

# Modulation of the angle of rigid ankle-foot orthosis to control knee hyperextension in children with unilateral cerebral palsy

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## ABSTRACT

The aim of this study was to compare the effects of a modified 5° dorsiflexion ankle-foot orthosis (AFO) to the traditional right angle rigid AFO on controlling knee hyperextension and improving spatiotemporal gait parameters in children with unilateral cerebral palsy (CP). We used a pretest-posttest experimental design in which forty children (2-6 years) of both genders with unilateral CP were randomly assigned into two equal groups (A and B). Group A used a traditional right angle rigid AFO and received a selective exercise program to enhance walking pattern while group B used a modified 5° dorsiflexion rigid AFO and received the same exercise program as group A. Assessments for the knee angle during mid-stance and spatiotemporal gait parameters were done pre and post-intervention programs for both groups. All statistical analyses were conducted using the Statistical Package for Social Studies (SPSS) version 25 for windows (IBM SPSS, Chicago, IL, USA). There was a significant decrease in the knee angle in mid-stance post-treatment in groups A and B compared to pre-treatment ( $p < 0.001$ ) but a significant increase in spatiotemporal gait parameters post-treatment in groups A and B compared to pre-treatment ( $p < 0.001$ ). There was a significant decrease in the knee angle in mid-stance of group B compared to group A in post-treatment ( $p < 0.001$ ). However, there was no significant difference in spatiotemporal gait parameters between groups post treatment ( $p > 0.05$ ). In conclusion, using a rigid AFO improves the spatiotemporal gait parameters and decreases knee hyperextension for children with unilateral CP.

Furthermore, a modified 5° dorsiflexion rigid AFO is recommended for better control of knee hyperextension than a traditional right angle rigid AFO for such cases.

## KEYWORDS

Ankle-Foot Orthoses; Cerebral Palsy; Gait kinematics; Knee Hyperextension

## 1. INTRODUCTION

Ankle-foot orthosis (AFO) is the most commonly described treatment option for children with cerebral palsy (CP) to correct their gait and posture (Feng & Song, 2017). Wearing an AFO improves gait pattern by maintaining the foot in a plantigrade position, promoting lower limb joint stability and enhancing weight-bearing capability (Tang, 2008; Hwang et al., 2012). AFOs have many different designs. Choosing the optimal design should be done according to the analysis of gait abnormalities' causes in each case (Feng & Song, 2017; Kane et al., 2020). AFOs are generally divided into two types: non-articulated AFOs (rigid or solid AFOs), which have fixed stiffness and joints determined during the fabrication process, and articulated AFOs (hinged AFOs), which have a flexible mechanical joint (Middleton et al., 1988).

True equinus, the most common gait deviation seen in hemiplegic CP is characterized by plantarflexion of the ankle joint throughout the gait cycle with full extension or recurvatum of the knee in the stance phase, as well as hyperflexion of the hip and increased lordosis (Winters et al., 1987). In such cases, spasticity of the triceps surae prevents the tibia from moving forward on the foot during the stance phase, resulting in knee extension or hyperextension in the middle and terminal stance phase (Tecklin, 2015). Hyperextension of the knee joint is a progressive deformity that affects its components and damages its internal structure. It applies stress to the posterior musculature and capsule of the knee, causing chronic knee pain and deformity in the adolescent (Loudon et al., 1998; Perry & Burnfield, 2010). The recurvatum also impairs forward momentum during walking, which decreases gait efficiency and increases energy consumption during walking (Miller, 2005).

A hinged AFO with a plantar flexion stop adjusted at 5 –7° dorsiflexion is recommended for controlling knee hyperextension in such cases to shift the tibia slightly forward and prevent the knee joint from moving toward hyperextension (Tecklin, 2015; Connor & Cobanoglu, 2016). Unfortunately, hinged AFOs are not appropriate for all such cases as they are contraindicated when less than 10° of dorsiflexion range of motion (ROM) is available, as the applied forces may buckle the multisegmental structure of the ankle and foot, causing hind-foot eversion or inversion and

midfoot collapse (Tecklin, 2015; Ridgewell et al., 2010; Karas, 2002; Maurer et al., 2013). Therefore, in this study, we tried to suggest a more suitable AFO for specific cases that suffer from true equinus with knee hyperextension gait pattern and have limited dorsiflexion ROM that prevents them from using the adjusted dorsiflexion hinged AFO. The purpose of the study is to investigate and compare the effects of a modified 5° dorsiflexion with the traditional right angle rigid AFO on controlling knee hyperextension and improving spatiotemporal gait parameters in children with unilateral CP. It is hypothesized that using a traditional right angle or a modified 5° dorsiflexion rigid AFO does not control the knee hyperextension nor improve the spatiotemporal gait parameters in children with unilateral CP.

