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Blood Flow Restriction Combined with Low-Load Resistance Training versus High-Load Resistance Training in Children with Cerebral Palsy

Engy Higazy El Sayed Higazy [1]*, Khaled Ahmad Mamdouh [1], Walid Ahmed Abdel Ghany [2], Alaa Al-Nemr [1]

[1] Department of Physical Therapy for Pediatrics, Faculty of Physical Therapy, Cairo University, Egypt.

[2] Neurosurgery Functional Surgery, Department of Neurological Surgery, Ain Shams University, Egypt.

*** Corresponding author:** Engy Higazy El Sayed Higazy, **Email:** engyhigazy88@gmail.com, **Phone:** (+20) 01016616165

ABSTRACT

Background: Spastic diplegia in children is characterized by bilateral lower limb (LL) spasticity and muscle weakness, leading to reduced functional mobility.

Aim: This investigation aimed to compare the effects of low-load resistance training combined with blood flow restriction (LLRT-BFR) versus high-load resistance training (HLRT) on LL muscle strength and gross motor function in pediatric patients with spastic diplegic cerebral palsy (CP).

Patients and methods: Thirty clinically and radiologically confirmed cases of spastic diplegic CP (aged 8–10 yrs) were randomly allocated into two equal groups. Group A (n = 15) underwent LLRT-BFR, whereas Group B (n = 15) received HLRT. Both protocols were applied over a 6-week period. LL muscle strength was evaluated via a handheld dynamometer (HHD), while gross motor function was assessed via the Gross Motor Function Measure-88 (GMFM-88).

Results: Both groups demonstrated statistically significant post-intervention gains in knee muscle strength and in the standing and walking dimensions of GMFM-88 compared to baseline ($p<0.001$). However, inter-group differences were not statistically significant ($p > 0.05$).

Conclusion: LLRT-BFR elicited strength and functional improvements comparable to those obtained with HLRT in children with spastic diplegic CP. This suggests LLRT-BFR may be a practical alternative when high-load regimens are contraindicated or poorly tolerated.

Keywords: Cerebral palsy, blood flow restriction, low-load resistance training, high-load resistance training, lower limb muscles strength, gross motor functions.

INTRODUCTION

Cerebral Palsy (CP) is a neurodevelopmental disease arising from injury to the immature brain during fetal or early infant life. It stands among the most common lifelong disabilities in childhood, with an estimated prevalence of about 2/1,000 live births [1]. While low birth weight and prematurity are recognized as primary risk factors, a spectrum of additional contributors, such as intrauterine infections, has been associated with elevated susceptibility to CP [2]. In the spastic diplegic (SD) subtype, bilateral weakness and elevated muscle tone of the lower extremities compromise mobility and functional independence. Given that adequate muscle strength (MS) underpins purposeful and autonomous movement, the search for an effective and sustainable strategy to enhance motor function in CP remains a central challenge in rehabilitation science [3].

One strategy for strengthening weak muscles is the restriction of blood flow. It is applied via a pneumatic tourniquet system, which restricts venous outflow and arterial blood flow distal to the cuff by employing an external pressure via the tourniquet cuff to the most proximal area of the lower limb (LL) [4].

High-load resistance training (HL-RT) necessitates high overload to achieve the best strength [5]. However, children with spastic diplegia may not be able to tolerate resistance training due to musculoskeletal dysfunction.

This work aimed to assess the effects of low-load resistance training (LL-RT) combined with blood flow restriction (BFR) on LL MS and gross motor function (GMF) in children with SDCP. It also examined the impact of HL-RT on these outcomes. Furthermore, the research investigated the effectiveness of LL-RT with BFR against HL-RT in improving LL MS and GMF in children with SDCP.

MATERIALS AND METHODS

This randomized controlled trial was done at the Faculty of Physical Therapy, Cairo University, from January-May 2024. A total of thirty children meeting the eligibility criteria were recruited for participation.

