RESEARCH PAPER

# Efficacy of Solid Versus Ground Reaction Ankle Foot Orthosis on Muscular Activity in Children with Spastic Diplegic Cerebral Palsy

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## ABSTRACT

**Background:** The most prevalent cause of motor disability in infants is cerebral palsy (CP). Physiotherapy and orthotic interventions are regarded as essential components of multimodal management for CP. We aimed to detect the impact of solid ankle foot orthosis (SAFO) and ground reaction ankle foot orthosis (GRAFO) on muscle activity in spastic diplegic CP Gross Motor Function Classification Scale (GMFCS) II children.

**Methods:** A cross-sectional study was started in February 2024 and it was conducted on 60 children aged 6 to 12 years, both sexes, with spastic diplegic CP and postural instability, GMFCS level II, spasticity level II in lower limb muscles according to the Modified Ashworth Scale, There are no fixed contractures, and passive range of motion (ROM) is preserved., mild spasticity in the gastrocnemius, and able to follow simple instructions. All children were subjected to full history taking and the following scales: Modified Ashworth Scale (MAS) and GMFCS used to rate muscle spasticity. Surface electromyography data were obtained from four muscles on both sides of the body, (Rectus Femoris, Semitendinosus, Medial Gastrocnemius, and Tibialis Anterior) during three ankle-foot conditions: barefoot during quiet standing, quiet standing wearing SAFO, and quiet standing wearing GRAFO.

**Results:** There was a significant difference in electromyography (EMG) amplitude between barefoot (BF), wearing SAFOs, and wearing GRAFOs ($p = 0.001$). There was a significant decrease in EMG amplitude across multiple muscle groups when wearing SAFOs compared with BF, between BF and GRAFOs, and when GRAFOs were compared with SAFOs ($p = 0.001$).

**Conclusions:** The use of GRAFOs significantly reduces EMG amplitude across multiple muscle groups compared to SAFOs.

**Keywords**: *Spastic Diplegic Cerebral Palsy, Ground Reaction Ankle Foot Orthosis, Solid Ankle Foot Orthosis, Muscular Activity, Electromyography.*

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**Conflict of interest:** None

## INTRODUCTION

Children's motor disabilities are most frequently caused by cerebral palsy (CP) [1]. Disabilities result from compensatory movements during development or lesion to an immature brain. Thus, children with CP typically exhibit a variety of motor impairments, including incoordination, spasticity, and muscular weakness, which can lead to difficulties with balance and walking and may restrict their participation [2]. In treating infants with CP, postural control is a critical goal. Balance and gait training are crucial for the majority of daily activities and aid in the recovery of children from balance, accident, and injury issues [3]

Muscle activation patterns during standing postural responses in children with cerebral palsy classified as GMFCS levels I–III show a greater reliance on **proximal-to-distal recruitment**, in contrast to the **distal-to-proximal pattern** typically seen in children with normal development. [4].

The inefficient and disorganized postural control experienced by CP children is a result of abnormal recruitment patterns and greater co-activation levels of agonist and antagonist muscles. Despite working harder, they are unable to maintain balance as efficiently as their typically developing peers [5].

Physiotherapy and orthotic interventions are regarded as essential components of multimodal management of CP [6].

The solid ankle foot orthosis (SAFO) and the ground reaction ankle foot orthosis (GRAFO) are both distinct varieties of ankle-foot orthoses (AFOs).

From a functional perspective, **GRAFO and SAFO provide similar effects**, as both generate a corrective internal plantarflexion moment at the ankle when

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dorsiflexion occurs. Nevertheless, they achieve this outcome through **distinct yet mechanically equivalent designs**. The SAFO uses a posterior shell combined with an anterior strap to stabilize the tibia and limit ankle dorsiflexion, whereas the GRAFO relies on an anterior tibial shell to engage the tibia and restrict dorsiflexion. [7].

We aimed to contrast the GRAFO and SAFO impact on muscle activity in spastic diplegic CP (GMFCS II) children.

