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Comparison of the Immediate Effect between Functional Electrical Stimulation and Ankle Foot Orthoses on Gait Parameters in Cerebral Palsy

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Authors' contributions

This work was carried out in collaboration between both authors. Author WSEDM designed the study, wrote the protocol and wrote the first draft of the manuscript. Author RKE managed the literature searches, analyses of the study performed the spectroscopy analysis and author WSEDM managed the experimental process and author RKE identified the species of plant. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: To compare the immediate effect of functional electrical stimulation (FES) to solid ankle foot orthosis (SAFO) concerning spatiotemporal parameters and ankle kinematics during gait in hemiplegic cerebral palsy (CP).

Methodology: Thirty spastic hemiplegic cerebral palsied children were randomly distributed into two equal groups; group A, who used the functional electrical stimulation (FES) and group B, who worn the solid ankle foot orthosis (SAFO). Vicon 3D motion analysis system was used to measure the spatiotemporal parameters of gait and ankle dorsiflexion angle at initial contact and mid-swing before intervention and with application of either FES or SAFO. Spasticity was ranged between 2 and 1+ and determined by Modified Ashworth Scale score.

Results: Following the application of solid AFO, stride length and walking speed significantly increased than next to FES (p=0.0001, p=0.001) respectively. Whereas, number of steps/minute

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significantly decreased (p=0.001). Further, Solid AFO increased ankle dorsiflexion at initial contact (6.2±4.7°) and mid-swing (3.4±0.6°) more than FES at initial contact (1.86±3.9°) and mid-swing (-4.6± 5°).

Conclusion: FES, unlikely found to evoke an immediate effect of spatiotemporal parameters while solid AFO improved the gait efficiency by enhancing spatiotemporal parameters. Both treatment interventions increased ankle dorsiflexion at initial contact and mid-swing but solid AFO was more effective immediately than FES.

Keywords: Cerebral palsy; functional electrical stimulation; ankle foot orthoses; spatiotemporal parameters of gait, ankle kinematics.

1. INTRODUCTION

Cerebral palsy (CP) is the most common cause of upper motor neuron lesions in children, causing spasticity and muscle tendon contractures, leading to bony deformation, weakness, and loss of selective motor control [1]. Although the clinical presentation is heterogeneous, abnormalities of ankle kinematics and ankle kinetics are always present with gait difficulties in cerebral palsied children [2]. Kinematic gait changes such as toe-walking, decreased walking speed with higher cadence and shorter stride length and a running-like gait pattern are commonly observed in children with spastic CP. Improving the gait patterns of children with spastic CP without invasive surgeries and neurochannel blockage is challenging. Even with these interventions, prolonged positive effects on gait have not been shown [3].

Efficient and effective walking is an important treatment goal for children with CP since mobility is associated with functional independence and participation of the child in society [4]. Positional bracing is the current standard of care for individuals with CP who have limited ankle dorsiflexion and a treatment modality to reduce gait abnormalities and related limitations in physical mobility. The most typical use of an ankle foot orthoses (AFO) is to optimize the normal dynamics of walking by applying a mechanical constraint (control moment) to the ankle to control motion and, at the same time, produce a more efficient gait. The solid AFO (SAFO) achieves the maximum orthotic control by restricting the movements of both plantar flexion and dorsiflexion in the stance and swing phases. Its rigid construction prevents ankle rocker function in stance. Improvements in walking pattern have been demonstrated with ankle foot orthosis in patients with planterflexion deformity [5,6].

Mild cerebral palsied children may be instructed to not wear orthoses for prolonged time to prevent muscle weakness or atrophy. In addition to issues with comfort or bad appearance, children may prefer another modality to use [7]. Although initial studies advocated the strengthening of non-spastic muscles only, for fear of exacerbating existing spasticity, more recent evidence suggests that strengthening these muscles may result in significant functional improvements. Both weakness and spasticity contribute to the higher energy expenditure during gait in children with CP compared with age-matched controls. This often leads to decreased levels of participation and the development of secondary complications due to a more sedentary lifestyle [8].

