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Original Article

Efficacy of neuromuscular electrical stimulation and interrupted serial casting in children with spastic diplegia

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الملخص

أهداف البحث: يهدف هذا البحث إلى مقارنة تأثيرات التحفيز الكهربائي العصبي العضلي مع القولبة التسلسلية المتقطعة إلى القولبة التسلسلية وحدها على جوانب مختلفة من وظيفة الطرف السفلي لدى الأطفال الذين يعانون من الشلل الدماغي المزدوج. تمثل القولبة التسلسلية تقنية سريرية تستخدم لزيادة المدى السلبي للحركة، وخفض فرط التوتر، وتحسين المشي لدى الأطفال المصابين بالشلل الدماغي.

طريقة البحث: شملت هذه التجربة المقارنة العشوائية ثلاثة وثلاثين طفلا مصابا بالشلل الدماغي المزدوج. عند دخولهم في البحث، تم تعيينهم بشكل عشوائي إما إلى المجموعة (أ) أو المجموعة (ب). تلقت المجموعة (أ) قولبة تسلسلية جنبا إلى جنب مع برنامج علاج طبيعي مخصص، بينما تلقت المجموعة (ب) تدخلات مماثلة مثل المجموعة أ جنبا إلى جنب مع التحفيز الكهربائي العصبي العضلي المطبق من خلال النوافذ أثناء القولبة. شملت التقييمات نطاق الحركة، ومقياس التارديو المعدل، ومقياس الديناومتر المحمول، ومقياس المشية الرصدي. وأجريت التقييمات قبل وبعد ثمانية أسابيع من التدخل.

النتائج: أظهرت كلا المجموعتين تحسينات كبيرة في نطاق عطف ظهري للحركة، والزاوية المأبضية، والتشنج الديناميكي في عضلات الساق، والتشنج الديناميكي في أوتار الركبة بعد التدخل. ومع ذلك، لوحظت فروق ذات دلالة إحصائية بين المجموعتين بعد التدخل في قوة المثنية الظهرية، وقوة الباسطة في الركبة، ودرجة مقياس المشية الرصدية، لصالح المجموعة (ب).

الاستنتاجات: قد يساعد استخدام التحفيز الكهربائي العصبي العضلي أثناء الشلل الدماغي في التغلب على الانخفاض الكبير في القوة الذي يحدث نتيجة للقولبة التسلسلية. يتيح ذلك تحقيق نتائج أفضل في تقليل النغمة وتحسين نطاق الحركة دون انخفاض كبير في القوة، بالإضافة إلى تحسن أكبر في وظيفة المشي.

الكلمات المفتاحية: الشلل الدماغي؛ شلل مزدوج؛ التحفيز الكهربائي العصبي العضلي؛ القولبة التسلسلية؛ شناج

Abstract

Objectives: This research was aimed at comparing the effects of neuromuscular electrical stimulation (NMES) combined with interrupted serial casting (SC) versus SC alone on various aspects of lower limb function in children with diplegic cerebral palsy. SC is a clinical technique used to increase passive range of motion (ROM), decrease hypertonicity, and improve walking in children with cerebral palsy (CP).

Methods: This randomized comparative trial involved 33 children with diplegic CP, who were randomly assigned to group A or group B at recruitment. Group A received SC along with a customized physical therapy program, whereas group B received the same interventions as group A along with NMES applied through cast windows during casting. Evaluations were based on ROM, the Modified Tardieu Scale, handheld dynamometer measurements, and the Observational Gait Scale. Assessments were conducted before and after 8 weeks of intervention.

Results: Both groups exhibited significant improvements in dorsiflexion ROM, popliteal angle, gastrocnemius dynamic spasticity, and hamstring dynamic spasticity after the intervention ($P = 0.0001$ for all). However, significant differences ($P < 0.05$) in dorsiflexor strength, knee extensor strength, and observational gait scale score were

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observed between groups after the intervention, favoring group B.

Conclusions: The use of NMES during SC may help overcome the substantial decrease in strength resulting from casting, thus achieving less reduction of tone, improving ROM without significantly decreasing strength, and attaining greater improvements in gait function.

Keywords: Cerebral palsy; Diplegia; Neuromuscular electrical stimulation; Serial casting; Spasticity

Introduction

Cerebral palsy (CP) is a condition characterized by abnormal tone, posture, and movement. CP is non-progressive and can be clinically categorized into types such as spastic quadriplegia, spastic diplegia, spastic hemiplegia, ataxic CP, or dyskinetic CP, according to primary motor condition.[1] Spastic diplegia is a prevalent type affecting 35% of children with CP.[2]

Spastic diplegia primarily impairs motor function in the lower extremities, particularly during walking. Although the upper limbs may appear to be relatively unaffected, fine motor function and dexterity are diminished. The motor disorder can progress to muscle shortening, tendon contractures, and bone and joint deformities.[3]