We hypothesized that there is no significant difference between SAFO and GRAFO on muscle activity in spastic diplegic CP (GMFCS II) children.

**Patients and Methods**

This cross-sectional study was performed on 60 children, both sexes, aged 6 to 12 years, diagnosed with CP spastic diplegia and postural instability, GMFCS level II, spasticity level II in lower limb muscles according to the Modified Ashworth Scale, no fixed contractures beyond passive range of motion (ROM), mild spasticity in the gastrocnemius, and able to follow simple instructions.

Exclusion criteria: Affections of the musculoskeletal system including fixed contractures, visually detected vestibular sensory disorders or cerebellar disease, cognitive deficits or disturbed consciousness, Botox injection within the last 6 months, any GMFCS level other than II, spastic genu recurvatum, and spasticity level in lower limb muscles more than 2 based on Modified Ashworth Scale.

**Grouping**:

All children were subjected to full history taking (name, age, sex, height, and weight), and the following scales: GMFCS and Modified Ashworth Scale (MAS) used to rate muscle spasticity.

**Procedure:**

First, all children were cast and fitted with SAFOs, as the SAFOs were created using a custom-fabricated cast for each child. In this investigation, the AFOs were custom-molded from 3-mm-thick polypropylene utilizing a negative cast technique. The brace's footplate extended to the toes' ends, and the proximal part extended posteriorly to just below the fibular head.

Additionally, a GRAFO was employed by a professional pediatric orthotist, using a custom-fabricated cast for each child. The GRAFOs were custom-molded from 3-mm-thick polypropylene utilizing a negative cast technique. The brace's footplate extended to the toes' ends, and the proximal portion extended anteriorly to just below the fibular head. Each subject was tested in three ankle-foot conditions in the following order: barefoot, wearing bilateral SAFOs, and wearing GRAFOs. The participants were asked to stand independently for up to one minute under each condition.

Electromyographic (EMG) data were recorded bilaterally from four muscles (gastrocnemius, tibialis anterior, rectus femoris, and semitendinosus) during quiet standing (feet side by side) via Neuro-EMG-Micro (LLC "Neurosoft", Russia). Electrode placement procedures were as follows:

- **Rectus femoris:** two active electrodes positioned 2 cm apart, parallel to the muscle fibers.
- **Semitendinosus:** two active electrodes affixed to the medial thigh, approximately 3 cm from the lateral thigh border and halfway from the gluteal fold to the back of the knee.
- **Tibialis anterior:** two active electrodes spaced 2 cm apart, positioned parallel and just lateral to the medial tibial shaft, one-quarter to one-third between ankle and knee.
- **Medial gastrocnemius:** two electrodes 2 cm apart, parallel to muscle fibers, just distal to the knee and 2 cm medial to midline.

**Primary outcome:** assessing muscle activation patterns.

**Statistical Analysis**

Descriptive statistics of frequencies, mean, and standard deviation were conducted for expression of the subject characteristics. ANOVA with repeated measure was conducted for comparison of EMG amplitude between Bare Feet, wearing AFOs, and wearing GRAFOs. Post-hoc tests were conducted to facilitate subsequent multiple comparisons, utilizing the Bonferroni correction.

The level of statistical significance was set at $p < 0.05$ for all analyses. All statistical tests were conducted using IBM SPSS Statistics for Windows, version 25 (IBM SPSS, Chicago, IL, USA).

**RESULTS**

**Subject Characteristics:**

There were sixty infants with spastic diplegic CP involved in this investigation. Their mean ± SD weight, age, and height were 31.62 ± 6.25 kg, 9.52 ± 1.74 years, and 133.92 ± 10.47 cm, respectively. Participant characteristics are presented in **Table 1**.

**Effect of orthosis on muscles EMG amplitude:**

**Table 2** indicates the mean EMG amplitude for various muscles in three different conditions (BF, SAFOs, GRAFOs). There was a significant difference in muscle EMG amplitude between barefoot, wearing SAFOs, and wearing GRAFOs ($p < 0.001$).

