Original Article

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Effect of Ankle Foot Orthoses on Gait Parameter among Children with Spastic Diplegic Cerebral Palsy

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Abstract:

Objective: This study evaluated the effects of solid ankle-foot orthosis (SAFO) and ground reaction ankle-foot orthosis (GRAFO) on gait parameters (kinematic and temporospatial) in children with diplegic spastic cerebral palsy (CP).

Material and Methods: This repeated-measure matched pair study included 11 children with diplegic spastic CP (Gross Motor Function Classification System, GMFCS III and IV) who presented with equinus gait from 2 tertiary hospitals in Kota Kinabalu. Participants walked 3 meters under 3 conditions: barefoot, with SAFO, and with GRAFO. Gait was recorded using a high-definition camera in the sagittal plane. Kinematic and temporospatial parameters were analyzed using the Kinovea system and compared with the Wilcoxon signed-rank test.

Results: The participants' average age was 6.91±3.02 years. Walking with SAFO and GRAFO significantly reduced velocity (p-value=0.021 and 0.008 respectively) and shortened step and stride lengths (p-value=0.006 for both). Both AFOs significantly reduced peak knee extension at stance (p-value=0.003 for both), while increasing peak ankle dorsiflexion at stance (p-value=0.003 for both) and ankle angle at initial contact (p-value=0.003 for both). GRAFO further reduced

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walking speed (p-value=0.008), step length (p-value=0.004), and stride length (p-value=0.005), but improved knee extension at stance (p-value=0.003) compared to SAFO.

Conclusion: Both SAFO and GRAFO improved knee flexion, ankle plantarflexion at stance, and ankle angle at initial contact in children with CP. GRAFO offered additional benefits by enhancing knee extension at stance.

Keywords: diplegic spastic cerebral palsy, ground reaction ankle-foot orthoses (GRAFO), gait deviations, solid ankle-foot orthosis (SAFO)

Introduction

Cerebral palsy (CP) is a permanent motor disorder that affects the development of movement and posture, causing activity limitations. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication, behavior, epilepsy, and musculoskeletal complications[1]. Spastic diplegic cerebral palsy is a common type of CP, where the motor impairment of the lower extremities is more affected compared to the upper extremities[2]. Motor impairment and musculoskeletal issues in the lower extremities result in difficulties with walking and lead to various gait deviations[3].

Children with spastic diplegic CP often experience difficulties with walking, primarily due to muscle spasticity and weakness, joint contracture, and bony deformities[4]. Apparent equinus gait is one of the gait patterns among children with diplegic CP. This gait pattern exhibits a normal range of ankle dorsiflexion; however, excessive hip and knee flexion throughout the stance phase results in toe-walking, creating the illusion of equinus[3]. An orthosis prescription is a common treatment for children with cerebral palsy[5]. Treatment options aim to maintain muscle strength, prevent complications such as bony deformities and joint contractures, and restore lever arm function[4]. Ankle-foot orthoses (AFOs) are commonly prescribed to improve function and prevent muscle contractures[5], achieving treatment goals in nearly three-fourths of cases. Solid ankle-foot orthosis (SAFO) is the most frequently prescribed orthosis in our clinical setting due to its simple fabrication and cost-effectiveness. However, studies show mixed results on SAFO's impact on gait velocity in children with CP. A study[6] found a significant increase in velocity with SAFO, while other studies reported no significant changes[7-12]. Another study recorded a non-significant decrease in velocity with AFOs[13].

Most studies found that stride length increased significantly with SAFO[6-9]; only a couple of studies[10,11] found no significant change. SAFO significantly improved ankle excursion, dorsiflexion, and equinus correction[6-8,14]. However, studies indicated no improvement in knee flexion during the stance phase with SAFO[6,7,9,15].

Floor Reaction Ankle Foot Orthosis (FRAFO), or ground reaction ankle-foot orthoses (GRAFO), stabilizes the paralyzed limb without limiting knee movement. GRAFO significantly improves ankle dorsiflexion during the stance phase in children with crouch gait[16-20]. Studies showed that GRAFO improved knee flexion in the stance phase[16,17,19,20]. GRAFO also improved hip flexion and range of movement[16,17], though some results were not significant[18]. GRAFO generally increased gait velocity compared to barefoot walking[16,19,20], but was slower than shoes-only[18]. Moreover, a study noted improved cadence with GRAFO, while another[16] study found a significant increase.

