



Effect of Blood Flow Restriction Training on Balance and Walking Speed in Children with Spastic Diplegic Cerebral Palsy: A Randomized Controlled Trial

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Abstract

Background: The neurodevelopmental condition known as cerebral palsy is characterized by a variety of motor dysfunctions, such as irregularities in posture and movement. Since these individuals are less tolerant of high-intensity exercises, a training program is required. This study aimed to assess how blood flow restriction training affected the balance and walking speed of children with spastic cerebral palsy.

Methods: This randomised controlled trial was conducted at the 'Cogniable, the child', Physiotherapy clinic and SGT Hospital, Gurugram, India from November 2023 to May 2024. Thirty-two children with spastic diplegic cerebral palsy who were between the ages of 8 and 15 years and met the selection criteria were included in the study and randomly assigned into two groups. Study group (n=16) received blood flow restriction training along with rehabilitation program and control group (n=16) received only rehabilitation program. The data was collected at baseline and at end of 4th week of the study. The outcome measures used were Time Up and Go test (TUG) and 6-min walk test. Data was statistically analysed by using independent t-test and paired t-test.

Results: After 4 weeks of intervention with blood flow restriction training combined with a rehabilitation program, the study group demonstrated significant improvements in both the TUG ($p=0.042$) and the 6-min walk test ($p=0.003$) compared to the control group. Within-group analysis showed significant improvements in the study group ($p<0.001$ for both tests) while control group revealed significant difference of $p=0.001$ for TUG and $p<0.001$ for 6-min walk test following four weeks of intervention.

Conclusion: The results indicated that adding blood flow restriction training to children with spastic cerebral palsy improves balance and walking speed.

Keywords: Balance, Blood flow restriction training, Cerebral palsy, Low load resistance training, Walking speed

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Introduction

A neurological disorder known as Cerebral Palsy (CP) is brought on by developmental defects and non-progressive brain damage (1). Central motor deficits and postural abnormalities are the main symptoms, though epilepsy, developmental delay, perceptual impairment, linguistic difficulty, and abnormalities in cognitive behaviour can also accompany these symptoms (2).

The World Health Organisation estimates that the incidence of CP is between 0.2 and 0.3% in developed countries and approximately 0.295% in India (3-5). The most common form of CP is spastic diplegia, which affects 80% of preterm infants and accounts for approximately 44% of the overall incidence of CP (6). The trunk is noticeably weaker and the extremities are highly spastic in children with spastic diplegia. In comparison to their lower extremities, they demonstrate milder motor impairment in their upper extremities (7).

The development of gross motor skills is impacted by CP, which is a major cause of physical disability in children. Secondary injuries such as limb stiffness, muscular atrophy, skeletal abnormalities, muscle weakness, and developmental coordination impairments can arise in children with CP due to delayed damage to the central nervous system (8,9). The gross motor skills needed for postural balance are limited by these alterations increasing the risk of falls and fear of falling (10,11). Furthermore, children with CP have been found to have deficiencies in the visual, somatosensory, and vestibular systems, which are necessary to ensure postural control. These impairments include abnormal balance, a reduction in reactive and anticipatory postural adjustments, and limitations in social life domains like education, entertainment, and social relationships (12-15). Children with CP require retraining for altered postural balance due to these balance abnormalities, which prevent them from learning appropriate patterns of stability and balance. Contractures, tiredness, muscle weakness, and abnormal muscle tone are among the motor deficits frequently observed in people with CP. These conditions can all have a substantial impact on the kinematics of an effective walking pattern, such as step length and gait velocity (16). The gait patterns of children with spastic CP

include crouching, internal rotation, and restricted sagittal plane mobility. Individuals with CP are less likely to participate in public places than their healthy counterparts because of their lower walking stability (17) and correspondingly elevated fear of falls (18). Walking speed becomes an important metric in evaluating functional levels, as it is predictive of community ambulation and impairment.