**Table 3** compares EMG amplitudes for various muscles under different conditions. A significant decrease was found in the EMG amplitude of the right and left medial gastrocnemius, right and left tibialis anterior, right and left rectus femoris, and right and left semitendinosus when wearing SAFOs or GRAFOs compared with barefoot ($p = 0.001$). There was also a significant decrease in the EMG amplitude of the right and left medial gastrocnemius, right and left tibialis anterior, right and left rectus femoris, and right and left semitendinosus when wearing GRAFOs compared with SAFOs ($p = 0.001$).

**Table 1.** Participant characteristics.

| | Mean ± SD | Minimum | Maximum |
|---|---|---|---|
| **Age (years)** | 9.52 ± 1.74 | 6 | 12 |
| **Weight (kg)** | 31.62 ± 6.25 | 21 | 42 |
| **Height (cm)** | 133.92 ± 10.47 | 110 | 150 |
| **Sex, N (%)** | | | |
| **Boys** | 22 (36.7%) | | |
| **Girls** | 38 (63.3%) | | |

**SD, Standard deviation**

**Table 2.** Mean EMG amplitude of left and right medial gastrocnemius, left and right tibialis anterior, left and right rectus femoris, left and right semitendinosus in BF, wearing SAFOs and wearing GRAFOs:

| | BF | SAFOs | GRAFOs | F- value | p- value |
|---|---|---|---|---|---|
| | mean ± SD | mean ± SD | mean ± SD | | |
| **Right medial gastrocnemius** | 380.77 ± 8.59 | 310.35 ± 7.93 | 208.42 ± 4.59 | 30588.83 | 0.001 |
| **Left medial gastrocnemius** | 428.10 ± 9.46 | 335.22 ± 6.98 | 257.72 ± 4.84 | 23169.27 | 0.001 |
| **Right tibialis anterior** | 585.90 ± 6.95 | 410.77 ± 8.58 | 304.12 ± 7.58 | 55425.81 | 0.001 |
| **Left tibialis anterior** | 418.07 ± 6.84 | 329.05 ± 6.19 | 281.60 ± 6.26 | 18981.86 | 0.001 |
| **Right rectus femoris** | 410.43 ± 5.48 | 367.60 ± 7.12 | 275.03 ± 7.92 | 21310.93 | 0.001 |
| **Left rectus femoris** | 336.48 ± 6.63 | 250.65 ± 6.17 | 187.02 ± 6.51 | 159077.79 | 0.001 |
| **Right semitendinosus** | 362.85 ± 8.21 | 279.28 ± 6.30 | 188.87 ± 4.77 | 56659.91 | 0.001 |
| **Left semitendinosus** | 310.72 ± 7.09 | 212.15 ± 7.03 | 126.43 ± 4.50 | 32444.49 | 0.001 |

**SD, Standard deviation; p value, Probability value**

**Table 3.** Comparison of left and right medial gastrocnemius, left and right tibialis anterior, left and right rectus femoris, left and right semitendinosus EMG amplitude between BF, wearing SAFOs and wearing GRAFOs.

