Ankle Foot Orthoses for Young Children with Cerebral Palsy: a Scoping Review

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Abstract

Aim: To describe research on outcomes associated with early Ankle Foot Orthosis (AFO) use, AFO use patterns, and parent and clinician perspectives on AFO use among young children with cerebral palsy. **Method:** Arksey and O'Malley's five-stage method was used to conduct a scoping review. MEDLINE (Ovid), PubMed, CINAHL, Cochrane Database of Systematic Reviews, EMBASE, PEDro, Web of Science and Scopus were searched for studies evaluating AFO use with children under the age of six years. Descriptive information was extracted and outcomes categorized according to the International Classification of Functioning, Disability and Health (ICF). Quality assessments were conducted to evaluate methodological rigor. **Results:** Nineteen articles were included in the review; 14 focused on body functions and structures, seven on activity level outcomes and no studies addressed participation outcomes. Evaluations of the effects of AFOs on gross motor skills other than gait were limited. Overall, the body of evidence is comprised of methodologically weak studies with common threats to validity including inadequate descriptions of study protocols, AFO construction, and comparison interventions. **Conclusion:** Research evaluating the effects of AFOs on age-appropriate, functional outcomes including transitional movements, floor mobility and participation in early childhood settings is needed to inform practice regarding early orthotic prescription.

Keywords: ankle foot orthoses, cerebral palsy, young children

Word count: 4071, excluding the abstract and bibliography

Introduction

Cerebral Palsy (CP) affects the development of movement and posture [1] and is characterized by primary impairments including muscle tone abnormalities, muscle weakness, disturbed coordination and decreased selective motor control, all of which can lead to secondary impairments such as muscle and joint contractures, bony deformities and gait deviations [2]. These impairments can cause activity limitations throughout the lifespan [1], and while CP is a non-progressive condition, secondary impairments can progress over time resulting in significant changes to motor function. Health care professionals aim to enhance functional abilities and participation of individuals with CP through a variety of strategies including some focused on the prevention of development of secondary impairments and optimizing efficiency of functional movement [3].

Ankle Foot Orthoses (AFOs) are frequently used with children with CP to prevent musculoskeletal deformities and to provide support and stability during standing and walking [4]. They are considered a mainstream treatment option and are often used in combination with other interventions to improve biomechanical alignment during gait. It is assumed that improved biomechanical alignment increases gait efficiency [5] and gait control [6-8]. For example, children with CP often present with spasticity in the gastrocnemius-soleus muscles and AFOs are used to control equinus position of the foot by limiting excessive ankle plantar flexion during gait [5, 9]. In addition to the biomechanical advantage of decreasing plantar flexion, AFOs may delay or prevent the alteration of the gastrocnemius musculotendinous unit architecture [10]. Multiple studies have suggested other positive, gait-related, biomechanical effects of AFOs with older children [9, 11, 12] including increased stride length [9, 11, 13-16], velocity [7, 13-17], and reduced energy expenditure [17-19]. The potential for adverse effects of long-term AFO use, particularly those related to decreased gastrocnemius and soleus muscle strength have also been proposed [5].

While gait-related outcomes associated with AFO use are important, the effects of AFOs on other gross motor skills, such as running, stair climbing, floor mobility [20], and participation in meaningful activities also require evaluation. A broad consideration of outcomes is particularly important for young children since orthoses are often prescribed before the age of six years [10], when they may prevent joint motion necessary for floor mobility and transitioning between positions on and off the floor. Since many young children with CP are still developing their motor skills [21], any devices perceived by parents to adversely affect movement, cause skin irritation, disuse atrophy, or movement limitations may offset suggested advantages of AFOs [22]. Therefore, in addition to understanding the effects of AFOs on outcomes, it is also imperative to have insight into the factors that influence AFO use in young children. Several reviews have addressed AFO use in children and youths with CP [6, 8, 12, 23, 24], however, none have focused on children under the age of six years. The overall aim of this scoping review was to describe the body of literature evaluating AFO use with young children with cerebral palsy.

Methods

Arksey & O'Malley's five-stage process for scoping review studies [25] was used to conduct this review. While systematic reviews typically focus on articles with high level of evidence and quality to determine evidence to support specific outcomes of interest [25], scoping reviews describe existing research literature and highlight evidence gaps, thus representing a better fit with the review objectives. Although quality appraisal is not discussed in the framework presented by Arksey & O'Malley [25], incorporating the quality analysis for scoping studies has been recommended as a strategy for identifying methodological gaps [26, 27]. In keeping with these more recent recommendations, we also conducted a quality analysis to describe the level of evidence and quality of existing research. We adhered to the Preferred Reporting Items for Systematic reviews and Meta-Analysis Extension for Scoping Reviews (PRISMA-ScR) reporting guidelines [28].