Equinus, the most prevalent mobility problem observed in children with spastic CP, causes an abnormal and ineffective walking pattern. Children with greater involvement of the hip flexors and hamstrings, along with calf spasticity, often exhibit a "jump" gait pattern. Without early intervention, this condition can result in irreversible foot abnormalities and require multiple surgical procedures.[4,5]

Various therapies and procedures, including medications, injections, orthoses, exercise programs, surgery, and casting, are combined to correct deformities and improve standing and walking.[6] Non-surgical methods for treating hypertonia in CP are particularly important before motor patterns mature, typically between the ages of 8 and 10 years.[7]

One such procedure is serial casting (SC), which entails the application of a sequence of progressive stretching casts to lengthen muscles and decrease contractures. SC has been demonstrated to enhance lower limb function (LLF) in children with CP, but additional research with more robust study designs is needed.[8,9] Most children who undergo SC have hypertonia, and 57.9% have spastic diplegia.[10]

However, casting can have adverse effects, such as muscle weakness and difficulty in performing daily tasks.[11] To counteract these effects, weight-bearing and isometric exercises are recommended for patients wearing casts.[12] Novak et al.[13] have suggested strengthening the lower limbs between cast applications and after casting, particularly when extended SC protocols are used.

The neuromuscular electrical stimulation (NMES) technique uses electrical current to stimulate muscle contraction and improve muscle strength by depolarizing nearby motor neurons. NMES can additionally help preserve the synthesis of muscle proteins and decrease muscle atrophy during periods of immobilization.[14]

Prior research has not examined the application of NMES during interrupted SC in children with CP, to minimize the negative effects of casting and maximize the positive benefits in LLF.

Therefore, we aimed to determine the effects of applying NMES during interrupted progressive SC, in comparison to SC alone, on the knee and ankle range of motion (ROM), dynamic spasticity of the hamstring and gastrocnemius muscles, muscle strength of the knee extensors and ankle dorsiflexion, and sagittal kinematic parameters of gait in children with spastic diplegic CP (SDCP). We hypothesized that applying NMES during interrupted progressive SC would not affect ROM, muscle tone, strength, and sagittal gait kinematic parameters in these children.

Materials and Methods

Study design

This study was conducted between May 2022 and July 2023 and used a pretest–posttest prospective randomized comparative trial design. Written permission was obtained from the parents of each participant, in accordance with the Declaration of Helsinki. The study was approved by our institutional Physical Therapy Faculty ethics committee (NO: P.T.REC/012/003675) and registered at ClinicalTrials.gov (NCT05504798). Sample size calculation was performed in the G*power program 3.1.9. The calculation considered F tests (multivariate analysis of variance [MANOVA]: special effects and interactions), type I error (α) = 0.05, power (1-β error probability) = 0.90, Pillai V = 0.6270952, and effect size f2 (V) = 0.4567652. The calculation indicated that, for the purposes of this study, a sample size of N = 30 children was appropriate. With a 15% dropout rate, the suitable minimum sample size for this investigation was determined to be 36 patients (at least 18 patients per group).

Participants

Forty children with diplegic CP (DCP), comprising 5 girls and 35 boys, were recruited from the Faculty of Physical Therapy and outpatient clinics at Nasr Hospital, Egypt. The children were 3–7 years of age and were assigned to two groups (A and B) in a random manner through simple randomization. An independent person determined the group assignment by selecting a paper from a sealed envelope. The participants had level two or three classifications according to the Gross Motor Function Classification System (GMFCS), and grade two or three spasticity according to the Modified Ashworth Scale (MAS) with jump gait or

equinus patterns.[15–17] The exclusion criteria comprised cognitive dysfunction, history of or recent nonunion fracture, previous tenotomies, or impaired circulation in the lower extremities. Four children withdrew from group A, and three children withdrew from group B because of allergic reactions to the cast material and swelling. The study was completed in 33 children.

Outcome variables and measurements

Measurements were taken before and after the 8-week intervention to compare the two groups. To minimize experimental biases, an external assessor who was blinded to the patient's allocation conducted the measurements.

Ankle dorsiflexion ROM was assessed with a GemRed digital angle ruler with the "neutral-null" approach. The dorsiflexion angle was measured in positive degrees above the neutral position and in negative degrees below it.[18] The standard unilateral popliteal angle was assessed with a GemRed digital angle ruler.[19]

The maximum voluntary isometric contraction of ankle dorsiflexors and knee extensors was assessed with a Lafayette Manual Muscle Tester (model 01165, USA). The examiner applied a continuous resistive force perpendicular to the limb segment long axis for 3–5 s to elicit an isometric muscular contraction. The children each underwent three trials, during which they were verbally encouraged to exert their maximum effort, and the peak force values indicated by the dynamometer were recorded.[20,21]

Dynamic spasticity of the hamstring and gastrocnemius muscles was evaluated with the Modified Tardieu Scale.[22] The measurement included R2–R1 (a spasticity dynamic component), R2 (passive ROM), and R1 (fast velocity movement of the knee or ankle through the entire ROM to identify the catch point in the ROM).[23–25]

