Journal of Taibah University Medical Sciences (2025) 20(1), 73–80

Taibah University

Journal of Taibah University Medical Sciences

www.sciencedirect.com

Original Article

Effect of leg pedaling exercise from an inclined position on functional ability and strength in children with diplegia

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Received 20 September 2024; revised 18 November 2024; accepted 21 January 2025; Available online 12 February 2025

الملخص

أهداف البحث: يمكن أن يصاب الأطفال المصابون بالشلل الدماغي التشنجي ثنائي الأطراف بمضاعفات مختلفة تؤثر على أنشطتهم اليومية ونوعية حياتهم، مثل ضعف القدرة الوظيفية، والتحكم في الجذع، وضعف العضلات. هدفت هذه الدراسة إلى تقييم تأثير تمارين الدواسة في الأطراف السفلية من وضع مائل على القدرة الوظيفية، والتحكم في الجذع، وقوة العضلات لدى هؤلاء الأطفال.

طريقة البحث: تم توزيع ثلاثين طفلا تم تشخيصهم بالشلل الدماغي التشنجي ثنائي الأطراف، تتراوح أعمارهم بين 6 و9 سنوات، بشكل عشوائي على مجموعتين: مجموعة الدراسة (أ) ومجموعة التحكم (ب). اتبعت كلتا المجموعتين برنامجا محددا للعلاج الطبيعي لمدة 45 دقيقة ثلاث مرات أسبوعيا لمدة شهرين متتاليين. قامت مجموعة الدراسة (المجموعة أ) بأداء تمارين الدواسة في الساق لمدة 30 دقيقة لكل جلسة من وضع مائل. تم تقييم القدرة الوظيفية، والتحكم في الجذع، وقوة العضلات قبل وبعد الدراسة باستخدام مقياس الوظيفة الحركية الإجمالية، ومقياس قياس التحكم في الجذع، ومقياس القوة المحمول باليد، على التوالي.

النتائج: أظهرت كلتا المجموعتين تحسنات ذات دلالة إحصائية في المتغيرات التي تم تقييمها بعد العلاج. وبالمقارنة مع المجموعة ب، أظهرت المجموعة أ تحسنات كبيرة في القدرة الوظيفية، والتحكم في الجذع، وقوة العضلات بعد العلاج.

الاستنتاجات: بالنسبة للأطفال المصابين بالشلل الدماغي التشنجي ثنائي الأطراف، فإن دمج تمارين الدواسة بالساق من وضع مائل في برنامجهم العلاجي يمكن أن يحسن قدرتهم الوظيفية، والتحكم في الجذع، وقوة العضلات.

الكلمات المفتاحية: الشلل الدماغي؛ المهارات الحركية الإجمالية؛ إعادة التأهيل؛ القوة؛ التحكم في الجذع.

الكلمات المفتاحية: الشلل الدماغي؛ المهارات الحركية الإجمالية؛ إعادة التأهيل؛ القوة؛ التحكم في الجذع.;

Abstract

Objectives: Children with spastic diplegic cerebral palsy (SDCP) can develop various complications that affect their daily activities and quality of life, such as impaired functional ability, trunk control, and muscle weakness. This study evaluated the effects of lower extremity pedaling exercise from an inclined position on functional ability, trunk control, and muscle strength in these children.

Methods: Thirty children diagnosed with SDCP, aged 6–9 years, were randomly assigned to two groups: a study group (Group A) and a control group (Group B). Both groups followed a designated physical therapy program for 45 min three times weekly for two consecutive months. Group A performed leg pedaling exercises for 30 min per session from an inclined position. Functional ability, trunk control, and muscle strength were assessed before and after the study using the Gross Motor Function Measure, Trunk Control Measurement Scale, and a handheld dynamometer, respectively.

Results: Both groups demonstrated statistically significant improvements in the assessed variables post-treatment ($P < 0.05$). Group A exhibited substantial improvements in functional ability, trunk control, and muscle strength following treatment ($P < 0.05$).