Functional electrical stimulation (FES) may be an effective alternative treatment for this population. In contrast to bracing, FES does not restrict motion, does produce muscle contraction, and thus has the potential to increase strength and motor control through repetitive neural stimulation over time [9]. Functional electrical stimulation (FES), a well-known intervention, has been used for many years to facilitate muscle groups during walking. Functional electrical stimulation system is designed to make synchronization between proper muscle contraction and time of contraction to induce a fine motor control. Controlling of dorsiflexion is special task of FES [10,11].

The purpose of this study was to compare the immediate effect of functional electrical stimulation to solid ankle foot orthoses in term of spatiotemporal parameters of gait and ankle kinematics at initial contact and mid-swing in hemiplegic CP.

2. METHODOLOGY

2.1 Subjects

Thirty cerebral palsy (CP) children with spastic hemiplegia between 5 and 12 years of age were recruited from the outpatient clinic of the physical therapy in the College of Applied Medical

Sciences, Prince Sattam bin Abdulaziz University, and King Khalid Hospital, Al-Kharj town, Saudi Arabia. Children were randomized and equally grouped into two groups: group A where the functional electrical stimulation (FES) was used and group B where children worn solid ankle foot orthosis (SAFO). The following inclusion criteria were met: (1) age ranged from 5 to 12 years, (2) physician's diagnosis of spastic hemiplegia of CP, (3) mild spasticity (2 or +1) on Modified Ashworth Scale, (4) able to ambulate independently without an assistive device or orthoses, (5) unable to achieve heel-strike at initial foot contact at a comfortable or fast walking speed, (6) no cardiovascular diseases, (7) no surgery within the previous 24 months, (8) no sensory defensiveness, and (9) ability to follow instructions.

Children of both groups walked barefoot first by self-preferred, comfortable speed for five trials as a pre measurement data. Then, children in group A walked with FES for 5 trials, and children in group B walked with solid AFO for 5 trials. All trials were conducted in one experimental session. The procedures were in accordance with local ethical standards. The parents or guardians signed informed consent forms.

2.2 Outcome Measures

The spatiotemporal variables chosen to represent general gait function were walking speed, cadence, and stride length. Walking speed and stride length were normalized to height. The kinematic variables chosen to represent ankle-specific function were mean dorsiflexion angle in initial contact and mid-swing.

2.3 Assessment Procedures

Vicon motion measurement and analysis system using Plug-in gait for gait analysis was used. This system consisted of 12 infrared cameras, a computer system for data acquisition, processing and analysis and a data station. 16 photo-reflexive markers were placed on the child's body in accordance with the procedure for Helen Hayes- Davis model [12]. The experimental model idealized the lower extremity as a system of rigid links with spherical joints. The joints were assumed to have a fixed axis of rotation. Skeletal movement can be described using surface markers placed in precise anatomical positions. Walking test consisted of walking for 5 min. on an indoor route with a length of 10 m. Data of 2 to 6 strides were collected during each trial.

2.3.1 Markers placement

The markers were placed on lateral epicondyle of the knee of both sides, lateral malleolus of both sides, lower 1/3 of the shank of tibia of both sides, over the second metatarsal head of both sides, and calcaneus at the same height above the plantar surface of the foot as the toe marker of both sides. When walking with the solid AFO and shoes with FES, the heel and toe markers were placed on the shoes at the positions best projecting the anatomical landmarks.

2.3.2 Spasticity measurement

The degree of planter-flexor spasticity was determined by using the Modified Ashworth Scale (MAS). The child was in a comfortable supine lying position with the head in midline position; the arms were extended beside the body and the lower limbs in extension. The therapist applied passive dorsiflexion of the ankle on the affected side by one hand while the other hand stabilized the limb around the ankle joint. The therapist performed three trials and then graded the amount of spasticity by a score according to the MAS [13].

