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Research Article

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Effects of High-Intensity Muscle Strength Training and Stretching Exercises on Strength, Spasticity, Postural Alignment, and Participation in an Adolescent with Spastic Diplegic Cerebral Palsy: A Single-Subject Design

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| Abstract |

PURPOSE: This study examined the effects of high-intensity (HI) muscle strength training and stretching exercises on muscle strength, spasticity, postural alignment, and participation in the activities of daily living (ADL) in an adolescent with cerebral palsy (CP).

METHODS: The study used a single-subject design with a 16-week follow-up. After a three-week intervention-free period, a participant underwent five data collection sessions for the baseline measurements. Subsequently, stretching and HI strength training occurred three times weekly for 48 sessions, with the outcome measures collected weekly post-treatment. Final measurements were taken the day after the last session, and a follow-up assessment occurred six weeks post-study to assess the learning effects.

RESULTS: After 16 weeks of treatment, the participant exhibited improved targeted muscle strength and postural alignment without increased spasticity. On the other hand, no significant change in participation in the ADL was observed.

CONCLUSION: The research findings suggest that HI strength training and stretching exercises may contribute to improvements in muscle strength and body alignment without increased spasticity in an adolescent with CP, but it may not have a significant impact on participation in ADL.

Key Words: Cerebral palsy, Muscle strength training, Physical therapy modality

Ⅰ. Introduction

Cerebral palsy (CP) is a well-recognized group of permanent disorders of the development of movement and posture, causing activity limitations beginning in early childhood and continuing throughout the lifespan. CP acknowledges coexistent sensory information and sensory processing deficits associated with this pathology [1]. Posture and movement disorders are critical problems in CP; postural asymmetry increases the risk of tissue adaptation, leading to contractures and progressive deformities [2,3].

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Contractures and bone and joint deformities most commonly affect the lower extremities and the spine, leading to scoliosis, pelvic obliquity, hip dislocations, windswept deformities, flexed hips and knees, and foot deformities [4]. The time spent in an abnormal posture is critical to developing a contracture. The longer a posture is held, the greater the risk for contracture [5].

Spastic CP is the most common form of CP that frequently alters the normal development of the somatosensory system. Postural symmetry is crucial for the development of the musculoskeletal system because it allows for the proper sensory input of the brain [6]. A functional magnetic resonance imaging (MRI) study that investigated tactile shape and grating discrimination found decreased cortical activity in the parietal and frontal cortical somatosensory regions of spastic CP compared to typically developing children [7].

Children with spastic diplegic CP will develop progressive musculoskeletal deformities, such as contractures of the two-joint muscles, and orthopedic surgery in children with spastic diplegia can be associated with insufficient physical therapy management [8]. The term 'posture' refers to the anatomical alignment of the body segments in relation to each other and the supporting surface, as well as the relationship between the body and the environment [9]. Postural alignment is a critical problem in adult CP. The body segments need to be aligned and stabilized to minimize the risk of musculoskeletal deformities and reduce the impact of gravity by providing one-joint muscle support [10].

Despite the recognized benefits of strength training in individuals with CP, there is a lack of consensus regarding the optimal approach. High-intensity (HI) strength training has gained attention in recent years because of its potential to improve muscle strength and functional outcomes [11]. The rationale for using HI strength training lies in its ability to induce neuromuscular adaptations that enhance muscle strength and motor performance [12].

Moreover, implementing resistance training after stretching exercises is grounded in physiological principles. Stretching exercises can help alleviate muscle tightness and improve flexibility, priming the muscles for subsequent resistance training [13]. By pre-conditioning the muscles with stretching exercises, individuals with CP may experience enhanced muscle recruitment and performance during resistance training sessions. Furthermore, stretching exercises can help reduce the risk of injury during resistance training by preparing the muscles and connective tissues for the demands of intense muscular contractions [14].

Acknowledging the gap in research targeting adolescents with CP on this topic is essential for highlighting the need for further investigation and tailored interventions in this population. It emphasizes the importance of conducting studies focusing on understanding the effects of stretching exercises and resistance training in children with cerebral palsy to optimize their rehabilitation and improve their overall health outcomes. Previous randomized controlled trials and meta-analyses reported no positive effects on the gait function after strength training [15,16]. Controversy also remains regarding strength training in relation to individuals with CP. Therefore, this paper describes how a program involving HI strength training and stretching exercises is associated with changes in muscle strength, postural alignment, and participation of ADL in a 16-year-old adolescent with postural asymmetry and a diagnosis of spastic CP.