Sample Size Determination

The required sample size was calculated a priori via G*POWER statistical software (V3.1.9.2; University of Kiel, Germany). The calculation was based on an alpha level of 0.05, a statistical power of 80%, and a large effect size, indicating a minimum of 14 participants / group. To compensate for an anticipated 15% dropout rate, the sample size was elevated to 15 participants / group, resulting in 30 contributors.

Randomization and Allocation

Participant allocation was done via simple randomization. An independent researcher, not involved in the assessment or intervention, assigned participants to groups via sealed opaque envelopes to ensure allocation concealment. The children were randomly and equally assigned to two groups according

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to the training protocol. Group A: 15 children (11 boys and 4 girls) who received LLRT-BFR, while Group B: 15 children (10 boys and 5 girls) who underwent HL-RT.

Inclusion Criteria

Eligible participants were required to have a confirmed diagnosis of SDCP, as established clinically and radiologically, and to be referred by their attending physicians. Both boys and girls aged between 8 and 10 years were eligible. Spasticity grades ranged from 1+ to 2 on the Modified Ashworth Scale (MAS). Functional abilities corresponded to levels II or III on the GMF Classification System – Expanded and Revised (GMFCS-E&R).

Exclusion Criteria

Children were excluded if they presented with congenital heart disease, severe cognitive impairment, epilepsy, or had received botulinum toxin injections to the LLs within the preceding six months. Further exclusion criteria included prior orthopedic surgery involving the LLs or pelvis, medical instability, or uncooperative behavior that could interfere with adherence to the intervention protocol.

Assessment procedures:

Comprehensive demographic data, including age, body weight, and height, were collected for all participants at baseline. Prior to study enrollment, the parents of each child received detailed verbal and written explanations outlining the purpose of the research, its scientific rationale, and the potential clinical benefits. Sufficient time was provided for questions, and written informed consent was obtained from the parents or legal guardians before any assessments were conducted.

Baseline measurements comprised three components: determination of the one-repetition maximum (1RM) strength, assessment of knee extensor MS via a handheld dynamometer (HHD), and evaluation of GMFM-88. These assessments were conducted by the same trained assessor at the beginning of the research and repeated at the end of the six-week intervention period to evaluate treatment outcomes.

One-Repetition Maximum Strength Test

The 1RM test was employed to identify the maximal load that could be lifted only once through the full range of motion with proper technique. Testing followed a standardized progressive loading protocol, beginning with submaximal warm-up sets, followed by incremental elevations in resistance interspersed with rest intervals. The process continued until the participant was able to complete only one repetition, which was then documented as the 1RM value **[6].**

2. Muscle strength measurement:

Isometric knee extensor strength was assessed via an HHD under standardized conditions to ensure reliability. Participants were seated on a stable surface with hips and knees positioned at 90° of flexion, and the dynamometer was placed anteriorly on the shank, immediately proximal to the ankle joint. A consistent resistive force was applied for 3–5 seconds, perpendicular to the limb's long axis, to evoke maximal voluntary contraction. Each child was instructed to "push as hard as possible" during each trial, with verbal encouragement provided to promote maximal effort **[7].** All measurements were taken on the dominant leg, and the average of three trials was documented for analysis (Fig. 1).

Fig. (1): HHD for knee extensors.

3. Gross motor function measurement:

GMF was evaluated via the GMFM-88, a validated, criterion-referenced observational tool designed specifically for children with CP. In the present investigation, only the standing and walking dimensions were assessed, as these domains most closely reflected the functional outcomes targeted by the intervention. Scoring was conducted via a standardized sheet in strict accordance with the GMFM-88 manual. For each dimension, the percentage score was calculated via the formula: (child's score / maximum possible score) × 100 [8].

Treatment:

All participants engaged in a structured physical therapy program delivered over six weeks, with each session lasting approximately 30 minutes. The core program was identical for both groups, but the resistance training protocol varied according to group allocation. Group A done LLRT-BFR, whereas Group B undertook HLRT.

Designed Physical Therapy Program

The standardized program incorporated exercises based on neurodevelopmental treatment (NDT) principles, aimed at enhancing balance, mobility, and functional independence. Activities included weight-shifting tasks on a balance board facilitated through visual cues or interactive play, sit-to-stand transitions from an inclined wedge with pelvic

support, squatting to standing while reaching, semi-kneeling to standing transfers, and step-up/step-down movements. Gait training within parallel bars included forward and lateral stepping, negotiation of obstacles, and stair climbing to improve coordination, stability, and endurance [9].

