Balance training versus reciprocal electrical stimulation on knee joint alignment in spastic diplegic cerebral palsy children

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Background and purpose

Spastic diplegia is the most common pattern of motor impairment in patients with cerebral palsy (CP) because of a number of deficits, including poor muscle control, weakness, impaired balance, and spasticity, which cause malalignment of the knee joint during standing and walking. This study aimed to evaluate the effect of balance training (BT) versus reciprocal electrical stimulation (RES) of knee extensors and flexors on knee joint alignment in spastic diplegic CP children.

Materials and methods

Thirty children with spastic diplegic CP of both sexes were selected, ranging in age from 6 to 8 years. Children were divided randomly into two equal groups (I and II). Evaluation was performed before and after 12 weeks of treatment using a digital goniometer to measure range of motion of the knee joint, tape measurement to measure the distance between the buttock and the heel, and gross motor functional measure to provide functional evaluation of standing and walking abilities. Group I received a BT program on the Biodex balance system in addition to a selected physical therapy program. Group II received RES of knee extensors and flexors in addition to the same selected physical therapy program.

Results

Both BT and RES for 12 weeks in spastic diplegic CP seem to yield a beneficial and statistically significant increase in adjusting knee alignment and improving the functional abilities in standing and walking ($P < 0.05$). However, BT seems to exert a more beneficially and statistically significant effect than RES.

Conclusion

BT and RES have a significant effect on improving knee alignment in spastic diplegic CP children.

Keywords:
balance, cerebral palsy, electrical stimulation, knee joint

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Introduction

Cerebral palsy (CP) involves a number of nonprogressive disorders of posture and motor impairment. It is a common cause of disability in childhood. The disorder results from various insults to different areas within the developing nervous system, which explains the variability in clinical findings [1]. Spastic diplegia is the common term applied to the variation of spastic quadriparesis in which the lower limbs are more affected than the upper limbs [2].

The primary functional problem includes difficulty with mobility and posture. Other problems include postural deviations including inability to sit without support, inability to stand, and difficulty in movement translation. Gait is usually crouched because of weakness in hip and knee extensors, with subsequent development of hip and knee flexor contractures. In spastic diplegia, standing and ambulation posture become more crouched with age [3]. Various gait patterns have been reported in ambulatory spastic diplegic children. These patterns are characterized by limited mobility in their lumbar spine, pelvis, and hip joints and show limited asymmetric pelvic tilt or pelvic rotation during gait. Many of the ambulatory children with spastic diplegia were able to walk with flexed hips, knees, and ankles; this gait pattern is known as the crouch gait. The crouch gait has been interpreted to result from overactivity or shortening of the hamstrings [4].

The impairment in balance in spastic diplegic children while standing may be because of difficulty in activating and timing muscle contraction. This impairment may be compounded by muscle weakness secondary to inactivity. Reduced ability to balance while standing interferes with functional activities such as walking, standing up, reaching while standing, and climbing stairs [5]. Balance control training is important for competence in the performance of most functional skills, helping children to recover from unexpected balance disturbances [3].

The treatment goals of spastic diplegic children focus on the prevention of disability by minimizing the effects of impairments and maximizing the gross motor function. Achieving these goals involves promotion and maintenance of musculoskeletal integrity, prevention of deformities, and improvement of posture and movement [6].

Neuromuscular electrical stimulation (NMES) is one of the physiotherapy modalities commonly used to decrease muscle spasticity [7], activate weakened muscle [8], improve gait in various neurological conditions including CP [9,10], increase blood circulation [11], and facilitate sensory awareness [12].

Reciprocal electrical stimulation (RES) is a novel application of electrical stimulation that can be used for neuromuscular reeducation and performance enhancement. RES differs from NMES in terms of replication of the typical firing series of muscle groups on the basis of electromyographic patterns derived from healthy participants during functional movement or activity. The stimulation pattern of a RES treatment is transferred into a pattern that results in a contraction of the quadriceps (agonist) muscle, the hamstring muscle (antagonist), and the quadriceps (agonist), again to mimic a voluntary movement pattern. This rhythmical pattern has been projected to improve the neural drive by stimulating muscle stretch receptors and sensory neurons in both flexor and extensor motor neurons that have been found to replicate spinal alterations that are seen during locomotion [13].