Ⅱ. Methods

1. Participant

The participant was a 16-year-old male adolescent diagnosed with spastic CP and diplegia who was ambulatory without walking aids and could walk for at least 10 minutes without resting. He was classified as level I according to the Gross Motor Function Classification System (GMFCS) [17].

This study was initiated following a recommendation by an orthopedic surgeon for orthopedic surgery, prompted by the mother's concerns about surgery and her desire for alternative options to improve her child's asymmetric standing posture. By two years of age, he was diagnosed with spastic diplegic CP and started physical, occupational services every week in the hospital. Based on his previous PT examination, he had excessive hip flexion with knee flexion, adduction and internal rotation of the hip, and an equinus foot. He had received high-intensity, multi-joint dynamic training, such as straight leg raising, heel raises, half squats, sit-to-stand, lateral step-up, and walking up and down stairs three times a week.

Clinical assessments during the examination identified asymmetries, with the child showing the predominant use of his right side for all tasks. Furthermore, frequent leaning on his right leg was observed while maintaining a standing position, with flexion evident in the left knee. He ambulated with an asymmetric step length (right step length dominance) without orthoses. The left foot was lifted, and the limb was advanced by hip flexion with knee extension. The ankle was only plantar flexed in the swing phase. He always tries to walk quickly. He could follow instructions and was not taking oral anti-spasticity medication. The examination results indicated that weaker knee extension (quadriceps femoris) was observed compared to other muscles, particularly in the left leg compared to the right leg. Written informed consent was obtained. This study was conducted ethically according to the principles of the Declaration of Helsinki [18].

2. Study Design

A single-subject design, with a 16-week follow-up after the end of the treatment period, was used. The participant underwent an initial three-week intervention-free period, during which five data collection sessions were randomly scheduled on different days for qualitative and quantitative outcome measures. The data collection sessions were measured at evenly spaced intervals to ensure representativeness over the baseline period. After these baseline measurements, stretching and strength training exercises were conducted three times a week for 48 treatment sessions. The outcome measures were collected approximately two hours after each treatment, once every week. The final measurements were obtained the day after the last treatment session. In addition, a follow-up assessment was conducted six weeks after the end of the study to evaluate the learning effect.

Among the measured data, the mean scores of the measured variables were tabulated to compare the changes in outcome before and after the intervention. The "pre-intervention" values represent the mean and (SD) of the five baseline assessments. The "post-intervention" values represent the mean and (SD) of the last three assessments conducted during the treatment phase. The last three weeks after the intervention were chosen as a specific measurement period to mitigate bias stemming from temporary fluctuations or short-term effects of the intervention. This focus enabled the study to concentrate on the lasting changes resulting from the intervention. Within the quantitative evaluation data, point estimates of the isometric strength of knee extensors and the percentage change in the isometric strength of the knee extensors before and after the intervention for the right and left legs were presented graphically.

This study used observation and description as primary research analysis methods. The graphs and tables were used to visualize and comprehend the changes in the isometric strength of the knee extensors, MTS, PPA, and modified K-CHAQ scores across various times. The individual significant changes, trends, and observed patterns were systematically identified and described. In addition, the treatment effects were assessed by comparing the changes in subjects over the study period and trends.

3. Outcome Measures

The outcome measures were conducted by a licensed physical therapist with five years of experience with the

CP treatment, ensuring precise and reliable data collection for the study. Importantly, the person performing the measurements was unaware of the specific details of the experiment, ensuring an unbiased assessment process. The assessment was conducted in an evaluation room without any observers present.

1) Muscle Strength

The isometric strength assessment of the knee extensors was conducted using a Microfet portable dynamometer manufactured by Biometrics located in Almere, Netherlands. When measuring the knee extensors, the assessment was conducted with the participant seated and their knees flexed at 90°. The stabilization location was at the pelvis, and the resistance was placed on the anterior tibia, positioned 5 cm proximal to the malleoli. Three measurements were taken, and the mean and standard deviation were calculated. The intrarater reliability for measuring the isometric strength of knee extensors was high, with intraclass correlation coefficients (ICCs) ranging from .80 to .90 [19]. This reliability was particularly observed in measurements obtained from children diagnosed with spastic diplegia classified as GMFCS level I.