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Peer review under responsibility of Taibah University.

Production and hosting by Elsevier

 https://doi.org/10.1016/j.jtumed.2025.01.001

Conclusions: For children with SDCP, integrating leg pedaling exercises from an inclined position into their therapeutic program can improve their functional ability, trunk control, and muscle strength.

Keywords: Cerebral palsy; Gross motor; Rehabilitation; Strength; Trunk control

Introduction

Cerebral palsy (CP) is the most common non-progressive neurodevelopmental disorder of the central nervous system, resulting in persistent disability in children, with an incidence of 1.5–3.8 per 1000 live births. Impaired muscle tone, mobility, and motor skills are hallmarks of CP, which are commonly associated with disabilities in children. Individuals with diplegic CP experience difficulties in trunk control due to muscle weakness, impaired neural control, and inadequate proprioception. In addition, motor function is impaired due to the persistence of primitive reflexes.[1,2]

Spastic diplegia is the most common form of CP. It primarily affects the bilateral lower limbs rather than the upper limbs. Children with diplegia exhibit rigidity in the extremities and diminished strength in the trunk. Mobility and postural problems present considerable functional difficulties.[3,4]

Spasticity is a primary motor disorder that disrupts muscle strength and selective movement control. In physical therapy programs, controlling spasticity and enhancing range of motion (ROM) to maintain functional movement are critical concerns.[5]

The trunk is essential for postural responses and control. A balanced sitting posture requires the coordinated function of the trunk's extensor, flexor, and hip muscles. Children with CP are unable to maintain a balanced sitting posture, resulting in spinal asymmetry.[6,7]

Cycling exercises, unlike treadmill exercises, are easy to perform and facilitate the measurement of the amount of load in the upper and lower limb training program. Regular use of an ergometer may improve motor function in patients with CP. Standard ergometry is limited in the paralyzed lower extremities, although it is beneficial for aerobic training in healthy individuals. Research on the impact of cycling exercises on CP is scarce and offers limited insights into their physiological effects.[8,9]

A few studies have investigated the effects of ergometric exercise on motor function or spasticity. Determining how ergometric exercise affects functional ability, trunk control, and muscle strength is essential in developing an exercise therapy program for CP. This study assessed and compared the impact of leg pedal exercise on functional abilities, trunk control, and muscle strength in patients with diplegic CP.

Material and Methods

Study design

The current study utilized a randomized controlled design (Registration No. NCT06233136), and was conducted at a center in Giza, Egypt from December 2022 to August 2023. All procedures adhered to the ethical standards of the Declaration of Helsinki. The ethics committee at Cairo University, Faculty of Physical Therapy approved the study (Approval No. P.T.REC/012/004085). Before commencing the study procedures, all parents provided written informed consent. A focus group session was held for parents to discuss the study's objectives, methods, potential benefits, and risks.

Participants

Thirty children, comprising 12 girls and 18 boys with spastic diplegia, were included in the study. The inclusion criteria were: 1) age between 6 and 9 years; 2) modified Ashworth scale grades of 1 and 1+; 3) Gross Motor Functional Classification System (GMFCS) levels II and III; and 4) the ability to pedal a stationary bicycle independently and follow instructions. Children were excluded from this study if they had: 1) structural or fixed abnormalities of the lower extremities; 2) underwent orthopedic or neurological surgery in the past 6 months; 3) received Botox injections in the lower extremities within the last 6 months; or 4) significant visual or auditory impairments.

Estimating the sample size

Data from the Trunk Control Measurement Scale (TCMS) were obtained from a pilot study involving 10 subjects, with five participants in each group. Analysis was conducted using G*Power statistics (version 3.1). The study required a sample size of 30 children, with a power of 80 %, α-level of 0.05, and effect size of 1.1.