The effectiveness of AFO in improving gait remains uncertain and unclear[21]. Many studies have examined the effectiveness of SAFO on gait parameters, but not all of them have investigated every gait parameter. Some studies[16–20] have looked into the effectiveness of GRAFO. To our knowledge, limited studies have compared the effects of SAFO and GRAFO on gait parameters. This limited comparison reduces the confidence in and use of orthosis in children with cerebral palsy. Therefore, this study was performed 1) to investigate kinematic data and temporospatial data in children with diplegic CP using SAFO versus barefoot, 2) to compare kinematic and temporospatial data in children with diplegic CP using GRAFO versus barefoot, and 3) to compare kinematic and temporospatial data in children with diplegic CP using SAFO versus GRAFO.

Material and Methods

Study design, population, and study site

It was a repeated-measure matched pair study design. The study was conducted at the Paediatric Neurology Department, Sabah Women and Children's Hospital, and the Rehabilitation Medicine Department in Queen Elizabeth Hospital. From 2022 to 2023, 40 cases of diplegic cerebral palsy in children were registered at Sabah Women and Children's Hospital.

The researcher obtained ethical clearance from the Medical Research and Ethics Committee (MREC), Ministry of Health Malaysia (MOH) [NMRR-19-3926-51550 (IIR)]. Out of 40 children screened, 14 were eligible and included in the study (Figure 1).

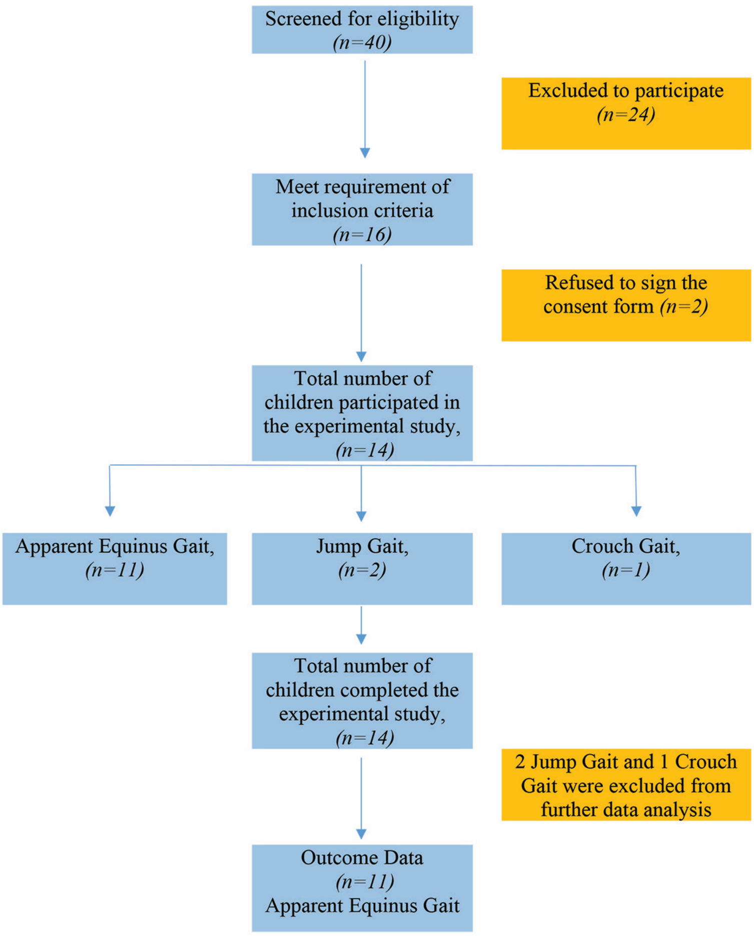

Figure 1 CONSORT flow diagram

Sample size

We planned a study of a continuous response variable from matched pairs of study subjects. Prior data indicate that the difference in the response of matched pairs is normally distributed with a standard deviation of 10.20. If the true difference in the mean response of matched pairs was 15.70, we needed 7 pairs of subjects to study to be able to reject the null hypothesis with 80% power. The Type I error probability associated with this test of the null hypothesis is 0.05. We recruited 11 eligible participants for this study.