2) Spasticity

The hamstring spasticity was assessed using the Modified Tardieu Scale (MTS) to determine if strength training influenced spasticity. This assessment was conducted with the hip flexed at 90°. The knee was then rapidly extended, and the angle at which a catch (R1) occurred was measured using a goniometer. After measuring R2, which indicates the angle at which the muscle reaches its maximum length during slow passive movements, the difference between R2 and R1 (R2–R1) is calculated, and the degree of spasticity was assessed by the absolute value of that difference [20]. The test was performed once, before the other assessments, to prevent additional tension and spasticity.

(3) Postural Alignment

The posture and postural ability (PPA) scale has two major categories: posture and postural ability. In this scale, the term ‘posture,’ refers to the anatomical alignment of the body segments in relation to each other, the supporting surface, and the relationship between the body and the environment. ‘Postural ability’ relates to controlling the center of gravity relative to the base of support under static and dynamic conditions. In this case report, the postural ability scales were excluded from measuring the posture because the postural ability scales did not match the purpose of the study. The quality of posture (PPA scale) contains a 48-point ordinal scale for the assessment of posture; each was scored on a two-point ordinal scale either “yes (1 point)” or “no (0 point).” The total score of 0–6 points was calculated separately for each position in the frontal and sagittal views. The scores were measured for one dimension, standing, for each of the four views: (A) standing, (B) sitting, (C) supine, and (D) prone. The PPA scale showed excellent interrater reliability (kappa score = .77 – .99), high internal consistency, and construct validity (alpha = .95 – .96; item-total correlation = .55 – .91) [21].

4) Participation

The ADL variables were measured using the Modified Korean version of the Childhood Health Assessment Questionnaire (Modified K-CHAQ). The CHAQ is a validated questionnaire with specific items designed to assess juvenile idiopathic arthritis in children and adolescents [22].

K-CHAQ was considered when assessing the health status of children with CP based on reliability and correlation with gross motor function [23]. K-CHAQ was used to assess the level of participation in the daily lives of children. From previous research, the goal was to discern the psychometric properties of the K-CHAQ using the Rasch model [24]. Among the 30 items in the K-CHAQ, two (nail-cutting and opening a bottle cap already opened) displayed low fitness as misfit items. An analysis of item difficulty indicated the necessity for modification, highlighting the need to incorporate items with higher and lower difficulty levels. Consequently, the two questions identified as misfit items were removed, and the number of questions in each section was augmented to 5, resulting in 40 questions. These questions were modified and utilized, considering the difficulty levels.

4. Intervention

The therapist leading the intervention was a licensed physical therapist with over five years of experience in pediatric physical therapy and was not involved in the evaluation. The patient was unaware of the specific details or objectives of this study. The therapist provided treatment to the participant for 16 weeks. The number of weeks recently recommended for meaningful improvements following strength training [25]. Pediatric resistance-training programs must be individualized to maximize the outcomes and reduce the risk of injury [26]. The participant underwent a specialized intervention program with two primary areas of focus. First, passive stretching was directed towards the left hamstring muscles, which exhibited more bending when standing than the right side. Second, HI strength training targeted the left quadriceps muscle, which displayed greater weakness than the right side. The intervention included three sessions per week. The intervention sessions adhered to a detailed protocol, individually customized and overseen by a physical therapist. Each session commenced with a five-minute warm-up through cycling on a stationary bicycle. During the stretching exercises, the participant underwent 60 seconds of passive stretching with support from the physical therapist. Subsequently, stretching exercises were conducted for 60 seconds, repeated five times unilaterally. [27]. HI strength training with the knee positioned prone and sandbag resistance was applied to the distal leg with a universal exercise unit. In HI strength training, the fundamental principle is a standardized progression in intensity based on the child’s strength level to ensure progressive overload, assessed by the repetition maximum (RM). The RM is the maximum number of repetitions that can be performed correctly under a given load, with the heaviest load for one complete repetition being the 1 RM, initially comprising 1 or 2 sets of 8–15 repetitions with a light to moderate load (approximately 30%–60% 1 RM) to learn the correct technique, followed by progression to 3–5 sets of 40 repetitions (approximately 70%–85% 1 RM) [28].

Ⅲ. Results

The analysis of the tabulated data revealed significant changes in the knee extensor peak isometric strength values, MTS, and PPA before and after the intervention (Table 1).