The hypothesis was that there is no superiority of any therapeutic intervention, balance training (BT), or RES in adjusting the knee joint malalignment in spastic diplegic children with CP. Therefore, the aim of this study was to evaluate the effect of a BT program versus RES of knee extensors and flexors on knee alignment during standing and walking in spastic diplegic CP children.

Materials and methods

Participants

Thirty spastic diplegic CP children of both sexes participated in this study. Children were recruited from the pediatrics outpatient clinic, Faculty of Physical Therapy, Cairo University. Their ages ranged from 6 to 8 years. Children were assigned randomly to two equal groups: a study group I and a study group II. Group assignments were chosen randomly using the opaque envelope method. Group I included 15 children (eight boys and seven girls) with a mean age of 7.9 (1.15) years. Children received a BT program on the Biodex balance system in addition to a selected physical therapy program. Group II included 15 children (nine boys and six girls) with a mean age of 7.76 (1.01) years. Children received electrical stimulation of quadriceps and hamstring muscles in addition to the same selected physical therapy program that was provided to the study group I. The participants were selected according to the following criteria.

Inclusion criteria

(1) A medical diagnosis of spastic diplegic CP was made by pediatricians specialized in pediatric neurology.
(2) Grade of spasticity ranged from 1 to 1+ according to modified Ashworth scale (MAS) [14].
(3) Children were able to stand alone with their heels on the ground without support.
(4) Children were able to understand and follow verbal commands and instructions included in both test and training procedures.

Exclusion criteria

(1) Children had fixed deformity (bony or soft tissue contractures) of both lower limbs.
(2) Children had undergone a previous surgical intervention to release the hamstrings.
(3) Children had visual or auditory defects.
(4) Children had IQ < 70.

Informed consent for participation was obtained from the parents of the participated children before study inclusion.

Evaluation procedures

(1) MAS was used to measure the degree of spasticity by passive movement from the supine position to enroll patients in the study.
(2) Digital baseline absolute + axis goniometer (Model 12-1027, version 7-08, Fabrication Enterprises, Inc., White Plains, New York) was used to measure the limited knee extension range of motion (ROM) from the supine position.
(3) Tape measurement was performed to measure the distance between the buttock (ischial tuberosity) and the heel in the point of extension limitation from the prone position.
(4) Gross motor functional measure (GMFM).

The GMFM is a standardized, valid, and reliable observational scale that was developed to measure changes in gross motor function over time in children with CP. It compares the CP child with normal children in the same age. GMFM measures the child's skill in 88 items across five dimensions:

(a) Lying and rolling,
(b) Sitting,
(c) Crawling and kneeling,
(d) Standing, and
(e) Walking, running and jumping, but does not measure the quality of the movement.

All items in GMFM usually could be accomplished by 5-years of age with normal motor abilities [15,16].

Scoring of the scale

Each GMFM item was scored on a four-point scale. The scoring key was as follows:

0 = does not initiate.
1 = initiates (<10% of the task).
2 = partially complete (10% to <100% of the task).
3 = task completion (100% task completion).

The measuring variables in this study were the standing and walking sections (D and E).

Treatment procedures

Biodex balance system

It is a dynamic postural control assessment and training system (Biodex Medical System, Shirley, New York, USA). It consists of a movable balance platform that can be set at variable degrees of instability and safety support rails. This system is interfaced with a computer software monitored through the control panel screen. Two BT routines were used, with the total duration of BT set at 20 min as follows:

(1) Dynamic BT routine.
It was used to increase the child's ability to control the platform's angle of tilt. A centering step was performed before each training session. The child was instructed to focus on the visual feedback screen directly in front of him/her and to attempt to maintain the cursor at the center of the bullseye on the screen while standing on the unstable platform. The duration of training was 10 min (2 min training and 1 min rest).
In the initial stage of BT during the suggested period of treatment as the children had minimal ability to control their center of gravity on unstable surface facilitation of postural control on the Biodex system was performed with minimal demand, which is stability level 8, the most stable state of platform tilt. Each child was trained on stability level 8 for the first three sessions and on stability level 7 for the next three sessions and so on. The transition from one level to another was based on the improved balance capability.
(2) Dynamic limits of stability training routine.
Dynamic limits of stability training were used to challenge the child by promoting the movement of the cursor to eight blinking targets within the dimension of limits of stability. A centering step was performed before each training session. Each child started training with the footplate centered and the cursor over the blinking central target. The child was instructed to hold the cursor inside that central flashing box until it stopped blinking. An instruction was then given to the child to shift his/her body weight, to move the cursor over the second randomly appearing flashing box, and also to hold it inside that flashing box until it stopped flashing. Finally, the child was asked to move the cursor back to the central flashing box as quickly and with as little deviation as possible. The same process was repeated for each of the eight targets.

The duration of the training session was 10 min (2 min training and 1 min rest). As in the dynamic BT routine, the child was trained on stability level 8 for the first three sessions and on stability level 7 for the next three sessions and so on if available. As the child was successful in controlling the movement of his/her center of gravity within the dimension of limits of stability in a less challenging situation, increasing postural demands were introduced by training him or her in a more unstable situation.

Reciprocal electrical stimulation

A specialized programmable electrical stimulation device was used (Uniphy is the manufacturer Phyaction 787; Uniphy, Eindhoven, the Netherlands). The device has two channels that can stimulate two opposing groups of muscles alternatively (reciprocate). The RES was used with the following parameters:

(1) Current type: asymmetrical biphasic pulsed current.
(2) Pulse duration: 300 μs (Faradic) increased gradually, but never to maximum contraction.
(3) Frequency: 5–7 pps (pulse/s) and increased gradually to 30 pps.
(4) On-time: 10 s.
(5) Off-time 20 s.

(6) Treatment duration: 20 min.
(7) Patient position: supine lying position or sitting with extended legs.
(8) Electrode placement: two channels were used as follows:
   (a) Channel 1 (stimulation of quadriceps muscles): one electrode at the outer surface of the upper thigh and the other electrode on the vastus medialis.
   (b) Channel 2 (stimulation of hamstring muscles): one electrode at the ischium and the other electrode on the posterior aspect of the thigh proximal to the popliteal fossa.

Physical therapy tools of different shapes in the form of mats, wedge, rolls, medical balls, tilting board, wooden blocks, standing bar, parallel bars, stepper, and large mirror were used to conduct the exercise program.

Physical therapy treatment program

The two groups received the physical therapy treatment program for 1½ h, three times per week, everyday for 3 successive months as follows:

(1) Neurodevelopmental approach directed toward inhibiting abnormal muscle tone and abnormal reflexes and facilitation of normal movement patterns of postural control through reflex-inhibiting positions using proximal and distal key points of control.
(2) Training for active trunk extension to improve postural control and balance.
(3) BT from different positions, from the quadruped position, kneeling, half kneeling, and standing position on the mat and tilting board.
(4) Facilitation of righting and equilibrium reactions to improve postural mechanism through a variety of exercises applied on a ball and balance board through tilting from different positions forward, backward, and sideways.
(5) Facilitation of protective reactions by applying a fast and large amplitude of stimulus to train saving reactions from sitting on roll, and also from the standing position by pushing the child to encourage the child to take protective steps either forward, backward, or sideways to regain balance.
(6) Approximation as a proprioceptive training applied in a slow and rhythmic manner for the upper limbs, lower limbs, and trunk to control spasticity and stimulate the joint mechanoreceptors from semi reclined and quadruped positions.
(7) Hand weight-bearing exercises and approximation to improve the hand function, and also facilitation of reaching, grasping, and release according to the child's abilities.
(8) Stretching exercises to maintain the length and the elasticity of the muscles, which are susceptible to shortening, especially the Achilles tendon, hamstrings, hip flexors, and adductors of both lower limbs and shoulder internal rotators, elbow and wrist extensors, pronators, and ulnar deviators of the upper limbs.
(9) Gait training activities were also important elements for BT including the following:
   (a) Sideways, forward, and backward walking between the parallel bars in front of a large mirror and walking training using a stepper.
   (b) Training for walking in an open environment by placing obstacles across the walking tract with different diameters and wedges of different heights.
   (c) Training for walking on different floor surfaces (spongy and hard surfaces) on the mat, on the floor, and on the carpets.