The Observational Gait Scale (OGS) was used to evaluate the children's gait while watching videos in split-screen slow motion. The knee and ankle kinematics were assessed in six sections (knee position in mid stance, initial foot contact, foot contact at mid stance, base of support, gait assistive devices, degree of change), with a total score of 17 per limb.[26,27]

Intervention

Children in group A received interrupted progressive SC with a Tomato fiberglass cast made in Korea for 5 days per week for eight consecutive weeks. This therapy was conducted in conjunction with a customized physical therapy program, in which casting sessions lasting 1 h were performed three times per week. Before the cast material was applied, an Orthopad soft cotton wrap from Egypt, 10 cm in width, was wrapped around the ankle, leg, and thigh. The casting involved application of a dual cast: a short leg cast and a circular cast from below the knee to above the knee. During casting, the child was positioned in a prone posture, with the knee flexed at a 90° angle and the ankle dorsiflexed to its maximum range. The hind foot was kept in a neutral position to stretch the calf muscle and prevent excessive mobility in the subtalar joint. Additional padding was provided over the pressure points in the short leg casts. Care was taken to gently extend the knee during the application of the circular casts, avoiding overextension of the posterior neural structures. The SC was terminated when the maximum ROM was achieved, or two serial cast changes no longer allowed for further ROM reduction. Between successive casts, the children were allowed to wear their own orthoses. The customized physical therapy program focused on weight bearing, balance, proprioception, stretching, and strengthening exercises.[15,28,29]

In group B, the children received the same interventions as group A, along with NMES administered with an EMS 1004 device made in Egypt, delivering a 50 Hz faradic current at the maximum tolerable intensity that caused a visible contraction without any discomfort. The stimulation targeted the knee extensor and ankle dorsiflexor muscles, inducing toe extension and quadriceps muscle contraction. The electrodes were attached to the skin over the motor points of these muscles through the cast windows. NMES was administered for 30 min three times weekly for eight consecutive weeks[30] (Figure 1).

Statistical analysis

Statistical analysis was performed in the SPSS Package, version 25 for Windows (SPSS, Inc., Chicago, IL). Data were analyzed to test for normality and variance homogeneity, and the data were found to follow a normal distribution, thus allowing for parametric analysis. Quantitative data, including clinical characteristics, ROM, muscle strength, dynamic spasticity, and gait scale scores, are reported as mean and standard deviation. To compare the clinical characteristics between groups, we used independent samples t-tests for numerical variables and chi-square tests for categorical variables. A mixed design 2 × 2 MANOVA was conducted to compare within-group (before-intervention vs. after-intervention) and between-group (group A vs. B) outcomes for the major variables. Bonferroni correction was applied for pairwise comparisons within and between groups for variables that showed significant differences according to the MANOVA. $P \leq 0.05$ was considered to indicate statistical significance.

Results

The statistical analysis of the general demographic data for children in the clinical study (Table 1) indicated nonsignificant differences ($P > 0.05$) in the mean age ($P = 0.890$), weight ($P = 0.957$), height ($P = 0.549$), sex ($P = 0.680$), MAS ($P = 0.776$), and GMFCS ($P = 0.922$) between groups.

The statistical multiple pairwise comparisons test for the main outcome variables within each group (Table 2) showed significant increases ($P < 0.05$) in right and left dorsiflexion

Figure 1: Application of the EMS1004 electrodes over the motor points of the knee extensors and ankle dorsiflexors.

ROM post-intervention versus pre-intervention in groups A ($P = 0.0001$ and $P = 0.0001$, respectively) and B ($P = 0.0001$ and $P = 0.0001$, respectively). The results also indicated significant decreases ($P < 0.05$) in the right and left popliteal angle, gastrocnemius dynamic spasticity, and hamstring dynamic spasticity after versus before the intervention in group A ($P = 0.0001$, $P = 0.0001$, and $P = 0.0001$, respectively) and group B ($P = 0.0001$, $P = 0.0001$, and $P = 0.0001$, respectively). The right and left dorsiflexor strength significantly decreased ($P < 0.05$) after the intervention in group A ($P = 0.0001$ and $P = 0.0001$, respectively), and non-significant differences ($P > 0.05$) were observed in group B ($P = 0.435$ and $P = 0.356$, respectively). After the intervention, the mean values of right and left knee extensor strength significantly decreased ($P < 0.05$) in group A ($P = 0.0001$ and $P = 0.0001$, respectively), and non-significant differences ($P > 0.05$) were observed in group B ($P = 0.139$ and $P = 0.145$, respectively). The findings indicated significant increases ($P < 0.05$) in the right and left observational gait scale scores after the intervention in groups A ($P = 0.0001$ and $P = 0.0001$, respectively) and B ($P = 0.0001$ and $P = 0.0001$, respectively).

