hip were considerably different between the two sides [17].

To our knowledge, there have been few studies that look at the effect of ankle loading on gait in children with hemiparesis, but none that look at the effect of ankle loading on hip flexion angles during gait in children with diplegia. It was hypothesised that there is no effect of using a weight around the ankle on the degree of hip flexion excursion in children with spastic diplegia. So, this study aimed to evaluate the effect of using a weight around the ankle on the degree of hip flexion excursion in children with spastic diplegia.

Subjects and methods

Study design

It is a randomised controlled trial. The randomisation and assessment were done by two independent physical therapy experts. The study was conducted from August to October 2022. The children were chosen, and the study was carried out at the Faculty of Physical Therapy's paediatric outpatient clinic.

Randomisation

Fifty children were divided randomly using a computer program (computer-generated random numbers in each group according to a predetermined ratio of 1:1) into two groups (A and B). Figure 1 represents the participants' flow diagram of the study.

Participants

Sixty children with spastic diplegic CP were assessed, five of them did not match the requirements for inclusion, and an additional five kids chose not to participate. The fifty children with diplegic CP who were included were between the ages of 7 and 10, able to follow simple basic commands, and identified with gait abnormalities described as level II on the Gross Motor Function Classification System (GMFCS) [18]. Exclusion criteria included severe visual or auditory problems, lower limb orthopaedic surgery or injection of BOTOX within 6 months preceding the start of the study, and uncontrolled seizures.

Children were chosen from the paediatric outpatient clinic of the Faculty of Physical Therapy. Before the therapy began, the purpose and methods were conveyed to the parents. Before enrolling, each parent completed a consent form.

Outcome measures

The primary outcome measure in this study was to assess the hip flexion excursion (excursion is the range of movement regularly repeated in the performance of a function [19]) during the stance and swing phases of gait.

Using a digital video camera, two-dimensional (2D) gait analysis was done to assess hip flexion excursion during walking from the sagittal plane before and after therapy.

As a method of assessment, 2D gait analysis may provide a reliable and cost-effective method of gait assessment that may be used in a variety of care settings. Measuring joint angles utilising 2D motion analysis software has been demonstrated to be substantially connected to goniometric measures [20–22]. Although 3D motion capture is the 'gold standard' for capturing and analysing kinematics, a study by Schurr et al. [23] found that 2D video analysis may be a more practical, affordable, and portable option for kinematic assessment and found that there were moderate to strong relationships between 2D video camera and 3D motion capture analyses at all joints in the sagittal plane despite the lack of precision to capture rotations.

Measurement procedure

Adhesive skin markers were placed on the skin at specific locations (lateral malleolus, tibial tuberosity, and greater trochanter for the right and left side). The angle of hip flexion excursion was determined as the angle between a vertical

