

A Comprehensive Review of Recent Advancements in Lower Extremity Orthoses and their Impact on Gait in Children with Cerebral Palsy

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ABSTRACT

Background: Cerebral palsy (CP) is a group of neurological disorders that affect movement, muscle tone, and motor skills. Recent advancements in gait analysis and treatment have significantly improved the diagnosis and management of cerebral palsy.

Objective: The objective of this literature review is to assess and evaluate the recent trends observing the effect of lower limb orthoses on gait parameters among children with Cerebral Palsy in order to attain a better knowledge which can be implemented in improvising the treatment protocol in terms of orthoses for Children with Cerebral Palsy.

Methodology: PubMed, Scopus, ISI Web of knowledge, Cochrane library, EMBASE and Google Scholar were searched for articles published between 2008 and 2023 of studies of children with CP wearing the AFOs. Outcomes investigated with a recent advancement in orthoses in last 15 years to encourage the treatment procedure.

Result: The review of fifteen studies involving 4361 children with cerebral palsy (CP) found that ankle foot orthoses, such as SAFO, SMO, PLS, FRAFO, and Thera suit, can improve gait parameters, walking speed, stride length, knee and ankle range of motion, and reduce energy consumption during the gait cycle. However, the efficacy of rehabilitation interventions for children with CP remains inconclusive. Most authors suggest that AFO can influence or help in postural control, while one study suggested that FRAFO can improve knee alignment but may not be helpful in improving postural control.

Conclusion: Overall orthoses can improve kinematics, kinetics & spatial temporal parameters of gait among patients with cerebral palsy.

Keywords: Cerebral Palsy, Gait, Lower Extremity Orthoses- AFO, SAFO, HAFO, DAFO, SMO, FRAFO, PLS, Therasuit.

INTRODUCTION

Children with cerebral palsy usually have impaired ambulation and reduced balance compared with children who are typically developing; therefore, orthoses are prescribed to improve their ambulatory function.¹ In addition, orthoses are of great importance for patients with cerebral palsy

as they can help improve or maintain function, enhance mobility, promote efficient movement patterns, and improve overall quality of life.² They provide support, stability, and correction of deformities, aiding in balance, movement control, and coordination. Orthoses also help stabilize and support correct

musculoskeletal alignment, promoting better form, conserving energy, and discouraging irregular movement patterns.^{2,3} Recent advancements are essential for resolving the particular musculoskeletal difficulties that people with cerebral palsy have, which in turn improves their general health and degree of functional independence. Cerebral palsy can lead to a variety of gait patterns, impacting individuals walking abilities. The gait patterns are often characterized by asymmetry, variability, and specific deviations in muscle tone and joint movements. Understanding these patterns is crucial for determining the most effective interventions.^{4,5} The impact on gait patterns has been the subject of extensive research, with studies focusing on asymmetry variability, and specific deviations in muscle tone and joint movements.^{6,7} Orthoses, such as ankle-foot orthoses (AFOs), are the most

frequently used orthoses in children with cerebral palsy.⁸

MATERIALS & METHODS

An electronic database search was conducted using google scholars, science direct, Pub med, Cochrane library and reference list from all the retrieved articles. the 15 articles have been reviewed using key words like cerebral palsy, AFO, Orthoses, temporal parameters, spatial parameters of gait kinetics, kinematics, energy expenditure etc. The review included both male and female sample with a total number of 4361 children having cerebral palsy (CP) and using different variants of Ankle Foot Orthoses, such as SAFO, SMO, PLS, FRAFO, and Thera suit. After retrieval of articles, they were reviewed and it has been summarized in the table below;

AUTHOR	YEAR	STUDY DESIGN	SAMPLE SIZE	PARTICIPANT CHARACTERISTICS	MAIN RESULT & AUTHORS CONCLUSION
Elyonara Mello Figueiredo ⁹	2008	Systematic Review	446	Mean age: 8.6 years (range: 2.5-19 years) total of 446 participants were investigated, 304 participants diagnosed of spastic diplegia, 113 participants diagnosed of spastic hemiplegia, 1 with brain injury in early childhood, and 28 participants who were healthy served as controls.	The results of the reviewed studies suggest positive effects of the use of AFOs on the passive and active ankle ROM, gait kinetics and kinematics, as well as on functional activities related to mobility of children with CP.
Atefeh Aboutrabi ¹⁰	2017	Systematic Review	1139	Mean age:7.58 years (1-18). A total of 1139 participants were examined, 893 with spastic diplegia, 128 spastic hemiplegia, 7 spastic triplegia, 59 quadriplegia and 9 a mixed type. One has athetoid CP and 4 children had dyskinesia.	For children with CP, use of specific types of AFOs improved gait parameters, including ankle and knee range of motion, walking speed and stride length. AFOs reduced energy expenditure in children with spastic CP. Evidence showed improvement in gross motor function with HAFO and SAFO in children with diplegic CP. AFOs could also improve ankle and knee ROM, walking speed and stride length. HAFO, CFO and DAFO were