Table 1. Mean scores of the measured variables

Outcome Variable	Pre-intervention	(SD)	Post-intervention	(SD)	Follow up
Lt. Knee extensor ($N \cdot kg^{-1}$)	4.6	0.2	6.6	0.1	6.5
Rt. Knee extensor ($N \cdot kg^{-1}$)	6.0	0.1	6.8	0.1	6.7
MTS[b] (degree)	10.4	2.3	9.8	1.8	10
PPA (standing: posture frontal)	1	0	2	0	2
PPA (standing: posture sagittal)	0	0	1	0	1
CHAQ	118	0	118	0	118

SD: Standard deviation, Lt: Left, Rt: right, MTS: Modified Tardieu scale, PPA: Posture and postural ability, CHAQ: Childhood health assessment questionnaire

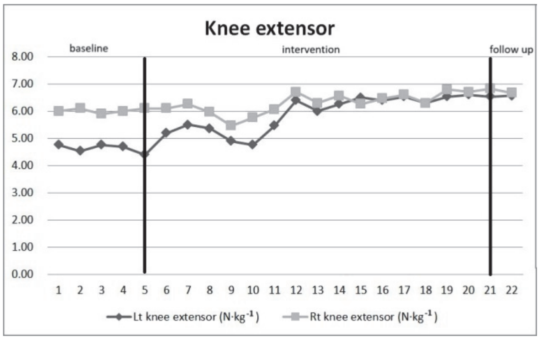

Fig. 1. Point estimate of the isometric strength of the knee extensors.

The mean improvement in the knee extensor peak Isometric strength values between pre-intervention and post-intervention was 43%. The analysis of the graphed data points indicates significant changes in knee extensor peak isometric strength values from the baseline to treatment sessions (Fig. 1). At the follow-up assessment conducted six weeks later, knee extensor peak Isometric strength values, popliteal angle, and PPA remained higher compared to baseline. The modified K-CHAQ scores in Table 1 did not exhibit significant changes from the baseline to the end of treatment, and no change was observed at the follow-up assessment.

Ⅳ. Discussion

Five systematic reviews concluded that strength training was effective for people with CP [29-33]. One systematic review reported that thirteen randomized controlled trial studies were selected and divided into categories according to the program type, mode, and outcome measures. Strengthening exercise improved muscle strength to a greater degree when practiced three times per week in 40 – 50 min sessions than in other categories of session length, and greater improvement was observed in younger children than in older children [34]. Another systematic review concluded that resistance training was ineffective in children with cerebral palsy [35] despite the progressive nature of strengthening interventions. These interventions were not administered consistently at the intensity recommended by the American College of Sports Medicine [36]. The intensity of the training may not have been sufficient to achieve substantial strength gains.

Adolescence is a critical transitional period, particularly for individuals with CP, because many are believed to undergo a decline in physical function during adolescence and early adulthood [37]. Secondary musculoskeletal impairments might worsen because of the fragmented provision of health services and reduced contact with the healthcare system after adolescents leave school [38]. The data suggested that HI strength training and hamstring stretching exercises were effective in improving the knee joint range of motion, power production of the knee extensors, and alignment of the body without increasing spasticity when standing in adolescent with CP who exhibit asymmetrical strength between their left and right legs and habitually assume asymmetrical postures. At the fourth week of the intervention, the participant caught a cold and was not feeling well. As a result, the measurements of the knee extension muscles appeared to be low, possibly because the temporary weakness or decreased muscle function is often associated with illness or reduced energy levels.

The improvement in body alignment during standing was associated with an increase in the power peak of the knee extensors and an increase in the flexibility of the hamstring muscles. The findings align with Merino-Andrés J et al. [39], who also observed positive effects on muscle strength, balance, gait speed, or gross motor function without increasing spasticity for children and adolescents with CP. After stretching the hamstring muscles, strengthening exercises of the quadriceps muscles were aimed to increase the power of the knee extensors. On the other hand, the change in postural alignment in the standing position indicates a more general benefit of these exercises and the treatment protocol. Furthermore, the absence of increased spasticity alongside these improved changes has significant meaning for clinicians. The changes observed in the measured variables did not occur concurrently with changes in participation in the activities of daily living. This highlights the need for training the body to adjust appropriately to meet the demands of various functional activities in different environmental conditions as part of the treatment protocol.