To compare improvement after the intervention in each group, a paired *t*-test was used and to assess the difference between the two groups an independent *t*-test was used. The Wilcoxon signed-ranks test was used to calculate the percentage difference in GMFM scores before and after treatment within each group. The Mann–Whitney *U*-test was used to calculate the percentage difference in GMFM scores between both groups. A significance level of *P*-value less than 0.05 was considered.

Results

The data collected from this study represent the statistical analysis of the limited knee extension ROM (in degrees) measured by a digital goniometer, the distance between the buttock and the heel (in cm) measured by tape measurement, and a GMFM scale (standing and walking domains) (in percentage). Data were obtained from both groups, the BT group (GI) and the RES intervention group (GII), before and after 3 months of treatment for the two groups.

Demographic and clinical characteristics of the patients in both groups

In GI, eight patients were male and seven patients were female whereas in GII, nine patients were male and six patients were female. No statistically significant differences were detected between both groups in mean age, weight, and height (P = 0.725, 0.336, and 0.223, respectively) (Table 1).

There were no statistical differences between groups for any pre treatment measures (Table 1). In GI, there were statistically significant improvements in passive knee joint extension, the length between the buttock and the heel, and functional performance as in GMFM compared with the initial values. Also, GII showed a statistically significant improvement as in GI, except for the knee extension, despite the decreased post-treatment values (Table 2).

The BT group showed a significant improvement in relation to the RES group on comparing the post-treatment values of all variables (Table 3).

Table 1 Demographic and clinical characteristics of the patients in both groups (I and II)

Variables	Study group (group I) (n = 15)	Study group (group II) (n = 15)	P-value
Sex[a] (M : F)	8 : 7	9 : 6	0.712
Age[b] (years)	7.9 (1.15)	7.76 (1.01)	0.725
Weight[b] (kg)	24.28 (3.1)	25.5 (3.7)	0.336
Height[b] (cm)	123.1 (3.7)	123.9 (4.2)	0.223
Limited knee extension ROM[b] (°)			
Right	47.07 (3.24)	47.4 (4.3)	0.814
Left	47.27 (3.08)	47.85 (3.9)	0.654
Distance between buttock and heel[b] (cm)			
Right	52.3 (2.4)	51.5 (2.5)	0.4360
Left	51.6 (3.1)	49.7 (1.9)	0.0526
GMFM[c] (%) (median)	68.16	65.23	0.1362

Values are represented as mean (SD). GMFM, gross motor function measure; ROM, range of motion. [a]The values are calculated using the χ^2-test. [b]The values are calculated using the independent t-test. [c]The values are calculated using the Mann–Whitney U-test.

Discussion

The present study included spastic diplegic-type CP, which constitutes a major classification among spastic types. This finding was reported by Damiano [17], who reported that spastic diplegia is the most common type of CP, found in nearly 44% of children with cerebral palsy. Children aged from 6 to 8 years were included in the present study as the control of posture and complete gait maturation were very similar to that of adults at this age [18]. This is also in agreement with the findings of Koop and Green [19], who reported that independent standing and walking in spastic diplegia can be delayed up to 6 years of age because of extensor and adductor spasticity of the legs.

The pretreatment mean values of the measured variables of the study groups indicated that those children had postural dysfunction during standing and walking. This is in agreement with Woollacott and Shumway-Cook [3], who reported that children with spastic diplegic CP show:

(a) Crouched posture, contributing toward decreased ability to recover balance (longer time/increased sway);
(b) Delayed responses in ankle muscles;
(c) Inappropriate muscle response sequencing; abs
(d) Increased coactivation of agonists/antagonists.