Stage 1: Identification of Research Questions

The three research questions were: 1) What outcomes associated with early AFO use in young children with cerebral palsy have been evaluated? 2) What research has been conducted to describe AFO use patterns in young children with cerebral palsy? 3) What studies have explored parent and clinician perspectives on AFO use among young children with cerebral palsy?

Stage 2: Identification of Relevant Studies

Search strategies were developed in collaboration with a medical librarian, using the keywords "cerebral palsy" and "ankle foot orthosis." The following eight databases were searched for relevant articles published until March 2018: MEDLINE (Ovid), PubMed, CINAHL, Cochrane Database of Systematic Reviews, EMBASE, PEDro, Web of Science and Scopus using database specific search queries. In addition, references in the selected articles were hand searched to ensure all relevant studies were identified. An example search strategy conducted in February 2018 is provided in Appendix A.

Stage 3: Study Selection

Inclusion criteria were original studies written in English that described outcomes associated with AFO use, AFO use patterns, or family and clinician experiences with AFO use with children with cerebral palsy under six years of age. Studies with a portion of participants six years and older were included if data for children under six years of age were extractable (e.g., case studies), or if the sample included at least 50% of children younger than six years. Where it was not possible to determine the proportion of children under six years of age, studies with a mean age less than six were included. Conference abstracts, reviews and study protocols were excluded but were used to search for additional, relevant articles. Studies that evaluated AFOs in conjunction with other rehabilitation interventions were also excluded.

Study selection was conducted in two phases according to the protocol outlined by Arksey & O'Malley [25]: 1) Titles and abstracts were reviewed and screened for relevance by one reviewer (PF). 2) Articles selected for full-text review were assessed independently by two reviewers (PF and LPW). The reviewers met to discuss discrepancies and to reach consensus on the articles to be included. The selection process is summarized in Figure 1.

[Insert Figure 1 approximately here]

Stage 4: Charting the Data

The authors developed a data charting form to facilitate documentation. The form was pilot tested by two reviewers and modified to ensure relevant information was included. Data from the studies were charted independently by two reviewers (PF and LPW) and then discussed for the purpose of reaching consensus. General descriptive information about the study including authors, year and country of publication, study design, research objectives, participant information (i.e., age, CP sub-type, and Gross Motor Function Classification System (GMFCS) levels), interventions, and results were charted and tabulated. Outcomes evaluated were then classified using the conceptual framework of the International Classification of Functioning, Disability and Health (ICF) framework [29].

In order to consider methodological rigor of this body of research, level of evidence and quality of quantitative studies were assessed using the American Academy for Cerebral Palsy and Developmental Medicine (AACPDM) methodology for systematic reviews study conduct rating tool [30]. Consistent with the AACPDM methodology for systematic reviews, only group and single case design studies with level of evidence I-III were considered for quality appraisal [30]. The AACPDM group study conduct evaluation tool includes seven questions designed to detect threats to internal validity including adherence to inclusion/exclusion criteria and group assignment, assessor's awareness of group assignment and adequate control for confounding variables. Group studies are classified as strong with a score of six or seven, moderate with a score of four or five and weak if the score is less than three. Single case design studies with a score of 11-14 out of 14 questions are considered strong, seven to ten as moderate, and less than seven as weak quality [30]. Critical appraisal of qualitative research was conducted using the Joanna Briggs Institute (JBI) checklist for qualitative studies [31]. This tool is a ten-item checklist intended to evaluate rigor, with an emphasis on methodological cohesiveness. A score of ten indicates high quality. Independent raters (PF and LW) completed ratings for all included studies and then met to compare responses and reach consensus. Discrepancies (n=2 levels of evidence) were resolved by a third rater (LS).

Stage 5: Summarizing and Reporting the Results

Results are provided in Table 1. The 19 included studies were published between 1986 and 2018; the number of publications remained relatively consistent over time. The largest proportion of studies (n=8) were authored by researchers in the USA [32-39], followed by the UK (n=2) [40, 41], Canada (n=2) [42, 43], China (n=2) [11, 44], South Korea (n=2) [45, 46], Egypt (n=1) [47], Iran (n=1) [48], and Belgium (n=1) [49] (Tables 1 & 2).

[Insert Table 1 approximately here]

[Insert Table 2 approximately here]

Study Design, Level of Evidence and Quality Assessment

Of the 19 included articles, five were randomized controlled trials [32, 33, 44, 47, 48], including two randomized cross over design studies [32, 33]. In addition, there were three single-case design studies [37, 38, 41], three case-control studies [11, 39, 49], four case reports [34-36, 42], two cohort studies; one with a concurrent control group [46] and one without a control group [45], and a case series [40]. Only one qualitative study, an interpretive description, was identified and included [43].

The AACPDM level of evidence and quality assessment ratings for group and single case design studies [30], are presented in Tables 1, 3 & 4. Of the 15 group design studies, one was level I [44], four were level II [32, 33, 47, 48], and one was level III [46]. The remaining nine studies were identified as level IV [11, 39, 40, 45, 49] and V [34-36, 42]. Of the three single case design studies, only one was level I [38], and the other two were classified as level IV [37, 41].