Randomization

Fifty-three children of both sexes with SDCP were evaluated. They were selected from outpatient clinics and private centers in Giza and the Tenth of Ramadan City. Seven children did not meet the inclusion criteria, and the parents of sixteen children declined to participate, leaving a total of thirty children. Two equal-sized groups (A and B) were randomized into two groups. Basic randomization was performed using opaque, sealed envelopes. Group A received a designed physical therapy program and pedaling exercise from an inclined position. Group B underwent the same physical therapy program without the pedaling exercise (Figure 1).

Outcome measures

Functional abilities, trunk control, and lower limb and abdominal muscle strength were assessed before and after the designated intervention period using the Gross Motor Function Measure (GMFM-88), TCMS, and handheld dynamometer (HHD), respectively. All children in both groups underwent assessments in the same order, with a 30-min break in between.

Procedures

Evaluation

Measured functional ability. The GMFM-88 has demonstrated efficacy as a reliable tracking tool for children with CP to monitor their developmental progress. It includes five dimensions: A) lying down and rolling; B) sitting; C) crawling and kneeling; D) standing; and E) walking, running, and jumping. Item scores range from 0 to 3. The total score for all dimensions was calculated.[10]

Measured trunk control. The trunk control was evaluated using the TCMS. This scale demonstrates validity and reliability for the CP pediatric population. The scale comprises 15 items assessing static and dynamic sitting balance, with a total scoring range of 0–58, with higher scores indicating better performance. The static sitting balance scale assesses the subject's ability to move their upper and lower extremities while maintaining trunk stability. The dynamic sitting balance encompasses selective movement control and the dynamic reaching subscales. Each item is assessed utilizing an ordinal scale comprising two, three, or four points, with questions formulated in both directions. Each item is assigned a score that can be determined unilaterally or bilaterally.[11]

Measurements of lower limb and abdominal strength. The Lafayette Manual Muscle Test (Model 01163; Lafayette Instrument Co., Lafayette, IN, USA) is an ergonomic handheld device designed to objectively measure muscular strength. The dynamometer handle was fully compressed, demonstrating validity and reliability in measuring muscle strength in the CP population. Every child performed three trials for each muscle group (abdominal muscles, hip flexors, knee extensors, and ankle dorsiflexion on both sides). Then the mean was used for analysis.[12]

Intervention

Designed program of physical therapy. Groups A and B underwent the designated physical treatment program, comprising three exercises: flexibility and strength training, static and dynamic balance, and functional exercises. The program was used three times a week for 45 min per session for two consecutive months.[13]

Leg pedaling training. Children in Group A participated in leg cycling exercises consisting of 30 min of leg pedaling from an inclined position three times per week over 2 months.[14] Each child was positioned in a semi-reclined position with a 30-degree trunk flexion. The warm-up (5 min) involved cycling at a selected speed, followed by cycling exercises (20 min) and cool-downs (5 min) that included regulated breathing exercises, passive lower limb stretching, and gentle pedaling.[15] Children initiated the exercise program with a lower resistance level (1 of 4) for pedaling, enabling speeds ranging from 40 to 60 rotations per minute. Initially, children pedaled at 40 rotations per minute, which increased to 60 rotations per minute by the end of the study. This motivated the participants to accelerate their speed during the study.[14] Pedaling commenced with 20 min of exercise per session, incorporating 2 min followed by an equal duration of rest. Following a duration of 4 weeks, the pedaling intensity was increased, and the rest duration was reduced to a maximum of 5 min of continuous exercise with 1-min rest intervals.[14]

Participants should be clinically stable before commencing exercises. The procedure must be stopped immediately if a participant exhibits or reports any adverse signs or symptoms.[9]

Statistical analyses

Statistical analyses were conducted utilizing IBM SPSS Statistics 25 for Windows (IBM Corp., Armonk, NY, USA). Age, height, and weight comparisons between groups were performed using the unpaired *t*-test. The distribution of sex and spasticity grades was analyzed using the χ^2 test, whereas median values of GMFCS were compared using the Mann–Whitney U test. The Shapiro–Wilk test was used to assess the normality of the data, whereas Levene's test was used to evaluate the homogeneity of variances between Groups A and B. A mixed model multivariate analysis of variance (MANOVA) examined the within and between-group effects on the GMFM scale, TCMS, and muscle strength. Post-hoc tests with Bonferroni correction were conducted for multiple comparisons. The level of statistical significance was set at $p < 0.05$.