Participants

Children with diplegic CP, aged 3 to 18 years old, GMFCS levels III, and IV who exhibited gait patterns, such as apparent equines gait, jump gait, and crouch gait, were included in this study. Children with cognitive impairments that could affect their ability to follow ambulation, children with a history of lower extremity surgery or who had received a Botulinum injection, and children whose parents or caregivers refused to participate in this study were excluded.

Study procedure

After receiving ethical approval (NMRR-19-3926-51550 (IIR)) from the MREC, the MOH, we recruited participants based on the inclusion and exclusion criteria. A registered rehabilitation physician conducted a clinical assessment of each participant with CP, including evaluation of GMFCS level, gait pattern, and ankle joint range of motion. All participants were classified under GMFCS III and IV, ambulated with assistive devices, and exhibited equinus, jump, or crouch gait patterns.

Each child walked 3 meters under 3 conditions: barefoot first, wearing a SAFO second, and using a GRAFO last, with at least 2 trials per condition. The study assessed the immediate effect of wearing AFO while walking on kinematic and temporospatial data in gait analysis. A 30-minute break was given between the SAFO and GR AFO assessments to eliminate any residual effects.

Gait was recorded using a high-definition (HD) video camera in the sagittal plane. Data were analyzed using the Kinovea Gait Analysis System to obtain kinematic data (knee flexion and ankle dorsiflexion during midstance) and temporospatial parameters (walking velocity, step length, stride length, and cadence).

Custom-made AFOs (SAFO and GRAFO) were fabricated from 3-mm-thick polypropylene, featuring anterior trim lines and ankle straps at 0° dorsiflexion. Motion analysis was conducted with an HD video camera and Kinovea software, using skin markers for precise skeletal tracking. The system processed data to determine ankle kinematics at initial contact and peak knee extension during the stance phase.

Data collection system

Kinovea is an open-access video analysis software that is available online (https://www.kinovea.org). Combining an HD VideoCam and Kinovea software created a motion capture-analysis system. Video recording served as the output from the HD VideoCam, which was then used as input data in the Kinovea open software. A study[22] explored this software for motion analysis. The system was validated by Hisham and colleagues[23] through a comparison with an established infrared motion capture system[24]. The results obtained by Hisham and colleagues[23] confirmed the accuracy of the Kinovea software system. They showed no significant difference (in mean, standard deviation, and variance) between the HD Video Cam-Kinovea System and the infrared motion capture system.

Callbration/platfrom preparation

A 3-meter walking platform was set up with 2 cameras positioned in front and at the side of the platform. The parameters of the HD cameras were adjusted, including camera position, camera focal length, aperture, focus point, motion speed, and capturing speed. This adjustment was crucial to achieve the best possible video quality and view. The optimum camera position and angle were determined and marked to ensure precise subject coverage during motion analysis. Accurate settings for camera focal length, aperture, focus point, motion speed, and capturing speed were applied to produce sharp images and videos. To maintain consistency in all positions throughout the experiment, essential positions, such as camera position, walking start and stop points, and center point, were marked[25-27].

Outcome measures

Tempo spatial parameter

A random 60-second interval was selected from the KINOVEA system to count the number of steps. Velocity was measured by the time taken to traverse 3 meters. Step length, the distance from the left heel to the right heel, and stride length, the distance from one heel to the same heel again, were randomly selected and calculated[28].

Kinematic parameter

Kinematic parameters refer to joint angles and segment orientation while walking. The stance phase covered 60% of the gait cycle. During the stance phase, a single leg and foot bear most or the entirety of the body's weight.

Statistical analysis

The mean values for tempo spatial data (velocity, step length, stride length, and cadence) and kinematic data (ankle angle at initial contact, ankle dorsiflexion peak, and knee extension at the stance phase) were calculated. One-way repeated measures ANOVA tests were conducted to determine the significant differences. These statistical analyses were performed using the SPSS software version 25. The temporospatial data for the velocity in walking with solid AFO, cadence in walking barefoot, and cadence in walking with GRAFO were not normally distributed. The rest of the data were normally distributed. The level of statistical significance was set to p-value<0.05.

Results

The gait assessment of the 14 children included in this study revealed that 11 participants demonstrated apparent equinus gait, while 2 children had a jump gait, and one child had a crouch gait. Since the biomechanical response to AFO varies among different gait types, and due to the small numbers in the jump and crouch gait groups, these participants were excluded from further analysis. The study, therefore, focused on the effectiveness of AFO in 11 participants with apparent equinus gait.