These findings align with Dodd et al., where significant results were found for strength and functional variables but not for activity or participation [40]. Ultimately, this study suggests that an adequate treatment duration, intensity, and frequency will likely lead to strength gains. On the other hand, in terms of participation, the lack of improvement was attributed to the absence of specific movement practices. These results cannot be generalized to all populations with CP. The participant in this study had spastic CP at GMFCS level 1. In addition, parents participated voluntarily, suggesting they were likely highly motivated and actively involved in their child's program. Another limitation was the lack of reliability and validity tests conducted on the modified Korean version of the CHAQ. Future research should apply this approach to various types of CP and include a larger sample size to enhance the generalizability and validity of the findings.

Ⅴ. Conclusion

These research findings suggest that HI strength training after stretching exercises may improve muscle strength and body alignment without increasing the spasticity in adolescents with CP. Nevertheless, it may not significantly impact participation in the activities of daily living.

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Appendix

수정된 Korean-CHAQ

이 질문지는 아동의 장애(수반장애 포함)가 일상생활에서 아동의 기능에 영향을 미치는지를 알아보기 위한 내용으로 구성되어 있습니다. 각각의 질문에 대해 지난 일주일 동안 아동의 일상적인 활동을 가장 잘 기술한 내용에 체크하여 주시기 바랍니다 (하루 평균). 이 질문지는 장애가 아동의 건강 상태에 어떠한 영향을 미치는지를 알아보기 위해 사용된 것입니다. 단지 아동의 장애로 인한 어려움이나 제한에 대한 것임을 고려하여 주시기 바랍니다. 만약 아동의 연령에서 수행할 수 없는 활동일 경우에는 “적용할 수 없음”에 체크하여 주시기 바랍니다. 예를 들어, 만약 아동의 질병으로 인한 제한이 아니라 아동이 너무 어리기 때문에 어떤 활동을 수행하는데 어려움이 있다면 “적용할 수 없음”에 체크하시면 됩니다.

	스스로 수행 (3점)	약간 도움을 주면 수행 (2점)	많은 도움을 주면 수행 (1점)	도움을 줘도 수행하기힘듬 (0점)	적용할 수 없음
1. 옷 입기와 몸 단장하기					
1. 바지 입기와 벗기					
2. 윗옷 입기와 벗기					
3. 양말 벗기					
4. 신발 벗기					
5. 머리 빗기					
2. 일어서기					
6. 쇼파에서 일어서기					
7. 침대에서 일어서기					
8. 식탁의자에서 일어서기					
9. 바닥에서 무릎으로 서기					
10. 바닥에서 일어서기					
3. 먹기					
11. 젓가락 사용하기					
12. 숟가락 사용하기					
13. 컵 들기와 입으로 가져가기					
14. 새 과자박스 열기					
15. 손가락으로 과자 집어 먹기					
4. 이동					
16. 실외 평평한 바닥에서 걷기로 이동					
17. 다섯 계단 오르기					

	스스로 수행 (3점)	약간 도움을 주면 수행 (2점)	많은 도움을 주면 수행 (1점)	도움을 줘도 수행하기힘듬 (0점)	적용할 수 없음
18. 무릎걷기로 거실이나 다른 방으로 이동					
19. 네발기기로 거실이나 다른 방으로 이동					
20. 배밀이로 거실이나 다른 방으로 이동					
5. 위생					
21. 몸을 씻고 물기 제거하기					
22. 욕조사용하기 (욕조 안으로 들어가고 나오기)					
23. 변기 사용하기					
24. 양치질하기					
25. 머리 빗기					
6. 손 뻗기					
26. 머리보다 높은 곳에 있는 책이나 장난감 가져오기					
27. 몸 앞쪽 바닥에 있는 옷을 집어 가져오기					
28. 몸 옆쪽 바닥에 있는 옷을 집어 가져오기					
29. 대각선 뒤에 바닥에 있는 옷을 가져오기)					
30. 식탁에서 반찬 가져와 먹기					
7. 잡기					
31. 연필이나 펜으로 쓰기					
32. 차문 열기					
33. 냉장고 문 열기					
34. 수도꼭지 잠그고 열기					
35. 손잡이를 돌려 열어야 하는 문 열기					
8. 활동					
36. 심부름하기와 물건사기					
37. 차, 장난감 차 혹은 학교 버스에 타고 내리기					
38. 두발 혹은 세발자전거 타기					
39. 집안일하기 (설거지, 쓰레기 버리기, 진공청소기 사용하기, 정원일, 침대정리, 방청소 등)					
40. 뛰어 놀기					
총 40문항	/ (120점)				