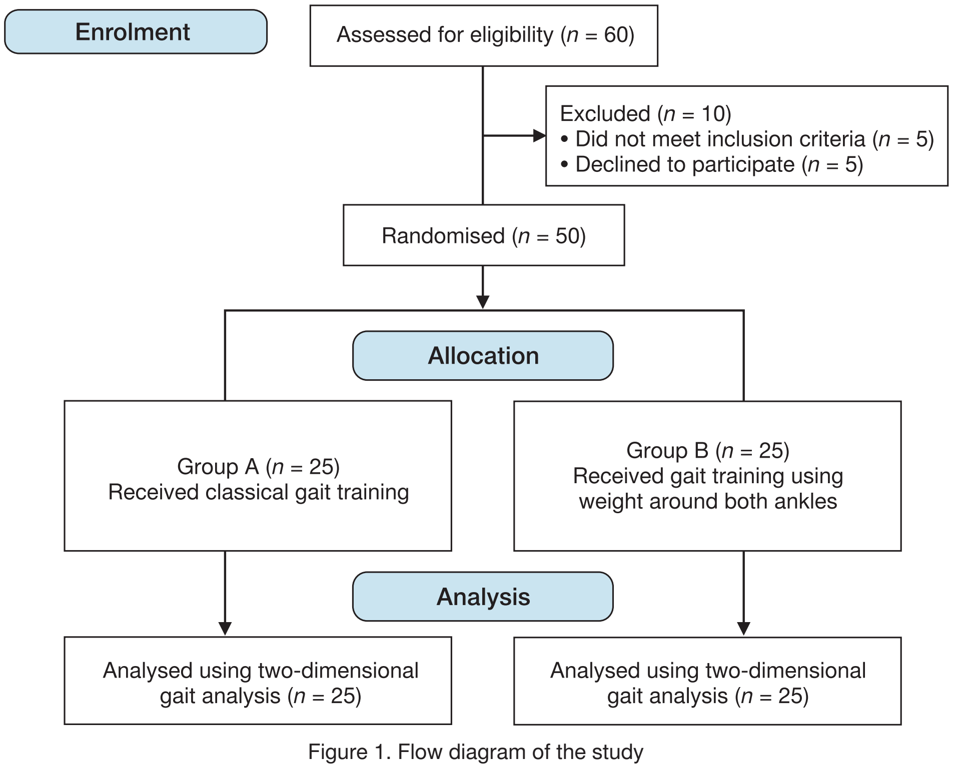

Figure 1. Flow diagram of the study

line from the greater trochanter of the femur perpendicular to the ground and the line passing from the greater trochanter to the lateral epicondyle of the femur. The children were instructed to walk down a 2-metre-long and 1-metre-wide walking path without a predetermined velocity. A digital video camera (Sony Cyber-Shot full HD 1080, 8.1 MEGA PIXELS) was held by a tripod stand placed in the middle point at a height of 1 m off the ground lateral to the walkway at a distance 2.4 m from the assessed child (to cover the whole walking path) to record from the sagittal plane, perpendicular to the centre of the pathway, and at the hip level. The Tracker software was used to assess hip flexion excursion during the swing and stance phases of the gait cycle [24]. At maximum hip flexion, a still image was produced in the sagittal planes. Using the retroreflective markers, the clinician calculated the joint peak hip flexion angle and measured the joint angles at the hip on each still image. Hip flexion was measured as the angle formed by the femur and a vertical line perpendicular to the ground, with the greater trochanter serving as the fulcrum.

Intervention

This research comprised fifty children with spastic diplegic CP. The participants were assigned to two groups at random (A and B groups). Both groups underwent the prescribed exercise program for diplegic children with classical gait training for group A and gait training using a weight around the ankle with 5% of body weight attached at 5 cm above the ankle of the left and right lower extremities for group B [13]. Treatment was conducted for 1 hour/day, 3 sessions/week for 3 successive months of treatment.

Prescribed physical therapy exercise program for both groups

Flexibility exercises were performed for the ankle plantar flexors, knee, and hip flexors of both lower limbs as well as balance exercises during standing and walking, and progressive resistance training for the hip extensors, knee extensors, and ankle dorsiflexors. Gait training exercises (walking forwards, backwards and sideways, walking on a stepper, walking across different obstacles comprising different sizes of rolls, wedges, and blocks) were also performed.

Statistical analysis

Data were analysed through the statistical package for social science (SPSS) version 25 for Windows (IBM SPSS, Chicago, IL, USA). The level of significance for all statistical tests was set at $p < 0.05$. The unpaired *t*-test and the chi-squared test were used to compare the characteristics of the subjects between groups. The Shapiro–Wilk test was used to determine if the data had a normal distribution. The homogeneity between groups was examined using Levene's test for homogeneity of variances. To examine effects within and across groups, a mixed-design MANOVA was conducted. Following multiple comparisons, post-hoc testing employing the Bonferroni correction was conducted.

Results

Subject characteristics

Table 1 shows the subject characteristics of the 2 groups. The Age, height, weight, BMI, and sex distribution did not significantly differ between the 2 groups ($p > 0.05$).

Table 1. Basic characteristics of participants

Subject characteristics	Group A mean ± *SD*	Group B mean ± *SD*	*p*-value
Age (years)	6.18 ± 1.17	5.98 ± 1.09	0.53
Weight (kg)	19.42 ± 3.64	19.14 ± 3.74	0.79
Height (cm)	114.6 ± 9.16	112.62 ± 9.47	0.45
BMI (kg/m²)	14.68 ± 1.26	15.03 ± 1.89	0.45
Sex [*n* (%)]			
males	16 (64)	12 (48)	0.25
females	9 (36)	13 (52)	

BMI – body mass index

Effect of treatment on degree of hip flexion excursion during the gait cycle

Mixed MANOVA showed that there was a significant interaction between treatment and time ($F = 4.38$, $p = 0.001$). There was a significant main effect of time ($F = 13.88$, $p = 0.001$). There was no significant main effect of treatment ($F = 1.36$, $p = 0.22$).