Results

There were no significant differences in the distribution of subjects' data regarding age, height, weight, GMFCS, sex, and spasticity grade between groups (Table 1).

Effects of treatment on TCMS, GMFM, and muscle strength

A mixed MANOVA analysis showed a significant interaction between treatment and time ($F = 25.76$, $p = 0.001$). The analysis revealed no significant main effect of treatment ($F = 1.39$, $p = 0.25$). However, a significant main effect of time was observed ($F = 88.99$, $p = 0.001$).

No statistically significant differences were detected in any of the assessed variables before treatment (Tables 2 and 3). The post-treatment GMFM scale and TCMS mean values in Groups A and B exhibited a significant increase compared to pre-treatment ($p < 0.05$) (Table 2). Furthermore, there was a notable enhancement in the strength of the abdominal muscles, hip flexors, knee extensors, and ankle dorsiflexion ($p < 0.05$) (Table 3).

The study group demonstrated a statistically significant improvement compared to the control group in the GMFM scale, TCMS, abdominal, hip flexors, knee extensors, and ankle dorsiflexion strength post-treatment ($p < 0.05$) (Tables 2 and 3).

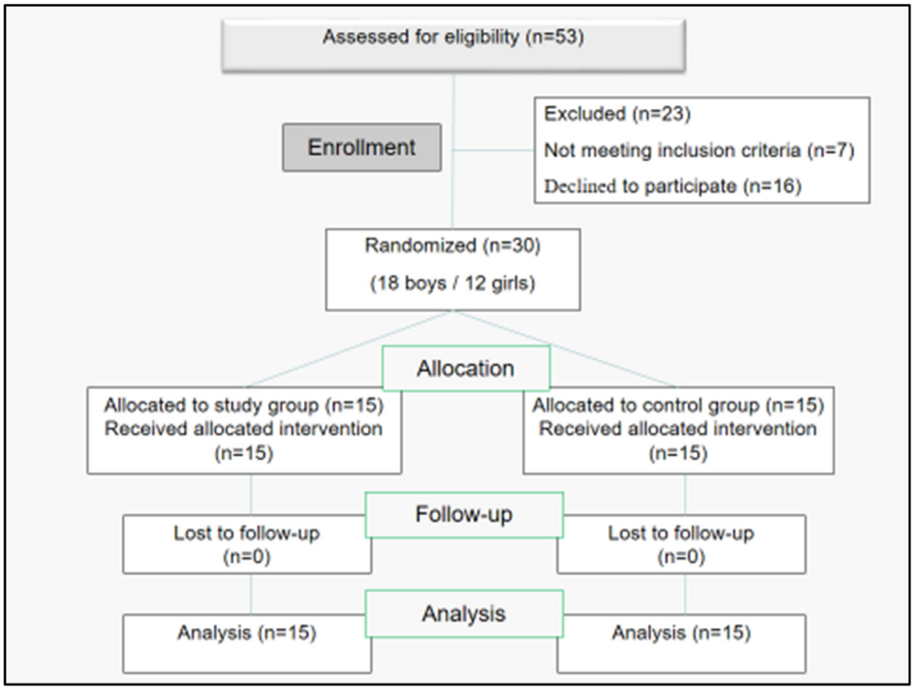

Figure 1: Flow chart.

Table 1: Basic characteristics of the participants.