					effective in restoring ankle rockers during gait and producing a more normal physiological gait pattern. HAFO can decrease energy expenditure and improve gait parameters in hemiplegic CP. SAFO and FRO were effective in improving gait parameters and reducing energy expenditure in diplegic CP.
Sung-gyung kim ¹¹	2012	Experimental Study	20	Mean age: 10.2(5.0-15.0) Twenty children with spastic CP (11 boys, 9 girls) participated	The present study examined the effects of foot orthotics applied to children with spastic CP for whom AFOs had been mostly prescribed. According to the results, the velocity, cadence, both step lengths, both stride lengths, both bases of support, and right toe angle of the gait increased during walking with foot orthotics when compared to without foot orthotics, with $p < .05$ being defined as statistically significant. Step length differential, left stance time and left single support time decreased significantly. As such, the researchers determined that foot orthotics positively affects gait and can be used as a gait assistance tool for children with spastic CP

Maria Wingstrand ¹²	2012	Cross sectional study	2200	In total, 2200 children and adolescents 0 to 19 years old (median age 7 years) Of those 1271 were boys and 929 were girls. In 2011, AFOs were used by 1127 (51%) of the children with similar percentages for boys (52%) and girls (51%). In 215 children (10%) the indication was to improve function, in 251 (11%) to maintain or increase range of motion, and 661 of the children (30%) used AFOs for both purposes.	Half of all children with CP in Sweden use AFOs to improve function and/or to maintain or improve range of motion. AFOs were used by 1127 (51%) of the children. In 215 children (10%), the indication was to improve function, in 251 (11%) to maintain or increase range of motion, and 661 of the children (30%) used AFOs for both purposes. The use of AFOs was highest in 5-year-olds (67%) and was more frequent at lower levels of motor function with 70% at
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					GMFCS IV-V. Physiotherapists reported achievement of functional goals in 73% of the children using AFOs and maintenance or improvement in range of ankle dorsiflexion in 70%. The use of AFO is most frequent at 4–6 years of age and in children with lower levels of gross motor function. In this study, three quarters of the children treated with AFO attained the treatment goals, i.e. improved function and/or maintained/improved range of motion. A higher proportion of the children with a lower range of motion at baseline improved their ankle dorsiflexion using AFOs compared to children with a higher initial range of motion.
Harald Bohm ¹³	2018	Cross sectional interventional study	22	Inclusion criteria were as follows: diagnoses of bilateral CP, between 6 and 17 years, Gross Motor Function Classification System (GMFCS) II–IV, and no surgeries in the last 2 years. Patients must have crouch gait without orthotics and were provided bilaterally with customized hinged FRAFOs with a rigid ventral shaft to improve crouch gait. Patients must have used their orthotics for a minimum of 3 months. A total of 22 age- and gender-matched typically developed children and adolescents were used as reference group	With appropriate patient selection, an improvement of crouch gait by ankle-foot orthoses of 17° (standard deviation=5°) can be expected. Patients with slow velocity, weak plantar flexors, and external foot progression benefit most. Joint contractures were no contraindications.