| EMG amplitude (μV) | BF vs SAFOs | | BF vs GRAFOs | | SAFOs vs GRAFOs | |
|---|---|---|---|---|---|---|
| | MD (95% CI) | p value | MD (95% CI) | p value | MD (95% CI) | p value |
| **Right medial gastrocnemius** | 70.42 (69.06, 71.78) | 0.001 | 172.35 (170.45, 174.25) | 0.001 | 101.93 (100.06, 103.80) | 0.001 |
| **Left medial gastrocnemius** | 92.88 (90.88, 94.89) | 0.001 | 170.38 (168.30, 172.46) | 0.001 | 77.5 (75.74, 79.26) | 0.001 |
| **Right tibialis anterior** | 175.13 (173.01, 177.26) | 0.001 | 281.78 (279.31, 284.26) | 0.001 | 106.65 (105.02, 108.28) | 0.001 |
| **Left tibialis anterior** | 89.02 (87.22, 90.82) | 0.001 | 136.47 (134.26, 138.67) | 0.001 | 47.45 (46.40, 48.50) | 0.001 |
| **Right rectus femoris** | 42.83 (40.92, 44.75) | 0.001 | 135.4 (133.49, 137.31) | 0.001 | 92.57 (91.64, 93.50) | 0.001 |
| **Left rectus femoris** | 85.83 (85.15, 86.52) | 0.001 | 149.46 (148.68, 150.25) | 0.001 | 63.63 (63.18, 64.08) | 0.001 |
| **Right semitendinosus** | 83.57 (82.51, 84.63) | 0.001 | 173.98 (172.32, 175.65) | 0.001 | 90.41 (89.43, 91.41) | 0.001 |
| **Left semitendinosus** | 98.57 (97.54, 99.60) | 0.001 | 184.29 (182.26, 186.30) | 0.001 | 85.72 (83.62, 87.82) | 0.001 |

**MD, Mean difference; CI, Confidence interval; p value, Probability value**

## DISCUSSION

Cerebral palsy (CP) encompasses a group of permanent disorders affecting movement and posture that lead to limitations in activity and arise from non-progressive disturbances to the developing fetal or neonatal brain. The motor impairments associated with CP are often accompanied by secondary musculoskeletal problems and may coexist with epilepsy, as well as impairments in sensation, perception, cognition, communication, and behavior. [8].

A variety of orthoses, involving SAFO, dynamic AFOs, and floor reaction AFOs, have been demonstrated to enhance balance through standing and walking in these children [7].

GRAFOs are modified solid orthoses intended to hold the ankle in an optimal position and reduce excessive knee flexion during standing and walking in children with cerebral palsy. They are distinguished by an anterior trim line at the ankle that extends along the tibia. [9].

In this study, the mean weight, age, and height were 31.62 ± 6.25 kg, 9.52 ± 1.74 years, and 133.92 ± 10.47 cm, respectively. The sex distribution of the study group revealed that there were 22 boys, representing 36.7%, while the number of girls was 38, representing 63.3%.

There was a significant decrease in EMG amplitude when wearing GRAFOs compared with SAFOs in the left and right medial gastrocnemius, left and right tibialis anterior, left and right rectus femoris, and left and right semitendinosus.

Abdelkader [10] detected that 30 spastic diplegic CP children were enrolled in a study that was classified into two groups. One group utilized SAFOs, while the other utilized GRAFOs. The study concluded that GRAFOs were superior to SAFOs in improving the overall balance of spastic diplegic CP children by maintaining proper ankle and foot alignment, as well as reducing knee flexion and crouching while assuming a standing posture, thereby augmenting the proximal strategy for postural balance and control.

The moderate impact of SAFOs and GRAFOs on balance in diplegic CP children was evaluated by Sanad [8]. The investigation involved thirty children of both genders with spastic diplegic CP, aged 6 to 9 years. The participants were randomly allocated to two study groups, each consisting of an equal number of participants. Study group A received the standard physical therapy regimen in addition to the AFO for a period of three months. Group B wore the GRAFO for three consecutive months in addition to the standard physical therapy program. The Biodex balance system (mediolateral and anteroposterior stability indices) was employed to assess balance prior to the commencement of the treatment program and three months later. The results indicated that all stability indices experienced significant improvement in both groups ($p < 0.05$). Additionally, there was a significant difference between the groups when comparing the post-treatment measured indices in favor of study group B ($p < 0.05$).

Furthermore, the findings of the present study are consistent with those of Woollacott et al. [21], who reported that a crouched posture may compromise the ability of children with cerebral palsy to regain postural control. Their results suggest that the use of GRAFOs to reduce crouch positioning may improve postural control and balance in children with spastic diplegic cerebral palsy.