In our assessment of group studies, only the small randomized cross over design study (Level II) received a strong score [32]. Three studies were assessed as moderate [33, 44, 46], and two as weak quality [47, 48]. The only eligible single subject design for quality appraisal, the alternating treatment design, was determined to be of moderate quality [38].

The one included qualitative study [43] received a score of eight out of 10 (Table 5). A description of interventions, outcomes evaluated, and key findings are presented according to the three study objectives below.

[Insert table 3 approximately here]

[Insert table 4 approximately here]

[Insert table 5 approximately here]

Outcomes Associated with AFO Use

Seventeen studies evaluated outcomes associated with AFO use. These outcomes are reviewed and summarized according to the ICF dimensions (Table 6).

Body Functions and Structures: Gait parameters including kinetics, kinematics and gait patterns (n=8) [11, 34, 35, 37, 40-42, 49], balance and stability (n=4) [38, 45-47], range of motion (n=8) [11, 34, 35, 37, 39, 41, 44, 49], and muscle activity with electromyography (EMG) (n=3) [11, 44, 49], were the outcomes evaluated in the ICF Body Functions and Structures dimension. Only three of these studies were identified as level I-III of evidence [38, 46, 47] and the quality of these studies ranged from weak [47] to moderate [38, 46]. These three studies evaluated the effects of AFOs on standing balance [47], independent standing [38], postural stability and postural control mechanisms [46]. Positive effects of AFOs on independent standing [38], standing balance [47], and postural control mechanisms were reported [46].

Activity and Participation: Outcomes evaluated in the ICF Activity domain included gross motor function as measured by the Gross Motor Function Measure (GMFM) (n=4) [32, 35, 36, 48], active time walking (n=1) [33], and motor strategies for sit-to-stand transition (n=1) [39]. Three of these studies were assessed as level II evidence, with quality ratings of weak [48], moderate [33], and strong [32]. Two of these studies reported positive effects of AFOs on gross motor skills (crawling, kneeling, etc.) [32], standing and walking abilities [48], while the authors of the moderate quality study did not report any improvement in community walking activity [33]. No studies included evaluations of participation. Outcomes and outcome measures used in the included studies are classified by ICF dimensions and summarized in Table 6.

[Insert Table 6 approximately here]

AFO Characteristics: Six studies compared the effects of two different types of AFOs [11, 34, 39, 42, 48, 49]. Three of these studies compared solid (rigid) with hinged AFOs [34, 42, 48]. All three studies reported improvements in gait and standing with hinged AFOs. However, the methodological quality varied among these studies; one was a level II with weak quality [48], and the other two were level V [34, 42]. Lam et al. [11] compared the effects of conventional (solid) and dynamic AFOs on gait and concluded that they have unique short-term effects; conventional (solid) AFOs increased the function of calf muscles and improved walking endurance while dynamic AFOs caused less ankle restriction and better management of equinus positioning of the foot [11]. Wilson et al. [39] evaluated articulated AFOs in locked and unlocked positions to determine the effect on sit-to-stand transfer time. The unlocked position decreased sit-to-stand time compared to the locked position [39]. The study that compared the effects of posterior leaf spring and dual carbon fiber spring AFOs on gait patterns demonstrated a greater improvement of ankle push-off with the latter AFO type [49]. However, all three studies [11, 39, 49] were classified as level IV evidence.

Four studies compared the effects of different AFO types on walking activity in community-based settings [33], walking patterns [41], subtalar joint alignment during molding of AFOs [35], and compensatory gait strategies due to orthoses induced restrictions in joint movement [36]. One of these studies was identified as level II [33] and three were classified as level IV-V evidence [35, 36, 41]. While the studies with lower levels of evidence reported positive effects of supramalleolar orthoses [35, 36], hinged [36, 41] and solid AFOs [35, 41], the study with level II evidence did not find any difference in either walking activity level (number steps/day & proportion of time walking) or intensity (number of strides/day & peak activity index) between supramalleolar orthosis, non-articulated, hinged, and solid AFOs [33].

Seven articles focused on one type of AFO [32, 38, 40, 44-47], either dynamic [32], inhibitive [38], three-side support [47], solid [40] or hinged [44-46]. These studies included evaluations of the effects of day vs. day-night use [44], sit-to-stand transfer time [45], and postural stability and control mechanisms [46] using hinged AFOs, and the effects of solid AFOs on gait [40]. In addition, one study evaluated the effects of dynamic AFOs on gross motor skills [32], and the effects of inhibitive AFOs [38] or three-side support AFOs [47] on standing balance. Two of the seven studies were identified as level I (moderate quality) [38, 44], two as level II (one strong [32] and one weak quality [47]) and one study as level III evidence (moderate quality) [46]. The remaining two studies were identified as level IV evidence [40, 45]. All studies reported positive effects associated with AFO use.

