The Effects of Anti-gravity Treadmill Training on Gait Characteristics in Children with Cerebral Palsy*

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Abstract— **Cerebral palsy is a disorder that affects muscle tone, movement and motor skills. Most of the children with cerebral palsy (CP) are not able to walk or can walk in incorrect pattern and are dependent on assistive devices. Recently an antigravity treadmill has been found to be beneficial as a new therapeutic approach. Thus, we aimed to investigate the effects of antigravity treadmill training (AlterG) on gait characteristic in children with cerebral palsy. We provided a 45-minute training program, 3 times a week for 8 weeks for six CP children as our experimental group. Our control group was a group consisted of four CP children who took typical occupational therapy, accordingly. All subjects in both AlterG and control groups were evaluated at the gait lab before and after 8 weeks training. Gait patterns were characterized using spatiotemporal parameters and dynamic balance features. We also evaluated the popular clinical gait measures including walking speed and endurance, and mobility and balance.**

Our results demonstrated that spatiotemporal, dynamic balance and clinical features all improved more after 8 weeks AlterG training rather than control group ones. These findings suggest that AlterG training can be considered as an effective approach for improving walking ability and gait characteristics in children with cerebral palsy.

Keywords—**cerebral palsy, unloading, gait, balance, clinical assessments.**

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I. Introduction

Cerebral palsy (CP) describes a group of permanent disorders, which results from a static injury of the developing brain[1]. This type of injury commonly presents abnormalities in motor function causing activity restrictions or disabilities, and abnormal gait pattern[1, 2]. Cerebral palsy is a common neuropediatric disorder with a prevalence of up to 3.5 per 1000 children in some countries [3, 4]. Due to this high prevalence, and also taking into consideration that impaired walking patterns lead to deformity and make CP children dependent on their parents or an assistive device isolating them from society, it seems necessary to aim for effective therapeutic approaches to optimize home and community participation by improving their ambulation. Studies showed that several gait deviations in neurologic patients are due to affected lower limb disabilities that bear the necessary amount of weight[5, 6]. Thus, reducing body weight during walking training should be taken into account. In this regard, two approaches have been proposed and commonly used. One of them is underwater training, which facilitates weight-bearing due to the buoyancy property of water[7]. This method is a popular type of therapy prescribed for children with cerebral palsy, and related to neuromotor impairments[8]. The only point is that drag forces from the fluid increase the resistance to forward propulsion and thus alter their walking pattern, which is unfavorable [7]. Another commonly used approach is treadmill training with partial body weight support in which patients are secured in a parachute harness, and part of their body weight is supported to let them walk easier [9-11]. Despite the fact that this method can improve walking ability in CP patients, the harness system can make subjects uncomfortable and therefore hinder the duration of training [12, 13]. Alternatively, a lower body positive pressure system (LBPPS) provided by the AlterG device has been proposed as a new therapeutic approach [14] with the air pressure uniformly distributed over the lower body, getting rid of discomfort of the traditional body weight support systems. LBPPS has been used for CP children and is reported to be effective in gait and balance recovery [14-19].

As the effective management of gait problems in CP individuals requires detailed examination to make decisions on therapeutic methods[20, 21], it is vital to evaluate the patients' gait characteristics as comprehensively as possible. Nevertheless, there are not many studies that investigate LBPPS on gait characteristics in CP children. Those of which have been done before described gait with few parameters, or because of the lack of a control group could not have determined whether their results were solely due to LBPPS training[14, 18].

In this study, we aimed to assess the therapeutic effects of LBPPS training on the walking ability and characteristics of CP children considering spatiotemporal parameters and dynamic balance while walking as well as clinical gait tests. We expected the systematic and intensive LBPPS training in an adequate period of time (8 weeks) to result in improved gait characteristics concurrent with brain neuroplasticity.

II. METHODOLOGY

A. Participants

A total of 11 children (age=9.8 ± 3.5) with a primary diagnosis of cerebral palsy participated in this study. Their Gross Motor Function Classification System (GMFCS) levels were I and II [22]. There were only 3 children using wheeled walker for mobility. Others could walk independently with GMFCS of II. They were divided into two groups: study groups (7 participants) and control group (4 participants) and. Participants were all asked to avoid receiving any other therapies during this study. Their parents agreed to sign a written informed consent, and the study has ethical approval from the Tehran University of Medical Sciences Institutional Review Board.

B. Experimental Protocol

Children were divided into two control and study groups both of which received a 45-minute therapeutic program, three days a week for two months. The control group participants received occupational therapy with particular focus on gait and walking ability. Instead, the study group participants were trained using an LBPPS system.

LBPPS consists of a treadmill that is enclosed in a pressurized bag as shown in Figure 1. Participants had to go through the bag wearing a pair of neoprene shorts that were zipped into the bag. At the beginning of the training session, an experienced trainer reduced the subject's body weight by 50 percent and let him/her walk in a low speed in order to warm up. After 4-5 minutes, the body weight support was gradually decreased while the speed was increased; the trainer adjusted these two parameters to help subject maintain a more accurate walking pattern. A transparent inflatable bag allowed the participants get visual feedback, watching their walking in a mirror placed beside the LBPPS system along with verbal encouragement of the trainer.