## **2. METHODS**

### **2.1. Study design**

A pretest-posttest experimental design was applied to compare the angle of the knee joint during mid-stance as well as the spatiotemporal gait parameters pre and post-treatment using rigid AFO with two different ankle angles (traditional right angle and 5° dorsiflexion).

### **2.2. Participants**

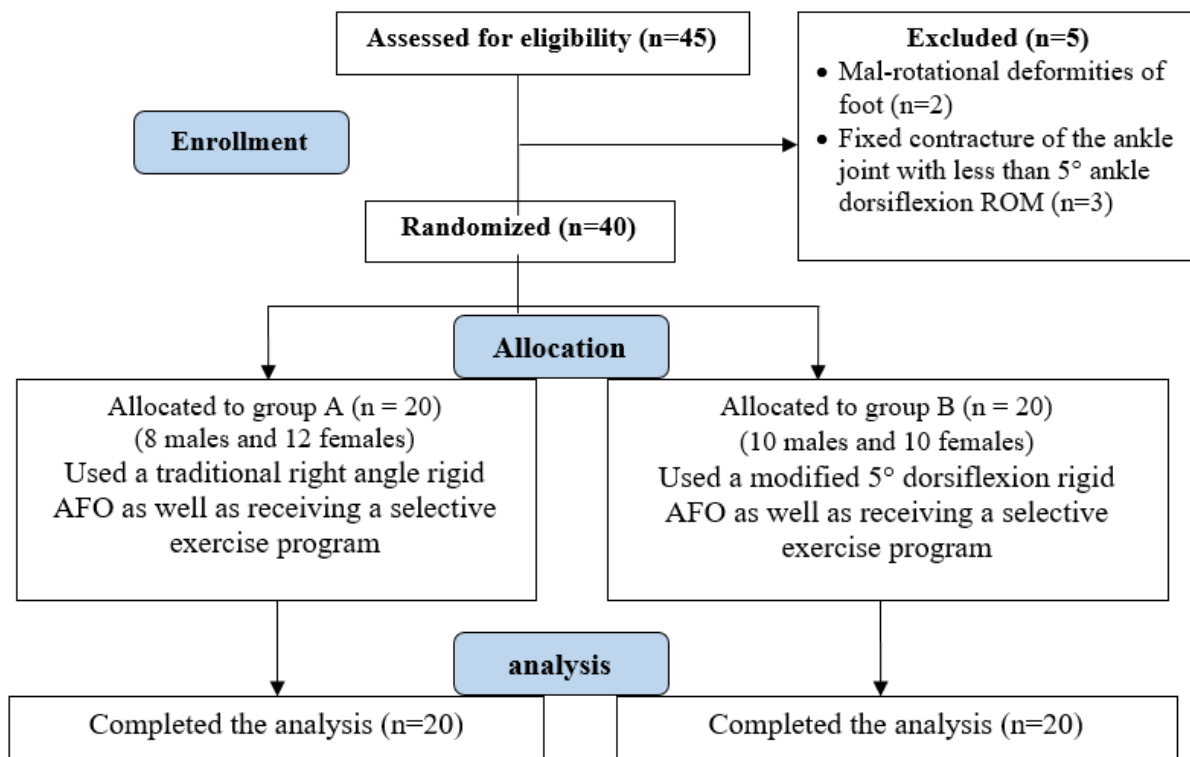
Forty children with unilateral cerebral palsy (22 females and 18 males) aged 2-6 years were recruited from the outpatient clinic, Faculty of physical therapy, MTI University. They were selected in accordance with the following criteria: unilateral spastic cerebral palsy diagnosed by a neurologist, level I to II according to GMFCS E&R (McDowell, 2008), spasticity level 1 to 1+ modified Ashworth scale (Bohannon & Smith, 1987), suffering from true equinus gait pattern with knee hyperextension when walking bare feet, and having at least passive or active 5° ankle dorsiflexion with knee extension confirmed by a goniometer (to fit the modified 5° dorsiflexion AFO). Subjects were excluded from the study if they had any mal-rotational deformities of the foot or tibia, fixed deformities of the lower limbs, visual impairment, or were unable to follow simple instructions.