One study (level IV evidence) evaluated the effect of Neurodevelopmental Treatment (NDT) in isolation and in combination with inhibitive AFOs [37]. It was reported that NDT was more effective in isolation for decreasing knee flexion over time, but the combined method had better immediate effects on decreasing excessive knee flexion [37]. However, since the study was non-randomized single case design (low level of evidence) and was not replicated across more than one subject, inferences about effectiveness are limited. No long-term longitudinal studies were included in the review. A description of the AFOs evaluated in each study and key findings are presented in Table 1.

AFO Use Patterns in Young Children with CP

Only one study addressed outcomes associated with AFO use patterns, a large RCT (level I, moderate quality) [44]. Zhao et al. [44], examined the effects of day vs. day-night use of hinged AFOs among young children with CP on gross motor skills, muscle activation (EMG), and passive ankle range of motion. There was an improvement in range of motion and GMFM scores after using AFOs for both day and day-night groups, but there was no difference in range of motion between the two groups. Also, GMFM scores were higher for the day wear group compared to the day-night wear group [44]. No studies describing actual AFO use patterns of young children were identified for inclusion in this review.

Parent and Clinician Experience with AFO Use

Only one study explored clinician experience with prescribing AFOs for children with CP. This qualitative study suggested that orthotic prescription is a dynamic process based on clinician assessment and collaboration of the rehabilitation team [43]. No studies about parent's perspective and experience associated with their children's AFO use were identified.

Discussion

This review confirmed a predominant focus on gait-related outcomes in research evaluating AFOs with young children with CP and revealed some gaps related to evaluating the effects on other age-appropriate gross motor skills. While a previous review suggested that wearing AFOs might create challenges for daily routines and floor mobility of young children who have less developed motor skills [20], the effects of AFOs on these outcomes have not been evaluated. Clinicians often recommend limiting AFO wear time to certain hours when children wear shoes. This strategy could overcome movement restrictions caused by AFOs that affect floor mobility when children are not wearing shoes. However, shoe removal may not be appropriate for some community settings such as preschools and daycares. In addition, adherence to limiting AFO wear time when shoes are on might not be an ideal strategy for younger children who spend a significant amount of time on the floor. Thus, additional research is required to evaluate the effects of AFOs on a broader range of age-appropriate gross motor skills and other meaningful outcomes including activities specific to young children who use different movement strategies, such as crawling and bottom shuffling to explore their environment. Furthermore, the effects of AFO-footwear combination tuning with younger children need to be evaluated. While one level IV study evaluated the effects of AFOs with shoes on/off in young children [49], none of the studies included evaluation of the effects of AFO-footwear combination tuning on functional outcomes with younger age groups. The effects of optimal AFO-footwear combination tuning on participation outcomes also requires attention since the main reason for providing AFOs is to improve walking function so that children can participate in the activities that are meaningful to them [50].

We conducted a quality appraisal to allow a description of the methodological quality of this body of literature. The level of evidence and quality evaluations revealed a weak evidence base with few studies using rigorous research designs and strategies to avoid threats to validity. Absence of power calculations [32, 33, 46-48], unmasked assessors [46, 47], lack of clear descriptions of interventions [44, 49], and inclusion/exclusion criteria [47, 48] were common sources of potential biases among the level I-III studies evaluated. This finding is consistent with systematic reviews on AFO use by older children [6, 24]. While case studies can be valuable for highlighting novel approaches and previously unreported findings, lack of randomized, controlled trials or rigorous single subject designs limits the ability to make inferences about effectiveness and inform practice. Single subject and randomized, cross over designs may be feasible in clinical settings as these designs allow for smaller sample sizes while still allowing for rigorous evaluations of the effects of AFOs.

This review also revealed a lack of a standard terminology about AFO types, which makes comparison across studies challenging; a limitation identified in previous reviews [6, 20, 24, 51]. Ambiguity creates challenges with generalizability of the findings and valid comparisons across studies. Ridgewell et al. [12] suggested use of reporting guidelines for AFO interventions for children with CP, and emphasized the importance of reporting AFO design and material details to facilitate comparison of different types of AFOs and to facilitate study replication [12]. Despite these recommendations, a recent literature review by Eddison et al. [51] confirmed that studies evaluating AFOs for children with CP still lack adequate descriptions of AFO construction. Adherence to reporting guidelines would provide consistency, facilitate comparison of findings across studies, and enable the conduct of meta-analyses.

The small number of articles included in our scoping review also highlighted the lack of studies focused on AFO use in children under the age of six. Assessing the effects of AFOs in natural environments, such as child care and community settings, may be an effective way to expand the evaluation of outcomes with this group of children and families. Evaluation of children's functioning in their homes, schools, and communities would provide valuable contextual information relevant to participation; daily challenges that may not be apparent in controlled, clinical settings. While research with this younger age group can be more challenging [39, 52], the different position transitions, variety of mobility methods, and potential for unique parent's perspectives on AFO use necessitate evaluations specific to this age group.