2.4 FES Intervention

The FES device used (WalkAide; Innovative Neurotronics, Austin, TX, USA). It delivers a bipolar square waveform for stimulation of the common fibular (formerly common peroneal) nerve. The FES was triggered by the foot's initial contact with the ground by even one of more foot switch sensors, the stimulator was remained on when the foot was in contact with the ground, and turned off when all the sensors lost contact with the ground. It triggered again by an individually programmed tilt sensor, to improve foot clearance during the swing phase of gait. The stimulator parameters were set at a pulse rate of 32 pulses per second (pps), for muscles of individuals who are healthy, muscle contraction usually becomes fused when stimulated at a frequency of approximately 30 pps [3], A ramp time of 0.2 second, and pulse duration of 300 microseconds. The amplitude of stimulation was increased gradually to each child's tolerance level with the child in a standing position and before experimental trials. The child was asked to let the investigator know when the stimulation became uncomfortable. There was no further increase in amplitude once the child indicated discomfort or showed any sign of distress. Tolerance levels for FES ranged from

10 to 40 mA. The amplitude of stimulation was maintained at that level during the experimental trials. Children walked over ground through the viewing volume at their self-selected speed for 5 trials. Electrodes of a variety of sizes were used to accommodate the individual child's limb size.

2.5 AFO Intervention

The solid AFO was custom-made for each child from a positive mold after casting by an orthotist. It was fabricated from 4.8-mm-thick polypropylene extending distally under the toes and on the mediolateral border of the foot and proximally on the posterior part of the leg to about 2.5 to 5 cm below the knee, with trim lines anterior to both malleoli and straps across the front of the ankle and anterior upper tibia. The children were first seated in a comfortable chair, and the equipment was put on. Children were asked to walk at their usual, self-preferred, comfortable speed for a 10-m walkway.

2.6 Data Analysis

Data analysis was carried out using the following software: SPSS version 16. Data of five trials were averaged for each child. Chi squared test (X^2) was conducted for comparison of the distribution of spasticity grades between two groups. Independent t-test was conducted for determining the pre and post treatment mean values of all measured variables between both groups and also for detecting changes between demographic data of children in both groups. Paired t-test was done for comparing barefoot and treatment conditions in each group. The level of significance was set at $p < 0.05$.

3. RESULTS

3.1 Demographic Characteristics

There were no significant differences of children characteristics (age, weight, and height) between both groups of the study. In group A, the mean age, weight and height of the children were (9.1±1.6 years), (30.2±1.7 kg), and (134.2±4.9 cm) respectively as shown in Table 1. For group B the mean age, height, and weight of the children were (9.5±1.7 years), (30.5±1.7 kg), and (134.5±4.4 cm) respectively as shown in Table 1.

3.2 Spasticity

There was no significant difference between both groups in the distribution of spasticity grades ($p= 0.143$; $X^2= 2.14$). Sixteen children had grade 1+ (53.3%) and 14 children had grade 2 (46.7%) as shown in Fig.1.

Table 1. Demographic characteristics of two groups

Variable	Group A Mean (±SD)	Group B Mean (±SD)	p-value*
Age (years)	9.1±1.6	9.5±1.7	N.S
Height (Kg)	134.2±4.9	134.5±4.4	N.S
Weight (cm)	30.2±1.7	30.5±1.7	N.S