### **2.3. Ethical considerations**

The study procedures were explained to all children and their parents as well as written informed consent was obtained from the parents of each participant. The study protocol was ethically approved by the Research Ethical Committee, Faculty of Physical Therapy, Cairo University (No: P.T.REC/012/003480).

## 2.4. Procedures

Children that met the study criteria were randomly assigned into two equal groups (A and B) using the computer program ‘Microsoft Excel’. Group A used a traditional right angle rigid AFO as well as received a selective exercise program to enhance walking pattern while the group B used a modified 5° dorsiflexion rigid AFO as well as received the same exercise program received by group A. Both groups applied their exercise program for one hour, three-time a week for three successive months as well as using their rigid AFO during daily activities (Figure 1). Assessments for knee angle during the mid-stance phase as well as spatiotemporal gait parameters were done pre and post-treatment programs for both groups (A and B).



**Figure 1.** Flow chart of the participants.

### 2.4.1. Measurement of the knee angle during the mid-stance phase

Three digital cameras (Nikon Coolpix L330 20.2MP) were fixed along a 6-meter walkway (1 camera/ 2 meter) for video recording the child while walking from the sagittal view. The camera is fixed on a stand 50 cm height. Reflected dots were placed on the anatomical landmark (greater trochanter, lateral femoral condyle of knee, lateral malleolus, and 5th metatarsal bone) in the affected lower limb for each child (Van Den Bogert et al., 2013). During post-assessment where the children

wore the rigid AFO, the distal two reflected dots were put over the AFO at the same points. Each child was encouraged to walk on the walkway at a self-selected speed. The Kinovea program was used for calculating the angles of the knee joint during the mid-stance phase. Kinovea is a valid and reliable tool for measuring joint angle (Puig-Diví et al., 2019).

#### 2.4.2. Measurement of the spatiotemporal gait parameters

Spatiotemporal gait parameters were assessed using the Tekscan HR walkway Mat™ pressure measurement system, Tekscan Inc. USA (Zammit et al., 2010; Coda et al., 2014). It is made up of a digital mat inserted into a wooden walkway, sensors (4senses/cm<sup>2</sup>) embedded in the mat, and a computer running the Tekscan software (version 7) for data extrapolation. The spatiotemporal measurement parameters including step length, stride length, cadence, and velocity are automatically calculated on the computer when the pressure generated from the foot contacts the walkway through the attached sensors. Each child was asked to practice three-time self-selected walks along the 6-meter walk away (the Tekscan walkway in the middle of the walkway) before starting video recording by cameras and Tekscan recording that important for the child to be familiarized with the procedures. Then three records were obtained and the mean was calculated.

#### 2.4.3. Rigid ankle-foot orthoses (AFO)

Both traditional right angle or inclined 5° dorsiflexion rigid AFO, have the same manufacture characteristics which are thermoplastic custom-made orthosis with about 5 mm thickness that fabricates according to the physical characteristics of the child, with three straps at foot, ankle, and tibia for AFO fixation. The top trim line was below the fibula head, the ankle trim line was anterior to malleoli, and the forefoot trim was line distal to metatarsophalangeal joints. The angle of the ankle joint was different in groups A and B. In the traditional rigid AFO used in group A, it was right-angled, while in the modified rigid AFO used in group B, it was 5° dorsiflexion.

#### 2.4.4. Exercise program

A selective exercise program was planned individually for each case by an expert physical therapist after physical therapy assessment. The program included a stretching exercise of the tight musculatures, strengthening exercises in form of functional training tasks, close and open environment gait training using different obstacles and stair activities as well as balance training exercises. Both groups applied their exercise program for one hour, three times a week for three successive months.

## 2.5. Sample size

The sample size was calculated using G\*POWER statistical software (version 3.1.9.2) based on the data of knee angle in mid stance pilot study conducted on 5 subjects in each group, and revealed that the required sample size for this study was 20 subjects per group. Calculations were made using  $\alpha = 0.05$ ,  $\beta = 0.2$  and effect size = 0.91 and allocation ratio  $N2/N1 = 1$ .