Socio-demographic characteristics

The mean age of the participants was 6.909±3.015 years. Most of the study participants were male, comprising 72.7% of the total. Out of the 11 participants, more than half were at Level III of GMFCS. None were recorded at Level I or II, indicating that all were at Level III or above. All participants were walking with an apparent equinus gait. The following were the demographic and clinical data of the participants (Table 1).

Solid ankle-foot orthosis

A Wilcoxon signed-rank test revealed significant differences between baseline (walking barefoot) and walking with SAFO. Walking with SAFO was significantly slower (p-value=0.021) with a median velocity of 0.0554 m/s compared to 0.0767 m/s barefoot. Step length and stride length were also significantly shorter with SAFO (step length: p-value=0.006, median 0.1470 m SAFO vs. 0.1800 m barefoot; stride length: p-value=0.006, median 0.2050 m SAFO vs. 0.2520 m barefoot). Significant differences were found in peak knee extension at stance (p-value= 0.003), peak ankle dorsiflexion at stance (p-value=0.003), and ankle angle at initial contact (p-value=0.003). Median peak knee extension decreased from 23.28° barefoot to 22.12° with SAFO. Median peak ankle dorsiflexion increased from -19.82° barefoot to 8.10° with SAFO, and ankle angle at initial contact increased from -16.11° barefoot to 7.940° with SAFO (Table 2).

Ground reaction ankle-foot orthosis

A Wilcoxon signed-rank test showed significant differences between baseline (walking barefoot) and walking with GRAFO. Walking with GRAFO was slower (p-value=0.008), with a median velocity of 0.0531 m/s compared to 0.0767 m/s barefoot. Step length and stride length were significantly shorter with GRAFO (step length: p-value=0.006, median 0.1360 m GRAFO vs. 0.1800 m barefoot; stride length: p-value=0.006, median 0.1900 m GRAFO vs. 0.2520 m barefoot). Significant differences were found in peak knee extension at stance (p-value=0.003), peak ankle dorsiflexion at stance (p-value=0.003), and ankle angle at initial contact (p-value=0.003). Median peak knee extension decreased from 23.28° barefoot to 21.31° with GRAFO. Median peak ankle dorsiflexion increased from -19.82° barefoot to 8.14° with GRAFO, and ankle angle at initial contact increased from -16.11° barefoot to 8.14° with GRAFO (Table 3).

Table 1 Sociodemographic characteristics of the participants (n=11)

Demographics variables	n	%
Gender		
Male	8	72.7
Female	3	27.3
Gross motor functional classification system (GMFCS)		
Level I	0	0
Level II	0	0
Level III	7	63.6
Level IV	4	36.4

Demographics variables	Mean (S.D.)	Shapiro-wilk		
		Statistic	df	Sig (p-value)
Age (years)	6.91 (3.02)	0.96	11	0.73
Weight (kg)	33.0 (5.46)	0.89	11	0.14
Height (kg)	1.14 (0.14)	0.96	11	0.74
BMI (kg/m^2)	14.47 (1.56)	0.89	11	0.13

kg=kilogram, m^2=square metre, S.D.=standard deviation, BMI=body mass index

Solid ankle-foot orthosis (SAFO) and ground reaction ankle-foot orthosis (GRFO)

A Wilcoxon signed-rank test indicated significant differences between walking with SAFO and GRAFO. Walking with GRAFO was slower (p-value=0.008), with a median velocity of 0.05310 m/s compared to 0.0554 m/s with SAFO. Step length and stride length were shorter with GRAFO (step length: p-value=0.004, median 0.1360 m GRAFO vs. 0.1470 m SAFO; stride length: p-value=0.005, median 0.1900 m GRAFO vs. 0.2050 m SAFO). Median cadence was lower with GRAFO (0.3624 steps/min) compared to SAFO (0.4786 steps/min), but it was not significant (p-value=0.182).

A significant difference was found in the peak knee extension of SAFO and GRAFO (p-value=0.003). Median peak knee extension improved more with GRAFO (22.12° with SAFO vs 21.3° with GRAFO). However, no significant differences were found in the peak ankle dorsiflexion at the stance and the ankle angle at initial contact between GRAFO and SAFO (Table 4).