Ali Abbaskhanian ¹⁴	2014	Systematic Review		Inclusion criteria: 1. Population Children with CP, 2. intervention (based on generally occupational therapy, physical therapy and Orthoses) 3. Outcome measures (type of measurement) Children with CP ages 7 months to 18 years were included, as well	The efficacy of rehabilitation interventions for children with CP is still inconclusive. Functional ability and social participation should be the main outcome measures in evaluating rehabilitation efficacy.	In future efficacy studies, a great deal of attention should be paid to methodological quality issues.
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				as all CP types and severities.		
Mahmood Bahramizadeh ¹⁵	2011	Quasi experimental study	8	Eight children with spastic diplegic CP and eight matched typically developing children participated in this study. Postural control of children with CP was assessed in a static standing position on a force platform with/without a FRAFO.	FRAFO can improve the alignment of the knee but may not be helpful in improving postural control in children with CP in a short period of time.	
Eva Swinnen ¹⁶	2017	Clinical Study	15	A total of 15 children with (12 boys, 3 girls, mean age-6-10 years)with bilateral spastic cerebral palsy performed a full body 3 dimensional gait analysis.	Wearing ankle foot Orthoses influences the postural control during walking in children with bilateral spastic cerebral palsy. Due to the increased ROM, the movement pattern of the trunk diverges from the typically developing children.	
Diogo Ricardo ¹⁷	2021	Scoping review	285	A scoping review was conducted including 10 studies considering a total of 285 children with spastic bilateral CP.	The use of AFO in children with spastic bilateral CP minimizes the impact of pathological gait, consistently improving some kinematic, kinetic and spatial temporal parameters and making the gait closer to a typically developing children.	Creating a standardised protocol for future studies involving AFO would facilitate the reporting of new scientific data and help clinicians use their clinical reasoning skills to recommending the best AFO for their patients.
Elisabete Martins ¹⁸	2019	Experimental study	7	Seven participants (3 females,4 males mean age-5-9 years) with unilateral spastic cerebral palsy with level I and II of Gross Motor Function	Wearing a Thera suit promotes positive kinematic changes on gait patterns in the paretic lower limb, decrease in hip flexion angle at initial contact in	

				Classification System (GMFCS) were evaluated.	both lower limb, increase of extension pattern at the hip joint during the stance phase and decrease of flexion pattern during swing phase and decrease of equines foot pattern at the ankle joint in the paretic lower limb.	
Mael Lintalf ¹⁹	2018	Systematic review	884	32 articles corresponding to 56 studies (884) children were included aged between 0-18 years	In children with spastic cerebral palsy, there is strong evidence that AFOs induce small improvements in gait speed and moderate evidence that AFOs have small to moderate effect on gross motor function. In children with equines gait, there is strong evidence that posterior AFOs induce large changes in distal kinematics.	
Alessandro Giurizatto ²⁰	2019	Case Control Study	24	Twenty-four subjects, 14 male and 10 female, with a mean age of 11(5-17years old) underwent a comprehensive gait analysis under both barefoot and braced walking conditions.	AFO prescribed for assistance by professionals without using gait data did not significantly impact the Gait Index, but improved the temporal data	The determination of quantitative clinical parameters for the prescription of orthotics in patients with bilateral CP, as well as orthotics that meets the specific requirements, are points to be addressed in the future to obtain more significant effects.
Firouzeh P ²¹	2019	A scoping review		Five stage method was used to conduct a scoping review, including children under the age of 6 years.	Research evaluating the effects of AFOs on age appropriate, functional outcomes including transitional movement, floor mobility and participation in early childhood settings is needed to inform practice regarding early orthotic prescription	

Xue Cheng Liu ²²	2017	Prospective Cohort Study	23	A total of 23 children with CP, mean age 10.5 years were clinically prescribed, either a solid ankle foot orthotic (SAFO) Hinged ankle foot orthotic (HKAFO) or supramalleolar orthotic.	The use of AFOs long term either maintained or improved foot deformities or dysfunction.	
Merel Anne Brehm ²³	2008	Retrospective Study	172	Barefoot and ankle foot orthosis data for 172 children with spastic cerebral palsy mean age 9 years were compared.	The use of ankle foot orthosis resulted in a significant decrease in the energy cost of walking of quadriplegic children with cerebral palsy, compared with barefoot walking whereas it remain unchanged in hemiplegic and diplegic children with cerebral palsy.	

RESULT

Present review included fifteen studies investigating an overall 4361 children with CP. Children with spastic diplegia, spastic hemiplegia, spastic triplegia, quadriplegia was included from the reviews of last 15 years encompassing four systematic reviews, two scoping reviews, two cross-sectional studies, two experimental study design, one retrospective study, one prospective study, one case control study, one clinical study with intrasubjective design and one quasi experimental study design. It was found that variants of Ankle foot orthoses including SAFO, SMO, PLS, FRAFO, Thera suit etc. can improve gait parameters specifically walking speed & stride length with improvement in knee and ankle range of motion thereby reducing the cost of energy consumption during gait cycle. Though some authors suggested that the efficacy of rehabilitation interventions for children with CP is still inconclusive, whereas most authors suggested that AFO can influence or help in postural control while one study suggested that FRAFO can

improve the alignment of knee but may not be helpful in improving the postural control.