The authors added that constraints on gait include the following:

(a) Crouched gait;
(b) Increased coactivation of agonists/antagonists;

Table 2 Comparison between pretreatment and post-treatment limited knee extension range of motion, distance between buttock and heel, and gross motor function measure percentage in both groups (I and II)

Variables	Pretreatment	Post-treatment	Percentage of change (%)	P-value
Limited knee extension ROM[a] (°)				
GI (n = 15)				
Right	47.07 (3.24)	41.67 (3.13)	−11.47	<0.0001*
Left	47.27 (3.08)	41.13 (2.8)	−12.98	<0.0001*
GII (n = 15)				
Right	47.4 (4.3)	44.73 (4.1)	−5.63	0.0928
Left	47.85 (3.9)	45.46 (3.6)	−4.99	0.0921
Distance between buttock and heel[a] (cm)				
GI (n = 15)				
Right	52.3 (2.4)	54.6 (2.3)	4.39	0.0122*
Left	51.6 (3.1)	53 (1.3)	2.71	0.0486*
GII (n = 15)				
Right	51.5 (2.5)	53.7 (2.2)	4.27	0.0412*
Left	49.7 (1.9)	51.3 (2.3)	3.21	0.0471*
GMFM[b] (%)				
GI (n = 15) (median)	68.16	74.22	8.89	0.0285*
GII (n = 15) (median)	65.23	71.3	9.3	0.0423*

Values are represented as mean (SD); GMFM, gross motor function measure; [a]The values are calculated using the paired t-test; [b]The values are calculated using the Wilcoxon signed-ranks test; *Significant at $P < 0.05$.

Table 3 Comparison between both groups (I and II) after treatment in terms of limited knee extension range of motion, distance between buttock and heel, and gross motor function measure percentage

Variables	Group I (n = 15)	Group II (n = 15)	P-value
Limited knee extension ROM[a] (°)			
Right	41.67 (3.13)	44.73 (4.1)	0.0293*
Left	41.13 (2.8)	45.46 (3.6)	0.0010*
Distance between buttock and heel[a] (cm)			
Right	54.6 (2.3)	53.7 (2.2)	0.0263*
Left	53 (1.3)	51.3 (2.3)	0.0068*
GMFM[b] (%)			
Median	74.22	71.3	0.0423*

Values are represented as mean (SD); GMFM, gross motor function measure; [a]The values are calculated using the independent t-test; [b]The values are calculated using the Mann–Whitney U-test; *Significant at $P < 0.05$.

(c) Decreased muscle activation; and
(d) Spasticity.

Statistical analysis of the post-treatment results of the two groups showed a significant improvement in both groups including postural stability and functional abilities, with the improvement in percentage being higher in the study group I, which involved maintaining the body segments properly aligned in an upright posture. The improvement in the study group I might be attributed to the effect of the BT program because the maintenance of stability is critical to all movements.

Balance control is important to perform most functional skills, serving a child to recover from sudden balance disturbances either because of slips and trips or self-induced instability when moving toward the edge of his or her limit of stability. The improvement found in the study group I might be attributed to the effect of the therapeutic exercise program, which focused on a group of exercises for facilitation of normal erect posture. This is in agreement with Kern *et al.* [20], who reported that traditional methods of treatment for children with CP are focused on the attainment of sequential development milestones and facilitation of normal movement patterns. Comerford and Mottram [21] pointed out that muscles have three important functions: static control of posture and alignment of joints, dynamic control and production of movement, and providing important proprioception input into the central nervous system. Thus, the balance between different muscle groups ensures that correct joint loading and correct alignment occurs.

The significant improvement in the post-treatment results in the study group I is in agreement with Sterba *et al.* [22], who recommended promotion of postural and equilibrium reactions and focus on postural alignment in sitting, standing, and walking, which are considered components of physical therapy treatment plans for pediatric therapists who rehabilitate children with neurological conditions. BT on the Biodex stability system that was used to facilitate the development of accurate sensory and motor strategies was effective in meeting postural control demands as normal postural control requires the ability to adapt responses to changed tasks and environmental demands. This flexibility requires the availability of multiple movement strategies and the ability to select the appropriate strategy for the task and environment.