The mean hip flexion excursion in the stance phase for both groups is shown in Table 2 before and after therapy. Table 3 shows the mean hip flexion excursion during the swing phase for both groups before and after treatment.

Discussion

This study aimed to evaluate the effect of using a weight around the ankle on the degree of hip flexion excursion in children with spastic diplegia. Normally, the hip flexes nearly up to 20 degrees at the start of heel contact, then decreases to 15 degrees in the loading response. By mid-stance, the hip is in a neutral position and begins to hyperextend for about 10 to 20 degrees during the remainder of the stance phase. During the swing phase, the hips revert to a maximum flexion pattern of 20 to 30 degrees. During the gait cycle, the hip flexes and extends once, with the limit of flexion occurring in the middle of the swing phase and the limit of extension occurring before the end of the stance phase. A maximum hip flexion of 30–35 degrees occurs in the late swing phase, around 85% of the way through the gait cycle; a maximum extension of about 10 degrees occurs near toe-off, around 50% of the way through the gait cycle. Hip ligaments help to stabilise the joint in extension [3, 25].

Children with spastic diplegia had considerably larger angles of the left and right pelvic and hip joints in the swing and stance phases than normally developing children. The angles of the hip are considerably different between the two sides [17].

The comparison between the 2 groups after treatment demonstrated a significant decrease in right and left hip flexion excursion in initial contact, mid-stance, pre-swing, initial swing, mid-swing, and terminal swing ($p > 0.01$).

The addition of weight around the ankle might promote proprioceptive sense in the lower limb. Children with CP have defective proprioception, most likely due to lesions in the central nervous system that impair all proprioceptive inputs to the cortex coming from the joints, Golgi tendon organs, and muscle spindles, as well as skin sensory afferents [26]. Neuromuscular impairments that associate with CP, such as increased muscle tone, muscle weakness or imbalance, and abnormal biomechanical alignment, leads to distorted pro-

Table 2. Mean hip flexion excursion (in degrees) in stance phase pre- and post-treatment for both groups

Stance phase	Group A mean ± *SD*	Group B mean ± *SD*	*p*-value
Rt Initial contact			
pre-treatment	31.69 ± 6.51	29.88 ± 7.15	0.35
post-treatment	28.29 ± 4.82	25.29 ± 3.57	0.01*
	p = 0.001*	*p* = 0.001*	
Lt Initial contact			
pre-treatment	30.68 ± 7.58	30.29 ± 7.55	0.85
post-treatment	28.43 ± 5.55	24.88 ± 4.05	0.01*
	p = 0.001*	*p* = 0.001*	
Rt loading response			
pre-treatment	29.42 ± 5.32	28.1 ± 7.42	0.47
post-treatment	26.82 ± 6.59	25.24 ± 3.8	0.3
	p = 0.008*	*p* = 0.004*	
Lt loading response			
pre-treatment	27.93 ± 6.55	27.8 ± 7.48	0.94
post-treatment	25.84 ± 4.81	24.5 ± 3.53	0.3
	p = 0.01*	*p* = 0.001*	
Rt Mid-stance			
pre-treatment	13.33 ± 8.42	11.19 ± 10.7	0.43
post-treatment	11.68 ± 7.11	5.32 ± 7.35	0.003*
	p = 0.07	*p* = 0.001*	
Lt Mid-stance			
pre-treatment	13.41 ± 8.79	12.17 ± 10.23	0.64
post-treatment	11.86 ± 7.49	5.02 ± 6.7	0.001*
	p = 0.14	*p* = 0.001*	
Rt Terminal stance			
pre-treatment	13.43 ± 3.55	12.14 ± 8.94	0.5
post-treatment	10.97 ± 3.91	–0.56 ± 8.67	0.001*
	p = 0.04	*p* = 0.001*	
Lt Terminal stance			
pre-treatment	14.16 ± 4.78	12.12 ± 7.9	0.27
post-treatment	11.27 ± 5.49	–0.35 ± 8.27	0.001*
	p = 0.01*	*p* = 0.001*	
RT Pre-swing			
pre-treatment	16.82 ± 6.4	14.85 ± 9.73	0.4
post-treatment	15.1 ± 5.81	9.4 ± 4.96	0.001*
	p = 0.08	*p* = 0.001*	
Lt Pre-swing			
pre-treatment	16.84 ± 8.58	15 ± 8.82	0.45
post-treatment	15.22 ± 8.03	8.92 ± 4.01	0.001*
	p = 0.07	*p* = 0.001*	