	Group A mean ± SD	Group B mean ± SD	t- value	p-value
Age (years)	7.53 ± 1.18	7.13 ± 1.13	0.94	0.35
Weight (kg)	26.53 ± 7.61	27.73 ± 6.76	−0.45	0.65
Height (cm)	125 ± 13.75	122 ± 14.61	0.74	0.46
Sex, n (%)				
Girls	5 (33.3 %)	7 (46.7 %)	(χ^2 = 0.55)	0.46
Boys	10 (66.7 %)	8 (53.3 %)		
Spasticity grades, n (%)				
Grade I	6 (40 %)	8 (53.3 %)	(χ^2 = 0.53)	0.46
Grade I+	9 (60 %)	7 (46.7 %)		
GMFCS, median (IQR)	2 (3−2)	2 (3−2)	U-value = 105	0.71

SD, standard deviation; χ^2, Chi squared value; GMFCS, Gross Motor Function Classification System; IQR, Interquartile range; U, Mann−Whitney U test value; p-value, probability value.

Table 2: Mean GMFM scale and TCMS pre- and post-treatment in Groups A and B.

	Pre-treatment Mean ± SD	Post-treatment Mean ± SD	MD	% of change	p value
GMFM scale					
Group A	56.88 ± 6.23	64.86 ± 5.35	−7.98	14.03	0.001*
Group B	56.24 ± 7.25	59.91 ± 6.31	−3.67	6.53	0.001*
MD	0.64	4.95			
	p = 0.79	**p = 0.02***			
TCMS					
Group A	20.33 ± 6.83	32.20 ± 6.48	−11.87	58.39	0.001*
Group B	21.73 ± 5.70	25.33 ± 5.49	−3.6	16.57	0.001*
MD	−1.4	6.87			
	p = 0.54	**p = 0.004***			

SD, Standard deviation; MD, Mean difference; p value, Probability value; GMFM, Gross Motor Function Measure; TCMS, Trunk Control Measurement Scale; *p < 0.05.

Table 3: Mean abdominal muscle, hip flexors, knee extensors and ankle dorsiflexors strength pre- and post-treatment of Groups A and B.

Strength (kg)	Pre-treatment	Post-treatment	MD	% of change	p value
	Mean ± SD	Mean ± SD			
Abdominal muscle					
Group A	4.75 ± 1.53	7.04 ± 1.74	−2.29	48.21	0.001*
Group B	4.68 ± 1.11	5.47 ± 1.24	−0.79	16.88	0.001*
MD	0.07	1.57			
	p = 0.88	**p = 0.008***			
Right hip flexors					
Group A	3.19 ± 1.15	4.78 ± 1.66	−1.59	49.84	0.001*
Group B	2.98 ± 1.43	3.29 ± 1.44	−0.31	10.40	0.03*
MD	0.21	1.49			
	p = 0.65	**p = 0.01***			
Left hip flexors					
Group A	3.28 ± 0.94	4.83 ± 1.26	−1.55	47.26	0.001*
Group B	3.08 ± 1.28	3.44 ± 1.36	−0.36	11.69	0.01*
MD	0.2	1.39			
	p = 0.62	**p = 0.007***			
Right knee extensors					
Group A	5.17 ± 1.94	7.71 ± 2.31	−2.54	49.13	0.001*
Group B	4.91 ± 1.37	5.41 ± 1.31	−0.5	10.18	0.001*
MD	0.26	2.3			
	p = 0.66	**p = 0.002***			
Left knee extensors					
Group A	5.46 ± 1.70	7.79 ± 2.18	−2.33	42.67	0.001*
Group B	5.11 ± 1.31	5.80 ± 1.37	−0.69	13.50	0.001*
MD	0.35	1.99			
	p = 0.53	**p = 0.006***			
Right ankle dorsiflexors					
Group A	1.48 ± 0.19	2.08 ± 0.26	−0.6	40.54	0.001*
Group B	1.40 ± 0.16	1.76 ± 0.19	−0.36	25.71	0.001*
MD	0.08	0.32			
	p = 0.22	**p = 0.001***			
Left ankle dorsiflexors					
Group A	1.43 ± 0.21	2.11 ± 0.24	−0.68	47.55	0.001*
Group B	1.45 ± 0.16	1.81 ± 0.21	−0.36	24.83	0.001*
MD	−0.02	0.3			
	p = 0.84	**p = 0.001***			

SD, Standard deviation; MD, Mean difference; p value, Probability value; *$p < 0.05$.