** Independent t-test with p < 0.05; N.S. = not significant*

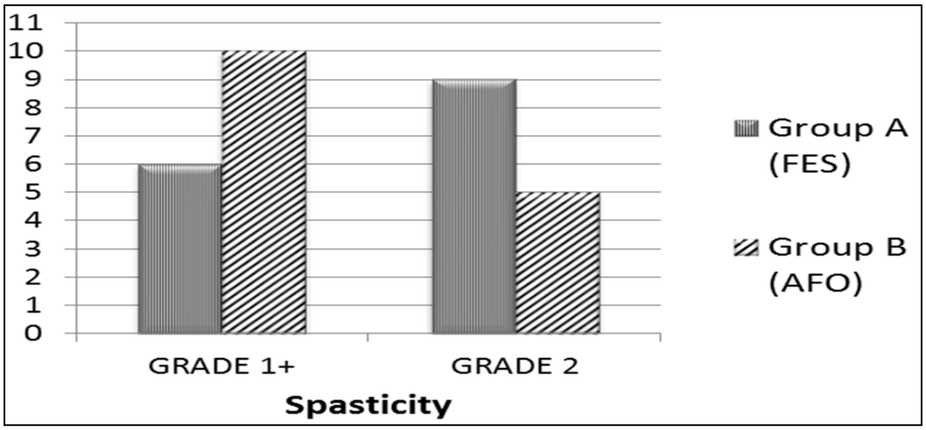

Fig. 1. Spasticity distribution between two groups

3.3 Spatiotemporal Parameters and Ankle Joint Kinematic within Groups

In group A there was no significant difference between barefoot and FES application concerning to stride length (p=0.858), speed (p=0.861), and cadence (p=0.160) as shown in Table 2. There was a significant increase in ankle dorsiflexion at initial contact between barefoot (-1.85±3.7º) and FES (1.86±3.9º) and significant increase in direction of ankle dorsiflexion at mid-swing between barefoot (-8.3±4.5º) and FES (-4.6±5º) as shown in Table 2.

In group B there was significant increase of stride length between barefoot (1.02±0.13) and solid AFO (1.24±0.13), increase of speed between barefoot (1.09±0.08) and solid AFO (1.2±0.06), however there was a significant decrease of cadence between barefoot (1.2±5.5) and solid AFO (1.1±4.7) as shown in table 3. The ankle dorsiflexion at initial contact significantly increased between barefoot (-1.2±3.8º) and solid AFO (6.2±4.7º) and significant increase of ankle dorsiflexion at mid-swing between barefoot (-8.6±4.7º) and solid AFO (3.4± 0.6º) as shown in Table 3.

3.4 Comparison between Immediate Effect of FES and Solid AFO on Spatiotemporal Parameters and Ankle Joint Kinematic between Groups

Solid AFO increased immediately the stride length than FES application (t=-5.6, *d*= 0.5, p=0.0001) as shown in Fig. 2, solid AFO increased significantly the walking speed immediately than FES (t= -3.6, *d*= 0.3, p=0.001) as shown in Fig. 3, and solid AFO also lowered number of steps slightly than FES (t= -3.63, *d*= 0.31, p=0.001) as shown in Fig. 4. At initial contact and mid-swing, the solid AFO increased ankle dorsiflexion than FES (t= -2.8, *d*= 0.5, p=0.009) and (t= -6.13, *d*= 0.6, p=0.0001) respectively as shown in Fig. 5.

Table 2. Immediate effect of FES on spatiotemporal parameters and ankle kinematics

Parameter	Barefoot Mean(±SD)	FES Mean(±SD)	t value	Effect size (*d*)	P-value*
Stride length (m)	1.01±0.14	1.02±0.09	-.183	0.002	N.S
Walking speed (m/s)	1.1±0.1	1.11±0.8	-.178	0.002	N.S
Cadence (steps/min)	1.19±5.23	1.17±4.1	1.48	0.14	N.S
Dorsiflexion at IC (°)	-1.85±3.7	1.86±3.9	-2.62	0.32	0.02
Dorsiflexion at mid-swing (°)	-8.3±4.5	-4.6±5	-2.2	0.24	0.045

** Paired t-test with p < 0.05; IC= Initial contact; FES= Functional electrical stimulation; N.S. = not significant; (d) = Cohen's d*

Table 3. Immediate effect of solid AFO on spatiotemporal parameters and ankle kinematics

Parameter	Barefoot Mean(±SD)	Solid AFO Mean(±SD)	t value	Effect size (*d*)	p-value*
Stride length (m)	1.02±0.13	1.24±0.13	-5.18	0.7	0.0001
Walking speed (m/s)	1.09±0.08	1.2±0.06	-3.97	0.5	0.001
Cadence (steps/min)	1.2±5.5	1.1±4.7	3.43	0.46	0.004
Dorsiflexion at IC (°)	-1.2±3.8	6.2±4.7	-4.86	0.62	0.0002
Dorsiflexion at mid-swing (°)	-8.6±4.7	3.4±0.6	-9.36	0.9	0.0002