The statistical multiple pairwise comparisons test for the main outcome variables between groups (Table 3) revealed non-significant differences ($P > 0.05$) pre- and post-intervention in the right and left dorsiflexion ROM, popliteal angle, gastrocnemius dynamic spasticity, and hamstring dynamic spasticity. Before treatment, the results showed non-significant differences ($P > 0.05$) between groups in right dorsiflexor strength ($P = 0.067$) and right knee extensor strength ($P = 0.071$). Additionally, left dorsiflexor strength ($P = 0.099$) and left knee extensor strength ($P = 0.153$) exhibited non-significant differences ($P > 0.05$). However, the findings indicated significant differences ($P < 0.05$) in right and left dorsiflexor strength ($P = 0.031$ and $P = 0.047$, respectively) and right and left knee extensor strength ($P = 0.0001$ and $P = 0.0001$, respectively) between groups post-treatment. No significant differences in the right and left observational gait scale scores ($P = 0.825$ and $P = 0.893$, respectively) were observed ($P > 0.05$) before the intervention between groups. Nonetheless, the results indicated significant differences ($P < 0.05$) between groups after the intervention in the right and left observational gait scale scores ($P = 0.031$ and $P = 0.019$, respectively).

Table 1: General clinical characteristics of children in both groups.

Quantitative variables	Group A (n = 16)		Group B (n = 17)		Statistic test values[a]	P-value
	Mean	±SD	Mean	±SD		
Age (years)	5.54	0.70	5.50	0.89	0.14	0.89
Weight (kg)	17.75	4.47	17.83	4.92	0.06	0.96
Height (cm)	106.18	8.91	108.24	10.60	0.61	0.55
Qualitative variables	Number	Percentages	Number	Percentages		
Sex						
Boys	14.00	87.50%	14.00	82.40%	0.17	0.68
Girls	2.00	12.50%	3.00	17.60%		
MAS						
II	4.00	25.00%	5.00	29.40%	0.08	0.78
III	12.00	75.00%	12.00	70.60%		
GMFCS						
II	4.00	25.00%	4.00	23.50%	0.01	0.92
III	12.00	75.00%	13.00	76.50%		

P-value: probability value; P-value > 0.05: non-significant.

[a] Data for quantitative variables (age, weight, and height) are reported as mean ± standard deviation and were compared with the independent samples t-test. Data for qualitative variables (sex, GMFCS, and MAS) are reported as frequencies (and percentages) and were compared with the chi-square test.

Table 2: Within-group comparisons for the main outcome variables.

Variables	Items	Right				Left			
		Group A (n = 16)		Group B (n = 17)		Group A (n = 16)		Group B (n = 17)	
		Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Dorsiflexion ROM	Before	−1.06	2.26	−1.06	2.65	0.25	2.76	0.59	2.52
	After	14.63	0.95	15.24	1.14	15.19	1.27	15.71	1.53
	Change	15.69		16.30		14.94		15.12	
	F-value	543.26		622.72		396.55		431.56	
	P-value	0.0001*		0.0001*		0.0001*		0.0001*	
Popliteal angle	Before	45.69	8.13	42.88	9.61	43.38	8.69	42.18	10.54
	After	10.13	4.03	6.94	3.76	8.75	3.69	6.18	3.26
	Change	35.56		35.94		34.63		36.00	
	F-value	213.23		231.40		180.76		207.62	
	P-value	0.0001*		0.0001*		0.0001*		0.0001*	
Dorsiflexor strength	Before	0.60	0.12	0.47	0.27	0.59	0.13	0.48	0.25
	After	0.28	0.11	0.42	0.18	0.29	0.11	0.42	0.19
	Change	0.32		0.05		0.30		0.06	
	F-value	22.83		0.62		20.69		0.86	
	P-value	0.0001*		0.44		0.0001*		0.36	
Knee extensor strength	Before	1.48	0.10	1.37	0.15	1.47	0.10	1.37	0.25
	After	0.81	0.11	1.25	0.16	0.82	0.07	1.28	0.24
	Change	0.67		0.12		0.65		0.09	
	F-value	185.44		2.32		93.86		2.18	
	P-value	0.0001*		0.14		0.0001*		0.15	
Gastrocnemius dynamic spasticity (R2−R1)	Before	16.88	4.31	17.12	5.03	14.94	3.82	14.47	3.81
	After	4.75	1.23	4.06	1.19	4.06	1.28	3.53	1.23
	Change	12.13		13.06		10.88		10.94	
	F-value	99.69		122.87		117.24		126.09	
	P-value	0.0001*		0.0001*		0.0001*		0.0001*	
Hamstring dynamic spasticity (R2−R1)	Before	22.63	3.36	25.18	6.93	20.75	2.95	23.65	7.85
	After	5.56	1.20	5.71	1.53	5.06	1.18	5.53	1.66
	Change	17.06		19.47		15.69		18.12	
	F-value	144.45		199.85		103.27		146.35	
	P-value	0.0001*		0.0001*		0.0001*		0.0001*	
Observational gait scale	Before	3.63	2.70	3.82	2.53	4.00	2.75	4.12	2.42
	After	7.50	2.55	9.47	2.45	7.31	2.33	9.41	2.47
	Change	3.87		5.65		3.31		5.29	
	F-value	18.32		41.35		14.05		38.14	
	P-value	0.0001*		0.0001*		0.0001*		0.0001*	

Data are reported as mean ± standard deviation (SD) and were statistically compared with 2 × 2 MANOVA.
MD: Mean difference; P-value: probability value; * Significant ($P < 0.05$).