Table 2 Comparison of baseline (barefoot) and post-intervention (SAFO) performance

Outcome measure	Median (IQR)		p-value
	Baseline (Barefoot)	Post-intervention (SAFO)	Barefoot vs SAFO
Tempo-spatial parameter			
Velocity (m/s)	0.08 (0.05–0.10)	0.06 (0.05–0.09)	0.021
Step length (m)	0.18 (0.09–0.23)	0.15 (0.07–0.20)	0.006
Stride length (m)	0.25 (0.13–0.32)	0.21 (0.10–0.27)	0.006
Cadence (steps/min)	0.46 (0.39–0.54)	0.48 (0.34–0.73)	0.859
Kinematic parameter			
Peak knee extension at stance (degree)	23.28 (19.66–27.54)	22.12 (18.68–26.16)	0.003
Peak ankle dorsiflexion at stance (degree)	-19.82 (-22.67– -13.94)	8.10 (7.70–8.90)	0.003
Angle of ankle at initial contact (degree)	-16.11 (-18.43– -11.33)	7.94 (7.33–8.57)	0.003

SAFO=solid ankle-foot orthosis, IQR=interquartile range, m=meter, s=second

Table 3 Comparison of baseline (barefoot) and post-intervention (GRAFO) performance

Outcome measure	Median (IQR)		p-value
	Baseline (Barefoot)	Post-intervention (GRAFO)	Barefoot vs GRAFO
Tempo-spatial parameter			
Velocity (m/s)	0.08 (0.05–0.10)	0.053 (0.04–0.07)	0.008
Step length (m)	0.18 (0.09–0.23)	0.14 (0.07–0.19)	0.006
Stride length (m)	0.25 (0.13–0.32)	0.19 (0.10–0.27)	0.006
Cadence (steps/min)	0.46 (0.39–0.55)	0.36 (0.32–0.77)	0.534
Kinematic parameter			
Peak knee extension at stance (degree)	23.28 (19.66–27.54)	21.31 (18.00–25.21)	0.003
Peak ankle dorsiflexion at stance (degree)	-19.82 (-22.67– -13.94)	8.14 (7.32–8.84)	0.003
Angle of ankle at initial contact (degree)	-16.11 (-18.43– -11.33)	8.14 (6.96–8.60)	0.003

GRAFO=ground reaction ankle-foot orthoses, IQR=interquartile range, m=meter, s=second

Table 4 Comparison of SAFO and GRAFO performance

Outcome measure	Median (IQR)		p-value
	SAFO	GRAFO	SAFO vs GRAFO
Tempo-spatial parameter			
Velocity (m/s)	0.06 (0.05–0.09)	0.05 (0.04–0.07)	0.008
Step length (m)	0.15 (0.07–0.19)	0.14 (0.07–0.19)	0.004
Stride length (m)	0.21 (0.10–0.27)	0.19 (0.10–0.27)	0.005
Cadence (steps/min)	0.48 (0.34–0.73)	0.36 (0.32–0.77)	0.182
Kinematic parameter			
Peak knee extension at stance (degree)	22.12 (18.68–26.16)	21.31 (18.00–25.21)	0.003
Peak ankle dorsiflexion at stance (degree)	8.10 (7.70–8.90)	8.14 (7.32–8.84)	0.075
Angle of ankle at initial contact (degree)	7.94 (7.33–8.57)	8.14 (6.96–8.60)	0.824

SAFO=solid ankle-foot orthosis, GRAFO=ground reaction ankle-foot orthoses, IQR=interquartile range, m=meter, s=second

Discussion

This study examined the effectiveness of SAFO and GRAFO in children with diplegic CP presenting with apparent equinus gait. The youngest participant in this study was 3 years old, with a mean age of 7, consistent with recommendations for early cerebral palsy intervention to prevent complications and support caregiver well-being. Early treatment in hospital and clinical settings plays a crucial role in minimizing contractures and enhancing functional development[29–30].