We identified only one study exploring clinicians' perspectives about AFO prescription for children with CP [43], and we found an absence of studies about parent experience. Kane et al.

[43], aimed to identify underlying patterns associated with clinical AFO prescription. Collaboration of rehabilitation team members and evaluation of AFO outcomes were presented as influential factors in decision making in regards to AFO prescription [43]. However, these factors could be affected by inexperienced individual clinicians, possibly resulting in children not receiving the optimal orthoses type. This insight into clinical practice highlights the value of qualitative research that elucidates the subjective experiences of clinicians that affect how they approach AFO prescription and consultation with families.

AFO use often declines after the age of five [10], and therefore, longitudinal research to explore use patterns and challenges associated with AFO use is also warranted. A qualitative study conducted with parents of children between 4-18 years [53] (not included in this review) suggested that parents perceived dynamic AFOs had positive effects on posture and alignment, and psychosocial factors such as participation in play and peer activities [53]. Research exploring parent perspectives would also be valuable for informing clinical practice as parent and child experience with AFO use in daily life will likely affect how much and where they decided to use them. Qualitative research with parents also has the potential to inform prescription guidelines for younger children as setting meaningful goals for AFO use is an important consideration during the prescription process [23]. Gaining insight into parent’s perspective and experience may also assist with the development of family-centered guidelines for wear time recommendations, ideal age or stage of development for prescription, as well as providing the basis for discussion about the activities that may be affected by AFOs.

Finally, there were no longitudinal studies included in our review. While we were likely to exclude those that evaluated older children or adults, this gap has been noted previously [8, 20]. Longitudinal study designs would provide additional information about the long-term effects of

AFO use, including possible contributions to muscle weakness, effects on the development of contractures and associated long-term effects on activity and participation level outcomes.

Limitation & Future Research Directions

Since we limited the search to children under six years, we may have excluded longitudinal studies that included some data for younger children.

Findings of this scoping review highlight the need for more rigorous research evaluating the effects of AFOs on activity and participation level outcomes for children with CP. In particular, the evidence base would benefit from studies with more rigorous methodologies, more detailed information about AFO design and parallel interventions, and additional qualitative studies to explore perspectives of parents regarding AFO prescription and use. A broader perspective on outcomes, in addition to evaluating the effects of AFOs on gait, would be beneficial. For example, studies with young children could include the effects of AFOs on floor mobility, transitional movements, and participation in age-appropriate play. Addressing these evidence gaps could inform evidence-based protocols for prescribing AFOs for young children with CP.

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Declaration of Interest

The authors report no conflict of interest.

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Appendix A. Search Strategy for Medline (Ovid) Database.

1. exp Foot Orthoses/
2. ((ankle-foot) adj2 (orthos$ or orthotic$ or brace$ or splint$ or support$)).mp
3. ((ankle or foot) adj2 (orthos$ or orthotic$ or brace$ or splint$ or support$)).mp
4. ((lower-limb$) adj2 (orthos$ or orthotic$ or brace$ or splint$ or support$)).mp.
5. ((lower extremit$) adj2 (Orthos$ or Orthotic$ or Splint$ or brace$ or support$))
6. exp Orthotic Devices/
7. exp Braces/
8. 6 OR 7
9. exp Ankle Joint/ or exp Ankle/
10. exp Foot/ or exp Foot Joints/
11. 9 OR 10
12. 8 AND 11
13. exp Lower Extremity/
14. 13 AND 8
15. 1 OR 2 OR 3 OR 4 OR 5 OR 12 OR 14
16. exp Cerebral Palsy/
17. (Cerebral Pals$).mp.
18. 16 OR 17
19. 15 AND 18