Discussion

The study included children with SDCP, the most common type affecting functional performance. Trunk control serves as a stable base of support, which is crucial for limb movements and essential in reaching and walking.[2,3] This study evaluated the effects of pedaling from an inclined position on functional ability, trunk control, and lower extremity and abdominal muscle strength in children with SDCP children. Following data analysis and interpretation, the study demonstrated significant increases in the GMFM, TCMS, and muscle strength post-intervention. The study group showed more significant improvements compared to the control group. This indicates the effectiveness of leg pedaling exercises from an inclined position in enhancing functional ability, trunk control, and muscle strength in SDCP children.

Comparing the pretreatment values of both groups revealed no significant differences across all measured variables. Both groups exhibited reduced mean values in the pretreatment assessments of GMFM, TCMS, and abdominal and lower limb muscle strength. Kallem Seyyar et al.[3] reported that individuals with SDCP had impaired trunk control related to their GMFCS level. The impairment in trunk control was significantly associated with their functional abilities. Children diagnosed with spastic diplegia exhibited weakness in abdominal muscles and demonstrated inadequate sitting ability.[16]

Comparing pretreatment with post-treatment mean GMFM, TCMS, and abdominal and lower limb muscle strength values showed statistically significant improvement in both groups. The improvement observed in Groups A and B can be attributed to the physical therapy program, which reduces muscle tone, enhances postural control, and promotes controlled movement patterns in the lower limbs. Passive stretching increases the length of soft tissues and improves flexibility. Merino-Andrés et al.[17] reported that strength exercises are crucial in CP therapy. Functional strengthening improves motor tasks without exacerbating spasticity. Ali and Abd el-aziz[16] reported that increased thickness of the abdominal muscles after participation in the therapeutic program indicates an appropriate gain in strength in subjects with SDCP, which likely affects function, particularly gross motor skills, in this population.

The post-treatment comparison of GMFM, TCMS, and muscle strength (abdomen, hip flexors, knee extensors, and dorsiflexors) between the two groups revealed a significant difference. The post-treatment mean value shows a greater improvement in Group A, suggesting a potential effect of leg pedaling from an inclined position. Pedaling generates repetitive muscle activities akin to those observed in gait. The rhythmic reciprocating movement is regulated by neural modulation at both spinal and supraspinal levels. It is suggested that di-synaptic reciprocal inhibition between agonist and antagonist and crossed spinal pathways contribute to pedaling movement.[18] The cerebellum, supplementary motor cortex, and primary motor cortex facilitate rhythmic activities during pedaling. A bilateral reciprocal training program was implemented to restore locomotion in children with SDCP.[19] Seated pedaling is a safe method that minimizes postural disturbances and does not necessitate balance during the initial stages of upright locomotor training.[20]

The mean value of GMFM in Group A exhibited greater positive effectiveness following treatment, as leg pedaling exercise reduces spasticity and increases ROM, preserving physical mobility and functional ability. Improvement in motor control can be attributed to the integration of primitive reflexes and excitation and reciprocal inhibition of antigravity and flexor muscles.[21]

Williams et al.[9] reported that a static bicycling program significantly improved functional ability in children with CP. Ibrahim and Abbass[22] found that a 20-min pedal exercise training, combined with selected exercise therapy over 6 consecutive weeks, 3 times per week, improved walking speed and step length in children with CP.

Ofori et al.[14] demonstrated that cycling regulates the lower extremity muscles. Cycling can achieve a greater range of motion than gait, enhancing functional ability. Fujimoto et al.[23] illustrated that a lower limb ergometer for 10 min improves knee extension and inhibits lower limb hypertonia. Repeated pedaling promotes equilibrium between the excitation and inhibition of primitive reflexes. The effects of pedaling on hypertonia, ROM, and motor control will enhance the development of exercise programs for CP.