Low-Load Resistance Training with Blood Flow Restriction (Group A)

The LLRT-BFR protocol targeted knee extensors via sandbag weights set at 40% of the individual's 1RM. Training sessions lasted 25 minutes, comprising four sets of 10 repetitions, with one-minute rest intervals, conducted three times / week for six consecutive weeks. Participants were seated with hips and knees flexed at 90°, and resistance was applied at the ankle joint.

BFR was implemented via a smart cuff device (V 4) in an intermittent protocol. Nylon cuffs were positioned proximally on the thigh and inflated to 40% of arterial occlusion pressure (AOP) for the first three weeks, then elevated to 50% AOP for the remaining period. Cuffs were inflated during active exercise and deflated during rest intervals. Safety precautions were observed, and exercises were immediately discontinued in the event of pain, discomfort, or skin redness [10]. Exercises were discontinued immediately if adverse symptoms such as pain or redness were observed (Fig. 2).

Fig. (2): Low-load resistance training with blood flow restriction for knee extensors.

High-load resistance training (Group B):

The HLRT protocol involved the same exercise sequence as Group A but employed greater loading parameters. Training intensity began at 60% of 1RM during the first two weeks, progressing to 80% by week six. Sessions lasted 25 minutes and included four sets of 10 repetitions, with one-minute rest intervals, conducted three times / week.

Resistance was progressively elevated by 5–10% in response to improvements in the child's strength capacity as shown in figure (3) [11].

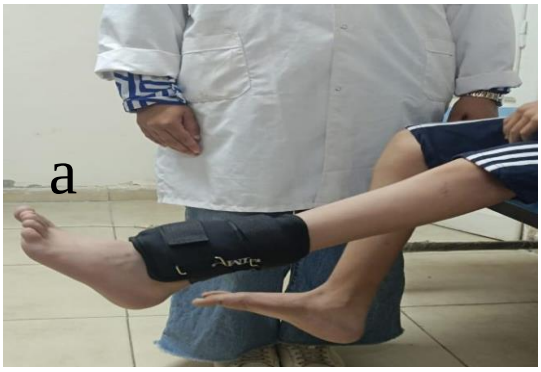

Fig. (3): High-load resistance training for knee extensors.

Ethical considerations

The study was conducted following approval from the Research Ethics Committee, Faculty of Physical Therapy, Cairo University (Reference No: P.T.REC/012/005132). Written informed consent was obtained from the parents or legal guardians of all participating children prior to enrolment. The consent form clearly stated their agreement to participate and to allow publication of anonymized data, with full assurance of confidentiality and privacy protection. All procedures were performed in accordance with the ethical principles of the World Medical Association's Declaration of Helsinki for research involving human subjects.

Statistical analysis

Data processing and analysis were done via the Statistical Package for the Social Sciences (SPSS), V 25 for Windows (IBM SPSS Inc., Chicago, IL, USA). Prior to conducting inferential tests, the dataset was examined to ensure compliance with test assumptions. The Shapiro–Wilk test was applied to verify the normal distribution of continuous variables, and Levene's test was used to confirm the homogeneity of variances between groups. Comparisons of baseline anthropometric characteristics (age, weight, height) were carried out via the unpaired t-test. The Mann–Whitney U test was employed to compare GMF Classification System (GMFCS) levels, while the chi-squared test assessed differences in sex distribution and spasticity grades between groups. For outcome analysis, between-group differences in knee extensor MS and GMFM-88 scores were evaluated via the unpaired t-test, whereas within-group changes from pre- to post-intervention were analyzed via the paired t-test. A significance threshold of $p<0.05$ was adopted for all analyses. All statistical decisions were made in accordance with accepted methodological standards to ensure reliability and validity of the findings.