Table 3: Between-group comparisons for the main outcome variables.

Variables	Items	Right				Left			
		Before		After		Before		After	
		Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
Dorsiflexion ROM	Group A	−1.06	2.26	14.63	0.95	0.25	2.76	15.19	1.27
	Group B	−1.06	2.65	15.24	1.14	0.59	2.52	15.71	1.53
	Change	0.00		0.61		0.34		0.52	
	F-value	0.000		0.85		0.21		0.49	
	P-value	1.00		0.361		0.649		0.486	
Popliteal angle	Group A	45.69	8.13	10.13	4.03	43.38	8.69	8.75	3.69
	Group B	42.88	9.61	6.94	3.76	42.18	10.54	6.18	3.26
	Change	2.81		3.19		1.120		2.57	
	F-value	1.37		1.76		0.22		1.03	
	P-value	0.25		0.19		0.64		0.31	
Dorsiflexor strength	Group A	0.60	0.12	0.28	0.11	0.59	0.13	0.29	0.11
	Group B	0.47	0.27	0.42	0.18	0.48	0.25	0.42	0.19
	Change	0.13		0.14		0.11		0.13	
	F-value	3.48		4.89		2.81		4.10	
	P-value	0.07		0.03*		0.09		0.05*	
Knee extensor strength	Group A	1.48	0.10	0.81	0.11	1.47	0.10	0.82	0.07
	Group B	1.37	0.15	1.25	0.16	1.37	0.25	1.28	0.24
	Change	0.11		0.44		0.10		0.46	
	F-value	3.59		83.27		2.10		48.05	
	P-value	0.07		0.0001*		0.15		0.0001*	
Gastrocnemius dynamic spasticity (R2−R1)	Group A	16.88	4.31	4.75	1.23	14.94	3.82	4.06	1.28
	Group B	17.12	5.03	4.06	1.19	14.47	3.81	3.53	1.23
	Change	0.24		0.69		0.47		0.53	
	F-value	0.04		0.33		0.22		0.29	
	P-value	0.84		0.57		0.64		0.59	
Hamstring dynamic spasticity (R2−R1)	Group A	22.63	3.36	5.56	1.20	20.75	2.95	5.06	1.18
	Group B	25.18	6.93	5.71	1.53	23.65	7.85	5.53	1.66
	Change	2.55		0.15		2.90		0.47	
	F-value	3.33		0.01		3.63		0.09	
	P-value	0.07		0.92		0.06		0.76	
Observational gait scale	Group A	3.63	2.70	7.50	2.55	4.00	2.75	7.31	2.33
	Group B	3.82	2.53	9.47	2.45	4.12	2.42	9.41	2.47
	Change	0.19		1.97		0.12		2.10	
	F-value	0.05		4.88		0.02		5.81	
	P-value	0.83		0.03*		0.89		0.02*	

Data are reported as mean ± standard deviation (SD) and were statistically compared with 2 × 2 MANOVA.
MD: Mean difference; P-value: probability value; * Significant ($P < 0.05$).

Discussion

In clinical practice, combination treatments are frequently used for managing children with CP rather than relying on a single approach. Our main focus was implementing various interventions simultaneously in the face of multiple challenges hindering progress.[31] Accordingly, we aimed to determine the effects of applying NMES during interrupted progressive SC in comparison to SC alone on various factors, including the knee and ankle ROM, the dynamic spasticity of the hamstring and gastrocnemius muscles, the strength of the knee extensors and ankle dorsiflexors, and the sagittal kinematics gait parameters in children with DCP. Our findings demonstrated statistically significant improvements in dorsiflexion ROM, popliteal angle, gastrocnemius dynamic spasticity, hamstring dynamic spasticity, and OGS score in both groups. These findings were consistent with those of a previous systematic review and other studies indicating that SC of the lower limbs enhances multiple LLF-associated outcomes. Therefore, the findings together support the clinical application of SC for passive ROM improvement, hypertonicity reduction, and gait enhancement in children with CP.[8,32–34] Both botulinum toxin-A and casting, in combination or as independent therapies, have been used to manage spasticity and increase both active and passive ROM in patients with CP.[12,25,35] However, a recent systematic review by Kumar et al.[36] has revealed a non-significant difference in effectiveness between these methods. Additionally, further research by JA et al.[37] has indicated that SC is an effective treatment for equinus, regardless of its cause.