## 2.6. Statistical analyses

The subjects' characteristics were compared between groups by using the unpaired t-test. The Chi-Square test was used to compare sex, GMFCS and spasticity level between groups. The normal distribution of the data was checked using the Shapiro-Wilk test. Levene's test for homogeneity of variances was conducted to test the homogeneity between groups. A mixed model MANOVA was performed to compare the effects within and between group on mid-stance knee angle, step length, stride length, cadence and velocity. For the subsequent multiple comparisons, post-hoc tests using the Bonferroni correction were carried out. The level of significance for all statistical tests was set at  $p < 0.05$ . All statistical analyses were conducted using the Statistical Package for Social Studies (SPSS) version 25 for windows (IBM SPSS, Chicago, IL, USA).

## 3. RESULTS

### 3.1. Subject characteristics

Table 1 shows the subject characteristics of both groups (A and B). There was no statistically significant difference between groups in age, weight, and height ( $p > 0.05$ ). Also, there was no statistically significant difference in sex, GMFCS, and spasticity level between groups ( $p > 0.05$ ).

**Table 1.** Subject characteristics of group A and B.

	<b>Group A</b>	<b>Group B</b>			
	<b>Mean <math>\pm</math>SD</b>	<b>Mean <math>\pm</math>SD</b>	<b>MD</b>	<b>t - value</b>	<b>p - value</b>
<b>Age (years)</b>	4.12 $\pm$ 1.29	4.37 $\pm$ 1.14	-0.25	-0.64	0.52
<b>Weight (kg)</b>	15.37 $\pm$ 1.91	15.55 $\pm$ 1.5	-0.18	-0.32	0.74
<b>Height (cm)</b>	99.55 $\pm$ 7.22	98.27 $\pm$ 6.39	1.28	0.59	0.55
<b>Leg length (cm)</b>	49.61 $\pm$ 3.72	49.22 $\pm$ 2.98	0.39	0.36	0.71
<b>Sex, n (%)</b>					
<b>Females</b>	12 (60%)	10 (50%)		$(\chi^2 = 0.4)$	0.52
<b>Males</b>	8 (40%)	10 (50%)			

<b>GMFCS</b>				
<b>Level I</b>	15 (75%)	16 (80%)	$(\chi^2 = 0.14)$	0.71
<b>Level II</b>	5 (25%)	4 (20%)		
<b>Spasticity</b>				
<b>Grade I</b>	17 (85%)	18 (90%)	$(\chi^2 = 0.22)$	0.63
<b>Grade I+</b>	3 (15%)	2 (10%)		

NOTE: SD (Standard deviation); MD (Mean difference);  $\chi^2$  (Chi Squared value); p-value (level of significance).

### 3.2. Effect of treatment on knee angle in mid-stance, step length, stride length, cadence and velocity

Mixed MANOVA revealed that there was a significant interaction of treatment and time ( $F = 16.58$ ,  $p = 0.001$ ). There was a significant main effect of time ( $F = 720.23$ ,  $p = 0.001$ ) and a significant main effect of treatment ( $F = 11.68$ ,  $p = 0.001$ ).

#### 3.2.1. Within group comparison

There was a significant decrease in the knee angle in mid-stance post-treatment in groups A and B compared to pre-treatment ( $p = 0.001$ ). The percentage of change of knee angle in mid-stance of group A was 2.89% and in group B was 6.26% (Table 2). There was a significant increase in step length, stride length, cadence and velocity post-treatment in group A and B compared to pre-treatment ( $p < 0.001$ ). The percentages of change step length, stride length, cadence and velocity of group A were 28.57, 30.24, 19.54 and 49.19% respectively, and in group B were 31.03, 32.92, 20.63 and 49.86%, respectively (Table 3).

#### 3.2.2. Between group comparison

There was no significant difference between groups in all parameters before treatment ( $p > 0.05$ ). In post-treatment, there was a significant decrease in the knee angle in mid-stance in group B compared to group A ( $p < 0.001$ ). However, there was no significant difference in step length, stride length, cadence and velocity between groups post-treatment ( $p > 0.05$ ) (Table 2 and 3).