As CP cannot be cured, management concentrates on resolving motor deficits to maximise a person's function and quality of life. Research has shown that a range of techniques and interventions, such as strengthening exercises, can improve gait and balance metrics. According to the American College of Sports Medicine (ACSM), High-Load Resistance Training (HL-RT), which uses a load of 70–85% of one-repetition maximum (1RM), has historically been the most successful strategy (19). Some CP patients, however, might not be able to handle this kind of training (20). Therefore, it is interesting to investigate different strengthening techniques utilising varying percentages of 1RM, such as Low-Load Resistance Training (LL-RT), which applies weights at roughly 20–50% of 1RM (19). Concurrent limb occlusion is used in this context to partially restrict arterial inflow and the venous return of blood from the working muscles, a training technique known as Blood Flow Restriction Training (BFRT).

An external pneumatic tourniquet is applied at the proximal end of the upper or lower limbs to promote ischaemia and blood pooling in the capillary beds of the musculature distal to the tourniquet. Muscle strength and hypertrophy are enhanced by ischaemia and mechanical strain during exercise, which provide a mechanotransductive and metabolic stress that results in higher neuromuscular and hormonal adaptations than LL-RT alone (21,22).

Few studies (23,24) have examined the impact of BFRT on strength or gait biomechanics; however, these investigations have primarily focused on adults with CP or on different populations such as individuals with multiple sclerosis. To the best of authors' knowledge, no published research has explored the mechanical effects of BFRT on gait spatiotemporal parameters and balance in children with spastic CP. The purpose of this study is to examine how walking speed and balance are affected by BFRT in children

with spastic CP. It was postulated that blood flow restriction exercise at a lower intensity would be more beneficial than training at a higher intensity. As far as authors know, this is the first study to look at how BFRT affects the spatiotemporal aspects of gait in children with CP.

Materials and Methods

Study design and subjects

This single blinded parallel group randomised controlled trial was carried out at 'Cogniable, the child', Physiotherapy clinic and SGT Hospital, Gurugram, India between November 2023 and May 2024. Research procedures were carried out in accordance with the Declaration of Helsinki, 1964 (World Medical Association, 1964). Parents of the subjects were informed about the study's purpose and provided their signed consent. The number of subjects was determined using Software G. Power 3.1.9.2 (Universität Kiel, Kiel, Germany) based on the data of balance changes from a study performed by Gupta *et al* (25), in which the effect of pelvic control exercises on balance was analysed. With an effect size of 1.46, an alpha level of 0.05, and a power ($1-\beta$) of 0.95, it was concluded that each group needed 14 participants. A total of 32 subjects were recruited into the study considering 10% drop out. The study included diagnosed cases with spastic diplegic CP in individuals aged 8 to 15 who were able to comprehend spoken instructions, spasticity of 1, 1+ or 2 on the Modified Ashworth Scale and were classified at levels I and II of the Gross Motor Function Classification System (GMFCS). Participants were excluded from the study if they had undergone botulinum toxin (BTX-A) treatment or serial casting to their lower limbs within the previous three months (or as planned for the intervention or control period), had finished a core exercise group within the six months prior, had behavioural problems that prevented them from participating in the group, or had any other musculoskeletal conditions that prevented them from doing resistance training.

Procedure

Being a single-blind study, the participants were blinded to the type of intervention they received. Simple random sampling was used to randomly assign

all the eligible participants to either the study group or the control group. The participants were divided into two equal groups using the lottery method, in which a researcher selects numbers at random, each of which represents a subject or object, in order to construct the sample. The researcher who enrolled the participants and generated the random allocation sequence was different from the one who randomly allocated the participants into the groups.