Our main findings indicated statistically significant differences between groups in ankle dorsiflexor strength, knee extensor strength, and OGS score, favoring the group receiving NMES with casting. Both groups showed decreased ankle dorsiflexor and knee extensor strength, but the decrease was more statistically significant in the group receiving interrupted casting alone. Previous studies have also reported muscle weakness as a negative effect of casting.[11,13]

Our findings are consistent with those reported by Stevens et al. and Yoshiko et al.,[38,39] who have found that a non-weight-bearing condition or lack of use can lead to changes in muscle composition, thereby decreasing in lower limb muscular performance and skeletal muscle mass.

Tustin and Patel[40] have emphasized the importance of using alternative forms of intervention during casting to mitigate the negative consequences of secondary weakening and impaired proprioception caused by casts. In the current study, the application of NMES during casting mitigated the decrease in ankle dorsiflexor and knee extensor strength, as indicated by the strength result statistics. These findings support the claims made by Gerovasili et al.[14] that NMES can help preserve muscle protein synthesis and prevent muscular atrophy during extended periods of immobilization. Additionally, Kimura et al.[41] have suggested that NMES may increase peripheral brain-derived neurotrophic factor in individuals who have difficulty exercising voluntarily or at high intensities; therefore, this treatment may play important roles in the neurological system, such as neuronal development.

Our study also indicated that the OGS score was enhanced in both groups, but to a greater extent in the group that received NMES. Applying NMES during the casting periods in our study helped counteract the significant decrease in strength, thus resulting in improved gait function. These findings are further supported by Cobo-Vicente et al.,[42] who have reported that NMES enhances muscle strength, functional mobility, and movement biomechanics in children with CP. Furthermore, recent evidence from systematic reviews and other studies supports using NMES for strengthening in individuals with spastic CP, to improve mobility and gross motor function, and safely induce restorative changes.[43–46]

Although SC and NMES have been effectively used for managing CP, previous studies have addressed their use only individually rather than in combination. However, Sumithra,[47] in a study on adult patients with stroke, have reported improvements in hand function with the use of these methods in combination.

This study is, to our knowledge, the first clinical trial to investigate combined treatment with SC and NMES in children with CP. Our findings demonstrate that a specific group of children with DCP with equinus or jump gait patterns may particularly benefit from the combination of interrupted SC and NMES. This finding aligns with the conclusions of Novak et al.,[48] who recommend NMES and casting as combined health interventions for managing CP. However, the generalizability of our results is limited for two reasons. First, the inclusion criteria were rigorous, considering baseline spasticity grade, GMFCS level, and specific gait patterns. Second, this study did not include a post-treatment follow-up assessment.

Conclusion

Our findings suggest that application of NMES during SC can help overcome the significant decrease in strength due to casting. The addition of NMES achieved the best results in tone reduction and ROM improvement without a significant decrease in strength, and led to greater enhancement of gait functions.

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Conflict of interest

The authors have no conflict of interest to declare.

Ethical approval

The study was approved by our institutional Physical Therapy Faculty ethics committee (NO: P.T.REC/012/003675) and was registered at ClinicalTrials.gov (NCT05504798). Written permission was obtained from the parents of each participant, in compliance with the Declaration of Helsinki.

Authors contributions

YMA, EES, and MAS designed the study and prepared the manuscript. YMA and MAS collected and organized data. All authors analyzed and interpreted the data. All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