**Table 2.** Pre and post-treatment mean values of knee angle in mid-stance of group A and B.

	<b>Group A</b>	<b>Group B</b>	<b>MD</b>	<b>p-value</b>
	<b>Mean ±SD</b>	<b>Mean ±SD</b>		
<b>Knee angle in mid-stance (degrees)</b>				
<b>Pre treatment</b>	187.52 ± 1.48	187.65 ± 0.98	-0.13	0.75
<b>Post treatment</b>	182.1 ± 2.31	175.9 ± 1.77	6.2	0.001
<b>MD (% of change)</b>	5.42 (2.89%)	11.75 (6.26%)		
	<b><i>p = 0.001</i></b>	<b><i>p = 0.001</i></b>		

NOTE: SD (Standard deviation); MD (Mean difference); p-value (significance level).

**Table 3.** Pre and post-treatment mean values of step length, stride length, cadence and velocity of group A and B.

	<b>Group A</b>	<b>Group B</b>	<b>MD</b>	<b>p-value</b>
	<b>Mean ±SD</b>	<b>Mean ±SD</b>		
<b>Step length (cm)</b>				
<b>Pre treatment</b>	20.65 ± 1.38	20.95 ± 1.09	-0.3	0.45
<b>Post treatment</b>	26.55 ± 2.08	27.45 ± 1.73	-0.9	0.14
<b>MD (% of change)</b>	-5.9 (28.57%)	-6.5 (31.03%)		
	<b><i>p = 0.001</i></b>	<b><i>p = 0.001</i></b>		
<b>Stride length (cm)</b>				
<b>Pre treatment</b>	39.85 ± 1.78	40.1 ± 1.25	-0.25	0.61
<b>Post treatment</b>	51.9 ± 4.02	53.3 ± 3.26	-1.4	0.23
<b>MD (% of change)</b>	-12.05 (30.24)	-13.2 (32.92)		
	<b><i>p = 0.001</i></b>	<b><i>p = 0.001</i></b>		
<b>Cadence (steps/min)</b>				
<b>Pre treatment</b>	104.9 ± 2.53	105.2 ± 1.76	-0.3	0.66
<b>Post treatment</b>	125.4 ± 2.6	126.9 ± 3.33	-1.5	0.12
<b>MD (% of change)</b>	-20.5 (19.54%)	-21.7 (20.63%)		
	<b><i>p = 0.001</i></b>	<b><i>p = 0.001</i></b>		
<b>Velocity (cm/sec)</b>				
<b>Pre treatment</b>	34.15 ± 1.92	34.9 ± 3.47	-0.75	0.4
<b>Post treatment</b>	50.95 ± 2.79	52.3 ± 3.26	-1.35	0.16
<b>MD (% of change)</b>	-16.8 (49.19%)	-17.4 (49.86%)		
	<b><i>p = 0.001</i></b>	<b><i>p = 0.001</i></b>		

NOTE: SD (Standard deviation); MD (Mean difference); p-value (significance level).



#### 4. DISCUSSION

The current study was conducted to investigate and compare the effect of a modified 5° dorsiflexion with the traditional right angle rigid AFO on controlling knee hyperextension and improving spatiotemporal gait parameters in children with unilateral cerebral palsy. Knee hyperextension that may appear in hemiplegic CP, results from triceps surae spasticity that pull the tibia excessively backward as well as knee joint to abnormal hyperextension position (Tecklin, 2015; Miller, 2019; Gage, 2009). Wearing the rigid AFO puts the foot in a plantigrade position and permits the heel to contact with the ground during the stance phase of walking, which moves the line of gravity slight posterior resulting in a decrease of the excessive extension moment around the knee joint (Morris, 2002). This explains the significant decrease in the knee angle in mid-stance post-treatment using the rigid AFO in both groups A and B compared to pre-treatment ( $p < 0.001$ ).

Comparison of the post-treatment effect of both AFO types to determine the best control of knee hyperextension, revealed a significant decrease in the knee angle in mid-stance in favor of group B compared to group A post-treatment. The percentage of change in group B was 6.26% while the percentage of change of group A was 2.89%. This finding supports the use of the modified 5° dorsiflexion for better controlling of knee hyperextension and achieving near-normal knee joint position during the mid-stance phase which is approximately 5° flexion in normal children (Perry & Burnfield, 2010).