The ankle strategy involved in balance control is more limited by AFOs, as these devices hold the ankle in a neutral position during standing. This restricts normal ankle motions, including dorsiflexion and plantarflexion, as well as subtalar movements such as inversion and eversion. As a result, balance control may rely more on rapid adjustments at the hip joint. In contrast, GRAFOs enhance balance by decreasing crouched posture during standing and promoting proper knee alignment in extension through the use of a hip-based strategy. [10].

Ferdjallah, et al.,[22] noted the preference for these proximal strategies to control static standing balance in CP children. The authors hypothesized that poor ankle control in CP children could result in an elevation in proximal strategy contributions to maintain postural stability.

Leonard et al. [23] investigated postural control and muscle activity in children with cerebral palsy during standing under three conditions: barefoot, wearing prescribed ankle–foot orthoses (AFOs), and using distal control orthoses (DCOs) with an anterior shell designed to stabilize the foot–ankle complex and align the shank. The study included 10 participants, all classified as GMFCS level III. Outcomes were assessed using standing duration and the modified Clinical Test of Sensory Interaction on Balance, with electromyographic (EMG) recordings from seven muscles. The results showed a significant reduction in center of gravity (COG) sway velocity when using the DCO compared with barefoot and AFO conditions, along with decreased loss of balance and increased standing duration relative to barefoot standing. However, DCO use produced minimal changes in EMG activity.They hypothesized that DCO would enhance static standing by influencing proximal–distal muscular relationships and total muscular activity; however, their results did not support this hypothesis.

Burtner et al. reported no significant differences in proximal–distal muscle activity. Although the distal control orthosis with an anterior shell reduced center-of-gravity sway velocity, the EMG findings did not indicate corresponding changes in muscular activity associated with the DCO. [24].

We recommend further studies comparing both orthoses to enhance the generalizability of our findings. Future research should involve larger sample sizes and multicenter collaboration to validate the results and to investigate the long-term effects of these orthoses on muscle strength and overall mobility. GRAFOs may represent a promising option for improving muscle activity in children with spastic diplegic cerebral palsy.

## LIMITATIONS:

There was a relatively modest sample size. A singular center was the location of the investigation.

## CONCLUSIONS

The use of GRAFOs significantly reduces EMG amplitude across multiple muscle groups compared to SAFOs.

The GRAFOs may alter muscle activation patterns, which could have implications for rehabilitation and functional outcomes in paediatric patients.

GRAFOs may serve as an initial stage in the therapeutic process to enhance standing, giving individuals the chance to practice intersegmental joints coordination to achieve more effective postural control and to reduce the amount of muscular effort required while standing.

**List of abbreviations:**

| CP | Cerebral Palsy |
|---|---|
| SAFO | Solid Ankle Foot Orthosis |
| GRAFO | Ground Reaction Ankle Foot Orthosis |
| GMFCS | Gross Motor Function Classification Scale |
| ROM | Range of Motion |
| MAS | Modified Ashworth Scale |
| EMG | Electromyography |
| BF | Barefoot |
| AFOS | Ankle-Foot Orthoses |

## DECLARATIONS

**Human Ethics and Consent to Participate declarations**

Written informed consent was obtained from the parents of all participating minors. The study was approved by the Ethical Committee of Cairo University (No. P.T.REC/012/004840) and was registered at ClinicalTrials.gov (ID: NCT06291974) in February 2024, in accordance with the Declaration of Helsinki.

**Consent to Participate:** Not applicable.

**Consent for publication**: All authors have provided their consent for publication in the journal.

**Availability of data and material:** The data and materials can be made available by the author upon reasonable request.

**Competing interests**: The authors report no conflicts of interest.

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**Authors' contributions:** MSM and KAO conceived and oversaw the study. MEM and KAO conducted the data collection. Data analysis and interpretation were performed by MEM and MMS. All authors contributed feedback during manuscript preparation, and all authors reviewed and approved the final version.

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