References

1. Patel DR, Neelakantan M, Pandher K, Merrick J. Cerebral palsy in children: a clinical overview. **Transl Pediatr 2020**; 9(Suppl 1): S125.
2. Baruah TS, Goswami P, Singha R, Dutta A. A comparative study on effectiveness of open versus closed kinetic chain exercises to improve gait in spastic diplegic cerebral palsy. **Int J Physiother 2016**; 3(2): 193–196.
3. Graham D, Aquilina K, Mankad K, Wimalasundera N. Selective dorsal rhizotomy: current state of practice and the role of imaging. **Quant Imag Med Surg 2018**; 8(2): 209.
4. Wright E, DiBello SA. Principles of ankle-foot orthosis prescription in ambulatory bilateral cerebral palsy. **Phys Med Rehabil Clin 2020**; 31(1): 69–89.
5. Park ES, Rha D-w, Yoo JK, Kim SM, Chang WH, Song SH. Short-term effects of combined serial casting and botulinum toxin injection for spastic equinus in ambulatory children with cerebral palsy. **Yonsei Med J 2010**; 51(4): 579–584.
6. Raja K, Gupta S, Shirsath P. Comprehensive management of people with cerebral palsy: an Indian perspective. **Disabil CBR Incl Dev 2021**; 32(1): 101–129.
7. Monbaliu E, Himmelmann K, Lin J-P, Ortibus E, Bonouvrié L, Feys H, et al. Clinical presentation and management of dyskinetic cerebral palsy. **Lancet Neurol 2017**; 16(9): 741–749.
8. Milne N, Miao M, Beattie E. The effects of serial casting on lower limb function for children with Cerebral Palsy: a systematic review with meta-analysis. **BMC Pediatr 2020**; 20: 1–23.
9. Flett PJ. Rehabilitation of spasticity and related problems in childhood cerebral palsy. **J Paediatr Child Health 2003**; 39(1): 6–14.
10. Ravindran S, Zachariah G, Padmakumar G, Varghese J. Clinical patterns of Cerebral palsy in children who underwent serial casting for improvement in mobility at a tertiary care centre. **JMSCR 2021**; 9(7).
11. Dursun N, Gokbel T, Akarsu M, Bonikowski M, Pyrzanowska W, Dursun E. Intermittent serial casting for wrist flexion deformity in children with spastic cerebral palsy: a randomized controlled trial. **Dev Med Child Neurol 2021**; 63(6): 743–747.
12. Dai AI, Demiryürek AT. Serial casting as an adjunct to botulinum toxin type a treatment in children with cerebral palsy and spastic paraparesis with scissoring of the lower extremities. **J Child Neurol 2017**; 32(7): 671–675.
13. Novak I, Mcintyre S, Morgan C, Campbell L, Dark L, Morton N, et al. A systematic review of interventions for children with cerebral palsy: state of the evidence. **Dev Med Child Neurol 2013**; 55(10): 885–910.
14. Gerovasili V, Tripodaki E, Karatzanos E, Pitsolis T, Markaki V, Zervakis D, et al. Short-term systemic effect of electrical muscle stimulation in critically ill patients. **Chest 2009**; 136(5): 1249–1256.
15. Rodda J, Graham H. Classification of gait patterns in spastic hemiplegia and spastic diplegia: a basis for a management algorithm. **Eur J Neurol 2001**; 8: 98–108.
16. Palisano RJ, Hanna SE, Rosenbaum PL, Russell DJ, Walter SD, Wood EP, et al. Validation of a model of gross motor function for children with cerebral palsy. **Phys Ther 2000**; 80(10): 974–985.
17. Ghotbi N, Ansari NN, Naghdi S, Hasson S, Jamshidpour B, Amiri S. Inter-rater reliability of the modified Ashworth Scale in assessing lower limb muscle spasticity. **Brain Inj 2009**; 23(10): 815–819.
18. Norkin CC, White DJ. *Measurement of joint motion: a guide to goniometry*. FA Davis; 2016.
19. Manikowska F, Chen BP-J, Józwiak M, Lebiedowska MK. The popliteal angle tests in patients with cerebral palsy. **J Pediatr Orthop B 2019**; 28(4): 332–336.
20. Thompson N, Stebbins J, Seniorou M, Newham D. Muscle strength and walking ability in diplegic cerebral palsy: implications for assessment and management. **Gait Posture 2011**; 33(3): 321–325.
21. Hirano M, Katoh M, Gomi M, Arai S. Validity and reliability of isometric knee extension muscle strength measurements using a belt-stabilized hand-held dynamometer: a comparison with the measurement using an isokinetic dynamometer in a sitting posture. **J Phys Ther Sci 2020**; 32(2): 120–124.
22. Numanoglu A, Gunel M. Intraobserver reliability of modified Ashworth scale and modified Tardieu scale in the assessment of spasticity in children with cerebral palsy. **Acta Orthop Traumatol Turc 2012**; 46(3): 196–200.
23. Choi JY, Park ES, Park D, Rha D-w. Dynamic spasticity determines hamstring length and knee flexion angle during gait in children with spastic cerebral palsy. **Gait Posture 2018**; 64: 255–259.
24. Fosdahl MA, Jahnsen R, Pripp AH, Holm I. Change in popliteal angle and hamstrings spasticity during childhood in ambulant children with spastic bilateral cerebral palsy. A register-based cohort study. **BMC Pediatr 2020**; 20: 1–9.
25. Dursun N, Gokbel T, Akarsu M, Dursun E. Randomized controlled trial on effectiveness of intermittent serial casting on spastic equinus foot in children with cerebral palsy after botulinum toxin-A treatment. **Am J Phys Med Rehabil 2017**; 96(4): 221–225.
26. Boyd RN, Graham HK. Objective measurement of clinical findings in the use of botulinum toxin type A for the management of children with cerebral palsy. **Eur J Neurol 1999**; 6: s23–s35.
27. Mackey AH, Lobb GL, Walt SE, Stott NS. Reliability and validity of the observational Gait Scale in children with spastic diplegia. **Dev Med Child Neurol 2003**; 45(1): 4–11.
28. Lannin NA, Novak I, Cusick A. A systematic review of upper extremity casting for children and adults with central nervous system motor disorders. **Clin Rehabil 2007**; 21(11): 963–976.
29. Long JT, Cobb L, Garcia MC, McCarthy JJ. Improved clinical and functional outcomes in crouch gait following minimally invasive hamstring lengthening and serial casting in children with cerebral palsy. **J Pediatr Orthop 2020**; 40(6): e510–e515.
30. Botter A, Oprandi G, Lanfranco F, Allasia S, Maffiuletti NA, Minetto MA. Atlas of the muscle motor points for the lower limb: implications for electrical stimulation procedures and electrode positioning. **Eur J Appl Physiol 2011**; 111: 2461–2471.
31. Kim H, Kolaski K. Is botulinum toxin type A more effective and safer than other treatments for the management of lower limb spasticity in children with cerebral palsy? A cochrane review summary with commentary. **NeuroRehabilitation 2021**; (Preprint): 1–4.
32. Kay RM, Rethlefsen SA, Fern-Buneo A, Wren TA, Skaggs DL. Botulinum toxin as an adjunct to serial casting treatment in children with cerebral palsy. **JBJS 2004**; 86(11): 2377–2384.
33. Glanzman AM, Kim H, Swaminathan K, Beck T. Efficacy of botulinum toxin A, serial casting, and combined treatment for spastic equinus: a retrospective analysis. **Dev Med Child Neurol 2004**; 46(12): 807–811.