Table 1.Quantitative Study Description

Author	Country	Participants*	Study Design, & Level-Quality**	Aim/Purpose of Study	Intervention(s)	Key findings
Bjornson et al. (2006) [32]	USA	n=23, 1 year 9 months - 7 years 3 months, spastic, GMFCS I (n=6), II (n=3) & III (n=14)	Randomized cross-over design, II- S (6/7)	To examine the immediate effect of bilateral dynamic AFOs on crawling, kneeling, standing, walking, running and jumping skills.	Dynamic AFOs	Dynamic AFOs improved gross motor skills in a clinical setting.
Bjornson et al. (2016) [33]	USA	n=11, 3 - 6 years old, bilateral CP, GMFCS I (n=1), II (n=9) & III (n=1)	Randomized cross-over design, II- M (4/7)	To examine the effects of AFOs on walking activity in the community	All participants wore prescribed orthoses (supramalleolar orthosis, non-articulated, hinged & solid AFOs) or no orthoses for two weeks in random order	AFO/footwear did not affect number steps/day, % time walking, number of strides/day >30 strides/min & peak activity index.
Butler et al. (1992) [40]	UK	n=6, 3 years 7 months - 6 years 5 months, hemiplegia (n=1), diplegia (n=5), GMFCS NR	Case series, IV	To examine the effects of adjusted, solid AFO use and balance training with children with CP	Solid AFOs with passive stretching of ankle dorsiflexion, balance training of 10-15 minutes for 4-6 months	Decreased magnitude of knee-extension moment arm toward normal occurred when barefoot. Improvement was noted for knee-extension moments, foot/ground contact and stance phase posture. Improvements were not related to range of motion or speed.
Carmick (1995) [34]	USA	n=1, 18 months, spastic diplegia, GMFCS NR; the participant was ambulatory	Case report, V	NR	Solid and then hinged AFOs with physical therapy once a week to increase ankle range of motion	Hinged AFOs allowed more ankle and forefoot mobility which led to biomechanical gait changes. They also were associated with improved balance, strong heel strike and less internal rotation of legs.
Carmick (2012) [35]	USA	n=4, Case 3: 4 years, spastic diplegia Case 4: 3 years 5 months, ataxia & hypotonia Both GMFCS III (Cases 1 & 2 excluded based on age)	Case report, V	To illustrate the importance of subtalar joint alignment during casting for an orthotic device.	Solid AFO & supramalleolar orthosis	Molding orthosis in a position other than the neutral position of the subtalar joint had detrimental impacts on lower limb joints alignment which contributed to gait deviation, pressure sores and inability to walk.
Carmick (2013) [36]	USA	n=3, Case 1: 4 years, spastic diplegia, GMFCS II	Case report, V	To illustrate compensation strategies while wearing AFOs	Hinged AFO & supramalleolar orthosis with electrical stimulation	Internal hip rotation and toe walking occurred when orthoses blocked digit extension.

		Case 2: 6 years, spastic quadriplegia, GMFCS II Case 3: 4 years 11 months, spastic diplegia GMFCS III				
Dalvand et al. (2013) [48]	Iran	I: n=20, C: n=10, 4 - 8 years old, spastic diplegia, GMFCS I (n=12), II (n=13) & III (n=5)	Randomized controlled trial, II- W (2/7)	To examine the effects of hinged and solid AFOs on standing and walking abilities	NDT for 3 months (3, 1 hour sessions/week) with hinged or solid AFOs for the intervention groups and barefoot for the control group	Hinged AFOs improved standing and walking.
Desloovere et al. (2006) [49]	Belgium	I: n=15, 4 - 10 years, spastic hemiplegia, GMFCS NR C: n=51 (historical TD controls), 3 to 11 years	Case-control study, IV	To evaluate the effects of two types of orthoses on gait in a homogeneous group of children, using both barefoot and shoe walking as a control condition.	Posterior leaf spring & dual carbon fiber spring AFOs combined with shoes for the intervention group.	Both AFOs improved gait patterns, however, push-off at the ankle improved significantly with the carbon fiber spring AFO. Combination of both orthoses and shoes were necessary for improving spatiotemporal parameters of gait.
Embrey et al. (1990) [37]	USA	n=1, 2 years 8 months, spastic diplegia, GMFCS NR; the participant ambulated independently	Single subject design (A-B-A-BC-A), IV	To examine the effectiveness of inhibitive ankle-height orthoses used in conjunction with NDT and effectiveness of NDT in isolation to decrease excessive knee flexion during gait.	Bilateral inhibitive AFOs with NDT (30-minute session, 3 times per week for 3 months)	The use of NDT alone was more effective than the combination of NDT and AFOs. However, the combination had a more immediate effect on excessive knee flexion during gait.
Hainsworth et al. (1997) [41]	UK	n=12, 3 years 11 months - 7 years 5 months, spastic diplegia (n=8) & spastic hemiplegia (n=4), GMFCS NR; all children were ambulatory	Single subject design (ABAB), IV	To examine the effects of AFOs on walking patterns	Hinged & solid AFOs with routine physiotherapy	AFOs improved joint range of movement and gait (mediolateral shear force).
Harris & Riffle (1986) [38]	USA	n=1, 4 years 5 months, spastic quadriplegia, GMFCS NR; the participant could sit, knee-walk, pull-to-stand by half-kneeling over the right foot and stand independently for 10 seconds without orthoses	Single subject design (alternating treatment), I-M (9/14)	To examine the effects of inhibitive AFOs on independent standing	Inhibitive AFOs	AFOs improved the duration and maintenance of standing balance as well as standing pattern symmetry.