Balance evaluation

Balance was assessed using Time Up and Go test (TUG) test. The TUG test has been used to evaluate balance in ambulatory children with CP since it can differentiate between children at levels I–III of the GMFCS and with various subtypes of CP (26,27). The TUG has a substantial effect size (MCIDs of 0.36 and 0.87) for GMFCS levels I and II, and it has great test-retest reliability in children with CP (ICC=0.91-0.98) (28). A substantial negative correlation (Spearman $\rho=-0.88$, $p<0.01$) has been seen between the TUG and the BBS total score. The test involved getting up, walking ten feet, turning at a predetermined location on the floor, returning to the chair, and finally sitting down. The test ended when the subjects sat down in the chair and stopped moving after being told to "get ready, go".

Walking speed evaluation

The participants' walking speed was measured with 6-min walk test. Children with CP can be reliably assessed for walking ability using the 6-min walk test (6MWT). It calculates the furthest a child can walk on a level surface in six minutes. Walking speed can be calculated by dividing the distance walked by 6 minutes (360 s). Test-retest reliability of 6MWT ICC is 0.98, and >0.90 in GMFCS subgroups (95% CI lower bound >0.64) (29).

Intervention

The participants were subjected to rehabilitation program with and without blood flow restriction for a period of 4 weeks, three sessions per week. Both groups participated in supervised exercise sessions that lasted approximately 30 min each. Rehabilitation program consisted of exercises like squats, leg extension exercises, walking, double leg stance on

wobble board. Both the groups performed exercises for 75 repetitions over four sets that is 30/15/15/15 with 30-sec rest interval between each set (Table 1, Figure 1).

During BFRT, a cuff (Regular size cuff, SAGA fitness, Australia) was applied on the proximal thigh with 40 to 80% of limb occlusion pressure (30), a pressure that resulted in venous not arterial occlusion, whereas in the control group, cuff was applied with

zero pressure.

Data analysis

SPSS 21 (IBM Corp., Armonk, NY, USA) was used to analyse the data. All the outcome measures' data were determined to be normally distributed after the Shapiro-Wilk test was used to evaluate the distribution scores' normality. The mean and standard deviations were used to express the descriptive data.

Table 1. Exercises involved in rehabilitation program

Exercise	Procedure	Dosage
Squats	Stand with feet a about shoulder-width apart. Bend through the hips, knees, and ankles as you descend slowly. When your knees are 90 degrees, stop. Then go back to where you started	4 sets with [30,15,15,15] reps
Leg extension exercise	Take a chair that supports your thigh and sit up straight. Straighten your knee as far as possible and hold for 5-10 s, then relax	4 sets with [30,15,15,15] reps
Walking	Sideways walking	10 steps × 4 sets
	Backward walking	10 steps × 4 sets
Double- leg stance on bosu ball	Place both feet evenly on the bosu ball, shoulder-width apart. Hold the position for 30 s or as long as comfortable, gradually increasing the duration as balance gets improved	10-sec hold, 4 sets with 5 reps