C. Quantitative Gait Evaluation

A quantitave gait test was performed in a gait laboratory using a 10 VICON motion capture system (VICON, Oxford Metrics, Oxford, UK). There was a walking pathway of 4 meters with 2 force plates in the middle of it (Figure 2). Participants were prepared with the placement of passive markers on their body landmarks based on the Helen Hayes model marker set[23]. Next, they were asked to stand on a force plate for 5 seconds to record their static data (Figure 2). Then, they started to walk on the pathway in a self-selective speed for 10 trials. Motion data was recorded with a motion capture system with a sampling rate of 120 Hz using the VICON NEXUS software. The 3-dimensional positions of the marker coordinates were filtered using a digital third-order low-pass zero lag Butterworth filter with a cutoff frequency of 6 Hz.

For calculating spatiotemporal parameters, such as stride length, stride time, stride width, stride height, walking speed, cadence and double support time, coordinates of the markers Placed on the heel, ankle and toe were used. The occurrence of toe-off and heel-strike were determined from the local minimums of the toe and heel marker position, and were used to calculate stride length (the horizontal distance between a toe-off of a foot and heel-strike of the same foot), stride time (time spent on each stride), stride width (the lateral displacement between the ankles of both feet), double support time (the amount of time that passes while both of the feet are in contact with the ground), walking speed (the ratio of covered distance to passed time) and cadence (the number of steps per minute). The ankle marker's position in the z-axis was used to calculate step height. For calculating the angles of the ankle and knee joints, the coordinates of the toe, ankle, knee, and upper thigh markers were used. The COM was evaluated by using a 12-segment model (2 feet, 2 shanks, 2 thighs, pelvis, trunk and head, 2 upper arms, 2 forearms and hands) using anthropometric data.

Kistler force plates with a sampling rate of 1200 Hz were used to collect ground reaction forces. The COP displacement was calculated with the equations described in Lafond's study [24]. The COM and COP were normalized to each person's leg length to eliminate the effect of the individual's stature[25]. In order to compare the COP and COM trajectories between cases, we used the peak to peak COP and COM data in both Medio-Lateral (ML) and Anterior-Posterior (AP) directions and the maximum of velocity of the COM in AP, ML and vertical directions as a measure of variability of signals. Finally, the RMS of COM-COP distance was used as a measure of dynamic stability [25, 26]. The signal processing was performed with a custom MATLAB (2017-a) program.

D. Clinical Gait Evaluation

Clinical gait assessments are easily and rapidly performed, but are not as precise as a quantitative gait test. Three common clinical tests inclusive of 10MWT in fast velocity [27], 6MWT [28] and Timed Up and Go [29] were conducted to evaluate endurance, walking speed and balance.

III. RESULTS

Figure 1 shows the percentage change of the spatiotemporal Parameters after 24 sessions of LBPPS training for 6 cases of the study group and 4 cases of the control group. As illustrated, the average of measured spatiotemporal gait parameters for AlterG patients improved from about 10% to 98% after the treatment, whereas the average improvements in some features in control group were less (about 2-39%). The minimum improvement in AlterG group features was 10% which is related to cadence and the three highest values are 44, 65 and 98% which are for temporal asymmetry, unaffected single support time and walking speed respectively. The amount of improvement in most features for control group were under 10%. The highest amounts were about 23 and 38% related to step width and walking speed respectively.

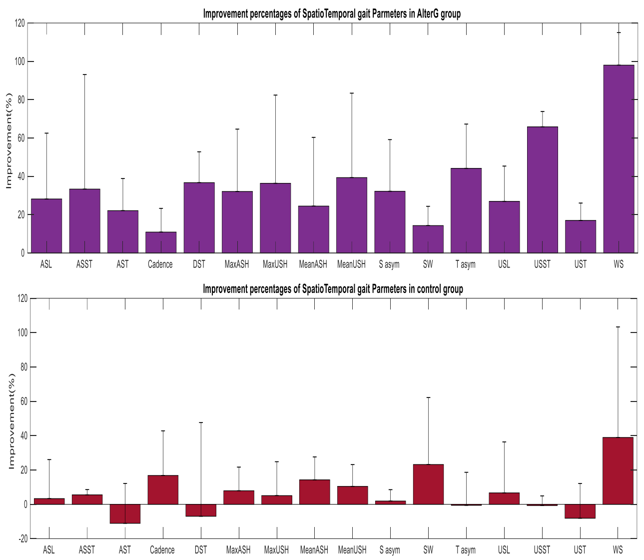

Fig 1: The average percent of changes in spatiotemporal gait parameters and their standard errors in patients both in control and experimental group. ASL is Affected Step Length, USL is Unaffected Step Length, ASST is Affected Single Support Time, USST is Unaffected Single Support Time, AST is Affected Step Time, AST is Affected Step Time, DST is Double Support Time, MaxASH is Maximum of Affected Step Height, MeanASH is Mean of Affected Step Height, MaxUSH is Maximum of Unaffected Step Height, MeanUSH is Mean of Unaffected Step Height, S asym is Spatial asymmetry, T asym is Temporal a symmetry, SW is Step Width and WS is Walking Speed.