** Paired t-test with p < 0.05; IC= Initial contact; AFO= Ankle foot orthoses; (d) = Cohen's d*

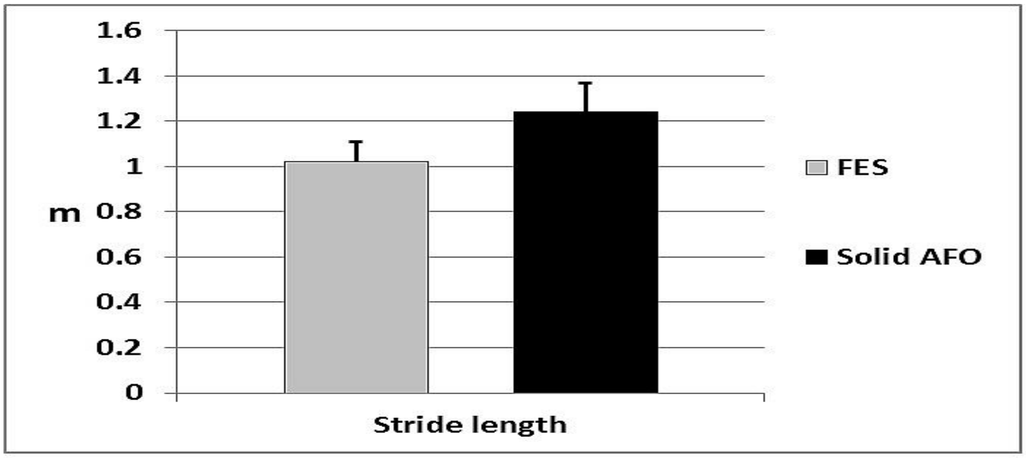

Fig. 2. Immediate effect of both FES and solid AFO on stride length

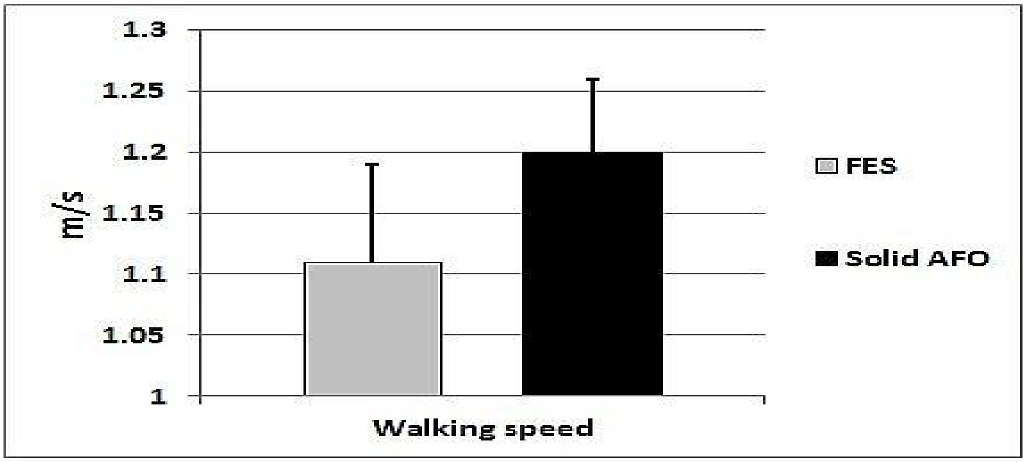

Fig. 3. Immediate effect of both FES and solid AFO on walking speed

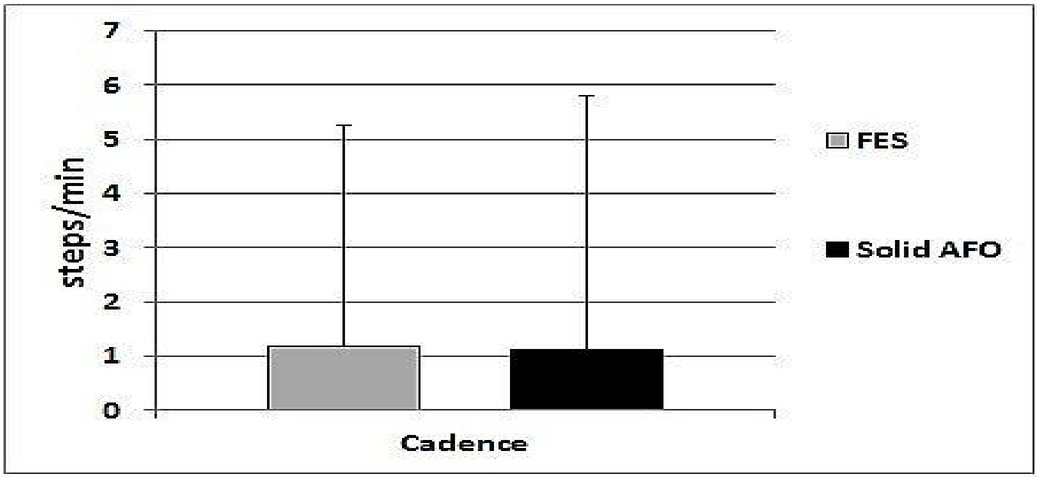

Fig. 4. Immediate effect of both FES and solid AFO on cadence

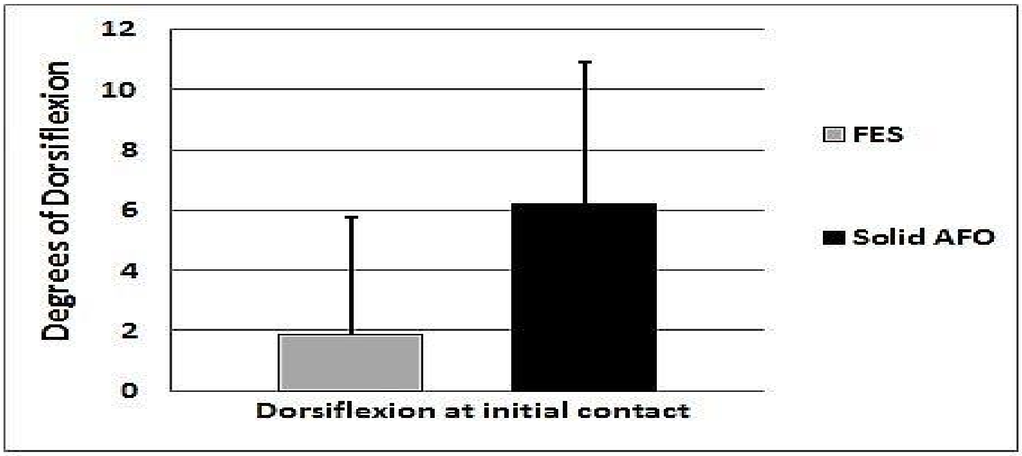

Fig. 5. Immediate effect of both FES and solid AFO on ankle dorsiflexion at initial contact

Fig. 6. Immediate effect of both FES and solid AFO on ankle dorsiflexion at mid-swing

4. DISCUSSION

This study aimed to compare the immediate effect of functional electrical stimulation compared to solid ankle foot orthosis on spatiotemporal parameters and ankle kinematics during gait in hemiplegic CP.

The immediate effects of solid AFO were obvious in improvement of gait Pattern than FES system. The results of present study were consistent with previous study that compared the effects of two types of AFOs on the gait of 10 children with CP, four of whom were hemiplegic. The orthoses increased stride length, decreased cadence, and decreased excessive ankle plantarflexion compared to barefoot walking. Radtka et al. [14] revealed that the conventional solid AFO and hinged ankle foot orthoses (HAFO) showed gait improvements, including a longer stride length, decreased cadence, and reduced excessive ankle plantar flexion at initial contact and mid-stance.

In present study, increasing walking speed and stride length were due to increased mean ankle dorsiflexion especially at initial contact and mid-swing of the gait cycle when solid AFO was worn. This comes in agreement with Romkes J, et al. [15] who stated that a higher walking speed was observed when walking with a HAFO due to larger steps in early stance]. However, no significant difference was shown in spatiotemporal parameters by using FES system. Previous study stated that no immediate effect on spatiotemporal variables of walking with FES in hemiplegic CP children [16]. However, two studies reported improvements in gait, voluntary walking speed, and energy efficiency of children with CP after FES [17,18].