Effect of SAFO and GRAFO on the temporospatial parameter

Both SAFO and GRAFO resulted in a significant reduction in walking velocity compared to barefoot walking. Walking velocity was slower with GRAFO compared to SAFO, with a statistically significant difference. The results for velocity were consistent with several studies that found no improvement in velocity when wearing SAFO[7–11,13] and GRAFO[17,18]. The reduction in velocity aligns with previous studies suggesting that AFOs, while providing stability, may initially limit walking speed due to constraints on ankle movement and adaptation challenges. Similarly, step length and stride length were significantly shorter with both SAFO and GRAFO compared to barefoot walking. However, the reduction was more pronounced with GRAFO, as step length decreased from 0.1800 m barefoot to 0.1360 m with GRAFO, compared to 0.1470 m with SAFO. Stride length followed a similar trend, suggesting that GRAFO may impose greater constraints on step advancement, possibly due to its rigid structure influencing knee mechanics. Our study findings contrast with earlier research, which improved step length in SAFO[7], and the previous studies that reported significant improvements in stride length[6,7,9]. One distinguishing factor between our study and these reports is the GMFCS level of participants. The aforementioned studies included children across GMFCS levels I, II, and III. In contrast, our study involved children at GMFCS levels III and IV[31]. The walking capabilities of children at levels I and II differ substantially from those at levels III and IV.

Effect of SAFO and GRAFO on peak knee extension

The peak knee extension mean was higher than in typically developed children, indicating excessive knee flexion, which can be improved with AFOs. Peak knee extension during the stance was reduced with SAFO compared to walking barefoot. Our finding is consistent with previous studies[6,7,9,15]. Similarly, GRAFO also decreased peak knee extension during the stance phase compared to walking barefoot, aligning with findings from prior studies[16–20].

Children exhibiting apparent equinus typically demonstrate knee flexion during the initial contact and terminal stance phases. Excessive knee flexion often occurs due to weakness in the quadriceps muscles or tightness in the hamstring and calf muscles. In our study, peak knee extension during the stance phase was reduced when walking with a SAFO and a GRAFO. This indicates that AFOs effectively mitigate excessive knee flexion throughout the stance phase and realign the ground reaction force to normalize knee and hip joint moments[32].

Effect of SAFO and GRAFO on peak ankle dorsiflexion at stance and angle of the ankle at initial contact

The results demonstrated that both SAFO and GRAFO effectively mitigated excessive dorsiflexion and plantarflexion during walking, significantly increasing peak ankle dorsiflexion. Initially, participants exhibited plantarflexion, but peak ankle dorsiflexion shifted to a positive value with the orthoses. This finding aligns with previous studies that reported improved ankle excursion with SAFO[6–8,14]. Studies investigating the impact of GRAFO on excessive ankle dorsiflexion similarly reported improvements[16–20]. Our findings confirm that both SAFO and GRAFO, with their rigid ankle design, effectively control ankle movement by preventing excessive plantarflexion and maintaining the ankle in a neutral position, thus improving ankle excursion in children with diplegic CP. SAFO and GRAFO also effectively prevent excessive dorsiflexion and plantarflexion during initial contact, shifting the ankle angle from plantarflexion (-7.2°) to dorsiflexion (7.5°). This indicates that the orthoses successfully maintain the ankle in a neutral position during the early stance phase.

Comparing GRAFO and SAFO on peak knee extension

Our study found that peak knee extension significantly improved with GRAFO compared to SAFO. GRAFO comprised a rigid anterior tibial shell and a rigid ankle joint structure. This design increased and stabilized the lever arm of the foot to provide a rigid lever required for an effective plantar flexion-knee extension couple. GRAFO is specifically designed to control excessive knee flexion. GRAFO is an effective brace for improving knee extension and ankle dorsiflexion during the stance phase of the gait cycle in children with CP.

GRAFO's design increases and stabilizes the foot's lever arm, providing a rigid lever for effective plantarflexion-knee extension coupling. All studies on GRAFO showed improvements in peak knee extension during the stance phase of crouch gait in children with CP. Our findings align with 4 studies demonstrating significant improvement in knee flexion with GRAFO[16,17,19,20]. However, another study found GRAFO decreased knee flexion at midstance but not significantly[18].

Both SAFO and GRAFO showed improvements in ankle excursion, preventing excessive plantarflexion or improving dorsiflexion compared to barefoot walking. GRAFO's anterior shell provides extra rigidity, enhancing its effectiveness in preventing excessive ankle plantarflexion compared to SAFO[17].