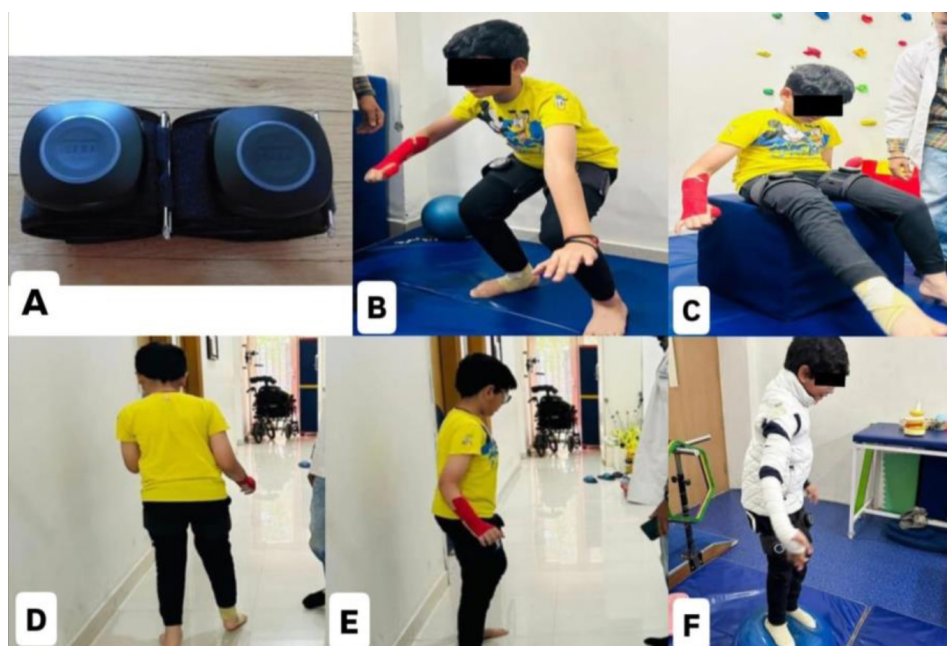


Figure 1. Intervention A) blood flow restriction cuff, B) squats, C) leg extension exercise, D) backward walking, E) side-wards walking, F) double-leg stance on bosu ball.

The demographic features were compared using an independent t-test for continuous data while categorical variables (gender, grade of GMFCS scale, spasticity grade) were presented as frequencies/percentages wherever required and chi square test was used to compare them. Following the completion of rehabilitation exercises and BFRT, the groups' TUG and 6MWT scores were compared using an independent sample t-test. The outcome measure's within-group change was examined using the paired t-test. Additionally, the significance level was kept at 5% with a 95% confidence interval.

Results

Baseline characteristics of the participants

Initially, 40 participants were recruited, of which eight participants dropped out during the course of the study. The final analysis was performed on 32 participants. Study group (n=16) received supervised rehabilitation program with blood flow restriction and control group (n=16) received supervised rehabilitation program with cuff remained deflated for the duration of the rehabilitation program (Figure 2). Table 2 displays the baseline and demographic

data for each participant. At baseline, there were no discernible differences between the groups. Moreover, all the participants were able to complete exercises and no one reported any adverse event (itching, dizziness, lower extremity paraesthesia).

Balance

Within group analysis revealed significant decrease in the TUG scores in both study and control groups ($p<0.01$). Between group comparison revealed significant reduction in TUG scores in the study group following the intervention ($p=0.02$) (Table 3, Figure 3).

Walking speed

When 6MWT scores were compared within groups after the intervention, both groups found statistically significant changes ($p<0.05$). According to table 3 and figure 3, the study group's 6MWT scores improved statistically significantly ($p<0.05$) for the between-groups comparison.

Discussion

The main goal of this study was to assess how

Table 2. Demographic characteristics between the groups

Characteristics	Study group (n=16) Mean±SD	Control group (n=16) Mean±SD	t value	p-value
Age (years)	10.04±1.51	10.46±1.56	-0.779	0.442
Height (m)	1.07±0.08	1.06±0.09	0.416	0.68
Weight (kg)	32.00±3.15	30.53±3.30	1.291	0.207
Gender ^a	M=9, F=7	M=10, F=6	0.13	0.719
BMI (kg/m ²)	27.99±3.54	27.36±3.21	0.528	0.602
GMFCS distribution				
Grade I	7	5	0.533	0.465
Grade II	9	11		
Spasticity grade distribution				
Grade I	4	3	0.519	0.771
Grade I+	6	5		
Grade II	6	8		

M: Male, F: Female, GMFCS: Gross Motor Function Classification System, SD: Standard Deviation, a: chi square test.