Figure 2 shows the percent change of the clinical parameters after 2 months of LBPPS training for all the cases. As the figure indicates, the improvements are 26, 18 and 20% in 10MWT in fast velocity, TUG and 6 minutes respectively which are more than the improvements in control group (24, 10 and 5%).

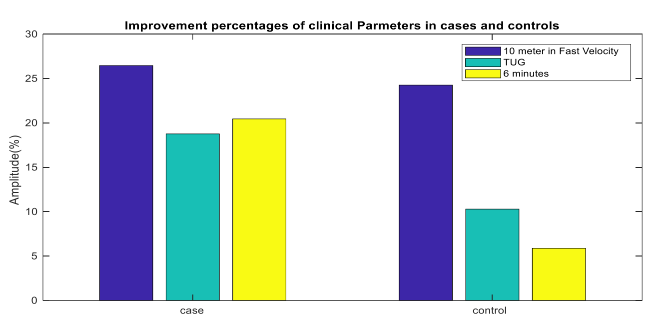

Fig 2: The average percent of changes in three clinical parameters in patients both in control and experimental group.

Pre-post changes were shown in a coordinate system in Fig.3, which had an x-dimension showing pre-treatment values and y-dimension showing post-treatment values. This figure indicates the changes in the features' scores after training. The recovery is evident from the increase in COM and COP in AP direction and the decrease in all the other features; the shapes under the line of equation y=x show decrease in those features and the shapes which are above this line have increased. In this study, we observed that all AlterG group features improved after the treatment, but the improvements in some control patients' features were less rather than the experimental group ones. The filled shapes in this figure show the features related to control group patients and the others are for AlterG group. From this figure, it is obvious that all AlterG group features improved after the treatment up to about 92%, while the improvements in some features of control group were up to about 78%.

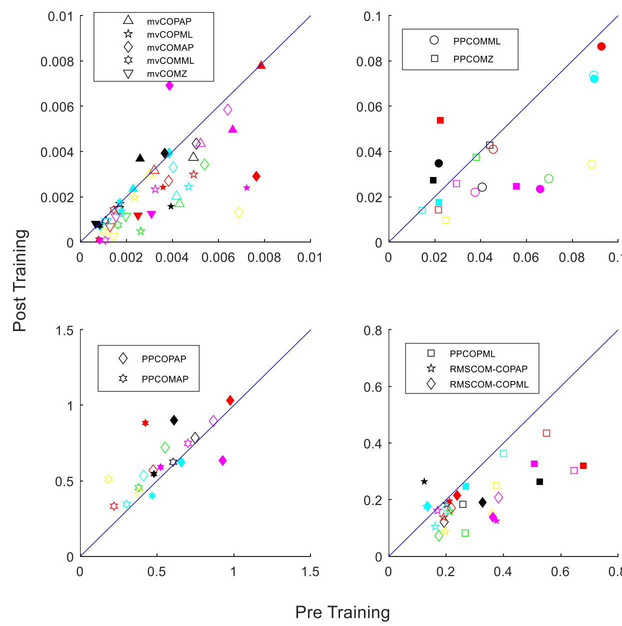

Fig3: Pre-Post treatment values of patients in the control and experimental groups. Filled shapes are related to the control patients and the others are for patients in the AlterG group. The shapes represent the parameters.

IV. Discussion and Conclusion

The improvement or increase in step length, walking speed, cadence, stride width and stride height and improvement or decrease in stride time and double support time represent improved walking ability. Comparing the results for study group and control group participants, spatiotemporal parameters changes are more in study group cases.

Decrease in 10MWT and TUG shows an increase in velocity in gait during walking, which was notably observed in study group cases.

The more peak to peak of COM and COP in the AP direction observed in AlterG group mean that children in this group can move more their COM and COP forward rather than control group and is also an indication of longer step length. The decrease in the COM in ML and vertical directions and COP displacement in ML direction of the AlterG group indicate that children in this group may be able to generate enough active hip abductor/adductor torque to keep the pelvis and trunk from dropping to the side of the swinging leg. This decrease also represents a smaller step width [30]. The maximum variability of the COM and COP separation which we quantified as the peak to peak of COM-COP, decreased for the experimental group; this leads to smaller moment arms for the body weight about the joints of the supporting limb and requires less muscular effort to maintain balance [26].

Our findings demonstrated that major gait characteristics including spatiotemporal parameters, dynamic balance features and popular clinical gait parameters have been improved after 8 weeks of AlterG training compared to control group ones. It represents that anti-gravity treadmill training can be considered as an effective approach for improving walking ability and gait characteristics in children with cerebral palsy.

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