34. Sousa RMD, Paro MdP, Simcsik AO, Airoldi MJ, Bvd Santos, ÍaPd Moraes, et al. The use of serial casting in the treatment of children with cerebral palsy: a study protocol. **J Hum Growth Dev 2023**: 95−104.
35. Ackman JD, Russman BS, Thomas SS, Buckon CE, Sussman MD, Masso P, et al. Comparing botulinum toxin A with casting for treatment of dynamic equinus in children with cerebral palsy. **Dev Med Child Neurol 2005**; 47(9): 620−627.
36. Kumar D, Kumar R, Mudgal SK, Ranjan P, Kumar S. The effects of botulinum toxin and casting in spastic children with cerebral palsy: a systematic review and meta-analysis. **Cureus 2023**; 15(3).
37. Conejero Casares JA, Romero Romero. Treatment of equinus with serial casting. **Rehabilitacion 2021**; 55(4): 273−281.
38. Stevens JE, Walter GA, Okereke E, Scarborough MT, Esterhai JL, George SZ, et al. Muscle adaptations with immobilization and rehabilitation after ankle fracture. **Med Sci Sports Exerc 2004**; 36(10): 1695−1701.
39. Yoshiko A, Yamauchi K, Kato T, Ishida K, Koike T, Oshida Y, et al. Effects of post-fracture non-weight-bearing immobilization on muscle atrophy, intramuscular and intermuscular adipose tissues in the thigh and calf. **Skelet Radiol 2018**; 47: 1541−1549.
40. Tustin K, Patel A. A critical evaluation of the updated evidence for casting for equinus deformity in children with cerebral palsy. **Physiother Res Int 2017**; 22(1):e1646.
41. Kimura T, Kaneko F, Iwamoto E, Saitoh S, Yamada T. Neuromuscular electrical stimulation increases serum brain-derived neurotrophic factor in humans. **Exp Brain Res 2019**; 237(1): 47−56.
42. Cobo-Vicente F, San Juan AF, Larumbe-Zabala E, Estévez-González AJ, Donadio MVF, Perez-Ruiz M. Neuromuscular electrical stimulation improves muscle strength, biomechanics of movement, and functional mobility in children with chronic neurological disorders: a systematic review and meta-analysis. **Phys Ther 2021**; 101(10):pzab170.
43. Greve KR, Joseph CF, Berry BE, Schadl K, Rose J. Neuromuscular electrical stimulation to augment lower limb exercise and mobility in individuals with spastic cerebral palsy: a scoping review. **Front Physiol 2022**; 13:951899.
44. Chen Y-H, Wang H-Y, Liao C-D, Liou T-H, Escorpizo R, Chen H-C. Effectiveness of neuromuscular electrical stimulation in improving mobility in children with cerebral palsy: a systematic review and meta-analysis of randomized controlled trials. **Clin Rehabil 2023**; 37(1): 3−16.
45. Salazar AP, Pagnussat AS, Pereira GA, Scopel G, Lukrafka JL. Neuromuscular electrical stimulation to improve gross motor function in children with cerebral palsy: a meta-analysis. **Braz J Phys Ther 2019**; 23(5): 378−386.
46. Carson RG, Buick AR. Neuromuscular electrical stimulation-promoted plasticity of the human brain. **J Physiol 2021**; 599(9): 2375−2399.
47. Sumithra S. *Effectiveness of inhibitory casting with electrical stimulation on improving the hand function in patients with middle cerebral artery stroke*. Coimbatore: PPG College of Physiotherapy; 2012.
48. Novak I, Morgan C, Fahey M, Finch-Edmondson M, Galea C, Hines A, et al. State of the evidence traffic lights 2019: systematic review of interventions for preventing and treating children with cerebral palsy. **Curr Neurol Neurosci Rep 2020**; 20: 1−21.

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