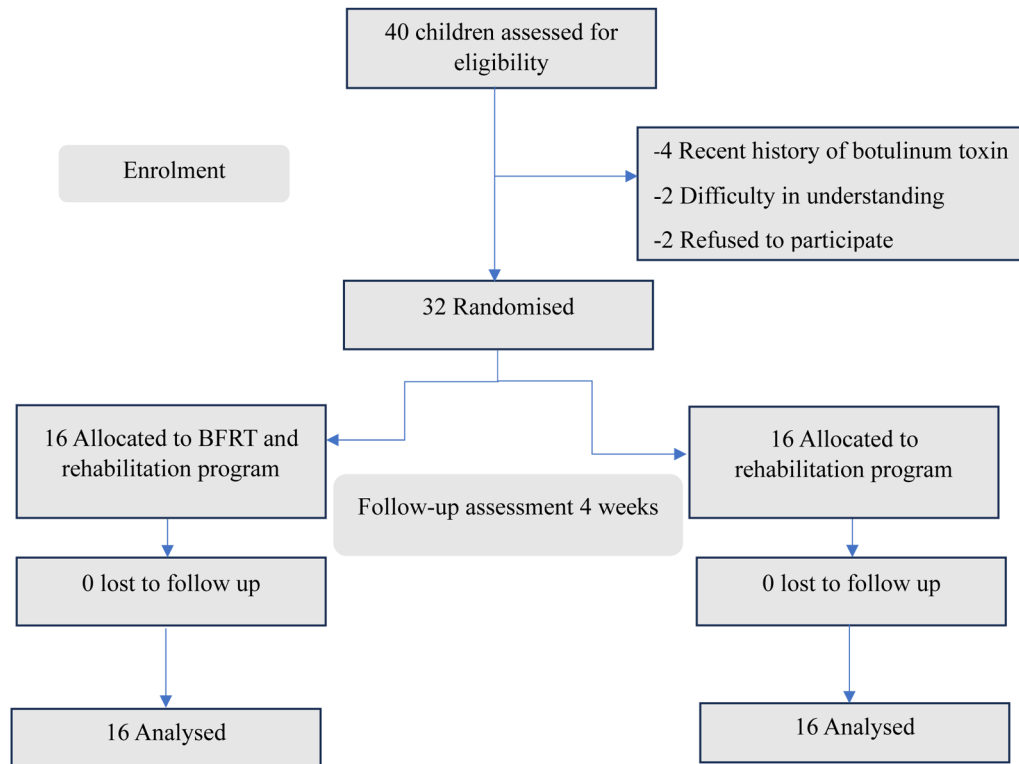


Figure 2. Flow chart of the participants.

Table 3. Comparison of mean values of TUG and 6MWT scores within and between groups

Variables	Parameter	Study group Mean±SD	Control group Mean±SD	p-value	Effect size cohen's d
TUG	Pre-intervention	90.87±8.23	90.75±21.28	0.983	0.01 [-0.69, 0.70]
	Post-intervention	77.75±7.75	89.68±21.04	0.042*	-0.73 [-1.45, -0.01]
	p-value	<0.001*	0.001*	-	-
6MWT	Pre-intervention	23.12±3.14	24.71±5.46	0.320	-0.35 [-1.05, 0.35]
	Post-intervention	31.00±4.10	25.43±5.61	0.003*	1.11 [0.35, 1.86]
	p-value	<0.001*	<0.001*	-	-

TUG: Time Up and Go test, 6MWT: 6-min walk test, SD: Standard Deviation, p: Probability value, *: Significant difference.