Clinical implications

The findings highlight the potential trade-offs in using SAFO and GRAFO in children with diplegic CP. While both orthoses reduced plantar flexion and excessive knee flexion, they also led to decreased walking velocity and spatial parameters. GRAFO demonstrated greater improvement in excessive knee flexion, making it a more suitable option for children with significant knee flexion issues. However, there was no significant difference between SAFO and GRAFO in their effects on ankle dorsiflexion.

Given that SAFO is more cost-effective, it may be the preferred choice when the primary goal is to correct ankle plantar flexion. Conversely, if the primary aim is to address excessive knee flexion, GRAFO may be more beneficial, though clinicians should consider the associated reduction in gait speed compared to SAFO. Ultimately, clinicians should weigh these biomechanical effects carefully to prescribe the most suitable AFO, optimizing gait function based on each child's individual needs.

Limitations and future direction

The study did not assess the long-term adaptation to AFO use, which could provide insights into whether the initial gait changes persist or improve with continued wear. Future studies with larger cohorts and extended follow-up periods are recommended to explore the long-term effects of AFOs on gait adaptation. Further research is also needed to refine AFO prescriptions and optimize gait outcomes in this population.

Conclusion

Both SAFO and GRAFO were effective in improving ankle plantarflexion and excessive knee flexion, reducing equinus posturing in children with diplegic CP. However, they also resulted in reduced walking velocity, shorter step and stride lengths. The choice between SAFO and GRAFO should be individualized, considering the child's specific gait impairments and functional goals.

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Conflict of interest

The authors declare no competing interests.

References

1. Rosenbaum P, Paneth N, Leviton A, Goldstein M, Bax M, Damiano D, et al. A report: the definition and classification of cerebral palsy April 2006. Dev Med Child Neurol Suppl 2007;109(suppl 109):8-14.
2. Ogoke CC. Clinical classification of cerebral palsy. Cere Pal Clin Thera Aspect 2018;1:1-23.
3. Rodda J, Graham HK. Classification of gait patterns in spastic hemiplegia and spastic diplegia: a basis for a management algorithm. Euro J Neurol 2001;8:98-108.
4. Armand S, Decoulon G, Bonnefoy-Mazure A. Gait analysis in children with cerebral palsy. EFORT Open Reviews 2016;1:448-60.
5. Wingstrand M, Hägglund G, Rodby-Bousquet E. Ankle-foot orthoses in children with cerebral palsy: a cross sectional population based study of 2200 children. BMC Musculo Dis 2014;15:1-7.
6. Abel MF, Juhl GA, Vaughan CL, Damiano DL. Gait assessment of fixed ankle-foot orthoses in children with spastic diplegia. Arch Phys Med Rehabil 1998;79:126-33.
7. Buckon CE, Thomas SS, Jakobson-Huston S, Moor M, Sussman M, Aiona M. Comparison of three ankle–foot orthosis configurations for children with spastic diplegia. Dev Med Child Neurol 2004;46:590-8.
8. Carlson WE, Vaughan CL, Damiano DL, Abel MF. Orthotic management of gait in spastic diplegia1. Am J Phys Med Rehabil 1997;76:219-25.
9. Radtka SA, Skinner SR, Johanson ME. A comparison of gait with solid and hinged ankle-foot orthoses in children with spastic diplegic cerebral palsy. Gait & posture 2005;21:303-10.
10. Rethlefsen S, Kay R, Dennis S, Forstein M, Tolo V. The effects of fixed and articulated ankle-foot orthoses on gait patterns in subjects with cerebral palsy. J Pediatr Orthop 1999;19:470-4.
11. Smiley SJ, Jacobsen FS, Mielke C, Johnston R, Park C, Ovaska GJ. A comparison of the effects of solid, articulated, and posterior leaf-spring ankle-foot orthoses and shoes alone on gait and energy expenditure in children with spastic diplegic cerebral palsy. Orthopedics 2002;25:411-5.
12. Carison W, Damiano D, Abel M, Vaughan C. Biomechanics of orthotic management of gait in spastic diplegia. Gait & Posture 1995;3:102.
13. Mossberg KA, Linton KA, Friske K. Ankle-foot orthoses: effect on energy expenditure of gait in spastic diplegic children. Am J Phys Med Rehabil 1990;71:490-4.
14. Lam WK, Leong JC, Li YH, Hu Y, Lu WW. Biomechanical and electromyographic evaluation of ankle foot orthosis and dynamic ankle foot orthosis in spastic cerebral palsy. Gait & posture 2005;22:189-97.
15. Wesdock KA, Edge AM. Effects of wedged shoes and ankle-foot orthoses on standing balance and knee extension in children with cerebral palsy who crouch. Pediatr Phys Ther 2003;15:221-31.
16. Bahramizadeh M, Arazpour M, William HS. The effect of modified floor reaction ankle foot orthoses on walking abilities in children with cerebral palsy. Pediatr Phys Ther 2015;1:95-101.
17. Böhm H, Matthias H, Braatz F, Döderlein L. Effect of floor reaction ankle–foot orthosis on crouch gait in patients with cerebral palsy: What can be expected? Prosthet Orthot Int 2018;42:245-53.
18. Kerkum YL, Buizer AI, Van Den Noort JC, Becher JG, Harlaar J, Brehm MA. The effects of varying ankle foot orthosis stiffness on gait in children with spastic cerebral palsy who walk with excessive knee flexion. PloS One 2015;10:e0142878.