The post-treatment mean value of TCMS shows a greater improvement in Group A, as pedaling enhances the activation and co-activation of trunk muscles, optimizes pelvic patterns, and decreases trunk tone, thereby facilitating improvements in static and dynamic sitting balance. The activation of neurons in extremity muscles during pedaling may affect pathways to trunk muscles, leading to neuroplasticity and improved trunk control. Altaim et al.[24] illustrated that static bicycle exercise improves the balance between the muscles of the quadriceps and hamstrings. Lower extremity movements can improve trunk stability and control, positively affecting both limbs' balance and function.[25] The cycle ergometer exercise improves trunk control while seated, muscle strength, and endurance by activating axial muscles and increasing their size and strength.[24–26]

Post-treatment, the improvement in the average muscle strength values was more pronounced in Group A, as low-impact pedaling and effective workouts can enhance muscle strength, endurance, balance, and coordination between agonist and antagonist muscles with selective motor control.[8] Armstrong et al.[26] conducted a meta-analysis demonstrating a notable enhancement in functional capabilities and hamstring strength in children with CP after cycling interventions. Children with CP who participated in virtual leg cycling training at home exhibited improvement in knee muscle strength.[15]

Cycling on a bicycle is significant in CP, particularly for wheelchair-bound patients, as it enhances movement, strengthens lower leg muscles, and prevents joint contractures.[27] Pedaling activates the quadriceps muscles without exacerbating antagonist co-contraction. Seated pedaling is a safer alternative for non-ambulatory individuals than assistive gait training, as it minimizes the burden on therapists.[28] Pedaling serves as an effective training method for the enhancement of motor performance in hemiparetic patients.[29]

This study demonstrated that incorporating lower limb pedaling exercise into the physical therapy regimen for rehabilitating children with SDCP improves their functional abilities, trunk control, and abdominal and lower limb muscle strength.

Study strengths

Previous studies have not thoroughly examined the role of leg pedaling from a semi-reclining position with 30° trunk flexion on functional performance in pediatric patients with SDCP. Incorporating a cycling program into the rehabilitation of children with diplegic CP has significant clinical implications, as it enhances the strength of abdominal and lower extremity muscles and controls static and dynamic trunk movements and functional motor abilities. This method aims to enhance the QoL by enhancing functional performance.

Study limitations

The study was conducted over a relatively short period, approximately two months. Consequently, follow-up may be essential to determine the long-term impacts of a cycling program on functional abilities in children with SDCP. In addition, the study did not examine the correlation between muscle strength, gross motor functional ability, and trunk control. The impact of leg pedal application on spasticity, quality of life, and muscle activity has not been determined. Therefore, future research should assess these factors.

Conclusion

An effective therapeutic method for improving functional ability, trunk control, and muscle strength in children with spastic diplegic CP is leg pedaling exercise from an inclined position. Consequently, it is advantageous to incorporate pedaling into the treatment protocol for children with SDCP.

Recommendations

Electromyography examines the axial and lower extremity muscles during cycling at various trunk inclinations, specifically no tilt, and angles of 15°, 30°, and 45° of trunk flexion. Investigating the effects of leg pedaling exercise from an inclined position on lower extremity ROM, spasticity, balance, and quality of life in different types of CP.

Source of funding

This research did not receive any specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of interest

The authors have no conflicts of interest to declare.

Ethical approval

The Research Ethics Committee at Cairo University, Faculty of Physical Therapy approved the study (Approval No. P.T.REC/012/004085 on October 11, 2022).

Authors' contributions

AFE, ABH, and NEM conceptualized and designed the study, collected data, and conducted analysis and interpretation of the results. AFE and NEM authored the manuscript, evaluated the findings, and completed the final version. All authors have critically reviewed and approved the final draft and are responsible for the content and similarity index of the manuscript.

Acknowledgments

The authors express gratitude to all participating subjects and their families.

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How to cite this article: El-Sheikh AF, Hassan AB, Mohamed NE. Effect of leg pedaling exercise from an inclined position on functional ability and strength in children with diplegia. J Taibah Univ Med Sc 2025;20(1):73−80.