RESULTS

- Subject characteristics:

Table 1 presents the demographics of participants in Groups A and B. The two groups exhibited comparability in age, body weight, height, GMFCS levels, sex distribution, and spasticity grades ($p > 0.05$).

Table 1: Demographics of participants.

		Group A (n=15)	Group B (n=15)	t-	P
Age (years)		8.93 ± 0.88	9.27 ± 0.96	-0.98	0.33
Weight (kg)		32.90 ± 4.14	33.20 ± 4.80	-0.18	0.86
Height (cm)		132.53 ± 5.25	133.87 ± 4.34	-0.75	0.46
GMFCS, median (IQR)		2 (3-2)	2 (3-2)	(U = 112.5)	1
Sex, n (%)					
Girls		4 (27%)	5 (33%)	(χ^2 = 0.16)	0.69
Boys		11 (73%)	10 (67%)		
Spasticity grades, n (%)					
Right side	**Grade I+**	8(53%)	9 (60%)	(χ^2 = 0.14)	0.71
	Grade II	7(47%)	6 (40%)		
Left side	**Grade I+**	10(67%)	8(53%)	(χ^2 = 0.56)	0.46
	Grade II	5(33%)	7(47%)		

Data presented as mean ± SD or median (IQR) or frequency (%); U, Mann–Whitney test value; χ^2, Chi squared value; P probability value, n=number.

Effect of treatment on knee muscles strength and GMFM-88:

- Within group comparison:

A statistically significant elevation in knee extensor strength was observed in both groups following the intervention as opposed to pre-treatment values (p<0.001). The percentage improvement in right and left knee extensors was 34.82% and 34.50%, respectively, in Group A, and 23.51% and 28.78%, respectively, in Group B (Table 2).

Similarly, both groups demonstrated significant post-treatment improvements in the standing and walking domains of the GMFM-88 as opposed to baseline scores (p<0.001). In Group A, the percentage changes for the standing, walking, and goal total scores were 13.67%, 13.85%, and 34.50%, respectively. Corresponding values in Group B were 11.09%, 13.44%, and 28.78%, respectively (Table 3).

Between-group comparison:

At baseline, the two groups exhibited comparability in knee extensor strength and GMFM-88 scores. Post-treatment comparisons showed that this comparability was maintained across both outcome measures (Tables 2 and 3).

Table 2: Mean knee extensors strength pre and post treatment of group A and B.

Strength (kg)	Pre-treatment	Post treatment	MD	% of change	t	p
Right knee extensors						
Group A	5.17 ± 0.98	6.97 ± 1.23	-1.8	34.82	-28.46	0.001
Group B	5.53 ± 1.41	6.83 ± 1.76	-1.3	23.51	-14.53	0.001
MD	-0.36	0.14				
t- value	-0.81	0.25				
	p = 0.43	***p = 0.80***				
Lef knee extensors						
Group A	5.42 ± 1.04	7.29 ± 1.31	-1.87	34.50	-27.02	0.001
Group B	5.49 ± 1.26	7.07 ± 1.53	-1.58	28.78	-19.05	0.001
MD	-0.07	0.22				
t- value	-0.16	0.44				
	p = 0.88	***p = 0.66***				

Data presented as mean ± SD or median (IQR) or frequency (%); MD, Mean difference; p value, Probability value.

Table 3: Mean standing and walking domains of GMFM-88 pre and post treatment of group A and B.

GMFM-88 (%)	Pre-treatment	Post treatment	MD	% of change	t	p
Standing						
Group A	55.90 ± 14.65	63.54 ± 14.37	-7.64	13.67	-22.43	0.001
Group B	59.44 ± 16.42	66.03 ± 16.51	-6.59	11.09	-22.93	0.001
MD	-3.54	-6.15				
t- value	-0.62	-1.15				
	p = 0.53	***p = 0.26***				
Walking						
Group A	47.42 ± 12.90	53.99 ± 12.68	-6.57	13.85	-18.11	0.001
Group B	53.57 ± 16.25	60.77 ± 16.70	-7.2	13.44	-15	0.001
MD	-2.49	-6.78				
t- value	-0.44	-1.25				
	p = 0.66	***p = 0.22***				
Goal Total GMFM-88						
Group A	51.66 ± 13.40	58.76 ± 12.99	-7.1	13.74	-27.21	0.001
Group B	56.51 ± 16.29	63.40 ± 16.55	-6.89	12.19	-30.91	0.001
MD	-4.85	-4.64				
t- value	-0.89	-0.85				
	p = 0.38	***p = 0.40***				

Data presented as mean ± SD; MD, Mean difference; p value, Probability value.