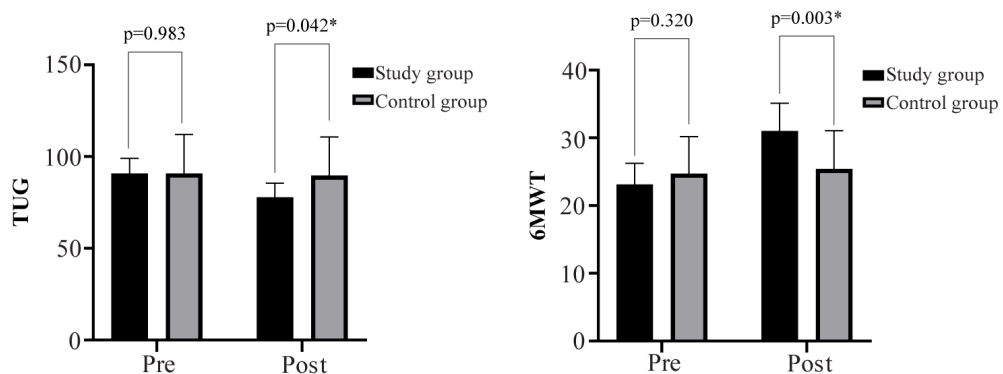


Figure 3. Mean and SD of TUG and 6MWT in study and control group before and after 4 weeks of intervention. Pre: pre-intervention, Post: post-intervention, SD: standard deviation, p: probability value.

BFRT, when combined with a rehabilitation program, affected the walking speed and balance of children with spastic CP. The study group, who performed a combination of BFRT along with conventional rehabilitation program, demonstrated greater improvement in walking speed and balance compared with the control group, who had undergone rehabilitation program only.

The results of current study demonstrated that both groups' 6MWT significantly improved following the intervention. These results are in accordance with a previous investigation (31) where simple walking exercises along with BFRT was found to be effective in increasing walking speed and enhancing physical function in older adults. High-intensity exercise is not always tolerable by children with CP; augmenting simple exercise with BFRT may provide an alternative exercise to improve physical function. A pressurised cuff is used in BFRT to limit the oxygen and blood flow to the limbs.

Prolonged exposure to a localized hypoxic environment may impair the contractile function of the leg muscles during walking. Of particular concern is the reduced contractility of the plantar-flexors, which serve as the primary power generators in gait. When their submaximal contractility is compromised, neuro-mechanical compensatory strategies may arise, leading to a redistribution of mechanical force from the ankle to the hip and knee.

These adaptations may help improve gait speed. Numerous prior researches have demonstrated the effectiveness of BFRT on muscular strengthening (32-34) and the findings support these as improved walking functions was also noticed when BFRT was used in conjunction with a traditional muscle-strengthening program.

In this study, a decrease in TUG score was observed after the 4-week exercise program. BFRT seems to have a stronger impact on muscle strength when paired with low-intensity training (35). Muscular contractions become stronger and more coordinated as muscular strength rises due to an increase in the synchronisation between motor units, or muscle fibres and the motor neurones that innervate them. Improved observation and control of movement states, less needless energy expenditure, and

optimised movement patterns all contribute to better balance management. Additionally, it encourages adaptive alterations in the central nervous system, such as improved neuronal connection, heightened synaptic plasticity, and neurotransmitter release modulation, enabling the CNS to react faster and process proprioceptor data more precisely in order to preserve body equilibrium (36).

The present study revealed a significant effect of BFRT on gait parameters and balance in children with spastic CP. Additionally, a prior study (23) documented the enhanced impact of BFRT in conjunction with traditional exercises on gait and balance outcomes in MS patients. BFRT may be more beneficial for subjects who are less tolerant of high-intensity exercise.

The present study suffered from certain limitations. Since only children with GMFCS I-II and spastic diplegia participated in this study, the data collected cannot be applied to all children with CP. In future studies, a larger number of children with CP should be divided by type and studied further. Another limitation is the short intervention period for BFRT and the rehabilitation program. Follow-up assessments were not performed. Finally, the participants were from a specific region.

Conclusion

The results of this research offer insights into the potential advantages of BFRT training in enhancing balance and walking speed among children with spastic CP in comparison to conventional resistance training, thus bearing implications for clinical application.

Acknowledgement

The current study was registered with ethics code SGTU/FPHY/2023/353 by the Institutional Ethical Committee of Faculty of Physiotherapy, SGT University, Gurugram, India. The authors want to express their sincere gratitude to all of the study participants and their parents who gave up their precious time.

Conflict of Interest

No possible conflicts of interest need to be disclosed.

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