AFO immediately reduced muscle activity of the ankle dorsiflexors. The reduction of tibialis anterior muscle activity could be partly related to the change of movement pattern, i.e. toe-walking to heel–toe gait pattern, and partly to the use of an AFO in that the AFO prevents plantarflexion and hence reduces the need to dorsiflex the foot [19]. The conventional solid AFO biomechanically prevents ankle plantar flexion using a three-force system at the calf; ankle, and foot [14]. AFOs typically provide support for or passively assist a weak muscle for example, position the ankle in dorsiflexion in swing to facilitate toe clearance [20].

FES stimulation in the present study increased dorsiflexion at initial contact by 3.71° and at mid swing by 3.7°. This may be caused by enhancement of motor neurone pool stimulation that achieved by FES. These results were consistent with study reported the use of FES of the gastrocnemius (GA) and tibialis anterior (TA) in 14 children with CP and found that FES training improved ankle position at initial foot contact by about 4° and immediate improvements in dorsiflexion at initial contact of about 10° in two adolescents with CP when they walked with FES applied to their dorsiflexors during swing [21].

Positive significant improvements of FES regarding increased swing phase dorsiflexion and improved prepositioning at initial contact were obtained [22]. Another study investigated the immediate effect of FES on ankle dorsiflexion at initial contact and mid swing reported that the use of FES for the dorsiflexors resulted in one statistically significant effect at the peak of swing phase and initial contact, providing individual improvements of up to 8.8° for both phases during gait [23].

Improvement of ankle dorsiflexion at initial contact by FES may be due to reduction in ankle absorption work during stance and resulting in more dorsiflexion of ankle at initial contact that allowed for a decreased plantarflexion moment and decreased energy absorption from decreased eccentric activity of the gastrocnemius [3].

Our results stated that immediate effect of AFO was more effective than FES concerning ankle dorsiflexion at initial contact and mid swing during gait. The inconsistency in obtaining stimulated motor responses, the inability to stimulate deeper muscles, and decreased skin tolerance were probably account for the weak immediate effect of FES. Increased speed and stride length and decreasing the adapted stiffness probably may require a longer period of training with FES [3,24]. This is consistent with Pierce et al. [25] who reported that stimulation of muscle contraction with FES of 31% of maximal voluntary effort was able to affect gait and it was suggested that the subject may have been unable to voluntarily recruit available muscle capacity appropriately while walking.

Another reason for low ability of FES to increase strength of dorsiflexors muscle and to improve gait pattern is insufficient time of FES system. This is very consistent with a previous study reported that to increase the volume and strength of muscle, regular use of FES should be used to grow muscle in CP, demonstrating use dependent plasticity. It was clear that to show increases in muscle size as a result of voluntary muscle training in CP, with increases in volume after progressive resistance exercise to the gastrocsoleus muscles of 16% after 5 weeks and an additional 7% in the second 5 weeks [26].

Using FES on dorsiflexors group only, may contribute to produce weak effect of ankle kinematics than SAFO. Both the dorsiflexors and plantarflexors are weak in CP. Targeting only one of these muscles can, thus, create a muscle imbalance, which could account for some of the deterioration in gait [8].

Gait parameters were improved by solid AFO than FES, this may be due to improvement of balance and stability that achieved efficiently by SAFO. This comes along with a previous study by Kirker et al. [27] who stated that cerebral palsy children have postural impairments that affect the balance which result in increases in tonic stretch reflexes, muscle weakness, excessive coactivation of antagonist muscles and increased stiffness around joints. It has been suggested that rigid AFOs are capable of improving the efficiency of gait and preventing deformities and preventing plantarflexion by improving stability and balance in the stance phase [28].

5. LIMITATION

Based on our own observations and data from the literature, it was difficult to collect the sample of the same degree of spasticity either grade 2 or 1+ for that recruited number of cerebral palsied hemiplegic children.

6. CONCLUSION

FES stimulation has no immediate effect on spatiotemporal parameters while solid AFO improved the gait efficiency by enhancing spatiotemporal parameters. Both treatment interventions increased ankle dorsiflexion at initial contact and mid-swing but solid AFO was more effective immediately than FES.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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