19. Rogozinski BM, Davids JR, Davis III RB, Jameson GG, Blackhurst DW. The efficacy of the floor-reaction ankle-foot orthosis in children with cerebral palsy. JBJS 2009;91:2440-7.
20. Skaaret I, Steen H, Terjesen T, Holm I. Impact of ankle-foot orthoses on gait 1 year after lower limb surgery in children with bilateral cerebral palsy. Prosthet Orthot Int 2019;43:12-20.
21. Kane K, Manns P, Lanovaz J, Musselman K. Clinician perspectives and experiences in the prescription of ankle-foot orthoses for children with cerebral palsy. Physiother Theory Pract 2019;35:148-56.
22. Guzmán-Valdivia CH, Blanco-Ortega A, Oliver-Salazar MA, Carrera-Escobedo JL. Therapeutic motion analysis of lower limbs using Kinovea. Int J Soft Comput Eng 2013;3:2231-307.
23. Hisham NA, Nazri AF, Madete J, Herawati L, Mahmud J. Measuring ankle angle and analysis of walking gait using kinovea. Int Med Dev Tech 2017;1:247-50.
24. Butler PB, Thompson N, Major RE. Improvement in walking performance of children with cerebral palsy: preliminary results. Dev Med Child Neurol 1992;34:567-76.
25. Balsalobre-Fernández C, Tejero-González CM, del Campo-Vecino J, Bavaresco N. The concurrent validity and reliability of a low-cost, high-speed camera-based method for measuring the flight time of vertical jumps. J Strength Cond Res 2014;28:528-33.
26. Khan AH, Bhuiyan MS, Kabir MF, Hossain MZ, Jahan S, Hossain KA, et al. Effectiveness of proprioceptive neuromuscular facilitation pattern on upper extremity and scapula in patients with adhesive capsulitis: a single-centre assessor-blinded randomised controlled trial (RCT). Trials 2025;26:146.
27. Chen J, Sun YH, Pickett KA, King B, Hu YH, Jiang H. A wearable gait monitoring system for 17 gait parameters based on computer vision. IEEE Trans Instrum Meas 2025;74:5027114.
28. Hösl M, Egger M, Bergmann J, Amberger T, Mueller F, Jahn K. Tempo-spatial gait adaptations in stroke patients when approaching and crossing an elevated surface. Gait Posture 2019;73:279-85.
29. Carse B, Bowers R, Meadows BC, Rowe P. The immediate effects of fitting and tuning solid ankle–foot orthoses in early stroke rehabilitation. Prosthet Orthot Int 2015;39:454-62.
30. Meadows B. Tuning of rigid ankle-foot orthoses is essential. Prosthet Orthot Int 2014;38:83.
31. Smith J, DiVito M, Fergus A. Reliability and discriminant validity of the quantitative timed up and go in typically developing children and children with cerebral palsy GMFCS levels I-II. J Pediatr Rehabil Med 2023;16:25-35.
32. Kerkum YL, Buizer AI, Van Den Noort JC, Becher JG, Harlaar J, Brehm MA. The effects of varying ankle foot orthosis stiffness on gait in children with spastic cerebral palsy who walk with excessive knee flexion. PloS One 2015;10:e0142878.