There were previous recommendations to dorsiflex the angles of the rigid AFO to decrease genu recurvatum (Tecklin, 2015; Miller, 2005), but no previous clinical studies have investigated its effect on a study sample before. The previous researches tried to solve the knee hyperextension pattern by using the hinged AFO with adjust the planterflexion stop to 3 to 5° dorsiflexion and reported its significance effect in controlling knee hyperextension (Connor & Cobanoglu, 2016; Kobayashi et al., 2006). Forward inclination of the lower leg will reduce the excess extension moment around the knee and realign the ground reaction force (GFR) appropriately and normalize knee position during the stance phase (Butler & Nene, 1991). Unfortunately, hinged AFO is not suitable for all cases as it permits the ankle joint to move into dorsiflexion during movement activities so it was contraindicated of children who have limited ankle dorsiflexion to less than 10 degrees (while knee in extension) where the rigid AFO is the only choice for these cases (Morris, 2002; Owen, 2010).

Wearing hinged AFO by the child who has limited passive dorsiflexion may cause mid-foot break deformity by forcing the mid-foot into dorsiflexion (Tecklin, 2015; Karas, 2002; Maurer et al.,

2013) Regrettably, limited ankle dorsiflexion ROM are very common in cerebral palsy due to hypertonicity of the calf muscle that eventually develops muscle contracture (Miller, 2019; Gage, 2009; Goldstein & Harper, 2001). Therefore, the modified rigid AFO with 5° dorsiflexion is a new hope for these cases. The use of a fixed AFO with individualized ankle angle had a positive impact on gait mechanism in 80% of children with equinus (CP). The greatest effect was reported in knee kinematics and kinetics parameters (Kane, 2020).

Previous research reported the positive impact of tuning the fixed AFO by modifying the heel height on controlling the excessive extension moment during the stance phase in CP cases (Butler et al., 2007). The process of tuning fixed AFO resembles our research aim which forward inclines the lower leg slightly to reduce the excess knee extension moment. But it is worth noting that, tuning the heel height may affect the total height of the leg which differs from the opposite non tuning leg in hemiplegic CP but our modified AFO will not affect the total height of the affected limb and no limb discrepancy will be found with this method.

Regarding spatiotemporal gait parameters, our result revealed a significant increase in step length, stride length, cadence, and velocity post-treatment in group A and B compared to pre-treatment. The percentages of change in step length, stride length, cadence, and velocity of group A were 28.57, 30.24, 19.54 and 49.19% respectively and in group B 31.03, 32.92, 20.63 and 49.86%, respectively, with no significant difference in all spatiotemporal between the two groups (A and B) post-treatment. This result comes in consistence with previous studies that reported that, spatiotemporal gait parameters were most significantly improved with wearing rigid AFO in children with CP than bare feet (Jagadamma et al., 2015; Aboutorabi et al., 2017) as the stride length was increased (Buckon et al., 2004; White et al., 2002; Dursun et al., 2002; Nikamp et al., 2017) by 11.7% (Hayek et al., 2007), walking speed was significantly improved (White et al., 2002; Dursun et al., 2002) by 34% (Brehm et al., 2008), and improving in cadence (Nikamp et al., 2017) with rigid AFO versus barefoot walking. While other studies found that cadence does not significantly change with the use of AFO (White et al., 2002; Dursun et al., 2002) and the same regarding walking velocity (Buckon et al., 2004; Hayek et al., 2007) and step length (Cruz & Dhaher, 2009).

The improvement of spatiotemporal gait parameters that occurred after using the rigid AFO in both groups A and B may be due to the improvement gait stability and balance from wearing the rigid AFO, which was previously reported (Hayek et al., 2007) as well as the decrease of energy expenditure by regular using of AFO (Uckun et al., 2004), which has a positive impact on children regarding improvement of their velocity and cadence that was reported in our study. By using AFO, the alignment of the GRF vector in relation to the hip, knee and ankle joints can modify and the

excessive moments acting around these joints in the spastic CP could be normalized with AFO enabling normalization of joint kinematics (Wright & DiBello, 2020) that decreasing the energy cost of walking. The reduction in energy costs was related with a faster and more efficient walking pattern with AFO (Aboutorabi et al., 2017).

## 5. CONCLUSIONS

Categorizing cerebral palsy according to their gait abnormalities is very important and the key to describe the optimal AFO for each case. In children with cerebral palsy who suffer from true equinus with knee hyperextension, the use of a rigid AFO could improve the spatiotemporal gait parameters and decrease knee hyperextension. Furthermore, a modified 5° dorsiflexion rigid AFO is recommended for better control of knee hyperextension than a traditional right angle rigid AFO for such cases.

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The authors declare no conflict of interest.

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