Lam et al. (2005) [11]	China	I: n= 13, 3 years 3 months - 9 years 7 months, spastic diplegia with moderate dynamic equinus, GMFCS NR C: n=18 , age: NR	Case-control study, IV	To examine the effects of different orthotics on gait	Conventional (solid) & dynamic AFOs for the Intervention group. Control group was assessed barefoot	Both AFOs were associated with increased stride length, better control of equinus and limited plantarflexion at push off. However, plantar flexion limitation at push-off was lesser with dynamic AFOs. Conventional AFOs reduced the median frequency of muscle firing which may result in improved walking endurance. Ankle movement was less restricted with dynamic AFOs.
Middleton et al. (1988) [42]	Canada	n=1, 4 years 5 months, spastic diplegia, GMFCS NR	Case report, V	To evaluate the effects of rigid & hinged AFOs on gait by using quantitative biomechanical techniques.	Hinged & rigid AFOs	More natural ankle motion, lower knee moment during stance phase and enhanced lower limb symmetry occurred with hinged AFOs compared to rigid AFOs.
Olama et al. (2013) [47]	Egypt	I: n=15 Mean age (SD)= 4.8 (0.77) years, spastic diplegia, GMFCS NR; all subjects could stand with support C: n= 15, Mean age (SD)= 4.4 (0.69) years, spastic diplegia, GMFCS NR; all subjects could stand with support	Randomized controlled trial, II- W (3/7)	To evaluate the effects of three-side support AFOs on standing balance	Three-side support AFOs (30-min session, three times weekly, for 6 months) with therapeutic exercise for the intervention group. Control group received a therapeutic program only.	Practicing with three side support AFO for 6 months, had positive effects on balance control and postural reactions.
Park et al. (2004) [45]	South Korea	I: n=19, 2 - 6 years, spastic diplegia, GMFCS NR; all participants could stand up from a chair independently C: n=21 (historical TD controls), 3-5 years	Cohort study without a concurrent control group, IV	To investigate the effects of hinged AFOs on sit-to-stand transfers	Hinged AFOs	Hinged AFOs improved temporal, kinetic and kinematic parameters of sit-to-stand transfers.
Rha et al. (2010) [46]	South Korea	I: n=21 Mean age (SD)= 6.10 (1.09) years, all with spastic bilateral CP, GMFCS I (n=4), II (n=13) & III (n=4)	Cohort study with a concurrent control group, III- M (5/7)	To compare postural stability and control mechanisms during quiet side by side standing between typically developing children and	Hinged AFO for the intervention group. Control group was assessed barefoot.	Hinged AFO did not improve postural stability in quiet side-by-side standing. They were assisted with postural control.

		C: n= 22, Mean age (SD)= 5.64 (0.49) years, TD controls		bilateral CP and to determine if hinged AFOs have any effects on improving the postural stability and control mechanisms in children with CP		
Wilson et al. (1997) [39]	USA	I: n=15 2 -5 years, spastic diplegia with dynamic equinus, GMFCS NR; children could sit on a bench or stand up from a bench unsupported or by using a pole. C: n=20 , age: NR	Case-control Study, IV	To evaluate the effects of solid and articulated AFOs on sit-to-stand.	Articulated AFOs in locked and unlocked positions (intervention group) compared to barefoot (control).	Articulated AFOs in the unlocked position improved control of equinus and efficiency of sit-to-stand transfers.
Zhao et al. (2013) [44]	China	Day group: n=56, Day-Night group: n=56, 13 months - 4 years, spastic diplegia, GMFCS I (n=48) & II (n=64)	Randomized controlled trial, I- M (5/7)	To compare day vs day and night wear of hinged AFOs	Hinged AFOs with conventional physiotherapy including NDT, hydrotherapy and NES for quadriceps 5 times/week.	No difference between groups

***Participant:** number, age, groups; control & intervention, CP sub-type and GMFCS levels.

**Strong (S) = a score of 6 or 7, Moderate (M) = a score of 4 or 5, Weak (W) = a score of ≤ 3

Abbreviations: I= Intervention group, C= Control group, GMFCS= Gross Motor Function Classification System, NR= Not Reported, AFO= Ankle Foot Orthoses, CP= Cerebral Palsy, NDT= Neuro Developmental Treatment, TD= Typically Developing, SD= Standard Deviation, NES= Neuromuscular Electrical Stimulation.

Table 2. Qualitative Study Description

Author	Methodology	Method	Phenomena of Interest	Setting	Participants	Data Analysis	Themes
Kane et al. (2018) [43]	Interpretive description	Semi-structured, in-person focus groups	AFO prescription and clinical decision-making practices of clinicians	Five rehabilitation centers in four Canadian provinces	Four physiatrists, 17 physiotherapists, 10 orthotists and one kinesiologist, (experience ranging from 1-39 years)	Comparative analysis	AFO prescription is a collaborative, iterative and individualized process.