DISCUSSION

In the present investigation, children with SDCP who underwent either LLRT-BFR or HLRT demonstrated significant improvements in the strength of knee extensors. The observed strength gains in the LLRT-BFR group may be attributed to Elevated muscle thickness and neural adaptations associated with BFR, including enhanced motor unit recruitment and neuromuscular signalling **[10- 13]**.

Similarly, HLRT-induced improvements are primarily driven by neural mechanisms such as Elevated motor neuron recruitment and cortical and subcortical adaptations that enhance muscle activation **[14-17]**. Additionally, resistance training has been shown to promote muscle hypertrophy in children with CP without exacerbating spasticity **[18,19]**.

Importantly, our findings revealed no significant difference between LLRT-BFR and HLRT in enhancing LL strength, suggesting that both interventions are equally effective. This similarity may be explained by the shared underlying mechanisms, namely, neural adaptations and muscle hypertrophy, that contribute to strength development in both protocols. **[12,13,20]**

Children with SDCP exhibit notable structural differences in skeletal muscle as opposed to typically developing peers. These include reduced muscle size, diminished contractile tissue, and excessively elongated sarcomeres **[28].**

Evidence from a systematic review by **Gillett *and co-authors***. indicates that strength training in children with CP can induce skeletal muscle hypertrophy [18] **.** Strength training does not appear to exacerbate spasticity; several studies have reported no adverse changes in spasticity levels following such interventions **[19]**.

In SDCP, muscle co-contraction is frequently Elevated, primarily due to central nervous system lesions that result in spasticity, impaired motor control, and reduced selective muscle activation. These factors collectively diminish force production capacity [31-29]. Resistance exercise has been shown to mitigate co-contraction, thereby enhancing net torque generation **[30]**.

Moreover, MS is moderately to strongly correlated with walking ability and GMF in children with CP, and weakness has been identified as a stronger predictor of mobility limitations than spasticity **[21-23]**.

Consistent with this evidence, both groups in the present study demonstrated significant post-intervention improvements in standing and walking performance (p = 0.001). The two groups exhibited comparability in post-treatment outcomes for standing (p = 0.22) and walking (p = 0.66), suggesting that beyond a certain functional strength threshold, further strength gains may not translate into proportional improvements in mobility **[21]**. Additional factors, such as balance, coordination, and selective motor control, are also likely to influence functional outcomes.

LLRT-BFR has been reported to elevation leg muscle thickness and density in children with CP, potentially through enhanced anabolic activity and consequent improvements in MS **[10-20]**

Furthermore, BFR exercise appears to promote neural adaptations, with low-intensity protocols eliciting changes in motor unit recruitment and

activation patterns that may contribute to Elevated thigh MS [12-13]

Our results are consistent with those of **Chang *et al.*** [24], who found that tailored, intermittent BFR protocols produced strength gains comparable to HLRT. Similarly, Jørgensen ***et al.*** [25] reported no significant differences between LLRT-BFR and HLRT across several measures, including MS, cross-sectional area, physical function, and patient-reported outcomes. However, some studies suggest HLRT may be more effective in maximizing strength gains. For example, **Lixandrão *et al.*** [26] concluded that while both approachs elevation muscle mass, HLRT may be superior for peak strength development. Likewise, **Vechin *et al.*** [27] found that although both interventions improved quadriceps strength and muscle mass in older adults, HLRT led to greater strength gains.

CONCLUSION

LLRT-BFR has been shown to produce comparable improvements in MS to those achieved with HLRT in children with SDCP. Therefore, it may serve as a viable alternative to high-load protocols, particularly when high loads are contraindicated or not well tolerated.

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