DISCUSSION

After regress literature review it is evident that Ankle foot orthoses improve the gait parameters specifically by improving the passive and active range of motion of knee and ankle by improving the ankle position during the swing phase of the gait cycle.

It was discovered that Ankle foot orthoses have numerous beneficial effects on both temporal and spatial characteristics. These temporal parameters include stance time, single limb support time, double limb support time, swing time, stride, step time, cadence, and speed. It may be associated with data showing that ankle-foot orthoses substantially lower the peak ankle power during terminal stance, suggesting an enhanced gait pattern at the cost of a decreased push-off power output. Additionally, SAFO can most effectively correct ankle functions by limiting the ankle to a single neutral angle, especially in the cases with diplegic cerebral palsy. Additionally, it was found that AFO helped

lower energy consumption, which resulted in faster and more effective walking pattern. The improvements in efficiency were reflected by Changes in stance and swing phase knee motion i.e., children who showed improved knee flexion angle toward the average normal range also showed a decreased energy cost of walking.

Effect of SAFO on walking parameters;

Brehm et al suggested that in CP, SAFO extends stride length. In children with diplegic CP, it also resulted in the greatest improvement in walking speed when compared to PLS and HAFO. In cases of diplegic CP, SAFO can most effectively restore normal ankle function by limiting the ankle to a single neutral angle. Results demonstrate an improvement in knee flexion angles, which is indicative of a decrease in the amount of muscle force needed during the stance phase.²³

Effect of HAFO on walking parameters;

Balaban et al suggested that HAFO enhanced gait symmetry, walking speed, stride length, and single limb support. In hemiplegic CP patients, HAFO improved knee and ankle range of motion as well as ankle power. In hemiplegic CP, it was also successful in reducing energy expenditure. In addition to effectively restoring the first ankle rocker of gait, HAFO permits free ankle dorsiflexion with blocked plantarflexion, preventing dynamic equine deformity of the ankle joint at initial foot contact and producing physiological heel contact.²⁴ According to Dalvand H et al., improvements in gross motor function were also noticeable.²⁵

Effect of FRO on walking parameters;

According to KT Michael et al, FRO helped people with diplegic cerebral palsy walk faster, with longer strides. Knee extension was improved with the help of FRO. By directing the ground response vector anterior to the knee joint, it creates an extensor moment at the knee and lessens the quadriceps workload.²⁶ According to Rodda J, FRO was the most efficient in

maintaining integrity to the ankle plantar flexion-Knee extension couple.²⁷

Effect of PLS on walking parameters;

PLS enables the hemiplegic CP patients walk faster and with better knee flexor moments. An AFO that resembles a spring can improve push-off and possibly lower energy costs. Only in limited research did the orthotic significantly reduce the energy cost of walking in quadriplegia and improve knee and ankle ROM in hemiplegic CP patients.

Effect of DAFO on walking parameters;

According to Wran TA et al., DAFO can encourage a more flexed posture (more dorsiflexion and knee flexion during stance), making it effective for kids with a crouched gait pattern when used in conjunction with an equinus pattern or dropped foot.²⁸

CONCLUSION

It can be concluded that the use of AFO has positive effects on the passive and active ankle ROM, gait kinetics and kinematics as well as on functional activities related to mobility of children with CP.

Overall, there was some improvement or maintained status in kinematics found for 3 orthoses groups (HAFO, SMO, or SAFO). HAFOs appear to alter the forefoot motion and reduce dorsiflexion overall but not enough to show clinical significance. SAFOs were able to provide the status quo of the foot segments and ankle joint movement between the first and final visits, but not as well as the other prescriptions for the midfoot coronal plane. The SMO group is the only group that continues to show intravisit changes, particularly in the sagittal forefoot motion along with a decrease in ankle eversion. However, the quality of matter of the 15 studies reviewed is low therefore further studies are needed, including a high-quality RCT, which provides the best design to control for potential bias.

Limitations

Fewer articles may lead to less comprehensive coverage, meaning certain subfields or nuanced aspects of the topic might not be thoroughly explored. In sum, while a 15-article review might offer useful insights, it may not provide a fully balanced picture of the research landscape.

Future Directions

Future research could expand the literature base by incorporating more studies to cover a broader range of perspectives, methodologies for better result outcomes.

Declaration by Authors

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