Table 3. Group Design Studies Conduct Rating Summary

Author	Study Design	Level/Quality*	Inclusion/Exclusion Criteria	Intervention Description	Reliable Outcome Measures	Blinded Assessors	Power Calculation	Dropout/ Loss to Follow-up	Controlling Bias
Bjornson et al. (2006) [32]	Randomized Cross-Over Design	II- S (6/7)	Yes	Yes	Yes	Yes	No	Yes	Yes
Bjornson et al. (2016) [33]	Randomized Cross-Over Design	II- M (4/7)	Yes	Yes	Yes	No	No	Yes	No
Dalvand et al. (2013) [48]	Randomized Controlled Trial, (small RCT, n <100)	II- W (2/7)	No	No	Yes	Yes	No	No	No
Olama et al. (2013) [47]	Randomized Controlled Trial (small RCT, n <100)	II- W (3/7)	No	Yes	Yes	No	No	No	Yes
Rha et al. (2010) [46]	Cohort Study with Concurrent Control Group	III- M (5/7)	Yes	Yes	Yes	No	No	Yes	Yes
Zhao et al. (2013) [44]	Randomized Controlled Trial, (large RCT, n >100)	I- M (5/7)	Yes	No	No	Yes	Yes	Yes	Yes

*Strong (S) = a score of 6 or 7, Moderate (M) = a score of 4 or 5, Weak (W) = a score of ≤ 3.

Table 4. Single Subject Design Conduct Rating Summary

Author	Study Design	Level/Quality	Participants' characteristics	Independent Variable	Intervention Description	Dependent Variable	Inter/Intra-rater Reliability	Blinded Assessor	Stability of Data	Type of Single Subject Design	Adequate Number of Data Points	Replication of Intervention across ≥3	Visual Analysis	Graph for Visual Analysis	Report of Statistical Analysis	Criteria for Statistical Analysis
Harris & Riffle (1986) [38]	Alternating Treatment Design	I-M (9/14)	Yes	No	No	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	No	Yes

*Strong (S) = a score of 11-14, Moderate (M) = a score of 7-10, Weak (W) = a score of < 7.

Table 5. Critical Appraisal Checklist for Qualitative Research

Author	Congruity between philosophical perspective & research methodology	Congruity between research methodology & objectives	Congruity between research methodology & methods	Congruity between research methodology & data analysis	Congruity between research methodology & interpretation of results	Statement to locate the researcher culturally or theoretically	Influence of researcher on the research & vice-versa	Representation of participants & their voices	Evidence of ethical approval by an appropriate body	Flow of conclusions from the analysis or interpretation of the data
Kane et al. (2018) [43]	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes

Table 6. ICF Classification of Outcome Measures

ICF Dimensions	Outcomes	Outcome Measures	Author(s)
Body Functions & Structures	Balance & Stability	Dynamic balance & biodex stability evaluation	Olama et al. (2013) [47]
		Pressure data, anteroposterior (AP) & mediolateral (ML) displacement, transverse body rotation strategies	Rha et al. (2010) [46]
		Duration of standing balance and independent standing	Harris & Riffle (1986) [38]
		Temporal, kinetic and kinematic data during sit to stand transfer	Park et al. (2004) [45]
	Gait Parameters	Gait kinematics and kinetics	Lam et al. (2005) [11], Embrey et al. (1990) [37], Butler et al. (1992) [40], Middleton et al. (1988) [42], Desloovere et al. (2006) [49]
		Gait pattern	Hainsworth et al. (1997) [41]
		Gait description	Carmick (1995) [34], Carmick (2012) [35]
	Muscle Activity	Electromyography	Lam et al. (2005) [11], Zhao et al. (2013) [44], Desloovere et al. (2006) [49]
	Lower Extremities Range of Motion	Active ankle dorsiflexion	Lam et al. (2005) [11], Carmick (1995) [34], Desloovere et al. (2006) [49]
		Active knee flexion	Embrey et al. (1990) [37]
		Passive ankle dorsiflexion	Wilson et al. (1997) [39], Hainsworth et al. (1997) [41], Zhao et al. (2013) [44]
		Passive knee and hip range of motion	Wilson et al. (1997) [39]
		Active knee and hip range of motion	Lam et al. (2005) [11], Desloovere et al. (2006) [49]
		Anatomical description of lower extremities	Carmick (2012) [35]
Activity	Gross Motor Function	GMFM-88	Bjornson et al. (2006) [32] (sections C, D and E), Dalvand et al. (2013) [48] (sections D and E)
		GMFM-66	Bjornson et al. (2006) [32], Carmick (2012) [35], Carmick (2013) [36], Zhao et al. (2013) [44]
		Total daily steps & active walking time	Bjornson et al. (2016) [33]
		Documentation of sit-to-stand strategies, sit to stand duration	Wilson et al. (1997) [39]
Participation		No studies that evaluated outcomes in the participation dimension were identified.	

Abbreviation: ICF= International Classification of Functioning, Disability & Health, GMFM= Gross Motor Function Measurement.

Figure 1. PRISMA Flow Chart [54]