Lt – left, Rt – right, * significant

Table 3. Mean hip flexion excursion (in degrees) in swing phase pre- and post-treatment for both groups

Swing phase	Group A mean ± *SD*	Group B mean ± *SD*	*p*-value
Rt Initial swing			
pre-treatment	21.7 ± 3.53	20.34 ± 5.18	0.28
post-treatment	19.64 ± 3.9	16.1 ± 2.84	0.001*
	p = 0.002*	*p* = 0.001*	
Lt Initial swing			
pre-treatment	21.37 ± 6.54	20.82 ± 6.56	0.76
post-treatment	19.17 ± 5.14	15.58 ± 4.1	0.009*
	p = 0.02*	*p* = 0.001*	
Rt Mid-swing			
pre-treatment	35.86 ± 7.71	33.47 ± 8.25	0.29
Post-treatment	31.42 ± 5.84	27.59 ± 4.39	0.01*
	p = 0.001*	*p* = 0.001*	
Lt Mid-swing			
pre-treatment	35.92 ± 7.41	33.62 ± 8.34	0.3
post-treatment	33.04 ± 6.22	27.83 ± 5.03	0.002*
	p = 0.002*	*p* = 0.001*	
Rt Terminal swing			
pre-treatment	32.5 ± 5.22	31.98 ± 6.07	0.75
post-treatment	30.87 ± 4.07	26.67 ± 3.42	0.001*
	p = 0.02*	*p* = 0.001*	
Lt Terminal swing			
pre-treatment	32.96 ± 5.01	32.25 ± 7.41	0.69
post-treatment	30.1 ± 4.31	26.91 ± 2.98	0.004*
	p = 0.001*	*p* = 0.001*	

Lt – left, Rt – right, * significant

prioceptive input and inhibits joint-position sense over time [26, 27], which affects the muscle-joint relationship [28] and disrupts muscle spindle sensitivity [29]. These problems may result in making children with CP rely on vision as a compensatory technique for joint-position sense-required activities, such as gait [30].

McLaughlin et al. detected passive sagittal plane movements of the big toe and knee and reported that diplegia is associated with proprioception abnormalities [31]. Damiano et al. [32] found that children with better lower limb proprioception had less postural sway, indicating a relationship between sensory and motor performance in the lower extremities. Ibrahim et al. [33] concluded that adding weight to the lower extremity in the form of using anti-gravity shoes helped to improve the proprioceptive and vestibular sense in the lower limbs, which leads to improving the child's balance and decreases the angles of the lower extremities' joints in the stance phase.

Improvements in hip joint kinematics may be attributed to probable mechanical and neuromuscular adaptations as a strategy for locomotor adaptation to loading [34, 35]. Simão et al. [14] studied the efficiency of loading a lower extremity during gait and found that children with diplegia modified lower extremity joint kinematics as an immediate response to loading. Also, Lam et al. [36] found that loading legs during training on a treadmill enhanced functional ambulation. Previous studies found that training with leg weights may improve gait kinematics to near-normal levels [36–40]. Leg loading enhances the flexor muscular activity of the lower extremity muscles [34, 35, 41, 42]. Also, alternative flexion and extension while using weights around the ankle during gait may result in improving lower extremity strength and sensorimotor function. This comes in agreement with a study by El-Saeed [43], who studied the effect of using of bicycle ergometer on improving quadriceps muscle torque.

Limitations

This study is limited by its use of 2D gait analysis rather than 3D gait analysis, which may result in parallax error, though it is more prominent in rotational angles than sagittal plane angles, which are what was measured in this study. In addition, there were no follow-up results to assess the retention of the outcomes and no sample size estimation. It is suggested that further research be conducted to explore the effect of weight loading during gait on lower limb strength and proprioception, and assessing muscle strength would help more in clarifying the effect of the weight loading on the power of the extensor muscles.

Conclusions

Using weight around the ankle during gait helped to decrease the degree of excessive hip flexion excursion in children with diplegic CP.

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Ethical approval

The research related to human use complied with all the relevant national regulations and institutional policies, followed the tenets of the Declaration of Helsinki, and was approved by the research ethical committee board of the Faculty of Physical Therapy, Cairo University (approval No.: P.T.REC/012/003863). The clinical trial was registered at clinical trials.gov with the number NCT05579535.

Informed consent

Informed consent has been obtained from all individuals included in this study.

Disclosure statement

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Conflict of interest

The authors state no conflict of interest.

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