The mechanism of maintaining postural balance includes a sensory process involving articular mechanoreceptors, the vestibular system, and the visual system. This sensorimotor information is processed in the central nervous system and then a motor response occurs involving various muscle groups, including those around the ankle, thigh, trunk, and neck [23–25]. The Biodex stability system enables the rehabilitation professional to perform BT including proprioception and stabilization exercise, and weight shift exercises. As gentle perturbations were used to displace the child's center of mass and stimulate postural adjustments by standing on a movable platform that produce displacement of the base of support, symmetrical posture was achieved as the child learned to actively control his/her posture while the platform was moving during the dynamic BT routine. The main criterion for the success of training was the ability of the treated children to withstand larger and faster platform movements.

Interpretation of the post-treatment results of this study was consistent with the findings of Okai and Kohn [26], who reported that electromyographic studies indicated that the number of muscles used increases with an increase in the displacement of the platform. With short stimuli, an increase in the activation of lower limb muscles such as tibialis anterior, soleus, and gastrocnemius occurred according to the intensity of the stimuli. These results indicate that ankle synergy stabilizes the erect body, whereas with greater stimuli, activation of the proximal muscles increased.

Improvement in the post-treatment mean values of the study group II may be attributed to the effect of RES of quadriceps and hamstring muscles. This is in agreement with Daichman *et al.* [7], who reported that an alternate NMES program for the quadriceps muscles has been reported to significantly reduce hamstrings spasticity associated with increased quadriceps strength and improvement in temporal spatial gait parameters. Activation of the reciprocal inhibition mechanism enables graded action between agonists (quadriceps) and antagonists (hamstrings). NMES seemed to activate the large diameter Ia muscle spindle afferent fibers originating in the hamstring muscle, which in turn inhibit activity in the motor neurons in the quadriceps muscle; this could interrupt the abnormal constant coactivation of the two muscles, provide stability around the knee, and facilitate proper standing and walking [27].

The NMES has been reported to improve voluntary muscle activation and prevent muscular disuse atrophy in different populations including CP [8–12–13–28–29]. The most likely explanation is that NMES has the same effect as normal voluntary muscle contraction in causing a temporary increase in muscle metabolism and greater blood flow and facilitating more spinal motor neuron pools, stimulating blood flow to atrophied muscles to deliver growth factors and nutrients necessary to improve muscle structure and function [30]. NMES is believed to provide proprioceptive input to enable muscle contraction and assist in increasing activity in that muscle [31,32]. Thus, as NMES continues, more muscle fibers are activated and contracted [33].

Furthermore, Camrick [34] reported that as the child becomes involved in task-specific activities with motivation. NMES provides sensory and motor input that helps to accomplish these tasks. This may explain the improvement reported in this study group II as physiologically the unused type II muscle fibers are also recruited when NMES is used, providing the chance to increase sensory effects on activity production [29–35].

It was clear that the physical therapy program that was included in the BT and the RES groups during the course of the treatment improved the outcomes in the current study. There was an increase in the limited ROM of knee extension and the flexibility of the hamstring was also increased after 3 months of intervention. This improvement in knee alignment may have encouraged the child to be more functional as can be seen in the increased scores of GMFM scale. The superior results of the BT group compared with the RES group can be attributed to the underlying mechanism of BT. Balance control requires the interaction of the nervous and musculoskeletal systems and contextual effects.

In addition to the effect of BT on motor control and strengthening of weak muscles, vestibular stimulation will trigger the vestibule - spinal tract, which affects alpha motor neuron - producing modulation of muscle tone and also stimulates the co-ordination of different body parts to learn the difficult and new situation as to overcome it after that [36].

Limitations

The design of the study does have limitations:

(a) The small number of participants in each group impaired the statistical power and the ability to conclude on significant effects (two groups); each group included 15 participants;
(b) The lack of a control group to test the effect of the designed physical therapy program alone;
(c) The study was limited to children who had grade 1 and 1+ MAS as to minimize the effect of spasticity; and
(d) Computerized motion analysis system would be more useful in the assessment of the knee joint ROM in relation to nearby joints during locomotion.

Conclusion

The children with spastic diplegic CP showed better response to the treatment administered. Therefore, this study showed that BT and RES on knee extensors and flexors might be useful therapeutic tools and could be included with the physical therapy as an additional modality to improve postural dysfunction by activating postural muscles during standing and walking in such children to enable greater integration into the community.

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Conflicts of interest

There are no conflicts of interest.

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